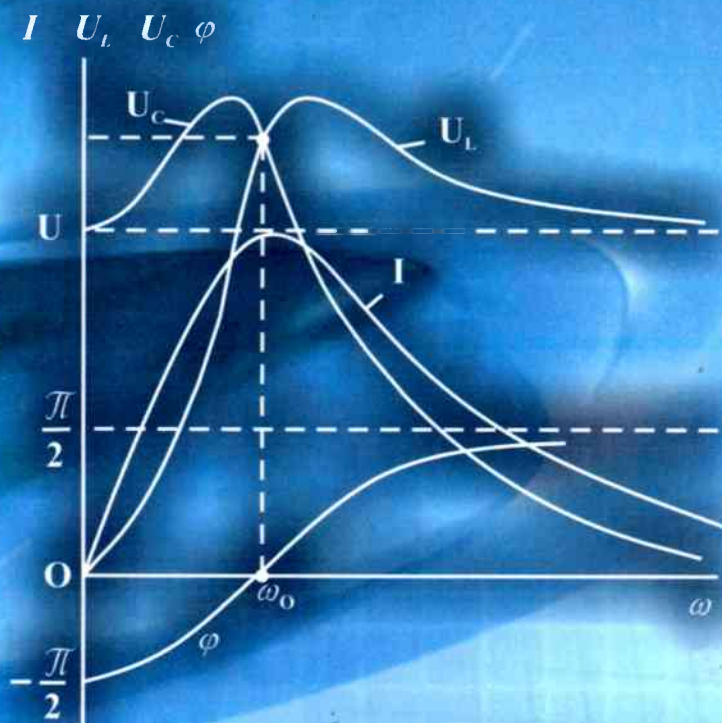


Muxtorxon Ibadullayev

NAZARIY ELEKTROTEXNIKA ASOSLARI

Masala va mashqlar to'plami



O'ZBEKISTON RESPUBLIKASI
OLY VA O'RTA MAXSUS TA'LIM VAZIRLIGI

MUXTORXON IBADULLAYEV

NAZARIY ELEKTROTEXNIKA ASOSLARI

MASALA VA MASHQLAR TO'PLAMI

I QISM

*Oliy o'quv yurtlarining 5310100-Energetika yo'nalishi
talabalari uchun o'quv qo'llanma*

Toshkent
«O'ZBEKISTON»
2015

UO'K: 62130(083)

KBK 24.1

I-13

Taqrizchilar:

ABDUQAYUMOV A.A.,

Toshkent davlat texnika universiteti professori, t.f.d.

G'AIPOV T.SH.,

Toshkent davlat texnika universiteti professori, t.f.d.

Ibadullayev M.

I-13 Nazariy elektrotexnika asoslari / M. Ibadullayev/ Toshkent: O'zbekiston, 2015. – 328 b.

ISBN 978-9943-28-252-0

Ushbu o'quv qo'llanma oliy o'quv yurtlarining energetika, elektroenergetika, elektrotexnika, elektromexanika, elektrotexnologiya, avtomatika, radioelektronika, aloqa, telekommunikatsiya yo'nalishlarida ta'lim olayotgan bakalavrlar uchun tavsiya etilib, shuningdek magistr, doktorant va soha mutaxassislari ham foydalanishlari mumkin.

UO'K: 62130(083)

KBK 24.1

*Abu Rayhon Beruniy nomidagi Toshkent davlat texnika universiteti
uslubiy Kengashi qaroriga asosan chop etishga ruxsat etilgan.
(Bayonnoma №5.13.03. 2014)*

ISBN 978-9943-28-252-0

© M. Ibadullayev, 2015.

© «O'zbekiston» NMIU, 2015.

KIRISH

Mamlakatimiz sanoatining rivojlanishida elektroenergetika sohasining ahamiyati beqiyos bo'lib, uning ilmiy-nazariy asosi bo'lmish nazariy elektrotexnikasiz tasavvur qilib bo'lmaydi.

Umuman olganda, elektrotexnika hamma zamonaviy elektrotexnik yo'nalishlar (energetika, avtomatika, elektronika, radiotexnika, aloqa, telekommunikatsiya, informatika va hokazo) uchun fundamental fan tarmog'i hisoblanadi.

Ushbu o'quv qo'llanma «Nazariy elektrotexnika asoslari» fani dasturi asosida tuzilgan bo'lib, chiziqli elektr zanjir qismiga doir yechilish uchun masala va mashqlar berilgan.

Har bir bobga oid fanning nazariy qismidan elektr zanjirni hisoblash uchun zarur bo'lgan qonun-qoidalar, formulalar, tenglamalar, analitik, grafik, kompleks usullar, vektor ifodalari va hisoblash usullari bo'yicha qisqacha asosiy tushunchalar o'z ifodasini topgan.

O'quv qo'llanma energetika, elektroenergetika, elektrotexnika, elektromexanika, elektrotexnologiya, avtomatika, radioelektronika, aloqa, telekommunikatsiya va axborot texnologiya soha yo'nalishlari bo'yicha ta'lim olayotgan talabalarga mo'ljallangan bo'lib, undan soha mutaxassislari, bakalavr, magistr va doktorantlar ham foydalanishlari mumkin.

O'quv qo'llanma talabalarga amaliy mashg'ulot darsini o'zlashtirishda mustaqil masalalar yechilish, hisob-grafik ishini bajarish va nazariy bilimlarini amalda sinab ko'rishlarida yordam bo'ladi degan umiddamiz.

I. O'ZGARMAS TOK ELEKTR ZANJIR

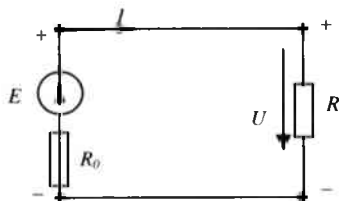
1.1. Asosiy nazariy tushunchalar

Elektrotexnika fanining rivojlanishiga buyuk fizik olimlar G. Oni, E. Lens, D. Joul, G. Kirxgof, M. Faradey, J. Maksvell va boshqalar asos solgan bo'lib, 1827-yilda nemis olimi Om tok, kuchlanish va qarshiliklar orasidagi o'zaro bog'lanish qonunini yaratdi. 1842-yilda rus olimi E. Lens va ingliz olimi D.Joul elektr energiyasini issiqlik energiyasiga aylantirish qonuniga asos soldi. 1845-yilda G. Kirxgof elektr zanjirni hisoblash uchun asosiy qonun tatbiq etdi.

1. O'zgarmas tok – vaqt bo'yicha o'zgarmas bo'lib, $I = \frac{q}{t}$ (A)

o'zgarmas tok generatori, akkumulator, galvanik elementlar, foto-elementlar, termopara, pyezodatchik va hokazolar elektr yurituvchi kuch (EYK) manbai hisoblanadi.

Amalda mexanik, kimyoviy, yorug'lik va boshqa xildagi energiyani elektr energiyasiga aylantirish yo'li bilan **elektr manbai** hosil qilinadi. Hosil qilingan elektr energiyasini iste'molchilarga uzatish liniyasi, kabel simlari va elektromagnit to'lqin orqali yetkaziladi. Bunday bog'lanishni elektrotexnikada **berk elektr zanjir** deyilib, quyidagi sxema ko'rinishida ifodalash mumkin.



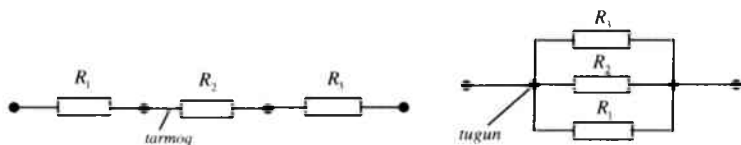
E – manba EYK

R – iste'molchi qarshiligi.

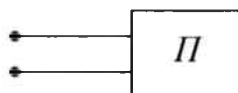
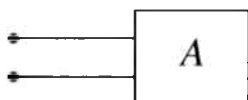
R_0 – manba ichki qarshiligi

Iste'molchilarda elektr energiyasi boshqa xildagi energiyaga o'zgaradi (mexanik, issiqlik, yorug'lik, kimyoviy va hokozolar).

Elektr zanjirlar tarmoqlangan va tarmoqlanmagan bo'lib, iste'molchilarni birlashtiruvchi simlar **tarmoq** (shoxobcha) va uchtdan ko'p shoxobchani birlashtiruvchi nuqtalar – **tugun** deb ataladi.



Ikki qutbli elektr zanjirda elektr energiya *aktiv* yoki aksincha, *passiv* bo'lishi mumkin.

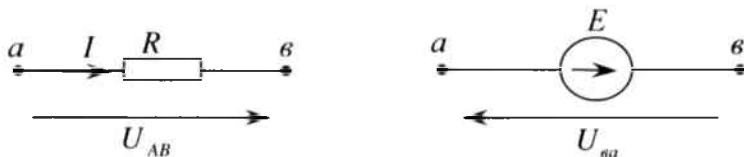


Elektr zanjirni hisoblashdan asosiy maqsad, iste'molchilar foydalanyotgan tok, kuchlanish va sarf bo'ladigan energiya quvvatini hisoblab topishdan iborat bo'lib, Om va Kirxgof qonunidan foydalaniladi.

2. Elektr kuchlanish yoki potentsiallar farqi deb, elektr maydon E (manba) ta'sirida biror musbat q zaryadning l masofaga ko'chirilishida bajarilgan ishga aytiladi va *Voltda* o'lchanadi.

$$U_{AB} = \frac{A}{q} = \int_A^B E dl = \varphi_a - \varphi_b \quad (\text{V}) \quad (1.1)$$

Masalan: R – qarshilikdagi kuchlanish potentsiallar ayirmasiga yoki manba kuchlanishiga teng:



Bunda:

$$\varphi_a - \varphi_b = U_{AB} = IR; \quad \varphi_b - \varphi_a = U_{ba} = E \quad U_{ba} = -U_{ab}$$

3. Elektr zanjir uchun Om qonuni.

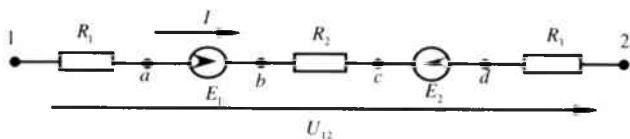
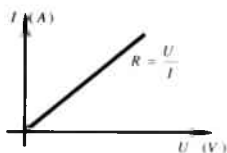
Aktiv qarshiligi bo'lgan zanjirning bir qismi uchun Om qonuni:

$$U_{ba} = U = RI \text{ (V)} \quad \text{yoki} \quad I = \frac{U}{R} \text{ (A)} \quad (1.2)$$

Bundan:

$$R = \frac{U}{I} \text{ (Om)}; \quad g = \frac{1}{R} \left(\frac{1}{\text{Om}} - \text{Simens} \right) - \text{o'tkazuvchanlik} \quad (1.3)$$

U holda qarshilik *Volt-Amper* xarakteristikasi $I = f(U)$ chiziqli o'zgaradi.



Elektr zanjirga manba ulangan holda butun zanjir uchun Om qonuni quyidagicha tenglama bilan ifodalanadi.

Potensiallar tenglamasiga asosan:

$$\varphi_d = \varphi_2 + R_3 I, \quad \varphi_c = \varphi_d + E_2, \quad \varphi_8 = \varphi_c + R_2 I,$$

$$\varphi_a = \varphi_8 - E_1, \quad \varphi_1 = \varphi_a + R_1 I$$

$$\text{yoki} \quad \varphi_1 = \varphi_2 + R_3 I + E_1 + R_2 I - E_2 + R_1 I, \quad \varphi_1 - \varphi_2 = U_{12}$$

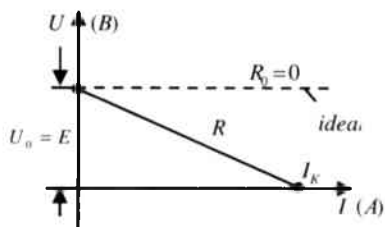
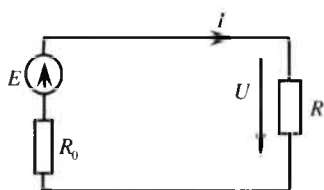
$$U_{12} = (R_1 + R_2 + R_3) I + E_1 - E_2$$

Bundan:

$$I = \frac{E_1 - E_2 + U_{12}}{R_1 + R_2 + R_3} \quad (1.4)$$

4. Elektr manbai ekvivalent sxemasi.

Amalda elektr zanjir tashqi *Volt-Amper* xarakteristikasi $U(I)$ quyidagicha ifodalaniladi:



Ushbu zanjirdan o'tuvchi tok: $I = \frac{E}{R_0 + R}$ yoki: $U = RI$

Kirxgof 2-qonuniga asosan: $R_0 I + RI = E$

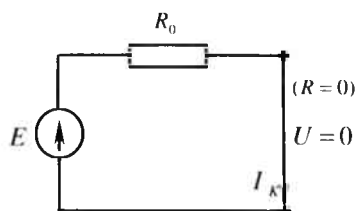
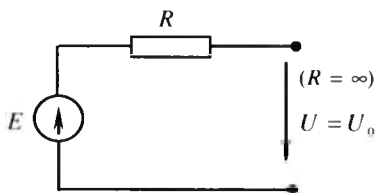
yoki: $U = E - R_0 I$ (1.5)

Volt-Amper xarakteristikasidan, ya'ni (15) tenglamadan: $E = \text{const}$ va $R_0 = \text{const}$ xarakteristikasi to'g'ri chiziqli bo'lib, kuchlanish manbai tashqi xarakteristikasini $U(I)$ ifodalaydi:

a) salt holatda: $R = \infty, I = 0$ bo'lib: $U = U_0 = E$ (1.6)

b) qisqa tutashtirilganda: $R = 0, U = 0$ bo'lib: $I = I_K = \frac{E}{R_0}$ (1.7)

$R_0 = 0$ bo'lganda esa ideal kuchlanish manbai bo'lib: $U = E = \text{const}$



Ushbu sxemani iste'molchi qarshiligiga nisbatan boshqa ko'rinishda keltirish mumkin.

Buning uchun (1.5) tenglamadan manba ichki qarshiligi R_0 ga bo'lib yuborilsa:

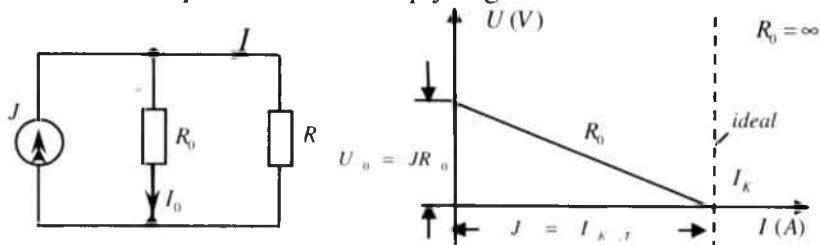
$$\frac{U}{R_0} = \frac{E}{R_0} - I \quad (1.8)$$

(1.7) tenglamaga asosan:

$$I_K = \frac{E}{R_0} = J \quad \text{va} \quad \frac{U}{R_0} = I_0 \quad \text{yoki} \quad I_0 = J - I \quad (1.9)$$

Bundan: $J = I_0 + I$ tok manbai bo'ladi yoki: $I = J - \frac{U}{R_0}$ (1.10)

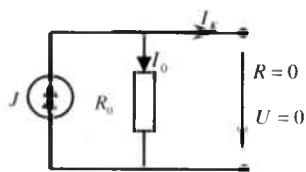
(1.10) tenglamaga asosan tok manbai (energiya) ekvivalent sxemasi va tashqi xarakteristikasi quyidagicha ifodalanadi:



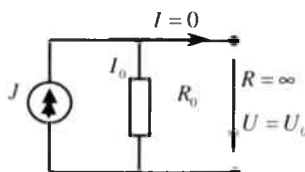
Tok manbai tashqi xarakteristikasi:

a) salt holatda: $R = \infty, I = 0$ yoki $J = I_K = \frac{U}{R_0}$; $U = U_0 = I_K R_0 = E$

b) qisqa tutashuvda: $R = 0; U = 0$ yoki $I = I_K = J = \frac{E}{R_0}$



a) Qisqa tutashuv.



b) salt holat

Agar $R_0 = \infty, (g_0 = 0)$ bo'lsa, ideal tok manbai bo'ladi: $J = I = \text{const}$.

Natijada elektr zanjirni hisoblashda ideal EYK manbaini ekvivalent tok manbaiga almashtirish yoki aksincha amalga oshirish mumkin bo'ladi.

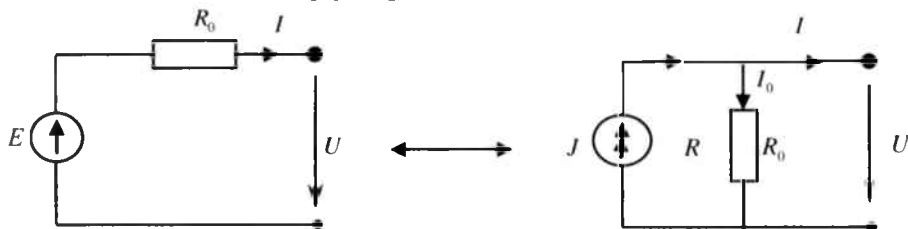
Masalan: berilgan sxemada EYK manbai $E = 12 \text{ V}$ ichki qarshiligi $R_0 = 2 \text{ Om}$. Tok manbaining ekvivalent sxemasi tuzilsin:

Yechish.

Om qonuniga asosan tok manbai qiymatini aniqlaymiz:

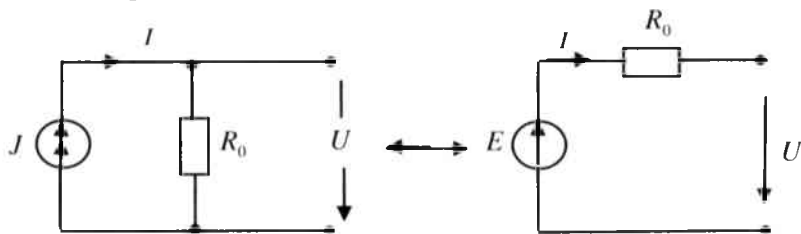
$$J = \frac{E}{R_0} = \frac{12}{2} = 6 \text{ A}$$

Ekvivalent sxemasi quyidagicha ifodalanadi:



Bunda EYK manbai E bilan tok manbai J yo'nalishi bir xil bo'ladi hamda ekvivalent sxemaga almashtirilganda tashqi qarshilik qiymati o'zgarmaydi. Ammo quvvat har xil bo'lishi mumkin.

Masalan. Elektr sxemada tok manbai $J = 10 \text{ A}$, ichki qarshilik $R_0 = 3 \text{ Om}$ bo'lganda ekvivalent EYK manbai sxemasi tuzilsin.



Yechish. EYK manba kuchlanishi $E = JR_0 = 10 \cdot 3 = 30 \text{ V}$

Eslatma: Keyinchalik ekvivalent sxemaga o'tishda manba ichki qarshiligi yoki o'tkazuvchanligini iste'molchilar tashqi qarshiligi yoki o'tkazuvchanligi bilan hisobga olamiz ($R_0 = 0$, $g = 0$). EYK manba bilan tok manbaini yoki aksincha almashtirilganda tashqi qarshilikga ta'siri bo'lmaydi, lekin manbadan chiquvchi elektr quvvat turlicha bo'lishi mumkin.

5. Elektr zanjirni hisoblashda Kirxgof qonuni.

Kirxgof qonun elektr zanjirni hisoblashda asosiy qonun bo'lib, barcha hisoblash usullarining negizi hisoblanadi.

Kirxgof qonuniga asosan p -tarmoq q -tugundan tashkil topgan elektr zanjirni hisoblab, tarmoqdagi tok uchun $K = p - (q - 1)$ tuzilgan tenglamani yechish bilan bajariladi.

Kirxgof 1-qonuni: $\sum_{k=1}^n I_k = 0$ – tarmoqdagi tok algebraik yig‘indisi nolga teng.

Kirxgof 2-qonuni: $\sum_{k=1}^n E_k = \sum_{k=1}^n R_k I_k$ – kontur EYK algebraik yig‘indisi shu konturga kiruvchi qarshilikdagi kuchlanishning algebraik yig‘indisiga teng.

6. Elektr zanjirda quvvat muvozanati.

Elektr zanjirda energiya muvozanatlanishi qonuniga asosan: manba elektr quvvati iste'molchilarda sarf bo'ladigan elektr quvvatga teng bo'ladi.

$$\sum_{k=1}^n P_{GEN} = \sum_{k=1}^n P_{Manb} \text{ yoki: } \sum_{m=1}^n E_m I_m + \sum_{n=1}^n J_n U_n = \sum_{K=1}^n I_K^2 R_K$$

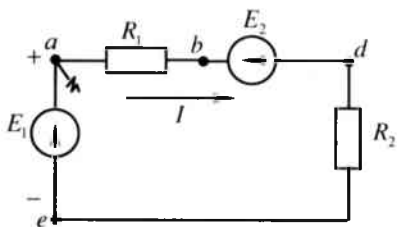
bunda: m – EYK manbalar soni n – tok manba

k – iste'molchilar soni U, I – bir xil yo'nalishdagi tok va kuchlanish.

1.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 1.1. Ketma-ket ulangan elektr zanjirda EYK $E_1 = 4 \text{ V}$, $E_2 = 2 \text{ V}$, qarshiligi $R_1 = 4 \text{ Ohm}$, $R_2 = 6 \text{ Ohm}$. Tok qiymati va potentsiali aniqlanib, diagrammasi tuzilsin.

Yechish. Om qonuniga asosan tokni topamiz:



$$I = \frac{E_1 - E_2}{R_{um}} = \frac{4 - 2}{R_1 + R_2} = \frac{2}{10} = 0,2 \text{ A}$$

Potensiallar farqini aniqlash uchun $\varphi_a = 0$ deb olamiz.

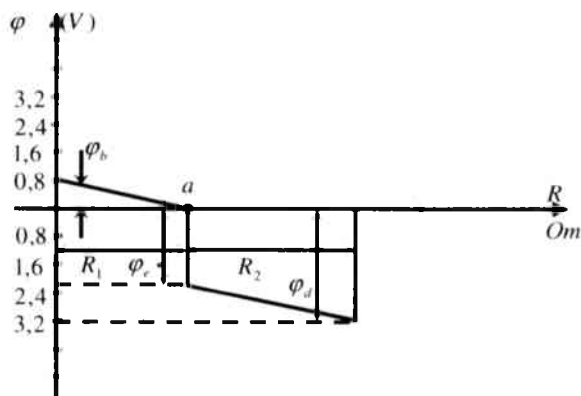
φ_d – potensiali: $\varphi_b - \varphi_d = E_1$ yoki $\varphi_d = \varphi_b - E_1 = -3,2 \text{ (V)}$

φ_e – potensiali: $\varphi_e - \varphi_d = IR$, yoki $\varphi_e = IR + \varphi_d = 0,2 \cdot 6 - 3,2 = -2$ (V)

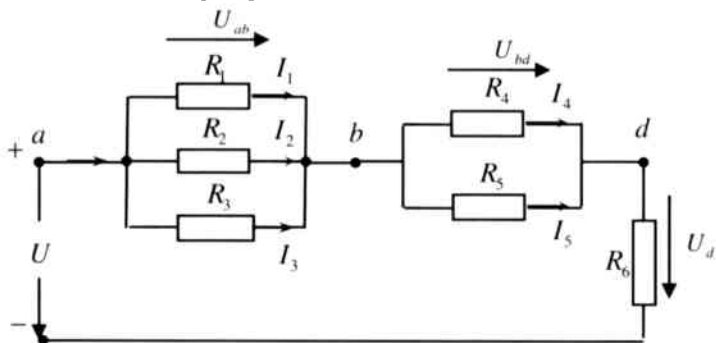
Ushbu tenglama asosida: $\varphi_a - \varphi_e = E_2$

$$\varphi_a = E_2 + \varphi_e = 2 - 2 = 0$$

Potensial diagramma chizamiz.

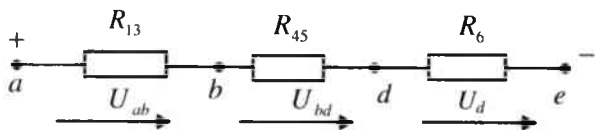


Masala 1.2. Tarmoqlangan elektr zanjir parametri $R_1=40\text{ Om}$, $R_2=120\text{ Om}$, $R_3=60\text{ Om}$, $R_4=90\text{ Om}$, $R_5=10\text{ Om}$, $R_6=10\text{ Om}$ bo'lib, $U=120\text{ V}$ o'zgarmas kuchlanishga ulangan. Ekvivalent qarshilik hamda tarmoqdagi tokni aniqlang.



Yechish.

Ekvivalent qarshilik sxemasini chizamiz:



Zanjirning ekvivalent yoki umumiy qarshiligini topamiz.

Buning uchun R_{13} va R_{45} qarshilikni parallel holda qo'shamiz:

$$\frac{1}{R_{13}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{40} + \frac{1}{120} + \frac{1}{60} = \frac{6}{120}$$

Bundan: $R_{13} = \frac{120}{6} = 20 \text{ Om}$

$$R_{45} = \frac{R_4 \cdot R_5}{R_4 + R_5} = \frac{90 \cdot 10}{90 + 10} = \frac{900}{100} = 9 \text{ Om}$$

Umumiy ekvivalent qarshilik:

$$R = R_{13} + R_{45} + R_6 = 20 + 9 + 11 = 40 \text{ Om}$$

Umumiy tokni aniqlaymiz: $I = \frac{U}{R} = \frac{120}{40} = 3 \text{ A}$

Tugun potentsiali yoki kuchlanishni aniqlaymiz:

$$U_{ab} = I \cdot R_{13} = 3 \cdot 20 = 60 \text{ V} \quad U_{bd} = I \cdot R_{45} = 3 \cdot 9 = 27 \text{ V}$$

$$U_d = I \cdot R_6 = 3 \cdot 11 = 33 \text{ V}$$

Endi tarmoqdagi tokini topamiz:

$$I_1 = \frac{U_{ab}}{R_1} = \frac{60}{40} = 1,5 \text{ A}$$

$$I_2 = \frac{U_{ab}}{R_2} = \frac{60}{120} = 0,5 \text{ A}$$

$$I_3 = \frac{U_{ab}}{R_3} = \frac{60}{60} = 1 \text{ A}$$

$$I_4 = \frac{U_{bd}}{R_4} = \frac{27}{90} = 0,3 \text{ A}$$

$$I_5 = \frac{U_{bd}}{R_5} = \frac{27}{10} = 2,7 \text{ A}$$

Masala yechimini tekshirib ko'ramiz:

$$U = U_{ab} + U_{bd} + U_d = 60 + 27 + 33 = 120 \text{ V}$$

$$I = I_1 + I_2 + I_3 = 1,5 + 0,5 + 1 = 3 \text{ A}$$

Quvvat muvozanati tenglamasiga asosan:

$$P_{manb} = P_{ist} = I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5 + I_6^2 R_6 =$$

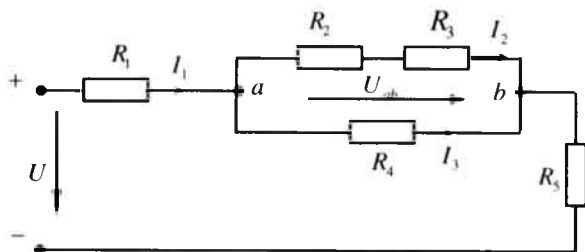
$$= (1,5)^2 \cdot 40 + (0,5)^2 \cdot 120 + (1)^2 \cdot 60 + (0,3)^2 \cdot 90 + (2,7)^2 \cdot 10 + (3)^2 \cdot 10 = 351 \text{ VT} = 360 \text{ VT}$$

Hisoblashdagi xatolik:

$$\gamma = \frac{P_{gen} - P_{ist}}{P_{ist}} \cdot 100\% = \frac{360 - 351}{351} 100\% = 2,7\%$$

Masala 1.3. Aralash sxemada ulangan elektr zanjir parametri: $R_1=19 \text{ Om}$, $R_2=2 \text{ Om}$, $R_3=4 \text{ Om}$, $R_4=4 \text{ Om}$, $R_5=0,6 \text{ Om}$ bo'lib, R_2 qarshilikda $P_2=32 \text{ VT}$ quvvat sarflanadi.

Zanjirning tarmoq tok manba kuchiamishi va quvvati aniqlansin.



Yechish.

R_2 qarshilikdan o'tuvchi I_2 tokni topamiz:

$$I_2 = \sqrt{\frac{P_2}{R_2}} = \sqrt{\frac{32}{2}} = 4 \text{ A}$$

a va b potensial kuchlanishni aniqlaymiz:

$$U_{ab} = I_2(R_2 + R_3) = 4(2 + 4) = 24 \text{ V}$$

R_4 qarshilikdan o'tuvchi tok:

$$I_3 = \frac{U_{ab}}{R_4} = \frac{24}{4} = 6 \text{ A}$$

Umumiy tok: $I_1 = I_2 + I_3 = 4 + 6 = 10 \text{ A}$

Zanjirning umumiy qarshiligini aniqlaymiz:

$$R_{um} = R_1 + \frac{R_4(R_2 + R_3)}{R_4 + R_2 + R_3} + R_5 = 19 + \frac{4(2 + 4)}{4 + 2 + 4} + 0,6 = 19 + 0,6 + \frac{24}{10} = 22 \text{ Om}$$

Manba kuchlanishi: $U = I_1 R_{um} = 10 \cdot 22 = 220 \text{ V}$

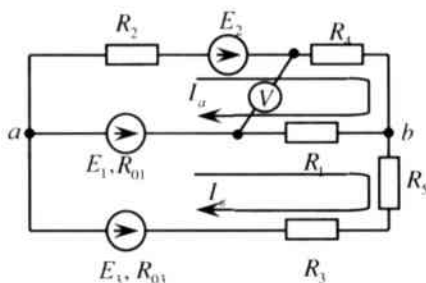
Manba quvvati: $P = U \cdot I_1 = 220 \cdot 10 = 2200 \text{ VT.}$

Masala 1.4. Ikki konturli elektr zanjir manba kuchlanishi: $E_1 = 8 \text{ V}$, $E_2 = 6 \text{ V}$, $E_3 = 36 \text{ V}$ qarshiligi: $R_1 = 3 \text{ Om}$, $R_2 = 1 \text{ Om}$, $R_3 = 2 \text{ Om}$, $R_{01} = 1,3 \text{ Om}$, $R_{03} = 1,2 \text{ Om}$, $R_4 = 6 \text{ Om}$, $R_5 = 8 \text{ Om}$ konturli tok usuli va tugunlararo kuchlanish usuliga asosan tarmoqdagi tok, voltmeter kuchlanishi va quvvatlar balansi aniqlansin.

Yechish.

Mustaqil konturdagi tok I_a , I_b yo'nalishini belgilaymiz.

Kirxgof 2-qonuniga asosan konturdagi tok tenglamasi quyidagicha bo'ladi:



$$\left. \begin{aligned} R_{11} \cdot I_a - R_{12} \cdot I_b &= E_{11} \\ -R_{11} \cdot I_a + R_{22} \cdot I_b &= E_{22} \end{aligned} \right\}$$

Bu yerda: $R_{11} R_{22}$ – konturning xususiy qarshiligi.

$$R_{11} = R_1 + R_{01} + R_2 + R_4$$

$$R_{22} = R_1 + R_{01} + R_3 + R_{03} + R_5$$

$$R_{12} = R_{21} - \text{konturlararo qarshilik: } R_{12} = R_{21} = R_1 + R_{01}$$

E_{11} va E_{22} – mos konturga aloqador bo'lgan manbaning EYKning algebraik yig'indisi.

Bu holda, agar manba EYK yo'nalishi bilan konturdagi tok yo'nalishi mos bo'lsa, uning ishorasi musbat yoki aksincha, manfiy olinadi.

$$\text{Bunga asosan: } E_{11} = E_2 - E_1 \quad E_{22} = E_1 - E_3$$

Tenglamaga aniqlangan qiymatni qo'yamiz:

$$\begin{cases} (3+1,3+6+2) \cdot I_a - (3+1,3) \cdot I_b = 6-8 \\ -(3+1,3) \cdot I_a + (3+1,3+1+1,2) \cdot I_b = 8-36 \end{cases}$$

$$\text{yoki: } \begin{cases} 12,3 \cdot I_a - 4,3 \cdot I_b = -2 \\ -4,3 \cdot I_a + 14,5 \cdot I_b = -28 \end{cases}$$

Tenglama Kramer usulida yechiladi:

$$\Delta = \begin{vmatrix} 12,3 & -4,3 \\ -4,3 & 14,5 \end{vmatrix} = 178,35 - 18,49 = 159,86$$

$$\Delta_1 = \begin{vmatrix} -2 & -4,3 \\ -2,8 & 14,5 \end{vmatrix} = -29 - 120,4 = -149,4$$

$$\Delta_2 = \begin{vmatrix} 12,3 & -2 \\ -4,3 & -28 \end{vmatrix} = -344,4 - 8,6 = -353,0$$

Bundan:

$$I_a = \frac{\Delta_1}{\Delta} = \frac{-149,4}{159,86} = -0,93 \text{ A}; \quad I_b = \frac{\Delta_2}{\Delta} = \frac{-353,0}{159,86} = -2,21 \text{ A};$$

Endi tarmoqdagi tokni aniqlaymiz:

$$I_1 = I_b - I_a = -2,21 - 0,93 = -1,28 \text{ A};$$

$$I_2 = I_a = -0,93 \text{ A};$$

$$I_3 = -I_b = 2,21 \text{ A};$$

I_1 va I_2 tokning minus ishorali bo'lishi, ularning zanjirdagi haqiqiy yo'nalishi, biz qabul qilganga nisbatan teskari ekanligini ifodalaydi.

Tugun potensial usuliga asosan hisoblash.

Tarmoqdagi tokni tugun potensialli orqali ifodalaymiz. Noma'lum potensialni aniqlash uchun tenglama tuzish kerak, ya'ni ixtiyoriy tugun potensialini «ma'lum» yoki «nol» ga teng deb qabul qilinadi. Berilgan sxema ikki tugundan iborat, demak φ_a tugun potensialini «nol», deb qabul qilgan holda tenglama tuzamiz.

$$g_{bb} \cdot \varphi_b = J_b$$

Bu yerda: φ_b – aniqlash kerak bo'lgan tugun potensialli.

g_{bb} – «b» tugunga kiruvchi tarmoqning o'tkazuvchanlik yig'indisi.

J_b – EYK ga ekvivalent bo'lgan tok manbaining algebraik yig'indisi.

Bunda, agar tok manbai yo'nalishi tugunga yo'nalgan bo'lsa, musbat va aksincha manfiy ishora bilan olinadi.

Demak:

$$g_{bb} = \frac{1}{R_2 + R_4} + \frac{1}{R_1 + R_{01}} + \frac{1}{R_3 + R_{03} + R_5}; \left(\frac{1}{Om} \right)$$

$$J_b = \frac{E_1}{R_1 + R_{01}} + \frac{E_2}{R_2 + R_4} + \frac{E_3}{R_3 + R_{03} + R_5}; (A)$$

Son qiymatlari qo'yilsa:

$$\left(\frac{1}{2+6} + \frac{1}{3+1,3} + \frac{1}{1+1,2+8} \right) \varphi_b = \frac{8}{3+1,3} + \frac{6}{2+6} + \frac{36}{1+1,2+86}$$

yoki: $\varphi_b = 13,49 (V)$

Tarmoqdagi tok:

$$I_1 = \frac{-\varphi_b + E_1}{R_1 + R_{01}} = \frac{-13,49 + 8}{3 + 1,3} = \frac{-5,49}{4,3} = -1,28 A;$$

$$I_2 = \frac{-\varphi_b + E_2}{R_2 + R_4} = \frac{-13,49 + 6}{2 + 6} = \frac{-7,49}{8} = -0,936 A;$$

$$I_3 = \frac{-\varphi_b + E_3}{R_3 + R_{03} + R_5} = \frac{-13,49 + 36}{1 + 1,2 + 8} = \frac{22,51}{10,2} = 2,206 A;$$

1. Voltmetr ko'rsatishini aniqlaymiz:

$$U_b = -I_2 R_4 + I_1 R_1 = -(-0,93) 6 + (-1,28) 3 = 1,74 \text{ V}$$

2. Quvvatlar balansi tenglamasiga asosan $P_{man} = P_{ist}$ teng bo'lib, manba quvvati:

$$P_{man} = E_1 I_1 + E_2 I_2 + E_3 I_3 = 8 (-1,28) + 6 (-0,93) + 36 2,21 = -10,24 - 5,58 + 79,56 = 63,74 \text{ Vt}$$

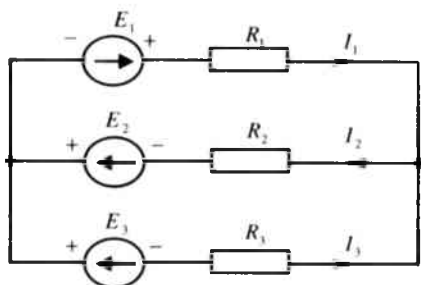
Iste'molchilarda sarf bo'ladigan quvvat:

$$P_{ist} = I_1^2 \cdot (R_1 + R_{01}) + I_2^2 \cdot (R_2 + R_4) + I_3^2 (R_3 + R_{03} + R_5) = 1,28^2 \cdot (3 + 1,3) + 0,93^2 (2 + 6) + 2,21^2 (1 + 1,2 + 8) = 7,045 + 6,91 + 49,81 = 63,76 \text{ Vt}$$

Hisoblashdagi xato:

$$j\% = \frac{|P_{ist} - P_{man}|}{|P_{ist}|} \cdot 100\% = \frac{63,76 - 63,74}{63,76} \cdot 100\% = 0,03\%$$

Masala 1.5. Elektr zanjirning manba kuchlanishi $E_1 = 10 \text{ V}$, $E_2 = 40 \text{ V}$, $E_3 = 5 \text{ V}$, qarshiligi $R_1 = 35 \text{ Om}$, $R_2 = 5 \text{ Om}$, $R_3 = 10 \text{ Om}$ ga teng. Ustma-ustlik usuliga asosan tarmoqdagi tok aniqlansin.



Yechish.

Ustma-ustlik usuliga asosan tarmoqdan o'tuvchi tok har bir EYK ta'sirida tarmoqdagi tokning algebraik yig'indisiga teng bo'ladi:

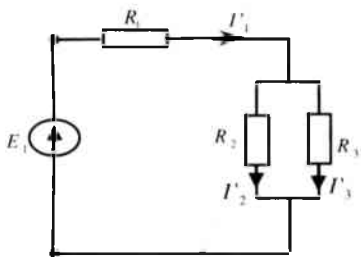
$$I_1 = I'_1 + I''_1 + I'''_1$$

$$I_2 = I'_2 + I''_2 + I'''_2$$

$$I_3 = I'_3 + I''_3 + I'''_3$$

Tok kuchini aniqlash uchun berilgan sxemani bitta EYK dan iborat bo'lgan oddiy ekvivalent sxemaga ajratamiz.

a) $E_1=10\text{ V}$, $E_2=E_3=0$ bo'lgan holat uchun tarmoqdagi tok I'_1 ni aniqlaymiz:

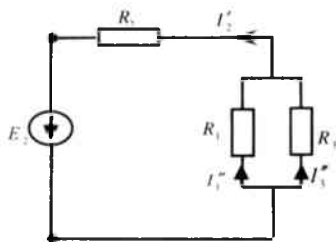


$$I'_1 = \frac{E_1}{R_{ekv}} = \frac{E_1}{R_1 + \frac{R_2 \cdot R_3}{R_2 + R_3}} = \frac{10}{\frac{115}{3}} = \frac{6}{23} \text{ A}$$

$$I'_2 = I'_1 \cdot \frac{R_3}{R_2 + R_3} = \frac{6}{23} \cdot \frac{10}{5+10} = \frac{4}{23} \text{ A}$$

$$I'_3 = I'_1 \cdot \frac{R_2}{R_2 + R_3} = \frac{6}{23} \cdot \frac{5}{5+10} = \frac{2}{23} \text{ A}$$

b) $E_2=40\text{ V}$, $E_1=E_3=0$ bo'lganda I''_1 tarmoqdagi tokni topamiz:

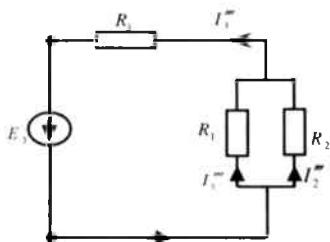


$$I''_2 = \frac{E_2}{R_{ekv}} = \frac{E_2}{R_1 + \frac{R_2 \cdot R_3}{R_2 + R_3}} = \frac{40}{\frac{115}{9}} = \frac{72}{23} \text{ A}$$

$$I''_1 = I''_2 \cdot \frac{R_3}{R_1 + R_3} = \frac{72}{23} \cdot \frac{10}{35+10} = \frac{16}{23} \text{ A}$$

$$I''_3 = I''_2 \cdot \frac{R_2}{R_1 + R_3} = \frac{72}{23} \cdot \frac{35}{35+10} = \frac{56}{23} \text{ A}$$

c) $E_3=5\text{ V}$, $E_1=E_2=0$ bo'lgan I'''_1 tarmoqdagi tokni aniqlaymiz:



$$I'''_3 = \frac{E_3}{R_3 + \frac{R_1 \cdot R_2}{R_1 + R_2}} = \frac{5}{\frac{115}{9}} = \frac{8}{23} \text{ A}$$

$$I'''_1 = I'''_3 \cdot \frac{R_2}{R_1 + R_2} = \frac{8}{23} \cdot \frac{5}{40} = \frac{1}{23} \text{ A}$$

$$I'''_2 = I'''_3 \cdot \frac{R_1}{R_1 + R_2} = \frac{8}{23} \cdot \frac{6}{6} = \frac{7}{23} \text{ A}$$

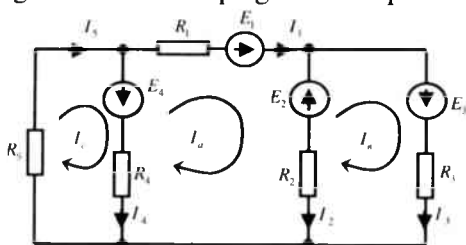
Aniqlangan tok yo'nalishi va ishorasini hisobga olgan holda tarmoqdagi tokni topamiz:

$$I_1 = I'_1 + I''_1 + I'''_1 = \frac{6}{23} + \frac{16}{23} + \frac{1}{23} = 1 \text{ A}$$

$$I_2 = I'_2 + I''_2 + I'''_2 = \frac{4}{23} + \frac{72}{23} - \frac{7}{23} = 3 \text{ A}$$

$$I_3 = I'_3 + I''_3 + I'''_3 = -\frac{2}{23} + \frac{56}{23} - \frac{8}{23} = 2 \text{ A}$$

Masala 1.6. Keltirilgan sxema parametri $R_1=5 \text{ Om}$, $R_2=R_3=10 \text{ Om}$, $R_4=5 \text{ Om}$, $R_5=3 \text{ Om}$, EYK $E_1 = 70 \text{ V}$, $E_2 = 5 \text{ V}$, $E_3 = 15 \text{ V}$, $E_4 = 10 \text{ V}$. Konturli tok usuliga asosan tarmoqdagi toki aniqlansin.



Yechish.

Berilgan elektr zanjir 3 ta konturdan tashkil topgan bo'lganligi uchun Kirxgof 2-qonuniga asosan konturdagi tok yo'nalishi bo'yicha uchta tenglama tuzamiz:

$$\left. \begin{aligned} R_{11}I_a - R_{12}I_b - R_{13}I_c &= E_a \\ -R_{21}I_a + R_{22}I_b + R_{23}I_c &= E_b \\ R_{31}I_a - R_{32}I_b - R_{33}I_c &= E_c \end{aligned} \right\} \quad (1)$$

Kontur qarshiliklarini topamiz:

$$R_{11} = R_1 + R_2 + R_4 = 20 \text{ Om}$$

$$R_{22} = R_2 + R_3 = 20 \text{ Om}$$

$$R_{33} = R_4 + R_5 = 8 \text{ Om}$$

Konturlararo qarshiliklarni topamiz:

$$R_{12} = R_{21} = R_2 = 10 \text{ Om}; \quad R_{23} = R_{32} = 0; \quad R_{13} = R_{31} = R_4 = 5 \text{ Om}$$

Konturga kiruvchi EYK ning qiymatini aniqlaymiz:

$$E_a = E_1 - E_4 - E_2 = 70 - 10 - 5 = 55 \text{ V}$$

$$E_b = E_2 + E_3 = 5 + 15 = 20 \text{ V}$$

$$E_c = E_4 = 10 \text{ V}$$

(1) tenglamaga asosan determinant usuliga asosan tenglama tuzamiz:

$$\Delta = \begin{vmatrix} R_{11} & -R_{12} & -R_{13} \\ -R_{21} & R_{22} & -R_{23} \\ -R_{31} & -R_{32} & R_{33} \end{vmatrix} = \begin{vmatrix} 20 & -10 & -5 \\ -10 & 20 & -0 \\ -5 & -10 & 8 \end{vmatrix} = 1900 \text{ (Om)}$$

$$\Delta_a = \begin{vmatrix} E_a & -R_{12} & -R_{13} \\ E_b & R_{22} & -R_{23} \\ E_c & -R_{32} & R_{33} \end{vmatrix} = \begin{vmatrix} 55 & -10 & -5 \\ 20 & 20 & -0 \\ 10 & -0 & 8 \end{vmatrix} = 11400 \text{ (V)}$$

$$\Delta_b = \begin{vmatrix} R_{11} & E_a & -R_{13} \\ -R_{21} & E_b & -R_{23} \\ -R_{31} & E_c & R_{33} \end{vmatrix} = \begin{vmatrix} 20 & 55 & -5 \\ -10 & 20 & -0 \\ -5 & 10 & 8 \end{vmatrix} = 7600 \text{ (V)}$$

$$\Delta_c = \begin{vmatrix} R_{11} & -R_{12} & E_a \\ -R_{21} & R_{22} & E_b \\ -R_{31} & -R_{32} & E_c \end{vmatrix} = \begin{vmatrix} 20 & -10 & 55 \\ -10 & 20 & 20 \\ -5 & -0 & 10 \end{vmatrix} = 9500 \text{ (V)}$$

Konturdagi tokni aniqlaymiz:

$$I_a = \frac{\Delta_a}{\Delta} = \frac{11400}{1900} = 6 \text{ A}$$

$$I_b = \frac{\Delta_b}{\Delta} = \frac{7600}{1900} = 4 \text{ A}$$

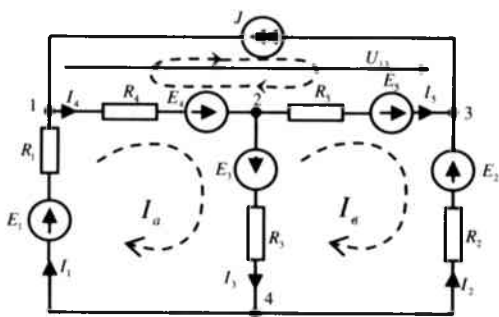
$$I_c = \frac{\Delta_c}{\Delta} = \frac{9500}{1900} = 5 \text{ A}$$

Konturdagi tok orqali tarmoqdagi tokni aniqlaymiz:

$$I_1 = I_a = 6 \text{ A}; \quad I_2 = I_a - I_b = 6 - 4 = 2 \text{ A};$$

$$I_3 = I_2 = 4 \text{ A}; \quad I_4 = I_a - I_c = 1 \text{ A}; \quad I_5 = I_c = 5 \text{ A}$$

Masala 1.7. Elektr sxema parametri: $R_1=R_3=R_5=58 \text{ Om}$, $R_2=R_4=40 \text{ Om}$, $E_1=10 \text{ V}$, $E_2=15 \text{ V}$, $E_3=10 \text{ V}$, $E_4=5 \text{ V}$, $E_5=20 \text{ V}$, $J=2 \text{ A}$. Tugun **potensiallar** usuliga asosan tarmoqdagi tokni aniqlab, quvvat muvozanat tenglamasi tuzilsin.



Yechish.

1) tugun potentsiallar usuli murakkab elektr zanjirini hisoblashda qulay bo'lib, Kirxgof va Om qonuniga asosan tugun potentsiallari nisbatan tuzilgan tenglamalarni yechish bilan tarmoqdagi tok aniqlanadi. Bunda ixtiyoriy tugun potentsialini «nol» ga tenglash bilan tenglamalar sonini $(q - 1)$ kamaytirish mumkin.

Berilgan sxemada 4 ta tugun bo'lib, to'rtinchi tugunni «nol» ga tenglaymiz. ($\varphi_4 = 0$) va Kirxgof 1-qonuniga asosan tugunlar uchun tenglama tuzamiz:

$$\left. \begin{aligned} 1 - \text{tugun } I_4 + J - I_1 &= 0 \\ 2 - \text{tugun } I_3 + I_5 - I_4 &= 0 \\ 3 - \text{tugun } J - I_2 - I_5 &= 0 \end{aligned} \right\} \quad (1)$$

Om qonuniga asosan tok ifodasini tugun potentsiallari ayirmasi orqali ifodalaymiz:

$$\left. \begin{aligned} \frac{\varphi_1 - \varphi_2 + E_4}{R_4} - J - \frac{\varphi_4 - \varphi_1 + E_1}{R_1} &= 0 \\ \frac{\varphi_2 - \varphi_3 + E_5}{R_5} + \frac{\varphi_2 - \varphi_4 + E_3}{R_3} + \frac{\varphi_1 - \varphi_2 + E_4}{R_4} &= 0 \\ J - \frac{\varphi_4 - \varphi_3 + E_2}{R_2} - \frac{\varphi_2 - \varphi_3 + E_5}{R_5} &= 0 \end{aligned} \right\} \quad (2)$$

Potensial $\varphi_4 = 0$ ekanligini mobatga olib, tenglamani quyidagicha yozamiz:

$$\left. \begin{aligned} \varphi_1 \left(\frac{1}{R_1} + \frac{1}{R_4} \right) - \varphi_2 \frac{1}{R_4} &= E_1 \frac{1}{R_1} + J - E_4 \frac{1}{R_4} \\ -\varphi_1 \frac{1}{R_4} + \varphi_2 \left(\frac{1}{R_4} + \frac{1}{R_3} + \frac{1}{R_5} \right) - \varphi_3 \frac{1}{R_5} &= E_4 \frac{1}{R_5} - E_3 \frac{1}{R_3} - E_5 \frac{1}{R_5} \\ -\varphi_2 \frac{1}{R_5} + \varphi_3 \left(\frac{1}{R_4} + \frac{1}{R_2} \right) &= E_2 \frac{1}{R_2} + E_5 \frac{1}{R_5} - J \end{aligned} \right\} \quad (3)$$

Qarshiliklar parametrimini $\frac{1}{R} = g$ o'tkazuvchanlik parametrlariga almashtirish bilan tarmoq o'tkazuvchanligini aniqlaymiz:

$$g_1 = g_3 = g_5 = 0,2 \text{ sim}, \quad g_2 = g_4 = 0,25 \text{ sim}$$

Tugunlararo tarmoq o'tkazuvchanligini topamiz:

$$g_{11} = g_1 + g_4 = 0,45 \text{ sim},$$

$$g_{22} = g_4 + g_3 + g_5 = 0,65 \text{ sim}$$

$$g_{33} = g_5 + g_2 = 0,45 \text{ sim}$$

Tugunlarni bog'lovchi tarmoqdagi o'tkazuvchanlikni topamiz:

$$g_{12} = g_{21} = g_4 = 0,25 \text{ sim},$$

$$g_{23} = g_{32} = g_5 = 0,2 \text{ sim}$$

(3) tenglamaning o'ng tomoni ifodalaridan tugundagi tok qiymatini aniqlaymiz:

$$\left. \begin{aligned} 1\text{-tugun: } I_a &= E_1 g_1 - E_4 g_4 + J = 2,75 A \\ 2\text{-tugun: } I_b &= E_4 g_4 - E_3 g_3 - E_5 g_5 = -4,75 A \\ 3\text{-tugun: } I_c &= E_5 g_5 - E_2 g_2 - J = 5,75 A \end{aligned} \right\} \quad (4)$$

(3) tenglamaga tarmoqdagi o'tkazuvchanlik qiymatini qo'yib, tugun potentsiallar tenglamasini tuzamiz:

$$\left. \begin{aligned} 0,45\varphi_1 - 0,25\varphi_2 &= 2,75 \\ -0,25\varphi_1 + 0,65\varphi_2 - 0,2\varphi_3 &= -4,75 \\ -0,2\varphi_2 + 0,45\varphi_3 &= 5,75 \end{aligned} \right\} \quad (5)$$

(5) tenglamalar sistemasini yechish bilan tugun potentsialli qiymatini topamiz:

$$\varphi_1 = 5,25 V, \quad \varphi_2 = 1,6 V, \quad \varphi_3 = 12,08 V, \quad (6)$$

Om qonuniga asosan tuzilgan (2) tenglamadan tarmoqdagi tokni topamiz:

$$\begin{aligned}
 I_1 &= (\varphi_0 - \varphi_1 + E_1)g_1 = 0,95 \text{ A} & I_2 &= (\varphi_0 - \varphi_3 + E_2)g_2 = 0,73 \text{ A} \\
 I_3 &= (\varphi_2 - \varphi_0 + E_3)g_3 = 1,68 \text{ A} & I_4 &= (\varphi_1 - \varphi_2 + E_4)g_4 = 2,96 \text{ A} \\
 I_5 &= (\varphi_2 - \varphi_3 + E_5)g_5 = 1,27 \text{ A}
 \end{aligned} \quad (7)$$

2) quvvatlar muvozanati tenglamasi quyidagicha ifodalanadi:

$$\sum EI + \sum JU = \sum I^2 R$$

Berilgan sxema uchun:

$$E_1 I_1 + E_2 E_2 + E_3 I_3 + E_4 I_4 + J U_{13} = I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5 \quad (8)$$

Tok manbaga J ulangan konturdagi U_{13} kuchlanishni topish uchun 1-va-3 tugun potensialiga nisbatan tenglama tuzamiz:

$$\begin{aligned}
 \varphi_1 - \varphi_3 &= U_{13} = -E_4 - E_5 + I_4 R_4 + I_5 R_5 = \\
 &= -5 - 20 + 5 \cdot 1,27 + 4 \cdot 2,5 = -6,84 \text{ V}
 \end{aligned}$$

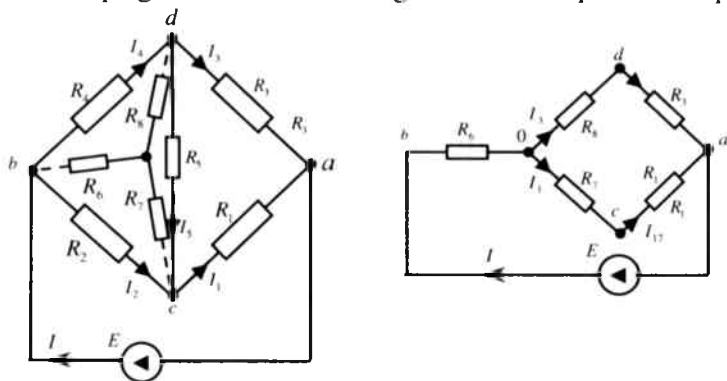
Barcha tok va kuchlanish qiymatlarini (8) tenglamaga qo'yish bilan quvvat qiymatini aniqlaymiz:

$$\begin{aligned}
 &10 \cdot 0,95 + 15 \cdot 0,73 + 10 \cdot 1,68 + 5 \cdot 2,95 + 20 \cdot 1,27 + 2 \cdot (-6,84) = \\
 &= (0,95)^2 \cdot 5 + (0,73)^2 \cdot 4 + (1,68)^2 \cdot 5 + (2,95)^2 \cdot 4 + (1,27)^2 \cdot 5
 \end{aligned}$$

Demak, quvvat muvozanati:

$$63,8 \text{ VT} = 63,8 \text{ VT}$$

Masala 1.8. Ko'prik sxemada ulangan elektr zanjir parametri: $R_1=R_3=R_5=50 \text{ Om}$, $R_2=R_4=4 \text{ Om}$ bo'lib, $E=30 \text{ V}$ o'zgarmas manbaga ulangan. Uchburchak sxemadan ekvivalent yulduzcha sxemaga o'tish bilan tarmoqdagi tok va sarf bo'ladigan elektr tok quvvati aniqlansin.



Yechish.

Berilgan sxemadan b, c, d uchburchak sxema potensialini ekvivalent yulduzcha sxemaga o'tish ifodasidan foydalanamiz:

$$R_6 = \frac{R_2 \cdot R_4}{R_2 + R_4 + R_5} = \frac{80 \cdot 120}{320} = 30 \text{ Om}$$

$$R_7 = \frac{R_2 \cdot R_5}{R_2 + R_4 + R_5} = \frac{120 \cdot 120}{320} = 45 \text{ Om}$$

$$R_8 = \frac{R_4 \cdot R_5}{R_2 + R_4 + R_5} = \frac{80 \cdot 120}{320} = 30 \text{ Om}$$

Tuzilgan yulduzcha sxemadan qarshilikni ketma-ket va parallel qo'shish bilan zanjir umumiy qarshiligini aniqlaymiz:

$$R_{um} = R_6 + \frac{(R_3 + R_8)(R_1 + R_7)}{R_3 + R_8 + R_1 + R_7} = 30 + \frac{210 \cdot 105}{315} = 100 \text{ Om}$$

$$\text{Tarmoqdagi tok: } I = \frac{E}{R_{um}} = \frac{30}{100} = 0,3 \text{ A}$$

Parallel tarmoqdagi tokni aniqlaymiz:

$$I_{17} = I \frac{R_8 + R_3}{R_3 + R_8 + R_1 + R_7} = \frac{210 \cdot 0,3}{315} = 0,2 \text{ A}$$

$$I_{38} = I \frac{R_1 + R_7}{R_3 + R_8 + R_1 + R_7} = \frac{105 \cdot 0,3}{315} = 0,1 \text{ A}$$

Bu yerda: $R_1 = R_3$ ga teng bo'lganligi uchun aniqlangan $I_{17} = I_1 = 0,2 \text{ A}$ va $I_{38} = I_3 = 0,1 \text{ A}$ ga teng.

Berilgan sxemaning qolgan tarmoqlaridan o'tuvchi toklarni aniqlash uchun tugun potensialiga asosan tenglama tuzamiz:

$$U_{bc} = IR_6 + I_1 R_7 = 0,3 \cdot 30 + 0,2 \cdot 45 = 18 \text{ V}$$

$$U_{bd} = IR_6 + I_3 R_8 = 0,3 \cdot 30 + 0,1 \cdot 30 = 12 \text{ V}$$

$$U_{dc} = U_{bc} - U_{bd} = 18 - 12 = 6 \text{ V}$$

$$\text{Tarmoqdagi tok: } I_2 = \frac{U_{bc}}{R_2} = \frac{18}{80} = 0,225 \text{ A}, \quad I_4 = \frac{U_{bd}}{R_4} = \frac{12}{120} = 0,1 \text{ A}$$

$$I_5 = \frac{U_{cd}}{R_5} = \frac{6}{120} = 0,05 \text{ A}$$

Masalaning yechimini tekshirib ko'ramiz.

Bunda: a – tarmoqdagi tok:

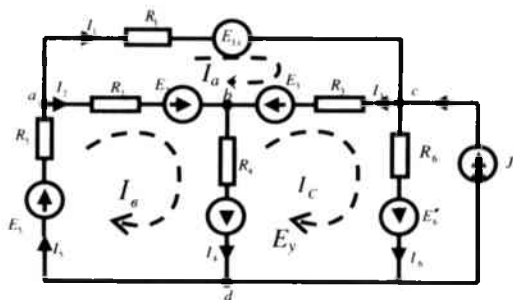
$$I = I_1 + I_3 = 0,2 + 0,1 = 0,3 \text{ A}$$

b – tugundagi tok: $I = I_4 + I_2 = 0,1 + 0,225 = 0,3 \text{ A}$

Zanjirda sarf bo'ladigan quvvat: $P = UI = I^2 R_{um} = 30 \cdot 0,3 = 9 \text{ VT}$

Masala 1.9. Berilgan elektr tok sxemasining parametri: $R_1=8 \text{ Om}$, $R_2=5 \text{ Om}$, $R_3=4 \text{ Om}$, $R_4=6 \text{ Om}$, $R_5=6 \text{ Om}$, $R_6=7 \text{ Om}$, EYK lari: $E_6=30\text{V}$, $E_2=30 \text{ V}$, $E_3=30 \text{ V}$, $E_4=40 \text{ V}$, $E_5=50 \text{ V}$ tok manbai $J=4\text{A}$ va birinchi tarmoqdagi tok $I_1=2 \text{ A}$ bo'lib, konturli tok usuliga asosan tarmoqdagi tok, E_{lx} – EYK qiymati va ekvivalent generator usuliga asosan I_2 tarmoqdagi tok aniqlansin.

Yechish.

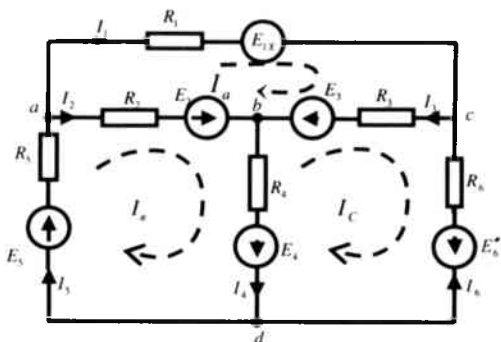


1. Tok manbaini ekvivalent kuchlanish manbai bilan almashtiramiz:

Bunda: $JR_6 = E'_6$; yoki $E'_6 = 4 \cdot 7 = 28 \text{ V}$;

Demak: $E''_6 = E_6 - E'_6 = 30 - 28 = 2 \text{ V}$;

2. Berilgan sxemani quyidagicha ekvivalent sxemaga keltiramiz.



Konturli tok usuliga asosan konturdagi tok I_a I_b I_c yo'nalishlari bo'yicha Kirxgof 2-qonuniga asosan tenglama tuzamiz:

$$\left. \begin{aligned} R_{11}I_a - R_{12}I_b - R_{13}I_c &= E_a \\ -R_{21}I_a + R_{22}I_b - R_{23}I_c &= E_b \\ -R_{31}I_a - R_{32}I_b - R_{33}I_c &= E_c \end{aligned} \right\} \quad (1)$$

Endi konturga kiruvchi qarshilikni aniqlaymiz:

$$R_{11} = R_1 + R_2 + R_3 = 17 \text{ Om}$$

$$R_{22} = R_2 + R_4 + R_5 = 17 \text{ Om}$$

$$R_{33} = R_3 + R_4 + R_6 = 17 \text{ Om}$$

Konturni bog'lovchi konturlararo qarshilikni aniqlaymiz:

$$\left. \begin{aligned} R_{12} &= R_{21} = R_2 = 5 \text{ Om} \\ R_{31} &= R_{13} = R_3 = 4 \text{ Om} \\ R_{23} &= R_{32} = R_4 = 6 \text{ Om} \end{aligned} \right\}$$

Konturni tashkil etuvchi EYK ni aniqlaymiz:

$$E_a = E_{1X} + E_2 - E_3 = (E_{1X} - 17) \text{ V}$$

$$E_b = E_2 + E_4 + E_5 = 140 \text{ V}$$

$$E_c = E_6 - E_4 - E_3 = -68 \text{ V}$$

I-konturdagi tok: $I_a = I_1 = 2 \text{ A}$

Aniqlangan qiymatni (1) tenglamaga qo'yamiz:

$$\left. \begin{aligned} 2 \cdot 17 - 5 \cdot I_b - 4 \cdot I_c &= E_{1X} - 20 \\ -2 \cdot 5 + 17 \cdot I_b - 6 \cdot I_c &= 140 \\ -2 \cdot 4 - 6I_b + 17 \cdot I_c &= -68 \end{aligned} \right\} \quad (2)$$

Ushbu tenglamadan noma'lum konturdagi tok (I_b, I_c) ni aniqlaymiz:

$$\text{yoki: } \left. \begin{aligned} 17I_b - 6I_c &= 150 \\ -6I_b - 17I_c &= -60 \end{aligned} \right\}$$

Bu tenglamani Kramer usuliga asosan yechamiz:

$$\Delta_a = \begin{vmatrix} 17 & -6 \\ -6 & 17 \end{vmatrix} = 289 - 36 = 253$$

$$\Delta_b = \begin{vmatrix} 150 & -6 \\ -60 & 17 \end{vmatrix} = 2550 - 360 = 2190$$

$$\Delta_c = \begin{vmatrix} 17 & 150 \\ -6 & -60 \end{vmatrix} = -1020 + 900 = -120$$

Bundan:

$$I_b = \frac{2190}{253} = 8,65 \text{ A}, \quad I_c = -\frac{120}{253} = -0,475$$

(2) tenglamadan E_{1x} – EYK qiymatini aniqlaymiz:

$$E_{1x} = 54 - 5 \cdot 8,65 + 4 \cdot 0,475 = 12,65 \text{ V}$$

Tarmoqdagi tokni aniqlaymiz:

$$I_1 = 2 \text{ A}, \quad I_2 = I_a - I_b = 2 - 8,65 = -6,65 \text{ A}$$

$$I_3 = I_a - I_c = 2 + 0,475 = 2,475 \text{ A}$$

$$I_4 = I_b - I_c = 8,65 + 0,475 = 9,125 \text{ A}$$

$$I_5 = I_b = 8,65 \text{ A}$$

$$I_6 = -I_c = 0,475 \text{ A}$$

Quvvat muvozanat tenglamasini tuzamiz:

$$I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5 + (I - I_2) R_6 =$$

$$E_1 I_1 + E_2 I_2 + E_3 I_3 + E_4 I_4 + E_5 I_5 + E_6 (I - I_6)$$

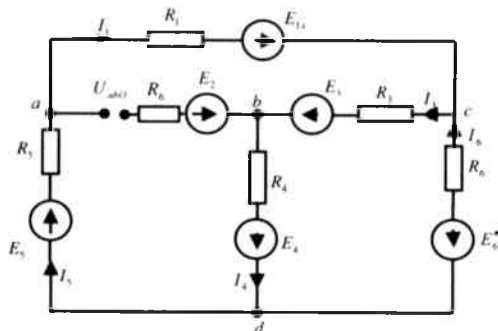
$$\text{Bundan: } 13335,86 \approx 13337 \text{ (VT)}$$

Hisoblashdagi xatolik 0,02% ga teng.

3. Ekvivalent generator usuliga asosan I_2 tarmoqdagi tokni aniqlaymiz.

$$\text{Bunda: } I_2 = \frac{U_{abo}}{R_o + R_2} \quad (3)$$

Ekvivalent sxemasini chizamiz:



2- tarmoqda uzilish bo'lganda elektr sxema ikki tugunli potensial ayirmasi bilan ifodalanib ($\varphi_c - \varphi_d$) tugunlararo potentsiallar ayirmasi tenglamasiga asosan:

$$U_{cd} = \frac{\sum_{n=1}^n E_n g_n}{\sum_{n=1}^n g_n} = \frac{(E_5 + E_{1X}) \frac{1}{R_1 + R_5} - (E_4 + E_3) \frac{1}{R_3 + R_4} - E_6^* \frac{1}{R_6}}{\frac{1}{R_1 + R_5} + \frac{1}{R_3 + R_4} + \frac{1}{R_6}} =$$

$$= \frac{\frac{62,65}{14} - \frac{70}{10} - 2 \frac{1}{7}}{\frac{1}{14} + \frac{1}{10} + \frac{1}{7}} = -8,95 \text{ V}$$

Om qonuniga asosan tarmoqdagi tokni aniqlaymiz:

$$I_1 = I_5 = \frac{(E_5 + E_{1X}) - U_{cd}}{R_1 + R_5} = \frac{(62,65 + 8,95)}{14} = 5,2 \text{ A}$$

$$I_3 = I_4 = \frac{(E_3 + E_4) + U_{cd}}{10} = \frac{70 - 8,95}{10} = 6,1 \text{ A}$$

$$I_6 = \frac{E_6^* + U_{cd}}{7} = \frac{2 - 8,95}{7} \approx -1$$

Potensial qiymatni aniqlaymiz:

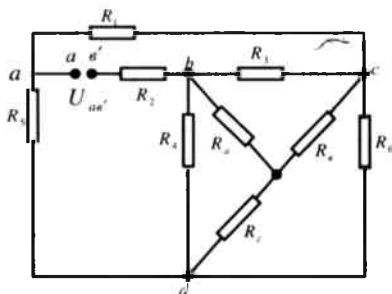
$$\varphi_a = \varphi_d + E_5 + I_5 R_5 = 0 + 50 - 5,2 \cdot 6 = 19,3 \text{ V}$$

$$\varphi_b = \varphi_d - E_4 + I_4 R_4 = 0 - 40 + 6,1 \cdot 6 = -3,37 \text{ V}$$

$$\varphi'_b = \varphi_b + E_2 = -3,37 - 50 = -53,37 \text{ V}$$

$$U_{abo} = \varphi_a - \varphi'_b = 19,3 + 53,37 = 72,67 \text{ V}$$

Endi (3) tenglamadagi R_0 - ichki ekvivalent qarshilikni aniqlaymiz. Buning uchun b, c, d potentsiallarni birlashtiruvchi qarshilikni uch-burchak sxemadan yulduzcha sxemaga keltirish formulasiga asosan ekvivalent sxemasini chizamiz:

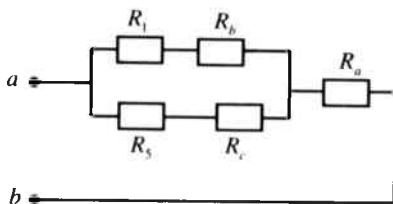


$$R_a = \frac{R_3 R_4}{R_3 + R_4 + R_6} = \frac{24}{17} (Om)$$

$$R_b = \frac{R_3 R_6}{R_3 + R_4 + R_6} = \frac{28}{17} (Om)$$

$$R_c = \frac{R_4 R_6}{R_3 + R_4 + R_6} = \frac{42}{17} (Om)$$

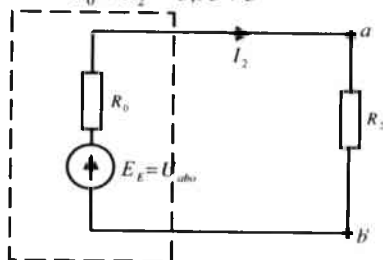
R_c qarshilikni R_5 bilan va R_1 qarshilikni R_b qarshilik bilan qo'shib ikkita parallel ulangan sxemaning umumiy qarshiligini topamiz:



$$R_0 = R_{um} = \frac{(R_c + R_5)(R_b + R_1)}{R_c + R_5 + R_b + R_1} + R_a = 5,95 (Om)$$

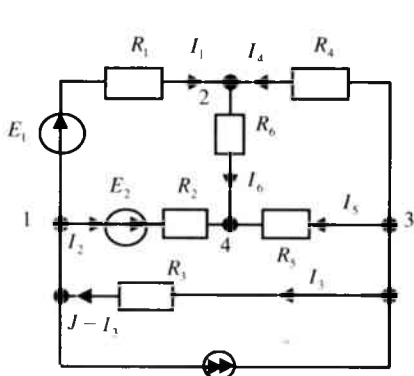
Uzilgan 2-tarmoqqa nisbatan ekvivalent sxemasini tuzamiz hamda aniqlangan qiymatni (3) tenglamaga qo'yish bilan I_2 tarmoqdagi tokni aniqlaymiz:

$$I_2 = \frac{U_{abo}}{R_0 + R_2} = \frac{72,6}{5,95 + 5} = 6,65 (A)$$

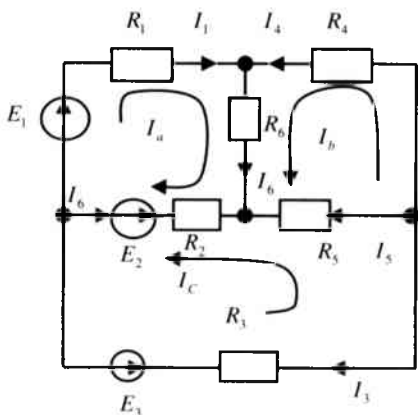


Masala 1.10. Murakkab elektr zanjir tarmoqlaridagi qarshilik:

$R_1 = R_2 = R_3 = 2 Om$, $R_4 = R_5 = R_6 = 6 Om$ va elektr yurituvchi kuch $E_1 = 68$, $E_2 = 12 V$ bo'lib, tok manbai $J = 9 A$ ga teng. Konturli tok va tugun potentsiallari usullariga asosan tarmoqdagi tokni aniqlang.



a)



b)

Yechish. a) tok manbaini elektr yurituvchi kuchlar manbai bilan almashtirilgandan keyingi ekvivalent sxema uchun (b) konturli tok usuliga asosan tenglama tuzamiz: $E_3 = J \cdot R_3 = 9 \cdot 2 = 18 \text{ V}$.

$$\left. \begin{aligned} I_a(R_1 + R_6 + R_2) + I_b R_6 + I_c R_2 &= E_1 - E_2 \\ I_a R_6 + I_b(R_4 + R_5 + R_6) - I_c R_5 &= 0 \\ I_a R_2 - I_b R_5 + I_c(R_2 + R_3 + R_5) &= E_3 - E_2 \end{aligned} \right\}$$

yoki:

$$\left. \begin{aligned} 10I_a + 6I_b + 2I_c &= -6 \\ 6I_a + 18I_b - 6I_c &= 0 \\ 2I_a - 6I_b + 10I_c &= 6 \end{aligned} \right\}$$

Tenglamalar sistemasini yechish bilan konturdagi tokni aniqlaymiz:

$$I_a = I_1 = -1,5 \text{ A}; \quad I_b = I_4 = 1 \text{ A}; \quad I_c = I_3 = 1,5 \text{ A}$$

Tarmoqdagi tokni aniqlaymiz:

$$I_6 = I_a + I_b = -0,5 \text{ A}; \quad I_5 = I_c - I_b = 0,5 \text{ A}; \quad I_2 = -(I_a + I_c) = 0$$

$$R_3 \text{ qarshilikdagi tok } J - I_c = 9 - 1,5 = 7,5 \text{ A.}$$

I_a va I_6 ishorasi tokning haqiqiy qiymati teskari ekanligini ifodalaydi.

b) **tugun potensial usuliga** asosan sxemadan 2-tugun potensialini $\varphi_2 = 0$ deb olamiz.

Bunda:

$$\left. \begin{aligned} \varphi_1(g_1 + g_2 + g_3) - \varphi_3 g_3 - \varphi_4 g_2 &= -E_1 g_1 - E_2 g_2 - E_3 g_3 \\ -\varphi_1 g_3 + \varphi_3(g_3 + g_4 + g_5) - \varphi_4 g_5 &= E_3 g_3 \\ -\varphi_1 g_2 - \varphi_3 g_5 + \varphi_4(g_2 + g_5 + g_6) &= E_2 R_2 \end{aligned} \right\}$$

yoki:

$$\left. \begin{aligned} 3\varphi_1 - \varphi_2 - \varphi_4 &= -36 \\ -3\varphi_1 + \varphi_3 - 5\varphi_4 &= 36 \\ -3\varphi_1 + 5\varphi_3 - \varphi_4 &= 54 \end{aligned} \right\}$$

Tenglamani yechish bilan tugun potentsiallar qiymatini topamiz:

$$\varphi_1 = -9 \text{ V}; \quad \varphi_3 = 6 \text{ V}; \quad \varphi_4 = 3 \text{ V}.$$

Bundan, tarmoqdagi tokni Om qonuniga asosan aniqlaymiz:

$$I_1 = (\varphi_2 - \varphi_1 - E_1)g_1 = (0 + 9 - 6)\frac{1}{2} = 1,5 \text{ A}$$

$$I_2 = (\varphi_1 - \varphi_4 + E_1)g_2 = (-9 - 3 + 12)\frac{1}{2} = 0$$

$$J - I_3 = (\varphi_3 - \varphi_1)g_3 = (6 + 9)\frac{1}{2} = 7,5 \text{ A}$$

$$I_4 = (\varphi_3 - \varphi_2)g_4 = (6 - 0)\frac{1}{6} = 1 \text{ A}$$

$$I_5 = (\varphi_3 - \varphi_4)g_5 = (6 - 3)\frac{1}{6} = 0,5 \text{ A}$$

$$I_6 = (\varphi_4 - \varphi_2)g_6 = (3 - 0)\frac{1}{6} = 0,5 \text{ A}.$$

Quvvat muvozanat tenglamasiga asosan:

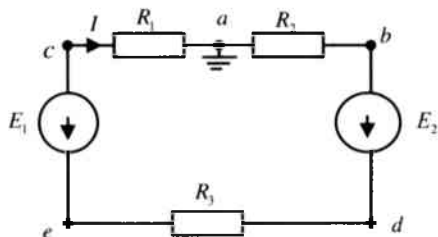
$$\sum P_{manba} = \sum P_{iste'molchi}$$

$$E_1 I_1 + E_2 I_2 + E_3 I_3 = I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5 + I_6^2 R_6.$$

$$\text{Demak: } P_{manba} = 36 \text{ VT} = P_{iste'm} = 36 \text{ VT}.$$

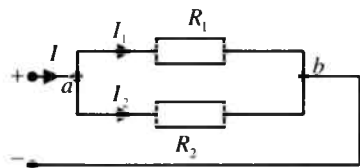
1.3. Mustaqil yechish uchun masalalar

Masala 1.1. Ketma-ket sxemada ulangan elektr zanjir parametri: $E_1=20 \text{ V}$, $E_2=12 \text{ V}$, $R_1=5 \text{ Om}$, $R_2=6 \text{ Om}$, $R_3=9 \text{ Om}$ ga teng. Tarmoqdagi tok va potentsiallari aniqlanib, potentsiallar diagrammasi tuzilsin.



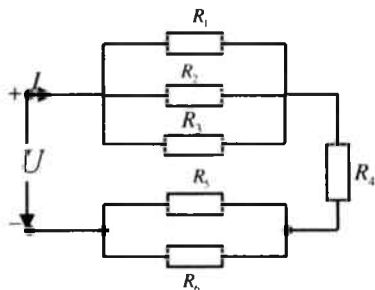
Javob: $I=0,4 \text{ A}$, $\varphi_a=0$, $\varphi_b=2,4 \text{ V}$, $\varphi_d=-14,4 \text{ V}$, $\varphi_e=-18 \text{ V}$, $\varphi_c=2 \text{ V}$

Masala 1.2. Parallel sxemada biriktirilgan elektr zanjirning a va b tugun potentsiallaridagi kuchlanish $U_{ab}=60 \text{ V}$ bo'lib, kiruvchi tarmoqdagi tok $I=1,5 \text{ A}$ va qarshilik $R_2=120 \text{ Om}$ ga teng. Tarmoqdagi tok qarshiligi va ekvivalent qarshiligini aniqlang.



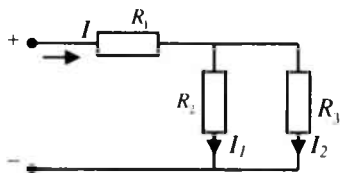
Javob: $R_1=60 \text{ Om}$, $R_{ekv}=40 \text{ Om}$, $I_1=1 \text{ A}$, $I_2=0,5 \text{ A}$,

Masala 1.3. Aralash sxemada biriktirilgan elektr zanjir $U=26 \text{ V}$ kuchlamishga ulangan bo'lib, qarshilik parametri: $R_1=8 \text{ Om}$, $R_2=14 \text{ Om}$, $R_3=4 \text{ Om}$, $R_4=5,16 \text{ Om}$, $R_5=7,5 \text{ Om}$, $R_6=5 \text{ Om}$. Zanjirning ekvivalent qarshiligi hamda tarmoqdagi tokni aniqlang.



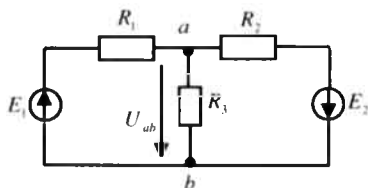
Javob: $R_{ekv}=10,4 \text{ Om}$, $I=2,5 \text{ A}$, $I_1=0,7 \text{ A}$, $I_2=0,4 \text{ A}$, $I_3=1,4 \text{ A}$, $I_5=1 \text{ A}$, $I_6=1,5 \text{ A}$.

Masala 1.4. Elektr zanjir $U=60\text{ V}$ kuchlanishga ulanganda $P=300\text{ W}$ quvvat sarflanadi. Qarshilik parametri $R_2=15\text{ Ohm}$, $R_3=5\text{ Ohm}$ ga teng bo'lganda, R_1 qarshilik qiymati va tarmoqdagi tokni aniqlang.



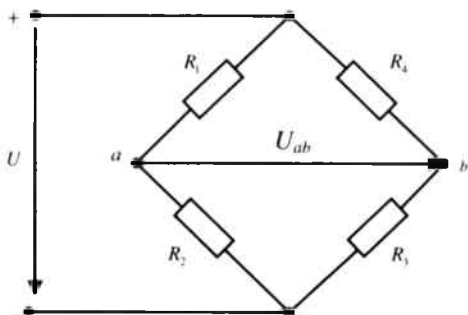
Javob: $R_1=8,25\text{ Ohm}$, $I_1=3,75\text{ A}$, $I_2=1,25\text{ A}$, $I=5\text{ A}$.

Masala 1.5. Keltirilgan sxemada $E_1=12\text{ V}$, $E_2=24\text{ V}$, $R_1=R_2=20\text{ Ohm}$, $R_3=10\text{ Ohm}$ bo'lsa, φ_a va φ_b tugunlar orasidagi kuchlanish necha voltga teng.



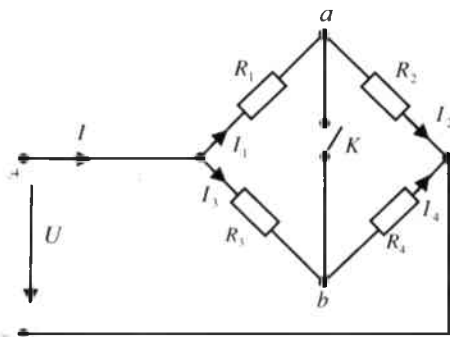
Javob: $U_{ab} = 9\text{ V}$.

Masala 1.6. Ko'prik sxemada ulangan zanjir qarshilik parametri $R_1=10\text{ Ohm}$, $R_2=20\text{ Ohm}$, $R_3=40\text{ Ohm}$, $R_4=30\text{ Ohm}$ bo'lib, $U=210\text{ V}$ kuchlanishga ulangan. U_{ab} – potensial kuchlanishni aniqlansin.



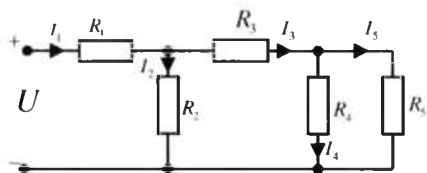
Javob: $U_{ab}=20\text{ V}$

Masala 1.7. Qarshiliklari ko'prik sxemada ulangan zanjir parametri: $R_1=10\text{ Om}$, $R_2=20\text{ Om}$, $R_3=40\text{ Om}$, $R_4=30\text{ Om}$, kuchlanish $U=15,6\text{ V}$. Kalit ulangan va uzilgan hollar uchun ekvivalent qarshilik va qarshilikdan o'tuvchi tok qiymati aniqlansin.



Javob: a) $R_{ekv}=8\text{ Om}$, $I=1,95\text{ A}$, $I_1=I_2=0,65\text{ A}$, $I_3=I_4=1,3\text{ A}$,
b) $R_{ekv}=7,8\text{ Om}$, $I=2\text{ A}$, $I_1=0,5\text{ A}$, $I_2=0,8\text{ A}$, $I_3=1,5\text{ A}$, $I_4=1,2\text{ A}$,

Masala 1.8. Aralash sxemada ulangan elektr zanjir parametri: $R_1=50\text{ Om}$, $R_2=80\text{ Om}$, $R_3=20\text{ Om}$, $R_4=30\text{ Om}$, $R_5=60\text{ Om}$ bo'lib, to'rtinchi tarmoqdan o'tuvchi tok $I_4=0,2\text{ A}$ ga teng. Tarmoqdagi tok, zanjir umumiy kuchlanishi va sarf bo'ladigan elektr quvvat aniqlansin.

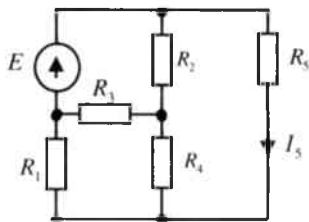


Javob: $U=34,5\text{ V}$, $P=15,5\text{ Vt}$

Masala 1.9. 1.7 masalada berilgan sxema parametri qiymati bo'yicha $U=50\text{ V}$ kuchlanishga ulangan. I_4 tarmoqdagi tok va sarf bo'ladigan quvvat aniqlansin.

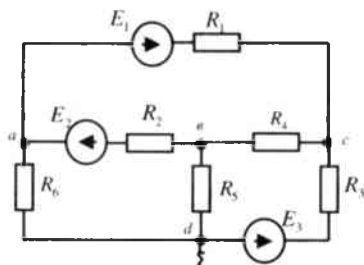
Javob: $P=32,5\text{ Vt}$, $I_4=290\text{ mA}$

Masala 1.10. Berilgan elektr sxemaning qarshilik parametri: $R_1=4\text{ Om}$, $R_2=6\text{ Om}$, $R_3=3\text{ Om}$, $R_4=20\text{ Om}$, $R_5=8,5\text{ Om}$. EYK $E=24\text{ V}$. Konturli tok va ekvivalent generator usuliga asosan beshinchi tarmoqdan o'tuvchi I_5 tok aniqlansin.



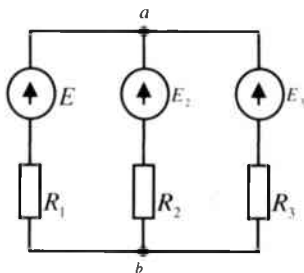
Javob: $I_5=2\text{ A}$

Masala 1.11. Berilgan elektr zanjir qarshilik parametri: $R_1=R_3=R_6=3\text{ Om}$, $R_2=R_4=R_5=1\text{ Om}$, EYK $E_1=E_2=E_3=48\text{ V}$. Konturli tok va tugunlararo kuchlanish usuliga asosan tarmoqdagi tok aniqlansin.



Javob: $I_4=8\text{ A}$, $I_1=5,33\text{ A}$, $I_2=8\text{ A}$, $I_3=13,33\text{ A}$, $I_5=0$, $I_6=13,33\text{ A}$,

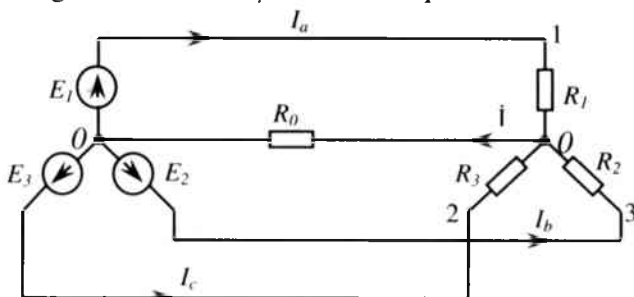
Masala 1.12. Berilgan elektr sxemaning parametri: $E_1=40\text{ V}$, $E_2=5\text{ V}$, $E_3=30\text{ V}$, $R_1=5\text{ Om}$, $R_2=1\text{ Om}$, $R_3=3\text{ Om}$. Ikkita tugun orasida



potensiallar kuchlanishi va ustma-ustlik usuliga asosan tarmoqdagi tok aniqlansin.

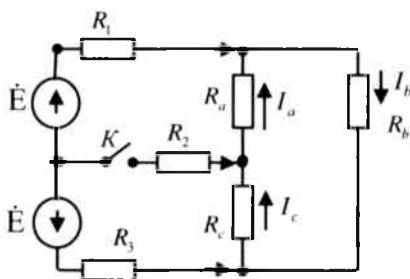
Javob: $I_1=5A$, $I_2=10A$, $I_3=5A$

Masala 1.13. Berilgan sxema parametri: $R_1=10\text{ Om}$, $R_2=20\text{ Om}$, $R_3=4\text{ Om}$. EYK $E_1=20V$, $E_2=100V$, $E_3=80V$ bo'lganda, tugunlararo kuchlanish usuliga asosan tarmoqdagi tok aniqlansin.



Javob: $I_1=-3,4A$, $I_2=2,3A$, $I_3=6,5A$, $I_4=-5,4A$

Masala 1.14. Berilgan elektr zanjir parametri: $R_1=R_2=R_3=10\text{ Om}$, $R_a=25\text{ Om}$, $R_b=50\text{ Om}$, $R_c=50\text{ Om}$ bo'lib, $E_1=E_2=120V$ o'zgarmas tok manbaga ulangan. Kalit (K) ulangan holat uchun tarmoqdagi tok aniqlansin.

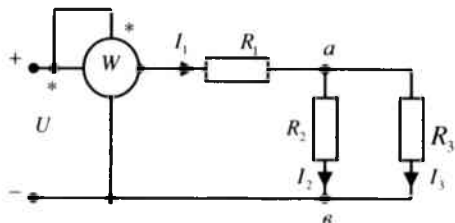


Javob: $I_a=2,4A$, $I_b=-2,85A$, $I_c=1,65A$

Masala 1.15. 1.13. masalada berilgan sxema sharti bo'yicha $I_a=2A$, $I_b=-3A$, $I_c=2A$ (tok yo'nalishi strelka ko'rsatishiga mos) bo'lganda E_1 va E_2 manba kuchlanishlari aniqlansin.

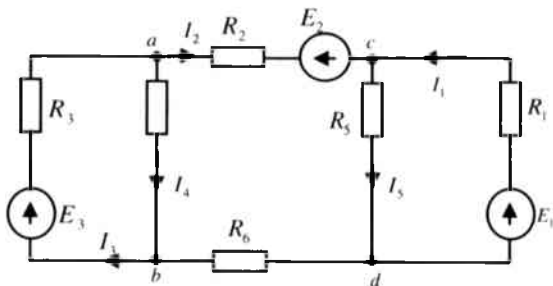
Javob: $E_1=100V$, $E_2=-150V$

Masala 1.16. Aralash sxemada ulangan elektr zanjir qarshilik parametri: $R_2=20\text{ Om}$, $R_3=30\text{ Om}$ bo'lib, $U=625\text{ V}$ kuchlanishga ulangan. Vattmetr ko'rsatishi $P=32,25\text{ KVt}$ bo'lgan holatda R_1 – qarshilik, tarmoqdagi tok I_2 , I_3 va R_2 , R_3 qarshiliklarda sarf bo'ladigan quvvat aniqlansin.



Javob: $I_2=3\text{ A}$, $I_3=2\text{ A}$, $R_1=113\text{ Om}$, $P_2=180\text{ Vt}$, $P_3=120\text{ Vt}$

Masala 1.17. Berilgan elektr zanjirning parametri: $R_1=6\text{ Om}$, $R_2=20\text{ Om}$, $R_3=2\text{ Om}$, $R_4=6\text{ Om}$, $R_5=2\text{ Om}$, $R_6=6\text{ Om}$, EYK $E_1=80\text{ V}$, $E_2=6\text{ V}$, $E_3=120\text{ V}$ bo'lib, birinchi tarmoq toki $I_1=8\text{ A}$ ga teng. Om va Kirxgof qonunga asosan tarmoqdagi tok aniqlansin.



Javob: $I_2=8\text{ A}$, $I_3=21\text{ A}$, $I_4=13\text{ A}$, $I_5=16\text{ A}$

Masala 1.18. Elektr isitgich $U=220\text{ V}$ kuchlanishga mo'ljallangan bo'lib, $P=600\text{ Vt}$ elektr sarflaydi. Agar shu elektr isitgich $U=110\text{ V}$ kuchlanishga ulanganda qancha quvvat sarflanadi.

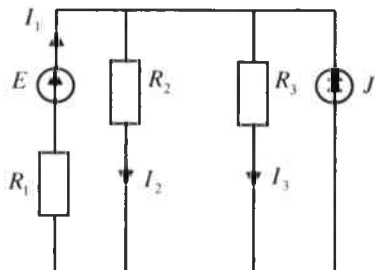
Javob: $P=150\text{ Vt}$

Masala 1.19. Elektr tok quvvati $P=40\text{ Vt}$ bo'lgan 10 ta lampochka har kuni 6 soat yonadi. 30 kun davomida sarf bo'ladigan elektr

energiyasi aniqlanib, 1 kVt/soat energiya 135 so'm bo'lganda, bir oylik xarajat hisoblab topilsin.

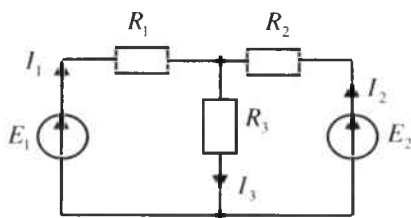
Javob: $W=72 \text{ kVt/soat}$, sarf puli: 11720 so'm.

Masala 1.20. Elektr zanjir manba qiymatlari: $E=32 \text{ V}$, $J=18 \text{ A}$, qarshiligi $R_1=1 \text{ Om}$, $R_2=6 \text{ Om}$, $R_3=2 \text{ Om}$ ga teng. Konturli tok, tugun potentsiali va ustma-ustlik usullariga asosan tarmoqdagi tok aniqlansin.



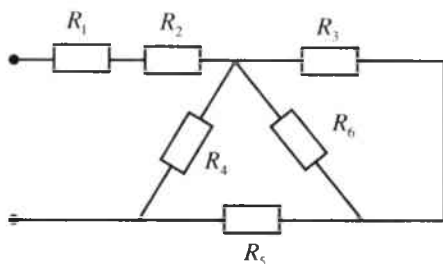
Javob: $I_1=2 \text{ A}$, $I_2=5 \text{ A}$, $I_3=15 \text{ A}$.

Masala 1.21. Elektr zanjir parametri: $R_1=R_2=R_3=2 \text{ om}$, EYK $E_1=24 \text{ V}$, $E_2=18 \text{ V}$ bo'lganda, Kirxgof qonuni va ustma-ustlik usullariga asosan tarmoqdagi tok hamda sarf bo'ladigan elektr quvvat qiymati topilsin:



Javob: $I_1=5 \text{ A}$, $I_2=2 \text{ A}$, $I_3=7 \text{ A}$

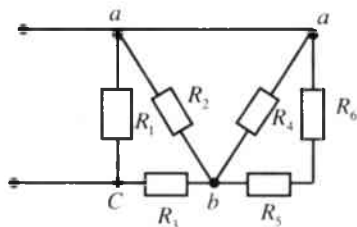
Masala 1.22. Elektr zanjir qarshiligi $R_1=R_2=R_3=R_5=5,5 \text{ Om}$, $R_4=12 \text{ Om}$, $R_6=3,25 \text{ Om}$ bo'lganda, umumiy qarshilik (R_{um}) aniqlansin.



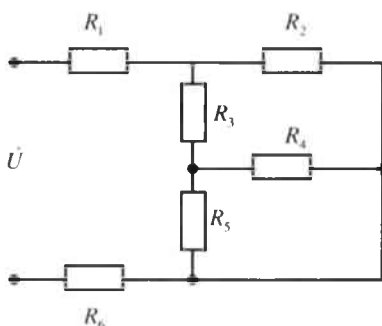
Javob: $R_{um}=15 \text{ Om}$.

Masala 1.23. Elektr zanjir qarshiligi: $R_1 = R_4 = 60 \text{ Om}$, $R_2 = R_5 = 40 \text{ Om}$, $R_3 = 10 \text{ Om}$, $R_6 = 80 \text{ Om}$ bo'lganda, umumiy qarshilik (R_{um}) aniqlansin.

Javob: $R_{um} = 20 \text{ Om}$.

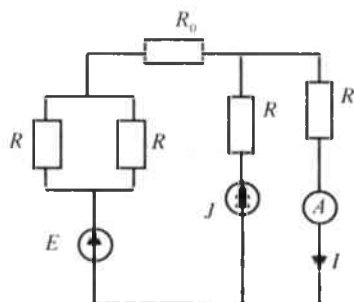


Masala 1.24. Elektr zanjir parametri $R_1 = R_6 = 4,5 \text{ Om}$, $R_2 = 22 \text{ Om}$, $R_3 = 7,6 \text{ Om}$, $R_4 = 24 \text{ Om}$, $R_5 = 36 \text{ Om}$ bo'lib, $U = 120 \text{ V}$ kuchlanishga ulangan. Tarmoqdagi tokni aniqlang.



Javob: $I_1 = 6 \text{ A}$, $I_2 = I_3 = 3 \text{ A}$, $I_4 = 1,8 \text{ A}$, $I_5 = 1,2 \text{ A}$

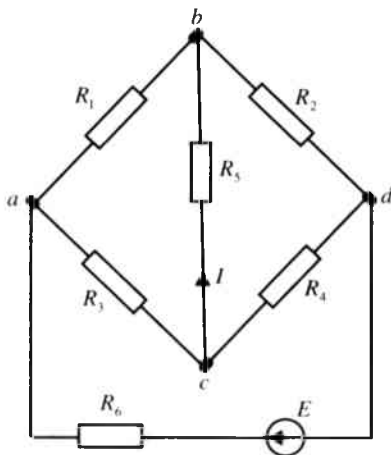
Masala 1.25. Ekvivalent generator usuliga asosan, elektr zanjir parametri $R = 1 \text{ Om}$, $R_0 = 0,5 \text{ Om}$, $E = 1 \text{ V}$, $J = 1 \text{ A}$ bo'lganda ampermetr qancha tok ko'rsatadi.



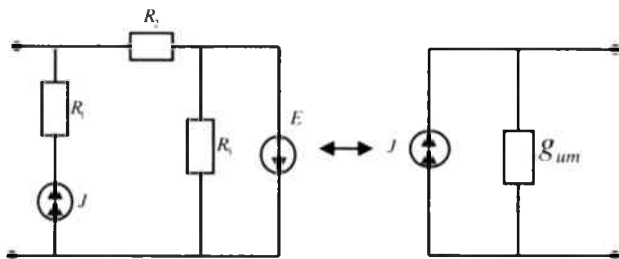
Javob: $I = 1 \text{ A}$

Masala 1.26. Koʻprik sxema parametri: $R_1=120\text{Om}$, $R_2=180\text{Om}$, $R_3=120\text{Om}$, $R_4=80\text{Om}$, $R_5=80\text{Om}$, $R_6=50\text{Om}$, EYK $E=12\text{ V}$. 5-tarmoqdagi tok I aniqlansin.

Javob: $I = -0,0084\text{ A}$



Masala 1.27: a) aktiv ikki qutbli zanjir parametri: $R_1 = 8\text{Om}$, $R_2 = 6\text{Om}$, $R_3 = 4\text{Om}$, $E = 6\text{ V}$, $J = 2\text{ A}$ ga teng. Ekvivalent tok manbai boʻlgan zanjirning (g_{um}) oʻtkazuvchanligi va tok qiymati aniqlansin.



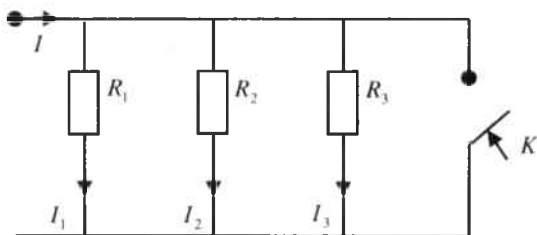
Javob: $g_{um} = \frac{1}{6}\text{ sim}$. $J = 1\text{ A}$.

1.4. Nazorat savollari

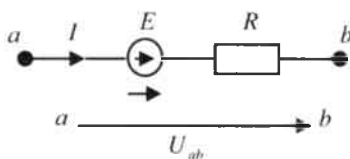
1. Elektrotexnika fani nimani oʻrgatadi?
2. Oʻzbekiston energetikasining rivojlanish tarixidan nimalarni bilasiz?
3. Elektr zanjir qanday qismlardan iborat?
4. Oʻzgarmas tok manbalarini bilasizmi?
5. EYK va tok manbai nima?
6. Elektr zanjir asosiy elementlari haqida maʼlumot bering.

7. Tarmoqlangan elektr zanjirlarni chlzb, tarmoq, tugun, kontur nima ekanligini izohlab bering.
8. Elektr maydon kuchlanganligi nima?
9. Elektr sig'imi izohlab bering va o'lchov birligi nima?
10. Elektr maydonining kuch chiziqlari ekvipotensial sirtga nisbatan qanday yo'nalgan?
11. Sig'imi $C=0,1 \text{ mkF}$ bo'lgan havoli kondensator qoplamalari orasidagi masofa $0,5 \text{ mm}$ ga teng bo'lsa, qoplamaning yuzasi (S) qancha bo'lishi kerak?
12. Kuchlanish $U=1 \text{ kV}$, sig'imi $C=0,1 \text{ mkF}$ bo'lgan kondensatorda qancha miqdorda energiya to'planadi?
13. Kondensatorlarning ketma-ket yoki parallel sxemada ulanishidan maqsad nima?
14. Nuqtaviy zaryadlangan zarrachalarning o'zaro ta'sir kuchi qaysi qonunga asosan aniqlanadi?
15. Potensiallar farqi, kuchlanish nima va o'lchov birligi nimadan iborat?
16. Zanjirning bir qismi va butun zanjir uchun Oni qonunini yozing.
17. Elektr zanjiri uchun Kirxgof qonunini ifodalab bering.
18. Elektr tok quvvati, (aktiv quvvat) qanday ifodalanadi va nimada o'lchanadi?
19. Elektr o'lchov asboblari: ampermetr, voltmeter va vattmetr elektr sxemaga qanday ulanadi?
20. Elektr manbai tashqi xarakteristikasini chizing va izoh bering. Qisqa tutashuv va salt holat deganda nimani tushunasiz?
21. Murakkab elektr zanjirni hisoblash usullariga izoh bering.
22. Potensial diagramma nima va u qanday chiziladi?
23. Quvvat balans tenglamasini yozing.
24. Qaysi holatda ekvivalent generator usulidan foydalanish qulay hisoblanadi va qanday amalga oshiriladi?
25. Aktiv va passiv ikki qutbli zanjir nima?
26. Elektr va magnit maydon energiyasi ifodasini yozing.
27. Ikkita potensialdan iborat bo'lgan sxema uchun tugunlararo usuliga asosan tenglama tuzing.
28. Ustma-ustlik usulini izohlab bering.

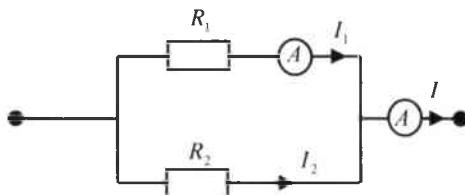
29. Yulduzchadan uchburchakga o'tish va aksincha holat almashtirish formulasini yozing.
30. Ikki qutbli liniyadan iste'molchiga maksimal quvvat uzatish shartini tushuntiring va tenglamasini yozing.
31. Aktiv qarshilik yoki o'tkazuvchanlik qanday ifodalanadi?
32. Manbaning ichki qarshiligi deganda nimani tushunasiz?
33. Elektr tok energiyasi bajargan ish tenglamasi qanday ifodalanadi?
34. Kuchlanishi 24 V bo'lgan manbaga ikkita qarshilik – $R_1 = 20\text{ Om}$; $R_2 = 28\text{ Om}$ ketma-ket ulangan. Tok necha amperga teng?
35. Ikkita qarshiligi bo'lgan tok zanjiri parallel ulanganda, umumiy qarshiligini ifodalang.
36. Parallel zanjirda K – kalit ulanganda tok qanday o'zgaradi?



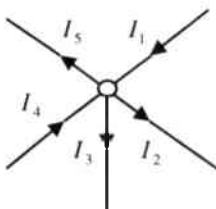
37. Ushbu sxemada tok qanday ifodalanadi?



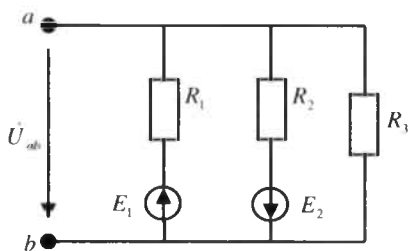
38. Parallel sxemada ulangan zanjirdagi tok $I_1 = 5\text{ A}$, $I = 8\text{ A}$ qarshiligi $R_1 = 3\text{ Om}$ bo'lganda, R_2 qarshilik qanchaga teng?



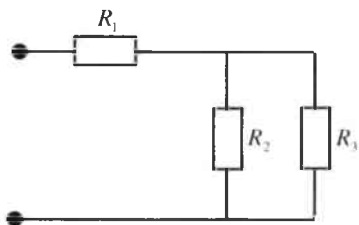
39. Tugun uchun Kirxgof 1-qonuniga asosan tenglama tuzing.



40. Parallel zanjir uchun ekvivalent kuchlanish ifodasiga asosan ekvivalent tok manbai sxemasi chizilsin .



41. Aralash sxemada ulangan zanjir qarshiligi $R_1=10\text{ Om}$, $R_2=R_3=4\text{ Om}$ bo'lib, $U = 40\text{ V}$ kuchlanishga ulanganda qancha aktiv quvvat sarflanadi?



42. Elektr quvvati $P= 600\text{ VT}$ bo'lgan issiqlik manbai (pechka) 5 soat davomida qancha elektr energiya sarflaydi?

II. SINUSOIDAL TOK ELEKTR ZANJIR

2.1. Asosiy nazariy tushunchalar

Sinusoidal davriy o'zgaruvchan tok, kuchlanishi va EYK oniy qiymati quyidagi funksiya ko'rinishda ifodalanadi.

$$\begin{aligned}i &= I_m \sin(\omega t + \varphi_i); \quad u = U_m \sin(\omega t + \varphi_u); \\e &= E_m \sin(\omega t + \varphi_u)\end{aligned}\quad (2.1)$$

Bunda:

i – sinusoidal o'zgaruvchan tokning oniy qiymati

I_m – amplituda, yoki maksimal qiymat

φ_i – boshlang'ich faza (grad)

ω – burchak chastota (rad/sek)

f – chastota (Gs)

T – davr (sek)

Sinusoidal o'zgaruvchan tokning effektiv yoki ta'sir etuvchi qiymati:

$$I = \sqrt{\frac{1}{T} \int_0^T i^2 dt} = \frac{I_m}{\sqrt{2}} \quad (2.2)$$

Sinusoidal o'zgaruvchan tokning yarim davrdagi o'rtacha qiymati:

$$I_{ur} = \frac{2}{T} \int_0^{\frac{T}{2}} i dt = \frac{2}{\pi} I_m \quad (2.3)$$

Sinusoidal o'zgaruvchan tokning forma va amplituda koeffitsienti:

$$K_f = \frac{I}{I_{or}}; \quad K_a = \frac{I_m}{I}; \quad (2.4)$$

Sinusoidal o'zgaruvchan elektr zanjir uchun Om qonuni:

$$I = \frac{U}{Z} = U_y (A); \quad (2.5)$$

yoki burchak koeffitsientlari:

$$\begin{aligned}\cos \varphi &= \frac{R}{z} = \frac{g}{y}; & \sin \varphi &= \frac{x}{y} = \frac{b}{y}; \\ \operatorname{tg} \varphi &= \frac{x}{R} = \frac{b}{g}; & \varphi &= \operatorname{arccctg} \frac{x}{R} = \frac{b}{g};\end{aligned}\quad (2.6)$$

To'la qarshilik:

$$Z = \sqrt{R^2 + x^2} \text{ (Om)}; \quad (2.7)$$

Ketma-ket ulangan R – aktiv; L – induktiv; C – sig'im qarshiliklar bo'lganda, reaktiv qarshilik:

$$X = X_L - X_C \quad (2.8)$$

Elektr zanjir induktiv xarakterga ega bo'lganda:

$$\omega L > \frac{1}{\omega C}; \quad \varphi > 0$$

Sig'im xarakterga ega bo'lsa: $\omega L < \frac{1}{\omega C}; \quad \varphi < 0$.

To'la o'tkazuvchanlik:

$$y = \sqrt{g^2 + b^2} \left(\frac{1}{\text{Om}} = \text{simens} \right); \quad (2.9)$$

Ekvivalent parametr o'xshashlik tenglamasi:

$$g = \frac{R}{z^2}; \quad b = \frac{X}{z^2}; \quad y = \frac{1}{z}; \quad (2.10)$$

$$R = \frac{g}{y^2}; \quad X = \frac{b}{y^2}; \quad z = \frac{1}{y}; \quad (2.11)$$

Iste'molchi ketma-ket ulangan elektr zanjirlarda ekvivalent qarshilik:

$$R_e = \sum_{\kappa=1}^n R_n; \quad X_e = \sum_{\kappa=1}^n X_n \quad (2.12)$$

Parallel ulangan holda:

$$g_e = \sum_{\kappa=1}^n g_n; \quad b_e = \sum_{\kappa=1}^n b_n \quad (2.13)$$

Tok va kuchlanishning aktiv va reaktiv tashkil etuvchilari:

$$U_a = IR = U \cos \varphi; \quad I_a = Ug = I \cos \varphi;$$

$$U_p = I_X = U \sin \varphi ; \quad I_p = Ub = I \sin \varphi ; \quad (2.14)$$

$$U = \sqrt{Ua^2 + Up^2}; \quad I = \sqrt{Ia^2 + Ip^2};$$

1. Sinusoidal o'zgaruvchan tokning quvvat ifodasi:

Sinusoidal o'zgaruvchan tokning o'riy qiymati $\varphi = 0$ bo'lganda:

$$R = ui [\cos \varphi - \cos(2\varphi t - \varphi)] \quad (2.15)$$

Aktiv quvvat:

$$P = UI \cos \varphi = I^2 R = U^2 g = U I_a = U_a I [\text{Vt, kVt}] \quad (2.16)$$

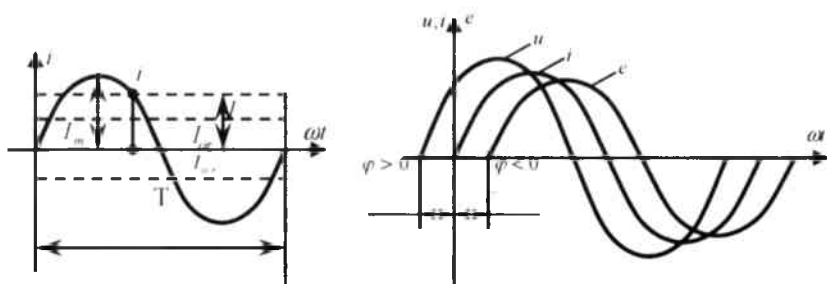
Reaktiv quvvat:

$$Q = UI \sin \varphi = I^2 x = U^2 b = U I_p = U_p I [\text{Var, kVar}] \quad (2.17)$$

To'la quvvat:

$$S = \sqrt{P^2 + Q^2} = UI = I^2 z = U^2 y [\text{Va, kVa}] \quad (2.18)$$

2. Sinusoidal o'zgaruvchan tok, kuchlanish va EYK grafik ifodasi:



Analitik ifodasi:

$$e = E_m \sin(\omega t + \phi_1); u = U_m \sin(\omega t + \phi_u); i = I_m \sin(\omega t + \phi_i) \quad (2.19)$$

Faza farqi:

$$\varphi = \varphi_u - \varphi_i \quad (2.20)$$

3. Sinusoidal o'zgaruvchan tokning vektor ifodasi yoki vektor diagrammasini tuzishda quyidagilarga e'tibor berish zarur:

a) aktiv qarshilikda tok va kuchlanish vektori ustma-ust tushadi ($\varphi=0$);

b) induktivlikda kuchlanish vektori U , tok vektori I ga nisbatan 90° farq qilib, oldinga ketadi ($\varphi > 0$);

d) sig'im qarshilikda kuchlanish U , I tokka nisbatan 90° orqada qoladi ($\varphi < 0$).

e) elektromagnit induksiya (o'z induksiya, o'zaro induksiya) qonuniga asosan induktivlikda, o'zgaruvchan tok hosil qiluvchi elektr yurituvchi kuch vektori E , magnit oqim vektori Φ yoki ψ nisbatan 90° farq qilib, orqada qoladi ($\varphi_c = -90^\circ$).

f) induktivlik kuchlanish U_L vektoriga nisbatan EYK vektori E 180° farq qilib, teng va qarama-qarshi yo'nalishda ifodalanadi.

g) qarshiliklar uchburchak vektor ifodasidan R va Z hamda g va u orasidagi burchak φ ga teng.

2.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 2.1. O'zgaruvchan magnit oqimi $\Phi = 0,01 \sin 314t$ (vb) bo'lib, chulg'amlar soni $W = 50$ bo'lganda g'altak aylanma harakatlaniishi natijasida hosil bo'ladigan EYKni aniqlang.

Yechish.

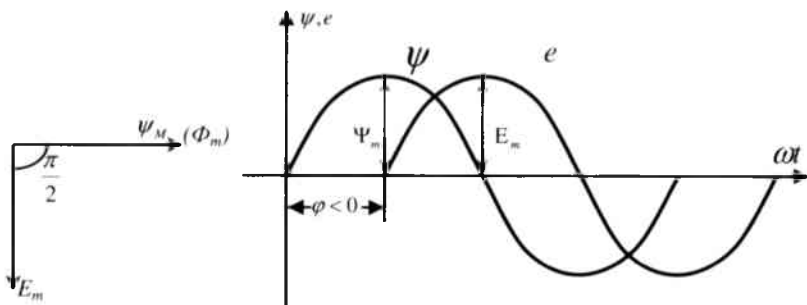
G'altakning ilashgan magnit oqimi: $\psi = w\phi = 0,5 \sin 314t = \psi_m \sin t$

O'zinduksiya qonuniga asosan:

$$e = -\frac{d\psi}{dt} = \omega\psi_m \cos \omega t = E_m \sin(\omega t - 90^\circ) \text{ yoki: } E_m = \omega\psi_m = 157(\text{V})$$

$$\text{EYK effektiv qiymati: } E = \frac{E_m}{\sqrt{2}} = 90(\text{V})$$

Vektor ifodasi va vaqt bo'yicha o'zgaruvchan grafigini chizamiz.



Masala 2.2. O'ramlar soni $W=20$, yuzasi $S=100\text{ (sm}^2\text{)}$ bo'lgan halqa, magnit induksiyasi $B=2\text{ (vb/m)}$ teng bo'lgan magnit maydon ichida $n=6000\text{ (ayl/min)}$ tezlik bilan aylanganda, halqada hosil bo'ladigan magnit oqim, oniy qiymat, EYK amplitudasi, davri va chastotasi aniqlanib, vektor ifodasi va vaqtga nisbatan o'zgaruvchan diagrammasi tuzilsin.

Yechish.

Halqaning boshlang'ich holati $\alpha=0$, $\alpha=\omega t$ bo'lib, halqa aylanishi natijasida kesib o'tuvchi magnit oqimning oniy qiymati:

$$\Phi = BS \cos \alpha = \Phi_m \cos \omega t$$

Halqada hosil bo'ladigan ilashgan magnit oqim oniy qiymati:

$$\begin{aligned} \psi &= \Phi W = W \Phi_m \cos \omega t = WBC \cos \omega t = \psi_m \cos \omega t = \\ &= 20 \cdot 2 \cdot 100 \cdot 10^{-4} \cos 628t = 0,4 \sin(628t + 90^\circ) \end{aligned}$$

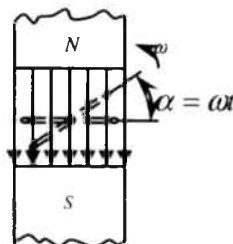
Bunda:

$$\omega = \frac{2\pi n}{60} = \frac{2 \cdot 3,146000}{60} = 628 \left(\frac{1}{\text{sek}} \right) - \text{burchak chastota}$$

Halqada hosil bo'ladigan EYK oniy qiymati:

$$\begin{aligned} e &= -\frac{d\Psi_m}{dt} = -\frac{d}{dt}(\Psi_m \cos \omega t) = \omega \Psi_m \sin \omega t = \\ &= E_m \sin \omega t = 251,2 \sin 628t \end{aligned}$$

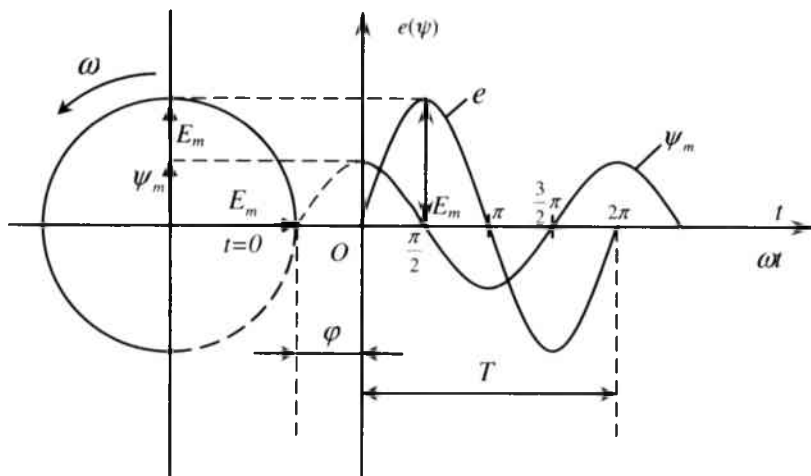
Halqa T davrda bir marotaba aylanadi: $\omega T = 2\pi$



Bundan: $T = \frac{2\pi}{\omega} = 0,01(\text{sek})$

O'zgaruvchan tok chastotasi: $f = \frac{1}{T} = \frac{1}{0,01} = 100\text{ (Gs)}$

Vektor ifodasi chizmada keltirilgan:



Masala 2.3. O'ramlar soni ψ bo'lgan aylanma harakatlanuvchi g'altakda induksiyalangan EYK to'g'ri burchakli impulsli formaga ega bo'lib, EYK amplitudasi: $E_m = 10$ (V) va $f = 50$ (Gs) ga teng. EYK E o'rtacha va effektiv qiymati, amplituda va forma koeffitsienti hamda magnit oqimi qiymatini aniqlang.

Yechish.

$$\text{EYK o'rtacha qiymati: } E_{o'r} = \frac{2}{T} \int_0^T e dt = \frac{2}{T} E_m \frac{T}{2} = E_m = 10 \text{ (V)}$$

$$\text{Effektiv qiymat: } E = \sqrt{\frac{1}{T} \int_0^T e^2 dt} = \sqrt{\frac{1}{T} E_m^2 T} = E_m = 10 \text{ (V)}$$

$$\text{Amplituda va forma koeffitsienti: } K_a = \frac{E_m}{E} = 1, K_\phi = \frac{E}{E_{o'r}} = 1$$

$$\text{O'zinduksiya qonuniga asosan: } \psi = - \int e dt$$

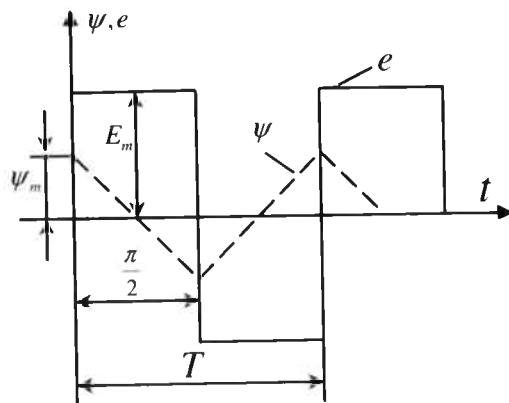
Keltirilgan funksiyada ψ to'g'ri burchakli uchburchak shaklida o'zgaruvchan bo'lib, $T = 0,02 \text{ sek} = 20 \text{ m sek}$ teng, yoki:

$$E_{ur} = \frac{\Delta \psi}{\Delta t}$$

Bundan $\Delta\psi = E_{o,r} \Delta t$ hamda $\Delta\psi = 2\psi_m, \Delta t = \frac{T}{2}$ bo'lganligi uchun

g'altakdagi magnit oqim ψ qiymati:

$$\psi_m = \frac{1}{2} \Delta\psi = \frac{1}{2} E_{cp} \frac{T}{2} = \frac{1}{2} \cdot 10 \cdot \frac{0,02}{2} = 0,05 \text{ vb} = 50 \text{ (mVb)}$$



Masala 2.4. Elektr o'lchov asboblari yordamida aktiv va induktiv qarishilik bo'lgan elektr zanjirining kuchlanish va chastotasi $U_R=20 \text{ V}$, $U_L=30 \text{ V}$, $I=5 \text{ A}$, $f=50 \text{ gs}$ bo'lganda, umumiy kuchlanishi, parametr, quvvat va magnit maydon elektr energiyasi aniqlansin.

Yechish. (2. 14) tenglamaga asosan:

$$U = \sqrt{U_R^2 + U_L^2} = \sqrt{400 + 900} = \sqrt{1300} = 36 \text{ V}$$

$$\text{Umumiy qarshilik: } Z = \frac{U}{I} = \frac{36}{5} = 7,2 \text{ Om}$$

$$\text{Aktiv qarshilik: } R = \frac{U_R}{I} = \frac{20}{5,2} = 4 \text{ Om}.$$

$$\text{Induktiv (reaktiv) qarshilik: } X_L = \frac{U_L}{I} = \frac{30}{5} = 6 \text{ Om}$$

(2. 6) tenglamaga asosan:

$$\cos \varphi = \frac{R}{Z} = \frac{4}{7,2} = 0,55; \quad \sin \varphi = \frac{X}{Z} = \frac{6}{7,2} = 0,8$$

$$\text{Aktiv quvvat: } P = I^2 R = UI \cos \varphi = 25 \cdot 4 = 100 \text{ Vt}$$

$$\text{Reaktiv quvvat: } Q_L = I^2 X_L = UI \sin \varphi = 25 \cdot 6 = 150 \text{ VAR}$$

To'la quvvat: $S = UI = I^2 Z = Z \sqrt{P^2 + Q^2} = 36 \cdot 5 = 180 \text{ VA}$

Induktivlik: $L = \frac{X_L}{\omega} = \frac{6}{314} = 0,018 \text{ GN} = 18 \text{ MGN}$.

Magnit maydon energiyasi:

$$W_M = \frac{LI^2}{2} = \frac{25 \cdot 9 \cdot 10^{-3}}{2} = 225 \cdot 10^{-3} = 0,225 \cdot \text{DJ}.$$

Masala 2.5. Sinusoidal o'zgaruvchan elektr kuchlanishi $u = 120 \sin 1000t$ bo'lgan generatorga induktiv qarshilik ulangan bo'lib, sinusoidal tok o'tadi: $i = 8 \sin(1000t - 53^\circ)$.

O'zgaruvchan kuchlanish chastotasi ikki martaga kamayganda: induktiv g'altakning aktiv qarshiligi, induktivligi, tok qiymati va faza burchagi aniqlansin.

Yechish.

Masalaning sharti bo'yicha umumiy qarshilik:

$$Z = \frac{U_m}{I_m} = 15 (\text{Om}) \text{ bo'lib, faza burchagi } \varphi = \varphi_u - \varphi_i = 53^\circ$$

Qarshilik uchburchak ifodaga asosan:

$$R = Z \cos \varphi = 15 \cos 53^\circ = 9 (\text{Om})$$

$$X = Z \sin \varphi = 15 \sin 53^\circ = 12 (\text{Om})$$

$$\text{Induktivlik: } L = \frac{x_L}{\omega} = \frac{12}{1000} = 0,012 \text{ gn} = 12 (\text{mGn})$$

Kuchlanish chastotasi ikki martaga kamaytirilgan holda induktiv qarshilik ham ikki martaga kamayadi: $x'_L = 6 \text{ Om}$

$$\text{Faza farqi: } \varphi' = \arctg \frac{x'_L}{R} = \frac{6}{9} = 33^\circ 40'$$

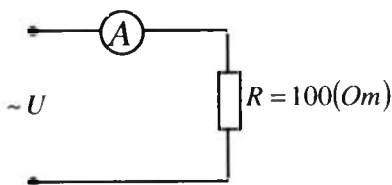
$$\text{To'la qarshilik: } Z' = \frac{x'_L}{\sin \varphi'} = 10,8 (\text{Om})$$

$$\text{Tok amplitudasi: } I'_m = \frac{U_m}{z'} = \frac{120}{10,8} = 11,09 (\text{A})$$

$$\text{Tokning oniy qiymati: } i = 11,09 \sin(500t - 33^\circ 40')$$

Masala 2.6. O'zgaruvchan tok kuchlanishi $U = 283 \sin t$ bo'lgan generatorga, aktiv qarshiligi $R = 10 (\text{Om})$ reostat ulangan. Reostatdan

o'tuvchi tokning effektiv oniy qiymati va o'rtacha quvvat qiymati aniqlanib, vaqt bo'yicha o'zgaruvchan diagrammasi chizilsin.



Yechish.

Tokning amplituda qiymati $I_m = \frac{U_m}{R} = \frac{283}{10} = 28,3(A)$; effektiv

qiymati: $I = \frac{I_m}{\sqrt{2}} = 20(A)$

Oniy qiymati: $i = I_m \sin \omega t = 28,3 \sin 314t$

Aktiv quvvatning o'rtacha qiymati:

$$P_{sp} = \frac{1}{T} \int_0^T P dt = UI = I^2 R = 4000 VT = 4(kVt)$$

Quvvatning oniy qiymati:

$$P = ui = UI + UI \sin(2\omega t - 90) = [4 + 4 \sin(2\omega t - 90)](kVt)$$

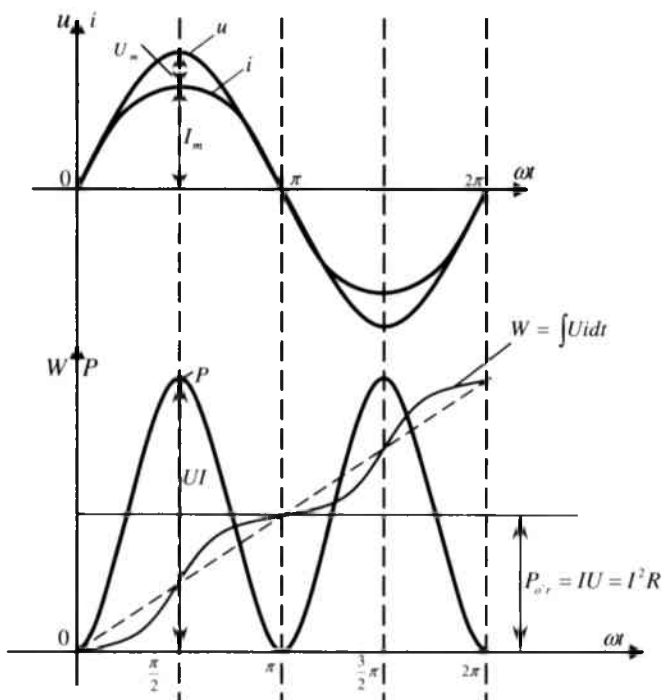
Elektr energiyasining oniy qiymati:

$$\begin{aligned} W &= \int P dt = UIt - \frac{UI}{2\omega} \sin 2\omega t = 4000t - \frac{4000}{2 \cdot 314} \sin \omega t = \\ &= (4000 - 6,37 \sin 2\omega t)(J) \end{aligned}$$

Demak Djoul-Lens qonuniga asosan aktiv qarshilik (reostatda)da o'zgaruvchan elektr tok energiyasi issiqlik energiyasi ajralib sarf bo'ladi.

Aktiv quvvat vaqt bo'yicha o'zgaruvchan diagrammasi chizmada keltirilgan.

Bunda tok va kuchlanish orasidagi burchak $\varphi=0$ bo'lib, I_m va U_m vektor ifodasi ustma-ust tushadi.



Masala 2.7. Induktivligi $L=0,27$ (Gn), aktiv qarshiligi $R=49$ (Om) bo'lgan reaktiv g'altak, sinusoidal o'zgaruvchan tok chastotasi $f=50$ (Gs), $U=220$ V kuchlanishga ulangan.

Tokning effektiv qiymati I , tok va kuchlanish orasidagi burchak φ aniqlanib vektor ifodasi tuzilsin.

Yechish.

Om qonuniga asosan:

$$I = \frac{U}{z} = \frac{220}{\sqrt{R^2 + (\omega L)^2}} = \frac{220}{\sqrt{49^2 + (314 \cdot 0,27)^2}} = 2,24(A)$$

Bunda:

$$\omega = 2\pi f = 314 \cdot 2 \cdot 50 = 314 (\text{rad / sek})$$

$$\text{Burchak fazasi: } \varphi = \arctg \frac{x}{R} = \frac{100}{49} = 2 = 60^\circ$$

$$\text{yoki fazadagi farq: } \varphi = \varphi_u - \varphi_i = 0 - 60^\circ = -60^\circ$$

Tokning oniy qiymati: $i = \sqrt{2}I = 3,16 \sin(\omega t - 60^\circ) (A)$

Kuchlanish oniy qiymati: $u = 310 \sin \omega t (V)$

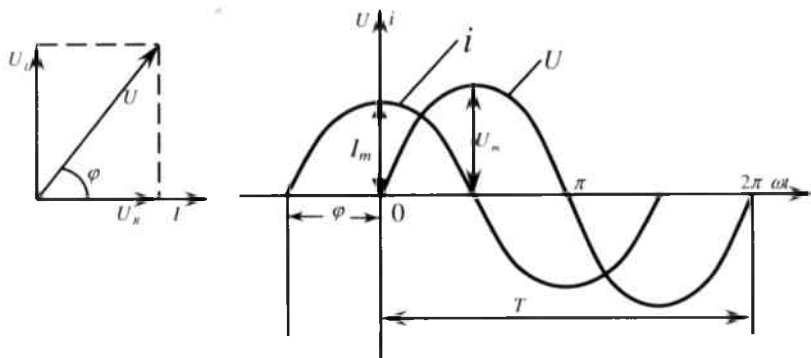
Bundan: $U_m = \sqrt{2}U = 1,41 \cdot 220 = 310 (V)$

Masshtab tanlab, tok va kuchlanish vektor ifodasini va vaqt bo'yicha o'zgaruvchan diagrammasini tuzamiz.

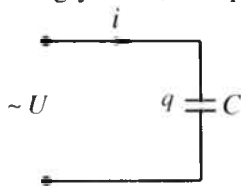
Bunda R va x_L qarshilikdagi kuchlanish:

$U_R = IR = 2,24 \cdot 49 = 115 (V);$

$U_L = I_L X_L = 2,24 \cdot 100 = 224 (V);$



Masala 2.8. Sig'imi $C = 41,6 (mkf)$ bo'lgan kondensator $U = 120 \sin(314t + \frac{\pi}{4})$ kuchlanishga ulangan. Sig'imdagi tok i , zaryadi q , quvvat P_c va elektr maydon energiyasi W_e aniqlansin.



Yechish.

Sig'im qarshiligini aniqlaymiz: $X_c = \frac{1}{\omega c} = \frac{1}{314 \cdot 41,6 \cdot 10^{-6}} = 76,6 \text{ } \Omega$

Tokning amplituda qiymati: $I_m = \frac{U_m}{X_c} = 1,57 (A)$

Tok va kuchlanish orasidagi faza farqi: $\varphi = \varphi_U + \varphi_I = \frac{\pi}{4} + \frac{\pi}{2} = \frac{3}{4}\pi$

Tokning oniy qiymati: $i = 1,57 \sin(314t + \frac{3}{4}\pi) (A)$

Sig'imdagi zaryadning oniy qiymati:

$$q = CU = 41,6 \cdot 10^{-6} \cdot 120 \sin(314t + \frac{\pi}{4}) = 5 \sin(314t + \frac{\pi}{4}) \text{ (kulon)}$$

Quvvatning oniy qiymati:

$$P = U_m I_m [\cos \varphi - \cos(2\omega t + 2\varphi_U - \varphi)] = -UI \cos 2\omega t$$

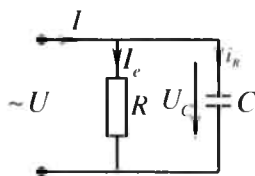
Bunda: $\varphi = -\frac{\pi}{2}$ va $\varphi_U = \frac{\pi}{4}$ bo'lganligi uchun:

$$P = \frac{120 \cdot 1,57}{2} \cos 2\omega t = 93,2 \cos 2\omega t (Vt)$$

Sig'imda hosil bo'ladigan elektr maydon energiyasi:

$$W_\gamma = \frac{CU^2}{2} = \frac{1}{2} \cdot 41,6 \cdot 10^{-6} \cdot 120^2 \sin^2(314t + \frac{\pi}{4}) = 0,15(1 + \sin 628t) (J)$$

Masala 2.9. Parallel sxemada ulangan elektr zanjir kuchlanishl $U=150 (V)$, $I=5(A)$, $I_R=3(A)$ va chastotasi $f=50 (Gs)$ ga teng. Sig'im parametri C , hamda zanjirda sarf bo'ladigan to'la quvvat aniqlansin.



Yechish.

Pifagor teoremasiga asosan tok uchburchak vektor ifodasidan:

$$I_C^2 = I^2 - I_R^2 = \sqrt{25 - 9} = 4(A)$$

Sig'imdagi kuchlanish: $U_C = U = 150 V$

Sig'im parametri: $C = \frac{I_C}{U_C \omega} = \frac{4}{150 \cdot 314} = 85 (mkF)$

Elektr zanjir to'la quvvati: $S = UI = 150 \cdot 5 = 750 (VA)$

Aktiv qarshilik quvvati: $P = UI_R = 150 \cdot 3 = 450 (Vt)$

Sig'im qarshilik reaktiv quvvati:

$$Q_C = \sqrt{S^2 - P^2} = \sqrt{750^2 - 450^2} = 600 \text{ (Vt)}$$

Masala 2.10. O'zgaruvchan tok chastotasi $f = 500 \text{ (Gs)}$ bo'lgan elektr zanjirda induktivligi $L = 5 \text{ (MGn)}$, tok $I = 10 \text{ (A)}$ bo'lib, $P = 1 \text{ (KVT)}$ quvvat sarflanadi.

Umumiy kuchlanish U va quvvat koeffitsienti $\cos \varphi$ aniqlansin.

Yechish.

$$\text{Aktiv quvvat tenglamasidan: } P = I^2 R; \quad R = \frac{P}{I^2} = \frac{1000}{10} = 100 \text{ (Om)}$$

G'altak to'la qarshiligi:

$$Z_k = \sqrt{R^2 + (\omega L)^2} = \sqrt{100^2 + (6,28 \cdot 500 \cdot 5 \cdot 10^{-3})^2} = 18,6 \text{ (Om)}$$

$$\text{Kuchlanish:} \quad U = I Z_k = 10 \cdot 18,6 = 186 \text{ (V)}$$

$$\text{Quvvat koeffitsienti:} \quad \cos \varphi = \frac{P}{S} = \frac{1000}{IU} = \frac{1000}{186 \cdot 10} = 0,54$$

Masala 2.11. Kuchlanish $U = 283 \sin 500t$ bo'lgan generatorga parametr $L = 0,016 \text{ Gn}$, $R = 6 \text{ Om}$ bo'lgan induktiv g'altak ulangan bo'lib, shu g'altakdan oqib o'tuvchi tokning oniy qiymati (i_t) kuchlanishi (U_a, U_p), to'la quvvat (S) aniqlanib, kuchlanish uchburchak vektor ifodasi chizilsin.

Yechish.

$$\text{Induktiv qarshilik: } X_L = \omega L = 500 \cdot 0,016 = 8 \text{ Om}$$

$$\text{Fazadagi farq: } \varphi = \arctg \frac{x}{R} = \frac{8}{6} = 53^\circ, \quad \varphi_i = \varphi_U - \varphi = -53^\circ$$

$$\text{To'la qarshilik: } Z = \sqrt{R^2 + x^2} = \sqrt{6^2 + 8^2} = 10 \text{ (Om)}$$

$$\text{Tok amplitudasi: } I_m = \frac{U_m}{z} = \frac{283}{10} = 28,3 \text{ (A)}$$

$$\text{Oniy qiymat: } i_m = 28,3 \sin(500t - 53^\circ) \text{ (A)}$$

Aktiv va reaktiv kuchlanish:

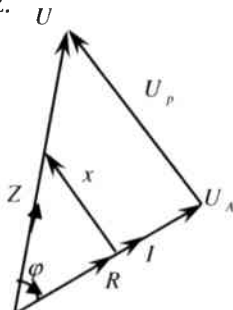
$$U_{ma} = U_m \cos \varphi = 170 \text{ (V)}, \quad U_{mp} = U_m \sin \varphi = 226 \text{ (V)}$$

To'la quvvat: $S = UI = \frac{U_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = 400 \text{ Vt} = 4 (\text{kVt})$

Aktiv quvvat: $P = S \cos \varphi = 4 \cdot 0,6 = 2,4 (\text{kVt})$

Reaktiv quvvat: $Q = S \sin \varphi = 4 \cdot 0,8 = 3,2 (\text{kVar})$

Vektor ifodasini chizamiz.

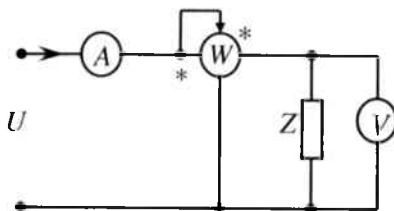


Aktiv qarshilikdagi kuchlanish vektori (U_a) tok vektori bilan ustma-ust tushadi, shu sababli $\varphi_{ua} = -53^\circ$ ga teng.

U_p – kuchlanish esa tok vektoriga nisbatan 90° farq qilib $\varphi_{Up} = 37^\circ$ ga teng.

Ya'ni: $U_a = 170 \sin(500t - 53^\circ) \text{ V}$, $U_p = 226 \sin(500t - 37^\circ) \text{ V}$

Masala 2.12. Berilgan elektr elektr zanjirga ulangan elektr asboblarida: ampermetr toki $I=20 \text{ A}$, voltmeterdagi kuchlanish $U=100 \text{ V}$ va vattmetr quvvati $P=1200 \text{ Vt}$ ga teng. Elektr zanjir induktiv ($\varphi > 0$) xarakterga ega bo'lgan holat uchun o'xshashlik ekvivalent sxemasi tuzilib, qarshilik parametri aniqlansin hamda uchburchak vektor ifodasi tuzilsin.



Yechishi.

To'la qarshilik: $Z = \frac{U}{I} = 5(\text{Om})$

Aktiv qarshilik: $R = \frac{P}{I^2} = \frac{1200}{20^2} = 3(\text{Om})$

Induktiv qarshilik: $x_L = \sqrt{Z^2 - R^2} = 4(\text{Om})$

Aktiv qarshilik kuchlanishi: $U_R = U_a = IR = 60(\text{V})$

Induktivlik reaktiv kuchlanishi: $U_L = U_p = Ix_L = 80(\text{V})$

Aktiv o'tkazuvchanlik (2.10) ifodaga asosan:

$$g = \frac{R}{Z^2} = 0,12 \left(\frac{1}{\text{Om}} \right)$$

Induktiv o'tkazuvchanlik: $b_L = \frac{x_L}{Z^2} = 0,16 \left(\frac{1}{\text{Om}} \right)$

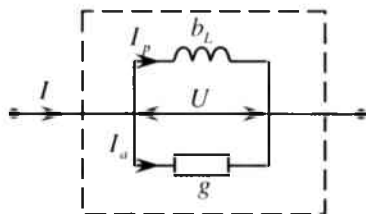
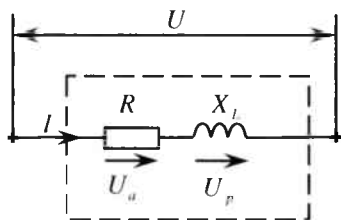
To'la o'tkazuvchanlik:

$$y = \frac{1}{Z} = \sqrt{g^2 + b_L^2} = 0,2 \left(\frac{1}{\text{Om}} \right)$$

Elektr o'lchov asboblari ko'rsatgan qiymatlari bo'yicha:

$$g = \frac{P}{U_2} = 0,12 \left(\frac{1}{\text{Om}} \right); \quad y = \frac{I}{U} = 0,2 \frac{1}{(\text{Om})}; \quad b_L = \sqrt{y^2 - g^2} = 0,16 \frac{1}{(\text{Om})}$$

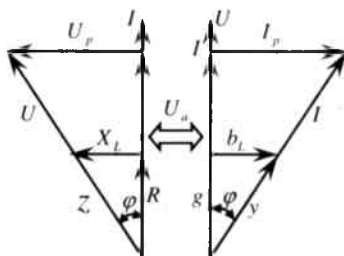
Aniqlangan qiymatlar asosida ekvivalent o'xshashlik sxemasini chizamiz.



Bundan aktiv qarshilikdagi tok: $I_R = I_a = Ug = 12(\text{A})$

Induktivlikdagi reaktiv tok: $I_L = I_p = Ub_L = 16(\text{A})$

Qarshilik va o'tkazuvchanlik, tok va kuchlanish ekvivalent (o'xshashlik) vektor ifodasi quyidagi ko'rinishda bo'ladi.



Masala 2.13. Induktivligi $L=0,18$ (Gn), aktiv qarshlligi $R=30$ Om ga teng bo'lgan induktiv g'altak, sig'imi $C=40$ (mkf) bo'lgan kondensator bilan ketma-ket sxemada biriktirilib, $U = 250 \sin 500t$ (V) manba kuchlanishiga ulangan. Tok (I_m), faza burchagi (φ), induktivlik va sig'im kuchlanishi aniqlanib vektor ifodasi tuzilsin.

Yechish.

Reaktiv qarshlik ifodasiga asosan:

$$x_L = \omega L = 500 \cdot 0,18 = 90(\text{Om})$$

$$x_C = \frac{1}{\omega C} = \frac{10^3}{500 \cdot 40} = 50(\text{Om})$$

$$x = x_L - x_C = 40(\text{Om})$$

$$\text{To'la qarshilik: } z = \sqrt{R^2 + x^2} = 50(\text{Om})$$

$$\text{Tok amplitudasi: } I_m = \frac{U_m}{z} = \frac{250}{50} = 5(\text{A})$$

Tok va kuchlanish orasidagi faza farqi:

$$\varphi = \arctg \frac{x}{R} = \arctg 1,33 = 53^\circ 8'$$

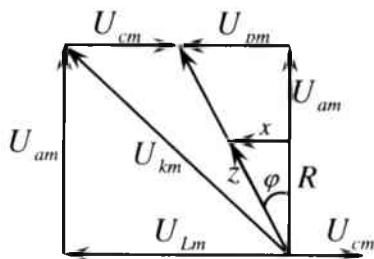
$$\text{Sig'imdagi kuchlanish: } U_{cm} = x_C I_m = 5 \cdot 50 = 250 \text{ V}$$

$$\text{Induktivlikdagi kuchlanish: } U_{Lm} = x_L I_m = 90 \cdot 5 = 450 \text{ V}$$

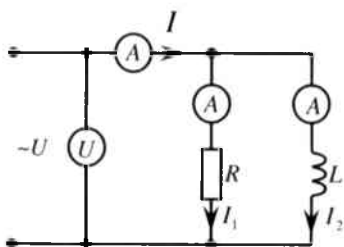
$$\text{Aktiv qarshilikdagi kuchlanish: } U_{Rm} = R I_m = 30 \cdot 5 = 150 \text{ V}$$

$$\text{G'altakdagi umumiy kuchlanish: } U_{km} = \sqrt{U_{Rm}^2 + U_{Lm}^2} = 470 \text{ V}$$

Aniqlang qiymatlar bo'yicha masshtab m_v , m_u tanlanib vektor diagrammasini tuzamiz.



Masala 2.14. Chizmada keltirilgan sxemaga ulangan elektro-dinamik asboblarning ko'rsatishi: $U=120$ V, $I=10$ A, $I_2=6$ A bo'lib, chastotasi $f=1$ kGs bo'lganda, tok I , aktiv qarshilik R va induktivlik L aniqlansin.



Yechish.

O'zgaruvchan tok burchak chastotasi: $\omega = 2\pi f = 6280 \left(\frac{1}{\text{sek}} \right)$

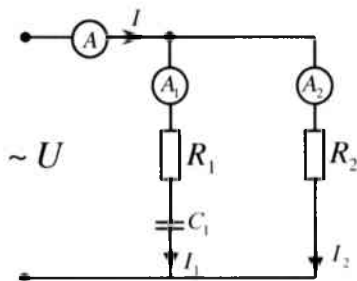
Induktiv qarshilik: $x_L = \frac{U}{I_2} = \frac{120}{6} = 20(\text{Om})$

Induktivlik: $L = \frac{x_L}{\omega} = 3,18(\text{mGn})$

Aktiv qarshilikdan o'tuvchi tok: $I_1 = \sqrt{I^2 - I_2^2} = 8(\text{A})$

Qarshiligi: $R = \frac{U}{I_1} = 15(\text{Om})$

Masala 2.15. Sxemaga ulangan ampermetrning ko'rsatishi: $I=25A$, $I_1=13,5A$, $I_2=15(A)$ va $R_2=20\text{ }Om$, $f=50\text{ (Gs)}$ ga teng bo'lgan holat uchun zanjir parametr va sarf bo'ladigan aktiv quvvat (P) hamda quvvat koeffitsienti ($\cos\varphi$) hisoblab topilsin.



Yechish.

Parallel ulangan holatda umumiy kuchlanish:

$$U = I_2 R_2 = 20 \cdot 15 = 300 \text{ (V)}$$

Umumiy tok: $I = \sqrt{I_a^2 + I_p^2}$

Bundan: $I_a = I_2 + I_1 \cos\varphi_1$, $I_p = I_1 \sin\varphi$

yoki:

$$I^2 = (I_2 + I_1 \cos\varphi_1)^2 = I_1^2 \sin^2\varphi_1 = I_1^2 + I_2^2 + 2I_1 I_2 \cos\varphi_1$$

Birinchi tarmoq burchagi: $\cos\varphi_1 = \frac{I^2 - I_1^2 - I_2^2}{2I_1 I_2} = 0,538$

To'la qarshilik: $z_1 = \frac{U}{I_1} = \frac{300}{13,5} = 22,2(Ohm)$

Aktiv qarshilik: $R_1 = z_1 \cos\varphi_1 = 11,9(Ohm)$

Sig'im qarshiligi: $x_1 = \sqrt{z_1^2 - R_1^2} = 18,8(Ohm)$

Sig'im parametri: $C_1 = \frac{1}{x_1 \omega} = 169 \cdot 10^{-6} F = 169(\mu F)$

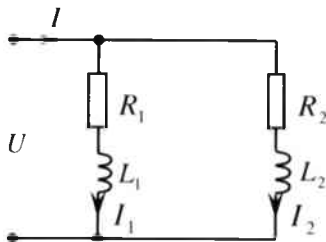
Elektr zanjirning quvvat koeffitsienti:

$$\cos\varphi = \frac{I_a}{I} = \frac{I_2 + I_1 \cos\varphi_1}{I} = 0,89$$

Zanjirda sarf bo'ladigan aktiv quvvat:

$$P = UI \cos \varphi = 300 \cdot 25 \cdot 0,89 = 6680 \text{ VT} = 6,68 (\text{kVt})$$

Masala 2.16. Kuchlanish $U=120 \text{ V}$ chastotasi $f=50 \text{ Gs}$ bo'lgan elektr zanjir parametri: $R_1=4 \text{ Om}$, $L_1=0,6 \text{ MGn}$, $R_2=6 \text{ Om}$, $L_2=25,5 \text{ MGn}$ bo'lgan ikkita induktiv iste'molchi parallel ulangan. Tarmoqdagi tok, zanjirning quvvat ko'effitsienti va iste'molchilarda sarf bo'ladigan aktiv quvvat aniqlansin.



Yechish.

Birinchi g'altak induktiv qarshiligi:

$$x_{L_1} = 2\pi f L_1 = 2 \cdot 3,14 \cdot 50 \cdot 0,6 \cdot 10^{-3} = 3 \text{ Om}$$

Birinchi g'altak to'la qarshiligi: $Z_1 = \sqrt{R_1^2 + x_{L_1}^2} = \sqrt{4^2 + 3^2} = 5 \text{ Om}$

Birinchi tarmoqdagi tok: $I_1 = \frac{U}{Z} = \frac{120}{5} = 24 \text{ A}$

Birinchi g'altak quvvat ko'effitsienti: $\cos \varphi_1 = \frac{R_1}{Z} = \frac{4}{5} = 0,8$

(burchak $\varphi_1 = 36^\circ 50'$ bo'lganda $\sin \varphi_1 = 0,6$)

Bunda birinchi tarmoqdagi tok aktiv tashkil etuvchisi:

$$I_{a_1} = I_1 \cos \varphi_1 = 24 \cdot 0,8 = 19,2 \text{ A}$$

Reaktiv tashkil etuvchisi:

$$I_{\rho_1} = I_1 \sin \varphi_1 = 24 \cdot 0,6 = 14,4 \text{ A}$$

Ikkinchi g'altak induktiv qarshiligi:

$$x_{L_2} = 2\pi f L_2 = 6,28 \cdot 50 \cdot 25,5 \cdot 10^{-3} = 10 \text{ Om}$$

Ikkinchi tarmoqdagi tok:

$$I_2 = \frac{U_2}{Z_2} = \frac{120}{10} = 12 \text{ A}$$

Ikkinchi g'altak quvvat ko'effitsienti:

$$\cos \varphi_2 = \frac{R_2}{Z_2} = \frac{6}{10} = 0,6$$

(burchak $\varphi_2 = 52^\circ 10'$ bo'lganda $\sin \varphi_2 = 0,8$)

Ikkinchi tarmoqdagi tok aktiv tashkil etuvchisi:

$$I_{a_2} = I_2 \cos \varphi_2 = 12 \cdot 0,6 = 7,2 \text{ A}$$

Reaktiv tashkil etuvchisi:

$$I_{p_2} = I_2 \sin \varphi_2 = 12 \cdot 0,8 = 9,6 \text{ A}$$

Umumiy tok aktiv tashkil etuvchisi qismi:

$$I_a = I_{a_1} + I_{a_2} = 19,2 + 7,2 = 26,4 \text{ A}$$

Reaktiv tashkil etuvchisi:

$$I_p = I_{p_1} + I_{p_2} = 14,4 + 9,6 = 24 \text{ A}$$

Umumiy tok qiymati:

$$I = \sqrt{I_a^2 + I_p^2} = 36 \text{ A}$$

Zanjirdagi quvvat ko'effitsienti:

$$\cos \varphi = \frac{I_a}{I} = \frac{26,4}{36} = 0,733$$

Birinchi g'altakda sarf bo'ladigan aktiv quvvat:

$$P_1 = UI_1 \cos \varphi_1 = 120 \cdot 24 \cdot 0,8 = 2304 \text{ Vt}$$

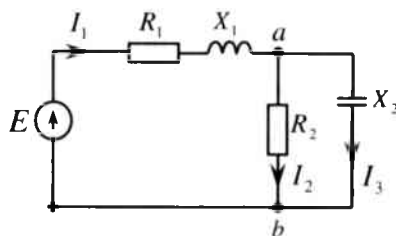
Ikkinchi g'altakda sarf bo'ladigan aktiv quvvat:

$$P_2 = UI_2 \cos \varphi_2 = 120 \cdot 12 \cdot 0,6 = 864 \text{ Vt}$$

Iste'molchilarda sarf bo'ladigan aktiv quvvat:

$$P = P_1 + P_2 = 2304 + 864 = 3168 \text{ Vt}$$

Masala 2.17. Chizmada keltirilgan sxemada o'zgaruvchan kuchlanish chastotasi $f=50 \text{ Gs}$ bo'lgan generatorning aktiv quvvati $P=31,25(\text{kVt})$, zanjir qarshiligi $R_1=2 \text{ Om}$, $x_1=36 \text{ (Om)}$, $R_2=75 \text{ Om}$, $x_2=100 \text{ (Om)}$ ga teng. Elektr zanjirdagi tok va kuchlanish hisoblansin.



Yechish.

Parallel ulangan tarmoq o'tkazuvchanligi:

$$g_{ab} = \frac{1}{R_2} = 1,33 \cdot 10^{-2} \left(\frac{1}{\text{Om}} \right); \quad b_{ab} = \frac{1}{x_3} = -0,01 \left(\frac{1}{\text{Om}} \right)$$

Umumiy o'tkazuvchanlik: $y_{ab} = \sqrt{g_{ab}^2 + b_{ab}^2} = 1,67 \cdot 10^{-2} \left(\frac{1}{\text{Om}} \right)$

Ikki qutbli elektr zanjirlar ekvivalent o'xshashlik tenglamasidan (2.11):

$$R_{ab} = \frac{g_{ab}}{y_{ab}^2} = 48(\text{Om}); \quad x_{ab} = \frac{b_{ab}}{y_{ab}^2} = -\frac{0,01}{2,78 \cdot 10^{-4}} = 36(\text{Om})$$

Zanjirning umumiy aktiv va reaktiv qarshiligi:

$$R = R_1 + R_{ab} = 50(\text{Om}); \quad x = x_1 + x_{ab} = 36 - 36 = 0$$

To'la qarshilik: $Z = \sqrt{R^2 + x^2} = 50(\text{Om})$

Birinci tarmoqdagi tok: $I_1 = \sqrt{\frac{P}{R}} = \sqrt{\frac{31250}{50}} = 25(\text{A})$

Umumiy kuchlanish $U = I_1 Z = 1250(\text{B})$ bo'lib, faza burchagi $\varphi = 0$

Birinci tarmoq kuchlanishi: $U_{1a} = R_1 I_1 = 25 \cdot 2 = 50(\text{V}),$

$U_{1p} = x_1 I_1 = 25 \cdot 36 = 900(\text{V})$

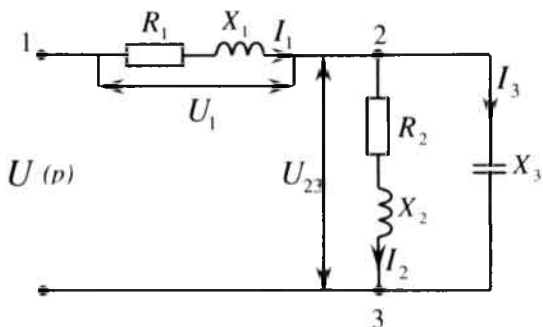
$$U_1 = \sqrt{U_{a1}^2 + U_{p1}^2} = 900(\text{V})$$

Parallel ulangan tarmoqdagi kuchlanish:

$$U_{ab} = \frac{I_{1e}}{y_{ab}} = \frac{25}{1,67 \cdot 10^{-2}} = 1500(\text{V})$$

Tarmoqdagi tok $I_2 = \frac{U_{ab}}{R_2} = 20(\text{A}), \quad I_3 = \frac{U_{ab}}{x_3} = 15(\text{A})$

Masala 2.18. Qarshiligi aralash sxemada ulangan elektr zanjirda sarf bo'ladigan aktiv quvvat $P=1,2$ (kVt) bo'lib, parametr qiymati: $R_1=2$ (Om), $x_1=26$ (Om), $R_2=10$ (Om), $x_2=10$, $x_3=-10$ (Om) ga teng. Zanjirdagi umumiy kuchlanish U tarmoqdagi tok I_1 , I_2 , I_3 , reaktiv quvvati (Q) aniqlanib vektor diagrammasi tuzilsin.



Yechish.

Zanjirning aktiv va reaktiv qarshiligini, qarshilik ekvivalent parametr o'xshashlik tenglamasiga asosan (2.10) aniqlaymiz:

$$g_2 = \frac{R_2}{R_2^2 + x_2^2} = \frac{10}{200} = 0,05 \frac{1}{\text{Om}}$$

$$b_2 = \frac{x_2}{R_2^2 + x_2^2} = \frac{10}{200} = 0,05 \frac{1}{\text{Om}}$$

Uchinchi tarmoq o'tkazuvchanligi: $g_3 = 0, b_3 = \frac{1}{x_3} = -0,1 \frac{1}{\text{Om}}$

Tarmoq parallel ulangan qismi uchun: $g_{23} = g_2 + g_3 = 0,05 \frac{1}{\text{Om}}$

Umumiy o'tkazuvchanlik: $y_{23} = \sqrt{g_{23}^2 + b_{23}^2} = \sqrt{0,005} \frac{1}{\text{Om}}$

O'xshashlik ekvivalent parametrlar tenglamasiga asosan (2.11) aktiv qarshilik:

$$R_{23} = \frac{g_{23}}{y_{23}^2} = \frac{0,05}{0,005} = 10 \text{ Om}$$

Reaktiv qarshilik: $x_{23} = \frac{b_{23}}{y_{23}^2} = \frac{0,05}{0,005} = -10 \text{ Om}$

To'la qarshilik: $z_{23} = \sqrt{R_{23}^2 + x_{23}^2} = 14,1 \text{ Om}$

Masala 2.19. Induktiv g'altak parametrlari $R = 3X_L = 4 \text{ Om}$ bo'lib, $U = 100 \text{ V}$ kuchlanishga ulangan. Aktiv, reaktiv, to'la o'tkazuvchanlik parametrlari, kuchlanish va tok qiymati aniqlanib, uchburchak vektor ifodalari chizib ko'rsatilsin.

Yechish.

To'la qarshilikni topamiz: $Z = \sqrt{R^2 + X_L^2} = \sqrt{9 + 16} = 5 \text{ Om}$

Om qonuniga asosan tokning haqiqiy qiymati: $I = \frac{U}{Z} = \frac{100}{5} = 20 \text{ A}$.

Qarshilik uchburchak vektor ifodasidan: $\cos \varphi = \frac{R}{Z} = \frac{3}{5} = 0,6$:

$\sin \varphi = \frac{X_L}{Z} = \frac{4}{5} = 0,8$

Shunga asosan: $\dot{U}_a = \dot{U} \cos \varphi = 100 \cdot 0,6 = 60 \text{ V}$

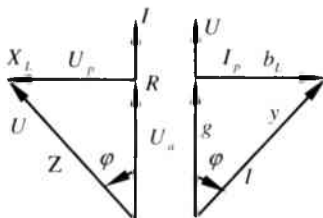
$\dot{U}_p = \dot{U} \sin \varphi = 100 \cdot 0,8 = 80 \text{ V}$

Tok qiymatini aniqlaymiz:

$I_a = I \cos \varphi = 20 \cdot 0,6 = 12 \text{ A}$; $I_p = I \sin \varphi = 20 \cdot 0,8 = 16 \text{ A}$

Aniqlangan tok va kuchlanish qiymatidan o'tkazuvchanlik parametri:

To'la o'tkazuvchanlik: $y = \frac{I}{U} = \frac{20}{100} = 0,2 \text{ sim}$.



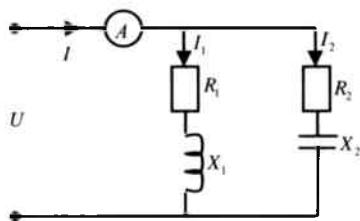
Aktiv o'tkazuvchanlik: $g = y \cos \varphi = 0,2 \cdot 0,6 = 0,12 \frac{1}{\text{Om}}$

Reaktiv o'tkazuvchanlik: $b_L = y \sin \varphi = 0,2 \cdot 0,8 = 0,16 \frac{1}{\text{Om}}$

Massstab tanlash bilan vektor ifodasini tuzamiz.

Masala 2.20. Parallel sxemada ulangan zanjirga kiruvchi tok $I = 2 \text{ A}$ bo'lib, parametri $R_1 = 3 \text{ Om}$, $X_1 = 4 \text{ Om}$, $R_2 = 6 \text{ Om}$, $X_2 = 8 \text{ Om}$ ga teng.

Umumiy kuchlanish U , tarmoqdagi tok I_1 , I_2 , aktiv, reaktiv va to'la quvvat qiymatlari aniqlanib vektor ifodasi tuzilsin:



Yechish. Birinchi tarmoq to'la qarshiligi: $Z_1 = \sqrt{R_1^2 + X_1^2} = \sqrt{3^2 + 4^2} = 5 \text{ Om}$. Ekvivalent parametr tenglamasidan (2.10) aktiv o'tkazuvchanlik: $g_1 = \frac{R_1}{Z_1^2} = \frac{3}{5^2} = 0,12 \text{ 1/Om}$.

Reaktiv o'tkazuvchanlik: $b_1 = \frac{X_1}{Z_1^2} = \frac{4}{5^2} = 0,16 \text{ 1/Om}$.

Ikkinchi tarmoq to'la qarshiligi: $Z_2 = \sqrt{R_2^2 + X_2^2} = \sqrt{6^2 + 8^2} = 10 \text{ Om}$.

yoki: $g_2 = \frac{R_2}{Z_2^2} = \frac{6}{10^2} = 0,06 \text{ 1/Om}$; $b_2 = \frac{X_2}{Z_2^2} = \frac{-8}{10^2} = -0,08 \text{ 1/Om}$

Zanjir to'la aktiv o'tkazuvchanligi:

$g = g_1 + g_2 = 0,12 + 0,06 = 0,18 \text{ 1/Om}$

To'la reaktiv o'tkazuvchanlik: $b = b_1 + b_2 = 0,16 - 0,08 = 0,08 \text{ 1/Om}$

Umumiy o'tkazuvchanlik: $y = \sqrt{g^2 + b^2} = \sqrt{(0,18)^2 + (0,08)^2} = 0,197 \text{ 1/Om}$

Om qonuniga asosan zanjirdagi kuchlanish: $U = \frac{I}{y} = \frac{2}{0,197} \approx 10 \text{ V}$

Tarmoqdagi tok: $I_1 = \frac{U}{Z_1} = \frac{10}{5} = 2 \text{ A}$ $I_2 = \frac{U}{Z_2} = \frac{10}{10} = 1 \text{ A}$

Faza burchagini topamiz: $\varphi = \arctg \frac{b}{g} = \arctg \frac{0,08}{0,18} = 24^\circ$

$\varphi_1 = \arctg \frac{X_1}{Z_1} \approx 53^\circ$; $\varphi_2 = \arctg \frac{X_2}{Z_2} = -53^\circ$

Quvvat ifodasidan: $P = U^2 g = 100 \cdot 0,18 = 18 \text{ W}$

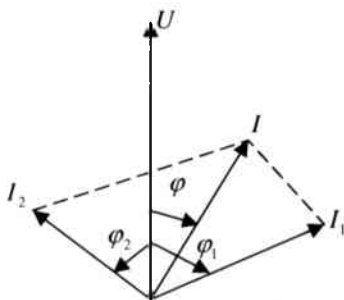
$Q = U^2 b = 100 \cdot 0,08 = 8 \text{ var}$. $S = U^2 y = 100 \cdot 0,197 = 19,7 \text{ VA}$

Quvvat koeffitsienti ifodasida: $\alpha = \frac{P}{S} = \frac{P}{UI} = \frac{210}{855} = 0,25$.

Quvvat siljish koeffitsienti ifodasidan: $P^2 + Q^2 = S^2 - T^2$

bundan:

$$T = \sqrt{S^2 - (P^2 + Q^2)} = \sqrt{855^2 - (210 - 173,3^2)} = 820 \text{ VA}$$



2.3. Mustaqil yechish uchun masalalar

Masala 2.1. Qutblar soni $P=3$ berk halqa magnit maydonida $n=1000$ ayl/min tezlik bilan aylanganda hosil bo'ladigan EYK chastotasi aniqlansin.

Javob: $f=50$ Gs.

Masala 2.2. O'zgaruvchan tok generatorining yakor aylanish tezligi $n=500$ ayl/min bo'lib, $f=50$ Gs chastotali EYK hosil qilganda qutblar soni nechta bo'ladi?

Javob: $P=6$

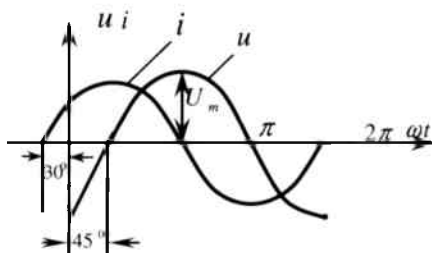
Masala 2.3. O'zgaruvchan EYK amplituda qiymati $E_m=120$ V chastotasi $f=100$ Gs bo'lganda, $t=0,0075$ sek vaqtda EYK oniy qiymati aniqlansin.

Javob: $e=120\sin 270^\circ$; $e=E_m=-120$ V

Masala 2.4. Magnit maydonida o'ramlar soni $W=40$ ga teng bo'lgan g'altak aylanganda hosil bo'ladigan magnit oqimi $\Phi=0,02\sin 314t$ bo'lib, g'altakda induksiyalanadigan EYK oniy qiymati aniqlansin.

Javob: $e=250\sin(314t-90^\circ)$

Masala 2.5. Rasmda keltirilgan sinusoidal funksiya uchun analitik ifoda yozilib, tok va kuchlanish orasidagi burchak φ aniqlansin.



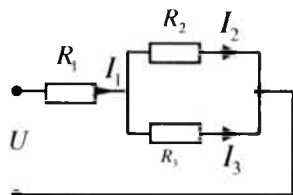
Masala 2.6. Kuchlanish va tok oniy qiymatlari $u=170\sin(\omega t+45^\circ)$ $i=10\sin(\omega t-45^\circ)$ bo'lganda, ular orasidagi burchak φ topilib, $t=0$ bo'lganda oniy qiymati aniqlansin.

Javob: $U_m = 120 \text{ V}$, $I_m = 7 \text{ A}$, $\varphi = 90^\circ$

Masala 2.7. Aktiv qarshilikga ega bo'lgan sinusoidal o'zgaruvchan elektr zanjirga $U=141\sin\omega t$ kuchlanish ulanganda, $i=7,05\sin\omega t$ tok o'tadi. Elektr quvvat $P_{o'r}$ – o'rtacha qiymati va R qarshiligi aniqlansin.

Javob: $P_{o'r} = 750 \text{ Vt}$ $R = 70(\text{Om})$

Masala 2.8. Sinusoidal o'zgaruvchan elektr zanjir aktiv qarshilik parametri: $R_1=24\text{Om}$, $R_2=10 \text{ Om}$, $R_3=15 \text{ Om}$ bo'lib, R_2 qarshilikda sarf bo'ladigan quvvat $P_2 = 58 \text{ Vt}$. Tarmoqdagi tok I_1 , I_2 , I_3 va umumiy kuchlanish U aniqlansin.

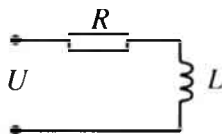


Javob: $I_1=4 \text{ A}$, $I_2=2,4 \text{ A}$, $I_3=1,6 \text{ A}$, $U=120 \text{ V}$

Masala 2.9. O'zgaruvchan tok chastotasi $f=160 \text{ Gs}$, $U=220 \text{ V}$ kuchlanishga ulangan bo'lib g'altakdan $I=4 \text{ A}$ tok o'tadi. G'altak induktivligi aniqlansin.

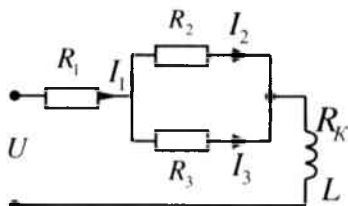
Javob: $L=30 \text{ MGn}$

Masala 2.10. Parametri $R=6 \text{ Om}$, $L=25 \text{ MGn}$ bo'lgan g'altak chastotasi $f=50 \text{ Gs}$ bo'lgan $U=120 \text{ V}$ sinusoidal o'zgaruvchan kuchlanishga ulangan. Quvvat koeffitsienti va aktiv, reaktiv quvvat aniqlansin.



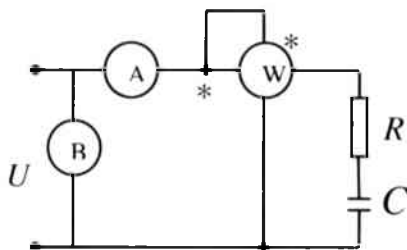
Javob: $\cos\varphi=0,6$, $P=864 \text{ Vt}$, $Q_L=1152 \text{ VAR}$

Masala 2.11. Sinusoidal o'zgaruvchan elektr zanjir parametri: $R_1=4\text{ Om}$, $R_2=10\text{ Om}$, $R_3=15\text{ Om}$ va induktivligi $L=95\text{ MGn}$ bo'lib, R_2 qarshilikdan chastotasi $f=50\text{ Gs}$ bo'lgan $I=2\text{ A}$ tok o'tadi. Umumiy kuchlanish U qiymati, burchak koeffitsienti $\cos\varphi$ va aktiv quvvat P aniqlansin.



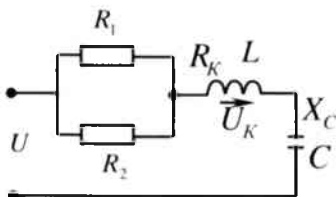
Javob: $U=100\text{ V}$, $\varphi=36^\circ 50'$, $P=160\text{ Vt}$

Masala 2.12. Elektr o'lchov asboblari ko'rsatishi: $U=200\text{ B}$, $I=2\text{ A}$, $P=240\text{ Vt}$ bo'lib, chastotasi $f=50\text{ Gs}$ ga teng. Aktiv va sig'im qarshilik parametri aniqlansin.



Javob: $R=60\text{ Om}$, $C=40\text{ mkF}$

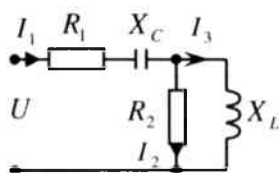
Masala 2.13. Sinusoidal o'zgaruvchan elektr zanjirning qarshiligi: $R_1=R_2=100\text{ Om}$, $R_K=30\text{ Om}$, $X_C=100\text{ Om}$, $X_L=40\text{ Om}$ bo'lib, g'altakdagi kuchlanish $U_K=100\text{ V}$ chastotasi $f=50\text{ Gs}$ ga teng. Zanjirdan o'tuvchi tokning haqiqiy qiymati I , umumiy kuchlanishi U , sig'im va induktivlik parametri L , C , aktiv quvvat P hamda elektr W_E va magnit W_L maydon energiyalari aniqlansin.



Javob: $U=200\text{ V}$, $I=2\text{ A}$, $L=0,127\text{ MGn}$ $C=32\text{ mkF}$,

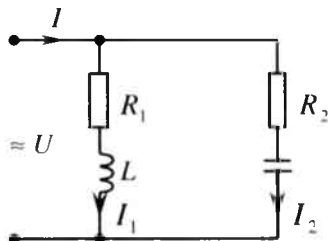
$P=320\text{ Vt}$, $W_E=1,24\text{ Dj}$, $W_L=0,5\text{ Dj}$

Masala 2.14. Qarshilik parametri:
 $R_1=12\text{ Om}$, $R_2=10\text{ Om}$, $X_C=24\text{ Om}$, $X_L=20\text{ Om}$
 bo'lgan elektr zanjir $f=50\text{Gs}$ bo'lgan $U=220\text{ V}$ sinusoidal kuchlanishga ulangan. Tarmoqdagi tok I_1 , I_2 , I_3 haqiqiy qiymati aniqlansin.



Javob: $I_1=6\text{ A}$, $I_2=4,4\text{ A}$, $I_3=5,25\text{ A}$

Masala 2.15. Parametri $R_1=160\text{ Om}$, $L=0,04\text{ MGn}$ bo'lgan induktiv g'altak aktiv qarshiligi $R_2=30\text{ Om}$, sig'imi $C=50\text{ mkF}$ bo'lib parallel sxemada ulangan. O'zgaruvchan tok kuchlanishi $U=110\text{ V}$, chastotasi $f=314\text{ Gs}$ bo'lganda umumiy o'tkazuvchanlik, tarmoqdagi tok va o'tkazuvchanligi aniqlansin.

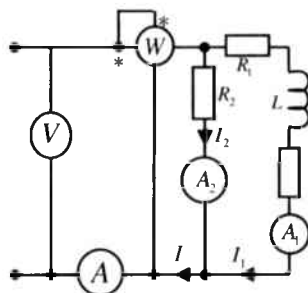


Javob: $y_1 = 0,036 \frac{1}{\text{Om}}$, $y_2 = 0,0316 \frac{1}{\text{Om}}$, $y = 0,036 \frac{1}{\text{Om}}$

$I_1=3,96\text{ A}$, $I_2=1,1\text{ A}$, $I_3=3,5\text{ A}$

Masala 2.16. Parallel zanjir parametri:
 $R_1=100\text{ Om}$, $R_2=200\text{ Om}$, $L=0,276\text{ gn}$,
 $f=100\text{ gs}$ bo'lib, $I_1=5\text{ A}$ ga teng. Elektr o'lchov asboblari ko'rsatish qiymati topilsin.

Javob: $U=200\text{ V}$, $I=1,73\text{ A}$,
 $P=300\text{ Vt}$.



2.4. Nazorat savollari

1. Sinusoidal o'zgaruvchan tok xususiyati nimadan iborat?
2. Sinusoidal o'zgaruvchan tok qanday hosil qilinadi, manbai nima?
3. Sinusoidal o'zgaruvchan tok bilan o'zgarmas tokning farqi nimada?
4. Sinxron generatorning tuzilishl va ishlash prinsipini bilasizmi?
5. O'tkazgich magnit maydonda harakatianganda unda hosil bo'ladigan EYK nimaga teng?
6. Elektr mashina va apparatlarida magnit o'zak (ferromagnetik) qanday maqsad uchun xizmat qiladi?
7. Magnit doimiyligi deganda nimani tushunasiz?
8. Induktivlik nima va qanday birlikda o'lchanadi?
9. O'zinduksiya qonuniga asosan induktivlikda hosil bo'lgan EYK yo'nalishi qanday aniqlanadi va haqiqiy qiymati nimaga teng?
10. Sinusoidal o'zgaruvchan tok qanday qiymatda ifodalanadi?
11. Sinusoidal o'zgaruvchan tok chastotasi, davri va oniy qiymat ifodalarini yozing.
12. Sinusoidal o'zgaruvchan tok vektor ifodasiga ta'rif bering. Elektr zanjir uchun vektor diagramma qanday tuziladi?
13. Sinusoidal o'zgaruvchan tok va kuchlanish boshlang'ich fazasi va faza farqi qanday aniqlanadi?
14. Aktiv induktivlik va sig'im qarshilik parametri uchun Om qonuni ifodasini yozing.
15. Ketma-ket va parallel sxemada ulangan R, L, C zanjir uchun Om qonuni tenglamasini yozing.
16. Ikki qutbli zanjir uchun ekvivalent o'xshashlik tenglamasini yozing.
17. Ketma-ket ulangan aktiv va induktiv qarshiligi bo'lgan elektr zanjir uchun vektor ifodasini tuzib, to'la qarshilik ifodasini yozing.
18. Aktiv va sig'im qarshiligi bo'lgan elektr zanjir uchun vektor ifoda tuzib, to'la qarshilik tenglamasi yozilsin.
19. Ketma-ket biriktirilgan R, L, C zanjirida $X_L > X_C$, $X_L < X_C$, $X_L = X_C$ bo'lgan holat uchun vektor ifoda tuzib, qaysi xarakterga ega ekanligini tushuntiring.
20. Aktiv, reaktiv va to'la quvvat tenglamasini yozing.

21. Aktiv va reaktiv elementlarda elektr energiyasi qayerda va qanday sarflanadi?
22. Quvvat koeffitsienti $\cos\varphi$ nima va qanday amaliy ahamiyatga ega?
23. O'zgarmas tokga nisbatan induktiv va sig'im qarshiligi nimaga teng?
24. Nima uchun sig'imdan o'zgaruvchan tok o'tadi, o'zgarmas tok esa o'tmaydi?
25. Ketma-ket sxemada ulangan R, L elektr zanjir qarshiligidagi kuchlanish: $U_r = 60V$, $U_L = 80V$ ga teng bo'lganda umumiy (U) kuchlanish nimaga teng?
26. Parallel sxemada ulangan R, C elektr zanjirda o'tuvchi tok $I_r = 3A$, $I_c = 4A$ bo'lganda, umumiy tok (I) qanchaga teng?
27. R, L, C ketma-ket ulangan zanjirning to'la qarshiligi $Z = 100\Omega$, $R = 80\Omega$, $X_C = 40\Omega$ bo'lsa, g'altakning induktiv qarshiligi X_L necha Ω ga teng?
28. Agar $C = 20\text{ mkf}$ bo'lgan sig'im parametri $U = 220(\sin 314t - 60)V$ kuchlanishga ulanganda tokning oniy qiymati (i) ni aniqlang.
29. Kuchlanish $U = 100\text{ V}$, tok kuchi $I = 5A$ va faza burchagi $\varphi = 60^\circ$ bo'lgan zanjirning aktiv quvvati necha vatt bo'ladi?
30. Kuch qarshilik va quvvat uchburchak vektor ifodasiga asosan $\cos\varphi$, $\sin\varphi$, $\tan\varphi$ tenglama tuzing.
31. Qarshilik va quvvatlar uchburchak vektor ifodasidan, aktiv va reaktiv tashkil etuvchi vektor qanday ma'noni bildiradi?
32. Sinusoidal elektr zanjir kuchlanishi $u = 141 \sin(314 + 80^\circ)$ va tok $i = 14,1 \sin(314 + 20^\circ)$ bo'lganda, aktiv quvvat necha vatt ga teng. (Javob: $P = 500Vt$).
33. Sinusoidal elektr zanjirda kuchlanish $u = 28,2 \sin(628 + 80^\circ)$ va tok $i = 2,82 \sin(628 + 50^\circ)$ bo'lganda, reaktiv quvvat qancha bo'ladi? (Javob: $Q = 20\text{ VAR}$).
34. Elektr zanjir to'la quvvati $S = 1000$ bo'lib $\cos\varphi = 0,8$ bo'lganda aktiv quvvat qiymatini toping.
35. Elektr zanjir kuchlanishi $U = 220\text{ V}$, tok $I = 10\text{ A}$, aktiv quvvat $R = 1,1\text{ kvt}$ ga teng bo'lganda $\cos\varphi$ nimaga teng?
36. Ketma-ket ulangan R, L, C zanjirning to'la qarshiligi $Z = 100\Omega$, aktiv qarshiligi $R = 30\Omega$ va sig'im qarshiligi $X_C = 40\Omega$ bo'lsa, induktiv qarshilik necha Ω bo'ladi?

37. Ketma-ket ulangan R , L , C zanjirdagi kuchlanish $U_R=30V$, $U_L=40V$, $U_C=40V$ bo'lganda umumiy kuchlanish (U) qancha bo'ladi?
38. Induktiv g'altakning to'la qarshiligi $Z = 10 \text{ } \Omega$, aktiv qarshilik qismidagi kuchlanish $U_R = 30 \text{ V}$, induktivlikda $U_L = 40 \text{ V}$ bo'lganda, umumiy kuchlanish U va tok I nimaga teng?
39. Parallel sxemada ulangan R , C zanjirdagi tok $I_R = 4A$, $I_C = 3A$ bo'lib, $U = 100 \text{ V}$ kuchlanisiga ulangan. To'la o'tkazuvchanlik (y) va to'la quvvat (S) qiymati qancha bo'ladi?
40. Tok va kuchlanish oniy qiymati: $u = 282 \sin(\omega t + 60^\circ)$; $i = 141 \sin(\omega t + 30^\circ)$ bo'lganda, faza burchagi φ , to'la, aktiv va reaktiv quvvat qancha bo'ladi?
41. Quvvat koeffitsienti $\cos=0,85$ bo'lgan elektrodvigatel $U = 120V$ kuchlanishga ulangan bo'lib, $I = 2A$ tok sarflaydi. To'la, aktiv va reaktiv quvvat qiymatini aniqlang.
42. Induktiv g'altak aktiv qarshiligi $R = 15 \text{ } \Omega$ bo'lib, ampermetr – $5A$ va voltmeter – 220 V ni ko'rsatadi. Zanjirning to'la, aktiv, reaktiv quvvati, induktiv qarshiligi, qarshiliklardagi kuchlanish va burchak $\cos \varphi$ nimaga teng?

III. SINUSOIDAL O'ZGARUVCHAN ELEKTR ZANJIRNI KOMPLEKS (SIMVOLIK) USULDA HISOBLASH

3.1. Asosiy nazariy tushunchalar

1. Kompleks son.

Kompleks son Eyler formulasiga asosan $e^{\pm i\varphi} = \cos\varphi + j\sin\varphi$ ifodalanadi, kompleks tekislikda nuqta yoki vektor ko'rinishda tasavvur qilish mumkin bo'lib, kompleks son uch xil ko'rinishda ifodalanadi.

$\dot{A} = a_1 + ja_2$ – algebraik

$\dot{A} = a(\cos \alpha + j \sin \alpha)$ – trigonometrik

$\dot{A} = ae^{j\alpha}$ – ko'rsatkichli

Bunda:

$a_1 = a \cos \alpha = \operatorname{Re} \dot{A}$ – haqiqiy qismi.

$a_2 = a \sin \alpha = \operatorname{Im} \dot{A}$ – mavhum qismi.

a – kompleks son moduli: $|a| = \sqrt{a_1^2 + a_2^2}$ α – kompleks son argumenti:

$\alpha = \operatorname{arctg} \frac{a_2}{a_1}$ Shuningdek: $e^{\pm \pi/2} = \pm j$; $\frac{1}{j} = -j$; $j^2 = 1$;

$j^3 = j$ va $j^4 = 1$

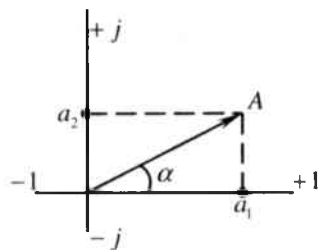
Kompleks sonlarni qo'shish yoki ayirish amalini bajarishda **algebraik ko'rinishda**, ko'paytirish va bo'lish amalini bajarishda esa **ko'rsatkichli** ifodasidan foydalaniladi.

Sinusoidal o'zgaruvchan tok, kuchlanishlar va EYK funksiyasini kompleks ko'rinishdagi ifodasi:

$$i = I_m \sin (\omega t + \varphi_i) = \dot{I}_m e^{j\omega t} \cdot I_m e^{j\varphi_i} = \dot{I}_m e^{j\omega t}$$

$$u = U_m \sin (\omega t + \varphi_u) = \dot{U}_m e^{j\omega t} \cdot U_m e^{j\varphi_u} = \dot{U}_m e^{j\omega t}$$

$$e = E_m \sin (\omega t + \varphi_e) = \dot{E}_m e^{j\omega t} \cdot E_m e^{j\varphi_e} = \dot{E}_m e^{j\omega t}$$



Bunda: $\dot{I}_m, \dot{U}_m, \dot{E}_m$ – sinusoidal o'zgaruvchan tok, kuchlamishi, va EYK kompleks amplitudasi.

Elektr zanjirni kompleks usulda hisoblash jarayonida faqatgina vaqt funksiyasi tarzida emas, balki uning hosilasi yoki integral tarzida ham uchrashi mumkin.

$$\frac{di}{dt} = \omega I_m \sin\left(\omega t + \psi_i + \frac{\pi}{2}\right) \doteq \omega \dot{I}_m e^{j(\omega t + \psi_i + \frac{\pi}{2})} = j\omega \dot{I}_m e^{j\psi_i} \cdot e^{j\omega t} = j\omega \dot{I}_m e^{j\omega t}$$

$$\int i dt = \frac{I_m}{\omega} \sin\left(\omega t + \psi_i - \frac{\pi}{2}\right) \doteq \frac{\dot{I}_m}{\omega} e^{j(\omega t + \psi_i - \frac{\pi}{2})} = \frac{I_m}{j\omega} e^{j\psi_i} \cdot e^{j\omega t} = \frac{\dot{I}_m}{j\omega} e^{j\omega t}$$

Demak, kompleks shaklda berilgan har qanday sinusoidal funksiya tasviri $\dot{I} m e^{j\omega t}$ bo'lsa, bu funksiya hosila olish « $j\omega$ » ko'paytirish yoki integrallash esa « $j\omega$ » ga bo'lishi bilan barobar ekan.

2. Sinusoidal o'zgaruvchan elektr zanjirni kompleks usulda hisoblash.

Om qonunining kompleks ifodasi: $\dot{I} = \frac{\dot{U}}{\underline{Z}} = \underline{Y} \dot{U} (A)$

To'la qarshilik: $\underline{Z} = R + jx = \underline{Z} e^{j\varphi} (Om)$

To'la o'tkazuvchanlik: $\underline{Y} = \frac{1}{\underline{Z}} = g - jb = Y e^{-j\varphi} \left(\frac{1}{Om}\right)$

To'la quvvat kompleks ifodasi:

$$\dot{S} = \dot{U} \dot{I} = \dot{U} e^{j\varphi_i} \cdot \dot{I} = \dot{U} \dot{I} e^{j\varphi} = \dot{U} \dot{I} \cos \varphi + j \dot{U} \dot{I} \sin \varphi = P + jQ (VA)$$

$\dot{I}$ – kompleks tokning teskari ishorasi bilan olingan qiymati.

Murakkab sinusoidal o'zgaruvchan elektr zanjirni hisoblashda, *Om* va Kirxgof qonuni bilan bir qatorda Kirxgof qonunini tatbiq etish konturli tok usuli, tugun kuchlanishlar, ustma-usilik (superpozitsiya) usuli, mutanosiblik prinsipi, ekvivalent generator usullaridan foydalaniladi.

Iste'molchilar ketma-ket ulangan oddiy elektr zanjirlarda tok umumiy bo'lib *Om* qonuniga asosan.

$$\dot{I} = \frac{\dot{U}}{Z}; \text{ bunda } \underline{Z} = \underline{Z}_1 + \underline{Z}_2 + \dots + \underline{Z}_n = \sum_{b=1}^{n=v} \underline{Z}_n$$

Iste'molchilar parallel ulangan elektr zanjirda kuchlanish umumiy

$$\text{bo'lib } \dot{I} = \dot{U} \underline{Y}; \text{ bunda } \underline{Y} = \underline{Y}_1 + \underline{Y}_2 + \dots + \underline{Y}_n = \sum_{b=1}^{n=v} \underline{Y}_n$$

Aralash sxemada ulangan elektr zanjir uchun kompleks qarshiligi

$$\underline{Z}_{12} = \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} \text{ bo'lib, tarmoqdagi tok: } \dot{I}_1 = \frac{\underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} \dot{I}; \quad \dot{I}_2 = \frac{\underline{Z}_1}{\underline{Z}_1 + \underline{Z}_2} \dot{I}.$$

$\dot{I}$ – umumiy tokning kompleks qiymati. Kirxgof qonunining kompleks ifodasi. 1-qonun; $\sum_{k=1}^n \dot{I}_k = 0$ 2-qonun; $\sum_{k=1}^n \dot{E}_k = \sum_{k=1}^n \underline{Z}_k \dot{I}_k$

3. Murakkab sinusoidal o'zgaruvchan elektr zanjirni kompleks usulda hisoblash.

a) Kirxgof qonunini tatbiq qilish.

Murakkab elektr zanjirni Kirxgof qonuniga asosan hisoblashda berilgan zanjir uchun elektr muvozanat tenglamasi tuziladi. Tuzilgan tenglama soni tarmoqdagi tok soniga teng bo'lishi kerak. Agar zanjirning tarmoqlar soni R , tugunlar soni q ga teng bo'lsa, u holda Kirxgof 1-qonuni $(p-q+1)$ tenglamasi tuziladi. Tenglamalar sistemasini yechish bilan $\dot{I}_1, \dot{I}_2, \dots, \dot{I}_p$ tarmoqdagi tok aniqlanadi.

b) konturli tok usuli.

Konturli tok usuli Kirxgof 2-qonuniga asoslangan bo'lib, berilgan zanjirning kontur uchun tuzilgan tenglamalar sistemasini yechish bilan konturdagi tok va tarmoqdagi tok aniqlanadi.

Umumiy holda konturdagi tok tenglamalar soni $(p-q+1)$ ga teng bo'ladi.

q – zanjirdagi tugunlar soni

p – tarmoqlar soni

Agar zanjir n ta kontur toklariga ega bo'lsa, uning tenglamasi quyidagicha tuziladi:

$$\left. \begin{aligned} \dot{I}_{k1} Z_{11} + \dot{I}_{k2} Z_{12} + \dots + \dot{I}_{kn} Z_{1n} &= \dot{E}_{11} \\ \dot{I}_{k1} Z_{12} + \dot{I}_{k2} Z_{22} + \dots + \dot{I}_{kn} Z_{2n} &= \dot{E}_{12} \\ \dot{I}_{k1} Z_{n1} + \dot{I}_{k2} Z_{n2} + \dots + \dot{I}_{kn} Z_{nn} &= \dot{E}_{nn} \end{aligned} \right\}$$

Bunda: Z_{nn} - n - konturning xususiy garshiligi Z_{-q} va S_{-q} - yon konturning o'zaro qarshiligi.

Agar yondosh konturdagi tokning $\dot{I}_{kq}$ va $\dot{I}_{ks}$ yo'nalishi mos bo'lsa, tarmoqning qarshiligi tenglamalar sistemasiga (+) ishora, qarama-qarshi bo'lsa, (-) ishora kiritiladi. $\dot{E}_{nn}$ - n - konturning xususiy EYK

d) tugun potentsiallar usuli.

Tugunlararo kuchlanishlar usulidan foydalanish asosan ko'p elementlardan tarkib topgan tarmoqlangan murakkab elektr zanjirni hisoblashda ancha qulay bo'lib, ixtiyoriy elektr zanjiridagi $q=(n+1)$ tugundan bittasini nisbiy kuchlanish (potensial) nolga teng deb olinadi ($\varphi_n=0$). Qolgan barcha tugun potensial tenglamasi shunga nisbatan tuziladi.

$$\left. \begin{aligned} \underline{y}_{11} \dot{U}_{10} + \underline{y}_{12} \dot{U}_{20} + \dots + \underline{y}_{1k} \dot{U}_{k0} &= \dot{I}_{11} \\ \underline{y}_{21} \dot{U}_{10} + \underline{y}_{22} \dot{U}_{20} + \dots + \underline{y}_{2k} \dot{U}_{k0} &= \dot{I}_{22} \\ \dots &\dots \\ \underline{y}_{n1} \dot{U}_{10} + \underline{y}_{n2} \dot{U}_{20} + \dots + \underline{y}_{nn} \dot{U}_{k0} &= \dot{I}_{nn} \end{aligned} \right\}$$

Bunda:

$$\left. \begin{aligned} \underline{y}_{nn} &= \sum_{\substack{p=1 \\ p \neq n}}^n \underline{y}_{pn} \\ \dot{I}_{nn} &= \sum_{\substack{p=1 \\ p \neq n}}^n \underline{y}_{pn} \dot{E}_{pn} \end{aligned} \right\}$$

Tenglamalar sistemasini yechish bilan tugun kompleks kuchlanishi:

$$\dot{U}_{10}, \dot{U}_{20}, \dot{U}_{n0} \quad (\varphi_1 - \varphi_0; \varphi_2 - \varphi_0; \varphi_3 - \varphi_0, \dots)$$

va tugunlar orasidagi kompleks kuchlanishlar aniqlanadi.

$$\dot{U}_{nm} = \dot{U}_{no} - \dot{U}_{mo}$$

Tarmoqdagi tok esa butun zanjir uchun Om qonuniga asosan

$$\dot{I}_{nm} = \underline{Y}_{nm} (\dot{E}_{nm} + \dot{U}_{nm})$$

Agar elektr zanjiri faqat ikkita tugundan iborat bo'lsa ($q = 2$) tenglama

$$\underline{Y}_{11} \dot{U}_{10} = \dot{I}_{11}; \quad \dot{U}_{10} = \frac{\dot{I}_{11}}{\underline{Y}_{11}}$$

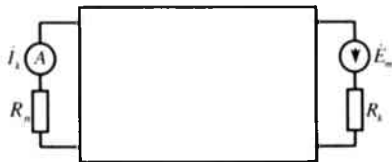
Ya'ni, tugunlararo kuchlanish tenglamasiga asosan ikkita tugun o'rtasidagi kuchlanish aniqlanib Om qonuniga asosan tarmoqdagi tok topiladi.

$$\dot{U}_{ab} = \frac{\underline{Y}_1 \dot{E}_1 + \underline{Y}_2 \dot{E}_2 + \underline{Y}_3 \dot{E}_3 + \dots + \underline{Y}_n \dot{E}_n}{\underline{Y}_1 + \underline{Y}_2 + \underline{Y}_3 + \dots + \underline{Y}_n} = \frac{\sum_{p=1}^n \underline{Y}_{-n} \dot{E}_n}{\sum_{p=1}^n \underline{Y}_{-n}}$$

e) ustma-ustlik (superpozitsiya) usuli.

Parametrlari chiziqli bo'lgan elektr zanjirning biror K tarmog'idan o'tuvchi tok shu zanjirni tashkil etuvchi EYK hosil qiladigan tokning yig'indisidan iborat bo'ladi. Shu sababli chiziqli murakkab elektr zanjirni hisoblashda, har bir EYK ta'sirida zanjir tarmoqlaridan o'tuvchi tok alohida aniqlanadi (qolgan EYK nolga teng deb olinib, zanjirning ichki qarshiligi saqlanadi). Natijada har bir EYK ta'sirida tarmoqdan o'tuvchi tokning algebraik yig'indisi umumiy tok qiymatiga teng bo'ladi: $\dot{I} = \dot{I}' + \dot{I}'' + \dots + \dot{I}_K$

Ustma-ustlik usuli yordamida faqatgina zanjirdagi tok va kuchlanish aniqlanib, quvvatni hisoblashda tavsiya etilmaydi.



f) mutanosiblik prinsipi.

Bu prinsip chiziqli elektr zanjir uchun Maksvell tomonidan taklif etilgan bo'lib, har qanday murakkab elektr zanjirning (K) tartibida joylashgan $\dot{E}_k = \dot{E}$ EYK manba (boshqa manbalar bo'lmagan holda), shu zanjirning ixtiyoriy p tarmog'ida $\dot{I}_n = \dot{I}$ tok hosil qilgan bo'lsa, shu EYK manbaning o'zi n tarmoqqa ko'chirilgan holda $\dot{E}_k = \dot{E}$ (K) tarmoqdagi tokni hosil qiladi.

Masalan: Konturli tok usuliga asosan k tarmoq zanjirining q konturiga, n tarmog'i S konturiga kirgan deb faraz qilamiz. Bu holda konturda kontur toklari $\dot{I}_k = \dot{I}_q$ va $\dot{I} = \dot{I}_3$ bo'ladi va EYK qaysi tarmoqqa ulanganidan qat'i nazar, ularning qiymati $\dot{I}_k = \dot{I}_q = \dot{E} \frac{\Delta_{qs}}{\Delta}$ va

$\dot{I}_n = \dot{I}_3 = \dot{E} \frac{\Delta_{qs}}{\Delta}$ ga teng bo'ladi.

Demak:

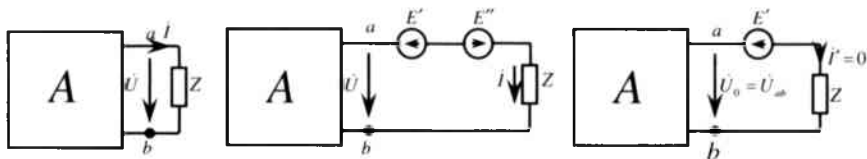
$$\dot{I}_k = \dot{I}_n = \dot{I}, \text{ chunki } \Delta_{qs} = \Delta_{sq} \text{ bo'lib, } \frac{\dot{E}_k}{\dot{I}_n} = \frac{\dot{E}_n}{\dot{I}_k} = \frac{\dot{E}}{\dot{I}} = Z - qs$$

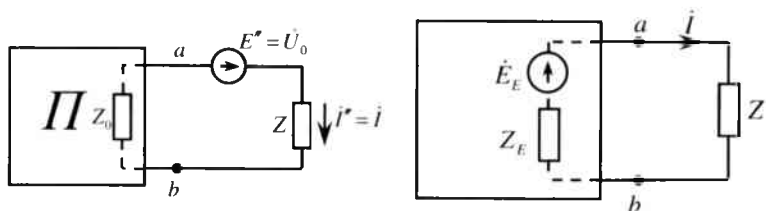
konturlararo qarshilik $Z - qs$ ga teng bo'lib, ushbu usulning mutanosibligini tasdiqlaydi.

g) ekvivalent generator usuli.

Bu usul murakkab elektr zanjirining biror qismidagi tarmoq tokini aniqlashda qulay bo'lib, amalda qisqa tutashtiruv yoki uzilish (salt holat) tajribalari o'tkaziladi. Elektr energiyasi bo'lgan ikki qutbli elektr zanjir ekvivalent manba va parametr bilan almashtiriladi. Bunda zanjir manba kuchlanish salt holat kuchlanishiga teng bo'ladi. $\dot{E} = \dot{U}_0 = \dot{U}_{ab}$ ichki qarshilik esa ekvivalent qarshilikga teng (3.3) $Z_0 = Z_E$

Ikki qutbli aktiv zanjirning biror (K) tarmoqdagi R qarshilik tokni aniqlash zarur bo'lsa, Om qonuniga asosan.

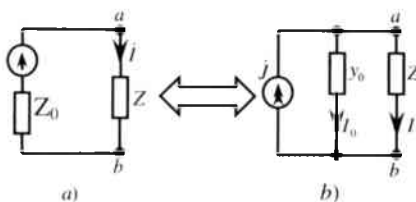




4. EYK manbaini tok manbaiga almashtirish.

Amalda EYK va tok manbaini almashtirishga imkon beruvchi, noldan farq qiladigan ichki parametrlar $R \neq 0$ va $g \neq 0$ mavjud; ularni o'zaro almashtirish mumkin. (a) manba kuchlanish tenglamasi:

$$\dot{U}_{ab} = E - Z_0 \dot{i}$$



Ba'zi hollarda manba kuchlanishi parallel sxema bilan almashtirilib tok manbai ko'rinishida ham ifodalanadi (b) .

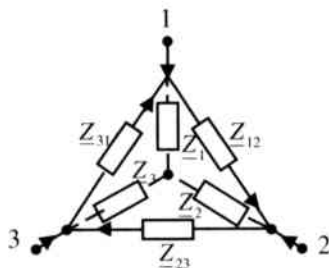
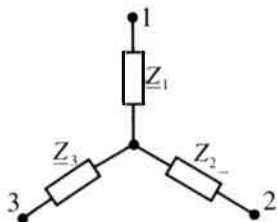
Bunda kuchlanish muvozanat tenglamasi manba qarshiligi Z_0 ga bo'linsa

$$\frac{\dot{U}_{ab}}{Z_0} = \frac{\dot{E}}{Z_0} - \dot{i} \text{ yoki } \dot{i}_0 = \dot{j} - \dot{i}$$

Bunda $\dot{j} = \frac{\dot{E}}{Z_0}$ va $\underline{y}_0 = \frac{1}{Z_0}$

Yulduzcha va uchburchak tarzida ulangan tarmoqlarni o'zaro almashtirish (ekvivalent parametrlar)

a) uchburchak shaklida ulangan qarshiliklarni yulduzcha shaklida almashtirish tenglamalari:



$$\underline{Z}_1 = \frac{\underline{Z}_{31} \cdot \underline{Z}_{12}}{\underline{Z}_{12} + \underline{Z}_{31} + \underline{Z}_{23}}; \quad \underline{Z}_2 = \frac{\underline{Z}_{12} \cdot \underline{Z}_{23}}{\underline{Z}_{12} + \underline{Z}_{23} + \underline{Z}_{31}}; \quad \underline{Z}_3 = \frac{\underline{Z}_{23} \cdot \underline{Z}_{31}}{\underline{Z}_{12} + \underline{Z}_{23} + \underline{Z}_{31}};$$

b) yulduzcha shaklidan uchburchak shakliga almashtirish tenglamalari:

$$\underline{Z}_{12} = \underline{Z}_1 + \underline{Z}_2 = \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_3}; \quad \underline{Z}_{23} = \underline{Z}_2 + \underline{Z}_3 = \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_1}; \quad \underline{Z}_{31} = \underline{Z}_3 + \underline{Z}_1 = \frac{\underline{Z}_1 \cdot \underline{Z}_3}{\underline{Z}_2}$$

3.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 3.1. Berilgan kuchlanish va tok $u = 100 \sin\left(\omega t + \frac{\pi}{6}\right) (V)$

$i = 5 \sin\left(\omega t + \frac{\pi}{6}\right) (A)$ funksiyalarining kompleks ifodasi, kompleks to'la qarshilik $\underline{Z}$, to'la o'tkazuvchanlik $\underline{Y}$ va to'la quvvat $\tilde{S}$ aniqlansin.

Yechish.

$$u = 100 \sin(\omega t + 30^\circ) \doteq 100 e^{j30^\circ} \quad i = 5 \sin(\omega t - 30^\circ) \doteq 5 e^{-j30^\circ}$$

$$\text{Kompleks to'la qarshilik: } \underline{Z} = \frac{\dot{U}_m}{\dot{I}_m} = \frac{100 e^{j30^\circ}}{5 e^{-j30^\circ}} = 20 e^{j60^\circ} = 10 + j17,3 \text{ (Om)}$$

$$\text{Kompleks to'la o'tkazuvchanlik: } \underline{Y} = \frac{1}{\underline{Z}} = 0,1 + j0,06 \quad \left(\frac{1}{\text{Om}} = \text{sim} \right)$$

Kompleks to'la quvvat:

$$\tilde{S} = \dot{U} \dot{I} = \dot{U} \cdot \dot{I} e^{j(\varphi_U - \varphi_I)} = 500 e^{j60^\circ} = 500 \cos 60^\circ + j500 \sin 60^\circ = 250 + j430 (VA)$$

Bundan aktiv quvvat: $P=250 \text{ Vt}$; Reaktiv quvvat: $Q=430 \text{ (VAR)}$.

Masala 3.2. Qarshiligi $R = 3 \text{ Om}$, $X = \pm 4 \text{ Om}$ bo'lgan elektr zanjir kuchlanishi $U = 100 \text{ V}$. Tok va to'la quvvat kompleks qiymati hisoblab topilsin.

Yechish.

To'la qarshilik kompleks ifodasi: $Z = R \pm jX = 3 \pm j4 = 5e^{\pm j53^\circ}$

$$\text{Tok: } \dot{I} = \frac{\dot{U}}{Z} = \frac{100e^{j0}}{5e^{\pm j53^\circ}} = 20e^{\pm j53^\circ} = 12 \pm j16$$

To'la quvvat kompleks ifodasi:

$$\tilde{S} = \dot{U} \dot{I} = 100 \cdot 20e^{\pm j53^\circ} = 2000\cos 53^\circ \pm j2000\sin 53^\circ = 1200 \pm j1600 (\text{BA})$$

Masala 3.3. Kuchlanish $\dot{U} = (80 + j60)$ tok $\dot{I} = (24 - j7)$ kompleks ifodalari uchun aktiv va reaktiv qarshilik qiymati aniqlamb, tok va kuchlanish vektor ifodasi chizilsin.

Yechish.

Tok va kuchlanish ko'rsatkichli ifodasi aniqlanadi

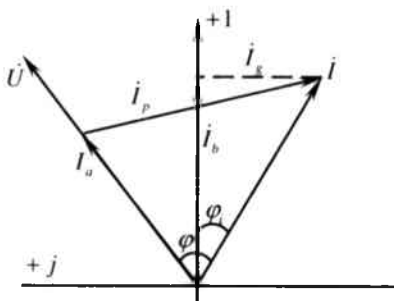
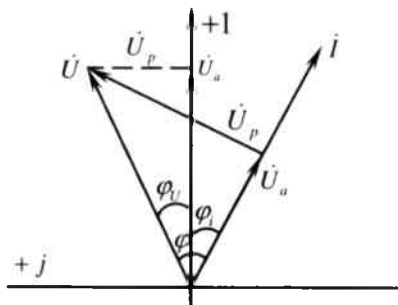
$$\dot{U} = (80 + j60) = 100e^{j36^\circ 50'} (\text{V}) \quad \dot{I} = (24 - j7) = 25e^{-j16^\circ 15'} (\text{A})$$

$$\text{Kompleks to'la qarshilik: } \underline{Z} = \frac{\dot{U}}{\dot{I}} = 4e^{j53^\circ} = (2,4 + j3,2) (\text{Om})$$

Bundan aktiv qarshilik $R = 2,4 \text{ Om}$; reaktiv qarshilik $X = 3,2 \text{ Om}$.

Kuchlanishi va tok orasidagi fazadagi farq: $\varphi = \varphi_u - \varphi_i = 53^\circ$

Kompleks tekislikda tok va kuchlanishlar vektor diagrammasini tuzamiz.



Vektor diagrammadan

$$\dot{U}_a = U \cos \varphi$$

$$\dot{U}_p = U \sin \varphi$$

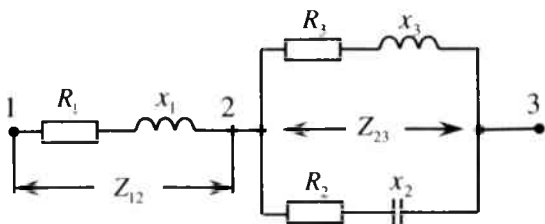
$$U = \sqrt{U_a^2 + U_p^2}$$

$$\dot{I}_a = I \cos \varphi$$

$$\dot{I}_p = I \sin \varphi$$

$$I = \sqrt{I_a^2 + I_p^2}$$

Masala 3.4. Elektr zanjir parametri: $R_1=30 \text{ Om}$, $X_1=20 \text{ Om}$, $R_2=50 \text{ Om}$, $X_2=-100 \text{ Om}$, $R_3=100 \text{ Om}$, $X_3=50 \text{ Om}$ ga teng bo'lganda, ekvivalent to'la, aktiv, reaktiv qarshilik qiymati topilsin.



Yechish.

Zanjirning parallel ulanlgan qismi uchun kompleks to'la qarshilik:

$$\begin{aligned} Z_{23} &= \frac{(R_3 + jx_3)(R_2 + jx_2)}{R_3 + jx_3 + R_2 - jx_2} = \frac{112e^{j26^\circ 30'} \cdot 112e^{-j63'}}{150 - j50} = \\ &= \frac{12550e^{-j37'}}{150e^{-j18^\circ 26'}} = 79,5e^{j18^\circ 26'} = 75,2 - j25,3 \end{aligned}$$

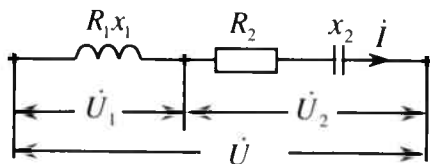
Endi umumiy kompleks ekvivalent qarshilikni topish uchun to'la kompleks qarshilikni qo'shamiz:

$$Z = R_1 + jx_1 + Z_{23} = 30 + j20 + 75,2 - j25,3 = 105,5 - j5,3$$

Bundan aktiv qarshilik $R=105,5 \text{ Om}$, reaktiv qarshilik $X_C=-5,3 \text{ Om}$ ga teng bo'lib, sig'im parametriga mos keladi.

Masala 3.5. Qarshiligi $R_1=10 \text{ Om}$, $X_1=50 \text{ Om}$ bo'lgan induktiv g'altak, aktiv qarshiligi $R_2=10 \text{ Om}$ va sig'im qarshiligi $X_2=-30 \text{ Om}$ bilan ketma-ket sxemaga biriktirilib va $U=127 \text{ V}$ kuchlanishga ulangan. Zanjirdan o'tuvchi tok, g'altakdagi kuchlanish va sig'im kuchlanishlari aniqlansin.

Yechish. Qarshilikning kompleks ifodasini yozamiz:



$$\underline{Z}_1 = 10 + j50 = 51e^{j78^\circ 40'}$$

$$\underline{Z}_2 = 1 - j30 = 30e^{-j88^\circ}$$

Umumiy kompleks qarshilik:

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_2 = 11 + j20 = 22,8e^{j61^\circ} \text{ Om}$$

Kompleks tok: $\dot{i} = \frac{\dot{U}}{\underline{Z}} = \frac{127}{22,8e^{j61^\circ}} = 5,56e^{-j61^\circ}$

G'altadagi kuchlanish: $\dot{U}_1 = \underline{Z}_1 \dot{i} = 284e^{j17^\circ 30'}$ yoki $\varphi_1 = 17^\circ 30'$

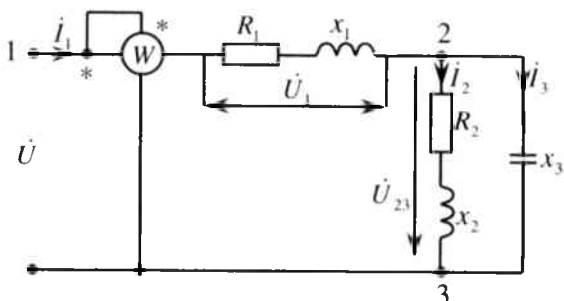
Sxemadagi kuchlanish:

$$\dot{U}_2 = \underline{Z}_2 \dot{i} = 30e^{-j88^\circ} \cdot 5,56e^{-j61^\circ} = 167e^{-j149^\circ}; \quad \varphi_2 = -149^\circ$$

Kuchlanishlar orasida fazadagi farq: $\varphi = \varphi_1 - \varphi_2 = 166^\circ 30'$

Masala 3.6. 2.18-masala shartiga asosan kompleks usuldan foydalanib tarmoq toklari aniqlansin.

Yechish. Kompleks to'la qarshilik:



Bunda:

$$\underline{Z}_1 = (2 + j26) \text{ Om} \quad \underline{Z}_2 = (10 + j10) \text{ Om} \quad \underline{Z}_3 = -j10 \text{ Om}$$

Zanjirning qarshiliklari parallel ulangan qismi uchun:

$$\underline{Z}_{23} = \frac{\underline{Z}_2 \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3} = (10 - j10) \text{ Om}$$

Zanjirning umumiy kompleks qarshiligi

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_{23} = (2 + j26) + (10 - j10) = (12 + j16) \text{ Om}$$

Aktiv quvvat ifodasidan $P = I_2 R$, zanjiriga kiruvchi tok:

$$I_1 = \sqrt{\frac{P}{R_1}} = \sqrt{\frac{1200}{12}} = 10 \text{ A, ya'ni } I_1 = 10 \text{ A teng va haqiqiy qiymatga}$$

ega. Zanjirdagi umumiy kuchlanish:

$$\dot{U} = I_1 \underline{Z} = (12 + j16) \cdot 10 = (120 + j160) \text{ V}$$

$$\text{Bundan: } U = \sqrt{120^2 + 160^2} = 200 \text{ V}$$

Parametrlari ketma-ket ulangan qismdagi kuchlanish:

$$\dot{U}_1 = \underline{Z}_1 \dot{I}_1 = (2 + j26) \cdot 10 = (20 + j260) \text{ yoki: } U_1 = \sqrt{20^2 + 260^2} = 261 \text{ V}$$

Parallel sxemada ulangan qismdagi kuchlanishi:

$$\text{yoki: } \dot{U}_{23} = \dot{I}_{23} (10 + j10) \cdot 10 = (100 + j100) \text{ V}$$

$$U_{23} = \sqrt{100^2 + 100^2} = 100 \text{ V}$$

$$\text{Tarmoqdagi tok: } \dot{I}_2 = \frac{\dot{U}_{23}}{\underline{Z}_1} = \frac{100 e^{-j45^\circ}}{10 e^{j45^\circ}} = 10 e^{-j90^\circ} = (-j10) \text{ A}$$

$$\text{yoki: } I_2 = 10 \text{ A.}$$

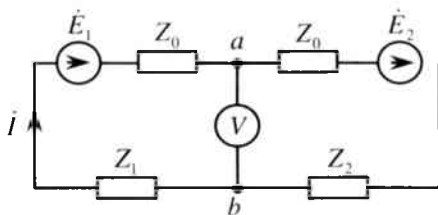
$$\dot{I}_3 = \frac{\dot{U}_{23}}{\underline{Z}_3} = \frac{100 e^{-j45^\circ}}{10 e^{-j90^\circ}} = 100 e^{-j45^\circ} = (10 + j10) \text{ A yoki: } I_3 = \sqrt{10^2 + 10^2} = 14,1 \text{ A.}$$

Masalaning yechimini tekshiramiz:

$$\dot{I}_1 = \dot{I}_2 + \dot{I}_3 = -j10 + 10 + j10 = 10 \text{ A}$$

Masala 3.7. Kompleks qarshiliklari:

$\underline{Z}_0 = (3 + j4)$; $\underline{Z}_1 = (44 + j74)$ $\underline{Z}_2 = -j80$ bo'lgan elektr zanjir ketma-ket sxemada ikkita generatorga ulangan bo'lib, tok qiymati va voltmetr kuchlanishi aniqlansin.



Yechish.

Zanjirdagi tok:

$$\dot{I} = \frac{\dot{E}_1 + \dot{E}_2}{2R_0 + \underline{Z}_1 + \underline{Z}_2} = \frac{220 + j220}{(6 + j8) + (44 + j74) + (-j80)} = \frac{220e^{j45}}{50 + j2} \approx 4,4e^{j45} = (4,4 + j4,4)$$

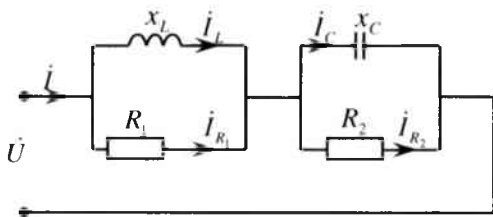
$$\text{yoki: } I = \sqrt{4,4^2 + 4,4^2} \approx 6 \text{ A}$$

Voltmetrdagi kuchlanish:

$$\dot{U}_{ab} = \frac{\dot{E}_1 + \dot{E}_2(\underline{Z}_0 + \underline{Z}_1)}{2\underline{Z}_0 + \underline{Z}_1 + \underline{Z}_2} = \frac{220 + j220[(3 + j4) + (4 + j74)]}{50 + j2} = 335 - j547$$

$$\text{Bundan: } U_{ab} = \sqrt{335^2 - 547^2} = 642 \text{ V}$$

Masala 3.8. Elektr zanjir qarshiliklari: $R_1=R_2=25\text{Om}$, $X_L=33,3\text{Om}$, $X_C=-33,3\text{Om}$ bo'lib, $U=320\text{V}$ kuchlanishga ulangan. To'la qarshilik $\underline{Z}$, burchak $\cos\varphi$ va toklari aniqlansin.



Yechish. Parallel ulangan birinchi kontur to'la qarshiligi:

$$\underline{Z}_1 = \frac{33,3e^{j90^\circ} \cdot 25}{25 + j33,3} = \frac{830e^{j90^\circ}}{41,5e^{j53^\circ}} = 20e^{j37^\circ} = 16 + j12 \text{ Om}$$

Ikkinchi kontur to'la qarshiligi:

$$\underline{Z}_2 = \frac{33,3e^{-j90^\circ} \cdot 25}{25 - j33,3} = \frac{830e^{-j90^\circ}}{41,5e^{-j53^\circ}} = 20e^{-j37^\circ} = 16 - j12 \text{ Om}$$

To'la kompleks qarshiligi: $\underline{Z} = \underline{Z}_1 + \underline{Z}_2 = 16 + j12 + 16 - j12 = 32 \text{ Om}$

$$\text{Umumiy tok: } \dot{I} = \frac{\dot{U}}{\underline{Z}} = \frac{320}{32} = 10 \text{ A}$$

$$\text{To'la quvvat: } \bar{S} = \dot{U}\dot{I} = 320 \cdot 10 = 3200 \text{ VA}$$

$$\text{Aktiv quvvat: } P = RI^2 = 32 \cdot 10^2 = 3200 \text{ W}$$

Zanjirning quvvat koefitsienti: $\cos \varphi = \frac{P}{S} = 1$ bo'lib, aktiv qarshilik xarakteriga ega.

Birinchi va ikkinchi kontur kuchlanishlar:

$$\dot{U}_1 = \dot{I} \underline{Z}_1 = 10 \cdot 20e^{j37^\circ} = 200e^{j37^\circ} \text{ (V)} \quad \dot{U}_2 = \dot{I} \underline{Z}_2 = 10 \cdot 20e^{-j37^\circ} = 200e^{-j37^\circ} \text{ (V)}$$

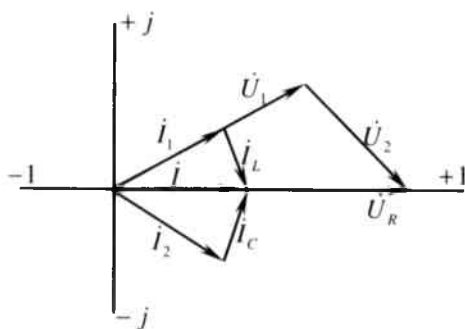
Tokni aniqlaymiz:

$$\dot{I}_1 = \frac{\dot{U}_1}{R_1} = \frac{200e^{-j37^\circ}}{25} = 8e^{j37^\circ} \text{ A} \quad \dot{I}_L = \frac{\dot{U}_L}{X_L} = \frac{200e^{j37^\circ}}{33,3e^{j90^\circ}} = 6e^{-j53^\circ} \text{ A}$$

Ikkinchi konturdagi tokni aniqlaymiz: $\dot{I}_2 = \frac{\dot{U}_2}{R_2} = \frac{200e^{-j37^\circ}}{25} = 8e^{-j37^\circ} \text{ A}$

$$\dot{I}_C = \frac{\dot{U}_C}{X_C} = \frac{200e^{-j37^\circ}}{33,3e^{-j90^\circ}} = 6e^{j53^\circ} \text{ A}$$

Kompleks tekislikda tok va kuchlanish vektor ifodasi:



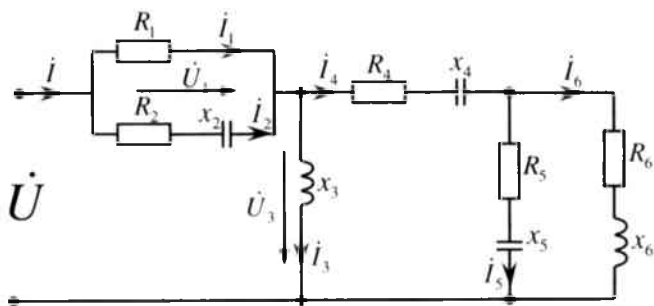
Masala 3.9. Berilgan elektr zanjir parametri: $R_1=50 \text{ Om}$, $X_2=-25 \text{ Om}$, $R_2=25 \text{ Om}$, $X_3=10 \text{ Om}$, $R_4=2,5 \text{ Om}$, $X_4=-50 \text{ Om}$, $R_5=1 \text{ Om}$, $X_5=-2 \text{ Om}$, $R_6=1 \text{ Om}$, $X_6=2 \text{ Om}$ bo'lib, $U=100 \text{ V}$ kuchlanishga ulangan. Tarmoqdan o'tuvchi $\dot{I}_1, \dot{I}_3$ va $\dot{I}_4$ kompleks tok qiymatlari aniqlansin.

Yechish.

Tarmoq kompleks qarshiligi aniqlanadi:

$$\underline{Z}_6 = R_6 + jX_6 = 1 + j2 = e^{j63^\circ} \quad \underline{Z}_5 = R_5 - jX_5 = 1 - j2 = e^{-j63^\circ}$$

Parallel ulangan tarmoq kompleks qarshiligi:



$$\underline{Z}_{56} = \frac{\underline{Z}_6 \cdot \underline{Z}_5}{\underline{Z}_6 + \underline{Z}_5} = 2,5 \text{ Om}$$

To'rtinchi tarmoq kompleks qarshiligi:

$$\underline{Z}_4 = R_4 - jX_4 + \underline{Z}_{56} = 2,5 - j5 + 2,5 = 5 - j5 = 7,1e^{-j45^\circ} \text{ Om}$$

Uchinchi tarmoq kompleks qarshiligi:

$$\underline{Z}_3 = \frac{\underline{Z}_4 \cdot X_3}{\underline{Z}_4 + jX_3} = \frac{7,1e^{-j45^\circ} \cdot 10e^{j90^\circ}}{5 - j5 + j10} = 10 \text{ Om}$$

Parallel ulangan birinchi kontur kompleks qarshiligi:

$$\underline{Z}_{12} = \frac{R_1(R_2 - jX_2)}{R_1 + R_2 - jX_2} = 20,6 - j10,3 = 23e^{-j26^\circ 30'} \text{ Om}$$

Zanjirning kompleks to'la qarshiligi:

$$\underline{Z} = \underline{Z}_{12} + \underline{Z}_3 = 20,6 + j10,3 + 10 = 30,6 - j10,3 = 32,4e^{-j12^\circ} \text{ Om}$$

Zanjirdan o'tuvchi tok qiymati: $\dot{i} = \frac{\dot{U}}{\underline{Z}} = \frac{100}{32,4e^{-j12^\circ}} = 3,1e^{j18^\circ} = 3 + j \text{ A}$

Tarmoqdagi kuchlanish:

$$\dot{U}_{R1} = \dot{I}_{12} \cdot R_1 = 3,1e^{j18^\circ} \cdot 23e^{-j26^\circ 30'} = 71,5e^{-j8^\circ 30'} = 70,5 - j10,5 \text{ V}$$

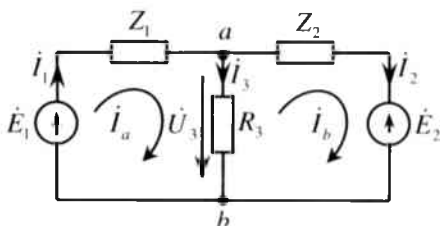
$$\dot{U}_{X3} = \dot{U} - \dot{U}_{R1} = 100 - 70,5 + j10,5 = 29,5 + j10,5 = 31,5e^{j19^\circ 30'} \text{ V}$$

Tarmoqdagi tok :

$$\dot{i}_3 = \frac{\dot{U}_{X3}}{jX_3} = \frac{31,5e^{j19^\circ 30'}}{10e^{j90^\circ}} = 3,15e^{-j70^\circ 30'} = -j3 + 1 \text{ A}$$

$$\dot{I}_4 = \dot{I}_1 + \dot{I}_3 = 3 + j - 1 + j3 = 2 + j4 \text{ A}$$

Masala 3.10. Ikki konturli elektr zanjirga ichki qarshiliklari $Z_1=Z_2=1+j2 \text{ Om}$; EYK $E_1 = 120 \text{ V}$, $E_2 = 115 \text{ V}$ ga teng. Ikkita generator o'rtasidagi qarshiligi $R_3=10 \text{ Om}$ bo'lgan iste'molchi ulangan. Tarmoqdagi tok va kuchlanishlari har xil usullar yordamida hisoblansin.



Yechish.

1. Konturli tok usuli.

Berilgan zanjir ikkita konturdan iborat bo'lib, tarmoq va konturdagi tok yo'nalishini shartli ravishda belgilab olamiz. EYK yo'nalishini hisobga olgan holda $\dot{I}_a, \dot{I}_b$ konturlar uchun ikkita tenglama tuzamiz.

$$\dot{I}_a(Z_1 + Z_3) - \dot{I}_b Z_3 = \dot{E}_1 \quad \dot{I}_b(Z_2 + Z_3) - \dot{I}_a Z_3 = \dot{E}_2$$

Tenglamalar sistemasini yechish bilan konturdagi tok aniqlanadi:

$$\begin{cases} \dot{I}_a(11+j2) - \dot{I}_b 10 = 120 \\ \dot{I}_b(11+j2) - \dot{I}_a 10 = -115 \end{cases} (1+j2)$$

$$\dot{I}_b(11+j2)(11+j2) - 100\dot{I} = 1200 - 115(11+j2)$$

Bundan: $\dot{I}_b = (-5,04 - j0,47) \text{ A}$

Birinchi tenglamadan: $\dot{I}_a = \frac{120 + \dot{I}_b 10}{11+j2} = (6,05 - j1,53) \text{ A}$

Birinchi generatordagi tok konturdagi tok qiymatiga teng:

$$\dot{I}_1 = \dot{I}_2 = (6,05 - j1,53) \text{ A} \quad \text{yoki} \quad I_1 = \sqrt{(6,05)^2 + (-1,53)^2} = 6,24 \text{ A}$$

Ikkinchi generatordagi tok:

$$\dot{I}_2 = \dot{I}_b = (-5,04 - j0,47) \text{ A} \quad \text{yoki} \quad I_2 = \sqrt{(-5,04)^2 + (-0,47)^2} = 5,28 \text{ A}$$

Iste'molchidagi tok:

$$\dot{I}_3 = \dot{I}_a - \dot{I}_b = \dot{I}_1 - \dot{I}_2 = (6,05 - j1,53) - (-5,04 - j0,47) = (11,09 + j1,06)$$

$$\text{yoki } I_3 = \sqrt{(11,09)^2 - (1,06)^2} = 11,14 \text{ A}$$

Iste'molchidagi va generatordagi kuchlanish:

$$\dot{U}_3 = \dot{I}_3 R_3 = (11,09 - j1,06) \cdot 10 = (110,9 - j10,6) \text{ V}$$

$$U_3 = \sqrt{(110,9)^2 + (-10,6)^2} = 111,4 \text{ V}$$

2. Ekvivalent generator usuli.

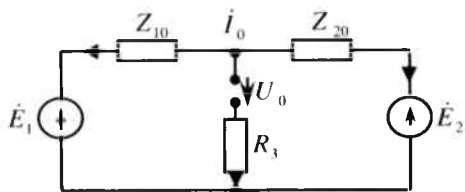
Zanjirning iste'molchi ulangan tarmog'i uzilgan bo'lsa.

Bunda:

$$\dot{U}_0 = \dot{E}_1 - \dot{I}_0 \underline{Z}_1 = \dot{E}_1 - \frac{(\dot{E}_1 - \dot{E}_2)}{\underline{Z}_1 + \underline{Z}_2} \underline{Z}_1 = 120 - \frac{120 - 115}{2(1 + j2)}(1 + j2) = 117,5 \text{ V}$$

Uzilgan holatda zanjirning ichki qarshiligi $\left(\dot{E}_1 = 0, \dot{E}_2 = 0 \right)$ ya'ni,

ekvivalent generator qarshiligi: $\underline{Z}_0 = \frac{\underline{Z}_1 \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} = (0,5 + j1) \text{ Om}$.



$$\text{Iste'molchidagi tok: } I_3 = \frac{\dot{U}_0}{R_3 + \underline{Z}_0} = \frac{117,5}{10 + (0,5 + j1)} = (11,09 - j1,06) \text{ A}$$

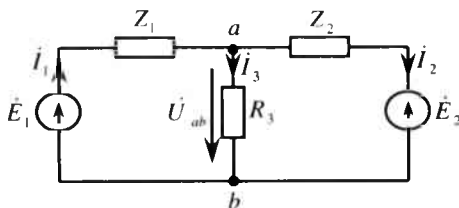
$$I_3 = \sqrt{(11,09)^2 + (-1,06)^2} = 11,14 \text{ A}$$

$$\text{Iste'molchidagi kuchlanish: } \dot{U}_3 = \dot{I}_3 R_3 = (110,9 - j10,6) \text{ V ;}$$

$$\text{yoki: } U_3 = \sqrt{(110,9)^2 - (10,6)^2} = 111,44 \text{ V}$$

3. Tugun kuchlanishlar usuli.

Zanjirning a va b tugun potensiallaridagi kuchlanish:



$$\dot{U}_{ab} = \frac{\dot{E}_1 Y_1 + \dot{E}_2 Y_2}{Y_1 + Y_2 + Y_3} = \frac{5}{2,1 + j0,2} = (2,36 - j0,225)$$

$$U_{ab} = \sqrt{(2,36)^2 - (0,225)^2} = 2,37 \text{ V}$$

Birinchi $\dot{E}_1$ generatoridagi tok:

$$\dot{i}_1 = \frac{\dot{E}_1 - \dot{U}_{ab}}{Z_1} = \frac{120 - (2,36 + j0,225)}{1 + j2} = (23,6 - j47)$$

$$\text{yoki: } I_1 = \sqrt{(23,6)^2 + (-47)^2} = 52,6 \text{ A}$$

Ikkinchi E_2 generatoridan o'tuvchi tok:

$$\dot{i}_2 = \frac{-\dot{E}_2 - \dot{U}_{ab}}{Z_2} = (23,41 - j47) \text{ yoki } I_2 = \sqrt{(23,41)^2 + (-47)^2} = 52,5 \text{ A}$$

$$\text{Iste'molchidagi tok: } \dot{i}_3 = \frac{\dot{U}_{ab}}{Z_3} = \frac{2,36 - j0,225}{10} = (0,24 - j0,023) \text{ A}$$

Bundan: $I_3 \approx 0,24 \text{ A}$

Masala 3.11.

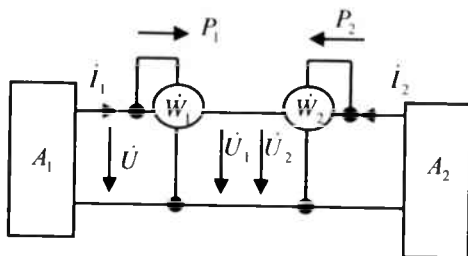
Elektr zanjir kuchlanishdagi va tok: $\dot{U} = 100 + j200 \text{ V}$, tok $\dot{i} = 8 + j2,5 \text{ A}$ bo'lganda, vattmetr ko'rsatishi aniqlansin.

Yechish. Birinchi vattmetr ko'rsatishi P_1 aniqlanadi:

$$\underline{U} = 100 + j200 = 223,6e^{j63,4^\circ} \quad \dot{I} = 8 + j2,5 = 8,4e^{j17^\circ}$$

yoki $\dot{I} = 8,4e^{-j17^\circ} \text{ A}$

$$P_1 = R_e[\dot{U} \cdot \dot{I}] = 223,6e^{j63,4^\circ} \cdot 8,4e^{-j17^\circ} = R_e[1874e^{j46^\circ}] = 1300 \text{ VT}$$



Ikkinchi vattmetr ko'rsatishini P_2 aniqlanadi.

$$\underline{U} = 100 + j200 = 223,6e^{j63,4^\circ} \quad \dot{I} = -[8,4e^{j17^\circ}] = 8,38e^{j163^\circ} \text{ A}$$

$$P_2 = R_e[\dot{U} \cdot \dot{I}] = R_e[223,6e^{j63,4^\circ} \cdot 8,38e^{j163^\circ}] = R_e[1873e^{j226^\circ}] = -1300 \text{ VT}$$

Bunda minus ishora birinchi vattmetr elektr energiyasiga nisbatan ikkinchi vattmetr energiyasiga qarama-qarshi ekanligini ifodalaydi.

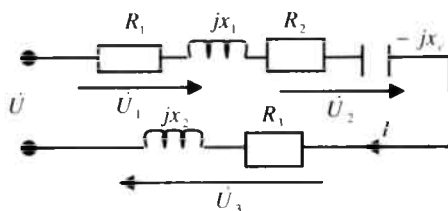
Agarda vattmetr, ampermetr va voltmeter ko'rsatish qiymati ma'lum bo'lsa, ikki qutbli passiv parametrni hisoblab topish mumkin bo'ladi.

$$\text{Ya'ni: } Z = \frac{U}{I}; \quad R = UI \cos \varphi; \quad \text{yoki } \cos \varphi = \frac{P}{UI}; \quad R = Z \cos \varphi;$$

$$X = \sqrt{Z^2 - R^2}$$

Eslatma: Ikki qutbli zanjir parametrini aniqlashda vattmetr o'rniga fazo metrdan ham foydalanish mumkin.

Masala 3.12. Ketma-ket ulangan elektr zanjirdan $I = 5A$ tok o'tadi. Tokga nisbatan ayrim qismlardagi kuchlanishlar: $\dot{U}_1, \dot{U}_2, \dot{U}_3$ va $\cos \varphi_1 = 0,707$, $\cos \varphi_2 = 0,8$, $\cos \varphi_3 = 0,6$ burchakka farq qilib, aktiv qarshilikdagi quvvat qiymati $P_1 = 250 VT$, $P_2 = 200 VT$, $P_3 = 300 VT$ bo'lganda, zanjir parametri va kuchlanish qiymati aniqlanib, vektor ifodasi tuzilsin.



Yechish. Aktiv qarshilik qiymatini aniqlashda quvvatlar ifodasiga asosan: $P_1 = R_1 I^2$; $P_2 = R_2 I^2$; $P_3 = R_3 I^2$

Bundan:

$$R_1 = \frac{P_1}{I^2} = \frac{250}{25} = 10 \text{ Om}; \quad R_2 = \frac{P_2}{I^2} = \frac{200}{25} = 8 \text{ Om}; \quad R_3 = \frac{P_3}{I^2} = \frac{300}{25} = 12 \text{ Om}$$

Reaktiv qarshilik qiymatini aniqlashda quyidagi ifodadan foydalanamiz: $tg \varphi_1 = \frac{x_1}{R_1}$; $tg \varphi_2 = \frac{x_2}{R_2}$; $tg \varphi_3 = \frac{x_3}{R_3}$

Bundan: $x_1 = 10 \text{ Om}$; $x_2 = 6 \text{ Om}$; $x_3 = 16 \text{ Om}$.

Kuchlanish kompleks ifodasi esa:

$$\dot{U}_1 = (R_1 + jx_{L1})\dot{I} = (10 + j10)5 = 150 + j50 \text{ V}$$

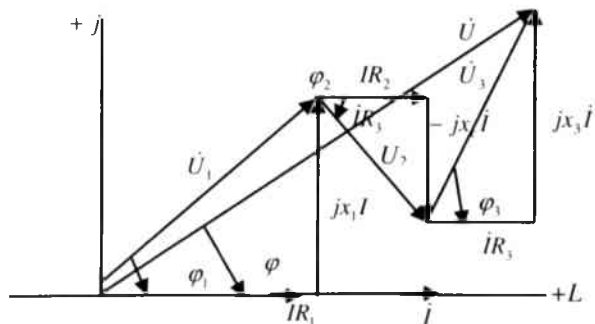
$$\dot{U}_2 = (R_2 - jx_c)\dot{I} = (8 - j6)5 = 40 - j30 \text{ V}$$

$$\dot{U}_3 = (R_3 + jx_{L2})\dot{I} = (12 + j16)5 = 60 + j80 \text{ V}$$

Umumiy kuchlanish:

$$\dot{U} = \dot{U}_1 + \dot{U}_2 + \dot{U}_3 = 250 + j100 = 180 e^{j33^\circ 45'}$$

Massstab tanlash bilan kompleks tekislikda vektor ifodasini tuzamiz.

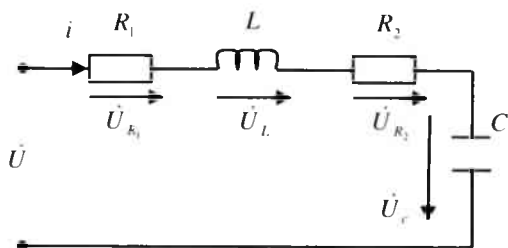


Masala 3.13. Ketma-ket ulangan zanjir parametri: $R_1 = 5 \text{ Om}$, $R_2 = 18 \text{ Om}$, $L = 50 \cdot 10^{-3} \text{ gn}$, $C = 30 \cdot 10^{-4}$ bo'lib, $U = 75 \sin(80t + 15^\circ)$ sinusoidal o'zgaruvchan kuchlanishga ulangan. To'la qarshilik, tok va kuchlanish haqiqiy qiymati va sarf bo'ladigan quvvat balans tenglamasi va vektor ifodasi tuzilsin.

Yechish. Reaktiv qarshilik qiymatini topamiz:

$$X_L = \omega L = 2\pi fL = 2 \cdot 3,14 \cdot 80 \cdot 50 \cdot 10^{-3} = 25 \text{ Om}$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{502 \cdot 30 \cdot 10^{-6}} = 66 \text{ Om}$$



Kompleks qarshilik:

$$Z = R_1 + jx_L + R_2 - jx_C = 5 + j25 + 18 - j66 = 23 - j41 = 47 e^{-j60^\circ}$$

Tokning haqiqiy qiymat kompleks ifodasi: $\dot{I} = \frac{52,9e^{j15^\circ}}{47e^{-j60^\circ}} = 1,2e^{+j75^\circ}$

Faza farqi: $\varphi = \varphi_u - \varphi_i = 15^\circ - 75^\circ = -60^\circ$

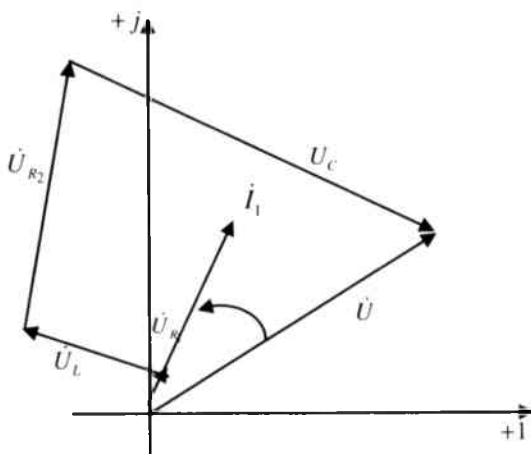
Quvvat balans tenglamasiga asosan:

$$\begin{aligned} S = \dot{U} \dot{I}^* &= 52,9e^{j15^\circ} \cdot 1,2e^{-j75^\circ} = 65e^{-j60^\circ} = \dot{I}^2 Z = 1,2^2 \cdot (23 - j41) = \\ &= 32 - j57(\text{VA}) = 65e^{-j60^\circ} \end{aligned}$$

Vektor ifodasini tuzish uchun qarshilikdagi kompleks kuchlanish qiymatini topamiz:

$$\begin{aligned} \bar{U} &= \bar{U}_{R_1} + \bar{U}_{L_1} + \bar{U}_{R_2} + \bar{U}_C = \bar{I}R + \bar{I}jX_L + \bar{I}R_2 - j\bar{I}X_C = \\ &= 1,2 \cdot e^{j75^\circ} \cdot (5 + j2,5 + 18 - j66) = \\ &= 6e^{j75^\circ} + 30e^{j165^\circ} + 22e^{j75^\circ} + 78e^{-j15^\circ} \end{aligned}$$

Tok va kuchlanish masshtabini tanlash bilan kompleks tekislikda moduli va faza burchaklari bo'yicha vektorni yo'naltirgan holda chizamiz.



Masala 3.14. Murakkab elektr zanjir parametri:

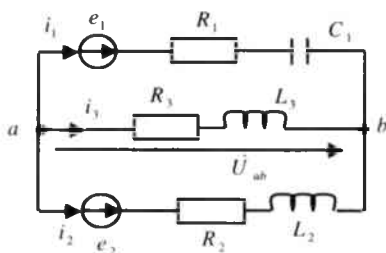
$$e_1 = 212 \sin(\omega t + 30^\circ) \text{ V}, \quad e_2 = 212 \sin \omega t (\text{V}), \quad R_1 = 80 \text{ Ohm}, \quad R_2 = 100 \text{ Ohm},$$

$$R_3 = 70 \text{ Ohm}, \quad L_2 = 32 \text{ mH}, \quad C_1 = 212 \text{ mF},$$

chastota $f = 50 \text{ Hz}$ bo'lganda tarmoqdagi tok aniqlansin.

Yechish. EYK kompleks ifodasini yozamiz:

$$\dot{E}_1 = \frac{212}{\sqrt{2}} e^{j30^\circ} = 150 e^{j30^\circ} = (130 + j75); \quad \dot{E}_2 = \frac{212}{\sqrt{2}} = 150 \text{ V.}$$



Tarmoqdagi kompleks qarshilik:

$$Z_1 = R_1 - \frac{1}{j\omega C} = 8 - \frac{10^6}{j(314 \cdot 212)} = 8 - j15 \approx 17 e^{-j62^\circ} \text{ Om.}$$

$$Z_2 = R_2 + j\omega L_2 = 10 + j314 \cdot 32 \cdot 10^{-3} = 10 + j10 = 10\sqrt{2} e^{j45^\circ} \text{ Om.}$$

$$Z_3 = R_3 + j\omega L_3 = 7 + j314 \cdot 32 \cdot 10^{-3} \approx 7 + j10 = 12,2 e^{j55^\circ} \text{ Om.}$$

Ikki tugun orasidagi potentsiallar usuliga asosan:

$$\begin{aligned} \dot{U}_{ab} &= \frac{\dot{E}_1 y_1 + \dot{E}_2 y_2}{y_1 + y_2 + y_3} = \frac{\dot{E}_1 \left(\frac{1}{Z_1} \right) + \dot{E}_2 \left(\frac{1}{Z_2} \right)}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} = \frac{\frac{150 e^{j30^\circ}}{17 e^{-j62^\circ}} + \frac{150}{14,1 e^{j45^\circ}}}{\frac{1}{17 e^{-j62^\circ}} + \frac{1}{14,1 e^{j45^\circ}} + \frac{1}{12,2 e^{j55^\circ}}} = \\ &= 53,7 e^{j36^\circ} \approx 43,4 + j31,6 \text{ V.} \end{aligned}$$

Tarmoqdagi tok:

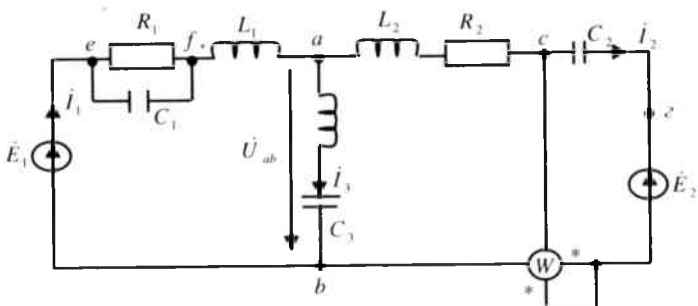
$$i_1 = \frac{\dot{E}_1 - \dot{U}_{ab}}{Z_1} = \frac{130 + j75 - 43,4 - j31,6}{17 e^{-j62^\circ}} = \frac{97 e^{j26^\circ}}{17 e^{-j62^\circ}} = 5,7 e^{j88^\circ}$$

$$i_2 = \frac{\dot{E}_2 - \dot{U}_{ab}}{Z_2} = \frac{150 - 43,4 - j31,6}{14,1 e^{j45^\circ}} \approx \frac{111 e^{-j16,5^\circ}}{14,1 e^{j45^\circ}} = 7,9 e^{j61,5^\circ}$$

$$i_3 = \frac{-\dot{U}_{ab}}{Z_3} = \frac{-53,7 e^{j36^\circ}}{12,2 e^{j55^\circ}} = -4,4 e^{j19^\circ}$$

$$\begin{aligned}\bar{S} &= \bar{S}_1 + \bar{S}_2 = \dot{E}_1 \cdot I_1^* + \dot{E}_2 \cdot I_2^* = 150e^{j30^\circ} \cdot 5,7e^{-j88^\circ} + 150 \cdot 7,9e^{-j61,5^\circ} = \\ &= 855e^{-j58^\circ} + 1195e^{-j61,5^\circ} = 855(\cos 58^\circ - j \sin 58^\circ) + 1195(\cos 61,5^\circ - j \sin 61,5^\circ) \\ &= (427 - j\sqrt{3} \cdot 427) + (600 - j\sqrt{3}600) = (1027 - j\sqrt{3} \cdot 2 \cdot 1027) \text{ BA}\end{aligned}$$

Masala 3.15. Murakkab elektr zanjir parametri: $\dot{E}_2 = 200e^{j45^\circ} \text{ V}$; $\dot{E}_2 = 240e^{j0^\circ} \text{ V}$; $R_1 = 12 \text{ Om}$; $L_1 = 2 \cdot 10^{-3} \text{ gn}$; $C_1 = 20 \cdot 10^{-6} \text{ f}$; $R_2 = 14 \text{ Om}$; $L_2 = 8 \cdot 10^{-3} \text{ gn}$; $C_2 = 100 \cdot 10^{-6} \text{ f}$; $R_3 = 4 \text{ Om}$; $L_3 = 5 \cdot 10^{-3} \text{ gn}$; $C_3 = 50 \cdot 10^{-6} \text{ f}$; $f = 500 \text{ gs}$ ga teng.



Tarmoqdagi tok, vattmetr ko'rsatish qiymati aniqlanib, quvvat muvozanat tenglamasi tuzilsin.

Yechish. Ikki tugunlararo potentsiallar usuliga asosan:

$$\dot{U}_{ab} = \frac{\dot{E}_1 y_1 + \dot{E}_2 y_2}{y_1 + y_2 + y_3} \quad (1)$$

Bu yerda: $y_1 = \frac{1}{Z_1} = \frac{1}{7,67e^{j40^\circ}} = 0,13e^{-j4^\circ} = 0,13 - j0,009 \frac{1}{\text{Om}}$

yoki:

$$Z_1 = Z_1^1 + j\omega L = \frac{R_1 + jX_{C_1}}{R_1 + jX_{C_1}} + j\omega L = (7,67 - j5,75) + j6,28 = 7,67e^{j40^\circ} \text{ Om}.$$

$$y_2 = \frac{1}{Z_2} = \frac{1}{26e^{j57^\circ 20'}} = 0,0385e^{-j57^\circ 20'} = 0,0208 - j0,0324 \frac{1}{\text{Om}}$$

$$y_3 = \frac{1}{Z_3} = \frac{1}{8,63e^{j90^\circ}} = 0,107e^{-j90^\circ} \frac{1}{\text{Om}}$$

Aniqlangan qiymatlarni (1) tenglamaga qo'yamiz:

$$\begin{aligned}\dot{U}_{ab} &= \frac{200e^{j45^\circ} \cdot 0,13e^{-j4^\circ} - 240 \cdot 0,0385e^{-j57^\circ 20'}}{(0,13 - j0,009) + (0,0208 - j0,0324) + (-j0,107)} = \\ &= \frac{26e^{j41^\circ} - 9,25e^{-j57^\circ 20'}}{0,151 - j0,157} = \frac{(20 + j17) - (5 - j7,8)}{0,218e^{-j45^\circ}} = \\ &= \frac{29e^{j58^\circ 40'}}{0,218e^{-j46^\circ}} = 133e^{j104^\circ 50'} = -34 + j127,5 \text{ V}.\end{aligned}$$

Om qonuniga asosan tarmoqdagi tokni aniqlaymiz:

$$\begin{aligned}I_1 &= (\dot{E}_1 - \dot{U}_{ab})y_1 = (200e^{j45^\circ} - 133e^{j104^\circ 50'})0,13e^{-j4^\circ} = \\ &= (175 + j13,5) \cdot 0,13e^{-j4^\circ} = 175e^{j4^\circ 20'} \cdot 0,13e^{-j4^\circ} = 22,7 \text{ A}.\end{aligned}$$

$$\begin{aligned}I_2 &= (\dot{E}_1 + \dot{U}_{ab})y_2 = (240 + 133e^{j104^\circ 50'}) \cdot 0,0385e^{-j57^\circ 20'} = \\ &= (206 + j127,5) \cdot 0,0385e^{-j57^\circ 20'} = 242e^{j31^\circ 75'} \cdot 0,0385e^{-j57^\circ 20'} = \\ &= 9,3e^{-j25^\circ 35'} = 8,35 - j4 \text{ A}.\end{aligned}$$

$$I_3 = \dot{U}_{ab}y_3 = 133e^{j104^\circ 50'} \cdot 0,107e^{j90^\circ} = 125e^{j14^\circ 50'} = 12,1 + j3,2 \text{ A}.$$

Masalaning yechimini tekshiramiz:

$$I_1 = I_2 + I_3 = (-8,35 + j4) + (-12,1 - j3,2) = -20,45 + j0,8 \approx 21 \text{ A}.$$

Sig'imdan o'tuvchi tokni topamiz:

$$I_{c_1} = \frac{U_{cf}}{jX_{c_1}} = \frac{I_1 Z_1^1}{jX_{c_1}} = \frac{22,7 \cdot 9,6e^{-j36^\circ 50'}}{16e^{-j90^\circ}} = 13,6e^{j52^\circ 10'} = 8,15 + j10,9 \text{ A}.$$

Quvvat muvozanat tenglamasiga asosan: $\tilde{S}_{gen} = \tilde{S}_{ist}$

Manbadagi to'la quvvat:

$$\begin{aligned}\tilde{S}_{gen} &= \dot{E}_1 I_1 + \dot{E}_2 I_2 = 200e^{j45^\circ} \cdot 22,7 - 240 \cdot 9,3e^{j25^\circ 35'} = 4550e^{j45^\circ} - 2240e^{j25^\circ 35'} = \\ &= (3200 + j3200) - (2002 - j965) = 5202 + j2235\end{aligned}$$

Aktiv quvvat: $P = 5202 \text{ VT}$. Reaktiv quvvat: $Q = 2235 \text{ VAR}$.

Iste'molchilarda sarf bo'ladigan to'la quvvat:

$$\begin{aligned}\tilde{S}_{ist} &= (I_{R1}^2)R_1 - j(I_{C1}^2)X_{c_1} + j(I_1^2)X_{L_1} + j(I_3^2)(X_{L_3} - X_{C_3}) + j(I_2^2)X_{L_2} + \\ &+ I_2^2 R_2 - j(I_2^2)X_{c_2} = 330 \cdot 12 - j185 \cdot 16 + j515 \cdot 6,28 + j156 \cdot 9,4 + \\ &+ j86 \cdot 25 + 86 \cdot 14 - j86 \cdot 3,2 = 3960 - j2960 + j3200 + \\ &+ j1460 + j2150 + 1260 - j276 = 5160 + j2600.\end{aligned}$$

Vattmetr ko'rsatish qiymatini aniqlaymiz:

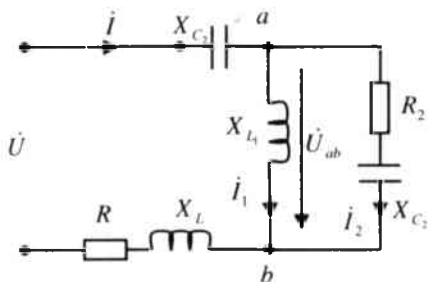
$$S = \dot{U}_{bc} \cdot \dot{I}_2 = 260e^{j174^\circ} \cdot 9,3e^{-j25^\circ 35'} = 2400e^{j148^\circ 25'} = 2040 + j1250 \text{ VA}.$$

Bundan: $P = 2040 \text{ VT}$,

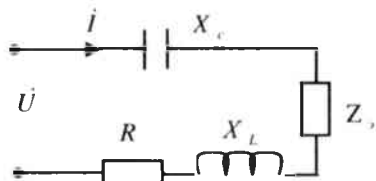
yoki $P = UI \cos \varphi = 260 \cdot 9,3 \cos 148^\circ 2' = 2040 \text{ VT}$.

Masala 3.16. Elektr zanjir qarshilik parametri:

$x_{c1} = 10 \text{ Om}$, $x_{L1} = 5 \text{ Om}$, $x_L = 4 \text{ Om}$, $R = 4 \text{ Om}$, $R_2 = 8 \text{ Om}$, $x_{c2} = 6 \text{ Om}$ bo'lib, $U = 11,45 \cdot \sqrt{2} \sin(\omega t - 102^\circ) \text{ V}$ kuchlanishga ulangan. Tarmoqdagi tok i , i_1 , i_2 toklar kompleks qiymati va to'la quvvat topilsin.



a)



b)

Yechish. Zanjirning parallel sxemada ulangan qismini ekvivalent to'la qarshilik bilan almashtiramiz (b)

$$Z_e = \frac{jx_{L1}(R_2 - jx_{c2})}{jx_{L1} + (R_2 + jx_{c2})} = \frac{j5(8 - j6)}{j5 + 8 - j6} = \frac{j40 + 30}{8 - j1} = \frac{50e^{j53^\circ}}{8e^{-j70^\circ}} = 6,2e^{j6^\circ} = 3,08 + j5,4 \text{ Om}.$$

Keltirilgan (b) ekvivalent sxemadan:

$$Z_{um} = -jx_c + Z_e + jx_L + R = -j10 + 3,08 + j5,4 + j4 + 4 = 7,08 - j0,6 = 7,1e^{-j4,8^\circ} \text{ Om}$$

$$\text{Zanjirga kiruvchi tok: } \dot{I} = \frac{\dot{U}}{Z_{um}} = \frac{11,45e^{j102^\circ}}{7,1 \cdot e^{-j4,8^\circ}} = 1,62e^{-j97,3^\circ}$$

Zanjirning tarmoqlangan qismlaridagi tok:

$$\dot{I}_1 = \frac{\dot{U}_{ab}}{Z_1} = \dot{I} \cdot \frac{R_2 + jx_{c2}}{jx_{L1} + R_2 - jx_{c2}} = \frac{1,62e^{-j97^\circ} \cdot (8 - j6)}{j5 + 8 - j6} = -1,2 - j1,6 \text{ A}$$

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{Z_2} = \dot{I} \cdot \frac{jx_L}{jx_{L1} + R_2 - jx_{c2}} = \frac{1,62e^{-j97^\circ} \cdot 5e^{j90^\circ}}{j5 + 8 - j6} = 1 \text{ A}$$

To'la quvvatni topamiz: $\tilde{S} = \dot{U} \cdot \dot{I} = 11,45e^{j102^\circ} \cdot 1,62e^{j97^\circ} = 18,4e^{j200^\circ} = 18,4(\cos 200^\circ + j \sin 200^\circ) \text{ VA}$

3.3. Mustaqil yechish uchun masalalar

Masala 3.1. Tok va kuchlanishning kompleks ifodasi:

$$1. \quad \dot{U} = 100 \text{ (V)} \quad \dot{I} = (16 + j12) \text{ A}$$

$$2. \quad \dot{U} = 60 + j80 \text{ (V)} \quad \dot{I} = 20 \text{ A}$$

$$3. \quad \dot{U} = 60 + j80 \text{ (V)} \quad \dot{I} = j20 \text{ A}$$

$$4. \quad \dot{U} = 100e^{j\frac{\pi}{3}} \text{ (V)} \quad \dot{I} = 20e^{j\frac{\pi}{6}} \text{ A}$$

bo'lgan qiymatlar uchun kompleks to'la qarshilik, aktiv va reaktiv tashkil etuvchi parametr aniqlansin.

Masala 3.2. Tok va kuchlanishning haqiqiy (effektiv) kompleks ifodasi $\dot{I} = (5 + j5)$ va $\dot{U} = (20 + j20)$ bo'lganda, tok va kuchlanish oniy qiymat ifodasi va to'la qarshiligi aniqlansin.

Javob: $\underline{Z} = -j4 \text{ Om}$

Masala 3.3. Tok va kuchlanish kompleks ifodasi:

$$1. \quad \dot{U} = 100e^{j\frac{\pi}{6}} \text{ (V)} \quad \dot{I} = 10e^{j\frac{\pi}{6}} \text{ A}$$

$$2. \quad \dot{U} = 10^5 e^{-j\frac{\pi}{3}} \text{ (V)} \quad \dot{I} = 50e^{j\frac{\pi}{6}} \text{ A}$$

bo'lganda aktiv quvvat, to'la qarshilik va to'la o'tkazuvchanlik kompleks ifodasi aniqlansin.

Javob: 1) $R = 1 \text{ kVt}$, 2) $R = 0$

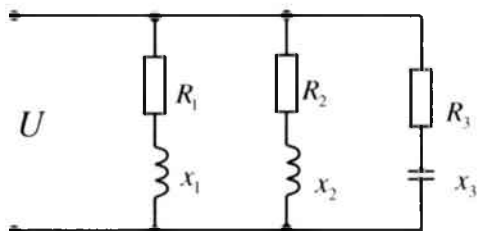
Masala 3.4. Induktiv g'altak $\dot{U} = 100 \text{ (V)}$ kuchlanishga ulangan bo'lib, qarshiligi $R = 3 \text{ Om}$, $X = \pm 4 \text{ Om}$. Tok va to'la quvvat kompleks ifodasi aniqlansin.

Javob: $\tilde{S} = \dot{U} \dot{I} = (1200 \pm j1600) \text{ VA}$

Masala 3.5. Qarshilik parametri $R=20 \text{ Om}$, $X_L=10 \text{ Om}$. Induktiv g'altak chastotasi $f=50 \text{ Gs}$ bo'lgan $U=100\sin(\omega t+45^\circ)$ (V) kuchlanish ulangan. Chastota ikki martagacha ko'paygan holat uchun kompleks to'la qarshiligi, tok va to'la quvvat aniqlansin.

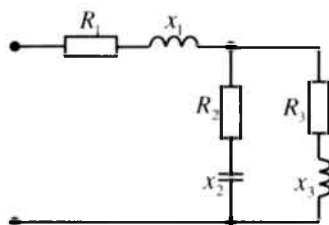
Javob: $\dot{I} = 2,5 \text{ A}$, $\tilde{S} = 177 \text{ VA}$

Masala 3.6. Parallel sxemada ulangan uchta iste'molchi parametrlari: $R_1=5 \text{ Om}$, $X_1=2 \text{ Om}$, $R_2=2,5 \text{ Om}$, $X_2=5 \text{ Om}$, $R_3=1,25 \text{ Om}$, $X_3=-2,5 \text{ Om}$ ga teng. Ekvivalent kompleks o'tkazuvchanlik parametri va umumiy zanjir uchun burchak $\cos\varphi$ aniqlansin.

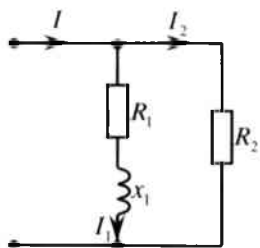


Javob: $\underline{y} = 0,425 \left(\frac{1}{\text{Om}}\right)$; $\cos\varphi=0,995$

Masala 3.7. Elektr zanjir parametri: $R_1=3 \text{ Om}$, $X_1=20 \text{ Om}$, $R_2=50 \text{ Om}$, $X_2=-100 \text{ Om}$, $R_3=100 \text{ Om}$, $X_3=50 \text{ Om}$ zanjirning ekvivalent aktiv va reaktiv qarshilik qiymati aniqlansin.



Javob: $R=105,5 \text{ (Om)}$, $X=-5,3 \text{ (Om)}$.



Masala 3.8. Tarmoqdagi tok $I=1,6 \text{ A}$, $I_1=8,93 \text{ A}$, $I_2=10 \text{ A}$ va qarshilik $R_2=2 \text{ Om}$ bo'lganda R_1 aktiv quvvat, $\cos\varphi$ quvvat koeffitsienti va R_1 , X_1 qarshilik parametrlari aniqlansin.

Javob: $R_1=800 \text{ Vt}$, $\cos\varphi=0,446$,
 $R_1=10 \text{ Om}$, $X_1=\pm 20 \text{ Om}$.

Masala 3.9. Elektr zanjirdagi tok $I=10 \text{ A}$ ulangan. Kuchlanish $U=130 \text{ V}$. Iste'mol qiladigan aktiv quvvati $R=500 \text{ Vt}$ bo'lib $\varphi>0$ va $\varphi<0$ bo'lgan holatlarda to'la qarshilik va o'tkazuvchanlik kompleks ifodasini yozing.

Javob: $Z=(5\pm j12) \text{ Om}$; $Y=(2,96\pm j7,1)110^2 \frac{1}{\text{Om}}$

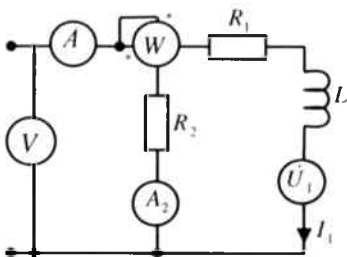
Masala 3.10. Kuchlanish va tok niy qiymati $u = 141 \sin(\omega t + 90^\circ)$, $i = 14,1 \sin(\omega t + 30^\circ)$ bo'lganda, to'la qarshilik Z va aktiv, reaktiv va to'la quvvat qiymati topilsin.

Javob: $Z = 5 + j5\sqrt{3} \text{ om}$, $\bar{S} = 500 + j500\sqrt{3} \text{ VA}$.

Masala 3.11. Kompleks sonlar soddalashtirilib, ko'rsatkichli va algebraik ifodalari yozilsin.

$$\frac{(4,36 - j \cdot 5,02)(-j \cdot 4,37) + 7,3e^{-j205}}{54e^{j180^\circ} + j0,437(j5,5)(e^{j90^\circ} + 5,07 - j2,5)}$$

Javob: $1,71e^{j6,8^\circ} = 1,7 + j0,2$.



Masala 3.12. Keltirilgan sxemada tok $I_1=1 \text{ A}$ va parametri $R_1=100 \text{ Om}$, $L=0,276 \text{ gn}$, $R_2=200 \text{ Om}$, $f=100 \text{ gs}$ bo'lganda, voltmetr, ampermetr, va vattmetr ko'rsatish qiymati aniqlansin.

Javob:
 $U = 200 \text{ V}$, $I = 1,73 \text{ A}$, $P = 300 \text{ VT}$.

Masala 3.13. Murakkab elektr zanjir parametri:

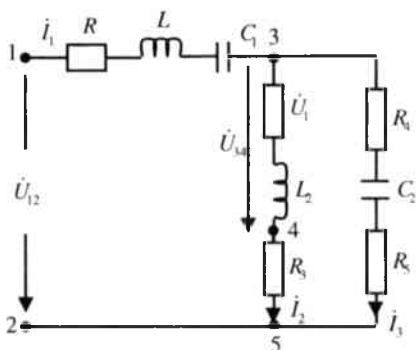
$$R_1 = 10 \text{ Om}, X_{L_1} = 7 \text{ Om},$$

$$X_{C_1} = 25 \text{ Om}, R_2 = 5 \text{ Om},$$

$$X_{L_2} = 20 \text{ Om}, R_3 = 12 \text{ Om},$$

$$R_4 = 15 \text{ Om}, R_5 = 9 \text{ Om}.$$

bo'lib, $\varphi_3 - \varphi_4$ potensial kuchlanish $\dot{U}_{34} = 60 \text{ V}$ ga teng kompleks qarshilik, kirishdagi kuchlanish $\dot{U}_{12}$, tarmoqdagi tok va kompleks quvvat qiymat aniqlansin.



Javob: $= 36,6e^{-j18^\circ}$; $i_1 = 2,9e^{-j75^\circ}$; $i_2 = 1,8e^{j30^\circ}$; $i_3 = 3e^{j40^\circ}$; $\dot{U}_{12} = 109,8e^{j60^\circ}$; $\bar{S} = 329e^{-j18^\circ} = 311 - j105 \text{ VA}$.

3.4. Nazorat savollari

1. Kompleks son matematik ifodasini yozing. Eyler formulasiga izoh bering.
2. Kompleks sonlar bilan qo'shish, ayirish, ko'paytirish va bo'lish amallari bajarilganda qanday ko'rinishda yoziladi?
3. Sinusoidal o'zgaruvchan elektr zanjirni kompleks (simvolik) usulda hisoblashda qanday afzalliklar bor?
4. Nima uchun kompleks ifoda $\pm j$ yoki $e^{\pm j\varphi}$ ga burilish burchagi deyiladi?
5. Sinusoidal o'zgaruvchan (tok, kuchlanish, EYK) funksiyalarni kompleks son ko'rinishda ifodalanishini isbotlang.
6. Sinusoidal o'zgaruvchan tok, kuchlanishi va EYKlar kompleks ifodasini yozing.
7. Kompleks sonlarhi differensiallash va integrallash qanday bajariladi?
8. Om va Kirxgof qonuni kompleks usulda qanday ifodalanadi?
9. Aktiv, reaktiv va to'la qarshilik kompleks ifodasini yozing.
10. Aktiv, reaktiv va to'la o'tkazuvchanlik kompleks ifodasini yozing.
11. Aktiv, reaktiv va to'la quvvat tenglamalarining kompleks ifodasini yozing.

12. $U=220\sin(\omega t + 45)$, $i=10\sqrt{2}\sin(\omega t+90)$ tok va kuchlanish funksiyalari kompleks usulda qanday ifodalanadi?

13. Kuchlanish $\dot{U}=100e^{j120}$ V, tok $\dot{I}=j10$ A bo'lganda, kompleks to'la qarshilik va to'la o'tkazuvchanlik qiymatini aniqlang.

14. To'la qarshilik $\underline{Z}_1=5+j11$ Om, $\underline{Z}_2 = 4-j2$ Om ga teng ketma-ket ulangan elektr zanjir sxemasini tuzing, umumiy va to'la qarshilikni aniqlang.

15. Kompleks ifodalari $\dot{U} = 60e^{j90}$, $\dot{I} = 5e^{j30}$ bo'lganda kompleks to'la quvvat ifodasi va aktiv, reaktiv quvvat qiymati qanday aniqlanadi?

16. Parallel sxemada biriktirilgan iste'molchilar kompleks qarshiligi $\underline{Z}_1=10e^{j60}$ Om, $\underline{Z}_2= 5e^{j30}$ Om bo'lganda, kompleks ekvivalent qarshilik qanchaga teng?

17. $\dot{U}= -220+j220$ V, $\dot{I} =15 -j5$ A kompleks ifodalarining oniy sinusoidal o'zgaruvchan qiymatini yozing.

18. $\dot{I} = -5e^{j90}$ A, $\dot{U}=j 141 e^{j90}$ V bo'lgan kompleks ifodalarning oniy qiymat tenglamasini tuzing.

19. Kompleks qarshilik $Z = 8 + j6$ Om bo'lganda, aktiv va reaktiv o'tkazuvchanlik qiymati nimaga teng?

20. Kompleks o'tkazuvchanlik: $y = 1,41 + j1,73 \frac{1}{\text{Om}}$ bo'lganda, aktiv va reaktiv qarshilikni aniqlang.

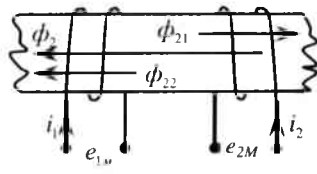
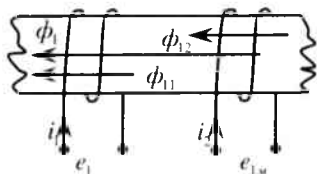
IV. O‘ZARO INDUKTIV BOG‘LANGAN O‘ZGARUVCHAN ELEKTR ZANJIRLAR

4.1. Asosiy nazariy tushunchalar

Elektromagnit induksiya qonuniga asosan induktiv g‘altakda, tok i , magnit oqimi Φ , yoki induktiv parametr L o‘zgaruvchan bo‘lsa, o‘zinduksiya EYK hosil bo‘ladi.

$$\ell_L = \frac{d\psi}{dt} = -W \frac{d\phi}{dt} = -L \frac{di}{dt}$$

Agarda ikkita induktiv elementlarning biridan o‘tuvchi tok ikkinchi induktivlikda EYK hosil qilsa, bunday elektr zanjir induktiv bog‘langan deyiladi (transformator).



Bunda induktivlikda hosil bo‘lgan magnit oqim:

$$\left. \begin{aligned} \Phi_1 &= \Phi_{11} + \Phi_{12} \\ \Phi_2 &= \Phi_{22} + \Phi_{21} \end{aligned} \right\} \text{yoki} \left\{ \begin{aligned} \Phi_{\text{lumumiy}} &= \Phi_1 \pm \Phi_{21} \\ \Phi_{2\text{lumumiy}} &= \Phi_2 \pm \Phi_{12} \end{aligned} \right\}$$

Chulg‘amga ilashgan magnit oqim:

$$\Psi_1 = W_1(\Phi_1 \pm \Phi_{21}) = \Psi_1 \pm \Psi_{21}$$

$$\Psi_2 = W_2(\Phi_2 \pm \Phi_{12}) = \Psi_2 \pm \Psi_{12}$$

Induktivlikda hosil bo‘lgan o‘zaro induksiyanuvchi EYK:

$$\begin{aligned} \ell_1 &= -\frac{d\Psi_1}{dt} = -\frac{d(\Psi \pm \Psi_{21})}{dt} = -\frac{d\Psi_1}{dt} \pm \frac{d\Psi_{21}}{dt} = -L_1 \frac{di_1}{dt} \pm M_{21} \frac{di_2}{dt} = \ell_{1L} + \ell_{1M} \\ \ell_2 &= -\frac{d\Psi_2}{dt} = -\frac{d(\Psi_2 \pm \Psi_{12})}{dt} = -\frac{d\Psi_2}{dt} \pm \frac{d\Psi_{12}}{dt} = -L_2 \frac{di_2}{dt} \pm M_{12} \frac{di_1}{dt} = \ell_{2L} + \ell_{2M} \end{aligned}$$

$M_{12} = M_{21} = M$ o‘zaro induktivlik koeffitsienti deyiladi va Gn da o‘lchanadi.

M – koeffitsient induktiv g‘altakning o‘ramlar somiga, o‘zaro joylashishiga va magnit tavsifiga bog‘liq bo‘ladi.

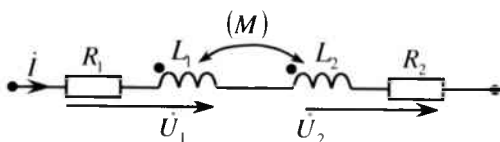
1. Ketma-ket sxemada ulangan induktiv g'altak.

Bu holda kompleks to'la qarshilik:

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_2 \pm 2\underline{Z}_M = (R_1 + j\omega L_1) + (R_2 + j\omega L_2) \mp 2\omega M$$

yoki $\underline{Z}_M = \mp 2\omega M$ – o'zaro induksiya kompleks qarshiligi.

Plus ishora ikkita induktivlik ketma-ket, **minus** ishora esa qarama-qarshi ulanishga mos bo'ladi.



Ekvivalent induktivlik o'zaro ulanish sxemasiga asosan:

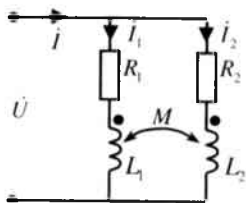
$$L_{mos} = L_1 + L_2 + 2M \quad L_{qarama-qarshi} = L_1 + L_2 - 2M$$

Induktivlikdagi kuchlanish:

$$\dot{U}_1 = \dot{I}_1 (\underline{Z}_1 \pm j\omega M) \quad \dot{U}_2 = \dot{I}_2 (\underline{Z}_2 \pm j\omega M)$$

2. Parallel sxemada ulanish.

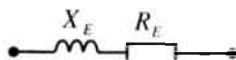
Parallel sxemada biriktirilgan induktiv bog'langan elektr zanjirni hisoblashda Kirxgof 2-qonuniga asosan har bir tarmoq uchun tuzilgan kompleks tenglamalar sistemasini yechish bilan tarmoqdagi tok aniqlanadi.



Tarmoq ekvivalent qarshiligi:

$$\underline{Z}_{1\varnothing} = \frac{\underline{Z}_1 \underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_2 - \underline{Z}_M} \quad \underline{Z}_{2\varnothing} = \frac{\underline{Z}_1 \underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_1 - \underline{Z}_M}$$

Tenglamaga asosan ekvivalent sxemasini tuzamiz.



Demak parallel sxemada ulangan induktiv g'altak elektr zanjirni ekvivalent sxema yoki qarshilik parametri orqali induktiv bog'lanmagan aktiv qarshilik R_E va X_E induktiv qarshilik ko'rinishda ifodalanishi mumkin.

$\underline{Z}_E = R_E + jx_E$ Agar ($R_1 = R_2 = 0$) bo'lsa,

$$\underline{L}_{1E} = \frac{L_1 L_2 - M^2}{L_2 \mp M}, \quad \underline{L}_{2E} = \frac{L_1 L_2 - M^2}{L_1 \mp M}$$

Zanjirning umumiy qarshiligi: $\underline{Z}_E = \frac{\underline{Z}_1 \underline{Z}_2 - \underline{Z}_M^2}{\underline{Z}_1 + \underline{Z}_2 \mp 2\underline{Z}_M}$

3. Induktiv bog'langan zanjirni hisoblashda bog'lanish koefitsienti K orqali ham ifodalanadi. $K = \frac{M}{\sqrt{L_1 L_2}} \leq 1$

Induktiv bog'langan g'altak mos ravishda yoki qarama-qarshi biriktirilgan bo'lsa:

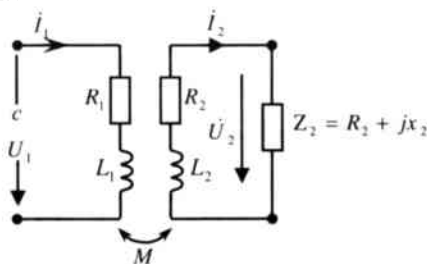
$$L_{mvs} = L - M > 0 ; \quad L_{qq} = L - M < 0 \quad \text{yoki} \quad M = \frac{L_M - L_{qq}}{4}$$

Induktivlik (L) va o'zaro induktivlik (M) muvozanat tenglamasi.

$$M^2 \leq L_1 L_2 \quad \text{yoki} \quad 2M^2 \leq L_1 + L_2$$

4. O'zaksiz transformator (havo transformatori).

Sxemada berilgan o'zaksiz transformator zanjirini hisoblashda konturli tok usuli yoki ekvivalent sxemasi bilan bajariladi. Agarda transformatorning birlamchi chulg'amidagi tokni aniqlash zarur bo'lsa, murakkab induktiv bog'langan elektr zanjir ekvivalent sxemasidan foydalangan holda ikkilamchi chulg'am kompleks qarshiligi o'rniga birlamchi chulg'amga kiruvchi aktiv R_0 va reaktiv x_0 qarshiliklar bilan almashtiriladi:



$$R_0 = \frac{\underline{Z}_M^2}{R_2^2 + x_2^2} R_{22}$$

$$x_0 = \frac{\underline{Z}_M^2}{R_2^2 + x_2^2} x_{22}$$

Bunda R_{22} va x_{22} transformatorning ikkilamchi chulg'am aktiv va reaktiv qarshiligi.

Iste'molchi qarshiligi imobatga olinganda:

$$R'_2 = R_2 + R_H, \quad x'_2 = x_2 + x_H.$$

Doimo $R' \geq 0$ bo'lib, sarf bo'ladigan quvvatni ifodalaydi.

Agar transformator ikkilamchi chulg'amiga induktiv qarshilik ulangan bo'lsa, bunda $x_{2L} > 0, x_0 < 0$ bo'lib, transformator magnit oqimi **susayadi**.

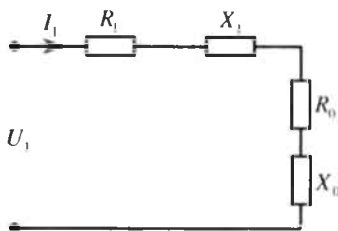
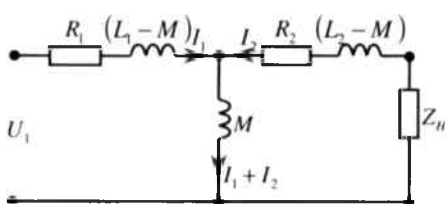
Agarda sig'im qarshiligi ulangan bo'lsa, $x_{2C} > 0, x_0 < 0$ bo'lib, transformatorning magnit oqimi **kuchayadi**.

Transformator tenglamasi:

$$\begin{cases} \dot{U}_1 = R_1 \dot{I}_1 + j\omega(L_1 - M)\dot{I}_1 + j\omega M(\dot{I}_1 + \dot{I}_2) \\ 0 = R_2 \dot{I}_2 + j\omega(L_2 - M)\dot{I}_2 + j\omega M(\dot{I}_1 + \dot{I}_2) + Z_2 \dot{I}_2 \end{cases}$$

Shunga asosan transformatorning ekvivalent sxemasini chizamiz.

5. Bir nechta induktiv bog'langan murakkab elektr zanjirni hisoblash, Kirxgof qonuni, konturli tok usuli, ustma-ustlik usuli va ekvivalent generator usulidan foydalaniladi.



O'zaro induktiv bog'langan elektr zanjirlar Kirxgof 2-qonuniga asosan tenglama tuzilganda qo'shimcha: $\dot{U}_M = \pm j\omega M_{nk} \cdot \dot{I}_k$ ifoda paydo bo'lib n g'altak $\dot{I}_k$ tok o'tganda hosil bo'ladigan kuchlanishni ifodalaydi. Bunda plus yoki minus ishora induktiv g'altakning ulanish sxemasi bilan bog'liq bo'ladi.

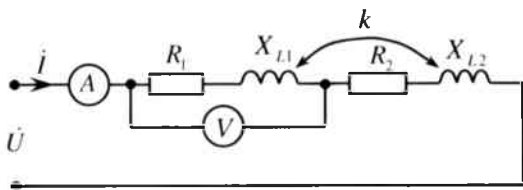
Induktiv bog'langan elektr zanjirni konturli tok usulidan foydalanib hisoblashda, n konturdagi $\pm j\omega M_{nk} \cdot \dot{I}_k$ ifoda ishorasini aniqlashda, n

va k konturlar boglovchl g' altakdagi kontur toklari $\dot{I}_n$ va $\dot{I}_k$ **bir xil** yo'nalishda bo'lsa **plus**, **qarama-qarshi** yo'nalishda bo'lsa **minus** **ishora** bilan olinadi. (Sxemada nuqta bilan belgilangan ishoralar tokning kirishiga mos keladi hamda plus ishorasi bilan hisobga olinadi.)

4.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 4.1. Ketma-ket ulangan ikkita reaktiv g' altak parametri $R_1 = 60 \text{ Om}$, $R_2 = 40 \text{ Om}$, $x_{L_2} = 8 \text{ Om}$; $x_{L_2} = 1 \text{ Om}$ bo'lib, $U = 300 \text{ V}$ kuchlanishga ulangan.

Bog'lanish koefitsienti $K=0,565$ bo'lgan ikkita g' altakning o'zaro mos va qarama-qarshi ulangan sxemasi uchun elektr o'lchov asboblarning ko'rsatish qiymati aniqlansin.



Yechish.

a) ketma-ket (mos) ulanish.

O'zaro induktiv qarshilik:

$$x_M = \omega M = k \sqrt{\omega L_1 \cdot \omega L_2} = 0,565 \sqrt{8 \cdot 1} = 1,6 \text{ Om}$$

$$\text{Kompleks tok: } \dot{I} = \frac{\dot{U}}{R + j\omega L_{\text{mos}}}$$

$$\text{Bunda: } L_{\text{mos}} = L_1 + L_2 + 2M; \quad R = R_1 + R_2$$

$$\text{Kompleks kuchlanish: } \dot{U} = U = 300 \text{ V}$$

$$\text{yoki: } \dot{I} = \frac{\dot{U}_2}{R + j\omega L_{\text{mos}}} = \frac{300}{10 + j12,2} = 12,05 - j14,7 \text{ A}$$

Ampermetr ko'rsatgan tokning haqiqiy qiymati:

$$I = \sqrt{12,05^2 + 14,7^2} = 19 \text{ A}$$

Birinchi g'altakdagi kompleks kuchianish:

$$\dot{U}_1 = \dot{I}_1 (R_1 + j\omega L + j\omega M) = (12,05 - j14,7) \cdot (6 + j4 + j1,6) = (2133,3 + j27,5)V$$

Voltmetrdagi kuchlanish: $U_1 = \sqrt{213^2 + 27,5^2} = 216V$

Ikkinchi g'altakdagi kompleks kuchianish:

$$\dot{U}_2 = \dot{I} (R_2 + j\omega L_2 + j\omega M_2) = (86,4 - j27,4) (V)$$

Masalaning yechimi:

$$\dot{U} = \dot{U}_1 + \dot{U}_2 = 213,3 + j27,48 + 86,4 - j27,4 = 299,7 + j0,06 \approx 300V$$

b) qarama-qarshi ulanish.

Kompleks tok: $I = \frac{U}{R + j\omega L_{qq}}$

Bunda: $L_{qarama-qarshi} = L_1 + L_2 - 2M$

Yoki:

$$X_{L_{qq}} = \omega L_{qq} = \omega L_1 + \omega L_2 - 2\omega M = 8 + 1 - 2 \cdot 1,6 = 5,8 \text{ Om}$$

Tok: $\dot{I} = \frac{300}{10 + j5,8} = (22,5 - j13) \text{ A}$

Ampermetr ko'rsatgan qiymat: $I = \sqrt{(22,5)^2 + (-13)^2} = 26A$

Birinchi g'altakdagi kuchianish kompleks ifodasi

$$\dot{U}_1 = \dot{I} (R_1 + j\omega L_1 + j\omega M) = (22,5 - j14) \cdot (6 + j8 + j1,6) = (218 - j65,6)$$

Voltmetrdagi kuchlanish:

$$U_1 = \sqrt{(218)^2 + (65,6)^2} = 226, V$$

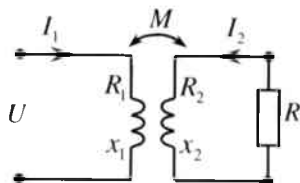
Ikkinchi voltmetrdagi kompleks kuchlanish:

$$\dot{U}_2 = \dot{I} (R_2 + j\omega L_2 - j\omega M) = (82,2 - j65,5) V$$

O'zaro induktiv qarshilik absolut qiymati $x_M = \omega M > x_{L_2} = \omega L_2$

bo'lib, reaktiv qarshiligi minus ishoraga teng hamda kompleks sig'im qarshiligiga mos ekanligini ifodalaydi.

Masala 4.2. O'zaksiz transformatorning (havo transformatori) ikkilamchi chulg'ami iste'molchi qarshiligi $R=10 \text{ Om}$; $x_M=18 \text{ Om}$ ulangan bo'lib, birlamchi chulg'ami $U=100 \text{ V}$ kuchlanishga ulangan.



Transformatorning salt ishlash holatida birlamchi va ikkilamchi chulg'amlaridagi tok, kuchlanish va quvvat qiymatlari: $I_{10}=10A$, $P_{10}=100VT$, $U_{10}=100V$, $U_{20}=100V$, $I_{20}=2.5A$, $P_{20}=100VT$ ga teng. Transformatorning birlamchi W_1 va ikkilamchi W_2 chulg'amlaridan o'tuvchi tok va foydali ish koeffitsienti aniqlansin.

Yechish.

$$\text{O'zaro induktiv qarshilik: } x_M = \omega M = \frac{180}{10} = 18 \text{ Om}$$

$$\text{Birlamchi chulg'am aktiv qarshiligi: } R_1 = \frac{P_{10}}{I_{10}^2} = \frac{100}{10^2} = 1 \text{ Om}$$

$$\text{Birlamchi chulg'am to'la qarshiligi: } z_1 = \frac{U_{10}}{I_{10}} = 10 \text{ Om}$$

$$\text{Birlamchi chulg'am reaktiv qarshiligi: } x_1 = \sqrt{z_1^2 - R_1^2} = 9,45 \text{ Om}$$

$$\text{Ikkilamchi chulg'am aktiv qarshiligi: } R_2 = \frac{P_{20}}{I_{20}^2} = 16 \text{ Om}$$

$$\text{Ikkilamchi chulg'am to'la qarshiligi: } z_2 = \frac{U_{20}}{I_{20}} = 40 \text{ Om}$$

$$\text{Ikkilamchi chulg'am reaktiv qarshiligi: } z_2 = \sqrt{z_2^2 - R_2^2} = 36,6 \text{ Om}$$

Kirxgof 2-qonuniga asosan tenglama tuzamiz:

$$\begin{cases} \dot{U}_1 = \dot{I}_1 (R_1 + jx_1) + \dot{I}_2 jx_M \\ 0 = \dot{I}_2 (R_2 + R) + jx_2 + \dot{I}_1 x_M \end{cases}$$

Ikkimchi tenglamadan:

$$\dot{I}_2 = -\dot{I}_1 \frac{jx_M}{(R_2 + R) + jx_2}$$

Tok $\dot{I}_2$ qiymatini birinchi tenglamaga qo'yamiz:

$$\begin{aligned} \dot{U}_1 &= \dot{I}_1 (R_1 + jx_1) - \dot{I}_1 \frac{jx_M}{(R_2 + R) + jx_2} jx_M = \dot{I}_1 \left\{ \left[R_1 + \frac{x_M^2 (R_2 + R)}{(R_2 + R) + x_2^2} \right] + j \left[x_1 - \frac{x_M^2 x_2}{(R_2 + R) + x_2^2} \right] \right\} = \\ &= \dot{I}_1 Z_E \end{aligned}$$

Elektr zanjirning ekvivalent to'la qarshiligi: $z_e = (4,46 + j8,29) \text{ Om}$

Birlamchi chulg'amdagi tok : $\dot{I}_1 = \frac{\dot{U}_1}{z_1} = \frac{100}{(4,46 + j8,3)} A$

Tokning haqiqiy qiymati: $I_1 = \sqrt{(5,1)^2 + (2,5)^2} = 10,72 A$

Ikkilamchi chulg'amdan o'tuvchi tokni ifodalovchi tenglama:

$$\dot{I}_2 = -\dot{I}_1 \frac{jx_M}{(R_2 + R) + jx_2} = -(5,1 - j9,5) \frac{j18}{(76 + j36,6)} = (-2,3 - j0,1) A$$

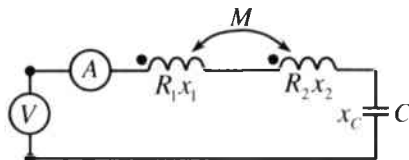
Ikkilamchi chulg'amdan o'tuvchi tokning haqiqiy qiymati:

$$I_2 = \sqrt{(2,3)^2 + (0,1)^2} = 2,3 A$$

Foydali ish koeffitsienti:

$$\eta = \frac{P_2}{P} = \frac{I_2^2 R}{(I_1^2 R) + I_2^2 (R_2 + R)} \cdot 100\% = \frac{(2,3)^2 \cdot 10}{10,7} \cdot 100\%$$

Masala 4.3. Induktiv bog'langan ikkita g'altak sig'im qarshiligi bilan ketma-ket ulangan bo'lib, qarshiliklar: $R_1=10.5 \text{ Om}$, $\omega L_1=14.6 \text{ Om}$, $R_2=10.6 \text{ Om}$, $\omega L_2=17 \text{ Om}$, $\omega M=32 \text{ Om}$, chastotasi $f=50 \text{ KGs}$ ga teng. Zanjirdan o'tuvchi tok $I=2,2 \text{ A}$, kuchlamish $U=88 \text{ mV}$. Sig'im qarshiligi va sig'im C aniqlansin.



Yechish.

Aktiv qarshiligi: $R = R_1 + R_2 = 21,1 \text{ Om}$

To'la qarshiligi: $z = \frac{U}{I} = \frac{8,8 \cdot 10^{-3}}{2,2 \cdot 10^{-3}} = 40 \text{ Om}$

Reaktiv qarshilik: $x = x_L - x_C = \pm \sqrt{z^2 - R^2} = \pm 34 \text{ Om}$

G'altak induktiv qarshiligi $x_L = \omega L_1 + \omega L_2 + 2\omega M = 38 \text{ Om}$

Sig'im qarshiligi $x = x_L - x_C = 38 \pm 34 \text{ Om}$

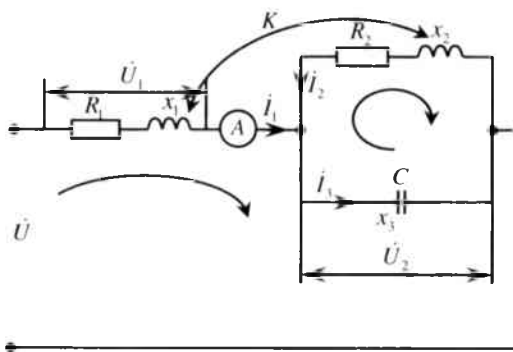
G'altaklarning o'zaro ulanish sxemasiga asosan sig'im ikki xil qarshilikga ega bo'ladi.

$$x'_{c_{moc}} = 38 - 34 = 4 \text{ Om}; \quad x'_{c_{kk}} = 38 + 34 = 72 \text{ Om}$$

yoki:

$$C' = \frac{1}{\omega x'_C} = 0,8 \cdot 10^{-6} \text{ F} = 0,8 \text{ mkF}, \quad C'' = \frac{1}{\omega x''_C} = 0,044 \cdot 10^{-6} \text{ F} = 0,044 \text{ mkF}$$

Masala 4.4. Sxemada keltirilgan o'zaro induktiv bog'langan elektr zanjirning birlamchi tarmogidan o'tuvchi tok $I=10\text{A}$, bog'lanish koeffitsienti $K=0,75$. Parametr qiymati: $R_1=2 \text{ Om}$, $x_1=10 \text{ Om}$, $R_2=1 \text{ Om}$, $x_2=4 \text{ Om}$, $x_3=2 \text{ Om}$. G'altakdagi kuchlanish, umumiy kuchlanish va quvvat qiymati aniqlansin.



Yechish.

Kirxgof qonuniga asosan konturdagi tok yo'nalishi bo'yicha tenglama tuzamiz:

$$\left. \begin{aligned} \dot{I}_1 + \dot{I}_2 &= \dot{I}_3 \\ \dot{U} &= \dot{I}R_1 + \dot{I}_1 j\omega L_1 - \dot{I}_2 R_2 - \dot{I}_2 j\omega L_2 + \dot{I}_1 j\omega M - \dot{I}_2 j\omega M \\ 0 &= -\dot{I}_2 R_2 - \dot{I}_2 j\omega L_2 - \dot{I}_3 \left(-j \frac{1}{\omega C} \right) + \dot{I}_1 j\omega M \end{aligned} \right\}$$

O'zaro induktiv qarshilik: $x_M = \omega M = k\sqrt{x_1 x_2} = 0,75\sqrt{1,4} = 1,5 \text{ Om}$

Tuzilgan tenglamalar sistemasini yechamiz. Bunda $\dot{I}_1 = I_1 = 10\text{A}$ bo'lib, haqiqiy son va kompleks tenglikda haqiqiy o'q bo'yicha yo'naltiriladi.

$$10 + \dot{I}_2 = \dot{I}_3 \quad (1)$$

$$\dot{U} = 10(2 + j2,5) - \dot{I}_2(1 + j5,5) \quad (2)$$

$$0 = -\dot{I}_2(1 + j4) + j15 + \dot{I}_3 \cdot j2 \quad (3)$$

Birinci tenglamani $10 + \dot{I}_2 = \dot{I}_3$ (3)- tenglamaga qo'yamiz.

$$-\dot{I}_2(1 + j4) + j15 + \dot{I}_3 \cdot j2 = -\dot{I}_2(1 + j2) + j35 = 0$$

Bundan: $\dot{I}_2 = \frac{j35}{1+j2} = (14 + j7) A$

Tokning effektiv qiymati: $I_2 = \sqrt{14^2 + 7^2} = \sqrt{245} = 15,6 A$

Birinci tenglamadan:

$$\dot{I}_3 = 10 + \dot{I}_2 = 10 + 14 + j7 = (24 + j7) A$$

$$I_3 = \sqrt{24^2 + 7^2} = \sqrt{625} = 25 A$$

Ikkinchi tenglamadan, zanjirdagi umumiy kuchlanish:

$$\dot{U} = 10(2 + j2,5) - (14 + j7)(1 + j5,5) V$$

Kuchlanish effektiv qiymati:

$$\dot{U} = \sqrt{(44,5)^2 + (59)^2} = \sqrt{5461} = 73,9 V$$

Birinci g'altakdagi kuchlanish:

$$\dot{U}_1 = \dot{I}_1(R_1 + j\omega L_1) - \dot{I}_2 j\omega M = (10(2 + j) - 14 + j7) j1,5 = (30,5 - j11) V$$

Kuchlanish effektiv qiymati:

$$\dot{U}_1 = \sqrt{(30,2)^2 + (11)^2} = \sqrt{1021,2} = 32,4 V$$

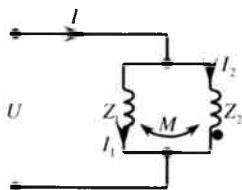
Ikkinchi g'altak yoki kondensatordagi kuchlanish:

$$\dot{U}_2 = -\dot{I}_2(R_2 + j\omega L_2) + \dot{I}_1 j\omega M = -(14 + j7)(1 + j4) + j15 = (14 - j48) V$$

Effektiv qiymat: $\dot{U}_2 = \sqrt{(14)^2 + (48)^2} = 50 V$

Zanjir aktiv quvvati: $P = P_1 + P_2 = I_1^2 R_1 + I_2^2 R_2 = 445, VT$

Masala 4.5. Induktiv bog'langan parallel sxemada ulangan tok zanjirining to'la qarshiligi $z_1 = (5 + j10) Om$, $z_2 = (100 + j20) Om$, $z_M = 10 Om$ bo'lib, $\dot{U} = 120 V$ kuchlanishga ulangan. Zanjirdan o'tuvchi tok va quvvat qiymati aniqlansin.



Yechish.

Parallel ulangan kompleks ekvivalent to'la qarshiligi

$$Z_{1E} = \frac{Z_1 Z_2 - Z_M^2}{Z_2 - Z_M} = (6.7 + j8.9) \text{ om}$$

$$Z_{2E} = \frac{Z_1 Z_2 - Z_M^2}{Z_1 - Z_M} = (56.4 - j6) \text{ om}$$

Tarmoqdagi tok:

$$I_1 = \frac{U}{Z_1} = (6.4 - j8.6) \text{ A} \quad I_1 = 10.8 \text{ A}$$

$$I_2 = \frac{U}{Z_2} = (2.1 - j0.27) \text{ A} \quad I_2 = 2.2 \text{ A}$$

$$\text{Umumiy tok: } I = I_1 + I_2 = (8.5 - j8.38) \text{ yoki } I = 8.4 \cdot \sqrt{2} \text{ A}$$

Birinchi g'altakdagi real aktiv quvvat:

$$P_1 = R_e(\dot{U} \dot{I}_1) = R_e[120(6.4 + j8.6)] = 768 \text{ Vt}$$

$$\text{G'altakdagi aktiv quvvat: } P'_1 = I_1^2 R_1 = 115 \cdot 5 = 574 \text{ VT}$$

$$\text{Quvvatlar farqi: } \Delta P_1 = P_1 - P'_1 = 768 - 574 = 194 \text{ VT}$$

Ikkinchi g'altakdagi real aktiv quvvat:

$$P_2 = R_e(\dot{U} \dot{I}_2) = R_e[120(2.1 + j0.22)] = 252 \text{ Vt}$$

$$\text{G'altakdagi aktiv quvvat: } P'_2 = I_2^2 R_2 = 4.46 \cdot 100 = 446 \text{ VT}$$

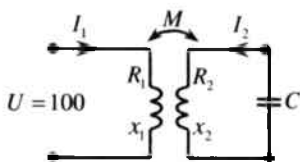
$$\text{Quvvatlar farqi: } \Delta P_2 = P_2 - P'_2 = 252 - 446 = -194 \text{ VT}$$

Bunda ikkinchi g'altakdagi yetishmaydigan $\Delta P_2 = -194 \text{ VT}$ aktiv quvvat o'zaro induksiya hodisasiga asosan energiya bilan ta'minlanadi:

$$P_M = P_{12} = R_e[j\omega M \dot{I}_1 \dot{I}_2] = R_e[j10(11.56 - j19.4)] = 194 \text{ Vt}$$

Masala 4.6. O'zaksiz transformatorning ikkilamchi chulg'am o'tuvchi tok $I_2 = 0.5 \text{ A}$ bo'lib, sig'im qarshiligi ulangan, g'altak parametrlari $R_1 = 60 \text{ Om}$, $\omega L_1 = 80 \text{ Om}$, $R_2 = 90 \text{ Om}$, $\omega L_2 = 45 \text{ Om}$, $\frac{1}{\omega C} = 21 \text{ Om}$ hamda bog'lanish koeffitsienti $k = 0.5$. Birlamchi chulg'amdagi tok va kuchlanish qiymati aniqlanib, vektor ifodasi tuzilsin.

Yechish.



O'zaro induktiv qarshilik: $x_M = \omega M = k\sqrt{\omega L_1 \cdot \omega L_2} = 30 \text{ Om}$

Kirxgof qonunlariga asosan konturdagi tok yo'nalishl bo'yicha tenglama tuzamiz: $\left[R_2 + j\left(\omega L_2 - \frac{1}{\omega C}\right)\right] \dot{I}_2 + j\omega M \dot{I}_1 = 0$

$$\text{Bundan } \dot{I}_1 = \dot{I}_2 \frac{R_2 + j\left(\omega L_2 - \frac{1}{\omega C}\right)}{-j\omega M} = \frac{90 + j(45 - 21)}{-j30} \cdot 0,5 = 3,14e^{j28^\circ} \text{ A}$$

Birlamchi chulg'amdagi kuchlanish:

$$\dot{U}_1 = (R_1 + j\omega L_1) \dot{I}_1 + j\omega M \dot{I}_2 = (60 + j80)14e^{j28^\circ} + j30 \cdot 0,5 = 328e^{j82^\circ}$$

Vektor ifoda tuzish uchun kuchlanishni aniqlash kerak:

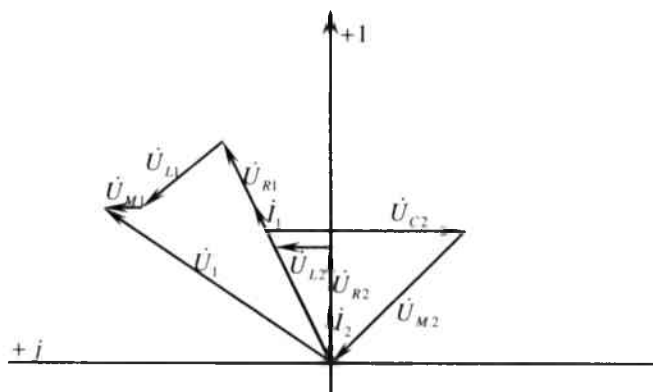
$$\dot{U}_{R1} = R_1 \dot{I}_1 = (165 + j90) \text{ (V)}; \quad \dot{U}_{R2} = R_2 \dot{I}_2 = 45 \text{ (V)}$$

$$\dot{U}_{L1} = j\omega L_1 \dot{I}_1 = (-120 + j220) \text{ (V)}; \quad \dot{U}_{L2} = j\omega L_2 \dot{I}_2 = j22,5 \text{ (V)}$$

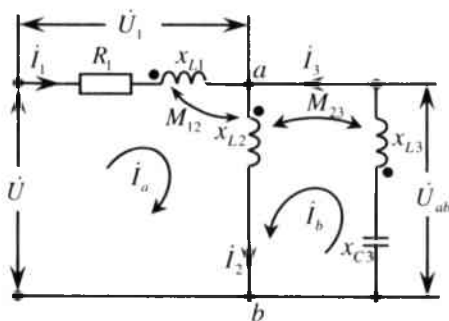
$$\dot{U}_{M1} = j\omega M_1 \dot{I}_1 = (-45 + j82,5) \text{ (V)}; \quad \dot{U}_{M2} = j\omega M_2 \dot{I}_2 = j15 \text{ (V)}$$

$$\dot{U}_{C2} = \frac{1}{j\omega C} \cdot \dot{I}_2 = -j105 \text{ (V)}$$

Kompleks tekislikda vektor ifodasini tuzamiz.



Masala 4.7. Sxemada berilgan elektr zanjirining qarshilik parametri: $R_1=2 \text{ Om}$, $x_1=10 \text{ Om}$, $R_2=1 \text{ Om}$, $X_{M23} = 10 \text{ Om}$ bo'lib, $\dot{U} = 150 \text{ V}$ kuchlanishga ulangan. Tarmoqdagi tok $\dot{U}_{ab}$ va kuchlanishni aniqlang.



1. Kirxgof qonuniga asosan yechish.

Kirxgof qonuniga asosan tenglama tuzamiz:

$$\left. \begin{aligned} \dot{I}_1 - \dot{I}_2 + \dot{I}_3 &= 0 \\ \underline{z}_1 \dot{I}_1 + \underline{z}_{M_{12}} \dot{I}_2 + \underline{z}_{M_{23}} \dot{I}_3 + \underline{z}_2 \dot{I}_2 + \underline{z}_{M_{12}} \dot{I}_1 &= U \\ \underline{z}_2 \dot{I}_2 + \underline{z}_3 \dot{I}_3 + \underline{z}_{M_{12}} \dot{I}_1 + \underline{z}_{M_{32}} \dot{I}_2 + \underline{z}_{M_{32}} \dot{I}_3 &= 0 \end{aligned} \right\}$$

Bunda: $\underline{z}_1 = (50 + j20)$

$$\underline{z}_2 = j20$$

$$\underline{z}_3 = (j20 - j50) = -j30$$

$$\underline{z}_{M_{12}} = j\omega M_{12} = j10$$

$$\underline{z}_{M_{23}} = j\omega M_{32} = j10 \text{ om}$$

Tenglamaga qarshilik va kuchlanish qiymatini qo'ysak:

$$\left. \begin{aligned} \dot{I}_1 - \dot{I}_2 + \dot{I}_3 &= 0 \\ (5 + j3)\dot{I}_1 + j3\dot{I}_2 + j\dot{I}_3 &= 25 \\ \dot{I}_1 + 3\dot{I}_2 - 2\dot{I}_3 &= 0 \end{aligned} \right\}$$

Determinant usul bilan yechish natijasi:

$$\Delta = 5(1 + j2), \quad \Delta_1 = 25, \quad \Delta_2 = -75, \quad \Delta_3 = -100$$

$$\text{Demak: } \dot{I}_1 = \frac{\Delta_1}{\Delta} = (1 + j2) \text{ (MA)}$$

$$\dot{I}_2 = \frac{\Delta_2}{\Delta} = -3(1 + j2) \text{ (MA)}$$

$$\dot{I}_3 = \frac{\Delta_3}{\Delta} = -4(1 + j2) \text{ (MA)}$$

U_{ab} potensial kuchlanish uchun tenglama tuzamiz:

$$\dot{U}_{ab} = j\omega M_{12} \dot{I}_2 + j\omega L_2 \dot{I}_2 + j\omega M_{23} \dot{I}_3 = (180 - j90) \text{ (MV)}$$

2. Konturli tok usuliga asosan yechish.

Kontur toklari yo'nalishi bo'yicha tenglama tuzamiz:

$$\left. \begin{aligned} (\underline{z}_1 + 2\underline{z}_{M_{12}})\dot{I}_a + (\underline{z}_2 + \underline{z}_{M_{23}} + \underline{z}_{M_{12}})\dot{I}_b &= \dot{U} \\ (\underline{z}_2 + \underline{z}_{M_{12}} + \underline{z}_{M_{23}})\dot{I}_a + (\underline{z}_{22} + 2\underline{z}_{M_{23}})\dot{I}_b &= 0 \end{aligned} \right\}$$

Bunda $\underline{z}_{11} = \underline{z}_1 + \underline{z}_2 = (50 + j40) \text{ Om}$ $\underline{z}_{22} = \underline{z}_2 + \underline{z}_3 = -j10 \text{ Om}$

Tenglamalar sistemasini yechish natijasida: $\dot{I}_a = \frac{\dot{U}(\underline{z}_{22} + 2\underline{z}_{M23})}{\Delta}$

$$\dot{I}_b = \frac{-\dot{U}(\underline{z}_2 + \underline{z}_{M12} + \underline{z}_{M23})}{\Delta}$$

Bunda: $\Delta = (\underline{z}_{11} + 2\underline{z}_{M12})(\underline{z}_{22} + 2\underline{z}_{M23}) - (\underline{z}_2 + \underline{z}_{M12} + \underline{z}_{M23})^2$

Qarshilik parametr qiymatini qo'yish bilan $\dot{I}_a$, $\dot{I}_b$ tok qiymatlari:

$$\dot{I}_a = (1 + j2) \text{ (MA)}$$

$$\dot{I}_b = (-4 - j8) \text{ (MA)}$$

Tarmoqdagi tokning kompleks ifodasi: $\dot{I}_1 = \dot{I}_a(1 + j2) \text{ (MA)}$

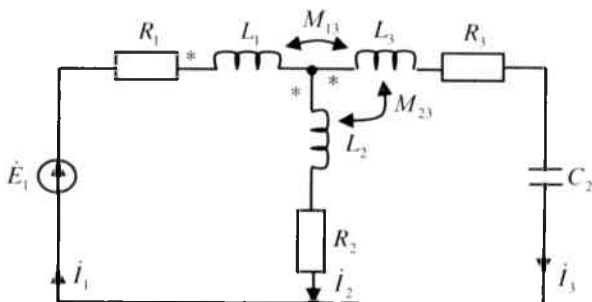
$$\dot{I}_2 = \dot{I}_a + \dot{I}_b = -3(1 + j2) \text{ (MA)}$$

$$\dot{I}_3 = -\dot{I}_b = (4 + j8) \text{ (MA)}$$

Kuchlanish:

$$\dot{U}_{ab} = j\omega M_{12}\dot{I}_1 + j\omega L_2\dot{I}_2 + j\omega M_{23}\dot{I}_3 = (180 - j90) \text{ MV}$$

Masala 4.8. O'zaro induktiv bog'langan zanjir parametri: $L_1 = 5 \text{ gn}$, $L_2 = 2 \text{ gn}$, $L_3 = 5 \text{ gn}$, $M_{13} = 1 \text{ gn}$, $M_{23} = 2 \text{ gn}$, $R_1 = 4 \text{ Om}$, $R_2 = 8 \text{ Om}$, $R_3 = 3 \text{ Om}$, $C = 0,025 \text{ f. bo'lib}$, $U = 100 \frac{1}{\sqrt{2}} \cos 2\omega t$ sinusoidal kuchlanishga ulangan. Kirxgof qonuniga asosan tarmoqdagi tok aniqlansin.



Yechish. Kirxgof qonuniga asosan kompleks ifodali tenglama tuzamiz:

$$-\dot{I}_1 + \dot{I}_2 + \dot{I}_3 = 0$$

$$R_1\dot{I}_1 + j\omega L_1\dot{I}_1 + j\omega M_{13}\dot{I}_3 + j\omega L_2\dot{I}_2 + j\omega M_{23}\dot{I}_2 + R_2\dot{I}_2 = \dot{E}$$

$$j\omega L_3 \dot{I}_3 + j\omega M_{13} \dot{I}_1 + j\omega M_{23} \dot{I}_2 + R_3 \dot{I}_3 + \frac{1}{j\omega c} I_c - R_2 \dot{I}_2 - j\omega L_2 \dot{I}_2 - jM_{23} \dot{I}_3 = 0$$

tenglamada tok yo'nalishiga nisbatan $M_{13} > 0$; $M_{23} < 0$, bunda $j\omega M_{23} = j2$.

Parametr qiymatlarini qo'yish bilan:

$$\begin{array}{rcl} \dot{I}_1 & -\dot{I}_2 & -\dot{I}_3 = 0 \\ (4+j10)\dot{I}_1 & +(8+j4)\dot{I}_2 & -j2\dot{I}_3 = 100 \\ -j2\dot{I}_1 & -(8+j8)\dot{I}_2 & +(3-j6)\dot{I}_3 = 0 \end{array}$$

$$\Delta = \begin{vmatrix} 1 & -1 & -1 \\ (4+j10) & (8+j4) & (-j2) \\ (j2) & (-8-j8) & (3-j6) \end{vmatrix} = 76 + j82 = 111,8e^{j47^\circ}$$

$$\Delta_1 = \begin{vmatrix} 0 & -1 & -1 \\ 100 & (8+j4) & (-j2) \\ 0 & (-8-j8) & (3-j6) \end{vmatrix} = 1100 + j200 = 1118e^{j10^\circ 20'}$$

Xuddi shunga o'xshash: $\Delta_2 = 300 - j400$, $\Delta_3 = 800 + j500$.

Tarmoqdagi toklarni topamiz:

$$\dot{I}_1 = \frac{\Delta_1}{\Delta} = 8 - j6 \text{ A}; \quad \dot{I}_2 = \frac{\Delta_2}{\Delta} = -0,8 - j4,4 \text{ A}; \quad \dot{I}_3 = \frac{\Delta_3}{\Delta} = 8,8 - j1,6 \text{ A}.$$

Haqiqiy qiymatlari: $I_1 = 10 \text{ A}$; $I_2 = 4,472 \text{ A}$; $I_3 = 8,944 \text{ A}$.

4.3. Mustaqil yechish uchun masalalar

Masala 4.1. Parallel sxemada ulangan g'altakning parametri $R_1=20 \text{ Om}$, $R_2=20 \text{ Om}$, $x_{L_1} = 10 \text{ Om}$, $x_{L_2} = 20 \text{ Om}$, $x_M = 10 \text{ Om}$ ga teng. Zanjirdagi tok ekvivalent qarshiligi $\underline{z}_0 = \underline{z}_e$ ni aniqlang.

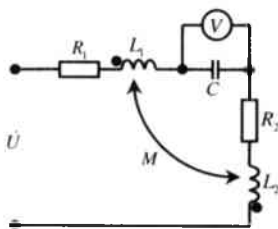
Javob: $\underline{z}_0 = \underline{z}_e = 16,27 \ell^{j49^\circ 20'}$

Masala 4.2. Induktiv bog'langan g'altakning parametri $x_{L_1} = 15 \text{ Om}$, $x_{L_2} = 20 \text{ Om}$, $x_M = 30 \text{ Om}$ bo'lganda, bog'lanish koeffitsientini (k) aniqlang.

Javob: $k=0,17$

Masala 4.3. Elektromagnit zanjir parametri: $C=43 \text{ mkf}$, $L_1=22 \text{ Gn}$, $L_2=18 \text{ Gn}$, $M=6.5 \text{ mGn}$, $R_1=10.5 \text{ Om}$, $R_2=9.2 \text{ Om}$, $U=100 \text{ V}$, $f=200 \text{ Gs}$ berilgan sig'imga ulangan voltmerning ko'rsatish qiymatini aniqlang.

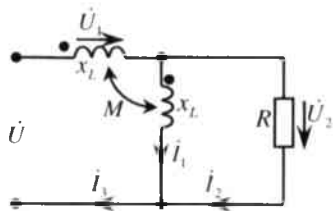
Javob: $U=48 \text{ V}$



Masala 4.4. Transformatorning qarshilik parametri $R_2=2.3 \text{ Om}$, $X_{L1}=8 \text{ Om}$, $X_{L2}=10 \text{ Om}$, $X_M=8 \text{ Om}$, $Z_H=3.351^{-j50^\circ} \text{ Om}$ bo'lib birlamchi chulg'ami $\dot{U}_1=100 \text{ V}$ kuchlanishga ulangan. Birlamchi va ikkilamchi chulg'amdan o'tuvchi tok kuchumi aniqlang.

Javob: $\dot{I}_1=21.9 \text{ A}$; $\dot{I}_2=22.8 \angle^{15.8^\circ}$

Masala 4.5. Sxemada keltirilgan elektr zanjirning parametri $X_L=140 \text{ Om}$, $X_M=60 \text{ Om}$, $R=30 \text{ Om}$ bo'lib, $\dot{U}=200 \text{ V}$ kuchlanishga ulangan. Tarmoqdagi tok, $\dot{U}_1, \dot{U}_2$ kuchlamish va quvvat balansini aniqlang.

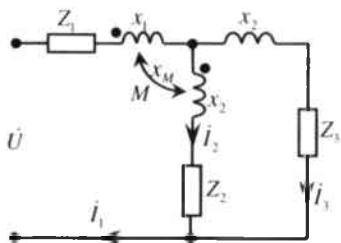


Javob: $U_1=171 \text{ V}$, $U_2=60 \text{ V}$, $I_1=0.67 \text{ A}$, $I_2=2 \text{ A}$, $I_3=1.43 \text{ A}$

$\bar{S} = \dot{U}I = 120 + j260 \text{ (VA)}$

$I_1 = -0.6 + j0.3 \text{ A}$; $I_2 = 1.2 - j1.6 \text{ A}$; $I = 0.6 - j1.3 \text{ A}$

Masala 4.6. Berilgan sxemaning parametri: $\bar{z}_1=(3+j) \text{ Om}$, $\bar{z}_2=-j10 \text{ Om}$, $\bar{z}_3=(12+j5) \text{ Om}$, $x_1=3 \text{ Om}$, $x_2=2 \text{ Om}$, $x_3=3 \text{ Om}$, $x_M=8 \text{ Om}$ bo'lib, uchinchi tarmoqdagi tok $I_3=1 \text{ A}$ ga teng.

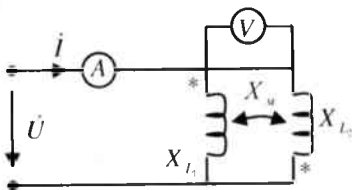


Tarmoq toklari I_1, I_2 va U_1 kuchlanish aniqlanib, topografik diagrammasini tuzing.

Javob: $I_1 = j2 A, I_2 = -1 + j2 A, U_1 = j12 V$

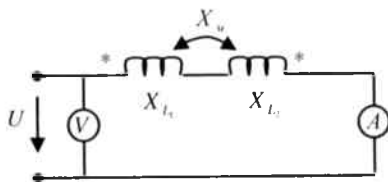
Masala 4.7. O'zaro induktiv bog'langan zanjir qarshiligi:

$X_{L_1} = X_{L_2} = 4 \text{ Om}$, $X_m = 3 \text{ Om}$ bo'lib, ampermetr 1 A bo'lganda voltmetr necha voltni ko'rsatadi?



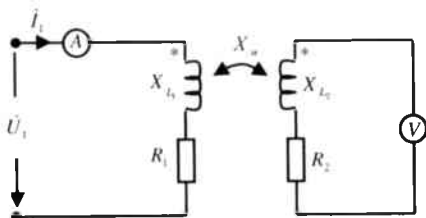
Javob: 7 V

Masala 4.8. O'zaro induktiv bog'langan zanjirga ulangan ampermetrdagi tok – 2 A, voltmetrdagi kuchlanish – 20 V ga teng. O'zaro induktiv bog'lanish qarshiligini X_m aniqlang.



Javob: $X_m = 5 \text{ Om}$

Masala 4.9. Transformator parametri $R_1 = R_2 = 1 \text{ Om}$, $X_{L_1} = 4 \text{ Om}$, $X_{L_2} = 5 \text{ Om}$, $X_m = 3 \text{ Om}$ bo'lib, ampermetrdagi tok 1 A. Voltmetr ko'rsatkichi necha voltni ko'rsatadi?



Javob: 6 V

4.4. Nazorat savollari

1. O'zinduksiya va o'zaro induksiya hodisalarining fizik ma'nosini tushuntirib bering.
2. Magnit induksiya, magnit oqim va induktivlik tenglamalari qanday ifodalanadi, o'lchov birligi nima?
3. Elektromagnit induksiya qonunini ifodalovchi tenglamadagi $\mathcal{E} = -W \frac{d\phi}{dt}$ «minus» ishorasiga izoh bering.
4. O'zaro induktiv bog'lanish ko'effitsient ifodasini yozing.
5. O'zaro induksiya EYK qanday ifodalanadi va yo'nalishi qanday aniqlanadi?
6. O'zaro induktiv bog'langan elektr zanjirlarining ulanish sxemasini chizing.
7. O'zaro induktiv bog'langan ketma-ket va parallel sxemada ulangan zanjirning ekvivalent induktivlik tenglamasini tuzing.
8. O'zaro induktiv bog'lanish ko'effitsienti M tajriba asosida qanday aniqlanadi?
9. Chiziqli havo transformatorini ta'riflab bering.
10. Transformatorning ekvivalent almashlash sxemasini chizing.
11. Transformator vazifasi, tuzilishi va ishlash prinsipini bilasizmi?
12. Transformatorning transformatsiyalash ko'effitsienti nima?
13. Transformatorning ishchi holat vektor ifodasini tuzing va tushuntirib bering.
14. Induktivligi $L=0,05 \text{ Gn}$ va o'zaro induktivlik ko'effitsienti $M=0,08 \text{ Gn}$ bo'lgan zanjirning o'zaro induktiv bog'lanish ko'effitsientini (K) aniqlang.
15. Induktivligi $L_1 = 0,1 \text{ Gn}$, $L_2 = 0,1 \text{ Gn}$, induktiv bog'lanish ko'effitsienti $K=0,8$ bo'lgan elektr zanjiri o'zaro induktivlik ko'effitsientini (M) aniqlang.
16. Ekvivalent induktivligi $L_e = L_1 + L_2 - 2M$ tenglama bilan ifodalanuvchi o'zaro induktiv bog'langan elektr zanjir sxemasini chizing.
17. O'zaro induktiv bog'langan uchta g'altakdan iborat ikki konturli elektr zanjiri uchun konturli elektr usuliga asosan tenglama tuzing.

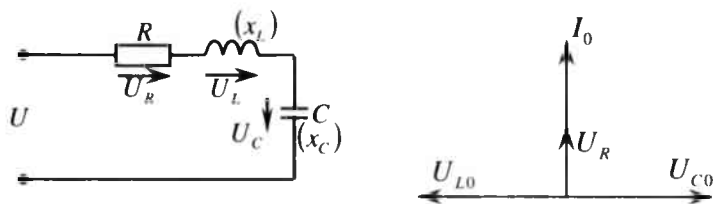
18. Mos sxemada ulangan ikkita induktiv bog'langan (g' altak) zanjir ifodalangan tenglamasini yozib, topografik vektor diagrammasini chizing.
19. Qarama-qarshi sxemada ulangan o'zaro induktiv bog'langan zanjir tenglamasini tuzib, vektor ifodasini chizig.
20. Transformatorlarning kuchlanishini kuchaytirish yoki pasaytirish nimaga bog'liq?
21. Induktiv bog'langan g' altakning o'zaro mos yoki qarama-qarshi ulanishida asosiy magnit oqim Φ qanday o'zgaradi?
22. Transformator magnitlovchi kuchiar tenglamasini yozing va fizik ma'nosini tushuntiring.
23. Transformatorning ikkilamchi chulg'amiga induktivlik yoki sig'im qarshiligi ulanganda magnit oqim Φ qanday o'zgaradi?

V. ELEKTR TOK ZANJIRDA REZONANS HODISALAR

5.1. Asosiy nazariy tushunchalar

Reaktiv elementlar, induktivlik va sig'im qarshiliklaridan tarkib topgan elektr zanjirda tok va kuchlanish vektorlari ustma-ust tushib, bular orasida burchak $\varphi=0$ bo'lgan holda, **rezonans hodisasi** yuzaga keladi.

1. Ketma-ket ulangan R,L,C zanjirda kuchlanishi rezonansi.



Zanjir rezonans holat vaqtida $X_L = X_C$, yoki; $\omega_0 L - \frac{1}{\omega_0 C} = 0$

Bundan rezonans chastota: $\omega_0 = \frac{1}{\sqrt{LC}}$ (rad/sek)

Rezonans hodisasiga o'zgaruvchan tok chastotasi f , induktivlik va sig'im parametrini o'zgartirish bilan erishiladi.

Rezonans holatida reaktiv element qarshiligi: $\omega_0 L = \frac{1}{\omega_0 C} = \rho$

yoki: $X_L = \omega_0 L = \frac{1}{\sqrt{LC}} \cdot L = \sqrt{\frac{L}{C}} = \rho$; $X_C = \frac{1}{\omega_0 C} = \frac{\sqrt{LC}}{C} = \sqrt{\frac{L}{C}} = \rho$; $\rho = \sqrt{\frac{L}{C}}$

to'liq qarshilik (Om) da o'lchanadi.

Rezonans holatda tok maksimal qiymatga erishadi:

$$I_0 = \frac{U}{R} = I_{\max} = \frac{U_{\rho}}{\rho}$$

Reaktiv elementlardagi kuchlanish: $U_{L0} = U_{C0} = I_0 \rho$

Agar $\rho > R$ bo'lsa, reaktiv qarshilikdagi kuchlanish manba kuchlanishidan katta bo'ladi. Necha martaga katta bo'lishi quyidagi formula bilan aniqlanadi:

$$Q = \frac{U_{L0}}{U} = \frac{U_{C0}}{U} = \frac{\omega_{0L}}{R} = \frac{\rho}{R}$$

Bunda Q – kontur **saxiyli**gi yoki **aslligi**, bazan sifat koeffitsienti ham deyiladi. Odatda $Q = (200 - 300)$ orahiqda o'zgaradi.

Unga teskari bo'lgan qiymat $d = \frac{1}{Q} = \frac{R}{\rho}$ **konturning so'nishi** deyiladi.

Rezonans holatda konturning energiya tebranishiga aktiv qarshilik ta'sirini hisobga olganda, kontur xususiy tebranish chastotasi:

$$f = f_0 \sqrt{1 - \frac{R^2 C}{4L}}$$

Reaktiv qarshiliklardagi kuchlanish $U_{L\max}$ va $U_{C\max}$ maksimal qiymatga rezonansdan oldin yoki keyin erishadi va quyidagi ifoda bilan izohlanadi.

$$\omega_L = \frac{\omega_0}{\sqrt{2 - d^2}} \text{ va } \omega_C = \omega_0 \sqrt{\frac{2 - d^2}{2}}$$

Rezonans kontur chastotasi (ω), zanjir parametri, tok va kuchlanishga nisbatan bog'liqlik funksiyasiga **chastotali xarakteristika** deyiladi.

$$f(\omega) = f(I_{(\omega)}, U_{(\omega)}, U_{L(\omega)}, U_{C(\omega)}, X_{L(\omega)}, X_{C(\omega)}, Z_{(\omega)})$$

Bu xarakteristikani analiz qilishda tok yoki chastotani nisbiy qiymat orqali ifodalash ancha qulay bo'lib, koeffitsient $\eta = \frac{\omega}{\omega_0}$ ga teng deb olinadi.

$$\text{Bunda: } \omega_0 = \frac{1}{\sqrt{LC}} \text{ (rad/sek); } I_0 = \frac{U}{R}, R = \rho d, h = \frac{\omega}{\omega_0}, I = \frac{U}{Z}$$

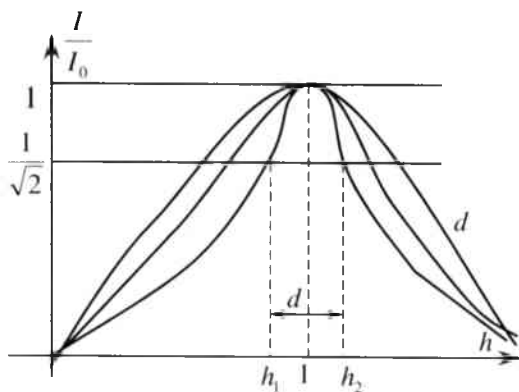
$$\frac{I}{I_0} = \frac{1}{\sqrt{1 + \left[\left(\eta - \frac{1}{\eta} \right) : d \right]^2}}$$

So'ndirish koeffitsienti: $d = \eta_1 - \eta_2$ Rezonans konturining ma'lum bir chastotani o'tkazish chegarasi:

$$\omega_0(\eta_2 - \eta_1) = \omega_0 d.$$

Rezonans holatda tebranuvchan elektromagnit maydon energiyasi o'zgarmas bo'ladi.

$$W_0 = W_M + W_C = \frac{1}{2} L I^2 + \frac{1}{2} C U^2 = \text{const}$$



2. Parallel ulangan L, C zanjirda toklar rezonansi.

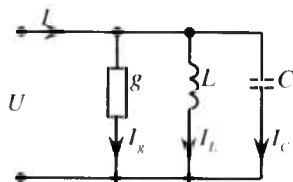
Parallel ulangan elektr zanjir rezonans holatda $\epsilon_L = \epsilon_C$ bo'lib, rezonans

chastota: $\frac{1}{\omega_0 L} - \omega_0 C = 0$

yoki: $\omega_0 = \frac{1}{\sqrt{LC}}$ (rad/sek)

Reaktiv elementlarning o'tkazuvchanligi:

$\frac{1}{\omega_0 L} = \omega_0 C = \gamma$ ga teng bo'lib, **to'liqin**

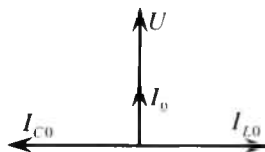


o'tkazuvchanligi deyiladi.

Rezonans holatda umumiy tok:

$$I_0 = U \gamma.$$

Reaktiv elementlardagi tok: $I_{L0} = I_{C0} = U \gamma$

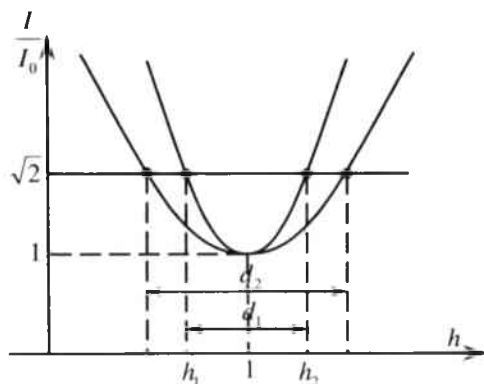


Agarda $g < \gamma$ bo'lganda, reaktiv qarshiliklarda tok umumiy tokdan katta bo'lib: $d = \frac{I}{I_{L_0}} = \frac{I}{I_{C_0}} = \frac{Ug}{U\gamma} = \frac{g}{\gamma}$ **kontur so'nishi** deyiladi.

Teskari qiymat: $Q = \frac{1}{d} = \frac{\gamma}{g}$ **kontur saxiyligi** yoki **asilligi** deyiladi.

Rezonans holat uchun chastotali xarakteristikalarini tuzishda tok va chastota qiymatiga nisbatan olingan tenglamadan foydalaniladi:

$$\frac{I}{I_0} = \sqrt{1 + \left[\left(\frac{1}{h} - h \right) : d \right]^2}$$



Keltirilgan xarakteristikadan rezonans chastota so'nish chegaralari $d = h_1 - h_2$ bilan ifodalaniladi.

Tok rezonans holatda ham elektromagnit maydon energiyasining tebramishi kuchlanishlar rezonans holatiga o'xshash va o'zgarmas bo'ladi.

$$W = \frac{1}{2} LI^2 = \frac{1}{2} CU^2 = \text{const}$$

Radiotexnikada elektromagnit maydon energiya tarqalishi tezligi to'liq uzunligiga nisbatan o'lchanib: $\lambda = vT$, λ – to'liq uzunligi (m), v – to'liq tarqalish tezligi (m/sek), T – davr (1/sek), bunda: $\lambda = \frac{v}{f}$. f – chastota. Tebranuvchian kontur to'liq uzunligi: $\lambda_0 = v \cdot 2\pi\sqrt{LC} = 3 \cdot 10^8 \cdot 2\pi\sqrt{LC}$ (m).

3. Tarmoqlangan elektr zanjirda rezonans.

Tarmoqlangan elektr zanjirda ham rezonans sharti $\varphi = 0$ bo'lib, tok va kuchlamish vektorlari orasidagi burchak nolga teng. $x_e = 0$; $\varphi_e = 0$.

Bir nechta induktivlik va sig'im elementlaridan tuzilgan murakkab elektr zanjirda rezonans hodisasi ba'zi kontur va tarmoqlarda ham hosil bo'lishi mumkin.

Radiotexnika, aloqa, avtomatika va boshqa sohalarda o'zaro bog'langan tebranuvchan konturlarda hosil bo'ladigan rezonans hodisasidan keng foydalanib, bular umumiy zanjir qarshiligi yoki elektromagnit maydon energiyasi orqali bog'langan bo'lishi mumkin.

Masalan: O'zaro induktiv bog'langan (transformator, avtotrans.), zanjirsimon sxemada bog'lanish, kondensatorli bog'lanish (ichki yoki tashqi), galvanik bog'lanish yoki konturlarning induktiv va sig'im parametrlari orqali bog'langan bo'lishi mumkin.

Konturlarning o'zaro bog'lanish koeffitsienti: $K = \frac{X_m}{\sqrt{X_1 X_2}} (*)$

bo'lib: X_m – elementlarning o'zaro bog'lanish qarshiligi.

X_1 – birinchi kontur reaktiv qarshiligi.

X_2 – ikkinchi kontur reaktiv qarshiligi.

a) o'zaro induktiv bog'langan zanjirlarda: $X_L = \omega M$ (Om).

Kontur reaktiv qarshiligi: $X_1 = \omega L_1$, $X_2 = \omega L_2$ (Om).

Shunga asosan: $K = \frac{\omega M}{\sqrt{\omega L_1 \cdot \omega L_2}} = \frac{M}{\sqrt{L_1 L_2}}$; M – o'zaro induktiv bog'lanish koeffitsienti.

b) Konturning o'zaro sig'im yoki kondensator qarshiligi orqali bog'lanishida: $X_M = \frac{1}{\omega C_0}$; $X_1 = \frac{1}{\omega C_1}$; $X_2 = \frac{1}{\omega C_2}$ yoki: $C_1 = \frac{C_1 C_0}{C_1 + C_0}$ – birinchi kontur umumiy sig'imi.

$C_2 = \frac{C_2 C_0}{C_2 + C_0}$ – ikkinchi kontur umumiy sig'imi.

Ushbu qiymatni (*) tenglamaga qo'yish bilan: $K = \sqrt{\frac{C_1 C_2}{(C_1 + C_0)(C_2 + C_0)}}$

Kontur elektr yurituvchi kuch o'zaro induktiv bog'lanishida:

$$K = \frac{E_2}{E_{2M}} = \frac{E_2}{I_1 \omega M}$$

Bunda I_1 – birlamchi konturdagi tok o'zaro induktiv bog'langan (transformator) zanjirda rezonans hodisasini tahlil qilishda ekvivalent keltirilgan aktiv va reaktiv qarshilik tenglamalaridan ham foydalaniladi:

$\Delta R_1 = \frac{\omega^2 M^2}{Z_2^2} R_{22}$ (aktiv qarshilik); $\Delta X_1 = -\frac{\omega^2 M^2}{Z_2^2} X_{22}$ – sig'im xarakterga ega bo'lgan reaktiv qarshilik.

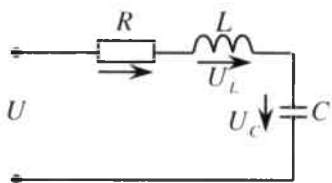
O'zaro induktiv bog'langan kontur quvvat muvozanat tenglamasi:

$$P_2 = I_1^2 \frac{\omega^2 M^2}{R_2} = \frac{E_2^2}{R_2} = I_2^2 R_2 \text{ (VT)}.$$

$$\text{Foydali ish koeffitsienti: } h = \frac{P_2}{P} = \frac{P_2}{P_1 + P_2} = \frac{I_1^2 \Delta R_1}{I_1^2 R_1^2 + I_1^2 \Delta R_1} = \frac{\Delta R}{R + \Delta R_1}.$$

5.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 5.1. Ketma-ket biriktirilgan elektr zanjirning parametri $L=150\text{mkGn}=15 \cdot 10^{-5}\text{Gn}$, $C=470\text{mkF}=47 \cdot 10^{-7}\text{F}$, $R=5\text{ Om}$ bo'lib, $U=10\text{ V}$ kuchlanishga ulangan. Rezonans chastotasi f_0 , reaktiv elementlardagi kuchlanish U_L , U_C , to'liq qarshiligi ρ , kontur asilligi Q va so'nish koeffitsienti d ni aniqlang.



Yechish.

Rezonans chastota:

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{705 \cdot 10^{-16}}} = \frac{1}{26,6 \cdot 10^{-8}} = 376 \cdot 10^4 \text{ (rad/sek)}$$

$$\text{Bundan: } f_0 = \frac{\omega_0}{2\pi} = \frac{376 \cdot 10^4}{6,28} = 6 \cdot 10^5 \text{ (gs)}$$

$$\text{Rezonans holatdagi tok: } I_0 = \frac{U}{R} = \frac{10}{5} = 2 \text{ (A)}$$

$$\text{Reaktiv qarshiligi: } x_L = \omega_0 L = 565 \text{ Om}$$

$$x_C = \frac{1}{\omega_0 C} = \frac{1 \cdot 10^7}{376 \cdot 10^4 \cdot 47} = 565 \text{ } \Omega$$

Reaktiv qarshiliklardagi kuchlanish:

$$U_L = I X_L = 565 \cdot 2 = 1130 \text{ V}, U_C = I X_C = -1130 \text{ (V)}$$

$$\text{To'liq qarshiligi: } \rho = \sqrt{\frac{L}{C}} = 565 \text{ } \Omega$$

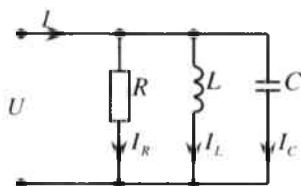
$$\text{Asillik koeffitsienti: } Q = \frac{U_C}{U} = \frac{\rho}{R} = 113$$

$$\text{So'nish koeffitsienti } d = \frac{1}{Q} = \frac{1}{113} = 0,885 \cdot 10^{-2}$$

Masala 5.2.

Parallel sxemada ulangan elektr zanjir parametri

$R = 50 \text{ } \Omega$ ($g = 0,02 \frac{1}{\Omega}$), $L = 16 \text{ mGn} = 16 \cdot 10^{-3} \text{ Gn}$,
 $C = 40 \text{ mkF} = 40 \cdot 10^{-6} \text{ F}$, bo'lib, $U = 200 \text{ V}$ kuchlanishga ulangan.
 Rezonans chastota f_0 , tok I , I_L , I_C so'nish koeffitsienti d va to'liq o'tkazuvchanligi γ ni aniqlang.



Yechish.

$$\text{Rezonans chastota: } \omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{64 \cdot 10^{-8}}} = \frac{1}{8 \cdot 10^{-4}} = 1250 \left(\frac{\text{rad}}{\text{sek}} \right)$$

$$\text{yoki: } f_0 = \frac{\omega_0}{2\pi} = 199, (\text{gs})$$

$$\text{Tok: } I = U g = 200 \cdot 0,02 = 4 \text{ (A)}$$

Induktiv va sig'im reaktiv o'tkazuvchanligi:

$$b_L = \frac{1}{\omega_0 L} = \frac{1}{1250 \cdot 16 \cdot 10^{-6}} = 0,05 \left(\frac{1}{\Omega} \right)$$

$$b_C = \omega_0 C = \frac{1}{1250 \cdot 40 \cdot 10^{-6}} = 0,05 \left(\frac{1}{\Omega} \right)$$

Induktivlik va sig'imdan o'tuvchi tok:

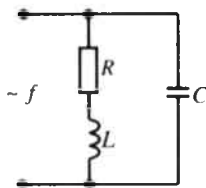
$$I_L = Ub_L = 10 \text{ (A)}, \quad I_C = Ub_C = 10 \text{ (A)}$$

$$\text{To'liqin o'tkazuvchanligi: } \gamma = \sqrt{\frac{C}{L}} = 0,05 \left(\frac{1}{\text{Om}} \right)$$

$$\text{Kontur asllligi: } Q = \frac{\gamma}{g} = 2,5$$

$$\text{Kontur so'nish koeffitsienti: } d = \frac{1}{Q} = 0,4$$

Masala 5.3. Sxemada keltirilgan elektr zanjir chastotasi $f=400 \text{ Gs}$ o'zgaruvchan tok manbaiga ulangan. Agar aktiv qarshilik $R=5 \text{ Om}$, sig'im parametri $C=10,5 \text{ mkF}$ bo'lsa, induktivlikning qanday qiymatida rezonans holat yuzaga keladi.



Yechish.

Ushbu elektr zanjir uchun rezonans sharti, reaktiv o'tkazuvchanlikning yig'indisi nolga tengligi bo'ladi. Yani: $y = y_1 + y_2$

$$\text{Bunda: } y_1 = \frac{1}{z_1} = j\omega c; \quad y_2 = \frac{1}{z_2} = \frac{1}{R + j\omega L} = \frac{R - j\omega L}{R^2 + \omega^2 L^2}$$

$$\text{yoki: } y = \frac{R}{R^2 + \omega^2 L^2} + j\left(\omega c - \frac{\omega L}{R^2 + \omega^2 L^2}\right)$$

Qavs ichidagi reaktiv o'tkazuvchanlik tenglamasini nolga tenglaymiz:

$$b = \omega c - \frac{\omega L}{R^2 + \omega^2 L^2} = 0$$

Umumiy inaxrajga keltirib ω ga bo'lib yuborilsa:

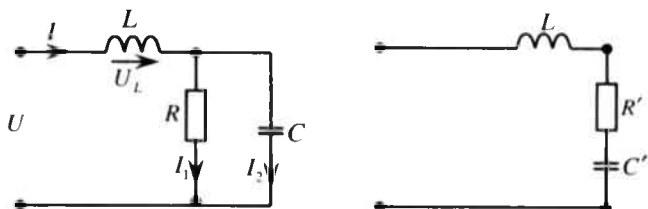
$$\omega^2 L^2 c^2 - L + cR^2 = 0$$

Induktivlikga nisbatan tenglama yechimi:

$$L_{1,2} = \frac{1 \pm \sqrt{1 - 4\omega^2 c^2 R^2}}{2\omega^2 c} = \frac{1 \pm 0,85}{132}$$

Demak zanjirda rezonans holat yuzaga kelishi mumkin bo'lgan induktivlik qiymati: $L_1 = 0.014 \text{ Gn} = 14 \text{ mGn}$; $L_2 = 0.00114 = 1.14 \text{ mGn}$.

Masala 5.4. Keltirilgan elektr zanjir uchun rezonans chastota (ω_0) tenglamasi va aktiv qarshilikning (Z_0) qanday qiymatida rezonans holat yuzaga kelishini aniqlang.



Yechish.

Zanjirning parallel ulangan qismini ekvivalent sxemasi bilan almashtiriladi.

$$R' = \frac{g}{y^2} = \frac{\frac{1}{R}}{\left(\frac{1}{R}\right)^2 + (\omega c)^2} = \frac{R}{1 + \omega^2 C^2 R^2}$$

$$x' = \frac{b}{y^2} = \frac{\omega C}{\left(\frac{1}{R}\right)^2 + (\omega c)^2} = \frac{\omega C R^2}{1 + \omega^2 C^2 R^2}$$

Ketma-ket ulangan ekvivalent sxema uchun rezonans sharti:

$$x = \omega L - \frac{\omega C R^2}{1 + \omega^2 C^2 R^2} = 0$$

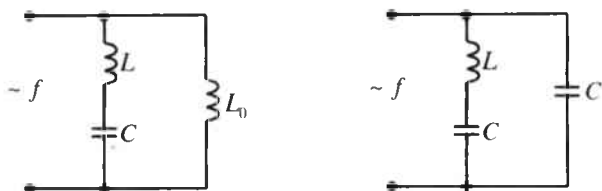
Tenglama umumiy maxraji berilib, (ω) ga bo'linsa:

$$L + \omega_0^2 C^2 R^2 L - C R^2 = 0 \quad \text{Bundan:} \quad \omega_0 = \sqrt{\frac{C R^2 - L}{C^2 R^2 L}} = \frac{1}{\sqrt{L C}} \sqrt{1 - \frac{L}{C R^2}}$$

Elektr zanjirda $R > \sqrt{\frac{L}{C}} = \rho$ bo'lgandagina rezonans holat yuzaga

keladi.

Masala 5.5. Berilgan elektr zanjir o'zgaruvchan tok chastotasi $f=10^5$ Gs bo'lgan generatorga ulangan. Induktivligi $L=100$ mkGn, sig'imi $C=500$ Pf. Zanjirda kuchlanishlar rezonansini hosil qiluvchi induktivlik qiymati L_0 aniqlanib, zanjirda tok rezonansi yuzaga kelishi uchun $f=2$ MGs bo'lganda qanday qilib iste'molchiga ulanishi mumkin?



Yechish.

Ushbu elektr zanjir uchun rezonans shartiga asosan reaktiv qarshiliklari nolga teng:

$$b=b_1+b_0=0$$

Bunda: $b_1 = \frac{\omega C}{\omega^2 LC - 1}$ - LC zanjir reaktiv o'tkazuvchanligi

$b_0 = \frac{\omega C}{\omega L_0}$ - L_0 induktivligi reaktiv o'tkazuvchanligi

$$\text{Demak: } -\frac{\omega C}{\omega^2 LC - 1} + \frac{1}{\omega L_0} = 0$$

$$\text{Bundan: } \omega^2 L_0 C + \omega^2 LC - 1 = 0$$

Tenglamani L_0 ga nisbatan yechish bilan:

$$L_0 = \frac{1 - \omega^2 LC}{\omega^2 C} = \frac{1}{\omega^2 C} - L = 0.0049 \text{ Gn} = 4.9 \text{ MGn}$$

Zanjirda kuchlanishlar rezonansi yuzaga kelishi uchun $L_0=4,9 \text{ MGn}$ teng bo'lishi kerak.

Masalaning ikkinchi sharti bo'yicha yana reaktiv o'tkazuvchanliklar tenglamasi nolga tenglanadi:

$$b = \frac{\omega C}{\omega^2 LC - 1} + b'_0 = 0$$

$\omega = 2\pi f = 4\pi \cdot 10^6 \text{ sek}^{-1}$ - teng bo'lganda, bunda b'_0 - zanjir tarmog'iga

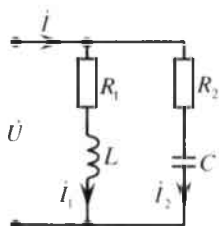
ulangan reaktiv o'tkazuvchanlik: $b'_1 = \frac{\omega C}{\omega^2 LC - 1} = -9,2 \cdot 10^{-4} \frac{1}{\text{Om}} < 0$

Demak, ushbu elektr zanjirida tok rezonansi hosil bo'lishi uchun induktivlik L_0 sig'im elementi bilan almashtirilishi kerak. Sig'im parametrlari esa $C_0 = \frac{b'_0}{\omega} = \frac{9,2 \cdot 10^{-4}}{4\pi \cdot 10^6} = 73,3 \text{ pf}$ ga teng.

Masala 5.6. Parallel ulangan elektr zanjirning parametri: $R_0=100 \text{ Om}$, $R_2=200 \text{ Om}$, $L=0,2 \text{ Gn}$, $C=1 \text{ mkf}$, manba kuchlanishi $\dot{E}=100 \text{ V}$. Rezonans chastota, reaktiv qarshiliklar va rezonans holatdagi tok kuchini aniqlang.

Yechish.

Umumiy ekvivalent o'tkazuvchanligi:



$$y = y_1 + y_2 = \frac{1}{R_1 + j\omega L} + \frac{1}{R_2 + \frac{1}{j\omega C}} = \frac{R_1 - j\omega L}{R_1^2 + \omega^2 L^2} + \frac{R_2 - \frac{1}{j\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}} =$$

$$= \frac{R_1}{Z_1^2} + \frac{R_2}{Z_2^2} - j \left(\frac{\omega L}{R_1^2 + \omega^2 L^2} + \frac{\frac{1}{\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}} \right) = g - jb$$

Parallel ulangan elektr zanjirida tok rezonans sharti $b_L=b_C$ bo'lib, bundan rezonans chastota tenglamasi:

$$\frac{\omega L}{R_1^2 + \omega^2 L^2} = \frac{\frac{1}{\omega C}}{R_2^2 + \frac{1}{\omega^2 C^2}} \text{ yoki } \omega_0 = \frac{1}{\sqrt{LC}} \sqrt{\frac{\frac{L}{C} - R_1^2}{\frac{L}{C} - R_2^2}} = 2414 \frac{1}{\text{sek}}$$

Reaktiv qarshiliklari: $x_L = \omega_0 L = 483 \text{ (Om)}$, $x_C = \frac{1}{\omega_0 C} = 414 \text{ (Om)}$

Birinchi tarmoq to'la qarshiligi:

$$\underline{z}_1 = R_1 + j\omega_0 L = 493 \cdot e^{j78^\circ} \text{ (Om)} \quad \underline{z}_2 = R_2 + j \frac{1}{\omega_0 C} = 460 \cdot e^{j64^\circ} \text{ (Om)}$$

$$\text{Birinchi tarmoqdagi tok: } \dot{I}_1 = \frac{\dot{U}}{\underline{z}_1} = \frac{100 e^{j0^\circ}}{493 e^{j78^\circ}} = (0,04 - j0,19) \text{ (A)}$$

$$\text{Ikkinchi tarmoqdagi tok } \dot{I}_2 = \frac{\dot{U}}{\underline{z}_2} = \frac{100 e^{j0^\circ}}{493 e^{-j64^\circ}} = (0,09 + j0,19) \text{ (A)}$$

$$\text{Umumiy tok: } \dot{I} = \dot{I}_1 + \dot{I}_2 = (0,04 - j0,19) + (0,09 + j0,19) = 0,13 \text{ (A)}$$

Rezonans holatda reaktiv qarshilik nolga teng ($x = 0$)

Masala 5.7. (5.6) masalada berilgan sxemaning qarshiligi $x_L=40 \text{ Om}$, $R_1=30 \text{ Om}$, $R_2=28 \text{ Om}$, chastotasi $f=1000 \text{ Gs}$ bo'lgan holatda zanjirda tok rezonansini yuzaga keltiruvchi sig'im qiymatini aniqlang.

Yechish.

Rezonans holatda reaktiv qarshilik nolga teng.

yani: $x_L - x_C = 0$ yoki: $x_L = x_C$

Bunda induktivlikdagi reaktiv quvvat:

$$Q_L = I_1^2 x_L = \frac{U^2}{R_1^2 + x_C^2} x_L$$

Sig'imdagi reaktiv quvvat: $Q_C = I_1^2 x_C = \frac{U^2}{R_2^2 + x_C^2} x_C$

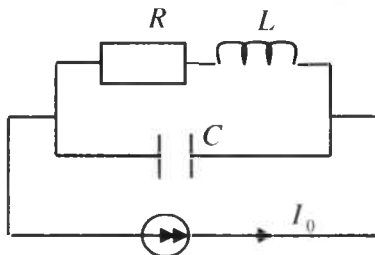
Demak: $\frac{U^2}{30^2 + 4} \cdot 40 = \frac{U^2}{28^2 + x_C^2} x_C$

Bundan sig'im qarshiligi: $x_C = 17,75 \text{ Om}$

Sig'im parametri: $C = \frac{x_C}{2\pi f} = \frac{17,75}{2 \cdot 3,14 \cdot 1000} = 2,28 \text{ mkf}$

Masala 5.8. Parallel sxemada ulangan rezonansli kontur parametri $R = 2 \text{ Om}$, $L = 0,4 \text{ mg}$, $C = 0,01 \text{ mkf}$ bo'lib, $I_0 = 10 \text{ mA}$ tok manbaiga ulangan:

Rezonans chastota ω_0 , asillik koeffitsienti Q va tok chastota $\pm 2 \%$ o'zgarganda rezonans kuchlanish va tok I_1, I_2 qiymatini aniqlang.



Yechish. Rezonans shartiga ko'ra: $b_1 = -b_2$ yoki: $\frac{\omega_0 L}{R + (\omega_0 L_0)^2} = \frac{1}{\omega_s}$

bundan: $\omega_0 = \frac{1}{\sqrt{LC}} \sqrt{\frac{\rho^2 - R^2}{\rho^2}} \approx 5 \cdot 10^5 \text{ rad/sek}$

$$\text{Kontur to'liq qarshiligi } \rho = \sqrt{\frac{L}{C}} = \sqrt{\frac{0,4 \cdot 10^{-3}}{10^{-8}}} = 200 \text{ Om}.$$

$$\text{Kontur asilligi } Q = \frac{\rho}{R} = 100.$$

$$\text{Rezonans holatda } b = b_1 + b_2 = 0, \text{ bo'lganligi uchun } R_0 = \frac{1}{g_{12}};$$

$$\text{aktiv o'tkazuvchanlik: } g_{12} = g_0 = \frac{R^2}{R^2 + (\omega_0 L)^2} \approx 0,5 \cdot 10^{-4} \frac{1}{\text{Om}}.$$

$$\text{Demak } R_0 = \frac{1}{0,5 \cdot 10^{-4}} = 20 \cdot 10^3 \text{ Om}.$$

$$\text{Rezonans kuchlanish: } U_p = I_0 R_0 = 10 \cdot 10^{-3} \cdot 20 \cdot 10^3 \approx 200 \text{ V}.$$

Rezonans holatda $R_1 \ll \omega_0 L$ ekanligini hisobga olinsa:

$$I_1 \approx I_2 = \frac{U_p}{\rho} = \frac{200}{200} \text{ A}.$$

Agar tok chastotasi 2% ko'paysa reaktiv o'tkazuvchanlik qiymati:

$$b_{12} = b_1 + b_2 = \frac{\omega L_1}{R_1^2 + (\omega L_1)^2} - \omega C_2 = -0,2 \cdot 10^{-3} \frac{1}{\text{Om}}.$$

$$\text{Bunda: } \omega^1 = (\omega_0 + 0,02\omega_0) = 5,1 \cdot 10^5 \text{ rad/sek}.$$

$$\text{Aktiv o'tkazuvchanlik qiymati: } g_{12} = \frac{R_{12}}{R^2 + (\omega L)^2} = 0,5 \cdot 10^{-4} \frac{1}{\text{Om}}.$$

$$\text{Kontur to'la o'tkazuvchanligi: } y_{12} = \sqrt{g_{12}^2 + b_{12}^2} = 2,06 \cdot 10^{-4} \frac{1}{\text{Om}}$$

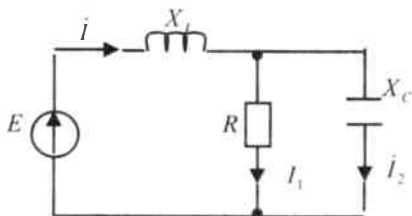
$$\text{To'la qarshiligi: } Z_{12} = \frac{1}{y_{12}} = 4855 \text{ Om}.$$

Demak rezonans kuchlanish qiymati chastota 2% o'zgarganda

$$\frac{R_0}{Z_{12}} = \frac{20 \cdot 10^3}{4855} = 4,1 \text{ marta kamayadi. Parallel kontur asilligi ham shunga nisbatan aniqlanadi.}$$

Masala 5.9. Keltirilgan sxemada kuchlanishlar rezonans holatida aktiv qarshilik $R = 200 \text{ Om}$, umumiy qarshilik esa $Z_{um} = 100 \text{ Om}$ bo'lib, $E = 200 \text{ V}$ kuchlanishga ulangan.

Rezonans vaqtidagi induktivlik x_L va sig'im x_C qarshiligi, tarmoqdagi tok kuchini toping.



Yechish. Umumiy kompleks qarshilik:

$$Z_{um} = jx_L + \frac{R(-jx_c)}{R - jx_c} = \frac{R(-jx_c)(R + jx_c)}{R^2 + x_c^2} + jx_L =$$

$$= \frac{Rx_c^2}{R^2 + x_c^2} + j\left(x_L - \frac{R^2 x_c}{R^2 + x_c^2}\right) = R_{um} + jx_{um}.$$

Bundan $R_{um} = 100 \text{ Om}$; $X_{um} = 0$.

Zanjir aktiv qarshiligi $R = 200 \text{ Om}$ bo'lsa, Ikkita noma'lum tenglama yozamiz:

$$R_{um} = 100 = \frac{Rx_c^2}{R^2 + x_c^2} \quad \text{yoki} \quad 100 = \frac{200x_c^2}{(200)^2 + x_c^2}.$$

Bundan: $x_c = 200 \text{ Om}$

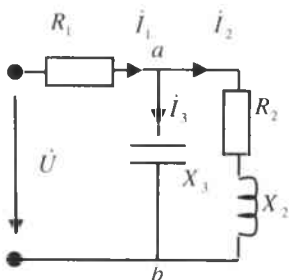
Endi umumiy reaktiv qarshilik: $X_{um} = 0 = X_L - \frac{R^2 x_c}{R}$,

$$x_L = \frac{200^2 \cdot 200}{200^2 + 200^2} = 100 \text{ Om}.$$

$$\text{Umumiy tok: } I = \frac{E}{R_{um}} = \frac{200 \angle 0^\circ}{100} = 2 \text{ A}$$

$$\text{Tarmoqdagi tok: } \dot{I}_1 = \dot{I} \frac{-jx_c}{R - jx_c} = 1 - j1 \text{ A}; \quad \dot{I}_2 = \dot{I} \frac{R}{R - jx_c} = 1 + j1 \text{ A}.$$

Masala 5.10. Zanjir qarshilik parametrlari $R_1 = 6 \text{ Om}$, $R_2 = 4 \text{ Om}$, $X_2 = 4 \text{ Om}$ bo'lib, $U = 120 \text{ V}$ kuchlanishga ulangan kondensator qarshiligini X_3 aniqlab, rezonans shartiga asosan $\varphi = 0$ holat uchun tarmoqdagi tok $\dot{I}_1, \dot{I}_2, \dot{I}_3$ va vektor ifodasini tuzing.



Yechish. Rezonans shartiga asosan tok va kuchlanish vektorlari ustma-ust tushadi va bular orasidagi burchak $\varphi = 0$, shunga asosan zanjirning ekvivalent umumiy reaktiv qarshilligini nolga tenglaymiz.

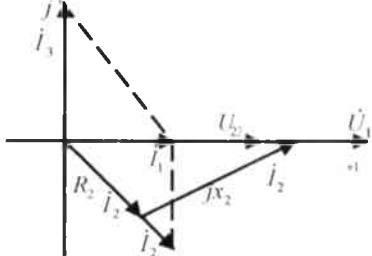
$$\text{yoki: } Z_{ab} = \frac{(R_2 + jx_2)(-jx_3)}{R_2 + j(x_2 - x_3)} = \frac{R_2 x_3^2}{R_2^2 + (x_2 - x_3)^2} + j \frac{x_2 x_3^2 - x_3 x_2^2 - x_3 R_2^2}{R_2^2 + (x_2 - x_3)^2}$$

Mavhum son qismini nolga tenglashtirish bilan:

$$x_2 x_3^2 - x_3 x_2^2 - x_3 R_2^2 = 0$$

Sig'im qarshiligi: $x_3 = x_2 + \frac{R_2^2}{x_2} = 4 + \frac{16}{4} = 8 \text{ Om}$.

Masalaning shartiga asosan R_1 qarshilik $\dot{I}_1$ tok bilan kuchlanish U orasidagi faza burchagiga ta'sir o'tkazmaydi. Shu sababli Om qonuniga asosan:



$$\dot{I}_1 = \frac{\dot{U}}{R_1 + \frac{R_2 X_3^2}{R_2^2 + (X_2 - X_3)^2}} = \frac{120}{6 + 8} = 8,57 \text{ A}$$

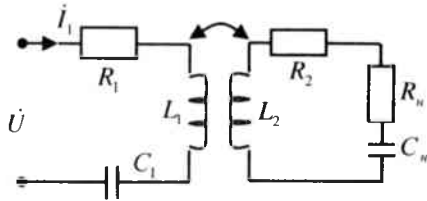
Zanjirning parallel ulangan qismi-dagi kuchlanish:

$$\dot{U}_{ab} = \dot{I}_1 \frac{R_2 x_3^2}{R_2^2 + (x_2 + x_3)} = 8,57 \cdot 8 = 68,5 \text{ V} \text{ Yoki tarmoqdagi tok:}$$

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{R_2 + jx_2} = \frac{68,5}{4 + j4} = \frac{68,5}{4 \cdot \sqrt{2} e^{j45^\circ}} = 8,57 - j8,57 \text{ A}; \dot{I}_3 = \frac{\dot{U}_{ab}}{-jx_3} = \frac{68,5}{-j8} = j8,57 \text{ A}$$

Tuzilgan vektor ifodadan $\dot{I}_1$ tok bilan $\dot{U}_{ab}$ va $\dot{U}$ kuchlanish vektorlari ustma-ust tushadi va R_1 qarshilik faza siljishiga ta'sir o'tkazmaydi.

Masala 5.11. O'zaro induktiv bog'langan rezonans zanjir parametri: $K = 0,42$, $R_1 = 5 \text{ Om}$, $R_2 = 10 \text{ Om}$, $R_H = 20 \text{ Om}$, $X_{L1} = 30 \text{ Om}$, $X_{L2} = 80 \text{ Om}$, $X_{c1} = 25 \text{ Om}$, $X_{cn} = 45 \text{ Om}$ bo'lib, $U = 60 \text{ V}$ kuchlanishga ulangan. O'zaro induktiv bog'langan reaktiv qarshilik, transformatorning «ortirma» kiritilgan aktiv ΔR va reaktiv ΔX qarshiliklari, umumiy to'la qarshilik I_1 , I_2 tok qiymati hamda ekvivalent sxema parametri va rezonans holatdagi X_{cn} — sig'im qarshilik qiymatini aniqlang.



Yechish. a) transformatorning bog‘lanish koefitsienti tenglamasiga asosan:

$$K = \frac{M}{\sqrt{L_1 \cdot L_2}} = \frac{\omega M}{\sqrt{\omega L_1 \cdot \omega L_2}}$$

Bundan: $X_M = \omega M = K \sqrt{\omega L_1 \cdot \omega L_2} = 0,42 \sqrt{30 \cdot 80} = 20,6 \text{ Om}$.

Ikkilamchi kontur xususiy to‘la qarshilikning kompleks ifodasi.

$$Z_{22} = X_{L_2} + R_2 + R_n - jx_c = j80 + 10 + 20 - j45 =$$

$$= 30 + j35 = R_{22} + jx_{22} = 46e^{j49^\circ} \text{ Om}$$

Yoki xususiy qarshilik: $Z_{22}^2 = \sqrt{R_{22}^2 + 35^2} = 2125 \text{ Om}$.

Shunga asosan birinchi konturga nisbatan kiritilgan qarshilik ifodasi:

$$\Delta R = \frac{X_M^2}{Z_{22}^2} R_{22} = \frac{(20,6)^2 \cdot 30}{2125} = 6 \text{ Om} \quad \Delta X = -\frac{X_M^2}{Z_{22}^2} X_{22} = \frac{(20,6)^2 \cdot 35}{2125} = -7 \text{ Om}.$$

Zanjirning kirish qismidagi to‘la qarshilik:

$$Z = R_0 + jx_1 + \Delta R_2 + j\Delta x - jx_{c1} = 5 + j30 + 6 - j7 - j25 =$$

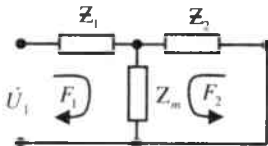
$$= 11 - j2 = 11e^{-j10^\circ} \text{ Om}$$

Birlamchi konturdagi tok: $i_1 = \frac{U}{Z} = \frac{60}{11e^{-j10^\circ}} = 5,5e^{j10^\circ} = 5,3 + j0,95 \text{ A}$

Ikkilamchi konturdagi tok:

$$i_2 = -i_1 \frac{jX_M}{Z_{22}} = -5,5e^{j10^\circ} \frac{j20,6}{46e^{j49^\circ}} = -2,42e^{j51^\circ} = -1,53 - j1,9 \text{ A}.$$

Transformatorning keltirilgan ekvivalent sxemasini chizamiz:



Birinci kontur to'la qarshiligi:

$$\begin{aligned} Z_1 &= Z_{11} - Z_M = (R_1 + jx_{L_1} - jx_{C_1}) - jx_M = \\ &= 5 + j30 - j25 - j20,6 = 5 - j15,6 \text{ om} \end{aligned}$$

Ikkimchi kontur to'la qarshiligi:

$$\begin{aligned} Z_2 &= Z_{22} - Z_M = (R_2 + R_H + jx_{L_2} - jx_H) - jx_M = \\ &= (10 + 20 + j80 - j45) - j20,6 = 30 + j14,5 \text{ om} \\ &\text{va } Z_M = j20,6 \text{ Om} \end{aligned}$$

b) rezonans holatdagi sig'im qarshiligi (X_{c_H}) ni topish uchun umumiy to'la qarshilik ifodasini yozamiz:

$$\begin{aligned} Z &= Z_1 + \frac{Z_2 \cdot Z_M}{Z_2 + Z_M} = R_1 + j(X_{L_1} - X_{C_1} - X_M) + \\ &+ \frac{[(R_2 + R_H) + j(X_{L_2} - jx_{c_H} - jX_M)] \cdot X_M}{[(R_2 + R_H) + j(X_{L_2} - jx_{c_H} - jX_M)] + jX_M} = \\ &= 5 + j(30 - 25 - 20,6) + \frac{[(10 + 20) + j(80 - X_{c_H} - 20,6)] j20,6}{[(10 + 20) + j(80 - X_{c_H} - 20,6)] + j20,6} = \\ &= 5 - j15,6 + \frac{[30 + j(60 - X_{c_H})] j20,6}{[30 + j(60 - X_{c_H})] + j20,6} \end{aligned}$$

$60 - X_{c_H} = X$ deb belgilash bilan maxrajdagi mavhum sondan qutilgan holda:

$$Z = 5 - j15,6 + \frac{12670 + j(20,6x^2 + 423x + 18,5)}{x^2 + 41x + 1,32}$$

Tenglamaning chap tomonini umumiy maxrajga keltirish bilan kompleks ifodaning haqiqiy va mavhum son ko'rinishida ifodalanadi:

$$Z = \frac{5x^2 + 205,5x + 19,3}{x^2 + 41x + 1,32} + j \frac{5x^2 - 216x - 2055}{x^2 + 41x + 1,32} = R + jX$$

Kuchlanishlar rezonans shartiga asosan $x = 0$:

$$5x^2 - 216x - 2055 = 0 \text{ yoki: } x^2 - 43,2x - 411 = 0$$

Tenglamani yechish:

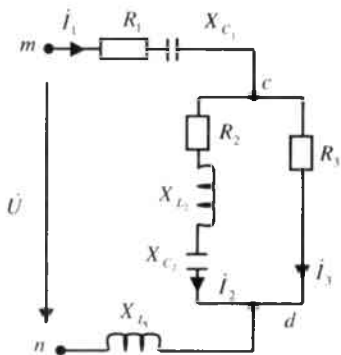
$$x = \frac{43,2}{2} \pm \sqrt{\left(\frac{43,2}{2}\right)^2 + 411} = 21,6 \pm 29,6; x_1 = 51,2; x_2 = -8$$

Bundan: $x_1 = 51.2 \text{ Om}$ qiymatni olsak, birlamchi konturda rezonans holat $x_{e1} = \frac{1}{\omega c_1} = 60 - x = 60 - 51.2 = 8.8 \text{ Om}$ qarshilikka teng bo'lganda rezonans holat yuzaga keladi.

Masala 5.12. Rezonansli elektr zanjir parametri $R_1 = 5 \text{ Om}$, $X_{c1} = 7 \text{ Om}$, $X_{L1} = 10 \text{ Om}$, $R_2 = 3 \text{ Om}$, $X_{L2} = 20 \text{ Om}$, $R_3 = 12 \text{ Om}$, $I_1 = 0.2 \text{ A}$ bo'lganda, sig'im qarshilik qiymati X_{c2} va I_2 tarmoqdagi tok qiymatini aniqlang.

Yechish. Parallel ulangan qismdagi cd potentsiallarga nisbatan kompleks to'la qarshilik.

$$Z_{cd} = \frac{[R_2 + j(X_{L2} - X_{c2})] \cdot R_3}{R_2 + j(X_{L2} - X_{c2}) + R_3}$$



Surat va maxrajlarini kompleks (manfiy) qiymatga ko'paytirish bilan haqiqiy va mavhum qismlardan iborat tenglama hosil qilamiz:

$$\begin{aligned} & \frac{[R_2 R_3 + j(X_{L2} - X_{c2}) \cdot R_3] [(R_2 + R_3) - j(X_{L2} - X_{c3})]}{(R_2 + R_3) + j(X_{L2} - X_{c2}) \cdot (R_2 + R_3) - j(X_{L2} - X_{L3})} = \\ & = \frac{R_2 R_3 (R_2 + R_3) + (X_{L2} - X_{c2})^2 R_3}{(R_2 + R_3)^2 + (X_{L2} - X_{c2})^2} + j \frac{(X_{L2} - X_{c3}) \cdot R_3 (R_2 + R_3) - R_2 R_3 (X_{L2} - X_{c2})}{(R_2 + R_3)^2 + (X_{L2} - X_{c2})^2} = \\ & = R_{cd} + jx_{cd} \quad \text{yoki} \quad Z_{cd} = R_{cd} + jx_{cd}. \end{aligned}$$

$$\text{Bundan: } X_{cd} = \frac{(X_{L2} - X_{c2}) R_3^2}{(R_2 + R_3)^2 + (X_{L2} - X_{c2})^2}$$

Zanjir umumiy kompleks qarshilik ifodasini yozamiz:

$$Z = R_1 - jx_{c1} + Z_{cd} + jx_{L1} = R_1 - jx_{c1} + (R_{cd} + jx_{cd}) + jx_{L1} = \\ = (R_1 + R_{cd}) + j(X_{L1} - X_{c1} + X_{cd}) = R + jX$$

Ushbu zanjirda rezonans shartiga asosan $X = 0$ bo'lganda:

$$X_{L1} - X_{c1} + X_{cd} = 0$$

$$\text{yoki: } X_{L1} - X_{c1} \cdot \frac{(X_{L2} - X_{c2})R_3^2}{(R_2 + R_3)^2 + (X_{L2} - X_{L3})} = 0$$

Bundan:

$$(X_{L1} - X_{c1})(R_2 + R_3)^2 + (X_{L1} - X_{c1})(X_{L2} - X_{c2})^2 + (X_{L2} - X_{c2})R_3^2 = 0$$

Sig'ım qarshiligi (X_{c2}) ni topish uchun:

$$(X_{L2} - X_{c2})^2 + \frac{R_3^2}{X_{L1} - X_{c1}}(X_{L2} - X_{c2}) + (R_2 + R_3)^2 = 0$$

Qarshilik qiymatini qo'yish bilan:

$$(20 - X_{c2})^2 + 48(20 - X_{c2}) + 225 = 0$$

Kvadrat tenglamani yechish bilan:

$$(20 - X_{c2}) = -\frac{48}{2} \pm \sqrt{\left(\frac{48}{2}\right)^2 - 225} = -24 \pm 18,7$$

$$\text{Bundan: } (20 - X_{c2}) = -24 + 18,7 = -5,27 \text{ Om}$$

$$\text{yoki: } X_{c2} = 20 - 5,27 \approx 25,3 \text{ Om.}$$

$$\hat{I}_2 = \hat{I}_1 \frac{Z_3}{Z_2 + Z_3} = \hat{I}_1 \frac{R_3}{[R_2 + j(X_{L2} - X_{c3})] + R_3} = 0,2 \cdot \frac{12}{3 + j(20 - 25,3) + 12} = \\ = (142,5 + j50) \cdot 10^{-3} \text{ A.}$$

$\hat{I}_2$ tokning haqiqiy qiymati:

$$\hat{I}_2 = \sqrt{(142,5010^3)^2 + (50 \cdot 10^{-3})^2} = 151 \cdot 10^{-3} \approx 0,151 \text{ A.}$$

5.3. Mustaqil yechish uchun masalalar

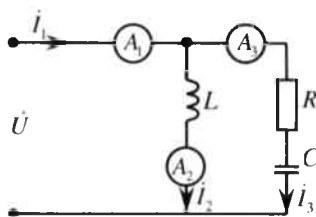
Masala 5.1. Ketma-ket ulangan elektr zanjirning parametri $R=100\text{Om}$, $L_1=0,2\text{ Gn}$, $S=1\text{ mkF}$, kuchlanishi $U=100\text{ mV}$ ga teng bo'lganda; rezonans chastota ω_0 , tok I_0 , kuchlanish U_{Cmax} , U_{Lmax}

qiymatga erishgan holatdagi ω_C va ω_L chastota, U_{Cmax} , U_{Lmax} qiymatlari, kontur asilligi Q , rezonans chastota chegaralarini $d = (\omega_2 - \omega_1)$ aniqlang.

Javob: $\omega_0 = 2236 \frac{1}{sek}$, $I_0 = 1 MA$, $\omega_L = 2264 \frac{1}{sek}$, $\omega_C = 2207 \frac{1}{sek}$, $U_{Cmax} = 0,45 V$, $U_{Lmax} = 0,45 V$, $Q = 4,47$, $\omega_2 - \omega_1 = 500$, $\omega_1 = 2000 \frac{1}{sek}$, $\Delta f = 79,6 gs$.

Masala 5.2. Keltirilgan sxemada rezonans holatda tarmoqdagi toklar $I_1=4 A$, $I_2=3 A$ ga teng bo'lib, I_3 tok qiymati aniqlansin.

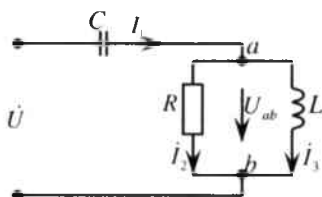
Javob: $I_3=5A$



Masala 5.3. Rezonans holatdagi elektr zanjir parametri $R=20 Om$, $X_L= 20 Om$ va $U=300 V$ bo'lganda, sig'im qarshiligi, umumiy ekvivalent qarshiligi va tok qiymati aniqlansin.

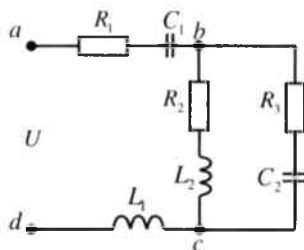
Javob:

$x_C = 10Om$, $Z_{\Sigma} = 10Om$, $U_{ab} = 300\sqrt{2}e^{j45^\circ}$, $I_1 = 30e^{j0} A$, $I_2 = 15 + j15(A)$, $I_3 = 15 + j15A$



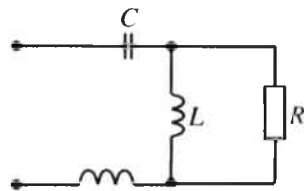
Masala 5.4. Elektr zanjir parametri $C_3=10 \cdot 10^{-6} F$, $L_2=18 \cdot 10^{-3} Gn$, $R_2=40 Om$, $R_3=30 Om$ bo'lganda, tok rezonansini yuzaga keltiruvchi rezonans chastotasini (ω_0) aniqlang.

Javob: $\omega_0=1560 rad/sek$



Masala 5.5. Induktiv galtakga, aktiv qarshilik R parallel va sig'im qarshiligiga $X_C=20 Om$ ketma-ket ulangan.

Chastota $f = 50 Gs$ qarshiliklari esa $R=40 Om$ va $X_L=80 Om$ bo'lganda rezo-



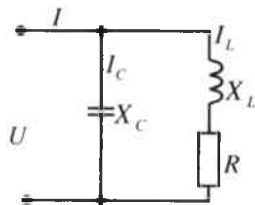
nans hosil qiluvchi induktivlik L qiymatini aniqlang va qanday hollarda umumiy qarshilik z_{min} minimal bo'lad.

Javob: 1) $R=40\text{ Om}$ bo'lganda, rezonans induktivlik $L=0,0128\text{ Gn}$, umumiy qarshiligi $Z=Z_{min}$, $L=0,052\text{ Gn}$.

2) $R=80\text{ Om}$ bo'lganda rezonans induktivlik $L=0,069\text{ Gn}$ va $L=0,95\text{ Gn}$, $Z=Z_{min}$; $L=0,061\text{ Gn}$.

Masala 5.6. Elektr tok zanjir rezonans holatda bo'lib, umumiy tok $I=10\text{ A}$, qarshilik $R=6\text{ Om}$, $x_L=8\text{ Om}$. Sig'imdan o'tuvchi tok I_C , reaktiv qarshilik va kuchlanishni aniqlang.

Javob: $I_C=13,3\text{ A}$, $x_C=12,5\text{ Om}$, $U=166,7\text{ V}$.

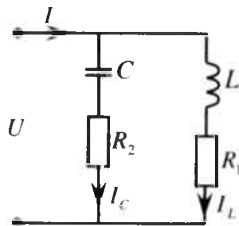


Masala 5.7. 5.6 masalada berilgan sxemaning induktiv qarshiligi $X_L=R$ va tok $I=10\text{ A}$. Rezonans holatdagi I_C , I_L , X_C , U tok qiymatini aniqlang.

Javob: $I_C=10\text{ A}$, $I_L=10\sqrt{2}\text{ A}$, $X_C=2X_L$, $U=20\text{ V}$

Masala 5.8. Parametri $L=6,4\text{ Gn}$, $R=10\text{ m}$ bo'lgan parallel zanjir chastotasi $f=50\text{ Gs}$, $U=100\text{ V}$, $I=75\text{ A}$ tokka ulangan. Rezonans holatdagi R_2, C tok qiymatni aniqlang.

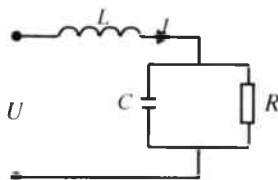
Javob: $R_2=1,16\text{ Om}$, $C=3540\text{ mkF}$



Masala 5.9. Ketma-ket ulangan elektr zanjirning parametri $R=40\text{ Om}$, $L=0,2\text{ Gn}$, $C=10\text{ mkF}$ ga teng bo'lgan holat uchun rezonans, chastota f_0 induktivlikdagi $U_{L\max}$ kuchlanishi va manba kuchlanishiga nisbatan necha marta katta bo'lishini aniqlang.

Javob: $f_0=112\text{ Gs}$, $X_L=140\text{ Om}$, $U_{L\max}=3,5\text{ V}$

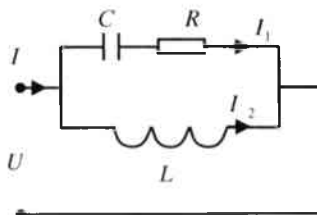
Masala 5.10. Elektr zanjir rezonans holatda bo'lib chastotasi $\omega_0=0$ bo'lganda $Z_{um(0)}=50\text{ Om}$ va rezonans chastota $\omega=\omega_0$ da $Z_{um(0)}=2,5\text{ Om}$.



Qarshilik parametri: R_L , X_L va X_C aniqlang hamda vektor ifodasini tuzing.

Javob: $R_L=5 \text{ Om}$, $X_L=2,5 \text{ Om}$, $X_C=5 \text{ Om}$

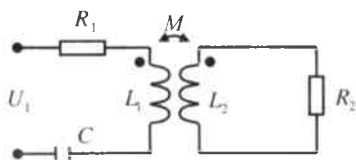
Masala 5.11. Elektr zanjirda rezonans holatdagi tok $I_1 = 7 \text{ A}$, $I=3,6 \text{ A}$ ga teng. Induktivlikdagi I_2 tokni aniqlab, vektor ifodasini tuzing.



Javob: $I_2 = 6 \text{ A}$

Masala 5.12. Induktiv bog'langan elektr zanjiri parametri:

$R_1=2 \text{ Om}$, $X_{L_1}=10 \text{ Om}$, $X_C=8 \text{ Om}$, $X_{L_2}=9 \text{ Om}$, $X_M=6 \text{ Om}$ bo'lib, $U=100 \text{ V}$ kuchlanish ulangan. R_2 ning qaysi qiymatida zanjirda rezonans holat yuzaga keladi.

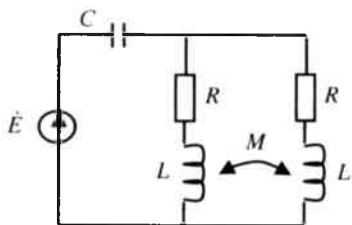


Javob: $R_2=9 \text{ Om}$.

Masala 5.14. Ikkita o'zaro induktiv bog'langan zanjir parametri: $L_1 = 100 \text{ mkgn}$, $L_2 = 250 \text{ mkgn}$, $R_2 = 80 \text{ Om}$, $M = 50 \text{ mkgn}$, $f = 800 \text{ kgs}$ va $C_2 = 1000 \text{ pf}$. Birlamchi kontur sig'im C_1 qiymati aniqlansin.

Javob: $C_1 = 440 \cdot 10^{-12} \text{ f} = 440 \text{ pf}$.

Masala 5.15. Parametrlari R, L, C bo'lgan o'zaro induktiv bog'langan zanjir chastotasi f bo'lgan sinusoidal kuchlanishga ulangan. M koeffitsient qanday qiymatida rezonans holat yuzaga keladi?



Javob: $M = L - \frac{2}{\omega^2 C}$

5.4. Nazorat savollari

1. Elektr zanjirda rezonans holat qanday yuzaga keladi?
2. Rezonans hosil qilish uchun elektr zanjir qaysi elementlardan tuzilgan bo'lishi zarur va sharti nimada?
3. Rezonans hodisasidan amalda qaysi sohalarda foydalaniladi?
4. Rezonans chastota tenglamasini yozib, rezonans holatga qanday erishilishini tushuntiring.
5. Tebranuvchan kontur induktivligi $L=25 \text{ MGn}$, sig'imi $C=4 \text{ mkF}$ bo'lganda, rezonans chastota f_0 qancha bo'ladi?
6. Kuchlanishlar rezonansi qanday hosil bo'ladi? Vektor ifodasini chizing. Tok va quvvat tenglamalarini yozing.
7. Tok rezonansi qanday hosil bo'ladi? Tok va quvvat tenglamalarini yozing.
8. Nima sababdan kuchlanishlar rezonans paytida sig'im va induktivlikdagi kuchlanishlar umumiy kuchlanishga nisbatan katta bo'ladi?
9. Chastotaga nisbatan reaktiv qarshilik yoki o'tkazuvchanlik qanday o'zgaradi? Chastota xarakteristikasini chizing.
10. Rezonans holatda quvvat koeffitsienti nimaga teng?
11. Kontur saxiyligi yoki kontur so'nishi nima va qanday ifodalanadi?
12. To'liq qarshiligi yoki o'tkazuvchanligi nima, qanday ifodalanadi?
13. Rezonans holatda elektr zanjirning tarmoqlanmagan qismidagi tok qanday qiymatga erishadi?

14. Rezonans kontur reaktiv qarshiliklari $X_L > X_C$, $X_L = X_C$, $X_L < X_C$ holatlar uchun vektor ifodasini tuzing va qanday xarakterga ega ekanligini tushuntiring.
15. Rezonans holatda elektromagnit maydon energiyasi tebranishi fizik ma'nosini tushuntiring.
16. Tok rezonans hodisasi bilan kuchlanish rezonansida qanday o'xshashliklar bor?
17. Rezonans holatda aktiv, reaktiv va to'la quvvatlar qanday bog'langan?
18. Qanday konturda va qaysi shartlar bajarilganda rezonans hodisasi yuzaga keladi?
19. Kuchlanishlar rezonansi vaqtida nima uchun tok maksimal qiymatga erishadi?
20. Tok rezonansi holatida nima uchun kuchlanish maksimal qiymatga erishadi?
21. Rezonans holatida sarf bo'lgan elektr energiyasi nimaning hisobiga to'ldiriladi?
22. Murakkab elektr zanjirida rezonans hosil bo'lish shartini tushuntiring.
23. Rezonans holatda to'la qarshilik yoki o'tkazuvchanlik nimaga teng?
24. Rezonansli kontur parametri $R = 10 \text{ } \Omega$, $L = 400 \text{ mH}$ va $C = 400 \text{ pF}$ bo'lsa, to'lqin uzunligi λ va Q nimaga teng? (Javob: $\lambda = 750 \text{ m}$, $Q = 100$)
25. Parallel sxemada ulangan zanjir rezonans holatda umumiy tarmoqdagi tok $I = 1,1 \text{ A}$, sig'imdagi tok $I_C = 6 \text{ A}$ ga teng. Agar kontur aktiv qarshiligi $R = 1 \text{ } \Omega$ bo'lsa, aktiv quvvat qancha bo'ladi? (Javob: $P = 37,21 \text{ Vt}$).

VI. UCH FAZALI SINUSOIDAL O'ZGARUVCHAN ELEKTR ZANJIR

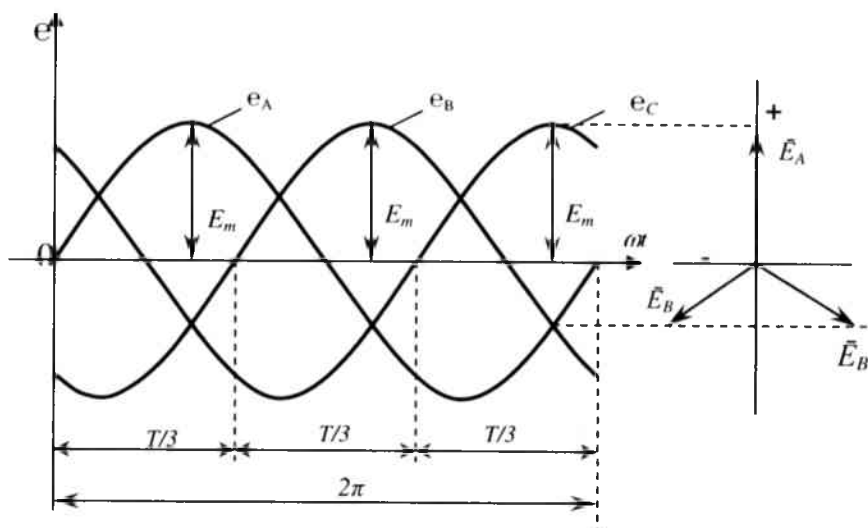
6.1. Asosiy nazariy tushunchalar

Fazalari bilan 120° farq qiluvchi, chastota va amplitudalari bir xil bo'lgan uchta bir fazali sinusoidal o'zgaruvchan elektr zanjirga **uch fazali tok sistemalari** yoki **zanjirlari** deyiladi.

Uch fazali tok manbai uch fazali **sinxron generatori** bo'lib, rotor aylanma harakatlanish natijasida stator qismida 120° farqi bilan joylashtirilgan chulg'amlarda induksiyanaladigan EYK analitik ifodasi quyidagicha ifodalanadi.

$$\begin{aligned} e_A &= E_m \sin \omega t \\ e_B &= E_m \sin(\omega t - 120^\circ) \\ e_C &= E_m \sin(\omega t + 120^\circ) \end{aligned} \quad (6.1)$$

Uch fazali sinusoidal o'zgaruvchan tok vaqt bo'yicha o'zgaruvchan grafigi va vektor ifodasi quyidagicha ifodalanadi:



EYK (kuchlanish, tok) kompleks shakldagi ifodasi.

$$\dot{E}_A = E, \quad \dot{E}_B = E e^{-j\frac{2\pi}{3}}, \quad \dot{E}_C = E e^{+j\frac{2\pi}{3}} \quad (6.2)$$

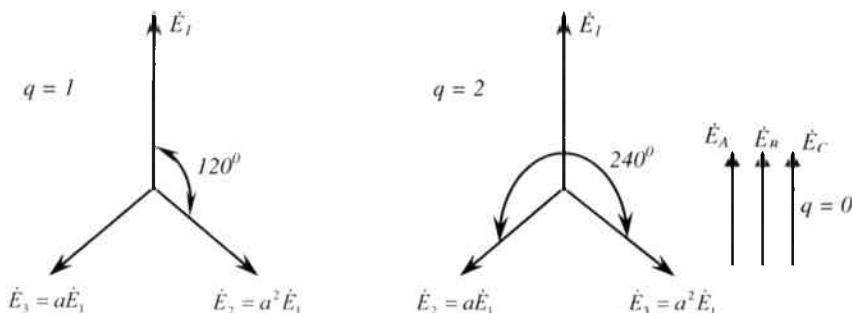
Vektorlarni kompleks shaklda qisqa yozish uchun fazoviy ko'paytiruvchi (buruvchi) belgilash kiritiladi yoki

$\alpha = e^{j\frac{2\pi}{3}} = (\cos 120^\circ + j \sin 120^\circ) = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$ faza burchagi 120° ga teng.

U holda $q=1$, $\dot{E}_1 = E$; $\dot{E}_2 = \alpha^2 E$; $\dot{E}_3 = \alpha E$ to'g'ri ketma-ketlik.

$q=2$, $\dot{E}_1 = E$; $\dot{E}_2 = \alpha E$; $\dot{E}_3 = \alpha^2 E$ teskari ketma-ketlik bo'ladi. $q=0$,

$\dot{E}_1 = \dot{E}_2 = \dot{E}_3$ – nol ketma-ketlik bo'ladi



yoki $\alpha^2 = e^{-j\frac{2\pi}{3}}$; $\alpha^3 = e^{j2\pi} = 1$; $\alpha^4 = \alpha = e^{j\frac{2\pi}{3}}$

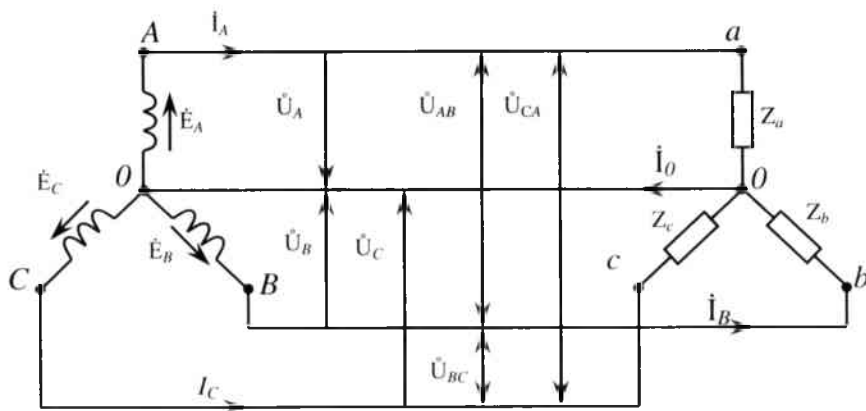
Shu ma'noda $\alpha + \alpha^2 + \alpha^3 = 0$ yoki $1 + \alpha + \alpha^2 = 0$.

Demak, vektorni « α »ga ko'paytirish, $\varphi = \frac{2\pi}{3}$ burchakga burish

bilan barobar.

Uch fazali elektr zanjirda generator (manba) hilan iste'molchilar o'zaro yulduzcha, uchburchak shaklida ulanishi mumkin.

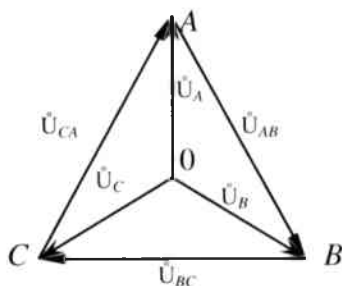
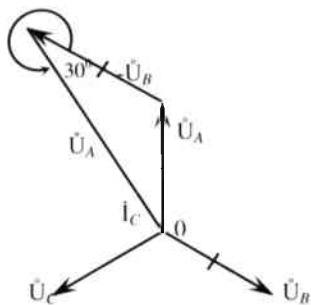
1. Uch fazali elektr zanjirning yulduzcha shaklida ulanishi.



Simmetrik yulduzcha shaklida ulangan elektr zanjirdagi $\dot{U}_{jl}$ liniyadagi kuchlanishi fazadagi kuchlanishga nisbatan: $\dot{U}_{jl} = \dot{U}_{AB} = \dot{U}_A - \dot{U}_B$.

yoki:

$$U_{jl} = \sqrt{3} \cdot \dot{U}_\varphi \quad \dot{I}_A = I_\varphi \quad (6,3)$$

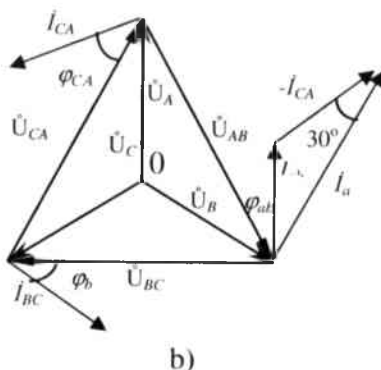
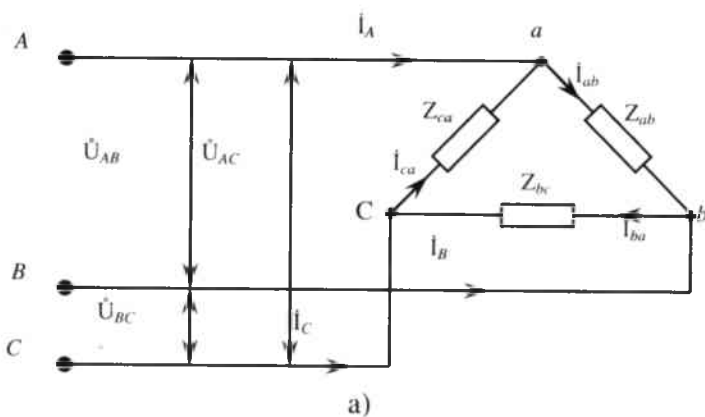


2. Uchburchak shaklida ulanish.

Liniyadagi tok fazadagi tok orqali ifodalanganda.

$$\dot{I}_A = \dot{I}_{ab} - \dot{I}_{ca}, \quad \dot{I}_B = \dot{I}_{bc} - \dot{I}_{ab}, \quad \dot{I}_C = \dot{I}_{ca} - \dot{I}_{bc} \quad (6.4)$$

Bunda: $\dot{I}_A = \sqrt{3} \cdot \dot{I}_F$; $\dot{U}_L = \dot{U}_{AB} = \dot{U}_F$



Agar neytral simli uch fazali elektr zanjirning faza kuchlanish va iste'molchi qarshiliklari berilgan bo'lsa:

$$\dot{U}_a = \dot{U}_A - \dot{U}_O; \quad \dot{U}_b = \dot{U}_B - \dot{U}_O; \quad \dot{U}_c = \dot{U}_C - \dot{U}_O.$$

Tugun potensiallar usuliga asosan manba bilan iste'molchi orasidagi 00' nuqtalar potentsiali:

$$\varphi_0 - \varphi_{0'} = \dot{U}_{00'} = \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_b + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c + \underline{y}_0} \quad (6.5)$$

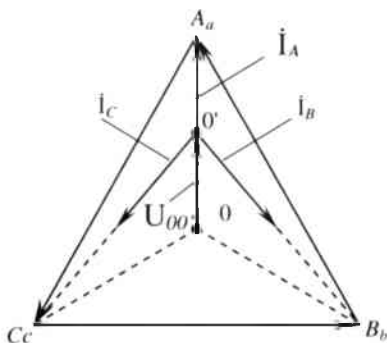
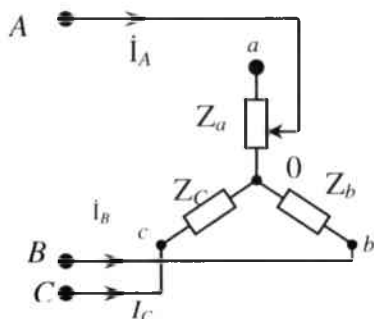
Neytral simsiz uch fazali elektr zanjirning liniya kuchlanishi ma'lum bo'lsa, faza kuchlanishi uchun tenglama:

$$\dot{U}_A = \frac{\dot{U}_{AB} \underline{y}_b - \dot{U}_{BC} \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} \quad \dot{U}_B = \frac{\dot{U}_{BC} \underline{y}_c - \dot{U}_{AB} \underline{y}_a}{\underline{y}_a + \underline{y}_b + \underline{y}_c}$$

$$\dot{U}_C = \frac{\dot{U}_{CA} \underline{y}_a - \dot{U}_{BC} \underline{y}_a}{\underline{y}_a + \underline{y}_a + \underline{y}_c} \quad (6.6)$$

1. Simmetrik yulduzcha yoki uchburchak shaklda ulangan uch fazali elektr zanjirlarni hisoblashda bir fazali elektr zanjirlar qoida va usullaridan foydalaniladi.

2. Nosimmetrik uch fazali elektr zanjir.



a) iste'molchi qarshiliklari nosimmetrik: $Z_a = \text{var}$, $Z_b = Z_c = \text{const}$. Bunday holatda I_A tok generator bilan iste'molchi potentsiallari orasida

$U_{00'}$ kuchlanish (0) nuqta bo'yicha siljiydi, hamda:

$$\Sigma I = I_a + I_b + I_c = 0 \quad Z_a > R$$

b) $\dot{U}_A$ – fazada qisqa tutashuv:

$$(\underline{Z}_a = 0, \underline{Y}_a = \infty, \underline{Z}_b = \underline{Z}_c = R = \text{const}, \underline{y}_b = \underline{y}_c = \frac{1}{R} = y = \text{const})$$

Qisqa tutashuv holatda $\dot{U}_{00'}$ – kuchlanish:

$$\dot{U}_{00'} = \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_b + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{\dot{U}_A}{2}$$

$\dot{U}'_A$ – faza kuchlanishi: $\dot{U}'_A = \dot{U}_A - \dot{U}_0 = \dot{U}_A - \dot{U}_0 = 0$

$\dot{U}'_B$ va $\dot{U}'_C$ – fazadagi kuchlanish tenglamasi:

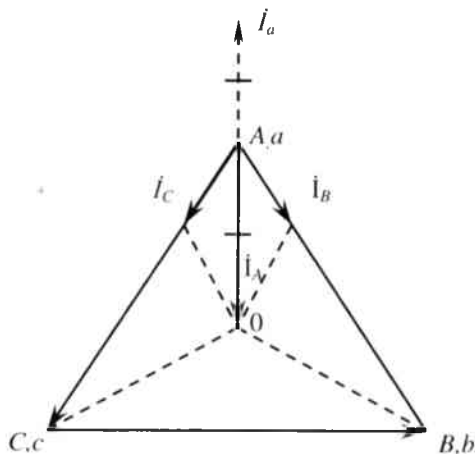
$$\dot{U}'_B = \dot{U}_B - \dot{U}_0 = \dot{U}_B - \dot{U}_A = \dot{U}_{BA} = -\dot{U}_{AB} = -\dot{U}_{ab}$$

$$\dot{U}'_C = \dot{U}_C - \dot{U}_0 = \dot{U}_C - \dot{U}_A = \dot{U}_{CA} = \dot{U}_{CA} = \dot{U}_{ca}$$

Fazadagi tok: $\dot{I}_b = \dot{I}_c = \frac{\dot{U}'_a}{\underline{Z}_\phi} = \sqrt{3} \dot{I}_\phi$

A – fazadagi tok: $\vec{I}_a = -(\vec{I}_b + \vec{I}_c) = \sqrt{3}\vec{I}_b = 3I_\phi$

Demak, A faza qisqa tutashtirilganda fazadagi tok 3 martaga ortadi va fazadagi kuchlanish $\vec{U}_A = 0$ bo'lib, bu fazaga ulangan lampochka o'chadi.



d) $\vec{U}_A$ – faza simining uzilishi:

$$\underline{Z}_a = \infty; \underline{Z}_b = \underline{Z}_c = R = const; \underline{y}_a = 0; \underline{y}_a = \underline{y}_c = \frac{1}{R}$$

Tugunlar orasidagi kuchlanish:

$$\vec{U}_{00'} = \frac{\vec{U}_A \underline{y}_a + \vec{U}_B \underline{y}_b + \vec{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(\vec{U}_B + \vec{U}_C) \underline{y}_b}{2 \underline{y}_b} = -\frac{\vec{U}_A}{2} = -\frac{U_\phi}{2}$$

Demak, iste'molchi kuchlanishi 00' nuqta bo'ylab pastga yo'naladi va $\vec{cb}$ vektor o'rtasini kesadi. Bunda $\vec{U}_A = 0$; $\vec{I}_A = 0$ bo'lib:

$$\vec{U}_{aA} = \vec{U}_{A0'} = \vec{U}_A - \vec{U}_0 = \vec{U}_A - \left(-\frac{\vec{U}_A}{2} \right) = \frac{2}{3} \vec{U}_A$$

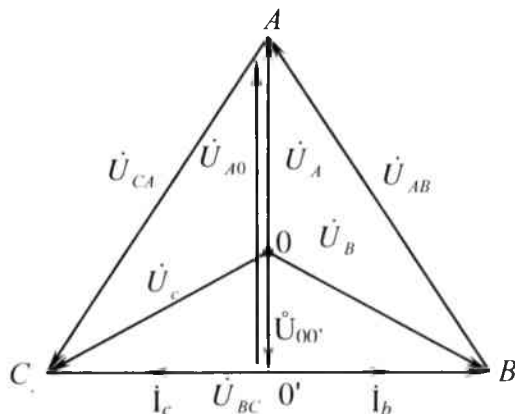
A va B fazadagi kuchlanish: $\vec{U}_B = \vec{U}_C = \frac{\vec{U}_\phi}{2}$

yoki $\vec{U}_\phi = \frac{\vec{U}_\phi}{\sqrt{3}}; \frac{\vec{U}_\phi}{\vec{U}_B} = \frac{\vec{U}_\phi}{\sqrt{3}} \div \frac{\vec{U}_\phi}{2} = \frac{2}{\sqrt{3}} \cdot \vec{U}_\phi;$

B va C fazadan o'tuvchi tokga teng bo'lib:

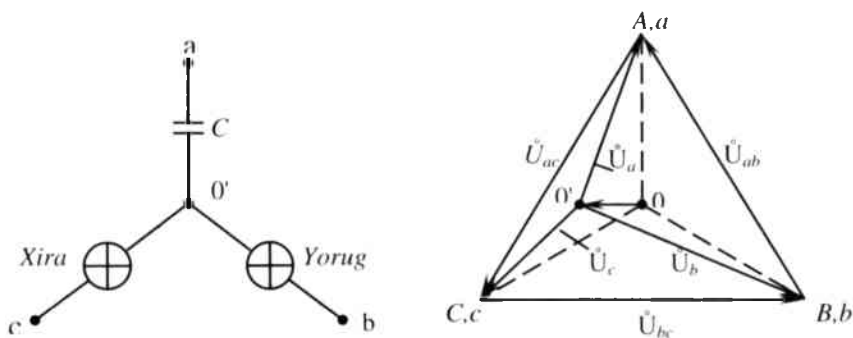
$$i_B = i_C - \frac{\dot{U}_L}{Z_b} = \frac{\sqrt{3}\dot{U}_\varphi}{2Z_\varphi} = \frac{\sqrt{3}}{2} i_\varphi$$

Demak, fazaga ulangan iste'molchi (lampa) A fazada o'chadi, B va C fazada xira yonadi.



e) uch fazali elektr fazalar ketma-ketligini aniqlash.

Bunda uch fazali elektr zanjirning A fazasiga sig'im C yoki induktivlik L ulanib, qolgan ikkita fazasiga bir xil qarshilikdagi lampochkalar ulanadi.



1) sxemada A fazaga sig'im qarshilik ulangan: $\underline{z}_a = -jx_c$;
 $\underline{z}_b = \underline{z}_c = R$

$$\text{yoki } \underline{y}_a = \frac{1}{-jX} = b; \quad \underline{y}_b = \underline{y}_c = \frac{1}{R} = g$$

Demak:

$$\begin{aligned} \dot{U}_{00} &= \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_b + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{U_A j b + \left(-0,5 - j \frac{\sqrt{3}}{2}\right) \dot{U}_A g + \left(-0,5 + j \frac{\sqrt{3}}{2}\right) \dot{U}_A g}{j b + g + g} = \\ &= 0,63 \dot{U}_A e^{j105^\circ 26'} = (-0,2 + j0,6) \dot{U}_A \end{aligned}$$

Iste' molchilardagi faza kuchlamishi:

$$\dot{U}_a = \dot{U}_A - \dot{U}_0 = \dot{U}_A - (-0,2 + j0,6) \dot{U}_A = 1,34 \dot{U}_A e^{-j26^\circ 34'}$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_0 = \left(-0,5 - j \frac{\sqrt{3}}{2}\right) \dot{U}_A - (-0,2 + j0,6) \dot{U}_A = 1,5 \dot{U}_A e^{-j101^\circ 33'}$$

$$\dot{U}_c = \dot{U}_C - \dot{U}_0 = \left(-0,5 + j \frac{\sqrt{3}}{2}\right) \dot{U}_A - (-0,2 + j0,6) \dot{U}_A = 0,4 \dot{U}_A e^{-j138^\circ 20'}$$

2) A fazaga induktiv qarshilik ulaymiz:

$$\underline{z}_a = jX_L = jR; \quad \underline{z}_b = \underline{z}_c = R$$

$$\text{yoki } \underline{y}_a = \frac{1}{jR} = -jg; \quad \underline{y}_b = \underline{y}_c = \frac{1}{R} = g$$

Tugun kuchlanishlar tenglamasiga asosan:

$$\begin{aligned} \dot{U}_{00} &= \frac{\dot{U}_A \underline{y}_a + \dot{U}_B \underline{y}_b + \dot{U}_C \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{U_A (-jg) + \left(0,5 - j \frac{\sqrt{3}}{2}\right) \dot{U}_A g + \left(0,5 + j \frac{\sqrt{3}}{2}\right) \dot{U}_A g}{-jg + g + g} = \\ &= 0,63 \dot{U}_A e^{j108^\circ 26'} = (-0,2 - j0,6) \dot{U}_A \end{aligned}$$

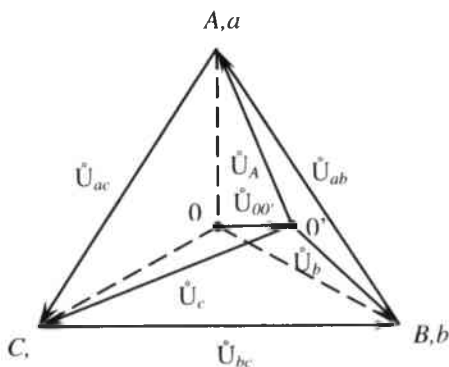
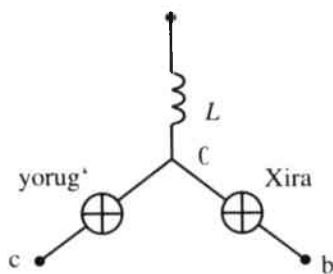
Faza kuchlanishlari:

$$\dot{U}_a = \dot{U}_A - \dot{U}_0 = \dot{U}_A - (-0,2 - j0,6) \dot{U}_A = (1,2 - j0,6) \dot{U}_A = 1,34 \dot{U}_A e^{j26^\circ 34'};$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_0 = \left(-0,5 - j \frac{\sqrt{3}}{2}\right) \dot{U}_A - (-0,2 - j0,6) \dot{U}_A = 0,4 \dot{U}_A e^{j138^\circ 20'};$$

$$\dot{U}_c = \dot{U}_C - \dot{U}_0 = \left(-0,5 + j \frac{\sqrt{3}}{2}\right) \dot{U}_A - (-0,2 - j0,6) \dot{U}_A = (0,3 + j1,47) \dot{U}_A = 1,5 \dot{U}_A e^{j101^\circ 53'};$$

2.

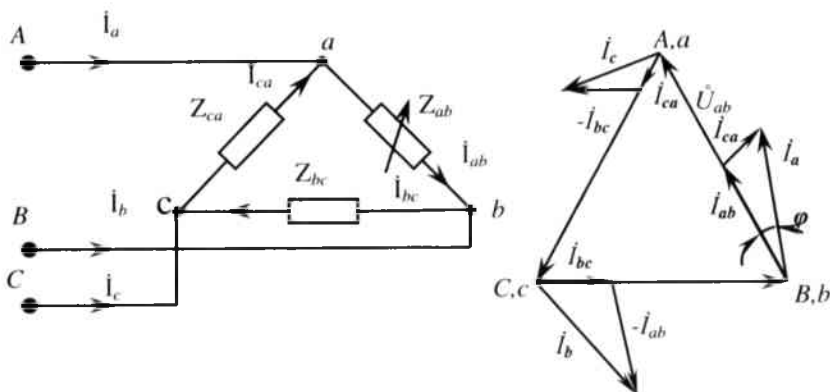


3. Uchburchak shaklida ulangan uch fazali elektr zanjir.

a) Simmetrik holat:

Simmetrik uchburchak shakilda ulangan elektr zanjirni hisoblashda bir fazali elektr zanjirni hisoblash usulidan foydalaniladi.

b) Nosimmetrik holat: ($\underline{Z}_{ab} = \frac{R}{2}$; $\underline{Z}_{bc} = \underline{Z}_{ca} = R = const$)



Fazadagi tokni aniqlaymiz:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{\underline{Z}_{ab}} = 2 \frac{\dot{U}_{ab}}{R};$$

$$\dot{I}_{bc} = \frac{\dot{U}_{bc}}{\underline{Z}_{bc}} = 2 \frac{\dot{U}_{ab}}{R} e^{-j120^\circ} = \left(-0,5 - j \frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{R}$$

$$\dot{I}_{ca} = \frac{\dot{U}_{ca}}{\underline{Z}_{ca}} = \frac{\dot{U}_{ca}}{\underline{Z}_{ca}} e^{-j120^\circ} = \left(-0,5 + j\frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{R};$$

Liniyadagi tok:

$$\dot{I}_a = \dot{I}_{ab} - \dot{I}_{ca} = \left(2,5 - j\frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{2} = 2,65 \frac{\dot{U}_{ab}}{R} e^{-j19^\circ};$$

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = \left(-2,5 - j\frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{R} = 2,65 \frac{\dot{U}_{ab}}{R} e^{-j161^\circ};$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = j\sqrt{3} \frac{\dot{U}_{ab}}{2} = 1,73 \frac{\dot{U}_{ab}}{R} e^{-j90^\circ};$$

d) birinchi A fazada qisqa tutashuv:

$$\underline{Z}_{ab} = 0; \quad \underline{Z}_{bc} = \underline{Z}_{ca} = R = const;$$

Qisqa tutashuvda $\dot{I}_{ab} = \infty$ bo'lib $\dot{I}_{ab}$ faza simi (saqlagich) uzilishi mumkin yoki $\underline{Z}_{ab} = \infty; \quad \underline{Z}_{bc} = \underline{Z}_{ca} = R = const;$

$$\text{Bunda fazadagi tok: } \dot{I}_{ab} = \frac{\dot{U}_{ab}}{\underline{Z}_{ab}} = 0;$$

$$\dot{I}_{bc} = \frac{\dot{U}_{bc}}{\underline{Z}_{bc}} = \frac{\dot{U}_{ab}}{R} e^{-j120^\circ} = \left(-0,5 - j\frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{R};$$

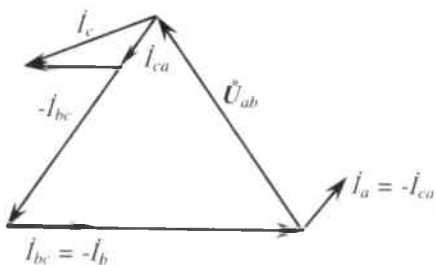
$$\dot{I}_{ca} = \frac{\dot{U}_{ca}}{\underline{Z}_{ca}} = \frac{\dot{U}_{ab}}{R} e^{j120^\circ} = \left(-0,5 + j\frac{\sqrt{3}}{2} \right) \frac{\dot{U}_{ab}}{2};$$

Liniyadagi tok:

$$\dot{I}_a = \dot{I}_{ab} - \dot{I}_{ca} = -\dot{I}_{ca};$$

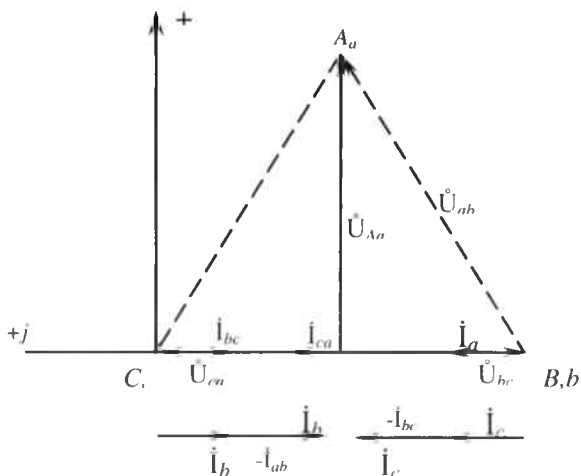
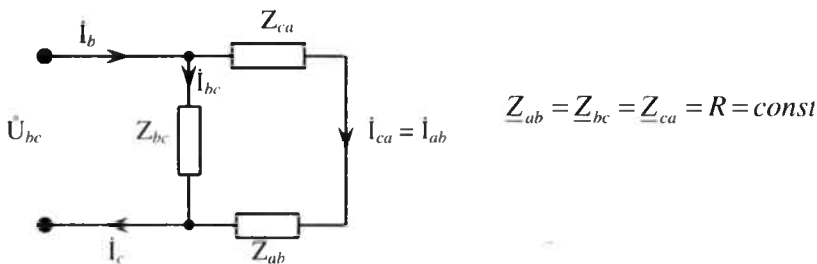
$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = -\dot{I}_{bc};$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc};$$



$$\text{Tekshiruv: } \dot{I}_a + \dot{I}_b + \dot{I}_c = -\dot{I}_{ca} + \dot{I}_{bc} + \dot{I}_{ca} - \dot{I}_{bc} = 0;$$

e) birinchi A liniya simidagi uzilish:



Ekvivalent sxemadan BC – faza kuchlanishi, liniya kuchlanishlga $\dot{U}_{bc} = \dot{U}_{Aa}$ va $\underline{Z}_{ab}$, $\underline{Z}_{bc}$, qarshiliklar ketma-ket ulangan holda bo'lib

$\dot{U}_{ab} = \frac{\dot{U}_L}{2}$; $\dot{U}_{ca} = \frac{\dot{U}_L}{2}$ ga teng bo'ladi

Bunda tok 2 marta kamayadi: $\dot{I}_{ca} = \dot{I}_{ab} = -0,5 \dot{I}_{bc}$;

O'z navbatida liniyadagi tok $\dot{I}_b$ va $\dot{I}_c$ kamayadi:

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = 1,5 \dot{I}_{bc};$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = -1,5 \dot{I}_{bc};$$

Uzilgan liniya simlari orasidagi kuchlanish potentsiali:

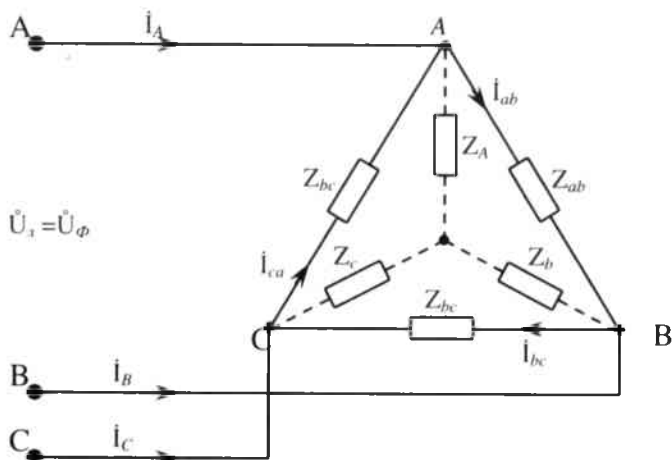
$$\dot{U}_{Aa} = \dot{U}_{AB} \cos 30^\circ = \frac{\sqrt{3}}{2} \dot{U}_L;$$

6.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 6.1. Uch fazali elektr zanjirga iste'molchi qarshiligi $\underline{z}_{ab} = \underline{z}_{bc} = \underline{z}_{ca} = \underline{z} = (12 + j10)$ uchburchak shaklda biriktirilgan holatda faza va liniyadagi tokmi aniqlang.

Yechish.

Uchburchak shaklda ulangan uch fazali elektr zanjirda:



$$\dot{U}_L = \dot{U}_{AB} = \dot{U}_\phi \quad 6600 \text{ B};$$

Fazadagi tok:

$$\dot{i}_{ab} = \frac{\dot{U}_{ab}}{\underline{z}_{ab}} = \frac{6600}{12 + j10} = (198 - j264) \text{ A};$$

$$\text{yoki } \dot{i}_{ab} = \dot{i}_\phi = \sqrt{(198)^2 + (264)^2} = 330 \text{ A};$$

$$\text{Liniyadagi tok } \dot{I}_L = \dot{I}_A = \sqrt{3} \dot{i}_{ab} = \sqrt{3} \cdot 330 = 571 \text{ A};$$

Sistema simmetrik bo'lganligi uchun uch fazali elektr zanjirning har uchala faza va liniyasidan bir xilda tok o'tadi.

Masala 6.2. Iste'molchilari yulduzcha shaklida biriktirilgan simmetrik uch fazali elektr zanjirning liniya qarshiligi $\underline{Z}_l = (1 + j1,73) \text{ Om}$ va faza qarshiligi $\underline{Z}_\phi = (4 + j5,34) \text{ Om}$ bo'lib, liniya kuchlanishi

$\dot{U}_l = 6600$ V ga ulangan. Liniya va fazadagi tok hamda kuchlanishni aniqlang.

Yechish.

Liniya va iste'molchilarning umumiy qarshiligini aniqlaymiz

$$Z_A = Z_\phi + \underline{Z}_\pi = (5 + j7,07) \text{ Om};$$

$$\text{Fazadagi kuchlanish: } \dot{U}_a = \frac{\dot{U}_\pi}{\sqrt{3}} = \frac{6600}{\sqrt{3}} = 3810 \text{ V}$$

$$\text{Fazadagi tok: } \dot{I}_a = \frac{\dot{U}_a}{\underline{Z}_a} = \frac{3810}{5 + j7,07} = (254 - j359) \text{ A};$$

$$\text{yoki } \dot{I}_a = \sqrt{(254)^2 + (359)^2} = 439 \text{ A};$$

Liniya qarshiligidagi kuchlanish:

$$\Delta \dot{U}_a = \dot{I}_a \underline{Z}_\pi = (254 - j359)(1 + j1,73) = (872 + j80) \text{ V};$$

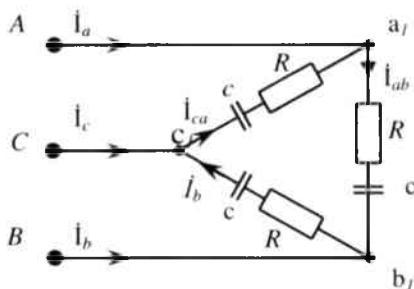
Fazadagi kuchlanish:

$$\dot{U}_A = \dot{I}_a \underline{Z}_\phi = (254 - j359)(4 + j5,34) = (2935 + j80) \text{ V};$$

Liniyadagi kuchlanish:

$$\begin{aligned} \dot{U}_{AB} &= \dot{U}_L = \dot{U}_A - \dot{U}_B = (2935 - j80)(1 - a^2) = \\ &= (2935 - j80)(1,5 + j0,867) = (4470 + j2430) \text{ V} \end{aligned}$$

Masala 6.3. Iste'molchilari uchburchak shaklida ulangan simmetrik uch fazali elektr zanjirning parametrlari $R=25 \text{ Om}$, $C=100 \text{ mkF}$ bo'lib, o'zgaruvchan tok kuchlanishi $e_A = 141 \sin(400t + 30^\circ)$ ulangan. Liniya va fazadagi tokni aniqlang.



Yechish.

A fazadagi kuchlanish kompleks ifodasi: $\dot{E}_A = 100e^{j30^\circ}$

Sig'ım qarshiligi: $\underline{x}_c = \frac{1}{\omega C} = 25 \text{ Om}$

Uchburchak shaklda ulangan uch fazali tok zanjirda: $\dot{E}_A = \dot{U}_{AB}$

bo'lib, birinchi fazadagi tok: $\dot{i}_{ab} = \frac{\dot{U}_{ab}}{\underline{z}} = \frac{100e^{j30^\circ}}{25 - j25} = 2\sqrt{2}e^{j75^\circ} \text{ A};$

Ikkinchi fazadagi tok -120° farq qilib :

$$\dot{i}_{bc} = a^2 \dot{i}_{ab} = \left(-0,5 - j\frac{\sqrt{3}}{2} \right) \cdot 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2}e^{j45^\circ} \text{ A};$$

Uchinchi fazadagi tok $+120^\circ$ farq qilib :

$$\dot{i}_{ca} = a \dot{i}_{ab} = \left(-0,5 + j\frac{\sqrt{3}}{2} \right) \cdot 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2}e^{j195^\circ} \text{ A}$$

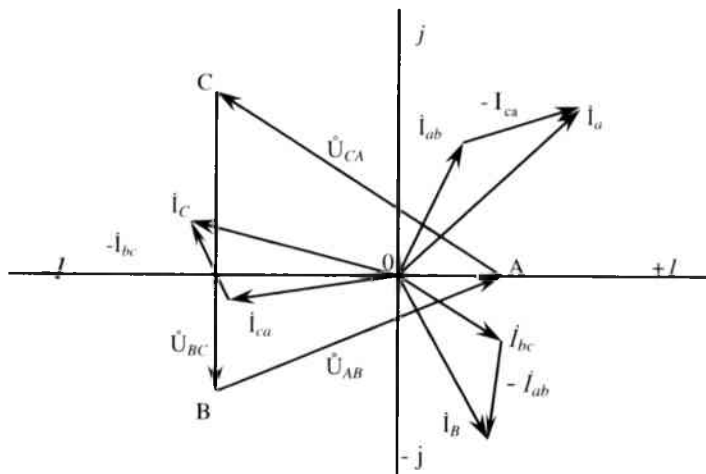
Kirxgof 1-qonuniga asosan liniyadagi tok:

$$\dot{i}_a = \dot{i}_{ab} - \dot{i}_{ca} = 2\sqrt{2}e^{j75^\circ} - 2\sqrt{2}e^{-j195^\circ} = 2\sqrt{2} \cdot \sqrt{3}e^{j45^\circ} \text{ A};$$

$$\dot{i}_b = \dot{i}_{bc} - \dot{i}_{ab} = 2\sqrt{2}e^{j45^\circ} - 2\sqrt{2}e^{j75^\circ} = 2\sqrt{2} \cdot \sqrt{3}e^{-j75^\circ} \text{ A};$$

$$\dot{i}_c = \dot{i}_{ca} - \dot{i}_{bc} = 2\sqrt{2}e^{-j195^\circ} - 2\sqrt{2}e^{-j45^\circ} = 2\sqrt{2} \cdot \sqrt{3}e^{j165^\circ} \text{ A};$$

Kompleks tekislikda vektor ifodasini tuzamiz:



Masala 6.4. Uchburchak shaklda ulangan uch fazali tok generator liniyadagi kuchlanishlari nosimmetrik: $\dot{U}_{AB} = 100 \text{ V}$, $\dot{U}_{BC} = (-50 - j100) \text{ V}$

va $\dot{U}_{CA} = (-50 + j100)$ bo'lib, qarshiligi $\underline{Z}_a = 100 \text{ Om}$, $\underline{Z}_b = -j100 \text{ Om}$, $\underline{Z}_c = j100 \text{ Om}$ ga teng va yulduzcha shaklda biriktirilgan iste'molchiga ulangan. Fazadagi kuchlanish va liniyadagi tokni aniqlang.

Yechish.

Iste'molchilar to'la o'tkazuvchanligi aniqlanadi:

$$\underline{y}_a = \frac{1}{\underline{Z}_a} = 0,01 \frac{1}{\text{Om}} \quad \underline{y}_b = \frac{1}{\underline{Z}_b} = j0,01 \frac{1}{\text{Om}} \quad \underline{y}_c = \frac{1}{\underline{Z}_c} = -j0,01 \frac{1}{\text{Om}}$$

Fazadagi kuchlanishni liniya kuchlanishlari orqali ifodalovchi tenglama:

$$\dot{U}'_A = \frac{\dot{U}_{AB} \underline{y}_b - \dot{U}_{CA} \underline{y}_c}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = (-100 + j50)V$$

$$\dot{U}'_B = \frac{\dot{U}_{BE} \underline{y}_c - \dot{U}_{AB} \underline{y}_a}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(-50 - 100j)(-j0,01) - 100(0,01)}{0,01} = (-100 + j50)V$$

$$\begin{aligned} \dot{U}'_C &= \frac{\dot{U}_{CA} \underline{y}_a - \dot{U}_{BC} \underline{y}_b}{\underline{y}_a + \underline{y}_b + \underline{y}_c} = \frac{(-50 + 100j) \cdot 0,01 - (-50 - j100) \cdot j0,01}{0,01} = \\ &= (-150 + j150)V \end{aligned}$$

Liniyadagi tok aniqlanadi. Bunda iste'molchilar yulduzcha shaklda ulanganligi uchun $I_A = I_\phi$

$$\dot{I}_A = \dot{U}'_A \cdot \underline{y}_a = (-1 + j0,5) A;$$

$$\dot{I}_B = \dot{U}'_B \cdot \underline{y}_b = (-0,5 - j2) A;$$

$$\dot{I}_C = \dot{U}'_C \cdot \underline{y}_c = (1,5 + j1,5) A;$$

Masala 6.5. Yulduzcha shaklda ulangan simmetrik uch fazali elektr zanjirda iste'molchi qarshiligi ($Z = 5 + j5$) bo'lib, fazadagi kuchlanish $U = 220V$ generatorga ulangan. Sxemaga ulangan vattmetr ko'rsatish qiymati aniqlanib, vektor ifodasi tuzilsin.

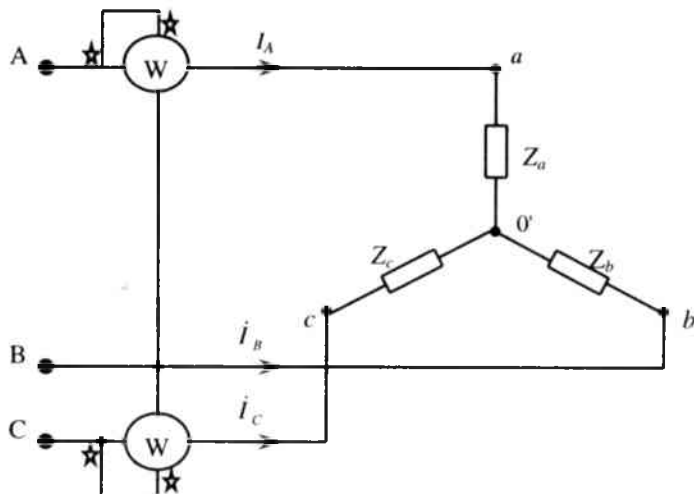
Yechish.

Birinchi fazadagi kuchlanish asosiy vektor qilib tanlanadi.

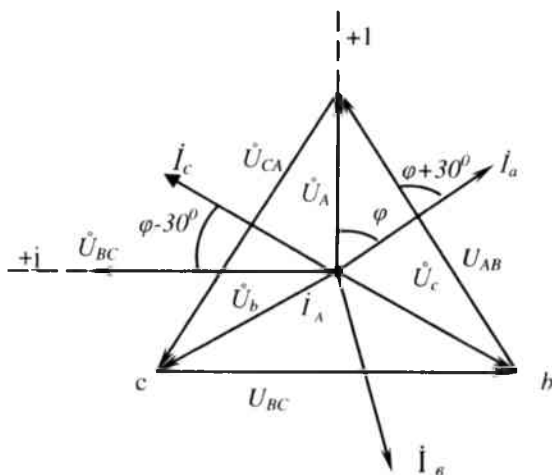
Bunda: $\dot{U}_a = \dot{U}_\phi = 220 V$,

$$\text{Fazadagi tok } \dot{I}_a = \frac{\dot{U}_a}{Z} = \frac{220}{5 + j5} = (22 - j22)A$$

yoki $I_a = \sqrt{22^2 + 22^2} = 31,1 \text{ A}$ $\text{tg}\varphi=1, \varphi=45^\circ$



Vektor ifodasi:



Bunda birinchi vattmetr quvvat tenglamasi:

$$\begin{aligned} \dot{P}_I &= \dot{U}_A \cdot \dot{I}_a \cos(\angle U_A \hat{I}_a) = \dot{P}_I = \dot{U}_B \cdot \dot{I}_c \cos(\angle U_B \hat{I}_c) = \\ &= \sqrt{3} \cdot 220 \cdot 31,1 \cos(30^\circ + \varphi) = 220 \sqrt{3} \cdot 31,1 \cos 75^\circ = 3060 \text{ Vt} = 3,06 \text{ kVt} \end{aligned}$$

Ikkinchi vattmetr tenglamasi:

$$\begin{aligned}\dot{P}_2 &= \dot{U}_J \cdot I_J \cos(U_{CB} \hat{I}_c) = 220 \cdot \sqrt{3} \cdot 31,1 \cos(30^\circ - \varphi) = \\ &= 380 \cdot 31,1 \cdot \cos 15^\circ = 11460 \text{ Vt} = 1,146 \text{ kVt}\end{aligned}$$

Demak: $R_{istem} = R_1 + R_2 = 3,06 + 11,46 = 14,52 \text{ kVt}$

Uch fazali tok quvvat tenglamasi.

$$P = \sqrt{3} \cdot I_a \cdot U_a \cos \varphi = \sqrt{3} \cdot 31,1 \cdot 380 \frac{\sqrt{2}}{2} = 14,49 \approx 14,5 \text{ kVt}$$

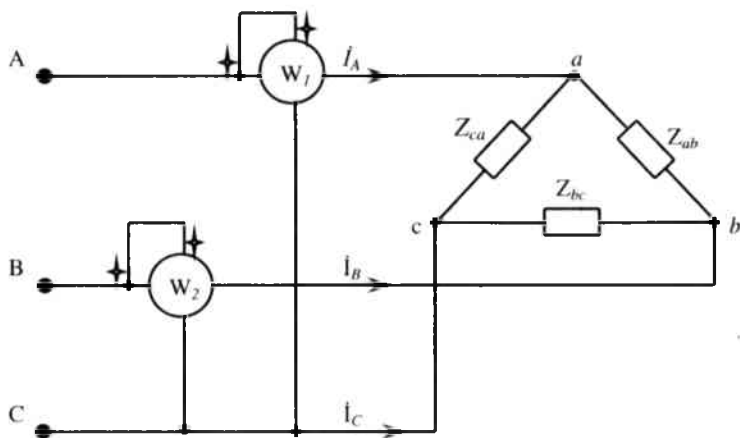
Masala 6.6. Uch fazali elektr zanjirda iste'molchi qarshiligi nosimmetrik: $Z_{ab} = 38 \text{ Om}$, $Z_{bc} = 38e^{j45} \text{ Om}$, $Z_{ca} = 38e^{-j45} \text{ Om}$ bo'lib, uchburchak shaklda ulangan. Fazadagi kuchlanish $U_\phi = 220 \text{ V}$ bo'lganda, sxemaga ulangan vattmetning ko'rsatish qiymatini aniqlang.

Yechish. Iste'molchi qarshiligi:

$$\underline{Z}_{ab} = 38(\text{Om})$$

$$\underline{Z}_{bc} = 38e^{j45} = (30 + j30) \text{ Om}$$

$$\underline{Z}_{ca} = 38e^{-j45} = (30 - j30) \text{ Om}$$



Fazadagi kuchlanishning vektor ifodasi:

$$\dot{U}_a = \dot{U}_\phi = 220 \text{ V}$$

$$\dot{U}_b = \dot{U}_\phi \cdot a^2 = 220 e^{j120} = (-110 - j190) \text{ (V)}$$

$$\dot{U}_c = \dot{U}_\phi \cdot a = 220 e^{j120} = (-110 - j190) \text{ (V)}$$

Liniyadagi kuchlanish:

$$\dot{U}_{ab} = \dot{U}_a - \dot{U}_b = 220(1 - a^2) = 220\sqrt{3} \cdot e^{j30^\circ} = 380 e^{j30^\circ} (V)$$

$$\dot{U}_{bc} = \dot{U}_b - \dot{U}_c = 220(a^2 - a) = 220\sqrt{3} \cdot e^{-j90^\circ} = 380 e^{-j90^\circ} (V)$$

$$\dot{U}_{ca} = \dot{U}_c - \dot{U}_a = 220(a - 1) = \sqrt{3} \cdot 220 e^{j150^\circ} = 380 e^{j150^\circ} (V)$$

Fazadagi tok:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{Z_{ab}} = \frac{380e^{j30^\circ}}{38} = 10e^{j30^\circ} = (8,67 + j5) A$$

$$\dot{I}_{bc} = \frac{\dot{U}_{bc}}{Z_{bc}} = 10e^{-j135^\circ} = (-7 - j7) A$$

$$\dot{I}_{ca} = \frac{\dot{U}_{ca}}{Z_{ca}} = 10e^{j195^\circ} = (9,65 - j2,6) A$$

Liniyadagi tok:

$$I_a = I_{ab} - I_{ca} = (18,3 + j7,6) = 20e^{j22^\circ 30'}$$

$$I_b = I_{bc} - I_{ab} = (-15,7 + j12) = 19,8e^{j217^\circ 30'}$$

$$I_c = I_{ca} - I_{bc} = (-2,6 + j4,5) = 5e^{j120^\circ}$$

Birinchil va ikkinchi vattmetrlarning quvvat tenglamasi:

$$P_1 = \operatorname{Re}[I_a^* U_{sa}] = \operatorname{Re}[20e^{-j22^\circ 30'} \cdot 380e^{j30^\circ}] = 7550 \cos 52^\circ 30' = 4580 (Vt)$$

$$P_2 = \operatorname{Re}[I_b^* U_{bs}] = 7550 \cos 52^\circ 30' = 4570 (Vt)$$

Uch fazali tok to'la quvvati

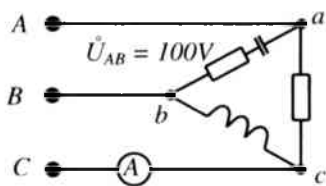
$$P = P_1 + P_2 = 4,58 + 4,58 = 9,16 (kVt)$$

Tekshiruv: Har bir iste'molchida sarf bo'lgan quvvat yig'indisi:

$$P = R_{ab} I_{ab}^2 + R_{bc} I_{bc}^2 + R_{ca} I_{ca}^2 = 38 \cdot 10^2 + 30 \cdot 10^2 + 30 \cdot 10^2 \approx 9,2 (kVt)$$

Masala 6.7.

Uchburchak shaklida biriktirilgan uch Z_{CA} fazali elektr zanjir iste'molchi qarshiliklari $Z_{ab} = (3 - j4) \Omega$, $Z_{bc} = j10 \Omega$, $Z_{ca} = 10 \Omega$ ga teng bo'lib, liniyadagi kuchlanish $U_l = 100V$ bo'lgan generatorga ulangan. Sxemaga ulangan ampermetr qiymati va sarf bo'ladigan quvvat aniqlansin.



Yechish.

Liniyadagi kuchlanishni aniqlaymiz:

$$\dot{U}_{ab} = 100 \text{ (V)}$$

$$\dot{U}_{bc} = 100 \cdot a^2 = (-50 - j \cdot 87) \text{ (V)}$$

$$\dot{U}_{ca} = 100 \cdot a = (-50 + j \cdot 87) \text{ (V)}$$

Fazadagi tok:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{Z_{ab}} = \frac{100}{3 - j4} = \frac{100 \cdot (3 + j4)}{9 + 16} = (2 + j16) \text{ A}$$

$$\dot{I}_{bc} = \frac{\dot{U}_{bc}}{Z_{bc}} = \frac{(-50 - j80) \cdot (-j10)}{100} = (-8,7 + j5) \text{ A}$$

$$\dot{I}_{ca} = \frac{\dot{U}_{ca}}{Z_{ca}} = \frac{-50 + j87}{10} = (-5 + j8,7) \text{ A}$$

Liniyadagi tok:

$$\dot{I}_a = \dot{I}_{ab} - \dot{I}_{bc} = 12 + j16 + 5 - j8,7 = (17 + j7,3) \text{ A}$$

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = -8,7 + j5 - 12 - j16 = (-20,7 - j11) \text{ A}$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = -5 + j8,7 - j5 + 8,7 = (3,7 + j3,7) \text{ A}$$

Tokning algebraik yig'indisi $\Sigma I = 0$

Ampermetr ko'rsatish qiymati: $I_c = \sqrt{(3,7)^2 + (3,7)^2} = 5,2 \text{ A}$

To'la quvvati:

$$\tilde{S}_{ab} = \dot{U}_{ab} \cdot \dot{I}_{ab} = 100(12 - j16) = (1200 - j1600) \text{ (VA)}$$

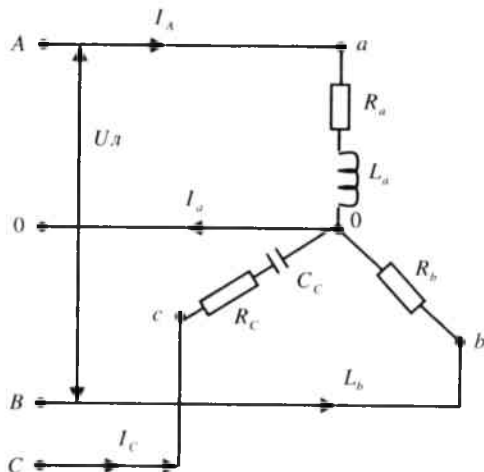
$$\tilde{S}_{bc} = \dot{U}_{bc} \cdot \dot{I}_{bc} = (-50 - j87)(-8,7 - j5) = j1000 \text{ (VA)}$$

$$\tilde{S}_{ca} = \dot{U}_{ca} \cdot \dot{I}_{ca} = (-50 - j87)(-5 - j8,7) = 1000 \text{ (VA)}$$

O'rtacha aktiv quvvat:

$$P = 1200 + 1000 = 2200 \text{ W}$$

Masala 6.8. To'rt simli yulduzcha shaklda ulangan uch fazali elektr zanjirning parametri: $R_a=80\text{sm}$, $L_a=0,18\text{gn}$, $R_b=70\text{sm}$, $R_c=40\text{sm}$, $C_c=30\text{mkF}$ bo'lib, chastotasi $f=50\text{Gs}$, liniyadagi kuchlanishi $U_l=380\text{V}$ bo'lgan generatorga ulangan. Tok va iste'molchidagi to'la quvvat aniqlansin.



Yechish.

Fazadagi kuchlanish: $U_F = \frac{380}{\sqrt{3}} = 220\text{V}$

Fazadagi to'la qarshilik:

$$Z_a = \sqrt{R_a^2 + x_{L_a}^2} = \sqrt{80^2 + (314 \cdot 0,18)^2} = 100 \text{ Om} \quad Z_b = R_b = 70 \text{ Om}$$

$$Z_c = \sqrt{R_c^2 + x_{C_c}^2} = \sqrt{(40)^2 + \left(\frac{1 \cdot 10^6}{314 \cdot 30}\right)^2} = 110 \text{ Om}$$

Fazadagi tok:

$$I_a = I_b = \frac{U_a}{Z_a} = \frac{220}{100} = 2,2\text{A} \quad I_b = \frac{U_b}{Z_b} = \frac{220}{70} = 3,15\text{A} \quad I_c = \frac{U_c}{Z_c} = \frac{220}{110} = 2\text{A}$$

Aktiv quvvat:

$$P_a = I_a^2 \cdot R_a = (2,2)^2 \cdot 80 = 400 \text{ Vt}$$

$$P_b = I_b^2 \cdot R_b = (3,15)^2 \cdot 70 = 700 \text{ Vt}$$

$$P_c = I_c^2 \cdot R_c = (2)^2 \cdot 40 = 160 \text{ Vt}$$

Reaktiv quvvat: $R=R_a+R_v+R_s=400+700+160=1260 \text{ Vt}$

$$Q_a = I_a^2 \cdot x_{lc} = (2,2)^2 \cdot 56,6 = 285 \text{ VAR} \quad Q_b = 0$$

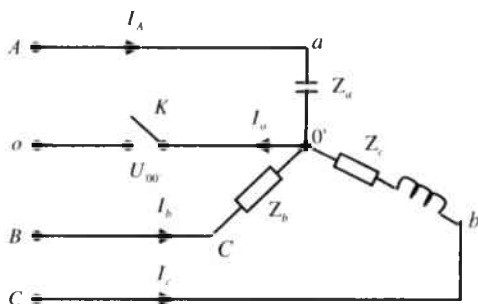
$$Q_c = -I_c^2 \cdot x_c = -(2^2 \cdot 106) = 425 \text{ VAR}$$

$$Q = Q_a + Q_c = 285 - 425 = -140 \text{ VAR}$$

Sarf bo'ladigan to'la quvvat:

$$S = \sqrt{P^2 + Q^2} = \sqrt{(1260)^2 + (140)^2} = 1280 \text{ VA} = 1,28 \text{ kVA}$$

Masala 6.9. Yulduzcha shaklida biriktirilgan neytral simli uch fazali elektr zanjirning parametri: $Z_1 = -j8 \text{ Om}$; $Z_2 = 10 \text{ Om}$; $Z_3 = (3 + j4 \text{ Om})$. Liniyadagi kuchlanish simmetrik bo'lib: $U_{ab} = U_{bc} = U_{ca} = 173 \text{ (V)}$. Neytral sim toki I_0 , neytral sim uzilgandagi potensial kuchlanish U_{00} va iste'molchi quvvatini aniqlang.



Yechish.

1) kalit K ulangan holda neytral sim yulduzcha shaklda ulangan bo'lib, fazadagi kuchlanishning kompleks ifodasi:

$$\dot{U}_\phi = \frac{\dot{U}_L}{\sqrt{3}} = 100 \text{ V}; \quad \dot{U}_A = \dot{U}_\phi = 100 \text{ (V)}$$

$$\dot{U}_B = \dot{U}_A \cdot a = (50 - j87) \text{ (V)}; \quad \dot{U}_C = \dot{U}_A \cdot a^2 = (-50 - j87) \text{ (V)}$$

Fazadagi tok:

$$\dot{I}_a = \frac{\dot{U}_a}{Z_a} = \frac{100}{-j8} = j12,5 \text{ A}$$

$$\dot{I}_b = \frac{\dot{U}_b}{Z_b} = \frac{-50 - j87}{10} = (-5 - j8,7) \text{ A}$$

$$\dot{I}_c = \frac{\dot{U}_c}{Z_c} = \frac{-50 + j87}{3 + j4} = (7,9 + j18,4) \text{ A}$$

Neytral simdagi tok: $\dot{I}_o = \dot{I}_a + \dot{I}_b + \dot{I}_c = (2,9 + j22,2) \text{ A}$

Effektiv yoki haqiqiy qiymat: $I_o = \sqrt{(2,9)^2 + (22,2)^2} = 22,4 \text{ A}$

Potensiallar orasidagi kuchlanish: $U_{oo}' = 0$.

To'la quvvat:

$$\tilde{S}_a = \dot{U}_a \cdot \dot{I}_a = 100 \cdot (-j12,5) = -j1250 \text{ (VA)}$$

$$\tilde{S}_b = \dot{U}_b \cdot \dot{I}_b = (-50 - j87) \cdot (-5 + j8,7) = 100 \text{ (VT)}$$

$$\tilde{S}_c = \dot{U}_c \cdot \dot{I}_c = (-50 + j87) \cdot (7,9 - j18,4) = (1220 + j1600) \text{ (VA)}$$

O'rta quvvat: $P = 1000 + 1200 = 2200 \text{ (W)} = 2,2 \text{ kW}$

2) kalit K uzilgan holda, neytral simsiz yulduzcha shaklidagi sxema.

Yechish.

Iste'molchi o'tkazuvchanligi:

$$\underline{y}_a = \frac{1}{Z_a} = \frac{1}{-j8} = j0,125 \quad \text{Om}$$

$$\underline{y}_b = \frac{1}{Z_b} = \frac{1}{10} = 0,1 \quad \text{Om}$$

$$\underline{y}_c = \frac{1}{Z_c} = \frac{3 - j4}{9 + j16} = (0,12 - j0,16) \quad \text{Om}$$

Generator bilan iste'molchi o'rtasidagi potensial kuchlanish:

$$U_{00}' = \frac{U_a \underline{y}_a + U_b \underline{y}_b + U_c \underline{y}_c}{\underline{y}_1 + \underline{y}_2 + \underline{y}_3} = (-2,8 + j100) \text{ V}$$

Fazadagi kuchlanish:

$$\dot{U}_a = \dot{U}_A - \dot{U}_{00}' = 100 - (-2,8 + j100) = (102,8 - j100) \text{ V}$$

$$\dot{U}_b = \dot{U}_B - \dot{U}_{00}' = -50 - j87 - (-2,8 + j100) = (-47,8 - j187) \text{ V}$$

$$\dot{U}_c = \dot{U}_C - \dot{U}_{00}' = -50 + j87 - (-2,8 + j100) = (-47,8 - j13) \text{ V}$$

Fazadagi tok. ($\dot{I}_\phi = \dot{I}_A$)

$$\dot{I}_a = \dot{U}_a \underline{y}_a = (102,8 - j100) \cdot j0,125 = (12,5 + j12,8) \text{ A}$$

$$\dot{I}_b = \dot{U}_b \underline{y}_b = (-47,8 - j187) \cdot 0,1 = (-4,78 - j18,7) \text{ A}$$

$$\dot{I}_c = \dot{U}_c \underline{y}_c = (-47,8 - j13) \cdot (0,12 - j0,16) = (-7,82 + j6,1) \text{ A}$$

Tokning algebraik yig'indisi $\sum \dot{I}_q = 0$;

Liniyadagi tok: $I_{\text{Л}} = \sqrt{(12,5)^2 + (12,8)^2} = 17,8 \text{ A}$.

Neytral nuqtadagi potentsiallarning effektiv qiymati:

$$\dot{U}_{oo'} = \sqrt{(-2,8)^2 + 100^2} = 100 \text{ V}$$

To'la quvvat:

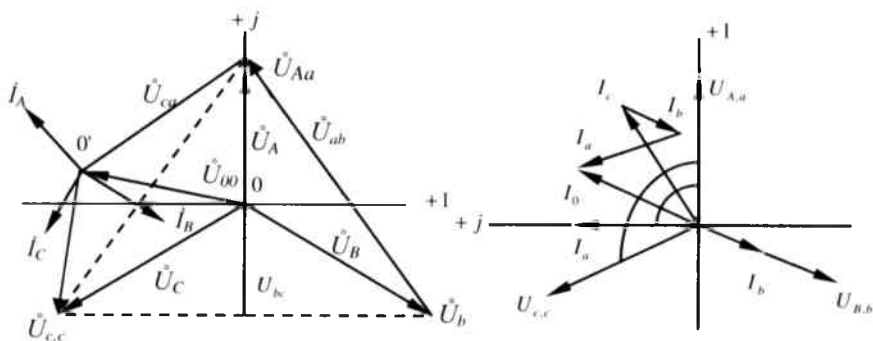
$$\tilde{S}_a = \dot{U}_a \dot{I}_a = (102,8 - j100)(12,5 - j12,84) = -j2560 \text{ VA}$$

$$\tilde{S}_b = \dot{U}_b \dot{I}_b = (-47,8 - j187)(4,78 - j18,7) = 3720 \text{ VA}$$

$$\tilde{S}_c = \dot{U}_c \dot{I}_c = (-47,8 - j13)(-7,8 - j6) = (293 + j393,5) \text{ VA}$$

Iste'molchilardagi sarf bo'ladigan aktiv quvvatning o'rtacha qiymati: $P = 3720 + 293 = 4013(\text{Vt})$

Vektor ifodasi:



Masala 6.10. Uch fazali elektr generatorning simmetrik tashkil etuvchilari $\dot{E}_1 = 100 \text{ V}$; $\dot{E}_2 = 25 \cdot e^{j120}$; $\dot{E}_0 = 100 \cdot e^{-j\frac{\pi}{3}}$ ga teng bo'lganda, nosimmetrik EYKning analitik va vektor ifodasi aniqlansin.

Yechish.

$$\dot{E}_1 = 100(\text{V}), \quad \dot{E}_2 = 25e^{j\frac{\pi}{3}} = (12,5 + j21,7)(\text{V}),$$

$$\dot{E}_0 = 100e^{-j\frac{\pi}{3}} = (50 - j86)(\text{V})$$

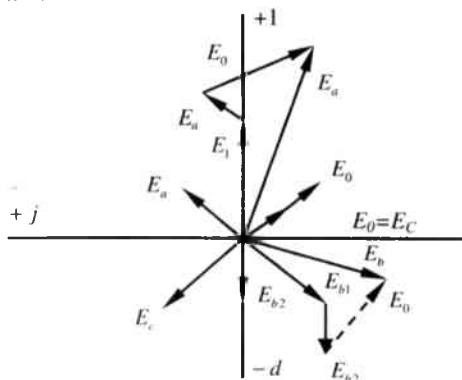
Nosimmetrik uch fazali tok sistemalarining simmetrik tashkil etuvchilarga ajratish tenglamasiga asosan:

$$\dot{E}_a = \dot{E}_0 + \dot{E}_1 + \dot{E}_2 = (50 - j86) + 100 + (12,5 + j21,7) = (162,5 - j65) \text{ V}$$

$$\dot{E}_b = \dot{E}_0 + a^2 \dot{E}_1 + a \dot{E}_2 = (50 - j86,7) - 50 + (-j86,7 + 25) = (-25 - j173,4) \text{ V}$$

$$\dot{E}_c = \dot{E}_0 + a \dot{E}_1 + a^2 \dot{E}_2 = (50 - j86,7) + (-50 + j86,7) + 25 = (12,5 + j21,7) \text{ V}$$

Vektor ifodasi:



Masala 6.11. Iste'molchi aktiv qarshiliklar nosimmetrik $R_a = 1 \text{ Om}$; $R_b = 2 \text{ Om}$; $R_c = 3 \text{ Om}$ bo'lgan neytral simsiz uch fazali elektr zanjir faza kuchlanishi $U_\phi = 220 \text{ V}$ bo'lgan simmetrik uch fazali manbaga ulangan. Fazadagi tok va kuchlanishni aniqlang.

Yechish.

Kuchlanish $\dot{U}_2 = 0$ teng. Fazadagi tok:

$$\dot{I}_a = \dot{I}_1 + \dot{I}_2 = \frac{(1-a)Z_b + (1-a^2)Z_c}{Z_a Z_b + Z_b Z_c + Z_c Z_a} \cdot \dot{U}_1 = (150 + j17,3) = 151 e^{j6^\circ} \text{ A}$$

$$\dot{I}_b = a^2 \dot{I}_1 + a \dot{I}_2 = \frac{(a^2 - a)Z_a + (a^2 - 1)Z_c}{Z_a Z_b + Z_b Z_c + Z_c Z_a} \cdot \dot{U}_1 = (-90 + j86,6) = 125 e^{j224^\circ} \text{ A}$$

$$\dot{I}_c = a \dot{I}_1 + a^2 \dot{I}_2 = \frac{(a - a^2)Z_a + (a - 1)Z_b}{Z_a Z_b + Z_b Z_c + Z_c Z_a} \cdot \dot{U}_1 = (-60 + j69) = 91,7 e^{j130^\circ 50'} \text{ A}$$

Fazadagi kuchlanish:

$$\dot{U}_a = \underline{Z}_a \dot{I}_a = 1 \cdot 151 = 151 \text{ V};$$

$$\dot{U}_b = \underline{Z}_b \dot{I}_b = 2 \cdot 151 = 250 \text{ V};$$

$$\dot{U}_c = \underline{Z}_c \dot{I}_c = 3 \cdot 91,7 = 275 \text{ V};$$

Masala 6.12. Fazadagi kuchlanish $\dot{U}_a = 220 \text{ V}$; $\dot{U}_b = (-110 - j150) \text{ V}$;

$\dot{U}_c = (-110 + j150)$ bo'lgan neytral simsiz uch fazali elektr zanjirning kompleks qarshiligi $Z_a = (2 + j3) (\Omega)$; $Z_b = (3 + j2) (\Omega)$ va $Z_c = (3 - j2) (\Omega)$ ga teng. Manbadagi kuchlanish to'g'ri, teskari va nol tashkil etuvchilari hamda faza toklari va kuchlanishlari aniqlansin.

Yechish.

Nosimmetrik kuchlanish sistemalarni simmetrik tashkil etuvchilarga ajratish tenglamasiga asosan:

$$\dot{U}_0 = \frac{1}{3}(\dot{U}_a + \dot{U}_b + \dot{U}_c) = \frac{1}{3}[220 + (-110 - j150) + (-110 + j150)] = 0;$$

$$\dot{U}_1 = \frac{1}{3}(\dot{U}_a + a\dot{U}_b + a^2\dot{U}_c) = \frac{1}{3}\left[220 + \left(-0.5 + j\frac{\sqrt{3}}{2}\right)(-110 - j150) + \left(-0.5 - j\frac{\sqrt{3}}{2}\right)(-110 + j150)\right] = 197 \text{ V};$$

$$\dot{U}_2 = \frac{1}{3}(\dot{U}_a + a^2\dot{U}_b + a\dot{U}_c) = \frac{1}{3}\left[220 + \left(-0.5 - j\frac{\sqrt{3}}{2}\right)(-110 - j150) + \left(-0.5 + j\frac{\sqrt{3}}{2}\right)(-110 + j150)\right] = 23 \text{ V}.$$

(5.31) tenglamaga asosan toklar tenglamasi:

$$\dot{I}_1 = \frac{(Z_a + Z_b + Z_c)\dot{U}_1 - (Z_a + a^2Z_b + aZ_c)\dot{U}_2}{Z_aZ_b + Z_bZ_c + Z_cZ_a} = (50 - j15) \text{ A}$$

$$\dot{I}_2 = \frac{(Z_a + aZ_b + a^2Z_c)\dot{U}_1 - (Z_a + Z_b + Z_c)\dot{U}_2}{Z_aZ_b + Z_bZ_c + Z_cZ_a} = (38 + j6,4) \text{ A}$$

(5.24) tenglamaga asosan fazadagi tok:

$$\dot{I}_a = \dot{I}_1 + \dot{I}_2 = 87,8 - j8,6 = 88,2e^{-j5^\circ} \text{ A}$$

$$\dot{I}_b = a^2\dot{I}_1 + a\dot{I}_2 = -62,4 - j6,1 = 62,6e^{j185^\circ} \text{ A}$$

$$\dot{I}_c = a\dot{I}_1 + a^2\dot{I}_2 = -(\dot{I}_a + \dot{I}_b) = -25,4 + j14,7 = 29,4e^{j150^\circ} \text{ A}$$

Iste'molchilardagi kuchlanish:

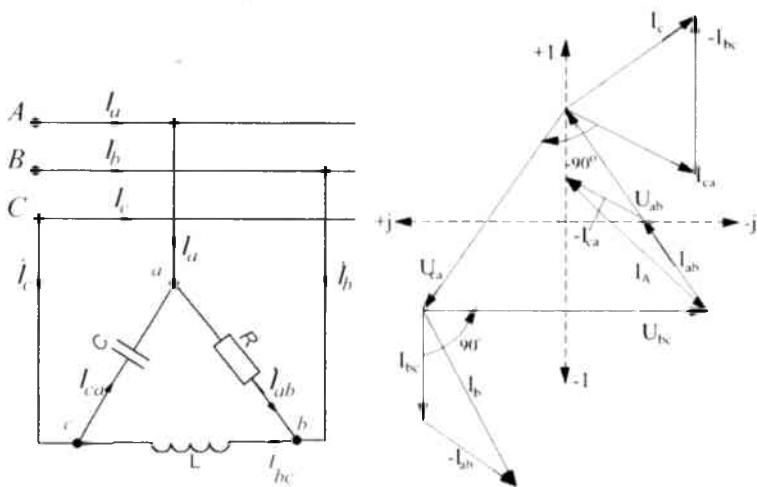
$$\dot{U}_a = \underline{Z}_a \dot{I}_a = 3,6 \cdot 88,4 = 318 \text{ V}; \quad \dot{U}_b = \underline{Z}_b \dot{I}_b = 3,6 \cdot 62,6 = 225 \text{ V};$$

$$\dot{U}_c = \underline{Z}_c \dot{I}_c = 3,6 \cdot 29,4 = 106 \text{ V};$$

Masala 6.13. Uchburchak shaklda ulangan uch fazali elektr zanjir-dagi kuchlanish $\dot{U}_n = 380V$ bo'lib faza qarshiligi $R = \dot{X}_L = \dot{X}_C = 10 \text{ Om}$ ga teng. Liniya va fazadagi tokni hisoblab, tok va kuchlanish topografik diagrammasi tuzilsin.

Yechish. Fazadagi qarshilik modullari bir xil bo'lib, argumenti bilan farqli.

$$\dot{Z}_{ab} = R = 10 \text{ Om}, \quad \dot{Z}_{bc} = jX_L = j10 = 10e^{j90^\circ} \text{ Om}, \quad \dot{Z}_{ca} = -jX_C = -j10 = 10e^{-j90^\circ} \text{ Om}$$



Liniya kuchlanish kompleks ifodasi:

$$\dot{U}_{ab} = 380e^{j30^\circ} V; \quad \dot{U}_{bc} = 380e^{-j90^\circ} V; \quad \dot{U}_{ca} = 380e^{j150^\circ} V$$

Fazadagi tok:

$$\dot{I}_{ab} = \frac{380e^{j30^\circ}}{10} = 38e^{j30^\circ} A; \quad \dot{I}_{bc} = \frac{380e^{-j90^\circ}}{10e^{j90^\circ}} = 38e^{-j180^\circ} A; \quad \dot{I}_{ca} = \frac{-380e^{j150^\circ}}{10e^{-j90^\circ}} = 38e^{j240^\circ} A.$$

Liniyadagi toki:

$$\dot{I}_a = \dot{I}_{ab} - \dot{I}_{ca} = 38e^{j30^\circ} - 38e^{j240^\circ} = 38 \left[\frac{\sqrt{3}}{2} + j\frac{1}{2} - \left(-\frac{1}{2}\right) - j\left(-\frac{\sqrt{3}}{2}\right) \right] = 51,9 + j51,9 = 73,4e^{j45^\circ}$$

$$\dot{I}_b = \dot{I}_{bc} - \dot{I}_{ab} = 38e^{-j180^\circ} - 38e^{j30^\circ} = 38 \left[-1 - j0 - \frac{\sqrt{3}}{2} - j\frac{1}{2} \right] = 70,9 - j19 = 73,4e^{j195^\circ} A$$

$$\dot{I}_c = \dot{I}_{ca} - \dot{I}_{bc} = 38e^{j240^\circ} - 38e^{-j180^\circ} = 38 \left[-\frac{1}{2} - j\frac{\sqrt{3}}{2} - (-1 - j0) \right] = 19 - j32,9 = 38e^{j300^\circ}$$

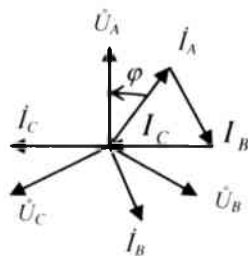
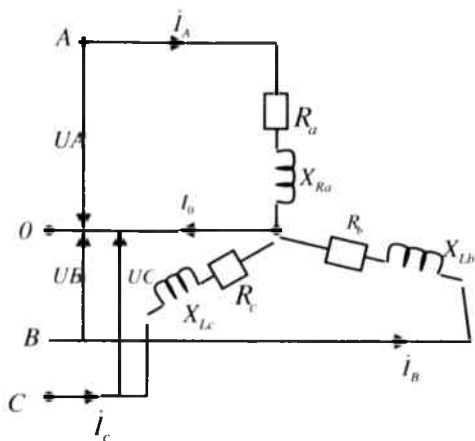
Tok va kuchlanish qiymatlari bo'yicha topografik kompleks vektor ifodasini tuzish uchun masshtab tanlanadi: $m_u = \left[\frac{B}{sm} \right]$; $m_i = \left[\frac{A}{sm} \right]$. Fazadagi tok vektorini $\vec{I}_{ab}, \vec{I}_{bc}, \vec{I}_{ca}$ liniyadagi kuchlanish vektorlariga $\vec{U}_{ab}, \vec{U}_{bc}, \vec{U}_{ca}$ nisbatan, $\varphi_{ab} = 0$; $\varphi_{bc} = 90^\circ$; $\varphi_{ca} = -90^\circ$ burchak asosida yo'naltiramiz. Endi fazadagi tok vektorini parallel ko'chirish bilan liniyadagi tok vektori $\vec{I}_a, \vec{I}_b, \vec{I}_c$ hosil qilinadi.

Masala 6.14. Yulduzcha shaklda ulangan uch fazali elektr zanjirga uchta bir xil induktiv g'altak ulangan bo'lib, aktiv qarshiligi $R = 16 \text{ Om}$, induktiv qarshilik $X_L = 12 \text{ Om}$. Bitta fazadagi aktiv quvvat: $P = 1,2 \text{ kv}$ bo'lganda, faza va liniyadagi kuchlanish U_ϕ, U_l , tok hamda to'la va reaktiv quvvatini aniqlang.

Yechish.

To'la qarshilik:

$$Z_\phi = \sqrt{R^2 + X_L^2} = \sqrt{16^2 + 12^2} = 20 \text{ Om}.$$



Quvvat koeffitsienti: $\cos \varphi = \frac{R}{Z} = \frac{16}{20} = 0,8$

Fazadagi kuchlanish quvvat ifodasida:

$$P_\phi = U_\phi I_\phi \cos \varphi = U_\phi \frac{U_\phi}{I_\phi} \cos \varphi = \frac{U_\phi^2}{I_\phi} \cos \varphi$$

Bundan: $U_\phi = \sqrt{\frac{R_\phi}{\cos \varphi}} = 175 \text{ V}.$

Liniyadagi kuchlanish: $U_l = \sqrt{3} \cdot 175 = 305 \text{ V}$

$$\text{Fazadagi tok: } I_\phi = \frac{U_\phi}{Z_\phi} = \frac{175}{20} = 8,8 \text{ A}$$

$$\text{Reaktiv quvvat: } Q_\phi = U_\phi I_a \sin \varphi = 175 \cdot 8,8 \cdot 0,6 = 924 \text{ VAR}$$

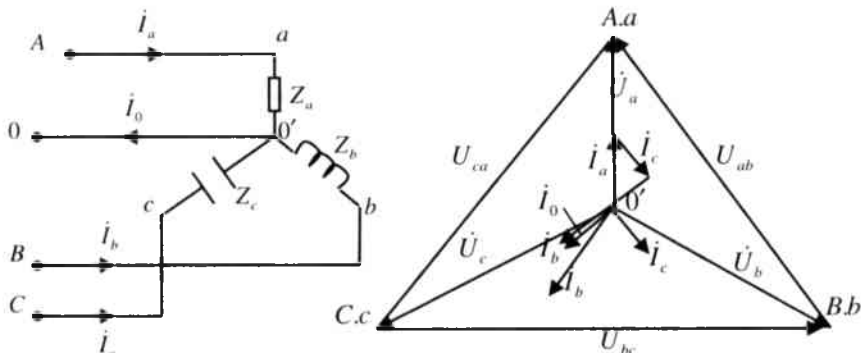
$$\text{To'la quvvat: } S = U_\phi R_\phi = 175 \cdot 8,8 = 1540 \text{ VA.}$$

Masala 6.15. Nosimmetrik neytral simli yulduzcha sxemada ulangan uch fazali elektr zanjir faza qarshiligi yoki o'tkazuvchanligi:

$$Z_a = R; \quad Z_b = jx_l = j\frac{R}{2}; \quad Z_c = -jx_c = -j3R;$$

$$y_a = \frac{1}{R} = g; \quad y_b = \frac{1}{j\frac{R}{2}} = -j2g; \quad y_c = \frac{1}{j3R} = j0,033g$$

bo'lib, neytral sim qarshiligi $Z_0=0$ yoki $y = \infty$ bo'lganda fazadagi tok $\dot{I}_a, \dot{I}_b, \dot{I}_c$ va neytral sim toki I_0 topilsin.



Yechish. Neytral sim potentsiali ustma-ust tushganligi uchun $U_{00'} = 0$ ga teng bo'lib, fazadagi tok:

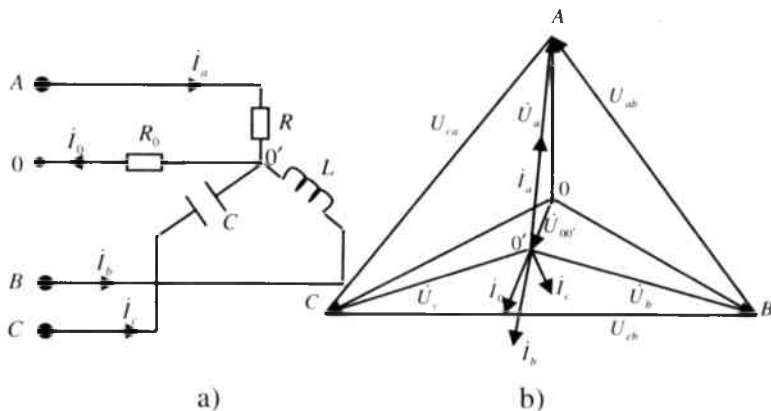
$$\begin{cases} \dot{I}_a = \frac{\dot{U}_a}{Z_a} = \frac{\dot{U}_a}{R}; \\ \dot{I}_b = \frac{\dot{U}_b}{Z_b} = \frac{\left(-0,5 - j\sqrt{\frac{3}{2}}\right)\dot{U}_a}{j\frac{R}{2}} = (-1,73 + j)\frac{\dot{U}_a}{R} = 2\frac{\dot{U}_a}{R} = 2\frac{\dot{U}_a}{R}e^{j150}; \\ \dot{I}_c = \frac{\dot{U}_c}{Z_c} = \frac{\left(-0,5 + j\sqrt{\frac{3}{2}}\right)\dot{U}_a}{-j3R} = (-0,288 - j0,17)\frac{\dot{U}_a}{R} = 0,334\frac{\dot{U}_a}{R}e^{-j1490} \end{cases}$$

Neytral simdagi tok:

$$\begin{aligned}\dot{I}_0 &= \dot{I}_a + \dot{I}_b + \dot{I}_c = (1 - 1,73 + j - 0,288 - j0,17) \frac{\dot{U}_a}{R} = \\ &= (-1,018 + j0,83) \frac{\dot{U}_a}{R} = 1,31 \frac{\dot{U}_a}{R} e^{j140^\circ}\end{aligned}$$

Masala 6.16. (6.15) masala shartiga asosan neytral sim qarshiligi $Z_0 = 0,1R$ yoki o'tkazuvchanligi $y = 10g$ bo'lgan fazadagi tok va neytral simdagi tok aniqlansin.

Yechish. Ushbu masala yechimi ham 6.15-masalaga o'xshash bo'lib, tugun potentsiallar ushiga asosan neytral simni bog'lovchi potentsiallar farqi $(6.5)U_{00'}$ ni tenglamaga asosan topamiz.



Neytral sim qarshiligi hisobiga tugun potentsiallari orasidagi kuchlanish:

$$\begin{aligned}\dot{U}_{00'} &= \frac{\dot{U}_A y_a + \dot{U}_B y_b + \dot{U}_C y_c}{y_a + y_b + y_c + y_0} = \frac{\dot{U}_A g + \left(-0,5 - j\frac{\sqrt{3}}{R}\right) \dot{U}_A (-j2g) + \left(-0,5 + j\frac{\sqrt{3}}{R}\right) \dot{U}_A 0,333g}{g - j2g + j0,333g + 10g} = \\ &= (-0,102 + j0,06) \dot{U}_A = 0,118 \dot{U}_A e^{j149,33^\circ}\end{aligned}$$

Fazadagi kuchlanish:

$$\begin{aligned}\dot{U}_a &= \dot{U}_A - \dot{U}_{00'} = \dot{U}_A - (-0,102 + j0,06) \dot{U}_A = (1,102 - j0,06) \dot{U}_A = 1,104 \dot{U}_A e^{-j3,07^\circ} \\ \dot{U}_b &= \dot{U}_B - \dot{U}_{00'} = \left(-0,5 - j\frac{\sqrt{3}}{R}\right) \dot{U}_A - (-0,102 + j0,06) \dot{U}_A = (-0,398 - j0,927) \dot{U}_A = 1,01 \dot{U}_A e^{-j113,91^\circ}\end{aligned}$$

$$\begin{aligned}\dot{U}_c &= \dot{U}_c - \dot{U}_{00'} = \left(-0,5 + j \frac{\sqrt{3}}{R} \right) \dot{U}_A - (-0,102 + j0,06) \dot{U}_A = \\ &= (-0,398 + j0,807) \dot{U}_A = 0,9 \dot{U}_A e^{j116^0_{15'}}\end{aligned}$$

Fazadagi tok:

$$\dot{I}_a = \frac{\dot{U}_a}{Z_a} = \frac{\dot{U}_a}{R} = 1,104 \frac{\dot{U}_A}{R} e^{-j3^0_{07'}} = (1,102 - j0,06) \frac{\dot{U}_A}{R}$$

$$\dot{I}_b = \frac{\dot{U}_b}{Z_b} = \frac{1,01 \dot{U}_A e^{-j113^0_{14'}}}{\frac{R}{2}} = 2,02 \frac{\dot{U}_A}{R} e^{-203^0_{14'}} = (-1,853 + j0,794) \frac{\dot{U}_A}{R}$$

$$\dot{I}_c = \frac{\dot{U}_c}{Z_c} = \frac{0,9 \dot{U}_A e^{j116^0_{15'}}}{-j3R} = 0,3 \frac{\dot{U}_A}{R} e^{j206^0_{15'}} = (-0,269 - j0,134) \frac{\dot{U}_A}{R}$$

Neytral simdagi tok:

$$\dot{I}_0 = \frac{\dot{U}_{00'}}{Z_0} = \frac{0,118 \dot{U}_A e^{j149^0_{33'}}}{0,1R} = 1,18 \frac{\dot{U}_A}{R} e^{j149^0_{33'}} = (-1,02 + j0,6) \frac{\dot{U}_A}{R}$$

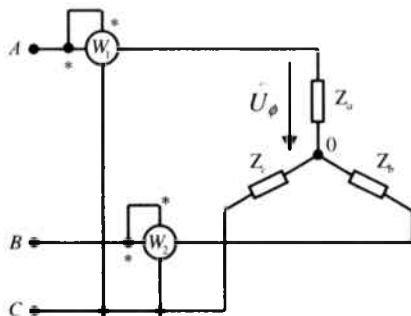
Tekshirish:

$$\begin{aligned}\dot{I}_0 + \dot{I}_b + \dot{I}_c &= \dot{I}_0 = (1,102 - j0,06 - 1,853 + j0,794 - 0,269 - j0,134) = \\ &= (1,02 - j0,6) \frac{\dot{U}_A}{R} = 0\end{aligned}$$

Neytral sim qarshiligini hisobga olganda tugun potentsiallari orasidagi siljish hisobiga $\dot{U}_{00'}$ kuchlanish hosil bo'ladi.

6.3. Mustaqil yechish uchun masalalar

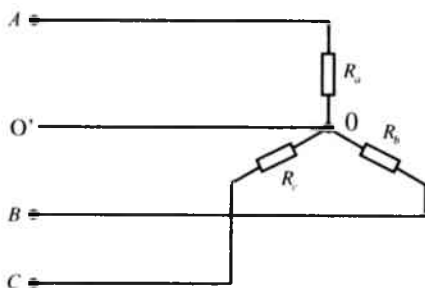
Masala 6.1. Yulduzcha shaklida ulangan uch fazali elektr zanjirning fazadagi kuchlanishi $U_\phi = 127$ V bo'lib, kompleks qarshiligi $Z_a = Z_\phi = 10 + j10$ bo'lgan simmetrik iste'molchiga ulangan. Sxemada ko'rsatilgan ulanish bo'yicha vattmetr qiymati va uch fazali tok quvvati aniqlanib, vektor ifodasi tuzilsin.



Javob: $P_1 = 805,8$ Vt; $P_2 = 805,8$ Vt; $P = 2417,4$ Vt.

Masala 6.2. To'rt simli yulduzcha shaklda ulangan uch fazali elektr zanjirning liniyadagi kuchlanishi $U_L=380$ V, iste'molchi aktiv qarshiligi $R=100$ Om. Fazadagi tok va sarf bo'ladigan quvvat aniqlansin.

Javob: $I=2,2$ A; $P=1452$ Vt.



Masala 6.3. To'rt simli yulduzcha shakldagi fazaga $P_a=40$ Vt, $P_B=100$ Vt, $P_C=60$ Vt quvvatga ega bo'lgan lampochka ulangan. Liniya kuchlanishi $U_L=220$ V bo'lganda fazadagi toklar aniqlamb, vektor ifodasi tuzilsin.

Javob: $I_a=0,3$ A; $I_b=0,75$ A; $I_c=0,45$ A; $\bar{I}_0 = \bar{I}_a + \bar{I}_b + \bar{I}_c \approx 0,38$ A.

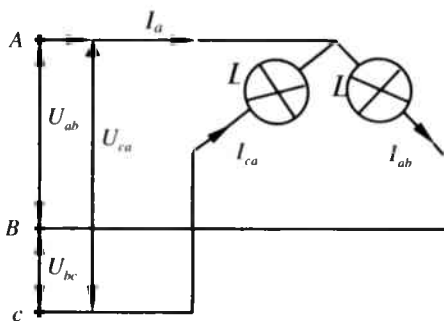
Masala 6.4. Liniyadagi kuchlanish $U_L=220$ V bo'lgan neytral simsiz yulduzcha shaklida ulangan uch fazali elektr zanjirning iste'molchi qarshiligi $R_a=40$ Om; $R_b=50$ Om; $R_c=20$ Om. Aktiv quvvati $P_a=40$ Vt; $P_b=100$ Vt; $P_c=60$ Vt. Fazadagi tok va kuchlanishi aniqlanib, vektor ifodasi tuzilsin.

Javob: $I_a=1$ A; $I_b=1,41$ A; $I_c=1,73$ A. $U_a'=401$ V; $U_b'=70,5$ V; $U_c'=34,6$ V.

Masala 6.5. Berilgan sxema-
da A va B fazaga $P=40$ Vt bo'lgan 21 dona lampa, C va A fazaga $P=60$ Vt 10 dona lampa ulangan bo'lib, liniya kuchlanishi $U_L = 120$ V. liniyadagi va fazadagi tok aniqlanib, vektor ifodasi tuzilsin.

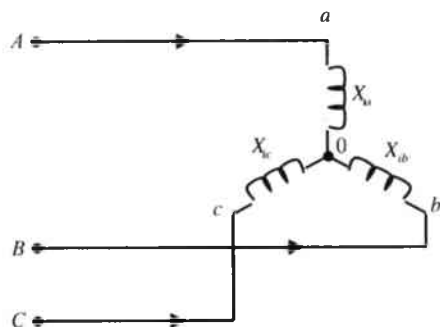
Javob:

$I_{ab} = 7$ A; $I_{bc}=5$ A; $I_A=I_L=2$ A.



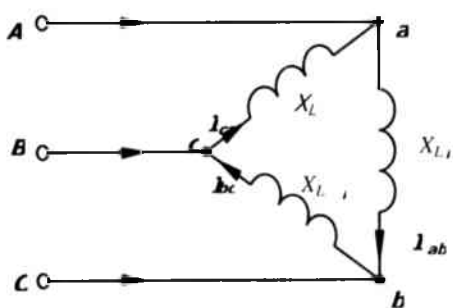
Masala 6.6. Induktivligi $L_1=L_2=L_3=126 \text{ mGn}$ bo'lgan uch fazali asimxron dvigatel chastotasi $f=50 \text{ Gs}$, faza kuchlanishlari $U_A=120 \text{ V}$ simmetrik generatorga ulangan. Fazadagi tok to'la quvvati aniqlansin.

Javob: $I_\varphi=3 \text{ A}$; $P=0$;
 $S=Q=1076 \text{ VA}$.

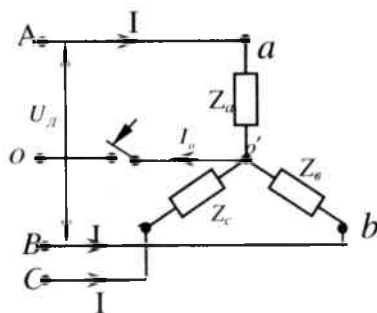


Masala 6.7. Uchburchak shaklida birlashtirilgan elektr zanjir iste'molchi qarshiligi $X_L=22 \text{ Om}$ bo'lib $\dot{U}_A=220e^{j45^\circ} \text{ V}$ kuchlanishga ulangan. Faza va liniyadagi tok aniqlanib, kompleks topografik diagrammasi tuzilsin.

Javob: $I_\varphi=10e^{-j45^\circ}$;
 $I_L=17,3 \text{ ye}^{-j45^\circ}$.



Masala 6.8. Yulduzcha shaklida birlashtirilgan 4 ta simli uch fazali elektr zanjir iste'molchi kompleks qarshiliklari: $Z_a=(40+j30) \text{ Om}$; $Z_b=50 \text{ Om}$, $Z_c=(25-j25) \text{ Om}$ ga teng bo'lib, $U=380 \text{ V}$ liniya kuchlanishi ulangan. Kalit ulangan yoki uzilgan holatlar uchun liniya va neytral



simdagi tok hamda neytral nuqtalar orasidagi $\dot{U}_{00'}$ kuchlanish aniqlanib, vektor ifodasi tuzilsin.

Javob: a) kalit ulanganda:

$$\dot{I}_a = 3,52 - j2,64 \text{ A}, \quad \dot{I}_b = -2,2 - j3,78 \text{ A}; \quad \dot{I}_c = -2,75 - j0,56 \text{ A};$$

$$\dot{I}_0 = \dot{I}_a + \dot{I}_b + \dot{I}_c = -2,71 - j0,56 \quad \dot{U}_{00'} = 0$$

b) kalit uzilganda:

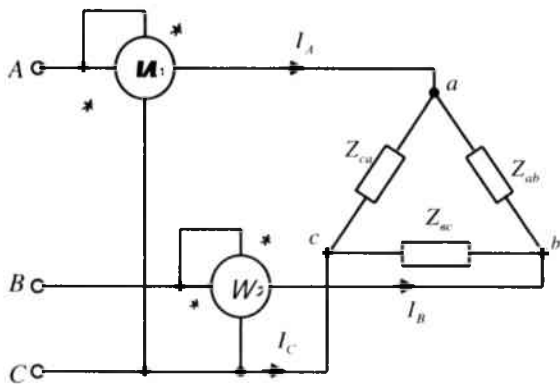
$$\dot{U}_0 = -35 - j175 \text{ B}, \quad \dot{I}_a = 6,18 - j0,26 \text{ A},$$

$$\dot{I}_a = 1,5 - j0,3 \text{ A}; \quad \dot{I}_a = 4,68 - j0,56 \text{ A}$$

Masala 6.9. Yulduzcha sxemada ulangan uch fazali elektr zanjirga parametri $R = 7 \text{ Om}$, $X_L = 24 \text{ Om}$ bo'lgan uchta bir xil g'altak ulangan (6.8-masala). Liniya kuchlanishi $U_n = 220 \text{ V}$. OA fazasidagi g'altak qisqa tutashganda tok qiymati aniqlanib, vektor ifodasi chizilsin.

Javob: $I_A = 15 \text{ A}$, $I_B = I_C = 8,8 \text{ A}$.

Masala 6.10. Uchburchak shaklda ulangan uch fazali elektr zanjir iste'molchilari: $Z_{ab} = 20 + j20 \text{ Om}$; $Z_{bc} = 50 \text{ Om}$, $Z_{ca} = -j40 \text{ Om}$ teng bo'lib, $U_L = 200 \text{ V}$ liniya kuchlanishiga ulangan. Liniyadagi tok va iste'molchilarda sarf bo'ladigan elektr quvvatni aniqlang.



Javob: $\dot{I}_a = 9,33 - j2,5 \text{ A}$, $\dot{I}_b = -7 + j1,54 \text{ A}$;

$$\dot{I}_c = -2,33 + j0,96 \text{ A};$$

$$P = P_1 + P_2 = 1366 + 434 = 1800 \text{ W}.$$

Masala 6.11. Uchburchak shaklda biriktirilgan uch fazali elektr zanjir iste'molchilari simmetrik ulangan bo'lib $I = I_A$ tok o'tadi. Liniya simi I_a va faza simi I_{ab} uzilgan holda liniyadagi tok qiymatini aniqlang.

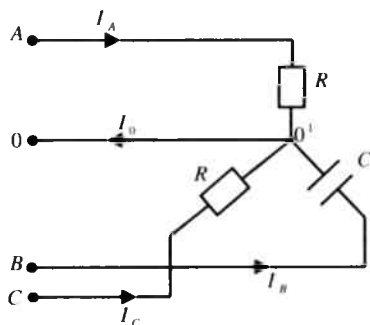
Javob: $I_{\Pi} = \sqrt{3}A$; $I_{\phi} = \sqrt{3}A$; $I_b = \sqrt{3}A$; $I_c = \sqrt{3}A$

Masala 6.12. Yulduzcha shaklda ulangan uchta simli uch fazali elektr zanjirning liniyadagi kuchlanishi $380V$, iste'molchi qarshiligi $R_a = X_b = 10 \, \Omega$, $X_c = -10 \, \Omega$ bo'lganda, fazadagi tok aniqlanib, tok va kuchlanish topografik vektor diagrammasi tuzilsin.

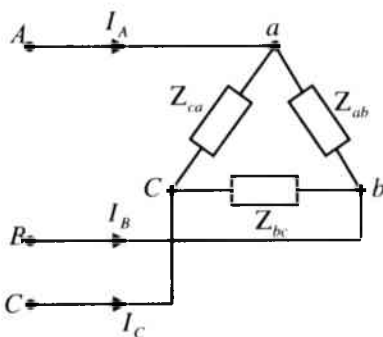
Javob: $\dot{I}_a = 16A$, $\dot{I}_b = 16e^{-j210^\circ} A$, $I_c = 16e^{j210^\circ} A$.

Masala 6.13. Yulduzcha shaklda ulangan elektr zanjir: liniyadagi tok $I_A = I_B = I_C = 3A$ bo'lganda topografik vektor ifodasini tuzish yordamida I_0 neytral tokni aniqlang.

Javob: $I_0 = 4,24 A$



Masala 6.14. a) uchburchak shaklda ulangan simmetrik uch fazali elektr zanjir faza qarshiligi: $Z_{ab} = Z_{bc} = Z_{ca} = -j\frac{1}{\omega C}$ bo'lib, $\dot{I}_{ca} = 8A$ ga teng. Z_{bc} faza uzilgan holatda liniyadagi tok $\dot{I}_A$, $\dot{I}_B$ va fazadagi $\dot{I}_{ca}$ tokni aniqlang.



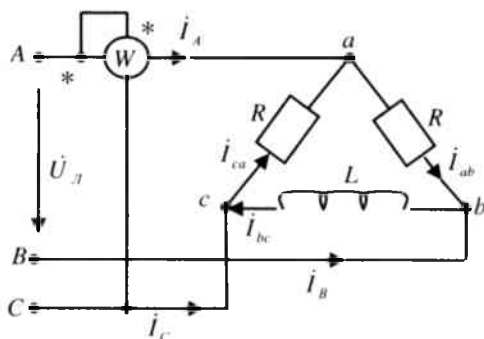
Javob: $\dot{I}_A = 8A$, $\dot{I}_{\Pi} = 13,8A$, $\dot{I}_{ca} = 13,8A$.

b) C liniya simi uzilgan holatda.

I_B liniyadagi tok va I_{ca} fazadagi tokni aniqlang:

Javob: $I_B = 12A$, $I_{ca} = 4A$

Masala 6.15. Uchburchak shaklda ulangan uch fazali tok parametri: $Z_{ab} = Z_{ca} = R$, $Z_{bc} = j\omega L$ bo'lib, simmetrik $\dot{U}_\Delta = 220 V$ kuchlanishga ulangan. Fazadagi tok $i_{ab} = 1 A$ va $i_{bc} = \frac{\sqrt{3}}{2} A$ bo'lganda, tok va kuchlanish topografik diagrammasini tuzish bilan vattmetr ko'rsatish qiymati aniqlansin.



Javob: $P = 330 VT$.

6.4. Nazorat savollari

1. Uch fazali sinusoidal o'zgaruvchan tok deb nimaga aytiladi?
2. Uch fazali tok sistemalarining bir fazali sinusoidal o'zgaruvchan tokga nisbatan qanday afzalliklari bor?
3. Uch fazali tok qanday hosil qilinadi va manbai nima? Sinxron generatorning tuzilishi va ishiash prinsipini bilasizmi?
4. Uch fazali generator statoriga joylashtirilgan chulg'am o'qlari qanday burchakda joylashtiriladi va qutblar soni nimaga teng?
5. Uch fazali tok chastotasi $f = 50 \text{ Gs}$, qutblar soni $2r = 6$ ga teng bo'lganda, magnit maydon aylanish tezligi n_0 nimaga teng?
6. Uch fazali tok grafigi va vektor ifodasini chizing. Analitik, kompleks ifodalarni yozing.
7. Uch fazali tok sistemalarining ulanish sxemalarini bilasizmi?
8. Ulanish sxemalariga qarab liniya, fazalardagi kuchlanish va tokning nisbiy bog'lanish tenglamasini yozing.
9. Agar yulduzcha shaklida ulangan iste'molchining simmetrik fazalari uchburchak shaklida ulansa, liniya va fazadagi tok qanday o'zgaradi?

10. 4 simli, uch fazali elektr zanjirda neytral simning vazifasi nimadan iborat?
11. Uch fazali tok sistemasi qaysi holatlarda nosimmetrik bo'ladi?
12. Uch fazali tokda aktiv, reaktiv va to'la quvvat ifodalarini yozing.
13. Uch fazali simmetrik va nosimmetrik elektr zanjirlarda aktiv quvvat o'lchash sxemasini chizing.
14. Neytral simli yulduzcha shaklda ulangan uch fazali tok iste'molchi qarshiliklari, aktiv, induktiv va sig'imdan iborat bo'lgan holat uchun vektor ifodasini tuzing.
15. Neytral simsiz yulduzcha shaklda ulangan elektr zanjirning faza simi uzilgan yoki qisqa tutashtirilgan holatda liniya va fazada tok qanday o'zgaradi?
16. Uch fazali tok vektorlarini operator «a» orqali «to'g'ri» va «teskari» ketma-ketlik ifodalanish tenglamasini yozing. Fazalar ketma-ketligini izohlab bering.
17. Nosimmetrik uch fazali elektr zanjirlarni simmetrik tashkil etuvchilarga ajratib hisoblash usulini izohlab bering. «To'g'ri», «teskari» va «nol» ketma-ketliklar bir-biridan qanday farq qiladi?
18. Nima uchun simmetrik tashkil etuvchilarga ajratib hisoblash usuli faqatgina chiziqli elektr zanjirni hisoblashda ishlatiladi?
19. Uch fazali tok hosil qiluvchi fazaviy aylanuvchi magnit maydon hosil bo'lishini tushuntirib bering.
20. Uch fazali tok asinxron dvigatelining tuzilishi va ishlash prinsipini bilasizmi?
21. Yulduzcha shaklda biriktirilgan uch fazali tok iste'molchilarda qaysi holatda neytral nuqtali siljish yuzaga keladi va aksincha?
22. Simmetrik uch fazada tok aktiv quvvatini ikkita vattmetr yordamida o'lchanganda, tok bilan kuchlanish orasida burchakning qanday qiymatida bir xilda ko'rsatadi?
23. Neytral simsiz yulduzcha shaklda ulangan uch fazali elektr zanjir neytral tugun orasidagi U_{00} , kuchlanish qanday ifodalanadi.
24. Quvvat koeffitsienti 0.8, umumiy quvvat 5.4 kVt bo'lgan elektro-dvigatel 220 V kuchlanishga ulangan bo'lsa, tok qiymati qancha bo'ladi?
25. Neytral simli yulduzcha shaklida ulangan zanjir faza kuchlanishi $U_{\phi} = 220V$ bo'lib, har bir fazaga 150 VT li 90 ta lampochka ulangan. Liniyadagi tok va sarf bo'ladigan quvvatni aniqlang.

VII. NOSINUSOIDAL ELEKTR ZANJIR

7.1. Asosiy nazariy tushunchalar

1. Davriy o'zgaruvchan funksiyalarni garmonik (Furye) qatorga yoyish.

Matematika kursidan ma'lumki, Dirixle shartini qanoatlantiruvchi har qanday uzluksiz davriy funksiya $f(t)$ ni Furye qatoriga yoyish mumkin:

$$f(t) = A_0 + A_1 \sin(\omega t + \varphi_1) + A_2 \sin(2\omega t + \varphi_2) + \dots + A_k \sin(k\omega t + \varphi_k)$$

A_0 – o'zgarmas tashkil etuvchi.

$A_1 \sin(\omega t + \varphi_1)$ – asosiy yoki birinchi garmonika.

$A_k \sin(k\omega t + \varphi_k)$ – «k» tartibli yuqori garmonika.

A_k va φ_k – yuqori garmonika amplituda va boshlang'ich fazasi.

Amalda elektrotexnika, elektronika, elektromagnit zanjirda uchraydigan nosinusoidal signallar miqdori (funksiyalar) Dirixle shartini qanoatlantiradi.

Furye qatorining koeffitsientini aniqlash uchun $f(t)$ funksiyani quyidagicha yozamiz:

$$f(\omega t) = A_0 + B_1 \sin \omega t + B_2 \sin 2\omega t + \dots + B_k \sin k\omega t + \dots + C_1 \cos \omega t + C_2 \cos 2\omega t + \dots C_k \cos k\omega t$$

Bu shartning koeffitsientini analitik, grafik usulda hisoblash bilan yoki elektrotexnik o'lchov asboblari yordamida aniqlanadi.

Analitik usulda quyidagi ifodadan foydalaniladi:

$$A_0 = \frac{1}{T} \int_0^T f(\alpha) d\alpha \quad B_k = \frac{1}{T} \int_0^T f(\alpha) \sin k\alpha d\alpha$$
$$C_k = \frac{1}{T} \int_0^T f(\alpha) \cos k\alpha d\alpha$$

Ushbu koeffitsientning qiymatini aniqlagach, «k» yuqori garmonika amplitudasi va fazasini aniqlash mumkin:

$$A_k = \sqrt{B_k^2 + C_k^2}; \quad \operatorname{tg} \varphi_k = \frac{C_k}{B_k}; \quad \varphi_k = \arctg \frac{B_k}{C_k};$$

yoki: $B_k = A_k \cos \varphi_k$ $C_k = A_k \sin \varphi_k$.

Agar davriy o'zgaruvchan nosinusoidal funksiya grafik ko'rinishda berilgan bo'lsa, koeffitsientni aniqlashda grafik usuldan (Chebishev usuli) foydalaniladi.

2. Nosinusoidal elektr zanjirni hisoblash.

Chiziqli nosinusoidal elektr zanjirlarni hisoblashda ustma-ustlik (superpozitsiya) usuli tatbiq etilib, har bir garmonikaning zanjir parametriga ta'siri alohida aniqlanadi va ularning oniy qiymatlari yig'indisi belgilanadi. Masalan, kuchlanish ifodasi:

$$u = u_0 + u_1 + u_2 + \dots + u_k \quad \text{bunda: } u_k = U_{km} \sin(k\omega t + \varphi_k)$$

$$\text{tok: } i = I_0 + i_1 + i_2 + \dots + i_k \quad i_k = I_{km} \sin(k\omega t + \varphi_{ik} - \varphi_{uk})$$

Ketma-ket ulangan oddiy R,L,C zanjir uchun «k» garmonika tok amplitudasi:

$$I_{km} = \frac{U_{km}}{\sqrt{R^2 + \left(k\omega L - \frac{1}{k\omega C}\right)^2}}$$

«k» garmonika faza burchagi:

$$\text{tg } \varphi_k = \frac{k\omega L - \frac{1}{k\omega C}}{R}$$

Murakkab nosinusoidal elektr tok zanjirni hisoblashda mavjud bo'lgan elektr zanjirni hisoblash usullari (kompleks usuldan tashqari) tatbiq etilib, har bir garmonika qiymati alohida hisoblanib topiladi. Shuni takidlash kerak: k yuqori garmonika induktiv qarshiligi «k» marta katta ($X_L = k\omega L$), sig'im qarshiligi «k» marta kamayadi ($X_C = 1/k\omega C$). Aktiv qarshilik chastotaga bog'liq emas va o'zgarmas bo'ladi (Zanjir chastotasi juda ham yuqori bo'lganda inobatga olinadi).

3. Nosinusoidal tok, kuchlanish va quvvatning haqiqiy yoki effektiv qiymati.

Nosinusoidal funksiya $f(\omega t)$ effektiv qiymati:

$$A = \sqrt{\frac{1}{T} \int_0^T f^2(\omega t) dt}$$

$$\text{Tokning effektiv qiymati: } I = \sqrt{I_0^2 + I_1^2 + I_2^2 + \dots + I_k^2}$$

$$\text{Kuchlanish effektiv qiymati: } U = \sqrt{U_0^2 + U_1^2 + U_2^2 + \dots + U_k^2}$$

$$\text{EYK effektiv qiymati: } Y_e = \sqrt{E_0^2 + E_1^2 + E_2^2 + \dots + E_k^2}$$

Nosinusoidal tok quvvati har bir yuqori garmonika uchun aniqlangan o'rtacha quvvatlar yig'indisiga teng. Nosinusoidal tok aktiv quvvati (o'rtacha quvvat).

$$P = P_0 + P_1 + \dots + P_k = U_0 I_0 + U_1 I_1 \cos \varphi_1 + U_2 I_2 \cos \varphi_2 + \dots + U_k I_k \cos \varphi_k$$

Reaktiv quvvat:

$$Q = Q_1 + Q_2 + \dots + Q_k = U_1 I_1 \sin \varphi_1 + U_2 I_2 \sin \varphi_2 + \dots + U_k I_k \sin \varphi_k$$

To'la quvvat:

$$S = UI = S_0 + S_1 + S_2 + \dots + S_k$$

Nosinusoidal tok aktiv quvvatning to'la quvvatga nisbati quvvat koeffitsienti deyiladi:

$$\alpha = \frac{P}{S} = \frac{P_0 + P_1 + P_2 + \dots + P_k}{\sqrt{U_0^2 + U_1^2 + U_2^2 + \dots + U_k^2} \cdot \sqrt{I_0^2 + I_1^2 + I_2^2 + \dots + I_k^2}}$$

$$\text{Nosinusoidal elektr zanjirda quvvat koeffitsienti } \alpha = \frac{P}{UI} < 1.$$

4. O'zgaruvchan tok kuchlanish formalarining zanjir parametrga bog'liqligi.

Yuqori garmonika formasi silliqilanish yoki buzilish $\frac{A_k}{A_1}$ nisbati

bilan xarakterlanib, bu nisbat qancha katta bo'lsa, shunchalik nosinusoidal funksiya sinusoidal formadan farqli bo'ladi.

O'zgaruvchan elektr zanjirga kiruvchi yuqori garmonikali nosinusoidal tok nisbatini quyidagi ko'rinishda ifodalash mumkin:

$$\frac{I_{km}}{I_{1m}} = \frac{Z_1}{Z_k} \cdot \frac{U_{km}}{U_{1m}}$$

a) agar elektr tok zanjiri aktiv qarshilikga ega bo'lsa: $Z_k = Z_1 = R$

$$\frac{I_{km}}{I_{1m}} = \frac{U_{km}}{U_{1m}}$$

tok va kuchlanish nosinusoidal formalari o'xshash bo'ladi.

b) agar elektr zanjir induktiv qarshilikka ega bo'lsa:

$$Z_k = k\omega L; \quad Z_1 = \omega L;$$

Bunda: $\frac{I_{km}}{I_{1m}} = \frac{1}{k} \frac{U_{km}}{U_{1m}}$

Tok garmonikasi kuchlanish garmonikasi amplitudaga nisbatan past bo'lib, induktivlik yuqori garmonikalarni so'ndiradi va tok formasini tekislaydi (silliqlaydi).

d) agar elektr zanjir sig'im qarshiligiga ega bo'lsa:

$$Z_k = 1 / k \omega C; \quad Z_l = 1 / \omega C$$

Bunda:
$$\frac{I_{km}}{I_m} = k \frac{U_{km}}{U_{lm}}$$

Tok garmonikalari kuchlanish garmonikalariga nisbatan katta bo'lib, sig'im tok garmonikalari buziladi, kuchlanish garmonikalari tekislanadi.

Reaktiv elementning bu xususiyati elektrotexnikada nosinusoidal formadagi tok va kuchlanishni filtrlash yoki silliqlashda keng foydalaniladi.

Reaktiv elementlardan tarkib topgan murakkab elektr zanjirning tarmoq yoki konturida ma'lum bir «k» garmonikali chastotada rezonans holat yuzaga kelishi mumkin.

5. Uch fazali elektr zanjirda yuqori garmonik tashkil etuvchillar.

Uch fazali elektr zanjir EYK va kuchlanishi nosinusoidal va bir xil formaga ega bo'lganda yuqori garmonikalar fazalar ketma-ketligi hosil bo'lib, $3n + 1$, (butun son yoki nol) uch fazali tok sistemasida faza to'g'ri, ketma-ketligi (1, 7, 13... garmonikalar). $3n-1$ bo'lganda uch fazali tok sistemasida fazalar teskari ketma-ketligi (5, 11, 17... garmonikalar) va $n=0$ bo'lganda «nol» fazalar ketma-ketligi (3, 9, 15...garmonikalar) ni hosil qiladi.

Uch fazali elektr zanjirda yuqori garmonikalarning bunday xususiyatlarini inobatga olgan holda:

a) generator chulg'amlari uchburchak shaklda ulangan bo'lsa:

$$I_{\Delta} = \sqrt{I_3^2 + I_9^2 + I_{15}^2 + \dots}$$

Bunda: I_3, I_9, I_{15} yuqori 3, 9, 15 garmonikali tok bo'lib, generator chulg'amlari hosil qiluvchi konturdagi tok $I_3 = \frac{E_3}{z_3}$; $I_9 = \frac{E_9}{z_9}$ ga teng.

b) generator chulg'amlari yulduzcha va uchburchak shaklda ulanganda, liniyadagi kuchlanish:

$$U_{\text{II}} = \sqrt{U_{\text{II1}}^2 + U_{\text{II5}}^2 + U_{\text{II7}}^2 + U_{\text{II11}}^2} < \sqrt{3}U_{\phi}.$$

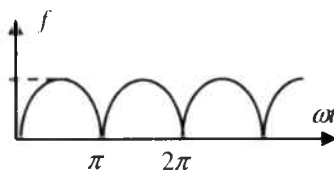
d) neytral simsiz simmetrik uch fazali tok sistemalarining EYK simmetrik bo'lganda 0 va 0' nuqta potensial kuchlanishi $U_{00'} \neq 0$ bo'lib:

$$U_{00'} = \sqrt{E_3^2 + E_9^2 + E_{15}^2 + \dots}$$

e) neytral simli iste'molchilar qarshiligi teng bo'lganda ham: $I_0 \neq 0$ teng bo'lmasdan: $I_0 = 3\sqrt{I_3^2 + I_9^2 + I_{15}^2}$

7.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 7.1. Amplituda kuchlanishi $U_m=100$ V bo'lgan to'g'rilagich (vipryamitel) hosil qiladigan $f = (\omega t)$ funksiyasini $U=100$ V Furye qatoriga yoyish bilan o'zgarmas, birinchi va U_{m2} ikkinchi yuqori garmonika tarkibi aniqlansin.



Yechish.

Kuchlanish funksiyasining ifodasi: $U_{\omega t} = U_m (\sin \omega t) = 100(\sin \omega t)$

Furye qatoriga yoyishda berilgan nosinusoidal funksiyaning ordinata o'qiga simmetrik ekanligini inobatga olamiz. Bunda kuchlanish o'rtacha qiymati:

$$U_0 = \frac{1}{T} \int_0^T U_m (\sin \omega t) d\omega t = \frac{1}{\pi} \int_0^{\pi} U_m \sin \omega t d\omega t = \frac{2U_m}{\pi}$$

$$\text{yoki } U_0 = \frac{2 \cdot 100}{3,14} = 63,6 \text{ V}$$

Birinchi garmonika koeffitsienti:

$$U_1 = \frac{1}{\pi} \int_0^{\pi} U_m (\sin \omega t) \cos \omega t d\omega t = 0 \quad - \text{ ya'ni, yarim davrdagi}$$

integrali nolga teng.

Ikkinchi garmonika koeffitsienti:

$$\begin{aligned}
 U_2 &= \frac{1}{\pi} \int_0^{2\pi} U_m (\sin \omega t) \cos 2\omega t d\omega t = \frac{U_m}{\pi} \left[\int_0^{\pi} \sin \omega t \cos 2\omega t d\omega t - \int_{\pi}^{2\pi} \sin \omega t \cos 2\omega t d\omega t \right] = \\
 &= \frac{U_m}{\pi} \left[\left(-\frac{1}{3} \cos 3\omega t + \cos \omega t \right) \Big|_0^{\pi} - \left(-\frac{1}{3} \cos 3\omega t + \cos \omega t \right) \Big|_{\pi}^{2\pi} \right] = \\
 &= \frac{U_m}{\pi} \left[\left(\frac{1}{3} + \frac{1}{3} - 1 - 1 \right) - \left(-\frac{1}{3} - \frac{1}{3} + 1 + 1 \right) \right] = -\frac{4U_m}{3\pi} (V)
 \end{aligned}$$

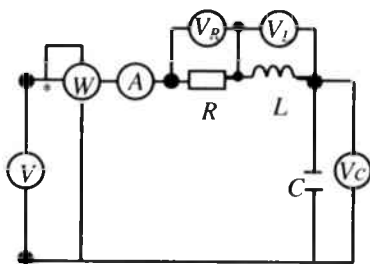
yoki: $U_2 = \frac{4 \cdot 100}{3 \cdot 3,14} = -42,4 \text{ V}$

Kuchlanish oniy qiymati:

$$U_{(\omega)} = \frac{2U_m}{\pi} - \frac{4U_m}{3\pi} \cos 2\omega t + \dots = 63,6 - 42,4 \cos 2\omega t$$

Masala 7.2. Ketma-ket sxema-
da ulangan elektr zanjir parametri:
 $R=3 \text{ Om}$, $L=636 \text{ mGn}$, $C=31,8 \text{ mkf}$
bo'lib, 1, 3, 5 yuqori garmonikalar-
dan tarkib topgan nosinusoidal
kuchlanish nisbatlari $\frac{U_3}{U_1} = 0,2$,

$\frac{U_5}{U_1} = 0,3$ ga teng. Sxemaga ulangan



voltmetr ko'rsatish qiymati $U=128 \text{ V}$. Barcha elektr o'lchov asbohlarining ko'rsatish qiymati aniqlansin.

Yechish.

Elektrodinamik o'lchov asbob tok va kuchlanish effektiv qiymatini ko'rsatadi: $U = \sqrt{U_1^2 + U_3^2 + U_5^2} = U_1 \sqrt{1^2 + 0,3^2 + 0,2^2} = U_1 \cdot 1,06$

Bundan: $U_1 = \frac{128}{1,06} = 120 \text{ V}$; $U_3 = 0,3 \cdot 120 = 36,6 \text{ V}$; $U_5 = 0,2 \cdot 120 = 24 \text{ V}$

Birinchi garmonikaga nisbatan zanjir reaktiv qarshiligini aniqlaymiz:

$$\omega = 2\pi \cdot 500 = 3140 \frac{1}{\text{sek}} \quad X_{L_1} = \omega L = 3140 \cdot 0,636 \cdot 10^{-3} = 2 \text{ Om}$$

$$X_{C_1} = \frac{1}{\omega C} = \frac{10^6}{3140 \cdot 31,8} = 10 \text{ Om} \quad X_1 = X_{L_1} - X_{C_1} = 2 - 10 = -8 \text{ Om}$$

Umumiy qarshiligi: $Z_1 = \sqrt{R^2 + X_1^2} = \sqrt{9 + 64} = 8,5 \text{ Om}$

Yuqori uchini garmonika uchun:

$$X_3 = 3\omega L - \frac{1}{3\omega C} = 3 \cdot 2 - \frac{10}{3} = 2,7 \text{ Om}$$

To'la qarshilik: $Z_3 = \sqrt{R^2 + X_3^2} = 4 \text{ Om}$

Beshinchi yuqori garmonika uchun: $X_5 = 5\omega L - \frac{1}{5\omega C} = 10 - 2 = 8 \text{ Om}$

To'la qarshilik: $Z_5 = \sqrt{R^2 + X_5^2} = 8,5 \text{ Om}$

Har bir garmonik tok effektiv qiymati:

$$I_1 = \frac{U_1}{Z_1} = 14 \text{ A} ; \quad I_3 = \frac{U_3}{Z_3} = 9 \text{ A} ; \quad I_5 = \frac{U_5}{Z_5} = 2,8 \text{ A}$$

yoki $I = \sqrt{I_1^2 + I_3^2 + I_5^2} = 17 \text{ A}$

Vattmetr ko'rsatgan quvvat: $P = RI^2 = 3 \cdot 17^2 = 867 \text{ Vt}$

Induktivlik va sig'im qarshiliklarida har bir yuqori garmonikalar hosil qiladigan kuchlanishlar qiymati :

$$U_{L_1} = \omega_1 LI_1 = 14 \cdot 2 = 28 \text{ V} \quad U_{L_3} = 3\omega_1 LI_3 = 9 \cdot \frac{10}{3} = 30 \text{ V}$$

$$U_{L_5} = 5\omega_1 LI_5 = 28 \text{ V} \quad U_{C_1} = \frac{1}{\omega_1 C} I_1 = 14 \cdot 10 = 140 \text{ V}$$

$$U_{C_3} = \frac{1}{3\omega_1 C} I_3 = 9 \cdot \frac{10}{3} = 30 \text{ V} \quad U_{C_5} = \frac{1}{5\omega_1 C} I_5 = 5,6 \text{ V}$$

Demak, induktivlikka ulangan voltmeter ko'rsatishi:

$$U_L = \sqrt{U_{L_1}^2 + U_{L_3}^2 + U_{L_5}^2} = \sqrt{28^2 + 30^2 + 28^2} = 676 \text{ V}$$

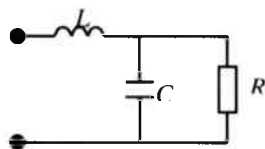
Sig'imga ulangan voltmeter ko'rsatishi:

$$U_C = \sqrt{U_{C_1}^2 + U_{C_3}^2 + U_{C_5}^2} = 144 \text{ V}$$

Aktiv qarshilikka ulangan voltmeter ko'rsatishi:

$$U_R = R \cdot I = 17 \cdot 3 = 51 \text{ V}$$

Masala 7.3. Sxemada keltirilgan elektr zanjirlar parametri: $L=0,5 \text{ Gn}, C=4 \text{ mkf}, R=300 \text{ Om}$ ga teng, hamda chastotasi $f=100 \text{ Gs}$ bo'lib, $U=100 \sin^3 \omega t$ nosinusoidal kuchlanishga ulangan. Tarmoq toklari oniy qiymati o'rganilib, buzilish koeffitsienti aniqlansin.



Yechish. Kuchlanish ifodasini Furye qatoriga yoyamiz:

$$\sin^3 \omega t = \sin \omega t \cdot \frac{1 - \cos 2\omega t}{2} = \frac{1}{2} (\sin \omega t - \sin \omega t \cos 2\omega t) = \frac{3}{4} \sin \omega t - \frac{1}{4} \sin 3\omega t;$$

Bunda zanjir kuchlanishining oniy qiymati:

$$U = 75 \sin \omega t - 25 \sin 3\omega t = 75 \sin \omega t + 25 \sin(3\omega t + \pi)$$

Birinci garmonika uchun zanjir qarshiligi:

$$\underline{Z}_{L_1} = j\omega L_1 = j628 \cdot 0,05 = j3,14 \text{ Om}; \quad \underline{Z}_{C_1} = \frac{1}{j\omega C} = -j398 \text{ Om}$$

Bunda: $\omega = 2\pi f = 628 \frac{1}{\text{sek}}$

Zanjirning kompleks to'la qarshiligi:

$$\underline{Z}_1 = \underline{Z}_{L_1} + \frac{R \cdot \underline{Z}_{C_1}}{R + \underline{Z}_{C_1}} = j31,4 + \frac{300(-j398)}{300 - j398} = 192 - j112,6 = 220e^{-j30^\circ}$$

Tarmoqdagi tok kompleks ifodasi:

$$\dot{I}_{L_1} = \frac{75}{\sqrt{2} \cdot 220e^{-j30^\circ}} = 0,24e^{j30^\circ} \quad \dot{I}_{C_1} = \frac{\dot{I}_{L_1} R}{R + \underline{Z}_{C_1}} = \frac{0,24e^{j30^\circ} \cdot 300}{300 - j398} = 0,145e^{j83^\circ}$$

$$\dot{I}_{R_1} = \frac{\dot{I}_{L_1} \underline{Z}_{C_1}}{R + \underline{Z}_{C_1}} = \frac{0,24e^{j30^\circ} \cdot 398e^{-j90^\circ}}{300 + j398} = 0,19e^{-j6^\circ 40'}$$

Tokning oniy qiymati:

$$i_{L_1} = 0,24\sqrt{2} \sin(\omega t + 30^\circ) \quad (A)$$

$$i_{C_1} = 0,145\sqrt{2} \sin(\omega t + 83^\circ 20') \quad (A)$$

$$i_{R_1} = 0,19\sqrt{2} \sin(\omega t - 6^\circ 40') \quad (A)$$

Uchinchi yuqori garmonika uchun reaktiv qarshilik:

$$\underline{Z}_{L_3} = j3\omega L = j94 \text{ Om} \quad \underline{Z}_{C_3} = -j \frac{10^6}{3 \cdot 628 \cdot 4} = -j133 \text{ Om}$$

To'la kompleks qarshilik:

$$\underline{Z}_3 = \underline{Z}_{L_3} + \frac{R \underline{Z}_{C_3}}{R + \underline{Z}_{C_3}} = j94 + \frac{300(-j133)}{300 - j133} = 49,6e^{-j19^\circ}$$

Uchinchi garmonika tarmoqdagi tok kompleks ifodasi:

$$\dot{I}_{L_3} = \frac{25e^{j180^\circ}}{\sqrt{2} 49,6e^{-j19^\circ}} = 0,36e^{j19^\circ} \quad \dot{I}_{C_3} = \frac{0,356e^{j199^\circ}}{300 - j179} = 0,144e^{j133^\circ}$$

$$\dot{I}_{R_3} = \frac{0,356e^{j199^\circ}}{300 - j179} = 0,144e^{j133^\circ}$$

Tokning oniy qiymati:

$$i_{L_3} = 0,356\sqrt{2} \sin(3\omega t + 191^\circ) \quad (A) \quad i_{C_3} = 0,325\sqrt{2} \sin(3\omega t + 223^\circ) \quad (A)$$

$$i_{R_3} = 0,144\sqrt{2} \sin(3\omega t + 132^\circ) \quad (A)$$

Tarmoqdagi tokning effektiv qiymati:

$$I_L = \sqrt{I_{L_1}^2 + I_{L_3}^2} = \sqrt{0,24^2 + 0,356^2} = 0,43 \quad A \quad I_C = \sqrt{I_{C_1}^2 + I_{C_3}^2} = 0,373 \quad A$$

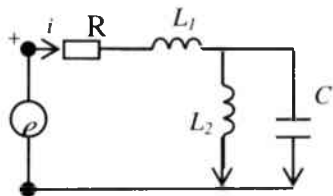
$$I_R = \sqrt{I_{R_1}^2 + I_{R_3}^2} = 0,24 \quad A$$

Buzilish koeffitsienti:

$$k_L = \frac{I_{L_1}}{I_{L_3}} = \frac{0,356}{0,43} = 0,83 \quad k_C = \frac{I_{C_1}}{I_{C_3}} = \frac{0,325}{0,373} = 0,87 \quad k_R = \frac{I_{R_1}}{I_{R_3}} = \frac{0,144}{0,240} = 0,33$$

Demak, sig'imdand o'tuvchi tok formasi ko'proq buzilar ekan.

Masala 7.4. Nosinusoidal elektr zanjirning parametri $R=300 \, Om$, $L_1=0,25 \, Gn$, $L_2=0,1 \, Gn$, $C=3,3 \, mkf$ va chastota $\omega=1000 \, rad/sek$ bo'lib, $E=60+250\sin\omega t+100\sin3\omega t$ garmonikalardan tarkib topgan manbaga ulangan. Birinchi tarmoqdagi tokning oniy, effektiv qiymati va aktiv quvvati aniqlansin.



Yechish. O'zgarmas tok kondensatordan oqib o'tmasligi ($I_C=0$) va induktiv qarshilik nolga tengligini ($L=0$) hisobga olsak:

$$I_0 = \frac{E_0}{R_1} = \frac{60}{300} = 0,2 \quad A$$

Masalani kompleks usul bilan yechamiz. Bunda birinchi garmonika uchun kompleks tok amplitudasi:

$$\dot{I}_{m_1} = \frac{\dot{E}_{m_1} e^{j0^\circ}}{\underline{Z}_1}$$

Reaktiv qarshiliklarni aniqlaymiz:

$$X_1 = \omega L_1 = 1000 \cdot 0,25 = 250 \, Om$$

$$X_2 = \omega L_2 = 1000 \cdot 0,1 = 100 \, Om$$

$$\text{Sig'imdagi qarshilik: } X_C = \frac{1}{\omega C} = \frac{1}{1000 \cdot 3,3 \cdot 10^{-6}} = 300 \, Om$$

Birinchi garmonikadagi kompleks to'la qarshilik:

$$\underline{Z}_1 = R_1 + j\omega L_1 + \frac{j\omega L_2 \left(-j\frac{1}{\omega C} \right)}{j\omega L_2 - j\frac{1}{\omega C}} = 300 + j400 = 500e^{j53^\circ}$$

Tok amplituda qiymati:

$$\dot{I}_{m_1} = \frac{250e^{j0^\circ}}{500 \cdot e^{j53^\circ}} = 0,5e^{-j53^\circ} \quad (A)$$

Tok oniy qiymati:

$$i_1 = 0,5 \sin(\omega t - 53^\circ) \quad (A)$$

Uchinchi garmonikadagi tokni aniqlaymiz. Manba kuchlanishi:

$$e_3 = 100 \sin \omega t = \dot{E}_{m_3} \cdot 100 e^{j0^\circ}$$

Uchinchi garmonika uchun reaktiv qarshilik:

$$X_{L_1} = 3\omega L_1 = 250 \text{ Om}, \quad X_{L_2} = 3\omega L_2 = 300 \text{ Om}, \quad X_C = \frac{1}{3\omega C_3} = 100 \text{ Om}$$

Umumiy kompleks qarshilik:

$$\underline{Z}_{(3)} = R_1 + jX_{L_1} + \frac{jX_{L_2} \left(\frac{-1}{jX_C} \right)}{jX_{L_2} - \frac{1}{jX_C}} = 300 + j750 + \frac{j300(-j100)}{j300 - j100} = 300 + j600 = 675e^{j63^\circ} \text{ Om}$$

Uchinchi garmonika tok amplitudasining kompleks ifodasi:

$$\dot{I}_{m_3} = \frac{\dot{E}_{m_3}}{\underline{Z}_{(3)}} = \frac{100}{675 \cdot e^{j63^\circ}} = 0,15 \cdot e^{-j63^\circ}$$

Tok oniy qiymati:

$$i_3 = 0,15 \sin(3\omega t - 63^\circ)$$

Zanjirga kiruvchi tok oniy qiymati :

$$i_1 = 0,2 + 0,5 \sin(\omega t - 53^\circ) + 0,15 \sin(3\omega t - 63^\circ) \quad A$$

Tok effektiv qiymati:

$$I = \sqrt{0,2^2 + \left(\frac{0,5}{\sqrt{2}} \right)^2 + \left(\frac{0,15}{\sqrt{2}} \right)^2} = 0,42 \quad A$$

Zanjir aktiv quvvati har bir garmonika tok va kuchlanish oniy qiymati ifodasidan:

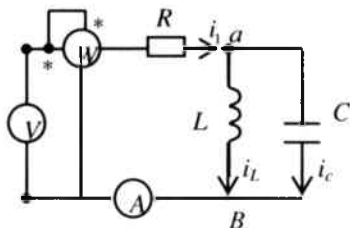
$$P = P_0 + P_1 + P_3 = 60 \cdot 0,2 + \frac{250}{\sqrt{2}} \cdot \frac{0,5}{\sqrt{2}} \cos 53^\circ + \frac{100}{\sqrt{2}} \cdot \frac{0,15}{\sqrt{2}} \cos 63^\circ = 52,8 \text{ Vt}$$

Masala 7.5. Berilgan elektr zanjirning induktivlikdagi nosinusoidal tok

$$i_L = 4 + 8\sin\omega t + 6\sin(2\omega t + 90^\circ)$$

bo'lib, qarshilik parametri

$$R = \omega L = 5 \text{ Om}, \quad \frac{1}{\omega C} = 20 \text{ Om} \text{ ga}$$



teng. Elektr o'lchov asboblari –

ampermetr, voltmeter va vattmetrning ko'rsatish qiymati aniqlansin.

Yechish. Induktivlikdagi tok ma'lum bo'lganligi sababli har bir garmonika uchun parallel ulangan tarmoq kuchlanishini aniqlaymiz.

$$U_{Lm_1} = I_{Lm_1} \cdot X_{L_1} = 8 \cdot 5 = 40 \text{ V}$$

$$U_{Lm_2} = I_{Lm_2} \cdot X_{L_2} = 6 \cdot 10 = 60 \text{ V}$$

Sig'im va induktivlikdagi kuchlanish ohiv qiymati:

$$U_C = U_L = 40 \sin(\omega t + 90^\circ) + 60 \sin(2\omega t + 180^\circ) = 40 \sin(\omega t + 90^\circ) - 60 \sin 2\omega t$$

Birinchi garmonika uchun parallel ulangan L, C kompleks reaktiv qarshilik:

$$\underline{Z}_{ab1} = X_{ab1} = \frac{jX_{L_1} \cdot jX_{C_1}}{jX_{L_1} + jX_{C_1}} = -j \frac{20 \cdot 5}{5 - 20} = -j6,67 \text{ Om}$$

Birinchi garmonika tok amplitudasi: $I_{m_1} = \frac{U_{Lm_1}}{Z_{ab1}} = \frac{40}{6,67} = 6 \text{ A}$

Ikkinchi garmonika uchun: $\underline{Z}_{ab2} = \frac{j2\omega L \cdot \frac{1}{j2\omega C}}{j\left(2\omega L - \frac{1}{2\omega C}\right)} = \infty$

Demak parallel ulangan reaktiv elementlarda tok rezonansi yuzaga kelib, birinchi tarmoqda ikkinchi garmonika tok ($I_{2m}=0$) nolga teng. Tok oniy qiymati:

$$i = I_0 + I_{m_1} \sin(\omega t + \varphi_u - \varphi) = 4 + 6 \sin(\omega t + 90^\circ - 90^\circ) = 4 + 6 \sin \omega t$$

Ampermetrdagi tok: $I = \sqrt{4^2 + \left(\frac{6}{\sqrt{2}}\right)^2} = 5,8 \text{ A}$

Har bir yuqori garmonika uchun zanjirning umumiy qarshiligini aniqlaymiz. Nolinchi va birinchi garmonika uchun aktiv qarshilik:

$$R_0 = R = 5 \text{ Om}$$

Birinchi garmonika to'la qarshiligi:

$$Z_1 = \sqrt{R^2 + (X_{ab})^2} = \sqrt{5^2 + (6.7)^2} = 8.3 \text{ Om}$$

Ikkinchi garmonikada $Z_2 = \infty$

Nar bir garmonika uchun kuchlanishni topamiz:

$$U_0 = I_0 R_0 = 4 \cdot 5 = 20 \text{ V} \quad U_{m_1} = I_{m_1} \cdot Z_1 = 6 \cdot 8.3 = 50 \text{ V} \quad U_{m_2} = U_{Lm_2} = 60 \text{ V}$$

$$\text{Faza burchagi} \quad \varphi_1 = \arctg \frac{X_{ab_1}}{R} = \frac{6.67}{5} = 53^\circ$$

Zanjirning umumiy kuchlanish oniy qiymati:

$$U = U_0 + U_1 + U_2 = U_0 + U_{m_1} \sin(\omega t + \varphi_1) + U_{m_2} \sin 2\omega t = 20 + 50 \sin(\omega t + 53^\circ) - 60 \sin 2\omega t$$

Voltmetr ko'rsatishi bo'yicha:

$$U = \sqrt{U_0^2 + U_1^2 + U_2^2} = \sqrt{20^2 + \left(\frac{50}{\sqrt{2}}\right)^2 + \left(\frac{60}{\sqrt{2}}\right)^2} = 58.6 \text{ V}$$

O'rtacha quvvat yoki voltmetr ko'rsatish:

$$P = U_0 I_0 + U_1 I_1 \cos \varphi_1 + U_2 I_2 \cos \varphi_2 = 170 \text{ Vt.}$$

Masala 7.6. Yulduzcha shaklda ulangan tok zanjirining iste'molchi kompleks qarshiligi:

$$Z_1 = Z_2 = Z_3 = (3 + j6) \text{ Om}$$

$$U_\phi = 141 \sin \omega t + 42.5 \sin 3\omega t + 5 \sin 5\omega t \text{ B}$$

bo'lib, faza kuchlanishi generatorga ulangan. Neytral sim toki I_0 fazadagi tokning oniy qiymati va uch fazali tok quvvati aniqlansin.

Yechish.

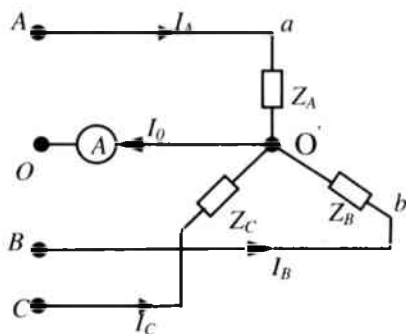
Birinchi garmonika uchun iste'molchi faza kuchlanishlari

$$\dot{U}_1 = 100 \text{ V}; \quad \dot{U}_2 = 100 e^{-j120^\circ} \text{ V}; \quad \dot{U}_3 = 100 e^{j120^\circ} \text{ V. Tokning effektiv qiymati:}$$

$$I_\phi = \frac{U}{Z} = \frac{100}{\sqrt{3^2 + 6^2}} = 15 \text{ A}$$

$$\text{Faza burchagi:} \quad \varphi = \arctg \frac{X_L}{R} = 63^\circ 30'$$

Neytral simda birinchi garmonika bo'lmaydi. ($I_0 = 0$)



Uchinchi garmonika fazadagi kuchlanish:

$$\dot{U}_1 = 30 \text{ V}, \quad \dot{U}_2 = 30e^{-j3 \cdot 120^\circ} = 30 \text{ V}, \quad \dot{U}_3 = 30e^{j3 \cdot 120^\circ} = 30 \text{ V}.$$

Kuchlanish effektiv qiymati: $U=30 \text{ V}$

Faza tok effektiv qiymati: $I_{\phi_1} = \frac{U}{Z} = \frac{30}{\sqrt{3^2 + 18^2}} = 1,65 \text{ A}$

Farqi: $\varphi_3 = \arctg \frac{X_{L_3}}{R} = \frac{3\omega L}{R} = 80^\circ 30'$

Neytral simda uchinchi garmonikadagi tok fazadagi tokdan uch barobar katta:

$$I_0 = 3I_{\phi_1} = 3 \cdot 1,65 = 5 \text{ A}$$

Liniya kuchlanishlari tarkibida uchinchi garmonika yo'q. ($U_{l(3)}=0$).

Beshinchi garmonika uchun fazadagi kuchlanish:

$$\dot{U}_1 = 3,54 \text{ V}; \quad \dot{U}_2 = 3,54e^{-j5(120^\circ)} = 3,54e^{j120^\circ} \text{ V}; \quad \dot{U}_3 = 3,54e^{j5(120^\circ)} = 3,54e^{-j120^\circ} \text{ V}$$

Kuchlanish effektiv qiymati: $U=3,54 \text{ V}$

Fazadagi tok: $I_{\phi_5} = \frac{U}{\sqrt{R^2 + (5\omega L)^2}} = \frac{3,54}{\sqrt{3^2 + 30^2}} = 0,117 \text{ A}$

Faza farqi: $\varphi_5 = \arctg \frac{5\omega L}{R} = 84^\circ$

Neytral simda beshinchi garmonikadagi tok nolga teng. ($I_{0(5)}=0$)

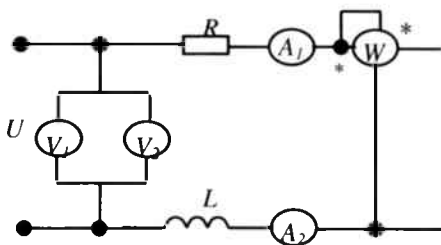
Birinchi fazadagi tok oniy qiymati:

$$i_1 = i_\phi = 15\sqrt{2} \sin(\omega t - 63^\circ 30') + 1,65\sqrt{2} \sin(3\omega t - 80^\circ 30') + \\ + 0,117\sqrt{2} \sin(5\omega t - 84^\circ 15')$$

Iste' molchilarda sarf bo'ladigan uch fazali tok o'rtachia quvvati:

$$P = 3(U_1 I_1 \cos \varphi_1 + U_3 I_3 \cos \varphi_3 + U_5 I_5 \cos \varphi_5) \approx 9980 \text{ Vt}$$

Masala 7.7. Sxemada berilgan induktiv g'altak kuchlanishi $U = U_0 + U_1 \sin \omega t$ (V) bo'lib, zanjirga ulangan elektr o'lchov asboblari: A_1 va V_1 —magnitoelektrik, A_2, V_2 va W — elektrodinamik. Bu o'lchov asboblari ko'rsatishi: $I_1=4\text{A}$, $I_2=5\text{A}$, $U_1=30\text{V}$, $U_2=90\text{V}$, $P=190\text{Vt}$ bo'lganda, quvvat koeffitsienti g'altak parametrlari va aktiv qarshilikning o'zgarmas tokga nisbatan qiymati aniqlansin.



Yechish.

Magnitoelektrik sistemali elektr o'lchov asboblari o'zgarmas tok yoki kuchlanish qiymatini o'lchaydi. (I_0 , U_0)

Elektrodinamik sistemali elektr o'lchov asboblari esa tok va kuchlanishning effektiv qiymatini ko'rsatadi. (I_1 , U_1)

Shunga asosan: $U_1 = \sqrt{U_2^2 - U_1^2} = \sqrt{90^2 - 30^2} = 85V$

$$I_1 = \sqrt{I_2^2 - I_0^2} = \sqrt{5^2 - 4^2} = 3 A$$

Nol garmonika quvvati: $P_0 = U_1 I_1 = 30 \cdot 4 = 120 Vt$

Birinchi garmonika quvvati: $P_1 = P_2 - P_0 = 190 - 120 = 70 Vt$

Sinusoidal o'zgaruvchan birinchi garmonikadagi to'la qarshilik:

$$Z_{(1)} = \frac{U_1}{I_1} = \frac{80}{3} = 26,6 Om$$

Aktiv qarshilik: $R_{(1)} = \frac{P_1}{I_1^2} = \frac{70}{3^2} = 7,78 Om$

Induktiv qarshilik: $X_L = \sqrt{Z_1^2 - R_1^2} = 25,5 Om$

O'zgarmas tokga nisbatan aktiv qarshilik: $R_0 = \frac{U_1}{I_1} = \frac{30}{4} = 7,5 Om$

Siljish koeffitsienti: $k = \frac{R_{(1)}}{R_0} = \frac{7.78}{7.5} = 1.036$

Masala 7.8. Ikki qutbli nosinusoidal zanjir kuchlanishi:

$$U = 100 + 50 \sin \omega t - 20 \sin \left(3\omega t + \frac{\pi}{6} \right) + 10 \sin \left(5\omega t - \frac{\pi}{3} \right)$$

$$i = 2 + 10 \sin \left(3\omega t - \frac{\pi}{3} \right) + 4 \sin 5\omega t \text{ ulangan.}$$

Kuchlanish va tok haqiqiy qiymati, aktiv, reaktiv, to'la quvvat, siljish va quvvat koeffitsenti aniqlansin.

Yechish. Kuchlanish va tok haqiqiy qiymati:

$$U = \sqrt{U_0^2 + \frac{U_{1m}^2}{2} + \frac{U_{3m}^2}{2} + \frac{U_{5m}^2}{2}} = \sqrt{1000 + \frac{2500}{2} + \frac{400}{2} + \frac{100}{2}} = \sqrt{11500} = 107,2V$$

$$I = \sqrt{4 + \frac{100}{2} + \frac{16}{2}} = \sqrt{62} = 7,87A$$

Aktiv quvvat yuqori garmonika algebraik yig'indisidan iborat bo'lib:

$$P = U_0 I + U_3 \dot{I}_3 \cos \varphi_3 + U_5 \dot{I}_5 \cos \varphi_5 = 100 \cdot 2 + \frac{20}{\sqrt{2}} \cos \varphi_3 + U_5 I_5 \cos \varphi_5 =$$

$$= 100 \cdot 2 + \frac{20}{\sqrt{2}} \cdot \frac{10}{\sqrt{2}} \cos(-90^\circ) + \frac{10}{\sqrt{2}} \cdot \frac{4}{\sqrt{2}} \cos(-60^\circ) = 200 + 0 + 20 \cdot \frac{1}{2} = 210Vt$$

Bu yerda: $\left(\varphi_3 = \varphi_{u3} - \varphi_{i3} = \frac{\pi}{6} - \pi + \frac{\pi}{3} = \frac{\pi}{2} \right) \quad \varphi_5 = \varphi_{u5} - \varphi_{i5} = -\frac{\pi}{3}$

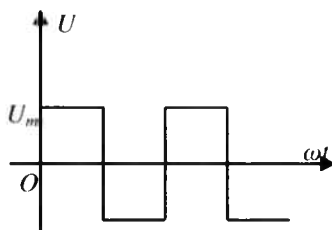
Reaktiv quvvat:

$$Q = U_3 I_3 \sin \varphi_3 + U_5 I_5 \sin \varphi_5 = \frac{20}{\sqrt{3}} \cdot \frac{10}{\sqrt{3}} \sin(-90^\circ) + \frac{10}{\sqrt{2}} \cdot \frac{4}{\sqrt{2}} \sin(-60^\circ) = -173,3VAR$$

To'la quvvat: $S = UI = 107,2 \cdot 7,87 = 855VA$.

7.3. Mustaqil yechish uchun masalalar

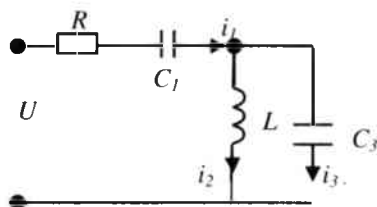
Masala 7.1. Kuchlanish amplituda qiymati $U_m=100$ B bo'lgan funksiyani Furye qatoriga yoyish bilan 1,2,3 garmonikalar ifodasi yoki kuchlanish oniy qiymati aniqlansin.



Javob: $U = 127,3 \sin \omega t + 42,4 \sin 3\omega t + 25,5 \sin 5\omega t (V)$

Masala 7.2. Berilgan sxemaning qarshilik parametri: $R_l=100Om$, $X_{L1} = 100 Om$, $X_{C1} = X_{C3} = 200 Om$ bo'lib, nosinusoidal manba

kuchlanishi $U = 100 + 500 \sin \omega t + 200 \sin \omega t$ ga ulangan. Tarmoqdagi tok oniy qiymati aniqlansin.



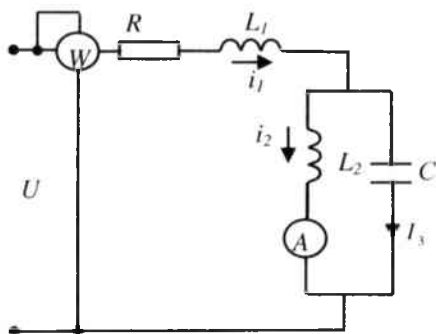
Javob:

$$i_1 = 3,54 \sin(\omega t - 45^\circ) + 0,743 \sin(2\omega t + 68^\circ) A$$

$$i_2 = 7,08 \sin(\omega t - 45^\circ) + 0,743 \sin(2\omega t + 12^\circ) A$$

$$i_3 = 3,54 \sin(\omega t + 135^\circ) + 1,5 \sin(2\omega t + 68^\circ) A$$

Masala 7.3. Berilgan sxema bo'yicha parametrlar $R=20 \text{ Om}$, $L_1=20 \text{ mGn}$, $L_2=60 \text{ mGn}$, $C=16.6 \text{ mkf}$, $\omega=1000 \text{ rad/sek}$ bo'lib, nosinusoidal kuchlanishga $U = 40 + 120 \sin \omega t + 60 \sin 2\omega t$ ulangan. Birinchi tarmoqdagi tok i_1 va elektr o'lchov asbobining ko'rsatish qiymatini aniqlang.



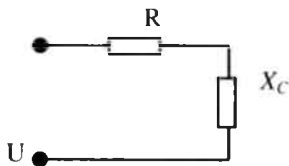
Javob: $i_1 = 2 + 1,06 \sin(\omega t + 45^\circ) A$

$$I_2 = 2.47 \text{ A}, \quad P = 102.5 \text{ W}$$

Masala 7.4. Elektr zanjir qarshilik parametri $R_1 = 10 \text{ Om}$,

$$X_c = \frac{1}{\omega C} = 27 \text{ Om} \text{ bo'lib, nosinusoidal kuchlanish}$$

$U = 100 + 200 \sin \omega t + 30 \sin(3\omega t - 90^\circ) + 50 \sin(5\omega t + 45^\circ)$ ga ulangan. Tokning oniy qiymati, kuchlanishi va quvvati aniqlansin.

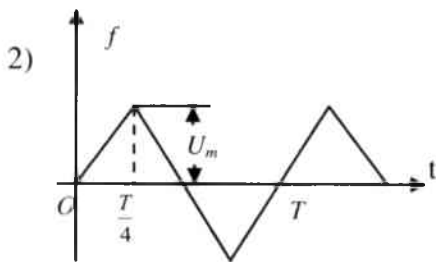
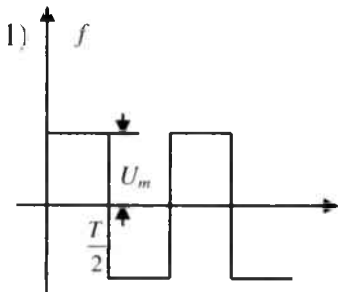


Javob:

$$i = 0,74 \sin(\omega t + 88^\circ) + 0,33 \sin(3\omega t - 6^\circ 30') + 0,97 \sin(5\omega t + 124^\circ 30')$$

$$U = 178 \text{ V}, \quad I = 0.863 \text{ A}, \quad P = 7.47 \text{ W}$$

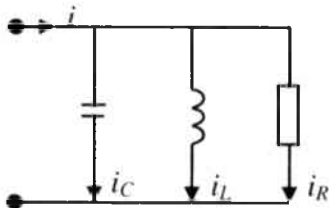
Masala 7.5. Grafikda keltirilgan kuchlanish funksiyasi uchun amplituda k_a , forma k_f va siljish k_{sil} koeffitsienti aniqlansin.



Javob: 1) $k_a = k_\phi = 1$; $k_{cus} = \frac{2\sqrt{2}}{\pi}$ 2) $k_a = \sqrt{3}$; $k_\phi = \frac{2}{\sqrt{3}}$; $k_{cus} = \frac{4\sqrt{6}}{\pi^2}$

Masala 7.6. Berilgan sxema parametri: $R = \frac{1}{\omega C} = \omega L = 10 \text{ Om}$

bo'lib, $u = (200 \sin \omega t + 60 \sin 3\omega t + 30 \sin 5\omega t)$ (V) kuchlanishga ulangan. Tokning oniy qiymati, effektiv qiymat va quvvati P aniqlansin.



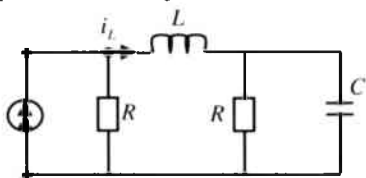
Javob: $i = 20 \sin \omega t + 17,4 \sin(3\omega t + 67^\circ) + 14,7 \sin(5\omega t + 178^\circ)$

$I = 32 \text{ A}, \quad P = 4450 \text{ Vt}$

Masala 7.7. (7.6) masaladagi parallel zanjir parametri $\omega = 1000 \frac{1}{\text{sek}}$
 $C = 10 \text{ mkf}, \quad L = 0,1 \text{ gn}, \quad g = \frac{1}{R} = 0,01 \text{ sim}$ bo'lib, nosinusoidal
 $u = 100 \sin(\omega t + 30^\circ) + 30 \sin 3\omega t + 10 \sin(5\omega t - 135^\circ)$ kuchlanishga
 ulangan. Tarmoq toklari oniy $i_{R(t)}, i_{L(t)}, i_{C(t)}$ va kuchlanish effektiv
 qiymati aniqlanib, vaqtga nisbatan o'zgaruvchan diagrammasi chlzilsin.

Javob: $U = 70 \text{ V}, \quad I_R = 0,71 \text{ A}, \quad I_L = 0,74 \text{ A}, \quad I_C = 1,02 \text{ A}.$

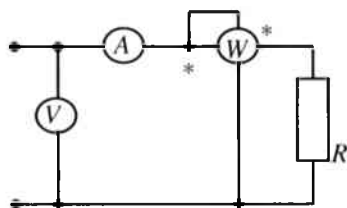
Masala 7.8: Nosinusoidal elektr
 zanjir parametri: $R = 10 \text{ Om}, \quad X_C = 10 \text{ Om},$
 $X_L = 0,5 \text{ Om}.$ $i = 10 + 30\sqrt{2} \sin \omega t +$
 $+ 15\sqrt{2} \sin 2\omega t$ tok manbaiga ulangan.
 Induktivlikdagi tok oniy va haqiqiy
 qiymati aniqlansin.



Javob: $i_L = 5 + 28,2 \sin \omega t + 15,8 \sin(2\omega t - 26^\circ);$

$I_L = 23,4 \text{ A}$

Masala 7.9. Elektr zanjir $U =$
 $220 + 180 \sin 314t$ nosinusoidal kuchla-
 nishga ulangan bo'lib, $R = 10 \text{ Om}$
 qarshiligiga ega. Elektromagnit o'lchov
 asboblari: ampermetr, voltmetr va vatt-
 metr ko'rsatish qiymatini aniqlang.



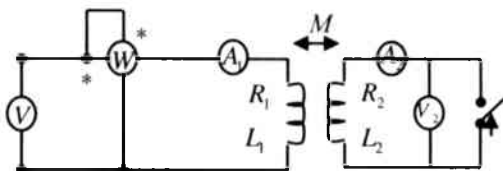
Javob: $U = 254 \text{ V}, \quad I = 25,4 \text{ A},$

$P = 6450 \text{ VT}.$

Masala 7.10. 7.3 masaladagi aralash sxemada ulangan
 nosinusoidal elektr zanjir parametri: $L_1 = 2,5 \text{ mgn}, \quad L_2 = 20 \text{ mgn}$
 $C = 50 \text{ mkf}, \quad R = 50 \text{ Om}$ bo'lib, $U = 50 + 60\sqrt{2} \sin 1000t +$
 $+ 200\sqrt{2} \sin 3000t$ kuchlanishga ulangan. Tarmoqlarga ulangan elek-
 trodinamik turdagi ampermetr ko'rsatish tok qiymatini aniqlang:

Javob: $I_1 = 4,12 \text{ A}, \quad I_2 = 3,24, \quad I_3 = 5,4 \text{ A}.$

Masala 7.11. Havo transformatori (o'zaksiz) $U_1 = 60 + 113 \sin 2000t$ kuchlanishiga ulangan bo'lib parametri: $R_1 = R_2 = 6 \text{ Om}$, $L_1 = L_2 = 4 \text{ mgn}$, $M = 1 \text{ mgn}$. Qisqa tutashuv holat *elektromagnit turdagi o'lchov asboblari* qiyinatini aniqlang.



Javob: $I_1 = 12,8 \text{ A}$; $I_2 = 1,6 \text{ A}$; $U_1 = 100 \text{ V}$; $U_2 = 0$.

7.4. Nazorat savollari

1. Nosinusoidal o'zgaruvchan tok va kuchlanishlarni izohlab bering.
2. Elektr zanjirda nosinusoidal tok, kuchlanish va EYK qanday hosil bo'ladi?
3. Nosinusoidal o'zgaruvchan funksiyalarni Furye qatoriga yoyish manosi tushuntiring.
4. Nosinusoidal tok funksiyasining trigonometrik qatoriga yoyilgandagi umumiy ifodasini yozing.
5. Nosinusoidal funksiyaning asosiy garmonikasi yoki yuqori garmonikasi deganda nimani tushunasiz?
6. Obsitsa, ordinata va koordinata boshiga simmetrik bo'lgan sinusoidal funksiya grafigini chizib ko'rsating.
7. Trapetsiadal ko'rinishdagi nosinusoidal funksiyaning analitik usulda trigonometrik qatorga yoying.
8. Nosinusoidal funksiyaning grafo-analitik usulda hisoblash qanday bajariladi?
9. Nosinusoidal funksiyaning koeffitsienti va boshlang'ich fazalarini aniqlash formulasini yozing.
10. Nosinusoidal tok kuchlanish va EYKning haqiqiy o'rtacha qiymatini ifodalovchi formulasini yozing.
11. Nosinusoidal tok quvvatini ifodalovchi tenglamani yozing.
12. Nosinusoidal funksiya amplituda, forma siljish koeffitsienti qanday ifodalanadi?

13. Nosinusoidal elektr zanjirni hisoblashda ustma-ustlik usulidan qanday foydalaniladi?
14. Induktivlik yoki sig'ım parametri yuqori garmonika tok, kuchlanishlarning birinchi garmonikaga nisbatan ifodalanuvchi tenglamasini yozing.
15. Nima sababdan iste'molchi induktiv xarakterga ega bo'lganda nosinusoidal tok formasi silliqilanib, kuchlanish buziladi?
16. Nima sababdan iste'molchi sig'ım xarakterga ega bo'lganda nosinusoidal kuchlanish formasi tekislanib, tok formasi buziladi?
17. Uch fazali sistema uchun asosiy va yuqori garmonikali kuchlanish ifodalovchi formulasini yozing.
18. Uch fazali tok sistemalarida qaysi garmonikalar «to'g'ri», «teskari» va «nol» ketma-ketlikni hosil qiladi?
19. Nima sababdan simmetrik uch fazali tok sistemasida nosinusoidal kuchlanish ulanganda neytral simdagi tok nolga teng emas?
20. Nima sababdan generator chulg'amlari uchburchak shaklda ulanganda liniya va faza kuchlanishlarida uch karrali garmonikalar yo'qoladi?
21. R, L, C parametrlarning nosinusoidal tok va kuchlanish formulalariga qanday ta'sir ko'rsatishini tushuntiring.
22. Elektr filtri nima va qanday maqsadda foydalaniladi?
23. Nosinusoidal elektr zanjirda rezonansli filtrlarning xususiyatlarini izohlab bering.
24. Uch fazali generator liniyalarida yuqori garmonika hosil bo'lishi sababi nimada va qanday xususiyatga ega?
25. $i = 5 + 3\sin(\omega_1 t + 30^\circ) + 2\sin(3\omega_1 t - 45^\circ) + 4\sin(5\omega_1 t - 30^\circ)$ (A) tok haqiqiy (effektiv) qiymatini toping.
26. Ketma-ket R, L, C zanjir nosinusoidal $U = U_0 + U_{1m} \sin(\omega_1 t + \varphi_{U_1}) + U_{5m} \sin(5\omega_1 t + \varphi_{U_5})$ kuchlanishga ulanganda, tok qiymati ifodasini yozing.
27. Pulsatsiya, modulatsiyalangan tebranish amplitudaviy modulatsiya qanday hosil bo'ladi?
28. Nosinusoidal elektr zanjiriga ulangan ampermetr, voltmeter, vattmeter ko'rsatishiga yuqori chastotali garmonikalar ta'sir o'tkazadimi yoki yo'qmi?

29. Magnitoelektrik elektr o'lchov asbobi nosinusoidal tok va kuchlanishning qaysi qiymatini o'lchaydi?

30. Induksion, elektromagnit, elektrodinamik issiqlik elektr o'lchov asboblari nosinusoidal tok va kuchlanishlarning qanday qiymatlarini o'lchaydi?

31. Vattmetr nosinusoidal quvvatning qaysi qiymatini o'lchaydi?

32. Zanjirga ketma-ket uchta ampermetr: elektromagnit, induksion va issiqlik turdagi tok o'lchov asbobi ulangan. Agar magnitoelektrik asbob ko'rsatishi $I_1 = 6A$, induksion ampermetr $I_2 = 8A$ bo'lsa, issiqlik ampermetr I_3 qiymati nimaga teng?

VIII. TO'RT QUTBLI ZANJIR

8.1. Asosiy nazariy tushunchalar

Ikkita kirish (1-1') va ikkita chiqish (2-2') qutblari bo'lgan har qanday elektr zanjirga to'rt qutbli zanjir deyiladi. Odatda kirish qismi manbaga U_1 , chiqish qismiga esa iste'molchi qarshiligi Z_2 ulanadi.

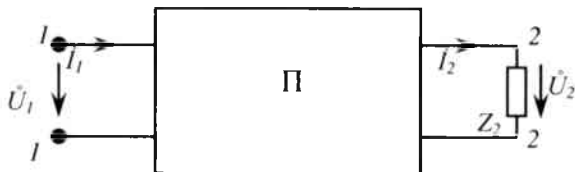
To'rt qutbli (ko'p qutbli) ko'rinishdagi murakkab elektr zanjirni o'rganishdan asosiy maqsad, to'rt qutbli ichki tuzilishidan qati nazar, zanjirning kirish va chiqish qismidagi funksional bog'lanish aniqlanadi. Ya'ni, to'rt qutbli kirish qismidagi tok va kuchlanish U_1 va I_1 ma'lum bo'lsa, chiqishdagi U_2 va I_2 ni aniqlash qonuniyati va bog'lanishini topish kerak.

To'rt qutbli ichki parametr tavsiyalariga ko'ra, kirish va chiqish qismlarini bog'lovchi tenglama chiziqli yoki nochiziqli bo'lishi mumkin.

Ichki tarmoqlarida EYK va tok manbai bo'lmasa to'rt qutbli passiv bo'ladi (liniya simlari, transformator, to'g'rilash sxemasi, to'g'rilagichi filtri va hokazolar)

Agarda to'rt qutbli ichida juda bo'lmaganda bitta energiya manbai bo'lsa, u *aktiv* bo'ladi.

1. Chiziqli passiv to'rt qutbli asosiy xususiyatini tahlil qilish.



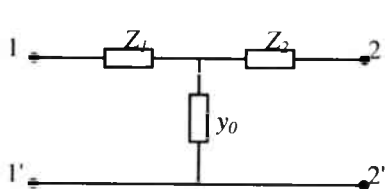
Passiv to'rt qutbli kirish $\dot{I}_1$, $\dot{U}_1$ va chiqish qismlaridagi $\dot{I}_2$, $\dot{U}_2$ tok va kuchlanish chiziqli bo'lgan ikkita tenglama bilan ifodalanadi:

$$\left. \begin{aligned} \dot{U}_1 &= A\dot{U}_2 + B\dot{I}_2 \\ \dot{I}_1 &= C\dot{U}_2 + D\dot{I}_2 \end{aligned} \right\} \quad (8.1)$$

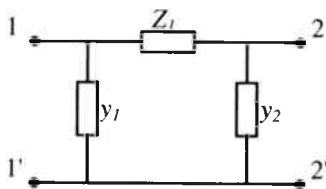
A, B, C, D – to'rt qutbli doimiy koeffitsientga ega bo'lib, bularning bog'lanishi:

$$AD - BC = 1 \quad (8.2)$$

Agarda to'rt qutbli kirish qismi chiqish qismi bilan almashtirilsa (8.1) tenglamadan A va D ko'effitsientining o'rnini almashadi:



T – sxema



Π – sxema

$$\left. \begin{aligned} \dot{U}_1 &= D\dot{U}_2 + A\dot{I}_2 \\ \dot{I}_1 &+ C\dot{U}_2 + A\dot{I}_2 \end{aligned} \right\} \quad (8.3)$$

To'rt qutbli ko'effitsienti: $A=D$ (8.4) bo'lsa simmetrik deyiladi.

To'rt qutblilar doimiy ko'effitsient zanjir parametrlari bilan bog'langan bo'lib, quyidagicha ifodalanadi:

$$A = \frac{\Delta_{2,2}}{\Delta_{1,2}}; \quad B = \frac{\Delta}{\Delta_{1,2}} (om); \quad C = \frac{\Delta_{1,1} \cdot \Delta_{2,2} - \Delta_{1,2}^2}{\Delta \cdot \Delta_{1,2}} \left(\frac{1}{om} \right); \quad D = \frac{\Delta_{1,1}}{\Delta_{1,2}} \quad (8.5)$$

Bunda Δ kontur uchun tuzilgan tenglama sistemasi asosiy xususiy qarshilik determinanti.

$\Delta_{1,1}$, $\Delta_{1,2}$ va $\Delta_{2,2}$ algebraik to'ldiruvchi tenglama tizimi determinanti.

2. Passiv to'rt qutbli almashinish sxemasi bo'yicha parametrini aniqlash.

T – sxemasi parametri $\underline{Z}_1 = \frac{A-1}{C}$; $\underline{Z}_2 = \frac{D-1}{C}$; $\underline{y}_0 = C$; (8.6)

Doimiy ko'effitsient parametrlari orqali:

$$\left. \begin{aligned} A &= 1 + \underline{z}_1 \underline{y}_0; \\ B &= \underline{z}_1 + \underline{z}_2 + \underline{z}_1 \underline{z}_2 \underline{y}_0; \\ C &= \underline{y}_0; \\ D &= 1 + \underline{z}_2 \underline{y}_0; \end{aligned} \right\} \quad (8.7)$$

Π – sxema parametri: $\underline{Z}_0 = B$; $\underline{y}_1 = \frac{D-1}{B}$; $\underline{y}_2 = \frac{A-1}{B}$; (8.8)

yoki ko'effitsient parametrlari orqali:

$$\left. \begin{aligned} A &= 1 + \underline{y_2 z_0}; \\ B &= \underline{z_0}; \\ C &= \underline{y_1} + \underline{y_2} + \underline{y_1 y_2 z_0} \\ D &= 1 + \underline{y_1 z_0}; \end{aligned} \right\} \quad (8.9)$$

3. To'rt qutbli parametrlarni tajriba asosida aniqlash.

Tajriba asosida to'rt qutbli doimiy koeffitsientni aniqlashda kirish va chiqish qismidan ikki marta salt va qisqa tutashuv tajribasi o'tkaziladi. Natijada chiqish qismida qisqa tutashuv bo'lganda (8.1) tenglamadan:

$$\underline{z_{1k}} = \frac{B}{D}; \quad (8.10)$$

$$\text{chiqish qismida salt holat tajribasiga asosan: } \underline{y_{1,0}} = \frac{C}{A}; \quad (8.11)$$

Endi to'rt qutbli kirish va chiqish qismlari o'rnini almashtirilib, tajriba o'tkazilganda:

$$\underline{z_{2k}} = \frac{A}{B}; \quad \underline{y_{2,0}} = \frac{C}{D}; \quad (8.12)$$

$$\text{To'rt qutbli parametri o'xshashligidan: } \underline{z_{1k} y_{1,0}} = \underline{z_{2k} y_{2,0}} \quad (8.13)$$

$$A = \sqrt{z_{1k} \cdot z_{10} / z_{20} (z_{10} - z_{1k})} \quad (8.13a)$$

4. Simmetrik to'rt qutbli uzatuvchanlik funksiya va tavsifiy (operator) qarshiligi.

$$\text{Tavsifiy qarshilik: } \underline{z_c} = \frac{\dot{U}_2}{\dot{I}_2} = \frac{\dot{U}_1}{\dot{I}_1} = \sqrt{\frac{B}{C}}; \quad (8.14)$$

Bunda uzatish koeffitsienti:

$$\left. \begin{aligned} \bar{g} &= \bar{a} + j\bar{b} = \ln \frac{\dot{I}_1}{\dot{I}_2} = \ln \left(A + \sqrt{A^2 + 1} \right) = \ln \left(A + \sqrt{BC} \right) \\ \text{So'nish koeffitsienti: } \bar{a} &= \text{Re } g = \ln \frac{\dot{U}_1}{\dot{U}_2} = \ln \frac{\dot{I}_1}{\dot{I}_2} \\ \text{Faza koeffitsienti: } \bar{b} &= \ln g = \bar{\varphi}_1 - \bar{\varphi}_2 = \bar{\varphi}_1 - \bar{\varphi}_2 \text{ (rad / sek)} \end{aligned} \right\} \quad (8.15)$$

Bu tenglamalardan to'rt qutbli kirish qismidagi tok va kuchlanish:

$$\dot{U} = \dot{U}_1 e^{j\varphi}; \quad \dot{I}_1 = \dot{I}_1 e^{j\varphi}; \quad (8.16)$$

Chiqish qismidagi tok va kuchlanish ifodalari (Z_2 – qarshilik ulanganda):

$$\dot{U}_2 = \dot{U}_2 e^{j\varphi_2}; \quad \dot{I}_2 = \dot{I}_2 e^{j\varphi_2} \quad (8.17)$$

Tavsifiy qarshilik (Z_c) bilan to'rt qutbli koeffitsient bog'lanish tenglamasi:

$$A = D = chg; \quad B = \underline{Z}_2 shg; \quad C = \frac{1}{\underline{Z}_2} shg; \quad (8.18)$$

Aniqlangan qiymatni (8.1) tenglamaga qo'yamiz:

$$\left. \begin{aligned} \dot{U}_1 &= \dot{U}_2 chg + Z_c \dot{I}_2 shg; \\ \dot{I}_1 &= \dot{U}_2 \frac{shg}{Z_c} + \dot{I}_2 chg \end{aligned} \right\} \quad (8.19)$$

8.19 tavsifiy qarshilik va uzatish koeffitsienti tajriba asosida salt holatda: $I_2 = 0$; $Z_0 = \frac{\dot{U}_{10}}{\dot{I}_{10}} = \frac{Z_c}{thg}$ yoki qisqa tutashuvga asosan:

$$\dot{Z}_q = \frac{\dot{U}_{1q}}{\dot{I}_{1q}} = \dot{Z}_c thg$$

$$\text{Bundan: } Z_s = \sqrt{Z_0 Z_q}; \quad thg = \sqrt{\frac{Z_q}{Z_0}}$$

5. To'rt qutbli har xil turda ifodalash tenglamalari.

To'rt qutbli ulanish sxemasiga qarab turli xil ko'rinishdagi tenglamalardan foydalanish mumkin:

$$\begin{aligned} \text{Ifoda [z]} \quad \dot{U}_1 &= \underline{z}_{11} \dot{I}_1 + \underline{z}_{12} \dot{I}_2; \\ \dot{U}_2 &= \underline{z}_{21} \dot{I}_1 + \underline{z}_{22} \dot{I}_2; \end{aligned} \quad (8.20)$$

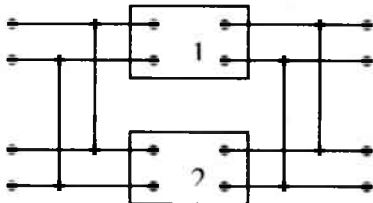
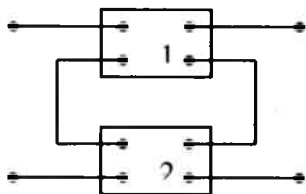
$$\begin{aligned} \text{Ifoda [y]} \quad \dot{I}_1 &= \underline{y}_{11} \dot{U}_1 + \underline{y}_{12} \dot{U}_2; \\ \dot{I}_2 &= \underline{y}_{21} \dot{U}_1 + \underline{y}_{22} \dot{U}_2; \end{aligned} \quad (8.21)$$

$$\begin{aligned} \text{Ifoda [g]} \quad \dot{I}_1 &= \underline{g}_{11} \dot{U}_1 + \underline{g}_{12} \dot{I}_2; \\ \dot{U}_2 &= \underline{g}_{21} \dot{U}_1 + \underline{g}_{22} \dot{I}_2; \end{aligned} \quad (8.22)$$

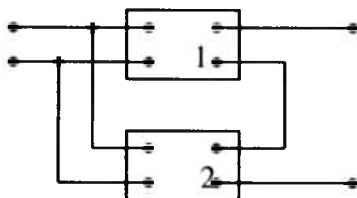
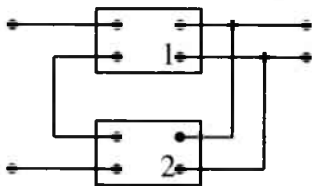
$$\begin{aligned} \text{Ifoda [h]} \quad \dot{U}_1 &= \underline{h}_{11} \dot{I}_1 + \underline{h}_{12} \dot{U}_2; \\ \dot{I}_2 &= \underline{h}_{21} \dot{I}_1 + \underline{h}_{22} \dot{U}_2; \end{aligned} \quad (8.23)$$

6. To'rt qutbli ulanishi sxemasi.

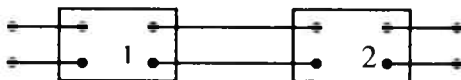
To'rt qutbli elektr zanjirni analiz qilishdan maqsad ekvivalent doimiy koeffitsientini aniqlashdan iborat bo'lib, ketma-ket ulangan to'rt qutbli doimiy koeffitsientini aniqlashda (z) tenglamasidan foydalaniladi.



Parallel ulangan to'rt qutbli (y) formadagi tenglamadan foydalaniladi.



To'rt qutbli ketma-ket va parallel sxemada ulanganda (h) tenglamasidan, parallel va ketma-ket sxemada ulanishda (g) tenglamasidan foydalangan qulay.



Kaskad sxemada ulangan bo'lsa (a) (8.1) tenglamadan foydalaniladi.

8.2. Masala yechish va uslubiy ko'rsatmalar

Masala 8.1. Simmetrik to'rt qutbli zanjirning doimiy koeffitsienti: $A = 2 + j3$ va $B = (1 + j)$ Om ga teng bo'lganda, C – koeffitsienti aniqlansin.

Yechish. (8. 2) va (8. 4) tenglamadan

$$C = \frac{A^2 - 1}{B} = \frac{(2 + j3)^2 - 1}{(1 + j)} = 3 + j9 \frac{1}{Om}$$

Masala 8.2. To'rt qutbli qisqa tutashuv va salt holat tajribalari o'tkazilib tok va kuchlanishning quyidagi qiymati aniqlangan.

a) qisqa tutashuv: $\dot{U}_2 = 0$; $\dot{I}_{2k} = 0,05e^{j93^\circ}$ (A);

$$\dot{U}_k = 100 \text{ (V)}; \dot{I}_{1k} = 0,04e^{j87^\circ} \text{ (A)};$$

b) salt holatda: $\dot{I}_{20} = 0$; $\dot{U}_{20} = 180e^{j15^\circ}$ (V);

$$\dot{U}_{10} = 100 \text{ (V)}; \dot{I}_{10} = 0,055e^{-j57^\circ} \text{ (A)};$$

To'rt qutbli doimiy koeffitsienti hisoblab topilsin.

Yechish. (8. 1) tenglamaga asosan qisqa tutashganda ($\dot{U}_2 = 0$):

$$\dot{U}_{1k} = B\dot{I}_{2k}; \quad \dot{I}_{1k} = D\dot{I}_{2k};$$

$$\text{Bundan: } B = \frac{\dot{U}_{1k}}{\dot{I}_{2k}} = 2000e^{-j93^\circ} \text{ (Om)}; \quad D = \frac{\dot{I}_{1k}}{\dot{I}_{2k}} = 0,8e^{-j16^\circ};$$

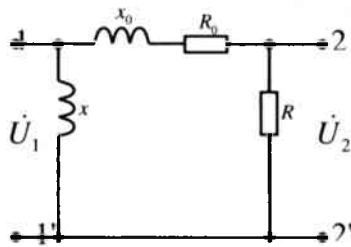
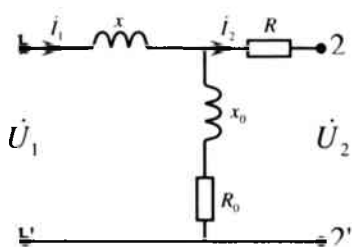
Salt holatda: $\dot{I}_2 = 0$; bo'lib (8. 1) dan: $\dot{U}_{10} = A\dot{U}_{20}$; $\dot{I}_{10} = C\dot{U}_{20}$;

$$\text{Bundan: } A = \frac{\dot{U}_{10}}{\dot{U}_{20}} = 0,555e^{-j15^\circ}; \quad C = \frac{\dot{I}_{10}}{\dot{U}_{20}} = 3,06 \cdot 10^{-4} e^{-j72^\circ} \left(\frac{1}{Om} \right);$$

Tekshiramiz:

$$AD - BC = 0,555e^{-j15^\circ} \cdot 0,8e^{-j16^\circ} - 2000e^{-j93^\circ} \cdot 3,06 \cdot 10^{-4} e^{j72^\circ} \approx 1$$

Masala 8.3. Parametri $R=10 \text{ (Om)}$, $x=10 \text{ (Om)}$, $x_0=5 \text{ (Om)}$, $R_0=5 \text{ (Om)}$ bo'lgan, T va Π shaklda ulangan to'rt qutbli doimiy A , B , C , D koeffitsienti aniqlansin:



Yechish. (8. 7) tenglamaga asosan T sxema uchun:

$$A = 1 + \underline{z}_1 \underline{y}_0 = 1 + \frac{\underline{x}}{R_0 + \underline{x}_0} = 1 + \frac{j10}{5 + j5} = 1 + \frac{10j^{90^\circ}}{5\sqrt{2}e^{j45^\circ}} = 1 + \sqrt{2}e^{j45^\circ} = 1 + 1 + j = 2 + j;$$

$$B = \underline{z}_1 \underline{z}_2 + \underline{z}_1 \underline{z}_2 \underline{y}_0 = \underline{x} + R + \frac{\underline{x}R}{R_0 + \underline{x}_0} = j10 + 10 + \frac{j10 \cdot 10}{5 + j5} = j10 + 10 + 10\sqrt{2}e^{j45^\circ} = \\ = j10 + 10 + 10 + j10 = 20 + j20 \text{ Om}$$

$$C = \underline{y}_0 = \frac{1}{R_0 + \underline{x}_0} = \frac{1}{5\sqrt{2}e^{j45^\circ}} = \frac{\sqrt{2}e^{-j45^\circ}}{10} = \frac{\sqrt{2}e^{j45^\circ}}{10} = 0,1 + j0,1 \left(\frac{1}{\text{Om}} \right);$$

$$D = 1 + \underline{z}_2 \underline{y}_0 = 1 + \frac{10}{5\sqrt{2}e^{j45^\circ}} = 1 + \sqrt{2}e^{-j45^\circ} = 1 + 1 - j = 2 - j;$$

(8. 9) tenglamaga asosan II sxema uchun:

$$A = 1 + \underline{z}_0 \underline{y}_2 = 1 + \frac{\underline{x}_0 + \underline{z}_0}{R_3} = 1 + \frac{5\sqrt{2}e^{j45^\circ}}{10} = 1 + 0,5 + j0,5 = 1,5 + j0,5;$$

$$B = \underline{z}_0 = \underline{x}_0 + R_0 = 5 + j5 \text{ Om};$$

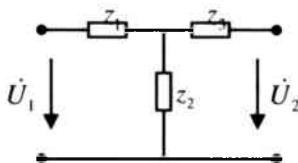
$$C = \underline{y}_1 + \underline{y}_2 + \underline{y}_1 \underline{y}_2 \underline{z}_0 = -j0,1 + 0,1 + \frac{5\sqrt{2}e^{j45^\circ}}{10 \cdot 10e^{j90^\circ}} = -j0,1 + 0,1 + 0,05\sqrt{2}e^{j45^\circ} = \\ = -j0,1 + 0,1 + 0,05 - j0,05 = 0,15 - j0,15 \left(\frac{1}{\text{Om}} \right);$$

$$D = 1 + \underline{z}_0 \underline{y}_1 = 1 + \frac{R_0 + \underline{x}_0}{\underline{x}} = 1 + \frac{5\sqrt{2}e^{j45^\circ}}{10e^{j90^\circ}} = 1 + 0,5 - j0,5 = 1,5 + j0,5;$$

Masala 8.4. To'rt qutbli doimiy koeffitsienti: $A = 1 - j3$, $B = -3 - j30$, $C = -j0,1$, $D = -1$ bo'lib, ekvivalent T va II shakldagi sxema tuzilsin.

Yechish. (8. 6) tenglamaga asosan T sxema tuzish uchun parametrlar aniqlanadi.

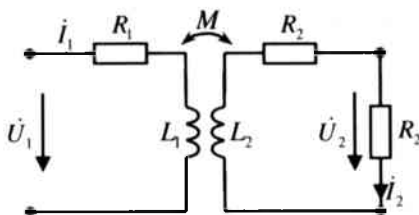
$$\underline{z}_1 = \frac{A-1}{C} = \frac{1-j3-1}{-j0,1} = 30(\text{Om}); \quad \underline{z}_2 = \frac{1}{C} = j10(\text{Om}); \quad \underline{z}_3 = \frac{D-1}{C} = \frac{-1-1}{-j0,1} = -j20(\text{Om});$$



(8.8) Tenglamaga asosan Π sxema tuzish uchun parametr aniqlanadi:

$\underline{z}_0 = B = -3 - j30$ teng Π – shakldagi sxemani tuzish mumkin emas, sababi aktiv qarshilik qiymati minus ishora bilan berilgan.

Masala 8.5. Transformatorning ikkilamchi chulg‘amidagi tok $I_2 = 1$ A, kuchlanishi $\dot{U}_2 = 20$ V bo‘lib, aktiv qarshilik ulangan. Transformatorning parametr qarshiligi $R_1 = R_2 = 1$ Om, $\underline{X}_{L_1} = \underline{X}_{L_2} = 25$ Om, o‘zaro induksiya $\underline{x}_M = \omega M = 20$ Om bo‘lganda, kirish qismidagi birlamchi chulg‘amdagi tok $\dot{I}_1$ va kuchlanish $\dot{U}_1$ aniqlansin.



Yechish.

Transformator ekvivalent sxemasi T sxemaga mos keladi, shuning uchun T sxema parametrini aniqlaymiz.

$$\underline{Z}_1 = \underline{Z}_2 = R + j\omega(L_1 - M) = 1 + j25 - j20 = 1 + j5 \text{ Om};$$

$$\underline{y}_0 = \frac{1}{j\omega M} = \frac{1}{j20} = -j0,05 \left(\frac{1}{\text{Om}} \right);$$

(8.7) tenglamaga asosan to‘rt qutbli doimiy koeffitsientni aniqlaymiz. Bunda $\underline{z}_1 = \underline{z}_2$ bo‘lganligi uchun: $A = D$

$$A = D = 1 + \underline{z}_1 \underline{y}_0 = 1 + (1 + j5) \cdot (-j0,05) = 1,25 - j0,05;$$

$$B = \underline{z}_1 + \underline{z}_2 + \underline{z}_1 \underline{z}_2 \underline{y}_0 = 2(1 + j5) + (1 + j5) \cdot (-j0,05) = 2,5 + j11,2 \text{ Om};$$

$$C = \underline{y}_0 = -j0,05 \left(\frac{1}{\text{Om}} \right);$$

Transformator ulangan iste‘molchi qarshiligi aktiv bo‘lganligi uchun:

$\dot{U}_2 = U_2 = 20$ (V); tok $\dot{I}_2 = I_2 = 1$ (A) teng ushbu qiymatlarini (8. 1) tenglamaga qo‘yamiz:

$$\dot{U}_1 = A\dot{U}_2 + B\dot{I}_2 = (1,25 - j0,05) \cdot 20 + (2,5 + j11,2) \cdot 1 = (27,1 + j10,2)$$

$$\dot{I}_1 = C\dot{U}_2 + D\dot{I}_2 = (-j0,05) \cdot 20 + (1,25 - j0,05) \cdot 1 = (1,25 - j1,05)$$

$$\text{Demak: } U_1 = \sqrt{27,5^2 + 10,2^2} = 28,5V; \quad I_1 = \sqrt{1,25^2 + 1,05^2} = 1,6A;$$

Masala 8.6. To'rt qutbli simmetrik bo'lib, koeffitsienti: $A = 1 + j2$ va $B = -80 + j240$ ga teng. Qisqa tutashuv va salt holat to'la kompleks qarshilikni hisoblang.

Yechish.

$$\text{To'rt qutbli simmetrik bo'lganligi uchun: } A = D = 1 + j2; \quad (8.2)$$

$$\text{tenglamadan } C \text{ koeffitsientni topamiz: } C = \frac{AD-1}{B} = \frac{A^2-1}{B}; \quad (8.1)$$

$$\text{tenglamadan to'rt qutbli salt holati uchun: } \dot{U}_{10} = A\dot{U}_2; \quad \dot{I}_{10} = C\dot{U}_2;$$

yoki $\frac{U_{10}}{I_{10}} = \frac{A}{C};$

$$\text{Bunda: } Z_{10} = \frac{AB}{A^2-1} = \frac{(1+j2) \cdot (-80+j240)}{(1+j2)^2-1} = 80 + j60 = 100e^{j36,45^\circ} (Om);$$

$$\text{Qisqa tutashuv holatdagi tenglama: } \dot{U}_{1k} = B\dot{I}_2; \quad \dot{I}_{1k} = D\dot{I}_2; \text{ yoki } \frac{\dot{U}_{1k}}{\dot{I}_{1k}} = \frac{B}{D};$$

$$Z_{1k} = \frac{-80 + j240}{1 + j2} = \frac{253e^{j108^\circ}}{2,24e^{j63^\circ}} = 112e^{j45^\circ} = 78 + j80,7 Om;$$

Masala 8.7. To'rt qutbli zanjir kirish qismida qisqa tutashuv va salt holat, chiqish qismida salt holat tajribasi o'tkazilib o'lchov asbobi yordamida quyidagi qiymatlar aniqlangan:

$$\dot{U}_{10} = 158 B; \quad \dot{I}_{10} = 10 A; \quad P_{10} = 500 \text{ Vt}; \quad \varphi_{10} > 0;$$

$$\dot{U}_{1k} = 126,5 B; \quad \dot{I}_{1k} = 10 A; \quad P_{1k} = 400 \text{ Vt}; \quad \varphi_{1k} > 0;$$

$$\dot{U}_{20} = 158 B; \quad \dot{I}_{20} = 10 A; \quad P_{20} = 1500 \text{ Vt}; \quad \varphi_{20} > 0;$$

To'rt qutbli zanjir doimiy koeffitsienti aniqlansin.

Yechish.

O'lchov asboblari ko'rsatish qiymatiga asosan to'rt qutbli salt holat uchun kirish qismidagi to'la qarshilik: $Z_{10} = \frac{U_{10}}{I_{10}} = \frac{158}{10} = 15,8 Om$

Quvvat koeffitsienti: $\cos \varphi_{10} = \frac{P_{10}}{\dot{U}_{10} \cdot \dot{I}_{10}} = \frac{500}{158 \cdot 10} = 0,316; \quad \varphi_{10} = 71^\circ 30'$

yoki: $\underline{Z}_{10} = 15,8e^{j71^\circ 30'} = 5 + j15$

Qisqa tutashuv holatda to'la qarshilik: $\underline{Z}_{1k} = \frac{\dot{U}_{1k}}{\dot{I}_{1k}} = \frac{126,5}{10} = 12,65 \text{ Om};$

Quvvat koeffitsienti:

$$\cos \varphi_{1k} = \frac{P_{1k}}{\dot{U}_{1k} \cdot \dot{I}_{1k}} = \frac{400}{126,5 \cdot 10} = 0,31; \quad \varphi_{1k} = 71^\circ 30',$$

yoki: $\underline{Z}_{1k} = 12,65e^{j71^\circ 30'} = 12,6 + j4,3$

To'rt qutbli chiqish qismidagi salt holat to'la qarshiligi:

$$\underline{Z}_{20} = \frac{\dot{U}_{20}}{\dot{I}_{20}} = 15,81 \text{ (Om)};$$

Quvvat koeffitsienti: $\cos \varphi_{20} = \frac{P_{20}}{\dot{U}_{20} \cdot \dot{I}_{20}} = \frac{1500}{158 \cdot 10} = \frac{1500}{1580} = 0,94; \quad \varphi_{20} = 19^\circ,$

yoki: $\underline{Z}_{20} = 15,81e^{j19^\circ} = 15 + j5$

To'rt qutbli (8.10), (8.11), (8.12) tenglamasiga asosan koeffitsientni aniqlaymiz:

$$A = \frac{\underline{Z}_{10}}{\sqrt{\underline{Z}_{20} \cdot \underline{Z}_{10} \cdot \underline{Z}_{1k}}} = \frac{5 + j15}{\sqrt{(15 + j5) \cdot (5 + j15) \cdot (12,6 + j4,3)}} = 1,023e^{j26^\circ}$$

$$C = \frac{1}{\underline{Z}_{10}} = \frac{1}{5 + j5} = 0,064e^{-j45^\circ};$$

$$D = C \cdot \underline{Z}_{10} = 0,064e^{j45^\circ} \cdot 15,8e^{j71^\circ 30'} = 1,02e^{j25^\circ 30'};$$

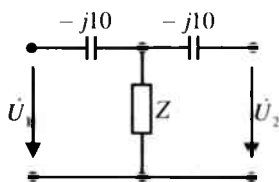
$$B = D \cdot \underline{Z}_{1k} = 1,02e^{j25^\circ} \cdot 12,65e^{j71^\circ 30'} = 13e^{j96^\circ 30'}.$$

Masala 8.8. Simmetrik T sxema parametri $\underline{x}_1 = -j10 \text{ Om}$, $\underline{x}_2 = -j10 \text{ Om}$, $\underline{z} = 100 \text{ Om}$ ga teng bo'lib, xarakteristik qarshiligi ($\underline{z}_C$) va uzatish koeffitsienti (g) aniqlansin.

Yechish.

To'rt qutbli koeffitsientni aniqlaymiz:

$$A = D = 1 + \underline{Z}_1 \underline{V}_0 = 1 + \frac{-j10}{100} = 1 - j0,1 = 1e^{j5^\circ 30'};$$



$$C = \underline{Y}_0 = \frac{1}{100} = 0,01 \left(\frac{1}{\text{Om}} \right); ;$$

$$B = \frac{1}{C} (A^2 - 1) = -1 - j20 = 20e^{-j93^\circ};$$

(8.14) tenglamaga asosan to'rt qutbli xarakteristik qarshiligi:

$$\underline{Z}_C = \sqrt{\frac{B}{C}} = 44,7e^{-j46^\circ 30'}; ;$$

Uzatish koeffitsienti (8. 15) tenglamadan:

$$g = \ln(\sqrt{A^2} + \sqrt{BC}) = \ln(A + \sqrt{BC})$$

$$\text{Bundan: } A + \sqrt{BC} = 1,31 - j0,42 = 1,38e^{j18^\circ 20'}$$

$$g = \ln 1,38e^{j18^\circ 20'} = \ln 1,38 - j18^\circ 20' = 0,322 - j0,32$$

So'nish koeffitsienti: $a = 0,322$ nep. Faza koeffitsienti:

$$b = -0,32 \text{ rad / sek}.$$

Masala 8.9. To'rt qutbli zanjir doimiy koeffitsient qiymati

$$A = 0,56e^{-j15^\circ}, B = 2000e^{-j93^\circ} (\text{Om}), C = 3,06 \cdot 10^{-4} e^{j72^\circ} \left(\frac{1}{\text{Om}} \right), D = 0,8e^{-j6^\circ} \text{ bo'lib,}$$

[z] forma tenglamasi koeffitsienti aniqlasin.

Yechish.

To'rt qutbli [a] forma tenglamasi:

$$\begin{cases} \dot{U}_1 = A\dot{U}_2 + B\dot{I}_2 \\ \dot{I}_1 = C\dot{U}_2 + D\dot{I}_2 \end{cases}$$

Bu tenglamada kompleks kuchlanishni chap tomonga o'tkazamiz:

$$\begin{cases} \dot{U}_1 - A\dot{U}_2 = B\dot{I}_2 \\ C\dot{U}_2 = \dot{I}_1 - D\dot{I}_2 \end{cases}$$

$$\text{Ikkinchi tenglamadan: } \dot{U}_2 = \frac{1}{C}\dot{I}_1 - \frac{D}{C}\dot{I}_2;$$

Ushbu tenglamani [a] tenglamaning birinchi ifodasidagi $\dot{U}_2$ o'rniga qo'yamiz:

$$\dot{U}_1 = B\dot{I}_2 + A \left(\frac{1}{C}\dot{I}_1 + \frac{D}{C}\dot{I}_2 \right) = \frac{A}{C}\dot{I}_1 - \frac{1}{C}\dot{I}_2;$$

[z] ifodali (6.19) tenglamadan doimiy koeffitsient kompleks qarshiligi:

$$\underline{z}_{11} = \frac{A}{C} = \frac{0,56e^{-j15^\circ}}{3,06 \cdot 10^{-4} e^{j72^\circ}} = 1830e^{j57^\circ};$$

$$\underline{z}_{12} = -\frac{1}{C} = -\frac{1 \cdot 10^4}{3,06 \cdot e^{j72^\circ}} = 3260e^{-j108^\circ}$$

$$\underline{z}_{21} = +\frac{1}{C} = \frac{1 \cdot 10^4}{3,06 \cdot e^{j72^\circ}} = 3260e^{-j72^\circ}$$

$$\underline{z}_{22} = -\frac{D}{C} = -\frac{0,8 \cdot e^{-j6^\circ}}{3,06 \cdot e^{j72^\circ}} = 2600e^{-j114^\circ}$$

Masala 8.10. To'rt qutbli doimiy A, B, C, D koeffitsientlari 8.9-masalada berilgan qiymatlar bo'yicha [y] forma tenglamadagi doimiy koeffitsient aniqlansin.

Yechish.

To'rt qutbli (8.1) tenglamadagi tok $\dot{I}_1$ va $\dot{I}_2$ ifodalarini chap tomonga o'tkazamiz:

$$\left. \begin{aligned} B\dot{I}_2 &= \dot{U}_1 - A\dot{U}_2 \\ \dot{I}_1 - D\dot{I}_2 &= C\dot{U}_2 \end{aligned} \right\}$$

Bundan $\dot{I}_1$ va $\dot{I}_2$ tokni topamiz. Ya'ni $\dot{I}_1 = \frac{\Delta_1}{\Delta}$ va $\dot{I}_2 = \frac{\Delta_2}{\Delta}$

$$\Delta = \begin{vmatrix} 0 & B \\ 1 & -D \end{vmatrix} = -B;$$

$$\Delta_1 = \begin{vmatrix} \dot{U}_1 - A\dot{U}_2 & B \\ C\dot{U}_2 & -D \end{vmatrix} = -\dot{U}_1 D + A D \dot{U}_2 - B C \dot{U}_2 = -D \dot{U}_1 + \dot{U}_2;$$

$$\Delta_2 = \begin{vmatrix} 0 & \dot{U}_1 - A\dot{U}_2 \\ 1 & C\dot{U}_2 \end{vmatrix} = -\dot{U}_1 + A \dot{U}_2;$$

yoki:

$$\left. \begin{aligned} \dot{I}_1 &= \frac{D}{B} \dot{U}_1 - \frac{1}{B} \dot{U}_2 \\ \dot{I}_2 &= \frac{D}{B} \dot{U}_1 - \frac{1}{B} \dot{U}_2 \end{aligned} \right\}$$

Bu toklar tenglamasi $[y]$ formadagi (8.21) tenglamaga o'xshashligi sababli doimiy koeffitsientini ifodalovchi parametrlarni topamiz:

$$\underline{y}_{11} = \frac{D}{B}; \quad \underline{y}_{12} = -\frac{1}{B}; \quad \underline{y}_{21} = \frac{1}{B}; \quad \underline{y}_{22} = -\frac{A}{B}$$

A, B, C, D koeffitsient qiymatini qo'ysak:

$$\underline{y}_{11} = \frac{0,8e^{-j6^\circ}}{2000e^{-j93^\circ}} = 10^{-4} (0,21 + j4) \left(\frac{1}{Om} \right);$$

$$\underline{y}_{12} = \frac{1}{2000e^{-j93^\circ}} = 10^{-4} (0,26 - j5) \left(\frac{1}{Om} \right);$$

$$\underline{y}_{21} = -\underline{y}_{12} = 10^{-4} (0,26 + j5) \left(\frac{1}{Om} \right);$$

$$\underline{y}_{22} = \frac{0,5e^{-j15^\circ}}{2000e^{-j93^\circ}} = 10^{-4} (-0,58 - j2,74) \left(\frac{1}{Om} \right);$$

Masala 8.11. To'rt qutbli doimiy koeffitsienti 8.9-masalada berilgan qiymatlar bo'yicha $[g]$ forma tenglamasidagi doimiy koeffitsient qiymati hisoblab topilsin.

Yechish.

To'rt qutbli asosiy $[a]$ forma tenglamasidagi (8.3) tok i_1 va kuchlanish $\dot{U}_2$ ga nisbatan yechamiz:

$$\text{bunda } \dot{U}_2 = \frac{1}{A} (\dot{U}_1 - B\dot{I}_2) = \frac{1}{A} \dot{U}_1 - \frac{B}{A} \dot{I}_2;$$

Bu tenglamani (8.3) tenglamadagi $\dot{U}_2$ kuchlanish o'rniga qo'yamiz:

$$\dot{I}_1 = \frac{C}{A} (\dot{U}_1 - B\dot{I}_2) + D\dot{I}_2 = \frac{C}{A} \dot{U}_1 - \frac{1}{A} \dot{I}_2;$$

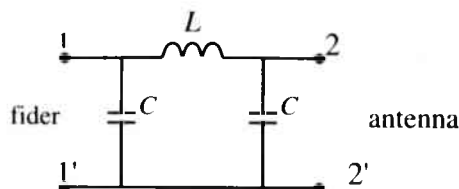
Bu ikkala tenglamaning to'rt qutbli $[g]$ formadagi (8.22) o'xshashligidan doimiy koeffitsient parametrini aniqlaymiz:

$$\underline{g}_{11} = \frac{C}{A} = \frac{3,06 \cdot 10^{-4} e^{-j72^\circ}}{0,56e^{-j15^\circ}} = 5,46 \cdot 10^{-4} e^{-j57^\circ} \left(\frac{1}{Om} \right);$$

$$\begin{aligned} \underline{g}_{12} &= \frac{1}{A} = \frac{1}{0,56e^{-j15^\circ}} = 1,78e^{j15^\circ} \left(\frac{1}{Om} \right); \\ \underline{g}_{21} &= -\frac{1}{A} = -\frac{1}{0,56e^{-j15^\circ}} = 1,78e^{j15^\circ} \left(\frac{1}{Om} \right); \\ \underline{g}_{22} &= -\frac{B}{A} = -\frac{2000e^{-j93^\circ}}{0,56e^{-j15^\circ}} = 3570e^{j102^\circ} \left(\frac{1}{Om} \right); \end{aligned}$$

Masala 8.12. To'liq qarshilik $\underline{z}_0 = 125(Om)$ $C_0 = 5 \cdot 10^5 \left(\frac{1}{sek} \right)$ bo'lgan

Π shaklidagi to'rt qutbli fiderga antennani rostdash uchun $R_A = 500(Om)$ aktiv qarshilik ulangan. To'rt qutbli parametri L, C ni hisoblab toping.



Yechish.

To'rt qutbli [a] tenglamasini (8.1) va (8.4) dan kuchlanish ifodasini tokga bo'lamiz hamda to'rt qutbli kirish qismida fider $\underline{Z}_F$ to'la qarshilik antenna bilan rostdanishini inobatga olamiz.

$$\text{Bunda: } \underline{Z}_F = \frac{A\dot{U}_2 + B\dot{I}_2}{C\dot{U}_2 + A\dot{I}_2} = \frac{A\underline{Z}_a + B}{C\underline{Z}_a + A};$$

Xuddi shunga o'xshash to'rt qutbli chiqish qismidagi antenna to'la qarshilikka: $\underline{Z}_a = \frac{A\dot{U}_1 + B}{C\dot{U}_1 + A}.$

Bu ikkita tenglamaga ($\underline{Z}_F, \underline{Z}_a$) to'rt qutbli (8.2) tenglamani qo'shib hisobga olgan holda, uchta noma'lum tenglama sistemasini A, B, C, D ko'effitsientga nisbatan yechamiz.

Berilgan qiymat qo'shilganda quyidagicha tenglama hosil bo'ladi:

$$\left. \begin{aligned} 375A + B + 250^2C &= 0; \\ -375A + B - 250^2C &= 0; \\ A^2 - BC &= 1; \end{aligned} \right\}$$

Birinchi tenglamadan ikkinchisini ayirsak: $A=0$;

Hamda: $\frac{B}{C} = 250^2$; $BC = -1$;

Bu qiymatni tenglama sistemasiga qo'shish bilan:

$$B = j250(\Omega m)$$

$$C = j4 \cdot 10^{-3} \left(\frac{1}{\Omega m} \right)$$

Π shaklda sxemaning Z va Y parametrlarini (8.8) tenglamaga asosan topamiz:

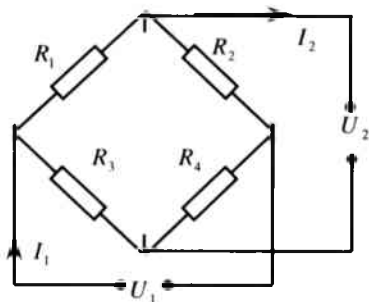
$$\underline{Z}_0 = B = j250 \Omega m$$

$$\underline{Y} = \frac{A-1}{B} = -\frac{1}{B} = -\frac{1}{j250} = 4 \cdot 10^{-3} \left(\frac{1}{\Omega m} \right)$$

Bundan induktivlik: $L = \frac{Z_0}{\omega} = \frac{250}{5 \cdot 10^5} = 5 \cdot 10^{-4} (Gn) = 0,5 (mGn)$

Sig'im parametri: $C = \frac{Y}{\omega} = \frac{4 \cdot 10^{-3}}{5 \cdot 10^5} = 0,8 \cdot 10^{-8} (F) = 8 (mgF)$

Masala 8.13. Ko'prik sxemada ulangan to'rt qutbli elektr zanjirning parametri: $R_1 = 1 \Omega m$, $R_2 = 3 \Omega m$, $R_3 = R_4 = 2 \Omega m$ ga teng. To'rt qutbli elektr zanjir doimiy koeffitsienti A,B,C,D ni aniqlang.



Yechish. To'rt qutbli zanjir doimiy koeffitsientini aniqlash uchun salt ishlash va qisqa tutashuv tajribasidan foydalanamiz:

yoki : $A = \sqrt{\frac{R_{10}}{R_{20} - R_{2K}}}$ bundan:

$$R_{10} = \frac{(R_1 + R_2)(R_3 + R_4)}{R_1 + R_2 + R_3 + R_4} = \frac{(1+3)(2+2)}{1+3+2+2} = \frac{16}{8} = 2 \text{ Om}$$

$$R_{20} = \frac{(R_1 + R_3)(R_2 + R_4)}{R_1 + R_2 + R_3 + R_4} = \frac{3 \cdot 5}{1+3+2+2} = \frac{15}{8} \text{ Om}$$

$$R_{2K} = \frac{R_1 R_2}{R_1 + R_2} + \frac{R_3 R_4}{R_3 + R_4} = \frac{3}{4} + 1 = \frac{7}{4} \text{ Om}$$

demak: $A = \sqrt{\frac{2}{\frac{15}{8} - \frac{7}{4}}} = 4$

(8.10), (8.11), (8.12) tenglamaga asosan

$$C = \frac{A}{R_{0x}} = \frac{4}{2} = 2 \frac{1}{\text{Om}} \quad B = R_{2x} = 4 \cdot \frac{7}{4} = 7 \text{ Om}$$

$$D = C R_{2K} = 2 \cdot \frac{15}{8} = 3,75 \text{ Om}$$

Tekshirib ko'ramiz: $AD - BC = 4 \cdot 3,75 - 7 \cdot 2 = 1$

Masala 8.14. T sxema to'rt qutbli parametri $Z_1 = j2 \text{ Om}$, $Z_2 = j2 \text{ Om}$, $Z_3 = 2 \text{ Om}$ bo'lganda, (b) formadagi koeffitsientini toping.

Yechish. (b) ko'rinishda ifodalanuvchi to'rt qutbli tenglamaga asosan:

$$\dot{I}_1 = 0 \text{ bo'lganda } B_{11} = \frac{\dot{U}_1}{\dot{U}_2} = \frac{Z_2 + Z_3}{Z_3} = 1 - j1$$

$$\dot{U}_1 = 0 \text{ bo'lganda } B_{12} = \frac{\dot{U}_2}{\dot{I}_1} = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3} = 2 \text{ Om}$$

$$\dot{I}_1 = 0 \text{ bo'lganda } B_{21} = \frac{\dot{I}_2}{\dot{U}_1} = \frac{1}{Z_3} = 0,5 \frac{1}{\text{Om}}$$

$$\dot{U}_1 = 0 \text{ bo'lganda } B_{22} = \frac{\dot{I}_2}{\dot{I}_1} = \frac{Z_1 + Z_3}{Z_3} = 1 + j1$$

Yechimini tekshiramiz: $B_{11} \cdot B_{22} - B_{12} B_{21} = \frac{Z_3^2}{Z_3^2} = 1$

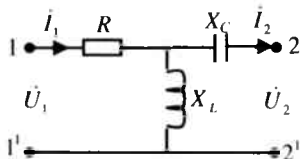
Masala 8.15: II sxemadagi to'rt qutbli elektr zanjirga $Z_2 = 5 + j5$ iste'molchi ulangan bo'lib, $\dot{U}_1 = 100 \text{ V}$ kuchlanish qo'yilgan. Tok $\dot{I}_1$ va iste'molchi kuchlanishi $\dot{U}_2$ qiymati aniqlansin.

Yechish. (8.1) tenglamadan iste'molchi kuchlanishini $\dot{U}_2 = \dot{Z}_2 \dot{I}_2$ inobatga olgan holda: $\dot{U}_1 = \left(A + \frac{B}{Z_n}\right) \dot{U}_2$; $\dot{I}_1 = \left(C + \frac{D}{Z_2}\right) \dot{U}_2$,

yoki:

$$\begin{aligned}\dot{U}_2 &= \dot{U}_1 \left(A + \frac{B}{Z_2}\right)^{-1} = 100 \left(1 - j + \frac{10}{5\sqrt{2}e^{j45^\circ}}\right)^{-1} = 100(1 - j + 1 - j)^{-1} = \\ &= 100(2 - j)^{-2} = \frac{100}{2\sqrt{2}e^{j45^\circ}} = \frac{50}{\sqrt{2}} e^{j45^\circ} B. \\ \dot{I}_1 &= \dot{U}_2 \left(C + \frac{D}{Z_2}\right) = \frac{50e^{j45^\circ}}{\sqrt{2}} \left(0,1 + \frac{\sqrt{2}e^{j45^\circ}}{5\sqrt{2}e^{j45^\circ}}\right) = \frac{50}{\sqrt{2}} e^{j45^\circ} (0,1 + 0,2) = \frac{15}{\sqrt{2}} e^{j45^\circ} A\end{aligned}$$

Masala 8.16. T sxemada ulangan to'rt qutbli elektr zanjir parametri $R = X_L = 10 \text{ Om}$, $X_C = 20 \text{ Om}$ ga teng. Salt holat va qisqa tutashuv tajriba va xarakteristik tenglamasi asosida A, B, C, koeffitsienti aniqlansin.



Yechish. a) to'rt qutbli elektr zanjirga U_1 kuchlanish ulahib, chiqish qismida salt holat bo'lganda (8.1) tenglamadan:

$$\begin{aligned}A &= \frac{\dot{U}_1}{\dot{U}_{20}} = \frac{\dot{U}_1}{\frac{\dot{U}_1}{R + jx_L} jx_L} = \frac{R + jx_L}{jx_L} = \frac{10 + j10}{j10} = \frac{\sqrt{2}10e^{j45^\circ}}{10e^{j90^\circ}} = \sqrt{2}e^{-j45^\circ} \\ C &= \frac{\dot{I}_{10}}{\dot{U}_{20}} = \frac{\dot{I}_{10}}{\dot{I}_{10} \cdot jx_L} = \frac{1}{jx_L} = \frac{1}{j10} = -j0,1 = 0,1e^{-j90^\circ} \left(\frac{1}{\text{Om}}\right)\end{aligned}$$

Chiqishda qisqa tutashuv bo'lganda :

$$\begin{aligned}B &= \frac{\dot{U}_1}{\dot{I}_{2q}} = \frac{\dot{U}_1}{\frac{\dot{U}_1}{\left(\frac{1}{R} + \frac{1}{jx_L} - \frac{1}{jx_C}\right)} (-jx_C)} = \\ &= -j200(0,1 - j0,1 + j0,05) = 22,4e^{-j116^\circ} \text{ Om}.\end{aligned}$$

$$D = \frac{\dot{I}_{1k}}{\dot{I}_{2k}} = \frac{\dot{I}_{1k}}{\frac{\dot{I}_{1k} jx_L}{jx_L - jx_C}} = \frac{j(X_L - X_C)}{jx_L} = \frac{-j10}{j10} = -1$$

Masalaning yechimini tekshiramiz:

$$\begin{aligned} AD - BC &= \sqrt{2}e^{-j45^\circ}(-1) - 22,4e^{-j116^\circ} \cdot 0,1e^{-j90^\circ} = \\ &= -(1-j) + j0,1(-10+j20) = -1+j-j+2=1. \end{aligned}$$

b) endi xarakteristik tenglama orqali to'rt qutbli koefitsientni aniqlaymiz.

Salt ishlash tajribasida, kirish qismida xarakteristik qarshiligi:

$$Z_{10} = R + jx_L = 10 + j10 = \sqrt{2} \cdot 10e^{j45^\circ} \text{ Om}$$

qisqa tutashuvda esa:

$$Z_{1k} = \frac{R + jx_L(-jx_C)}{j(X_L - X_C)} = \frac{10 + j10(-j20)}{-j10} = 10 + j20 = 22,8e^{j63^\circ} \text{ Om}$$

Kirishda qisqa tutashtirilgan holda, chiqishdagi xarakteristik qarshilik:

$$\begin{aligned} Z_{2k} &= \frac{-jx_C + R_j X_L}{R + jx_L} = \frac{-j20 + 10 \cdot j10}{\sqrt{2}e^{j45^\circ}} = -j20 + \frac{10}{\sqrt{2}}e^{j45^\circ} = \\ &= -j20 + 5 + j5 = 5 - j15 = 15,8e^{-j71,5^\circ} \text{ Om}. \end{aligned}$$

(8.10, ÷ 8.13a) tenglamaga asosan to'rt qutbli koefitsientni topamiz:

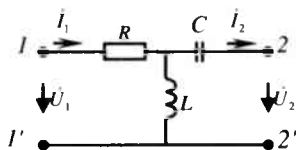
$$\begin{aligned} A &= \sqrt{\frac{(22,8e^{j63^\circ}) \cdot (10\sqrt{2}e^{j45^\circ})}{(15,8e^{-j71,5^\circ})(10 + j10 - 10 - j20)}} = \sqrt{\frac{322e^{j108^\circ}}{15,8e^{-j71,5^\circ} \cdot 10e^{-j90^\circ}}} = \\ &= \sqrt{2} \cdot e^{j270^\circ} = 1,41e^{j135^\circ} \end{aligned}$$

$$\begin{aligned} C &= \frac{A}{Z_{10}} = \frac{\sqrt{2}e^{-j45^\circ}}{10\sqrt{2}e^{j45^\circ}} = -j0,1 \left(\frac{1}{\text{Om}} \right); \quad B = A \cdot Z_{2k} = \\ &= \sqrt{2}e^{-j45^\circ} \cdot 15,8e^{j71,5^\circ} = 22,3e^{-j116,5^\circ} \text{ Om} \end{aligned}$$

$$D = \frac{B}{Z_{1k}} = \frac{22,3e^{-j116,5^\circ}}{22,36e^{j63,5^\circ}} = -1$$

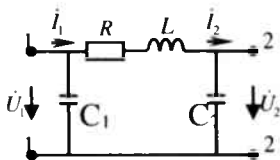
8.3. Mustaqil yechish uchun masalalar

Masala 8.1. T sxema shaklidagi to'rt qutbli elektr zanjir qarshiligi $R = x_L = x_C = 10 \text{ (Om)}$ A, B, C, D doimiy koeffitsientni aniqlang:



Javob: $\sqrt{2}e^{-j45^\circ}$, $10e^{-j90^\circ} \text{ (Om)}$, $0, 1e^{-j90^\circ} \left(\frac{1}{\text{Om}} \right)$.

Masala 8.2. Π sxema shaklidagi to'rt qutbli elektr zanjir parametri $\underline{Z} = (10 + j20) \text{ Om}$, $\underline{y}_1 = j0,1 \left(\frac{1}{\text{Om}} \right)$, $\underline{y}_2 = j0,25 \left(\frac{1}{\text{Om}} \right)$ doimiy A, B, C, D doimiy koeffitsientlari aniqlansin.



Javob: $A = -4 + j2,5$, $B = 10(1 + j2) \text{ (Om)}$,

$C = -0,05(5 + j3) \left(\frac{1}{\text{Om}} \right)$, $D = -1 + j$

Masala 8.3. n sxemadagi to'rt qutbli elektr zanjir doimiy koeffitsienti $A = -4 + j2,5$, $B = 10(1 + j2) \text{ (Om)}$, $C = -0,05(5 + j3) \left(\frac{1}{\text{Om}} \right)$,

$D = -1 + j$ bo'lganda, parametrini aniqlang.

Javob: $\underline{z}_0 = 10(1 + j2) \text{ (Om)}$, $\underline{y}_1 = j0,1 \left(\frac{1}{\text{Om}} \right)$, $\underline{y}_2 = j0,25 \left(\frac{1}{\text{Om}} \right)$

Masala 8.4. (8. 1) masaladagi T sxema bo'yicha to'rt qutbli parametri $R = \underline{x}_2 = 10 \text{ (Om)}$, $\underline{x}_C = 20 \text{ (Om)}$ to'rt qutbli kirish (1 – 1') va chiqish (2 – 2') qismlarida qisqa tutashuv va salt holat tajribalari asosida doimiy koeffitsienti aniqlansin.

Javob: $A = \sqrt{2}e^{-j45^\circ}$, $C = 0,1e^{-j90^\circ} \left(\frac{1}{Om} \right)$, $B = 22,4e^{-j116^\circ} Om$, $D = -1$

Masala 8.5. T sxema shaklidagi to'rt qutbli parametri $\underline{Z}_1 = 10 (Om)$, $\underline{Z}_2 = -j10 (Om)$, $\underline{y}_0 = 0,1 \left(\frac{1}{Om} \right)$ bo'lib, $\underline{Z}_{ist} = 5 - j5$ iste'molchi qarshiligi ulangan to'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1 = 100 (V)$ ga teng bo'lganda $\dot{I}_1$ va $\dot{I}_c$ tok aniqlansin.

Javob: $\dot{I}_1 = 35\sqrt{2}e^{-j45^\circ} (A)$, $\dot{I}_2 = 5(A)$

Masala 8.6. Doimiy koeffitsienti $A_2 = 2$, $B = j10$ ga teng simmetrik to'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1 = 100 (V)$ bo'lib xarakteristik qarshilikga ulangan. Xarakteristik qarshilik, uzatish koeffitsienti va $\dot{U}_2$ kuchlanishni aniqlang.

Javob: $\dot{U}_2 = 268 (V)$, $g = 1,32 (Np)$, $a = 0$, $b = j5,77 (rad)$

Masala 8.7. Xarakteristik qarshiligi $\underline{z}_c = 100 (Om)$, $a = 0$, $b = 0,785 (rad)$ bo'lgan simmetrik to'rt qutblik $\underline{z}_{ucm} = 100 + j100 (Om)$ iste'molchi qarshiligiga ulangan. To'rt qutbli kirish qismidagi kuchlanish $\dot{U}_1 = 100 (V)$ bo'lganda, ekvivalent umumiy qarshilik $\underline{z}_{yml}$ va $\dot{I}_2$ tok hisoblab topilsin.

Javob: $\underline{z}_{yml} = 223,6e^{-j26^\circ} (Om)$, $\dot{I}_2 = 0,632e^{-j63^\circ} (A)$

Masala 8.8. Simmetrik to'rt qutblida o'tqazilgan qisqa tutashuv va salt holat tajribalari asosida quyidagilar aniqlansin:

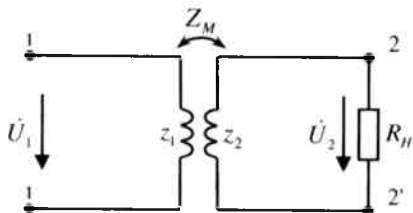
$$\dot{U}_{10} = 10 (V), \dot{I}_2 = 1(A), P_{10} = 10 (Vt),$$

$$\dot{U}_{1k} = 10 (V), \dot{I}_{1k} = 0,8(A), P_{1k} = 8 (Vt)$$

To'rt qutbli doimiy koeffitsient aniqlanib, T shakldagi sxemasi tuzilsin.

Javob: $A = j2$, $B = 25e^{j90^\circ} Om$; $C = 0,2e^{j90^\circ} \left(\frac{1}{Om} \right)$

Masala 8.9. Qarshilik parametri $x_1 = x_2 = R_1 = R_2 = 10(Ohm)$ induktiv bog'lanish koeffitsienti $K = 0,5$ ga teng, transformator $R = 10(Ohm)$ aktiv qarshilikga ulangan bo'lib, birlamchi chulg'am kuchlanishi $\dot{U}_1 = 184(V)$. To'rt qutbli doimiy koeffitsienti A, B, C, D, $\dot{U}_2$ kuchlanish va kirish qismidagi $\underline{Z}_{um}$ qarshilik aniqlanib, T ekvivalent sxemasi tuzilsin.



Javob: $A = 2 - j2$, $B = 40 - j5(Ohm)$, $C = -0,2\left(\frac{1}{Ohm}\right)$ $D = 2 - j2$,

$\underline{Z}_{um} = 14,6e^{-j14^\circ} (Ohm)$, $\dot{U} = 28,4(V)$

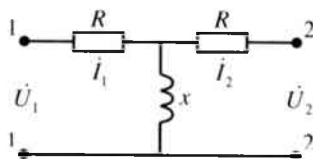
Masala 8.10. To'rt qutbli transformator $A = \frac{1}{3}(-5 + j)$,

$B = -\frac{1}{3}(10 + j15) (Ohm)$, $C = \frac{j}{3}\left(\frac{1}{Ohm}\right)$ teng va $f = 50 \cdot 10^3 (Gs)$ bo'lganda

transformatorning parametrlari: R_1, R_2, L_1, L_2, M aniqlansin: (Gn)

Javob: $R_1 = R_2 = 1(Ohm)$, $L_1 = L_2 = -10^{-4}(Gn)$, $M = 0,6 \cdot 10^{-4}(Gn)$

Masala 8.11. To'rt qutblining parametri $R_{12} = x = 1(Ohm)$ bo'lib, salt holat va qisqa tutashuv tajribalari asosida quyidagilar aniqlangan:



1) $\dot{U}_2 = 1 (V)$; $\dot{I}_2 = 5(A)$; $\cos \varphi_2 = 0,8$; $\varphi_2 > 0$;

2) $\dot{U}_2 = 10 (V)$; $\dot{I}_2 = 10(A)$; $\cos \varphi_2 = 0,8$; $\varphi_2 < 0$;

3) $\dot{U}_2 = 5 (V)$; $\dot{I}_2 = 1(A)$; $\cos \varphi_2 = 1$; $\varphi_2 < 0$;

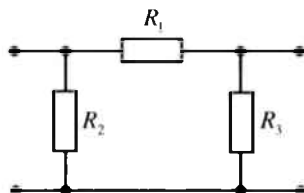
To'rt qutbli kirish qismidagi tok $\dot{I}_1$ va kuchlanish $\dot{U}_2$ aniqlansin.

Javob:

1) $\dot{U}_1 = 12,5(V)$; $\dot{I}_1 = 8,05(A)$; 2) $\dot{U}_1 = 32,5(V)$; $\dot{I}_1 = 18,4(A)$;

3) $\dot{U}_1 = 8,05(V)$; $\dot{I}_1 = 6,08(A)$;

Masala 8.12. II sxemada ulangan to'rt qutbli parametri $R_1 = 450 \text{ Om}$, $R_2 = 1800 \text{ Om}$, $R_3 = 900 \text{ Om}$ bo'lganda, doimiy koeffitsienti aniqlansin.



Javob: $A = 1,5$, $B = 450 \text{ Om}$, $C = 1,95 \cdot 10^{-3} \frac{1}{\text{Om}}$, $D = 1,25$

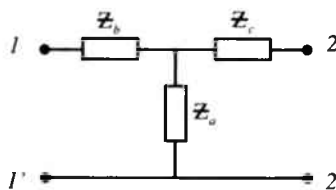
Masala 8.13. Nosimmetrik to'rt qutbli koeffitsienti $A = 1$; $B = 2,83e^{j45^\circ} \text{ Om}$, $C = j0,5 \text{ sm}$, $D = j1$ ga teng. Xarakteristik qarshiligi va uzatish koeffitsienti aniqlansin.

Javob: $s_1 = \pm 2,38e^{-j67,5^\circ} \text{ Om}$; $s_2 = \pm 2,38e^{j22,5^\circ} \text{ Om}$,
 $g = 0,765 + j1,0$ ($\alpha = 0,765 \text{ NP}$, $\beta = 1 \text{ rad}$)

Masala 8.14. Simmetrik to'rt qutbli zanjir $\dot{U}_1 = 100V$ kuchlanishga ulangan. Ikkilamchi parametri $Z_1 = 100 \text{ Om}$, $\alpha = 0$; $\beta = 0,785 \text{ rad}$ bo'lib, $Z_2 = 100 + j \cdot 100 \text{ Om}$ qarshilikga ulanganda, kirish qismidagi qarshilik Z_1 va I_2 tok qiymati aniqlansin:

Javob: $Z_1 = 223,6e^{-j26,6^\circ} \text{ Om}$; $\dot{I}_2 = 0,632e^{-j63,5^\circ}$

Masala 8.15. T sxemada ulangan to'rt qutbli elektr zanjir parametri: $Z_a = 30 - j40 \text{ Om}$, $Z_b = Z_c = 12 + j16 \text{ Om}$. So'nish koeffitsienti a va faza koeffitsienti b aniqlansin.



Javob: $a = 0,562 \text{ nep}$, $b = 0,703 \text{ rad}$.

8.4. Nazorat savollari

1. To'rt qutbli elektr zanjir nima? Asoslab bering.
2. Elektr zanjirni to'rt qutbli ko'rinishida ifodalash bilan qanday masalalar yechiladi?
3. To'rt qutbli elektr zanjir doimiy koeffitsienti nechta?
4. Aktiv va passiv to'rt qutbli nima? Amalda qanday elektrotexnik uskuna va sxemalar misol bo'la oladi?
5. Elektr energiyasi uzatish liniyasi to'rt qutblimi?
6. Passiv to'rt qutbli kirish ($\dot{I}_1, \dot{U}_1$) va chiqish ($\dot{I}_2, \dot{U}_2$) qismidagi tok va kuchlanish bog'lanishini ifodalovchi tenglamani yozing.
7. To'rt qutbli A, B, C, D koeffitsientlar bog'lanish tenglamasini yozing.
8. To'rt qutbli qanday holatda simmetrik bo'ladi?
9. To'rt qutbli almashinish (ekvivalent) sxemasi bo'yicha parametrini aniqlash tenglamasini yozing.
10. To'rt qutbli parametri qanday aniqlanadi?
11. To'rt qutbli qanday sxemada ulanadi va qaysi turdagi (formadagi) tenglamadan foydalaniladi?
12. To'rt qutbli elektr zanjirning chiqish qismidagi to'la qarshilik uzatish va tutashtiruv tajribasiga asosan ($\underline{Z}_{20}, \underline{Z}_{2K}$) doimiy koeffitsientlari bilan bog'lanish tenglamasini yozing.
13. To'rt qutbli elektr zanjirining kirish qismidagi to'la qarshilik uzilgan va qisqa tutashtirilgan tajribasiga o'tqazilganda ($\underline{Z}_{10}, \underline{Z}_{1K}$) doimiy koeffitsient bilan ifodalanish tenglamasini yozing.
14. Parametri T, Π , Γ shaklda ulangan to'rt qutbli sxemani chizing va doimiy koeffitsient bilan bog'lanish tenglamasini yozing.

15. Simmetrik to'rt qutblida tajriba o'tqazish (salt holat, qisqa tutashtirish) natijasida kirish qismidagi kompleks qarshilik: $\underline{Z}_{10}=10e^{-j90} Om$, $\underline{Z}_{1K}=10e^{j30} Om$ bo'lganda, A – doimiy koeffitsient qiymati nimaga teng? (Javob: $A=e^{-j30}$)

16. Differensiallovchi yoki integrallovchi to'rt qutbli sxemani chizing va ta'riflab bering.

17. Chastotaviy elektr filtr nima va qaysi maqsadda foydalaniladi?

18. Aktiv to'rt qutbli elektr zanjirining kirish qismidagi R_1 aktiv quvvatga nisbatan, chiqish qismidagi R_2 aktiv quvvat katta bo'lishi mumkinmi?

19. Π shaklida ulangan to'rt qutbli elektr zanjir parametri: $R_1=450 Om$, $R_2=1800 Om$, $R_3=900 Om$ ga teng. Doimiy koeffitsient qiymati nimaga teng? (Javob: $A=1,5$, $B=450 Om$, $C=1,95 \cdot 10^{-3} \frac{1}{Om}$, $D=1,25$)

20. Π shaklida ulangan to'rt qutbli elektr zanjir kirish qismidagi kuchlamish $U_1 = 60 (V)$ bo'lib, $R_2 = 1000 Om$ iste'molchiga ulangan. Chiqish qismidagi U_2 kuchlanish va I_2 tok aniqlansin. Javob: $U_2=35,3V$, $I_2=35,3 mA$

21. Simmetrik to'rt qutbli tavsifiy tenglamasi uzatish koeffitsienti ifodalari ma'nosini tushuntiring.

22. To'rt qutbli uzatish koeffitsienti qanday ifodalanadi?

IX. ELEKTR FILTR

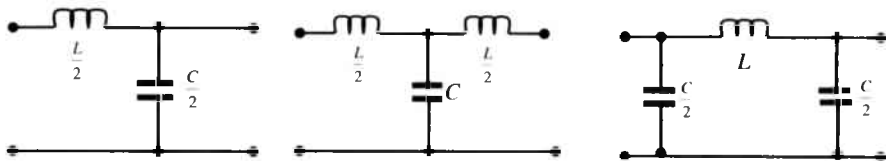
9.1. Asosiy nazariy tushunchalar

Reaktiv elementlardan tarkib topgan to'rt qutbli zanjirsimon chastota ajratuvchi elektr filtr radiotexnika, aloqa, avtomatika va boshqa sohalarda keng foydalaniladi. Elektr filtrlarining turlicha elektr signallarini kuchaytirish, pasaytirish, tekislash yoki chegaralash xususiyatlariga ega bo'lishi induktivlikning past chastotaga qarshiligi kichik, sig'imda esa qarshiligi yuqori yoki aksincha ekanligi sabab bo'ladi.

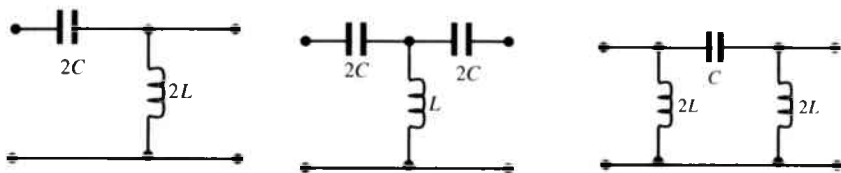
Chastota ajratuvchi filtrlarning ishiash prinsipi L va C qarshilikning (o'tkazuvchanliklari) signal chastotasi ω ga bog'liq holda o'zgarishga asoslangan bo'lib, turli xildagi Γ , T , Π sxemalarda ulash bilan signallar maqsadli filtrlanadi.

Shuni ta'kidlash kerakki, chastota ajratuvchi filtrlarning reaktiv elementlar L , C dan tuzilishiga asosiy sabab aktiv energiya isrofi minimal bo'lishidadir.

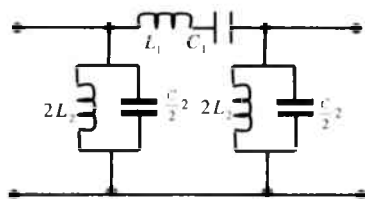
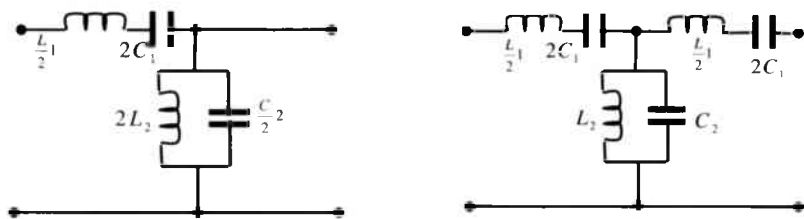
Elektr filtr vazifasi va sxemasining tuzilishi jihatdan quyi chastotali, yuqori chastotali, hududli (chastotalararo) va to'suvchi filtrlarga bo'linadi:



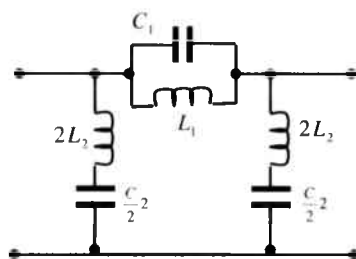
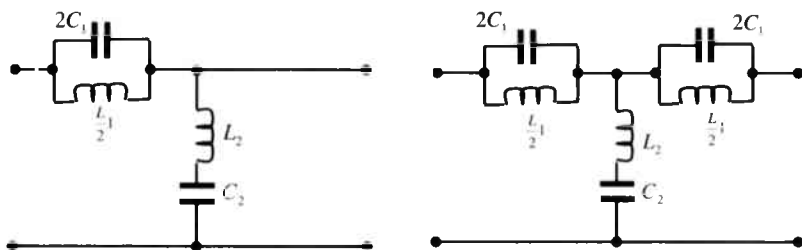
a) quyi chastotali



b) yuqori chastotali



d) hududli



e) to'suvchi.

Past chastotali filtrlar tok chastotasini

$$0 \div f_0 \text{ gacha } \left(0 \leq f \leq \frac{1}{\pi(LS)} \right).$$

Yuqori chastotali filtr $f_0 \div \infty$ gacha $\left(\frac{1}{4\pi\sqrt{LC}} \leq f \leq 0 \right)$ o'tkazadi.

Hududiy filtrlar esa: $f_1 \div f_2$ gacha $f_{1,2} = \frac{1}{2\pi} \left(\sqrt{\frac{1}{L_1 C_2} + \frac{1}{L_1 C_1}} \mp \frac{1}{\sqrt{L_1 C_2}} \right)$ tok

chastotasini oraliqda chegaralaydi.

To'sib qoluvchi filtr $0 \div f_1$ va $f_2 \div \infty$ gacha

$f_{1,2} = \frac{1}{8\pi} \left(\sqrt{\frac{1}{L_2 C_1} + \frac{16}{L_1 C_2}} \mp \frac{1}{\sqrt{L_2 C_1}} \right)$ bo'lgan tok chastotasini o'tkazadi.

Odatda hududiy yoki to'suvchi elektr filtrda $L_1 C_1 = L_2 C_2$ shart bajarilishi kerak. Elektr filtr kaskadli zanjirsimon to'rt qutbli reaktiv elementlardan tuzilgan sxemalar bo'lib, chiqish yoki keyingi filtrga kiruvchi tavsifiy qarshilik Z_S ga teng bo'ladi.

Bunda filtrdan chiquvchi tok va kuchlanish kompleks ifodasi $e^{ng} = e^{na} \cdot e^{jnb}$ bo'lib, moduli kirishdagi signalga nisbatan e^{na} marta kichik bo'ladi.

n – zanjirsimon sxemada ulangan filtrlar soni, α – chastotaga bog'liq to'rt qutbli so'nish koeffitsienti bo'lib, (8.8) tenglamaga asosan:

$$A = chg = ch(\alpha + jb) \quad (9.1)$$

$$T - \text{sxema uchun: } A = 1 + \frac{y_T Z}{2} \quad (9.2)$$

$$\Pi - \text{sxema uchun: } A = 1 + \frac{y_0 Z}{2} \quad (9.3)$$

(9.2), (9.3) y, z mavhum son bo'lib, A koeffitsient mavhum son bo'la olmaydi, shunga asosan:

$$A = ch(a + jb) = cha \cos b + j sha \sin b. \quad (9.4)$$

$$ya'ni: sha \sin b = 0 \quad (9.5)$$

$$cha \cos b = A = 1 + \frac{yZ}{2} \quad (9.6)$$

Bu tenglamadan chastota o'zgarishi bilan y, z parametr ikki holatda bo'ladi.

a) agar $sha = 0$ bo'lganda, $\alpha = 0$ bo'lib, $cha = 1$.

$$\text{Shunga asosan: } \cos b = A + \frac{yZ}{2} \quad (9.7)$$

Tenglamada y, z qiymatlar bir xil mavhum son bo'lib, chastotaviy chegarasi:

$-1 \leq 1 + \frac{y}{2} \leq +1$, unda chastota o'tkazish chegaralari:

$$\begin{aligned} -y &= \{0 \\ -y &= \{4. \end{aligned} \quad (9.7a)$$

Agarda: $\frac{Z}{2} + \frac{2}{y} = 0$ bo'lsa, bundan $yz + 4 = 0$ bo'lib, filtr rezonans

holatda bo'ladi.

Tavsifiy qarshilik tenglama ham chastotaga bog'liq bo'lib, to'rt qutbli koeffitsientlar orqali quyidagicha bog'langan:

T – sxema bo'lganda: $Z_{st} = \sqrt{\frac{B}{C}} = \sqrt{\frac{A^2 - 1}{C^2}};$

Π – sxema uchun: $Z_{sn} = \sqrt{\frac{B}{C}} = \sqrt{\frac{B^2}{A^2 - 1}}$

yoki: st va sp tavsifiy qarshilikni to'rt qutbli koeffitsient orqali ifodalash bilan (9.2), (9.3) tenglamaga asosan:

$$Z_{st} = \sqrt{\frac{A^2 - 1}{y^2}} = \sqrt{\frac{Z}{y}} \sqrt{1 + \frac{yZ}{4}}; \quad (9.8)$$

$$Z_{sp} = \sqrt{\frac{Z_p^2}{A^2 - 1}} = \sqrt{\frac{Z}{y}}; \sqrt{1 + \frac{yZ}{4}} \quad (9.9)$$

(9.8), (9.9) formuladan chegaraviy hududlari: $0 \leq -y \leq 4$

Chastotaviy chegara T sxema uchun: $0 \div Z_s = \sqrt{\frac{Z}{y}} = \sqrt{\frac{B}{C}}$

Π sxema uchun: $Z_s \div \infty$ gacha bo'lib $Z_s = R$.

Elektr filtr chastotani chegaralashda, chastota o'zgarishiga nisbatan faza koeffitsienti ham o'zgaradi. (5.7) tenglamani (8.18) tenglamaga qo'yish bilan

$$sh = sh(a + jb) = CZ_c = \frac{B}{Z_c}$$

Bunda: $b = 0$: $j \sin b = Cz_c = y_T Z_{cT}$; yoki $j \sin b = \frac{B}{Z_c} = \frac{Z_p}{Z_{sp}}$.

Faza koeffitsienti ishorasi o'tkazuvchanlik parametri bilan bog'liq ekan.

b) endi (9.5) tenglamadan $\sin b = 0$, $\sin b = 0$, bo'lganda, $\sin a \geq 1$ bo'lib, $\cos b = -1$. Unda (9.6) dan $\cos a = -A = -\left(1 + \frac{yZ}{2}\right)$ (9.10)

So'nish koeffitsienti $b = 0$, signalni filtrlash chegarasi:

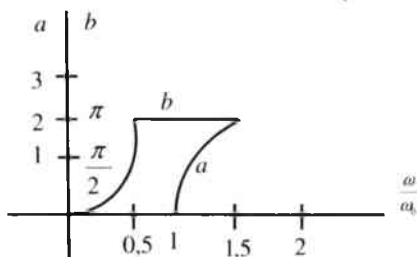
$$\left. \begin{aligned} 1 \leq -\left(1 + \frac{yZ}{2}\right) \leq \infty \\ \text{yoki} \quad \begin{aligned} -yZ &= 4 \\ -yZ &= \infty \end{aligned} \end{aligned} \right\}$$

Bu esa filtr sxemasining $R = 0$; $y = \infty$ ekanligini belgilaydi.

Bu holda: $A^2 - 1 = \chi^2 a - 1 \geq 0$ bo'lib, (9.8), (9.9) tenglamaga asosan so'nish chegarasida tavsifiy qarshilik mavhum son bo'lib, T va Π filtr sxema uchun ishorasi har xil bo'ladi.

Tahlil qilingan elektr filtr xususiyatiga asosan:

a) quyi chastotali filtr: T sxemadan $z = j\omega L$, $y = j\omega c$ bo'lganda, filtrlash chegarasi (9.7a) asosan $-yZ = \omega^2 LC = \begin{cases} 0 \\ 4 \end{cases}$

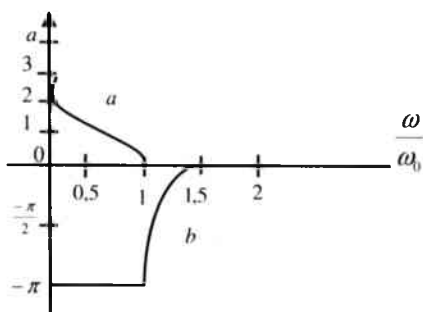


Demak: $\omega_1 = 0$; $\omega = \frac{2}{\sqrt{LC}} = \omega_0$

b) yuqori chastotali filtr: (b) T sxema reaktiv qarshilik parametri

$Z = \frac{1}{j\omega c}$; $y = \frac{1}{j\omega L}$ bo'lib, $-yZ = \frac{1}{\omega^2 LC} = \begin{cases} 0 \\ 4 \end{cases}$ filtrlash chegarasi

$\omega_1 = \frac{1}{2\sqrt{LC}} = \omega_0$ va $\omega_2 = \infty$ gacha bo'ladi.



d) hududiy filtr: Yuqorida keltirilgan shartga asosan: $L_1 C_1 = L_2 C_2$ bo'lib,

$$\omega_0 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}}$$

$$\text{yoki: } Z = j\omega L_1 + \frac{1}{j\omega C_1} = \frac{1}{j\omega C_1} (1 - \omega^2 L_1 C_1) = \frac{1}{j\omega C_1} \left(1 - \frac{\omega^2}{\omega_0^2}\right)$$

$$Y = j\omega C_2 + \frac{1}{j\omega L_2} = \frac{1}{j\omega L_2} \left(1 - \frac{\omega^2}{\omega_0^2}\right)$$

Keltirilgan tenglamalar quyidagi chegarada ifodalanadi

$$-ZY = \frac{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2}{\omega^2 L_2 C_1} = \begin{cases} 0 \\ 4 \end{cases}$$

$$\text{bundan: } \omega^2 \pm 2\omega\omega_0^2 \sqrt{L_2 C_1} - \omega_0^2 = 0$$

$$\omega_1 = \omega_0 (\sqrt{k^2 + 1} - k); \quad \omega_2 = \omega_0 (\sqrt{k^2 + 1} + k); \quad k = \omega_0 \sqrt{L_2 C_1} = \sqrt{\frac{L_2}{L_1}}$$

Demak filtr chastotani ω_1 va ω_2 oraliqda chegaralaydi. ω_0 esa oraliq chastotani ifodalaydi, ya'ni: $\omega_1 \omega_2 = \omega_0^2$

e) to'suvchi filtr:

Bu filtr sxemasidan yuqoridagi shartga asosan:

$$L_1 C_1 = L_2 C_2 \quad \text{va} \quad \omega_0 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}}$$

$$Z = \frac{1}{j\omega C_1 + \frac{1}{j\omega L_1}} = \frac{j\omega L_1}{1 - \frac{\omega^2}{\omega_0^2}}; \quad Y = \frac{1}{j\omega L_2 + \frac{1}{j\omega C_2}} = \frac{j\omega C_2}{1 - \frac{\omega^2}{\omega_0^2}}$$

Chastotani to'sish chegarasi esa:

$$-ZY = \frac{\omega^2 L_1 C_1}{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2} = 0; \quad -YZ = \frac{\omega^2 L_1 C_2}{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2} = 4.$$

Birinchi tenglama ikkita qiymat beradi: $\omega_1 = 0; \omega_4 = \infty$. Ikkinchisi: $\omega_2 = \omega_0 \left(\sqrt{k^2 + 1} - k\right)$; uchinchi: $\omega_3 = \omega_0 \left(\sqrt{k^2 + 1} + k\right)$

Bunda: $k = \frac{\omega_0 \sqrt{L_1 C_2}}{4} = \frac{1}{4} \sqrt{\frac{L_1}{L_2}}$

Demak filtr chastotani $0 \div \omega_2$ va $\omega_3 \div \infty$ o'tkazib, chastotani to'sish chegarasi: $\omega_2 \div \omega_3$ ga teng yoki: ω_0 – chegara ichida bo'lib: $\omega_0^2 = \omega_2 \omega_3$.

9.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 9.1. T sxemadagi filtr parametrlari $L = 20 \text{ mgn}$, $C = 20 \text{ mkf}$ bo'lganda chastota o'tkazish chegaralari aniqlanib, $\omega = 2000 \text{ rad/sek}$ va tok $I_2 = 0,1 \text{ A}$ bo'lganda so'nish koeffitsient a topilsin.

Yechish. T sxema uchun (9.2) ifodaga asosan:

$$A = 1 + \frac{Z_1}{Z_3} = 1 + j\omega L \cdot j\omega C = 1 - \omega^2 LC$$

Agarda $A = 1$; bo'lsa $\omega_1 = 0$; yoki $A = -1$ bo'lganda;
 $-1 = 1 - \omega^2 LC$; (1)

Bundan: $\omega_2 = \sqrt{\frac{2}{LC}} = 2235 \text{ rad/sek}$ Chastotani filtrlash chegarasi:
 $b = \arccos A = \arccos(1 - \omega^2 LC)$.

Chastota $\omega = 2000 \text{ rad/sek}$ bo'lganda, tavsifiy qarshilik:

$$Z_c = \sqrt{\frac{2L}{C} - \omega^2 L^2} = 80 \text{ om.}$$

filtr tavsifiy qarshiligi 80 Om bo'lganda chiqishdagi kuchlanish:

$$U_2 = I_{2s} = 0,1 \cdot 80 = 8 \text{ V.}$$

So'nish koeffitsient a chastotaga nisbatan o'zgarishini topish uchun
 (9.1) tenglamadan $cha = -A = \omega^2 LC - 1$

Bundan $\omega = 2\omega_2 = 2 \cdot 2235 = 4470 \text{ rad/sek}$ teng bo'lganda:

$$cha = (4470) \cdot 20 \cdot 10^{-3} \cdot 20 \cdot 10^{-6} - 1 = 8, \quad a = 2,8 \text{ nep.}$$

Masala 9.2. K turdagi quyi chastotali filtr yuqori chegaralash chastotasi $f_0 = 0,5 \text{ kgts}$ bo'lib, $R = 500 \text{ Om}$ iste'molchi qarshiligiga ulangan.

a) filtr parametri L, C , b) $f_1 = 1 \text{ kgts}$ bo'lgan so'nish koeffitsienti a kirish va chiqishdagi kuchlanishga nisbatan qiymatlari $nep, detsb$ o'lchamlari topilsin; b) ekvivalent sxemasi tuzilsin.

Yechish. K turdagi quyi chastotali filtrlarning yuqori chastota chegarasi quyidagicha ifodalanadi.

$$L = \frac{R}{\pi f_0} = 0,317 \text{ gn}, \quad C = \frac{1}{\pi f_0 R} = 1,27 \text{ mkf}.$$

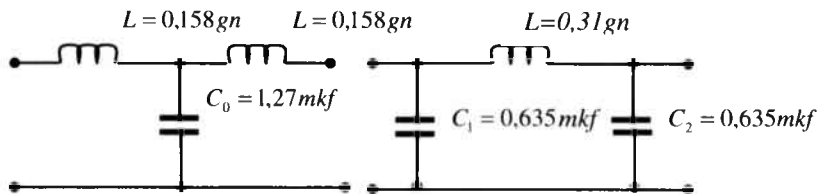
So'nish koeffitsienti $f_1 = 1 \text{ kgts}$ bo'lganda $chL = 2\eta_1^2 - 1$;

$$\text{Bundan } \eta = \frac{\omega_1}{\omega_0} = \frac{f_1}{f_0} = 2:$$

Demak: $ch\alpha = 7$, $\alpha = 2,64 \text{ nep} = 22,9 \text{ dtsb}$.

Bundan: $\alpha = \ell n \frac{U_1}{U_2}$ yoki $\frac{U_1}{U_2} = e^\alpha = 14$

Ekvivalent sxema T yoki Π ko'rinishda bo'ladi:



Masala 9.3. T sxemada filtr parametri $C_3 = 0,08 \text{ mkf}$ va $L_2 = 0,02 \text{ gn}$ bo'lganda, filtrlash chegarasi aniqlanib, iste'molchi qarshilik R_2 ning qaysi chastota formasi buzilmasligi va chastotaning $f_1 = 0$; $f_2 = \frac{f_s}{2}$; $f_3 = 0$; $f_4 = 2f_s$ (f_s – rezonans chastota) qiymatida tavsifiy qarshilik Z_C va so'nish koeffitsienti a aniqlansin.

Yechish. Masalaning shartiga ko'ra T sxema quyi chastotali filtr bo'lib, filtrlash oralig'i tenglamaga asosan: $-1 \leq \frac{1}{y_2} \leq 0$

$$\text{Bunda: } Z_1 = j\omega L \text{ va } Z_2 = \frac{1}{j\omega C}.$$

Shunga asosan quyi chegarasi $f_1 = 0$ dan yuqori chegarasi $f_s = \frac{1}{\pi\sqrt{LC}} = 8000 \text{ gs}$ oralig'ida chastota filtrlanadi.

T sxema uchun tavsifiy qarshilik tenglamasi:

$$Z_c = \sqrt{Z_1 Z_2 \left(1 + \frac{Z_1}{Y Z_2}\right)} = R_0 \sqrt{1 - \left(\frac{f}{f_c}\right)^2}.$$

Bunda: $R_c = \sqrt{\frac{L}{C}}$ filtrlarning tavsifiy qarshilik tenglamasi.

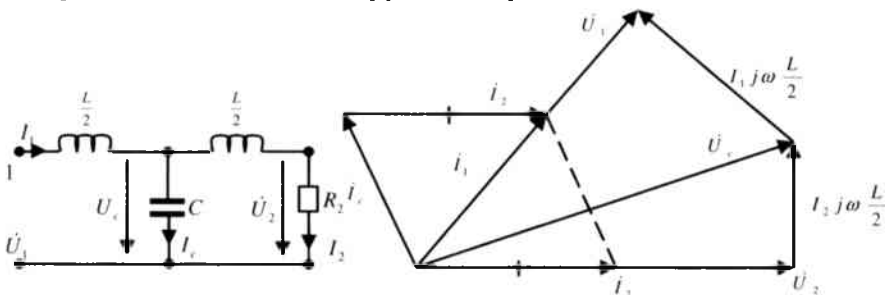
Filtr soʻnishini ifodalovchi tenglama: $ch \frac{a}{2} = \sqrt{\frac{x_1}{4x_2}} = \sqrt{\frac{\omega^2 LC}{4}} = \frac{f}{f_c}$

Qiyamatlarini tablitsa asosida keltiramiz.

$f(gs)$	0	$f_s/2$	f_s	$2f_s$
$Z_c Om$	500	433	0	$j865$
$a.(nep.)$	0	0	0	2,64

Shuni taʼkidlash kerakki, filtrning $f = 0$ dan $f = f_c$ filtrlash chegaralarida tavsifiy qarshilik qiymati haqiqiy, soʻnish chegarasida esa mavhum son qiymatiga ega. Demak T shakldagi quyi chastota filtrlash hususiyati xarakteristik tenglamaning $Z_c = R_0$ dan $Z_s = 0$ oraligʻida boʻlar ekan.

Masala 9.4. T sxema shaklidagi quyi chastotali xarakteristik parametri $L = 0,02$ gn, $C = 8$ mkf boʻlib, R_2 qarshiligiga $U_2 = 13$ B kuchlanish ulangan. Chastota filtrlash chegarasi $\omega_1 = \frac{\omega_0}{2}$, va soʻnish $\omega_2 = 2\omega_0$ boʻlganda tok va kuchlanish qiymati aniqlanib, vektor ifodasi tuzilsin:



Yechish. Rezonans holatda burchak chastota:

$$\omega_0 = \frac{2}{\sqrt{LC}} = \frac{2}{\sqrt{0,02 \cdot 8 \cdot 10^{-6}}} = 500 \text{ rad/sek}$$

$$\text{Demak: } \omega_1 = 2500 \text{ rad/sek; } \omega_2 = 10^4 \text{ rad/sek}$$

Salt yoki qisqa tutashuv tajribasiga asosan xarakteristik qarshilikni topamiz:

$$Z_{1x} = j\omega_1 \frac{L}{2} + \frac{1}{j\omega_1 C} = j25 - j50 = -j25 \text{ Om};$$

$$Z_{1k} = jx_L + \frac{jx_L \cdot jx_C}{j(x_L - x_C)} = j25 + \frac{j25(-j50)}{j25 - j50} = j75 \text{ Om}.$$

Tavsifiy qarshiligi: $R_2 = Z_0 = \sqrt{Z_{1x} \cdot Z_{1k}} = 25\sqrt{3} \text{ Om}.$

$$\text{Tok: } i_2 = \frac{\dot{U}_2}{R_2} = \frac{13}{25\sqrt{3}} = 0,3 \text{ A}.$$

$$\text{Filtr sxemasidan: } \dot{U}_c = \dot{U}_2 + j\omega \frac{L}{2} i_2 = (13 + j7,5) \text{ V}$$

$$i_c = \frac{\dot{U}_c}{-jx_C} = \frac{13 + j7,5}{-j50} = (-0,15 + j0,26) \text{ A}$$

Kirish qismidagi tok:

$$i_1 = i_2 + i_c = 0,3 - 0,15 + j0,26 = 0,15 + j0,26 = 0,3e^{j60^\circ} \text{ A}$$

Kuchlanish:

$$\dot{U}_1 = U_c + j\omega_1 \frac{L}{2} i_1 = 13 + j7,5 + j25(0,15 + j0,26) = 6,5 + j11,25 = 13e^{j60^\circ} \text{ V}$$

So'nish chegarasi $\omega_2 = 10^4 \text{ rad/sek}$ bo'lganda, tok va kuchlanish qiymatini topamiz.

$$\dot{U}_c = \dot{U}_2 + j\omega_2 \frac{L}{2} i_2 = 13 + j100 \cdot 0,3 = (13 + j30) \text{ V}$$

$$i_c = \frac{\dot{U}_c}{jx_C} = \frac{13 + j30}{-j12,5} = (-2,4 + j1,04) \text{ A}$$

$$i_1 = i_2 + i_c = 0,3 - 2,4 + j1,04 = -2,1 + j1,04 \approx 2,34e^{j153^\circ} \text{ A}$$

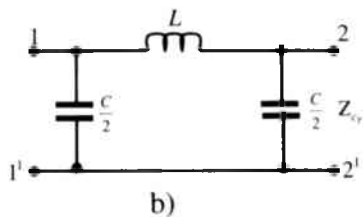
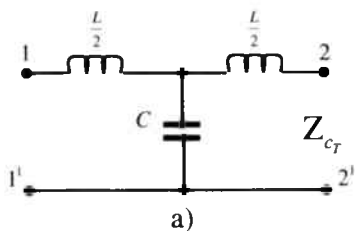
$$\dot{U}_1 = \dot{U}_c + j\omega_2 \frac{L}{2} i_1 = 13 + j30 - j210 - 104 = -91 - j180 \approx 202, e^{j117^\circ} \text{ V}$$

Masala 9.5. Quyi chastotali (K turdagi) T va II sxemadan iborat bo'lgan elektr filtr burchak chastotasi $\omega_0 = 3,14 \cdot 10^{-3} \frac{1}{\text{sek}}$ bo'lib, $R_c = R_2 = 0,5 \cdot 10^{-3} \text{ Om}$ tavsifiy aktiv qarshilikga ulangan.

a) elektr filtr parametrlari L, C.

b) chastotani filtrlash chegarasi $\omega = 0,5 \cdot \omega_0$ bo'lganda, tavsifiy qarshiligi Z_{st}, Z_{sp} faza koeffitsienti $b/2$.

d) $\omega = 1,5\omega_0$ bo'lganda (chastotani to'sishda) so'nish koeffitsienti $b/2$ qiymati aniqlansin.



Yechish.

a) quyi chastotali T shakldagi elektr filtr parametri yuqori chegarasini aniqlaymiz:

$$L = \frac{2R}{\omega_0} = \frac{2 \cdot 0,5 \cdot 10^3}{3,14 \cdot 10^3} = 0,318 \text{ gn}, C = \frac{2}{\omega_{0R}} = \frac{2}{3,14 \cdot 10^3 \cdot 0,5 \cdot 10^3} = 1,274 \cdot 10^{-6} \text{ f}$$

b) K turdagi elektr filtr tavsifiy qarshiligi:

$$K = Z_c = \sqrt{\frac{L}{C}} = \sqrt{\frac{0,318}{1,27 \cdot 10^{-6}}} = 0,5 \cdot 10^3 \text{ Om}.$$

d) filtr chastotasi $\omega = 0,5\omega_0 = 1,57 \cdot 10^3 \frac{1}{\text{sek}}$ bo'lganda, filtr reaktiv qarshiligini aniqlaymiz:

$$X_L = \omega \left(\frac{L}{2} \right) = 1,57 \cdot 10^3 \cdot \frac{0,318}{2} = 250 \text{ Om};$$

$$X_c = \frac{1}{\omega \left(\frac{C}{2} \right)} = \frac{1}{1,57 \cdot 10^3 \cdot \frac{1}{2} \cdot 1,27 \cdot 10^{-6}} = 1000 \text{ Om}$$

e) endi $\omega = 0,5\omega_0$ bo'lganda quyi chastotani filtrlar tenglamasiga asosan T, Π sxema tavsifiy qarshiligini aniqlaymiz:

$$Z_{CT} = K \sqrt{1 - \left(\frac{\omega}{\omega_0} \right)^2} = 0,5 \cdot 10^3 \cdot \sqrt{1 - \left(\frac{0,5 \cdot \omega_0}{\omega_0} \right)^2} = 0,433 \cdot 10^3 \text{ Om};$$

$$Z_{CH} = \frac{K}{\sqrt{1 - \left(\frac{\omega}{\omega_0} \right)^2}} = \frac{0,5 \cdot 10^3}{\sqrt{1 - \left(\frac{0,5 \omega_0}{\omega_0} \right)^2}} = 0,577 \cdot 10^3 \text{ Om}.$$

f) chastota o'tkazish chegarasi $\omega = 0,5 \omega_0 \frac{1}{\text{sek}}$ bo'lganda, so'nish koeffitsienti $\frac{a}{2} = 0$ bo'lib, faza koeffitsienti:

$$\frac{b}{2} = \arcsin \frac{\omega}{\omega_0} = \arcsin 0,5 = 30^\circ$$

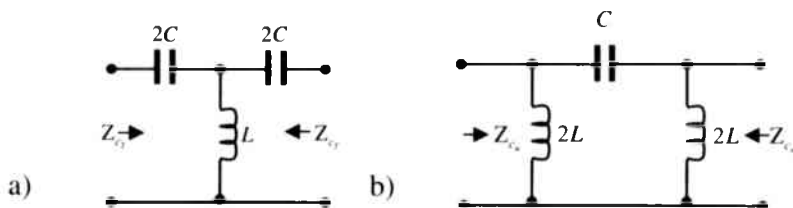
g) $\omega = 1,5 \omega_0 = 4,77 \cdot 10^3 \frac{1}{\text{sek}}$, chastotani to'sish chegarasida, so'nish koeffitsienti: $\frac{a}{2} = \text{arcch} \frac{\omega}{\omega_0} = \text{arcch} 1,5 = 0,963 \text{ NP} = 8,345 \text{ Db}$.
(1 NP = 8,686 Db)

Faza koeffitsienti: $\frac{b}{2} = 90^\circ$.

Masala 9.6. (9.5) masala shartiga asosan yuqori chastotali K turdagi filtr parametri L, C va tavsifiy qarshiligi Z_c va $a/2$, $b/2$ koeffitsienti aniqlansin:

Masala 9.7. K turdagi yuqori chastotali filtr burchak chastotasi $\omega = 3,14 \cdot 10^3 \frac{1}{\text{sek}}$ bo'lib, $R = Z_c = 2 \cdot 10^3 \text{ Om}$, $\left(R = K = \sqrt{\frac{L}{C}}\right)$ tavsifiy qarshiligi ulangan.

Filtr o'tkazish chegarasi $\omega = 1,5 \omega_0$ bo'lganda, tavsifiy qarshilik qiymati Z_{CT}, Z_{CH} va faza koeffitsienti $b/2$ hamda to'sish chegarasi va $\omega = 0,5 \omega_0$ bo'lganda so'nish koeffitsienti $a/2$ qiymati aniqlansin.



Yechish.

a) yuqori chastotali filtr parametrini (9.10) ifodaga asosan:

$$L = \frac{R}{2\omega_0} = \frac{2 \cdot 10^3}{2 \cdot 3,14 \cdot 10^3} = 0,318 \text{ gn};$$

$$C = \frac{1}{2\omega_0 R} = \frac{1}{2 \cdot 3,14 \cdot 10^3 \cdot 2 \cdot 10^3} = 0,0795 \cdot 10^{-6} \text{ f}.$$

b) K turdagi yuqori chastotali filtr tavsifiy qarshiligi:

$$K = Z_c = \sqrt{\frac{L}{C}} = \sqrt{\frac{0,318}{0,08 \cdot 10^{-6}}} = 2 \cdot 10^3 \text{ Om}.$$

d) $\omega = 1,5 \omega_0 = 1,5 \cdot 3,14 \cdot 10^3 = 4,7 \cdot 10^3 \frac{1}{\text{sek}}$ bo'lganda filtr reaktiv qarshiligini topamiz:

$$X_c = \frac{1}{\omega(2c)} = \frac{1}{4,7 \cdot 10^3 \cdot 2 \cdot 0,08 \cdot 10^{-6}} = 1335 \text{ Om};$$

$$X_L = \omega(2L) = 4,7 \cdot 10^3 \cdot 2 \cdot 0,3 = 3000 \text{ Om}.$$

e) Π sxemadagi filtr chastota o'tkazish chegarasidagi tavsifiy qarshilik qiymatini ($\omega = 1,5\omega_0$) aniqlaymiz:

$$Z_{CT} = K \cdot \sqrt{1 - \left(\frac{\omega_0}{\omega}\right)^2} = 2 \cdot 10^3 \sqrt{1 - \frac{\omega_0}{1,5\omega_0}} = 1,5 \cdot 10^3 \text{ Om}.$$

$$Z_{CH} = \frac{K}{\sqrt{1 - \left(\frac{\omega_0}{\omega}\right)^2}} = \frac{2 \cdot 10^3}{\sqrt{1 - \left(\frac{\omega_0}{1,5\omega_0}\right)^2}} = 2,7 \cdot 10^3 \text{ Om}.$$

f) chastota o'tkazish chegarasi:

$$\omega = 1,5\omega_0 = 4,7 \cdot 10^3 \frac{1}{\text{sek}} \text{ bo'lganda, so'nish koeffitsienti } a/2 = 0,$$

faza koeffitsienti:

$$b/2 = \arcsin\left(-\frac{\omega_0}{\omega}\right) = \arcsin\left(-\frac{1}{1,5}\right) = -42^\circ.$$

$$\text{Chastotani to'sish chegarasi: } \omega = 0,5\omega_s = 1,57 \cdot 10^3 \frac{1}{\text{sek}}$$

g) so'nish koeffitsienti:

$$\frac{a}{2} = \text{arch} \frac{\omega_c}{\omega} = \text{arch} \frac{1}{0,5} = \text{Arch} = 2 = 1,32 \text{ NP} = 11,45 \text{ Db};$$

Faza koeffitsienti: $b = -90^\circ$

Masala 9.8. K turdagi hududiy filtr burchak chastotasi

$$\omega_{01} = 62,8 \cdot 10^3 \frac{1}{\text{sek}}; \quad \omega_{02} = 75,4 \cdot 10^3 \frac{1}{\text{sek}} \text{ bo'lib, tavsifiy qarshiligi}$$

$$R = R_c = 10 \cdot 10^3 \text{ Om} \quad \left(R_{yuk} = K = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}} \right).$$

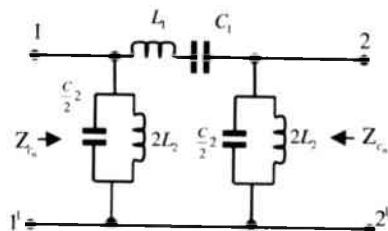
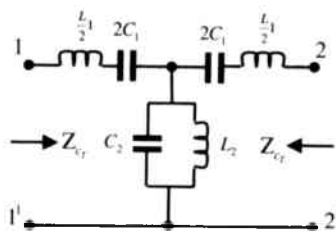
a) filtr parametrlari: L_1, C_1, L_2, C_2 .

b) $\omega = 0,5 \cdot (\omega_{01} + \omega_{02})$ chastota o'tkazish chegarasida Z_{st}, Z_{sp} tavsifiy qarshiligi va faza koeffitsienti $b/2$

d) filtr chap tomonida to'sish chastotasi $\omega = 0,5\omega_{01}$ bo'lganda, so'nish koeffitsienti $a/2$ qiymatni aniqlang.

Yechish.

a) hududiy filtr signallarini o'tkazish ifodasiga yoki chegaralanish ifodasiga asosan:



$$L_1 = \frac{2R}{\omega_{02} - \omega_{01}} = \frac{2 \cdot 10 \cdot 10^3}{75,4 \cdot 10^3 - 62,8 \cdot 10^3} = 1,59 \text{ gn}$$

$$C_1 = \frac{\omega_{02} - \omega_{01}}{2R\omega_{02} \cdot \omega_{01}} = \frac{75,4 \cdot 10^3 - 62,8 \cdot 10^3}{2 \cdot 10 \cdot 10^3 \cdot 75,4 \cdot 10^3 \cdot 62,8 \cdot 10^3} = 0,133 \cdot 10^{-9} = 0,133 \text{ nf.}$$

$$L_2 = \frac{R(\omega_{02} - \omega_{01})}{2\omega_{02} \cdot \omega_{01}} = \frac{10 \cdot 10^3 (75,4 \cdot 10^3 - 62,8 \cdot 10^3)}{2 \cdot 75,4 \cdot 10^3 \cdot 62,8 \cdot 10^3} = 0,0133 \text{ gn}$$

$$C_2 = \frac{2}{R(\omega_{02} - \omega_{01})} = \frac{2}{10 \cdot 10^3 (75,4 \cdot 10^3 - 62,8 \cdot 10^3)} = 15,88 \cdot 10^{-9} \text{ f} = 15,9 \text{ nf}$$

b) K turdagi hududiy filtr tavsifiy qarshiligi:

$$Z_s = K = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{1,59}{15,9 \cdot 10^{-9}}} = 10 \cdot 10^3 \text{ om;}$$

$$Z_c = K = \sqrt{\frac{L_2}{C_1}} = \sqrt{\frac{0,0133}{0,133 \cdot 10^{-9}}} = 10 \cdot 10^3 \text{ f.}$$

d) filtrning ketma-ket yoki parallel ulangan konturlardagi rezonans chastotasini topamiz:

$$\omega_0 = \frac{1}{\sqrt{\frac{L_1}{2} \cdot 2C_1}} = \frac{1}{\sqrt{1,59 \cdot 0,133 \cdot 10^{-9}}} = 68,8 \cdot 10^3 \frac{1}{\text{sek}}$$

$$\text{yoki: } \omega_0 = \frac{1}{\sqrt{2L_2 \frac{C_2}{2}}} = \frac{1}{\sqrt{0,0133 \cdot 1,59 \cdot 10^{-9}}} = 68,8 \cdot 10^3 \frac{1}{\text{sek}}.$$

Filtrning chastota o'tkazish chegaralanish qiymatini aniqlaymiz:

$$\omega = 0,5(\omega_{01} + \omega_{02}) = 0,5(62,8 \cdot 10^3 + 75,4 \cdot 10^3) = 69,1 \cdot 10^3 \frac{1}{\text{sek}}$$

Chap tomondagi to'sish chastotasi:

$$\omega = 0,5\omega_{01} = 0,5 \cdot 62,8 \cdot 10^3 = 31,4 \cdot 10^3 \frac{1}{\text{sek}}$$

e) T, Π shakldagi hududiy filtrning $\omega = 0,5(\omega_{01} + \omega_{02}) = 69 \cdot 10^3 \frac{1}{\text{sek}}$

qiymatidagi tavsifiy qarshiligini topamiz:

$$\begin{aligned} Z_{CT} &= K \cdot \sqrt{1 - \left[\frac{\omega^2 - \omega_0^2}{\omega_0(\omega_{02} - \omega_{01})} \right]^2} = \\ &= 10 \cdot 10^3 \sqrt{1 - \left[\frac{(69 \cdot 10^3)^2 - (68,8 \cdot 10^3)^2}{69 \cdot 10^3 \cdot (75,4 \cdot 10^3 - 62,8 \cdot 10^3)} \right]^2} = 9,99 \cdot 10^3 \text{ Om} \\ Z_{CH} &= \frac{K}{\sqrt{1 - \left[\frac{\omega^2 - \omega_0^2}{\omega_0(\omega_{02} - \omega_{01})} \right]^2}} = \frac{10 \cdot 10^3}{\sqrt{1 - \left[\frac{(69 \cdot 10^3)^2 - (68,8 \cdot 10^3)^2}{69 \cdot 10^3 \cdot (75,4 \cdot 10^3 - 62,8 \cdot 10^3)} \right]^2}} = \\ &= 10 \cdot 10^3 \text{ Om} \end{aligned}$$

Chastotaning filtrlash chegarasi:

f) $\omega = 0,5 \cdot (\omega_{01} + \omega_{02}) = 69 \cdot 10^3 \frac{1}{\text{sek}}$ bo'lganda so'nish koeffitsienti

$a/2$ va faza koeffitsienti $b/2$ qiymatlarini aniqlaymiz:

So'nishi: $a/2 = 0$; faza koeffitsienti

$$b/2 = \arcsin \frac{\omega^2 - \omega_0^2}{\omega(\omega_{02} - \omega_{01})} = \arcsin 0,0382 = 2,11^\circ$$

g) chap tomon filtr to'sish chastotasi: $\omega = 0,5 \cdot \omega_{01} = 31,4 \cdot 10^3 \frac{1}{\text{sek}}$

bo'lganda, so'nish va faza koeffitsienti:

$$a/2 = \text{Arch} \left[\frac{\omega^2 - \omega_0^2}{\omega(\omega_{02} - \omega_{01})} \right] \text{arch} 9,45 = 2,934 NP = 25,5 \text{ Db}$$

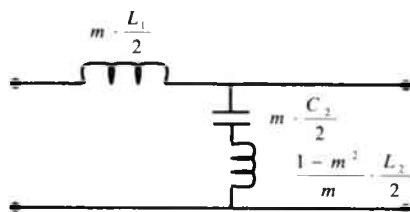
$b/2 = -90^\circ$. «minus» ishora filtr chap tomon to'sish chegarasini ifodalaydi.

Masala 9.9. m turkumidagi quyi chastotali G shaklidagi differensiallovchi filtr burchak chastotasi $\omega_0 = 6,28 \cdot 10^3 \frac{1}{\text{sek}}$; $m=0,6$ bo'lib, $R = Z_c = 0,5 \cdot 10^3 \text{ Om}$ aktiv tavsifiy qarshilik yuklangan.

a) Γ shakldagi quyi chastotali filtr, K turkumidagi o'xshashligiga asoslanib L, C parametri;

b) T turdagi differensial filtr L_1, C_2, L_2 parametri;

d) $\omega_0 = \infty$ bo'lgandagi (ketma-ket ulangan rezonansli kontur) so'nish chastota qiymati hisoblab topilsin.



Yechish. Avval K turkumidagi Γ sxema uchun L, C parametrlarni topamiz:

$$L = \frac{2R}{\omega_0} = \frac{2 \cdot 0,5 \cdot 10^3}{6,28 \cdot 10^3} = 0,16 \text{ gn}; \quad C = \frac{2}{\omega_0 R_n} = \frac{2}{6,28 \cdot 10^3 \cdot 0,5 \cdot 10^3} = 0,637 \cdot 10^{-6} \text{ f}.$$

Endi Γ shakldagi m turkumli quyi chastotali filtr doimiy koeffitsienti $m = 0,6$ bo'lganda parametrini aniqlaymiz:

$$L_1 = m \frac{L}{2} = 0,6 \cdot \frac{0,16}{2} = 0,0477 \text{ gn} = 47,7 \text{ mgn}.$$

$$C_2 = m \frac{C}{2} = 0,6 \cdot \frac{0,637 \cdot 10^{-6}}{2} = 0,19 \cdot 10^{-6} \text{ f} = 0,191 \text{ mkf}$$

$$L_2 = \frac{1 - m^2}{m} \cdot \frac{L}{2} = \frac{1 - 0,6^2}{0,6} \cdot \frac{0,16}{2} = 0,085 \text{ gn} = 85 \text{ mgn}.$$

m turkumidagi differensiallovchi quyi chastotali filtr: $\omega_\infty = \omega_0$ da so'nish chastotasi:

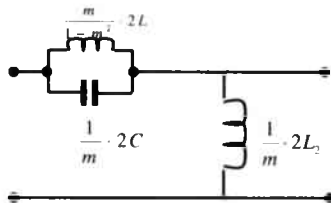
$$\omega_{\infty} = \omega_0 \cdot \frac{1}{\sqrt{1-m^2}} = 6,28 \cdot 10^3 \cdot \frac{1}{\sqrt{1-0,6^2}} = 7,85 \cdot 10^3 \frac{1}{\text{sek.}}$$

Masala 9.10. Γ shakldagi m turkum yuqori chastotali filtr hurchak chastotasi $\omega_0 = 31,4 \cdot 10^3 \frac{1}{\text{sek}}$; $m = 0,6$ bo'lib, $R = Z_c = 25 \cdot 10^3 \text{ Om}$ aktiv tavsifiy qarshilik ulangan $\left(R = K = \sqrt{\frac{L}{C}} \right)$.

a) K turdagi yuqori chastotali filtr parametri;

b) m turkumidagi Γ shakldagi differensiallovchi filtr parametri L_1 , C_1 , L_2 ;

d) parallel sxemadagi rezonansli kontur xususiyatiga asosan m turkumidagi differensiallovchi filtr $\omega = \infty$ so'nish chastota qiymati hisoblab topilsin.



Yechish.

a) R aktiv qarshilikga yuklangan K turkumda filtr parametrini aniqlaymiz:

$$L = \frac{R}{2\omega_0} = \frac{25 \cdot 10^3}{2 \cdot 31,4 \cdot 10^3} = 0,4 \text{ gn};$$

$$C = \frac{1}{2\omega_0 R} = \frac{1}{2 \cdot 31,4 \cdot 10^3 \cdot 25 \cdot 10^3} = 0,637 \cdot 10^{-9} \text{ f} = 0,637 \text{ nf}.$$

b) endi $m = 0,6$ ga teng bo'lgandagi differensiallovchi yuqori chastotali filtr parametrini topamiz:

$$L_1 = \frac{m}{1-m^2} 2L = \frac{0,6}{1-0,6^2} \cdot 2 \cdot 0,4 = 0,747 \text{ gn}.$$

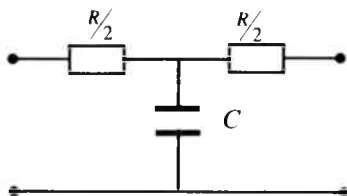
$$C_1 = \frac{1}{m} 2C = \frac{1}{0,6} \cdot 2 \cdot 0,637 \cdot 10^{-9} = 0,764 \cdot 10^{-9} \text{ f} = 0,764 \text{ nf}.$$

$$L_2 = \frac{1}{m} 2L = \frac{1}{0,6} \cdot 2 \cdot 0,4 = 0,478 \text{ gn}.$$

d) cheksiz so'nish chastota qiymati:

$$\omega_{\infty} = \omega_0 \sqrt{1-m^2} = 31,4 \cdot 10^3 \sqrt{1-0,6^2} = 25,1 \cdot 10^3 \frac{1}{\text{sek}}$$

Masala 9.11. T sxemadagi induktivsiz quyi chastotali R, C parametri: $R = 2 \cdot 10^3 \text{ Om}$; $C = 0,5 \cdot 10^{-9} \text{ f} = 0,5 \text{ nf}$ bo'lganda, chastota o'tkazish chegarasi aniqlanib, filtr tavsifiy qarshiligi hisoblab topilsin.



Yechish. a) quyi chastotali R, C filtr, chastota o'tkazish chegarasi chap va o'ng tarmoq aktiv qarshilik bilan ularni bog'lovchi tarmoqdagi sig'im reaktiv qarshilik tomon tengligidan topamiz:

$$\frac{R}{2} = \frac{1}{\omega_0 \frac{C}{2}}; \text{ bundan: } \omega_0 = \frac{4}{RC} = \frac{4}{2 \cdot 10^3 \cdot 0,5 \cdot 10^{-9}} = 4 \cdot 10^6 \frac{1}{\text{sek}}$$

$$\text{yoki: } (f_0 = 637 \cdot 10^3 \text{ gts})$$

b) $\omega = \omega_0$ shart uchun tavsifiy qarshilik Z_C ni salt yoki qisqa tutashuv tajriba asosida aniqlaymiz. Filtr chiqish qismida salt holatda bo'lganda:

$$Z_0 = \frac{R}{2} - j \frac{1}{\omega_0 C} = \frac{2 \cdot 10^3}{2} - j \frac{1}{4 \cdot 10^6 \cdot 0,5 \cdot 10^{-9}} = 1,11 \cdot 10^3 e^{-j26^\circ 34'} \text{ Om}$$

$\omega = \omega_0$ shartga asosan chiqishda qisqa tutashtirish bilan:

$$Z_k = \frac{R}{2} + \frac{\frac{R}{2} \cdot \left(-j \frac{1}{\omega_0 C} \right)}{2 - j \frac{1}{\omega_0 C}} = \frac{2 \cdot 10^3}{2} + \frac{\frac{2 \cdot 10^3}{2} \cdot \left(-j \frac{1}{4 \cdot 10^6 \cdot 0,5 \cdot 10^{-9}} \right)}{\frac{2 \cdot 10^3}{2} - j \frac{1}{4 \cdot 10^6 \cdot 0,5 \cdot 10^{-9}}} = 1,26 \cdot 10^3 e^{-j18^\circ} (\text{Om})$$

T shakldagi filtr chastotani o'tkazishda chegaralanish tavsifiy qarshiligi ($\omega = \omega_0$):

$$Z_c = \sqrt{Z_0 \cdot Z_k} = \sqrt{1,11 \cdot 10^3 e^{-j26^\circ 34'} \cdot 1,26 \cdot 10^3 e^{-j18^\circ}} = 1,2 \cdot e^{-j22^\circ 30'} (\text{Om})$$

9.3. Mustaqil yechish uchun masalalar

Masala 9.1. Parametri $L_1 = 0,02 \text{ gn}$ $C = 0,08 \text{ mkf}$ bo'lgan T sxemadagi filtrning salt, qisqa tutashuv va tavsifiy qarshiligi hamda chastota filtrlash chegarasi aniqlansin.

Javob: $Z_0 = j(0,01\omega - 125 \cdot 10^5) \text{ Om}$;

$$Z_q = j \left(0,01\omega + \frac{125 \cdot 10^3 \omega}{125 \cdot 10^5 - 0,01\omega^2} \right) \text{ Om. } Z_s = \sqrt{Z_0 Z_k} = \sqrt{2,5 \cdot 10^5 - 10^{-4} \omega^2} \text{ Om.}$$

Bundan $0 \leq \omega \leq 5 \cdot 10^4$

Masala 9.2. II sxemadagi filtr parametri $C=0,08 \text{ mkf}$, $L=0,02 \text{ gn}$ bo'lganda, chastota o'tkazish chegarasi aniqlanib, xarakteristik qarshilik va faza koeffitsienti topilsin.

Javob: Chastota $12,5 \cdot 10^3 \leq \omega \leq \infty$ oraliqda chegaralaydi.

$$Z_{in} = \sqrt{\frac{Z_1 Z_2}{1 + \frac{Z_1}{4Z_2}}} = \frac{500}{\sqrt{1 - \frac{156 \cdot 10^6}{\omega^2}}} \text{ om. } 500 \leq Z_s \leq \infty. \quad -\pi \leq b \leq 0; \quad 500 \div \infty$$

Masala 9.3. 9.1-masalada T sxema kesish chastotasi $\omega_c = 10^{-4} \frac{1}{\text{sek}}$ va tavsifiy qarshiligi $R=60 \text{ Om}$ bo'lib, chastotasi $\omega = 0,5\omega_c$ ga teng bo'lganda filtr parametrlari L , C qiymatlari aniqlansin:

Javob: $L = 69,3 \text{ mgn}$, $C = 0,289 \text{ mkf}$.

Masala 9.4. T sxemada filtr parametri $L_1=100 \text{ mgn}$, $L_2=100 \text{ mgn}$, $C=0,005 \text{ mkf}$ bo'lganda, chastota o'tkazish chegarasi aniqlansin.

Javob: $2 \cdot 10^4 \frac{1}{\text{sek}} \leq \omega \leq 4,47 \cdot 10^4 \frac{1}{\text{sek}}$.

Masala 9.5. K tartibli quyi chastotali filtr chastota chegarasi $f_0 = 8 \text{ kgts}$ bo'lganda, so'mish koeffitsienti $f_1 = 12 \text{ kgts}$, $f_2 = 4 \text{ kgs}$ ga teng. Faza koeffitsientini aniqlang.

Javob: $\alpha = 1,93 \text{ nep}$, $\beta = \frac{\pi}{3}$.

Masala 9.6. Quyi chastotali filtr chastota chegarasi $f_0 = 8 \text{ kgs}$ bo'lganda, chastotaning qanday qiymatida faza koeffitsienti 60° ga teng bo'ladi.

Javob: $f_0 = 7,12 \text{ kgs}$.

Masala 9.7. K turdagi yuqori chastotali filtr chastota chegarasi $f = 250 \text{ gs} \div \infty$ ga teng bo'lganda: 1) so'nish koeffitsienti α ; faza koeffitsienti β chastotaning $f_1 = 125 \text{ gs}$ da, $f_2 = 200 \text{ gs}$ va $f_3 = 500 \text{ gs}$ qiymatida aniqlansin.

Javob: 1) $\alpha = 2,64 \text{ nep}$; $\beta_2 = \pi$; $\beta_3 = -\frac{\pi}{3}$

Masala 9.8. Quyi chastotali filtr chastotalar chegarasi $f = 1000 \text{ gs}$, xarakteristik qarshiligi $Z_1 = 100 \text{ om}$ ($f_0 = 0$) ga teng, filtr parametri aniqlansin.

Javob: $L = 31,8 \text{ mgn}$, $C = 3,18 \text{ mkf}$.

Masala 9.9. T shakldagi sxema parametri $L=0,4 \text{ gn}$, $C=0,1 \text{ mkf}$ bo'lib, $R=1000 \text{ Om}$ qarshilikga ulangan. ω chastotaning qanday qiymatida kirishdagi to'la qarshilik $Z_1 = \frac{\dot{U}_1}{I_1}$ haqiqiy qiymatga erishadi va Z_2 qiymati nimaga teng.

Javob: $\omega_1 = 5000 \frac{1}{\text{sek}}$; $\omega_2 = 6620 \frac{1}{\text{sek}}$; $Z = 4000 \text{ Om}$; $Z_2 = 1000 \text{ Om}$.

9.4. Nazorat savollari

1. K turdagi filtrga qaysi filtr kiradi?
2. Chastotaviy elektr filtr nima va qaysi maqsadda foydalaniladi?
3. So'nish koeffitsienti α , faza koeffitsienti β , uzatish koeffitsienti b nimani ifodalaydi va qanday birlikda ulanadi?
4. Filtr xarakteristik tenglama ifodasini yozing.
5. Filtr uzatish funksiyasi $H_u(j\omega)$ ixtiyoriy Z_2 yoki induktivlik L va sig'im C parametr bilan qanday bog'lanishga ega?

6. Ko'prik sxemada ulangan to'rt qutblik filtr signallarni o'tkazish chegarasi qanday aniqlanadi?
7. So'nish koeffitsienti $\alpha(\omega)$ bilan $L_n\left[\frac{1}{H(\omega)}\right]$ qiymat farqi nimada?
8. Filtrdan o'tuvchi signal formasi buzilmasligi uchun kompleks kuchlanish uzatish funksiyasi qanday shartga asoslanishi zarur?
9. Filtrdan o'tuvchi signal buzilmasligi uchun so'nish koeffitsienti α va faza koeffitsienti β chastota ω o'zgarishiga nisbatan qanday o'zgarishi kerak?
10. Aktiv qarshiligini hisobga olmaganda har qanday filtr ideal bo'lishi mumkinmi?
11. Zanjirsimon sxemada ulangan filtr xususiyatini ta'riflang.
12. Simmetrik passiv to'rt qutbli elektr zanjir so'nish koeffitsienti α – manfiy bo'ladimi?
13. Nosimmetrik filtrning xarakteristik qarshiligi salt yoki qisqa tutashuv tajribalari orqali qanday aniqlanadi?
14. Xarakteristik qarshilik chastotaga bog'liq bo'lganda filtrlarning chastotaviy chegarasi qanday aniqlanadi?
15. Filtr tavsifiy qarshiligi $Z_c = \sqrt{\frac{R}{C}}$ chastota o'zgarishi bilan qanday bog'liqligini tushuntiring.
16. Filtrlarning chastotani filtrlash yoki so'nish chegarasida xarakteristik qarshilik qiymati qanday xarakterga ega bo'ladi?
17. Turlicha xildagi filtr elektr sxemasini chizing va chastota chegaralash xususiyatini tushuntiring.
18. Elektr filtr uzatish funksiyasi tenglamasini yozing va mohiyatini tushuntiring.
19. Filtr faza koeffitsienti b ning fizik ma'nosini tushuntiring.

X. CHIZIQLI ELEKTR ZANJIRLARDA O'TKINCHI JARAYON

10.1. Asosiy nazariy tushunchalar

Elektr zanjirning bitta turg'unlashgan holatdan boshqasiga o'tishni ifodalovchi jarayon **o'tkinchi jarayon** deyiladi.

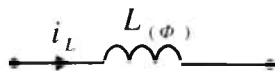
Elektr zanjirda o'tkinchi jarayon elektr zanjirning manbaga ulanish, uzilish tarmoqlardagi parametrning o'zgarishi, qisqa tutashuv kabi holatlarda yuzaga kelib, bu jarayon bir necha millisekund bir necha sekundgacha davom etishi mumkin. Elektr zanjir holatini o'zgarishiga olib keluvchi barcha sabablarga **kommutatsion jarayon** deyiladi.

Elektr zanjirda o'tkinchi jarayon hosil bo'lishiga asosiy sabab reaktiv elementlardagi (L, C) elektromagnit maydon energiyasining energiya saqlanish qonuniga asosan sakrab (bordan yo'q, yo'qdan bor bo'laolmasligi sababli) o'zgaraolmasligi, yani vaqt o'tishi bilan asta-sekin kamayib yoki ko'payib borishi sabab bo'ladi.

Induktivligi L , sig'imi C elementlarning bunday xususiyatlaridan ikkita o'tkinchi jarayon qonuni – **kommutatsiya qonuni** kelib chiqadi.

a) kommutatsiya birinchi qonuni:

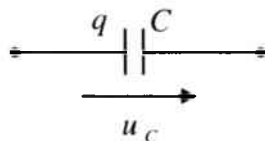
Har qanday induktivlikka ega bo'lgan tarmoqdagi tok – i yoki magnit oqimi Φ (kommutatsiya vaqtida $t=0$) kommutatsiyaga bo'lgan qiymati, kommutatsiyadan keyingi qiymatga teng bo'lib, **tok sakrab o'zgara olmaydi**.



$$i_{L(0^+)} = i_{L(0^-)} \left[\Phi_{(0^+)} = \Phi_{(0^-)} \right]$$

b) kommutatsiya ikkinchi qonuni:

Har qanday tarmoqda sig'im kuchlanishi – U va zaryad – q (kommutatsiya vaqtida $t=0$) kommutatsiyaga bo'lgan kuchlanish qiymati, kommutatsiyadan keyingi kuchlanish qiymatiga teng bo'lib, **kuchlanish sakrab o'zgarolmaydi**.



$$u_{C(0^+)} = u_{C(0^-)} \left[q_{(0^+)} = q_{(0^-)} \right]$$

Chiziqli elektr zanjiridagi o'tkinchi jarayonni ta'dil qilish uchun klassik usul, operator usuli Dyumel integrali (formularini ustma-ustlash usuli) va Fyurje integralidan (chastotali usul) foydalaniladi.

1. Klassik usulga asosan elektr zanjir uchun tuzilgan chiziqli differensial tenglamani yechish bilan bajariladi:

Masalan: koeffitsienti o'zgarmas chiziqli differensial tenglama:

$$A_0 \frac{d^n i_K}{dt^n} + A_1 \frac{d^{n-1} i_K}{dt^{n-1}} + \dots + A_{n-1} \frac{di_K}{dt} + A_n i_K = F_{K(+)}$$

Bunday differensial tenglama yechimi yoki integrali xususiy va umumiy yechimdan iborat bo'lib:

$$i_{K(t)} = i_{K(t)}^{\prime} + i_{K(t)}^{\prime\prime} \quad (10.1)$$

$i_{K(t)}^{\prime}$ differensial tenglamaning xususiy yechimi bo'lib, elektr zanjirining kommutatsiyadan keyingi turg'un holatini ifodalaydi.

$i_{K(t)}^{\prime\prime}$ differensial tenglamaning umumiy yechimi bo'lib, o'tkinchi jarayon vaqtidagi erkin holatdagi tok va kuchlanishni ifodalaydi:

$$A_0 \frac{d^n i_K^{\prime\prime}}{dt^n} + A_1 \frac{d^{n-1} i_K^{\prime\prime}}{dt^{n-1}} + \dots + A_{n-1} \frac{di_K^{\prime\prime}}{dt} + A_n i_K^{\prime\prime} = 0$$

Ya'ni, fizik manoda kommutatsiyadan keyin reaktiv elementlarda to'plangan elektromagnit maydon energiyasi erkin kamayishi va ko'payishini ifodalaydi va vaqtga nisbatan so'nuvchan yoki kamayuvchan bo'ladi:

$$\text{Ya'ni: } i_K^{\prime\prime} = A_1 e^{\alpha_1 t} + A_2 e^{\alpha_2 t} + \dots + A_n e^{\alpha_n t} = \sum_{K=1}^n A_K e^{\alpha_K t}$$

$$(9.1) \text{ tenglamadan: } i_{K(t)} = i_{K(t)}^{\prime} + \sum_{K=1}^n A_K e^{\alpha_K t} \quad (10.2)$$

Bunda A doimiy integrallash koeffitsienti bo'lib, boshlang'ich shartdan yoki kommutatsiya qonuniga asosan topiladi.

α_K differensial tenglama ildizi bo'lib, xarakteristik tenglamadan topiladi.

a) **R, L zanjirida o'tkinchi jarayon:**

Bunday zanjir tenglamasi birinchi tartibli differensial tenglama bilan ifodalanadi: $L \frac{di}{dt} + iR = U$ (10.3)

Xarakteristik tenglamasi: $LP + R = 0$; Bundan: $p = -\frac{R}{L} = -\frac{1}{\tau} \left(\frac{1}{\text{sek}} \right)$

O'tkinchi jarayondagi tok $i_t = i' + Ae^{-\frac{t}{\tau}}$ (10.4)

τ – o'tkinchi jarayondagi vaqti sekunda ifodalanadi.

b) **R, C zanjirida o'tkinchi jarayon:**

Bunday zanjirning differensial tenglamasi:

$$RC \frac{dU_c}{dt} + U_c = U \quad (10.5)$$

Yechimi quyidagicha bo'ladi:

$$\begin{cases} U_c = U'_c + Ae^{-\frac{t}{\tau}} \\ i = i' - \frac{A}{R} e^{-\frac{t}{\tau}} \\ \tau = RC(\text{sek}) \end{cases} \quad (10.6)$$

A doimiy integrallash koeffitsienti boshlang'ich shartdan, ya'ni kommutatsiya qonuniga asosan aniqlanadi.

d) **R, L, C zanjirning razryadlanishi:**

Bu zanjirning differensial tenglamasi:

$$\left. \begin{aligned} L \frac{di}{dt} + Ri + \frac{q}{C} &= 0 \\ L \frac{d^2 i}{dt^2} + R \frac{di}{dt} + \frac{1}{C} i &= 0 \end{aligned} \right\} \quad (10.7)$$

Ushbu tenglamaning yechimi:

$$i_{(t)} = i' + i'' = A_1 e^{P_1 t} + A_2 e^{P_2 t} \quad (10.8)$$

R_1 va R_2 ildiz koeffitsienti xarakteristik tenglamadan aniqlanadi:

$$LP^2 + RP + \frac{1}{C} = 0 \quad (10.9)$$

$$\text{Bundan: } P_{1,2} = -\delta \pm \sqrt{\delta^2 - \omega_0^2} \text{ yoki: } \delta = \frac{R}{2L}; \omega_0^2 = \frac{1}{LC} \quad (10.10)$$

A_1 va A_2 – koeffitsient boshlang'ich shart, ya'ni kommutatsiya qonuniga asosan aniqlanadi.

Ushbu R, L, C zanjirda uch xil holat yuzaga kelishi mumkin:

a) aperiodik zaryadsizlanish: $\delta^2 > \omega_0^2$; $R > 2\sqrt{\frac{L}{C}}$

Bunda $i_{(t)}$ tok o'zgarishi: $i_{(t)} = \frac{U_0}{2L\gamma}(e^{\alpha_2 t} - e^{\alpha_1 t})$ bunda $\gamma = (P_1 - P_2)$

b) tebranuvchan zaryadsizlanish: $\delta^2 < \omega_0^2$; $R < 2\sqrt{\frac{L}{C}}$

Bunda $i_{(t)}$ tok: $i_{(t)} = -I_0 e^{-\delta t} \sin \omega t = -\frac{U_0}{\omega L} e^{-\delta t} \sin \omega t$

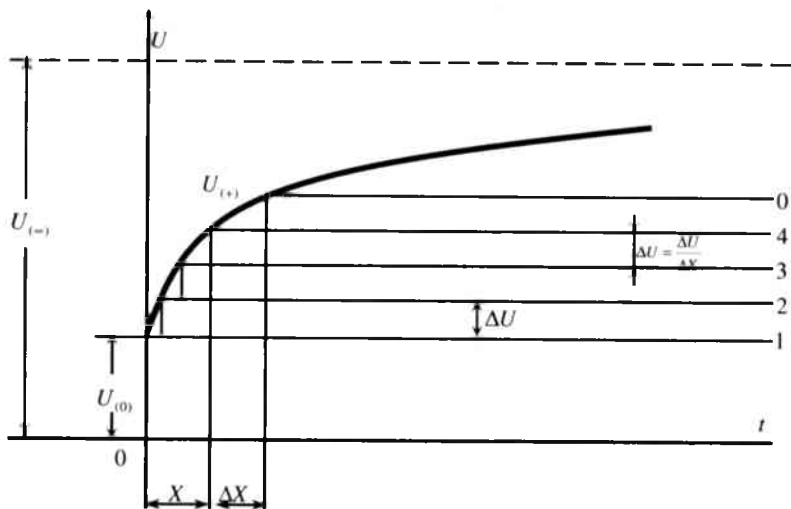
U_0 – kondensatordagi boshlang'ich kuchlanish

d) kritik holat: $\delta^2 = \omega_0^2$; $R = 2\sqrt{\frac{L}{C}}$. Bunda: $i_{(t)} = \frac{U_0}{L} t e^{-\delta t}$

10.2. Ixtiyoriy sliakldagi kuchlanish ta'sir etgan zanjirdagi o'tkinchi jarayonni hisoblash (Dyuamel integrali)

Strukturasi ma'lum bo'lgan passiv zanjirga kuchlanishi vaqtga nisbatan ixtiyoriy qonunga (funksiyaga) asosan o'zgaruvchan bo'lsa, o'tkinchi jarayon masalasi quyidagicha hal qilinadi.

Masalan: elektr zanjir $t=0$ vaqtda qandaydir o'zgarmas U_0 kuchlanishga ulangan deb faraz qilaylik. Zanjir iste'mol qiladigan



o'tkinchi tok shu kuchlanishning o'tkinchi o'tkazuvchanligi deb ataladigan $y_{(t)}$ ga ko'paytmasini ifodalovchi funksiya bo'ladi.

$$i_{(t)} = y_{(t)} U_0 \quad (10.11)$$

Funksiya $y_{(t)}$ faqat zanjirning strukturasiga bog'liq bo'lib, berilgan kuchlanish U_0 ning miqdoriga bog'liq emas.

Masalan, ketma-ket ulangan R, L zanjirida:

$$i_{(t)} = U_0 y_{(t)} = \frac{U_0}{R} \left(1 - e^{-\frac{t}{\tau}} \right) \quad (10.12)$$

bo'lib, tok $i_{(t)}$ ning o'zgarish qonuni ushbu zanjir o'tkinchi jarayon o'tkazuvchanligining o'zgarish qonuni $y_{(t)} = \frac{1}{R} (1 - e^{-\frac{t}{\tau}})$ da aks ettirilgan.

Shunga o'xshash berilgan egri chiziqli kuchlanish funksiyasini ΔU bo'lakchalarga bo'lib, har birining ta'siridan aniqlangan tokning yig'indisi o'tkinchi jarayon tokni ifodalaydi. Bunga Dyumel integrali deyilib, oltita formula ko'rinishida ifodalanadi:

$$\left. \begin{aligned} 1. \quad i_{(t)} &= U_{(0)} y_{(t)} + \int_{x=0}^{x=t} y(t-x) U'_{(t)} dx \\ 2. \quad i_{(t)} &= U_{(0)} y_{(t)} + \int_{x=0}^{x=t} y(t) U'_{(t-x)} dx \\ 3. \quad i_{(t)} &= U_{(t)} y_{(0)} + \int_{x=0}^{x=t} U(x) \frac{d}{dx} y(t-x) dx \\ 4. \quad i_{(t)} &= U_{(t)} y_{(0)} + \frac{d}{dx} \int_{x=0}^{x=t} y(x) U_{(t-x)} dx \\ 5. \quad i_{(t)} &= \frac{d}{dt} \int_{x=0}^{x=t} y(t-x) U_{(t)} dx \\ 6. \quad i_{(t)} &= \frac{d}{dt} \int_{x=0}^{x=t} y(x) U_{(t-x)} dx \end{aligned} \right\} \quad (10.13)$$

3. Operator usuli.

Original deb ataluvchi har qanday vaqt funksiyasi $f(t)$ ni unga ekvivalent bo'lgan kompleks o'zgaruvchan $p = S + j\omega$ argumentli $F(p)$ funksiyasi bilan almashtirish mumkin.

Matematik ko'rinishda:

$$f(x) \stackrel{*}{=} F(p) \text{ yoki } F(p) = f(t) \quad (10.14)$$

Berilgan funksiya $f(t)$ tasviri $F(p)$ «Laplas almashtirishi» deb ataladigan formulaga asosan:

$$F(p) = \int_0^{\infty} e^{-Pt} f(t) dt \quad (10.15)$$

Bu integral birmuncha chegaralangan bo'lganligi uchun, original $f(t)$ dan uning tasviri $F(p)$ ga o'tish uchun «Karson-Xevidsayd almashtirishi» deb ataluvchi formuladan foydalaniladi:

$$F(p) = p \int_0^{\infty} e^{-Pt} f(t) dt$$

Bu formula operator R ga ko'paytirish bilan farq qiladi. Funksiya hosilasi va integralining Laplas bo'yicha tasviri:

$$f'(t) \stackrel{*}{=} p[F(p) - f_{(0)}] \quad (10.16)$$

Bunda, $f_{(0)}$ funksiyasining $t = 0$ bo'lgandagi qiymati.

Integrali:

$$\int_0^t f(t) dt = \frac{1}{p} F(p) \quad (10.17)$$

Om qonuni operator ifodasi:

$$I_{(p)} = \frac{U_{(p)}}{Z_{(p)}} \quad (10.18)$$

Kirxgof qonuni operator ifodasi:

$$\sum E_{K(p)} = \sum [I_{K(p)} Z_{K(p)} - p L_K i_{K(0)} + U_{CK(0)}] \quad (10.19)$$

Bunda: $i_{K(0)}$ - $t = 0$ da L_K - induktivlikdagi tok:

$U_{CK(0)}$ - $t = 0$ da Ck - sig'imdagi kuchlanish:

$PL_K i_{K(0)}$ va $U_{CK(0)}$ – boshlang‘ich shartga asosan hosil bo‘ladigan tok va kuchlanishni ichki manba bilan almashtirilgan ifodasi.

O‘tkinchi jarayon boshlang‘ich shartlarini ichki manba bilan almashtirish natijasida ustma-ustlash usuliga asosan masalani yechish mumkin, natijada operator formada tok tenglamasini quyidagicha ifodalaymiz:

$$I_{(P)} = P \frac{G_{(P)}}{H_{(P)}} \quad (10.20)$$

$G_{(P)}$ va $H_{(P)}$ ko‘rsatkichli funksiya butun sonlar m va n polinomlari bunda ($m \leq n$)

Keltirilgan tenglamadagi (yoyish teoremasi) $H_{(P)} = 0$ deyilib ildiz operatori $R_1, R_2, R_3, \dots, R_n$ topiladi.

Barcha ildizlar R_K aniqlangandan keyin tok funksiyasi $i_{(t)}$ (original) quyidagicha ifodalanadi:

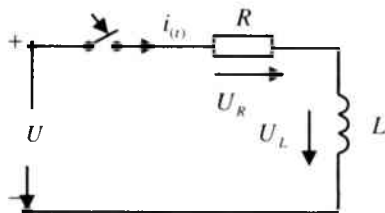
$$i_{(t)} = \sum_{K=1}^n \frac{G_{(P)}}{H'_{(P)}} e^{P_K t} \quad (10.21)$$

Bunda $H', \frac{dH}{dP}$ – olingan hosila. Agarda elektr zanjir sinusoidal o‘zgaruvchan kuchlanishga ulangan bo‘lsa, $U = U_m \sin(\omega t + \varphi)$ kompleks ifodasiga o‘tilib, keyin operator ko‘rinishida yoziladi:

$$\dot{U}_m e^{j\omega t} = \frac{\dot{U}_m P}{P - j\omega} \quad (10.22)$$

10.2. Masalalar yechish va uslubiy ko‘rsatmalar (klassik usul)

Masala 10.1. Ketma-ket ulangan elektr zanjirning aktiv va induktiv parametri $R=10 \text{ Om}$, $L=40 \text{ MGn}$ bo‘lib, o‘zgarmas kuchlanishga $U=100 \text{ V}$ ulanganda o‘tkinchi tok $i_{(t)}$ aniqlanib, grafigi chizilsin.



Yechish.

Kalit zanjirga ulangan paytda induktivlikda o'zinduksiya hodisiga asosan elektr yurituvchi kuch induksiyanlanadi $e_L = -L \frac{di}{dt}$

Kirxgof 2-qonuniga asosan differensial tenglamasi:

$$U = iR + L \frac{di}{dt}$$

Bu birinchi tartibli differensial tenglama bo'lib, o'tkinchi tok quyidagicha ifodalanadi:

$$i_{(t)} = i' + i'' = i' + Ae^{Pt}$$

$i_{(t)}$ – o'tkinchi jarayondagi tok.

i' – differensial tenglamaning xususiy yechimi bo'lib, kommutatsiyadan keyingi turg'un holatdagi tok.

i'' – differensial tenglamaning umumiy yechimini ifodalovchi (kommutatsiya vaqtidagi) erkin tok. Kommutatsiya birinchi qonuniga asosan aniqlanadi.

A – doimiy integrallash koeffitsienti boshlang'ich shart yoki kommutatsiya qonuniga asosan aniqlanadi.

P – xarakteristik tenglama ildizi.

Kommutatsiyadan keyin zanjirdan o'tuvchi turg'un tok.

$$i' = \frac{U}{R} = \frac{100}{10} = 10 \text{ A}$$

Erkin holatdagi tok i'' topish uchun tenglamani quyidagicha ifodalaymiz:

$$L \frac{di''}{dt} + Ri'' = 0$$

Bu differensial tenglamaning yechimi: $i'' = Ae^{Pt}$

Xarakteristik tenglamadan ildizni topamiz: $LP + R = 0$

$$\text{Bunda: } P = -\frac{R}{L} = -\frac{10}{40 \cdot 10^{-3}} = -0,25 \cdot 10^3 = 250 \cdot \left(\frac{1}{\text{sek}}\right)$$

Zanjirdagi o'tkinchi tok ifodasi:

$$i_{(t)} = 10 + Ae^{-250t}$$

A – integrallash koeffitsienti kommutatsiya birinchi qonuniga asosan $t=0$ bo'lganda:

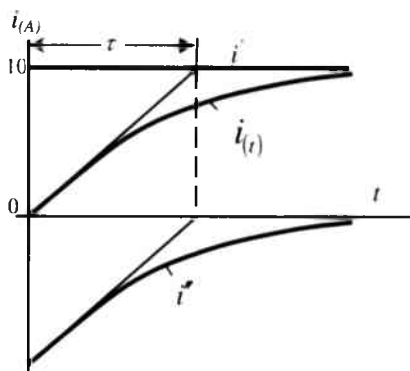
$$i_{(0)} = i_{(0-)} = 10 + A; \quad A = -10$$

Demak, o'tkinchi jarayon tok ifodasi:

$$i_{(+)} = 10 - 10e^{-250t} = 10(1 - e^{-250t}) \text{ (A)}$$

Bunda: $p = -\frac{1}{\tau}$ yoki $\tau = 40 \cdot 10^{-3}$ sek o'tkinchi jarayon vaqti

yoki R, L janjir uchun: $\tau = \frac{L}{R}$ (sek)



Masala 10.2. Induktiv g'altakning aktiv qarshiligi $R=10 \text{ Om}$, induktivligi $L=0,01 \text{ Gm}$ bo'lib, $e = 100\sqrt{2} \sin(1000t + 15^\circ) \text{ B}$ kuchlanishga ulanganda o'tkinchi jarayon tok $i_{(t)}$ aniqlansin.

Yechish.

Zanjirning differensial tenglamasi :

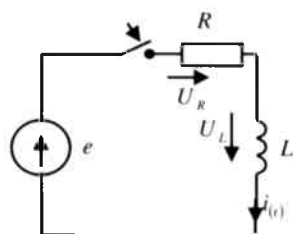
$$L \frac{di}{dt} + Ri = e_{(t)}$$

Tenglamaning yechimi:

$$i_{(t)} = i' + i'' = i' + Ae^{pt}$$

Xarakteristik tenglamadan: $LP + R = 0$

$$P = -\frac{R}{L} = -\frac{10}{0,01} = -10^3 \left(\frac{1}{\text{sek}} \right)$$



Bunda kommutatsiyagacha bo'lgan tok nolga teng ($i_{(0)} = 0$).

Kommutatsiyadan keyingi turg'un holatdagi tokni topamiz.

$$I'_m = \frac{\dot{E}}{Z} = \frac{100\sqrt{2}e^{j15^\circ}}{10 + j10} = 10e^{-j30^\circ} = 10\sin(\omega t - 30^\circ)$$

Kommutatsiya vaqtida $t=0$;

$$i'_{(0)} = 10\sin(-30^\circ) = -5 \text{ A}$$

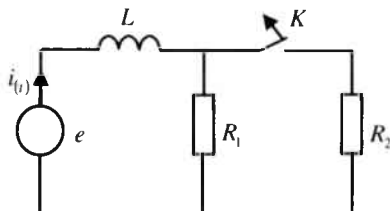
Kommutatsiya qonuniga asosan $i_{L(0^-)} = i_{L(0^+)}$

O'tkinchi jarayondagi tok $t=0$ bo'lganda:

$$i''_{(0)} = i_{(0^-)} - i'_{np} = 0 + 5 = 5 \text{ A}$$

Demak: $i_{(t)} = i' + i'' = 10\sin(\omega t - 30^\circ) + 5e^{-10t}$

Masala 10.3. Elektr zanjiri parametri $R_1=R_2=5 \text{ Om}$, $L=10\text{mGn}$ bo'lib, chastotasi $f=50 \text{ Gs}$, $U=220\sin(\omega t+90^\circ)$ kuchlanishga ulangan. Kalit uzilgan holatidagi $i_{(t)}$ o'tkinchi jarayondagi tok aniqlansin.



1. Kommutatsiyagacha bo'lgan tokni topamiz:

$$\dot{I}_{(0)} = \frac{220\sqrt{2}e^{j90^\circ}}{Z} = \frac{220\sqrt{2}e^{j90^\circ}}{j\omega L + \frac{R_1 \cdot R_2}{R_1 + R_2}} = \frac{220\sqrt{2}e^{j90^\circ}}{2,5 + j314 \cdot 0,01} = \frac{220\sqrt{2}e^{j90^\circ}}{4e^{j51^\circ 30'}} = 77,5e^{j38^\circ 30'} \text{ A}$$

2. Kommutatsiyadan keyingi turg'un holatdagi tokni topamiz:

$$\dot{I}' = \frac{220\sqrt{2}e^{j90^\circ}}{Z} = \frac{220\sqrt{2}e^{j90^\circ}}{5 + j3,14} = \frac{220\sqrt{2}e^{j90^\circ}}{5,89e^{j32^\circ 10'}} = 52,6e^{j57^\circ 50'} \text{ A}$$

Bunda doimiy vaqt koeffitsienti: $\tau = \frac{L}{R_1} = \frac{0,01}{5} = 0,002 \text{ (sek)}$

O'tkinchi jarayondagi tok: $i_{(t)} = i'_{(+)} + i''_{(+)} = 52,6\sin(\omega t + 57^\circ 30') + Ae^{-\frac{t}{\tau}}$

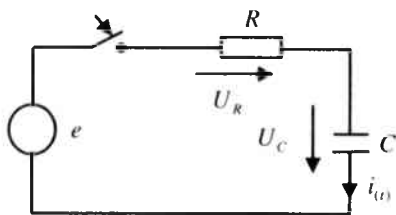
bundan $t=0$ bo'lgandagi boshlang'ich shartdan, ya'ni kommutatsiya birinchi qonuniga asosan $(i_{L(0^-)} = i_{L(0^+)})$ A – koeffitsientni aniqlaymiz:

$$i_{(0)} = 52,6 \sin(57^\circ 30') + A = 77,5 \sin(38^\circ 30') \text{ yoki: } A = 48,3 - 44,3 = 4 \text{ A.}$$

Kommutatsiyadan keyingi umumiy tok ifodasi:

$$i_{(t)} = 52,6 \sin(\omega t + 57^\circ 30') + 4e^{\frac{t}{0,002}}$$

Masala 10.4. Ketma-ket ulangan aktiv qarshiligi $R=100 \text{ Om}$ va sig'imi $C = 10^{-5} \text{ F}$ bo'lgan elektr zanjir sinusoidal o'zgaruvchan EYK $e = 100 \sin(10^3 t - 90^\circ)$ B ulangandan keyingi o'tkimchi jarayon (sig'im) $U_{C(t)}$ kuchlanishi va tok $i_{(t)}$ aniqlansin.



Yechish.

1. R, C zanjir uchun differensial tenglamani tuzamiz:

$$e = iR + U_C = RC \frac{dU_C}{dt} + U_C \quad (1)$$

differensial tenglamaning yechimi quyidagicha ifodalanadi:

$$U_{C(t)} = U'_C + U''_C = U'_C + Ae^{pt} \quad (2)$$

2. (1) dan xarakteristik tenglamaga asosan ildizni aniqlaymiz:

$$Z_{(p)} = 0; \quad RCp + 1 = 0$$

Bundan:

$$p = -\frac{1}{RC} = -\frac{1}{100 \cdot 10^{-5}} = -10^3 \left(\frac{1}{\text{sek}} \right)$$

O'tkinchi jarayon vaqti: $\tau = \frac{1}{p} = RC = 10^{-3} (\text{sek})$

3. Ushbu zanjirda kommutatsiyagacha bo'lgan tok $i_{(0^-)} = 0$,

$U_{C(0^-)} = 0$ bo'lib, kommutatsiya ikkinchi qonuniga asosan:

$$u_{C(0^-)} = u_{C(0^+)} = 0$$

4. Kommutatsiyadan keyingi sig'im turg'un holat kuchlanishini aniqlaymiz:

$$U'_C = \frac{100e^{-j90^\circ}}{100e^{-j100^\circ}}(-j100) = \frac{100}{\sqrt{2}}e^{-j135^\circ} \quad U'_{C(t)} = \frac{100}{\sqrt{2}}\sin(\omega t - 135^\circ)$$

$$\text{yoki } t=0 \text{ da } U'_{C(0)} = \frac{100}{\sqrt{2}}\sin(-135^\circ) = \frac{100}{\sqrt{2}} \cdot \frac{\sqrt{2}}{2} = -50 \text{ (V)}$$

(2) tenglamadan $t=0$ bo'lganda $U_{C(0)} = U'_{C(0)} + A$ yoki $0 = -50 + A$;
 $A = 50$. Sinusoidal o'tkinchi jarayon kuchlanish ifodasi:

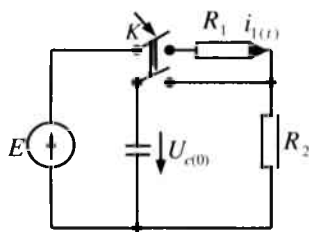
$$U_{C(t)} = \frac{100}{\sqrt{2}}\sin(\omega t - 135^\circ) + 50e^{-10^3 t} \text{ (V)}$$

O'tkinchi jarayon tok ifodasini aniqlash uchun quyidagi tenglamadan foydalanamiz:

$$i_{C(t)} = C \frac{dU_C}{dt} = \frac{100}{\sqrt{2}}10^{-5}10^310^{-5}\cos(\omega t - 135^\circ) + 5010^{-5}10^3e^{-10^3 t} =$$

$$= \frac{1}{\sqrt{2}}\sin(\omega t - 45^\circ) + 0,5e^{-10^3 t} \text{ A}$$

Masala 10.5. Elektr zanjir parametri $R_1=40\text{m}$, $R_2=20\text{m}$, $C=300(\text{mkF})$ va manba kuchlanishi $E=12 \text{ V}$ bo'lib, kommutatsiyagacha sig'im kuchlanishi $U_{C(0^-)}=6 \text{ V}$ kuchlanishga ega. Kalit ulangandan keyin R_1 qarshilikdan o'tuvchi $i_{1(t)}$ o'tkinchi jarayondagi tok aniqlansin.



Yechish.

1) kommutatsiyagacha bo'lgan tok nolga teng $i_{(0^-)} = 0$.

O'tkinchi jarayondagi tok: $i_{(t)} = i'_{(t)} + i''_{(t)} = i' + Ae^{pt}$ (1)

2) kommutatsiyadan keyingi turg'un holatdagi tok:

$$i' = \frac{E}{R_1 + R_2} = \frac{12}{6} = 2 \text{ A}$$

O'tkinchi jarayon vaqti: $\tau = \frac{R_1 \cdot R_2}{R_1 + R_2} \cdot C = 4 \cdot 10^{-4} \text{ (sek)}$

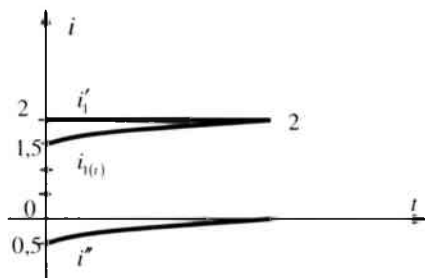
3) Kirxgof qonuniga asosan $t = 0$ bo'lgan holat tenglamasini tuzamiz va kommutatsiya ikkinchi qonuniga asosan $U_{C(0^-)} = U_{C(0^+)}$ ekanligini hisobga olsak: $i_{1(0)}R_1 + U_{C(0)} = E$ $i_{2(0)}R_2 - U_{C(0)} = 0$

$$\text{Bundan: } i_{2(0)} = \frac{U_{C(0)}}{R_2} = \frac{6}{2} = 3A \quad i_{1(0)} = \frac{E - U_{C(0)}}{R_1} = \frac{12 - 6}{4} = 1,5A$$

$$(1) \text{ tenglamadan } z=0 \text{ bo'lganda: } i_{1(0)} = i'_{1(0)} + i''_{1(0)} = i'_{1(0)} + A$$

$$\text{Bundan: } A = i''_{1(0)} - i'_{1(0)} = 1,5 - 2 = -0,5A$$

$$\text{O'tkinchi jarayon toki: } i_{1(t)} = 2 - 0,5e^{-2,5 \cdot 10^3 t}$$



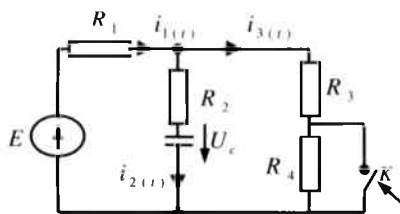
Masala 10.6. Parametri: $R_1 = R_2 = R_3 = R_4 = 10 \text{ Om}$, $C=1$ va EYK $E = 60 \text{ V}$ ga teng bo'lgan elektr zanjirda kalit ulangandan keyingi o'tkinchi jarayondagi $i_{1(+)}$ tok aniqlansin.

Yechish.

1. Kommutatsiyagacha bo'lgan tarmoqdagi tokni aniqlaymiz:

$$i_{1(0^-)} = i_{3(0^-)} = \frac{E}{R_1 + R_1 + R_1} = \frac{60}{30} = 2(A)$$

Sig'imdan o'zgarmas tok o'tmasligi sabib: $i_{2(0^-)} = 0$



$$\text{Sig'imdagi kuchlahish: } u_{C(0^-)} = i_{3(0^-)} (R_3 + R_4) = 2 \cdot 20 = 40 (V)$$

$$\text{Kommutatsiya qonuniga asosan: } u_{C(0^+)} = u_{C(0^-)} = 40 (V)$$

2. Kommutatsiyadan keyingi elektr tokni aniqlash uchun Kirxgof qonuniga asosan tenglama tuzamiz:

$$\begin{cases} i_{1(0^+)} R_1 + i_{2(0^+)} R_2 + u_{1(0^+)} = E \\ i_{1(0^+)} R_1 + i_{3(0^+)} R_3 = E \\ i_{1(0^+)} = i_{2(0^+)} + i_{3(0^+)} \end{cases} \quad (1)$$

Tok qiymatini topamiz:

$$i_{2(0^+)} = \frac{E - u_{C(0^+)} - i_{1(0^+)} R}{R_2}; \quad i_{3(0^+)} = \frac{E - i_{1(0^+)} R_1}{R_3}$$

$$i_{1(0^+)} = \frac{E_1 - u_{C(0^+)} - i_{1(0^+)} R_1 + E - i_{1(0^+)} R_1}{R} = \frac{2E - u_{C(0^+)} - 2i_{1(0^+)} R_1}{R}$$

$$\text{Bundan: } i_{1(0^+)} = \frac{2E - u_{C(0^+)}}{3R_1} = \frac{120 - 40}{30} = 2.66A$$

3. O'tkimchi jarayondagi tok ifodasi:

$$i_{1(t)} = i_1' + i_1'' = i_1' + Ae^{pt} \quad (2)$$

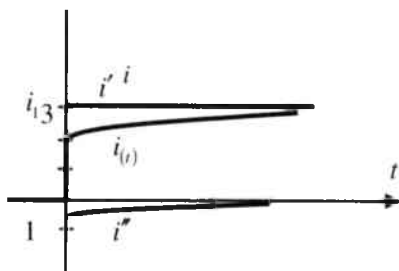
$$\text{Turg'un holatdagi tok: } i_1' = \frac{E}{2R} = \frac{60}{20} = 3(A)$$

(2) tenglamadan $t=0$ bo'lganda:

$$i_{1(0)}'' = i_{1(0^+)} - i_1' = 2.66 - 3 = -0.33(A) \text{ yoki: } i_{1(0)}'' = A = -0.33(A)$$

4. Zanjirning xarakteristik tenglamasiga asosan ildiz P ni aniqlaymiz: $Z(p) = 0$

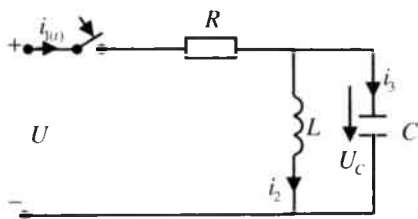
$$Z(p) = R + \frac{R \left(R + \frac{1}{pc} \right)}{R + R + \frac{1}{pc}} = 0$$



$$\text{yoki: } 3R^2 Cp + 2R = 0; p = -\frac{2R}{3R^2 C} = -\frac{2}{3 \cdot 10^{-6}} = -6,66 \cdot 10^4 \left(\frac{1}{\text{sek}} \right)$$

$$\text{O'tkinchi jarayondagi tok: } i_{1(t)} = i'_1 + i''_1 = 3 - 0,33 e^{6,66 \cdot 10^4 t}$$

Masala 10.7. Tarmoqlangan elektr zanjir parametri R , L , C bo'lib, o'zgarmas kuchlanishga ulangandan keyingi o'tkinchi jarayondagi tok $i_{2(t)}$ va sig'im $U_{C(t)}$ ifodalari aniqlansin.



Yechish.

1. Kirxgof qonuniga asosan differensial tenglama tuzamiz:

$$\begin{cases} u = i_{1(0^+)} R + L \frac{di_{2(t)}}{dt} \\ u_{C(t)} = L \frac{di_{2(t)}}{dt} \\ i_{1(t)} = i_{2(t)} + i_{3(t)} = i_{2(t)} + C \frac{du_{C(t)}}{dt} \end{cases} \quad (1)$$

Ushbu tenglamaning $i_{2(t)}$ nisbatan differensial tenglamasini yechamiz:

$$\frac{di_{2(t)}}{dt^2} + \frac{1}{RC} \frac{di_{2(t)}}{dt} + \frac{1}{LC} i_{2(t)} = \frac{U_{(t)}}{RLC} \quad (2)$$

Differensial tenglama bo'lib quyidagicha ifodalanadi:

$$i_{2(t)} = i'_{2(t)} + i''_{2(t)} = i'_{2(t)} + A_1 e^{p_1 t} + A_2 e^{p_2 t} \quad (3)$$

(2) tenglamaga asosan xarakteristik tenglama ildizini aniqlaymiz:

$$p^2 + \frac{1}{RCL} p + \frac{1}{CL} = 0$$

Ildizlari:
$$p_{1,2} = -\frac{1}{2RC} \pm \sqrt{\frac{1}{4R^2 C^2} - \frac{1}{LC}} \quad (4)$$

Elektr zanjirda kommutatsiyagacha bo'lgan tok va $i_{(0^+)} = 0, u_{C(0^+)} = 0$

Kommutatsiya qonuniga asosan $t = 0$ bo'lganda:

$$\begin{aligned} i_{2(0^+)} &= i_{2(0^-)} = i_{2(0^+)} = 0 \\ u_{C(0)} &= u_{C(0^-)} = u_{C(0^+)} = 0 \end{aligned} \quad (5)$$

Kommutatsiyadan keyingi turg'un holatdagi tok:

$$i_2' = \frac{U}{R} \quad (6)$$

(3) tenglamadan $t = 0$ bo'lganda:

$$i_{2(0)} = i_{2(0)}' + A_1 + A_2 = \frac{U}{R} + A_1 + A_2 = 0 \quad (7)$$

(1) tenglamalar sistemasidagi: $u_{L(t)} = L \frac{di_{2(t)}}{dt}$ ga (3) tenglamadagi

$i_{2(t)}$ tok hosilasini (1) tenglamaga qo'yamiz:

$$\text{Bunda: } u_{L(t)} = L(A_1 P_1 e^{P_1 t} + A_2 P_2 e^{P_2 t})$$

$$\text{yoki } t = 0 \text{ bo'lganda: } u_{L(0)} = A_1 P_1 + A_2 P_2 = 0 \quad (8)$$

(7) va (8) tenglamalar sistemasini yechish bilan integrallash koeffitsienti A_1 va A_2 aniqlanadi:

$$\begin{cases} A_1 + A_2 + \frac{U}{R} = 0 \\ A_1 P_1 + A_2 P_2 = 0 \end{cases}$$

$$\text{Bundan: } A_1 = \frac{UP_2}{R(P_1 - P_2)}; \quad A_2 = \frac{UP_1}{R(P_1 - P_2)}$$

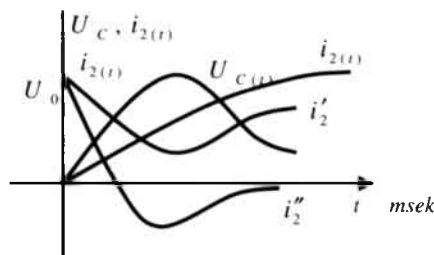
Topilgan barcha qiymatni (3) tenglamada qo'yish bilan o'tkinchi jarayondagi tokni $i_{2(t)}$ topamiz:

$$i_{2(t)} = \frac{U}{R} + \frac{U}{R(P_1 - P_2)} (P_2 e^{P_1 t} - P_1 e^{P_2 t})$$

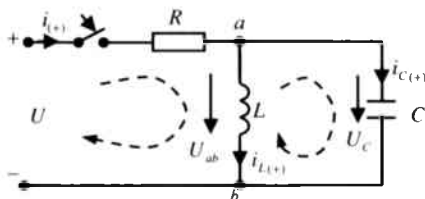
$$u_{C(t)} = L \frac{di_2}{dt} = \frac{ULP_1 P_2}{R(P_1 - P_2)} (e^{P_1 t} - e^{P_2 t})$$

Agarda: $P_1 = P_2 = \frac{1}{LC}$ bo'lsa $u_{C(t)} = \frac{U}{RC(P_1 - P_2)} (P_1 e^{P_1 t} - P_2 e^{P_2 t})$ aperiodik

zaryadsizlanish holati yuzaga keladi.



Masala 10.8. Aralash sxemada birlashtirilgan elektr zanjir parametri: $R=50\Omega$, $L=300\text{mH}$, $C=100\text{mkF}$ bo'lib, $u=1000\sin 314t$ (V) sinusoidal o'zgaruvchan kuchlanishga ulanganda, $i_{(t)}$ o'tkimchi jaryondagi tok aniqlansin.



Yechish.

1. Bu elektr zanjirda kommutatsiyagacha bo'lgan tarmoqdagi tok nolga teng:

$$i_{(0^-)} = 0, \quad i_{L(0^-)} = 0, \quad i_{C(0^-)} = 0$$

2. Kalit ulangandan keyin turg'un holatdagi tokni aniqlaymiz:

Umumiy tarmoqdagi tok:

$$\dot{i}'_m = \frac{\dot{U}_m e^{j\omega t}}{Z} = \frac{1000}{R + \frac{jx_L(-jx_C)}{jx_L - jx_C}} = \frac{1000}{10 + \frac{31,8e^{j90^\circ} \cdot 34e^{-j90^\circ}}{j31,8 - j34}} = 14,4e^{j44^\circ}$$

Tok o'liy qiymati: $i' = 14,4\sin(314t + 44^\circ)$

Bunda: $t=0$ bo'lganda $i'_{(0)} = 14,4\sin 44^\circ = 10A$

$$\text{Induktivlik: } \dot{i}'_{mL} = \frac{\dot{U}_{ab}}{Z_{ab}} = \dot{i}'_m \frac{jx_C}{jx_L - jx_C} = 14,4e^{j44^\circ} * \frac{-j34}{j31,8 - j34} = -7,22e^{j44^\circ}$$

yoki: $i'_L = -7,22\sin(314t + 44^\circ)$

Bunda: $t=0$ bo'lganda $i'_{L(0)} = -7,22\sin 44^\circ = -5,1A$

$$\text{Sig'imdagi tok: } i'_{mC} = i'_m \frac{jx_L}{jx_L - jx_C} = 14,4e^{j44^\circ} * \frac{-j31,8}{j31,8 - j34} = 21,66e^{j44^\circ} \text{ yoki}$$

$$i'_C = 21,66 \sin(314t + 44^\circ) \text{ Bunda } t=0 \text{ bo'lganda}$$

$$i'_{C(0)} = 21,66 \sin 44^\circ = 15,1A$$

3. Xarakteristik tenglama tuzib, ildizni aniqlaymiz: $Z_{(P)} = 0$

$$\text{Bunda: } R + \frac{PL \cdot \frac{1}{PC}}{PL + \frac{1}{PC}} = 0 \quad \text{yoki: } P^2 + \frac{1}{RC}P + \frac{1}{CL} = 0$$

$$\frac{RP^2CL + R + RL}{PC} = 0 \quad P_{1,2} = -\frac{1}{2RC} \pm \sqrt{\frac{111}{4R^2C^2} - \frac{1}{LC}}$$

$$P_1 = -100 + j153 \cdot \left(\frac{1}{\text{sek}}\right) \text{ yoki } P_2 = -100 - j153 \cdot \left(\frac{1}{\text{sek}}\right)$$

4. Ushbu zanjirda o'tkimchi jarayonni ifodalovchi (2) differensial tenglama yechimi quyidagicha ifodalanadi:

$$i_{(t)} = i_{(t)} + Ae^{p_1 t} + Ae^{p_2 t} \quad (1)$$

$$\text{Hosilasi: } \frac{di_{(t)}}{dt} = A_1 P_1 e^{p_1 t} + A_2 P_2 e^{p_2 t} \quad (2)$$

$$\left. \begin{aligned} i_{(0)} &= A_1 + A_2 \\ \text{yoki } t=0 \text{ bo'lganda: } \frac{di_{(0)}}{dt} &= A_1 P_1 + A_2 P_2 \end{aligned} \right\} \quad (3)$$

Bu tenglamani yechish uchun kommutatsiya qonuniga asosan erkin tok qiymatini aniqlaymiz, yoki $t=0$ bo'lganda

$$i''_{(0)} = i' + A_1 + A_2 = i'_{(0-)} = 0$$

$$\text{yoki: } i'_{(0)} = 0 - 10 = -10 \text{ Bundan: } A_1 + A_2 = -10; \quad A_2 = -A_1 - 10$$

(2) tenglamadan $\frac{di_{(t)}}{dt}$ aniqlash uchun Kirxgof qonumiga asosan elektr

zanjir differensial tenglamasini tuzamiz:

$$i'' = i''_L + i''_C \quad (*)$$

$$0 = Ri'' + L \frac{di''_L}{dt} \quad (**)$$

$$L \frac{di''_L}{dt} = \frac{1}{C} \int i''_C dt \quad (***)$$

$$(**) \text{ tenglamadan: } i'' = -\frac{L}{R} \frac{di_L''}{dt}, \text{ Hosilasi: } \frac{di_L''}{dt} = -\frac{L}{R} \frac{di_L''^2}{dt^2} \quad (4)$$

$$(***) \text{ tenglama hosilasi: } \frac{di_L''^2}{dt^2} = \frac{1}{LC} i_C''$$

$$\text{Bu ifodani (4) tenglamaga qo'y sak: } \frac{di_L''}{dt} = -\frac{1}{RC} i_C'' \quad (5)$$

Bundan $t = 0$ bo'lganda induktivlikdagi tok kommutatsiya qonuniga asosan $i_{L(0^-)} = i_{L(0^+)} = 0$. Hamda:

$$i_{C(0)}'' = -i_{L(0)}'' - i_{(0)}'' = -10 - 5,1 = -15,1 \text{ A}$$

$$\text{Topilgan qiymatni (5) tenglamaga qo'y sak: } \frac{di_L''}{dt} = -\frac{1}{RC} (-15,1) = 3020$$

Barcha aniqlangan qiymatni (3) tenglama sistemasiga qo'yib tenglamani yechamiz:

$$A_2 = -A_1 - 10$$

$$A_1 P_1 + A_2 P_2 = A_1 (-100 + j153) + (A_1 + 10) \cdot (100 + j153) = 3020 \quad \left. \vphantom{\begin{matrix} A_2 = -A_1 - 10 \\ A_1 P_1 + A_2 P_2 = A_1 (-100 + j153) + (A_1 + 10) \cdot (100 + j153) = 3020 \end{matrix}} \right\}$$

$$\text{yoki: } A_1 = \frac{2020 - j1530}{j306} = -5 - j6,6 = -8,3e^{j53^\circ}$$

$$\text{Bunda: } A_2 = -5 - j6,6 - 10 = -15 - j6,6 = -15,9e^{-j53^\circ}$$

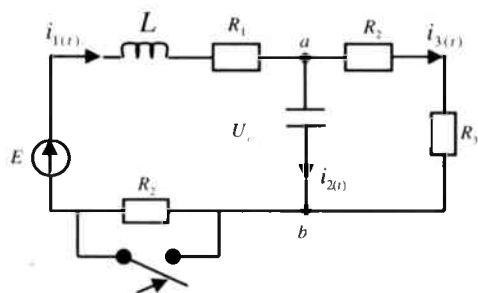
Integrallash koeffitsienti A_1 va A_2 qiymatni (1) tenglamaga qo'yamiz:

$$\begin{aligned} i'' &= A_1 e^{P_1 t} + A_2 e^{P_2 t} = -8,3e^{j53^\circ} \cdot e^{(-100+j153)t} - 15,9e^{-j53^\circ} \cdot e^{(-100-j153)t} = \\ &= -8,3e^{-100t} \cdot [e^{j(153t+53^\circ)} + e^{-j(153t+53^\circ)}] = -8,3e^{-100t} \cdot 2 \cos(153t + 53^\circ) = \\ &= -16,6e^{-100t} \cos[90^\circ - (37^\circ - 153t)] = -16,6e^{-100t} \cdot \sin(153t + 37^\circ) \end{aligned}$$

o'tkimchi jarayondagi tok $i_{(t)}$:

$$i_{(t)} = 14,4 \sin(314t + 44^\circ) - 16,6e^{-100t} \sin(153t - 37^\circ) \text{ A}$$

Masala 10.9. Elektr zanjir parametri: $L=1 \text{ MGn}=10^{-3} \text{ Gn}$; $C=1500 \text{ MkF}=1,5 \cdot 10^{-3} \text{ F}$, $R_1=2 \text{ Om}$, $R_2=13 \text{ Om}$, $R_3=1 \text{ Om}$, $R_4=4 \text{ Om}$ bo'lib, $E=50 \text{ V}$ o'zgarmas kuchlanishga ulangan. R_2 qarshilik qisqa tutashtirilgan holat uchun $i_1(t)$ o'tkimchi jarayondagi tok va induktivlik, sig'im qarshiligidagi kuchlanish $u(t)$ o'tkimchi jarayon klassik usulida hisoblansin.



Yechish. a) kommutatsiyagacha bo'lgan tok qiymatini topamiz:
Sig'imdan o'zgarmas tok o'tmasligi sababli: $i_{2(0)} = 0$.

Om qonuniga asosan:

$$i_{1(0)} = i_{2(0)} = \frac{E}{R_1 + R_2 + R_3 + R_4} = \frac{50}{20} = 2.5 \text{ A}$$

Sig'imdagi kuchlanish: $U_c = i_{3(0)} \times (R_2 + R_3) = 2.5 \times 5 = 12.5 \text{ V}$

b) kommutatsiyadan keyingi turg'un holatdagi tok va sig'imdagi kuchlanishni aniqlaymiz.

Bu holatda: $i_{2(0^+)} = 0$;

Birinchi tarmoqdagi tok:

$$i_{1(0^+)} = i_{3(0^+)} = \frac{E}{R_1 + R_3 + R_4} = \frac{50}{7} = 7.1 \text{ A}$$

Sig'imdagi kuchlanish $U_c = i_{3(0^+)} (R_3 + R_4) = 7.1 \cdot 5 = 35.5 \text{ V}$

Xarakteristik tenglama ildizlarini topamiz:

$$\begin{aligned} z_{(p)} &= PL + R_1 + \frac{1}{\frac{PC}{1 + PCR_3 + PCR_4}} (R_3 + R_4) = PL + R_1 + \frac{R_3 + R_4}{\frac{PC}{1 + PCR_3 + PCR_4}} = \\ &= \frac{PL + R_1 + P^2 LCR_3 + PCR_1 R_3 + P^2 LCR_4 + R_3 + R_4}{1 + PCR_3 + PCR_4} = 0 \end{aligned}$$

Ushbu tenglamada surat nolga teng

$$P^2 \cdot 6 \cdot 10^{-6} + 18 \cdot 10^{-3} P + 7 = 0$$

Bundan:

$$P_{12} = \frac{-9 \cdot 10^{-3} \pm \sqrt{(9 \cdot 10^{-3})^2 - 7 \cdot 6 \cdot 10^{-6}}}{6 \cdot 10^{-6}} = \frac{-9 \cdot 10^{-3} \pm \sqrt{39 \cdot 10^{-6}}}{6 \cdot 10^{-6}}$$

$$P_{12} = \frac{-9 \cdot 10^{-3} \pm \sqrt{(9 \cdot 10^{-3})^2 - 7 \cdot 6 \cdot 10^{-6}}}{6 \cdot 10^{-6}} = \frac{-9 \cdot 10^{-3} \pm \sqrt{39 \cdot 10^{-6}}}{6 \cdot 10^{-6}}$$

$$P_1 = \frac{-2800}{6} = -470 \frac{1}{\text{sek}}; \quad P_2 = \frac{-15200}{6} = -2530 \frac{1}{\text{sek}};$$

Xarakteristik tenglama ildizi $P_1 \neq P_2$ ga teng emas, haqiqiy sonlar bo'lganligi uchun o'tkinchi jarayon ifodasi: (*)

$$(*) \begin{cases} \dot{i}_1 = A_1 e^{P_1 t} + A_2 e^{P_2 t} \\ \frac{di_1}{dt} = P_1 A_1 e^{P_1 t} + P_2 A_2 e^{P_2 t} \end{cases}$$

yoki $t=0$ bo'lganda: (**)

$$\begin{cases} i_{1(0)} A_1 + A_2 \\ \frac{di_{1(0)}}{dt} = P_1 A_1 + P_2 A_2 \end{cases}$$

Kalit ulangandagi o'tkinchi jarayon: $i_{1(t)} = \dot{i}_1 + i_1 = \dot{i}_1 + A_1 e^{P_1 t} + A_2 e^{P_2 t}$

Kommutatsiya qonuniga asosan: $t=0$ da $i_{1(0)} = i_{1(0^-)} = i_{1(0)} = 2,5A$

Sig'imdagi kuchlanishi: $U_{1(0^-)} = U_{1(0^+)} = U_{c(0)} = 12,5V$

Shunga asosan: o'tkinchi jarayondagi tok va sig'imdagi kuchlanish:

$$\dot{i}_1 = i_{1(0)} - i_{1(0^+)} = 2,5 - 7,5 = -5A$$

$$U_c = U_{c(0)} - U_{1(0^+)} = 12,5 - 35,5 = 23V$$

(*) tenglamada $\frac{di_1}{dt}|_{t=0}$ qiymatni topish uchun Kirxgof qonuniga asosan tenglama tuzamiz:

$$(***) \begin{cases} \dot{i}_{1(0)} = \dot{i}_{2(0)} + \dot{i}_{3(0)} \quad (1) \\ \left(L \frac{di_1}{dt} \right)_{t=0} + i_{1(0)} R_1 + U_{c(0)} = 0 \quad (2) \\ -U_{c(0)} - i_{3(0)} (R_1 + R_4) = 0 \quad (3) \end{cases}$$

$$(2) \text{ tenglamadan: } \frac{di_{1(0)}}{dt} = \frac{-i_{1(0)} R - U_{c(0)}}{L} = \frac{10 + 23}{10^{-3}} = 33 \cdot 10^3 \frac{a}{\text{cek}}$$

Aniqlangan qiymatni (**) tenglamaga qo'yish bilan integrallash koeffitsienti A_1 va A_2 ni topamiz:

$$\begin{cases} -5 = A_1 + A_2; \\ 33 \cdot 10^3 = -470A_1 + 2530A_2 \end{cases}$$

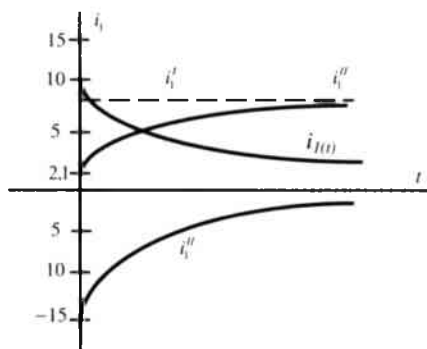
Tenglama yechimi: $33 \cdot 10^3 = 470A_2 + 2350 - 2530A_2$

Bundan: $A_2 = \frac{-300}{20} = -15, A_1 = -5 - A_2 = -5 + 15 = 10$

O'tkinchi jarayon: $i_{(t)}$ tok:

$$i_{(t)} = i_1 + A_1 e^{p_1 t} + A_2 e^{p_2 t} = 7,1 + 10e^{-470t} - 15e^{-2530t} \text{ (A)}$$

O'tkinchi jarayon grafigi:



Induktivlikda o'tkinchi jarayondagi kuchlanishi:

$$U_L = L \frac{di_{(t)}}{dt} = 10^{-3} (-470 \cdot 10e^{-470t} + 2530 \cdot 15e^{-2530t}) = -4.7e^{-470t} + 38e^{-2530t}$$

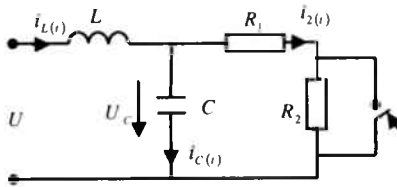
Sig'imdagi o'tkinchi jarayondagi kuchlanish:

$$U_C = \frac{1}{C} \int_{2(t)} dt = \frac{10^3}{1.5} \left(\frac{1}{-470} e^{-470t} - \frac{10.6}{-2530} e^{-2530t} \right) = -1.7e^{-470t} + 3e^{-2530t}$$

Masala 10.10. Elektr zanjir parametri $R_1 = 30 \text{ Om}$, $R_2 = 10 \text{ Om}$, $C = 5 \cdot 10^{-5} \text{ F}$ bo'lib, chastotasi $f = 50 \text{ Gs}$ bo'lgan sinusoidal o'zgaruvchan kuchlanish $U = 220 \text{ V}$ ga ulangan. Zanjirning R_2 qarshiligi qisqa tutashtirilganda (kalit ulanganda) o'tkimchi jarayondagi tok $i_{L(t)}$ va kuchlanish $U_{C(t)}$ aniqlansin.

Yechish. 1. Kommutatsiyagacha bo'lgan tok va kuchlanish qiymatini topamiz.

Umumiy qarshilik:



$$\underline{Z} = j\omega L - \frac{j \frac{R}{\omega C}}{R - j \frac{1}{\omega C}} = j1,5 + 33,8e^{-j33^\circ} = 28,6 + j133 = 136e^{j77^\circ}$$

Induktivlikdagi tok: $\dot{i}_{L(0)} = \frac{\dot{U}}{\underline{Z}} = \frac{220}{136e^{j77^\circ}} = 1,62e^{-j77^\circ}$

Tok oniy qiymati: $i_{L(0)} = 2,3 \sin(314t - 77^\circ)$; yoki: $t=0$ bo'lganda:

$$i_{L(0)} = -2,24 \text{ A}$$

Sig'imdagi kuchlanish:

$$\dot{U}_{C(0)} = \dot{I}_L - \frac{j \frac{R}{\omega C}}{R - j \frac{1}{\omega C}} = 1,62e^{-j77^\circ} 33,8e^{j33^\circ} = 54,8e^{j110^\circ}$$

Kuchlanish oniy qiymati: $u_{C(0)} = 54,8 \sin(314t - j10^\circ)$ yoki: $t=0$ bo'lganda: $U_{L(0)} = -73,5 \text{ (V)}$

Aktiv qarshilikdagi tok: $\dot{i}_{2(0)} = \frac{\dot{U}_{C(0)}}{R_1 + R_2} = \frac{54,8e^{-j110^\circ}}{40} = 1,37e^{-j110^\circ}$

Oniy qiymati: $i_{2(0)} = 1,37 \sin(314t - 110^\circ)$ yoki: $t=0$ bo'lganda:

$$i_{2(0)} = -1,25 \text{ A}$$

2. Kommutatsiyadan keyingi turg'un holatdagi tok va kuchlanishni aniqlaymiz.

To'la kompleks qarshilik: $\underline{Z} = j\omega L - \frac{j \frac{R}{\omega C}}{R - j \frac{1}{\omega C}} = 142e^{j80^\circ}$

Induktivlikdagi tok: $\dot{i}_{L(0^+)} = \frac{\dot{U}}{\underline{Z}} = \frac{220}{142e^{j80^\circ}} = 1,65e^{j80^\circ}$

yoki: $i'_{L(0)} = 1,65 \sin(314t - 80^\circ)$; $t=0$ bo'lganda: $i'_{L(0)} = -2,16 \text{ A}$

$$\text{Sig'imdagi tok: } \dot{i}'_C = \dot{i}'_L \frac{R_1}{R_1 - j \frac{1}{\omega C}} = 0,66e^{-j15^\circ}$$

Oniy qiymat: $i'_C = 0,66 \sin(314 + 15^\circ)$ yoki: $t=0$ bo'lganda: $i'_{C(0^+)} = -0,6 \text{ A}$

$$\text{Tok: } \dot{i}'_2 = \dot{i}'_1 \frac{-j \frac{1}{\omega C}}{R_1 - j \frac{1}{\omega C}} = 1,4e^{-j105^\circ}$$

Oniy qiymat: $i'_2 = 1,4 \sin(314 + 105^\circ)$ yoki: $t=0$ bo'lganda: $i'_{2(0^+)} = -1,3 \text{ A}$

Sig'imdagi kuchlanish: $U'_C = I'_2 \cdot R_1 = 1,4e^{-j105^\circ} 30 = 42e^{-j105^\circ}$.

Oniy qiymat: $U'_C = 42 \sin(314t - 105^\circ)$ yoki: $t=0$ bo'lganda: $U'_{C(0^+)} = -56,5 \text{ (V)}$

3. Kommutatsiyadan keyingi o'tkinchi jarayon erkin tok va kuchlanishni aniqlash uchun (kommutatsiya qonunini inobatga olgan holda) Kirxgof qonuniga asosan tenglama tuzamiz:

$$\left. \begin{aligned} i''_L &= i''_C + i''_2 \quad (1) \\ L \frac{di''_L}{dt} + i''_2 R_1 &= 0 \quad (2) \\ L \frac{di''_L}{dt} + \frac{1}{C} \int i''_C dt &= 0 \quad (3) \end{aligned} \right\} \quad (1)$$

(1) tenglamadan: $i''_2 = i''_L + i''_C$

Buni (2) tenglamadagi i''_2 o'rniga qo'yamiz:

$$L \frac{di''_L}{dt} + i''_L R_1 - i''_C R_1 = 0$$

Bundan: $i''_C = \frac{1}{R_1} (L \frac{di''_L}{dt} + i''_L R_1) = \frac{L}{R_1} \frac{di''_L}{dt} + i''_L \quad (2)$

Ushbu ifodani (3) tenglamaga qo'yib differensiallaymiz:

$$L \frac{d^2 i''_L}{dt^2} + \frac{1}{C} i''_C = L \frac{d^2 i''_L}{dt^2} + \frac{1}{C} \left(\frac{L}{R_1} \frac{di''_L}{dt} + i''_L \right) = L \frac{d^2 i''_L}{dt^2} + \frac{L}{CR_1} \frac{di''_L}{dt} + \frac{1}{C} i''_L = 0 \quad (3)$$

$$\text{Bundan:} \quad \frac{d^2 i_L''}{dt^2} + \frac{L}{CR_1} \frac{di_L''}{dt} + \frac{1}{LC} i_L'' = 0 \quad (4)$$

4. Differensial tenglama yechimi:

$$\left. \begin{aligned} i_L'' &= A_1 e^{P_1 t} + A_2 e^{P_2 t} \\ \frac{di_L''}{dt} &= P_1 A_1 e^{P_1 t} + P_2 A_2 e^{P_2 t} \end{aligned} \right\} \quad (5)$$

Xarakteristik tenglama (4) dan ildizlari P_1 va P_2 ni topamiz:

$$\text{Ya'ni:} \quad P^2 + \frac{1}{R_1 C} P + \frac{1}{LC} = 0$$

$$P_{1,2} = \frac{-L \pm \sqrt{L(R_1 - 4R_1^2 C)}}{2R_1 CL} = \frac{-0,48 \pm 0,38}{144 \cdot 10^{-5}} \quad P_1 = -69,5; \quad P_2 = -596$$

Induktivlikdagi tok ; $i_L'' = A_1 e^{-69,5t} + A_2 e^{-596t}$

Sig'imdand o'tuvchi tok (2) tenglamadan:

$$i_C'' = \frac{L}{R_1} (-69,5) A_1 e^{-69,5t} + \frac{L}{R_1} (-596) A_2 e^{-596t} + A_1 e^{-69,5t} + A_2 e^{-596t}$$

Endi sig'imdagi kuchianishni aniqlash uchun i_C'' tokni integral-laymiz:

$$U_C'' = \frac{1}{C} \int i_C'' dt = \frac{1}{C} \left[\left(\frac{0,11}{69,5} A_1 e^{-69,5t} + \frac{8,65}{596} A_2 e^{-596t} \right) \right] = 316 A_1 e^{-69,5t} + 290 A_2 e^{-596t}$$

Kommutatsiya birinchi qonuniga asosan induktivlikda:

$$i_{L(0^-)} = i_{L(0^+)} = -2,24 \text{ A}$$

Kommutatsiya ikkinchi qonuniga asosan sig'imdagi kuchianish:

$$U_{C(0^-)} = U_{C(0^+)} = -73,5 \text{ B}$$

Demak $t=0$ bo'lganda (5) tenglamadan:

$$\left. \begin{aligned} -2,24 &= -2,16 + A_1 + A_2 \\ -73,5 &= -53,5 + 316 A_1 + 290 A_2 \end{aligned} \right\} \quad \text{yoki:} \quad \left. \begin{aligned} -0,08 &= A_1 + A_2 \\ -17 &= 316 A_1 + 290 A_2 \end{aligned} \right\}$$

$$\text{Bundan:} \quad A_2 = -0,08 - A_1 \quad -17 = 316 A_1 - 23,2 - 290 A_1$$

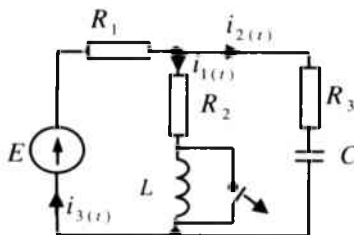
$$\text{yoki:} \quad A_1 = \frac{6,2}{26} = 0,258; \quad A_2 = -0,338$$

$$\text{Demak:} \quad i_{L(t)} = i' + i'' = 2,24 \sin(314t - 80^\circ) + 0,258 e^{-69,5t} - 0,338 e^{-596t}$$

$$\begin{aligned} U_{C(t)} &= U_C' + U_C'' = 42 \sin(314t - 105^\circ) + 316 \cdot 0,258 e^{-69,5t} - 290 \cdot 0,338 e^{-596t} = \\ &= 42 \sin(314t - 105^\circ) + 81 e^{-69,5t} - 98 e^{-596t} \end{aligned}$$

Demak, tok va kuchlanish tenglamasida o'tkinchi jarayon aperiodik qonunga asosan o'zgarar ekan.

Masala 10.11. Elektr zanjir parametri: $R_1 = 8,5 \text{ Om}$, $R_2 = 11 \text{ Om}$, $R_3 = 197,4 \text{ Om}$, $L_1 = 11 \text{ Gn}$, $C = 1 \text{ mkF}$ bo'lib, $E = 24 \text{ B}$ o'zgarmas tok manbaiga ulangan. Induktivlikdagi kalit uzilgan holatda o'tkinchi tok $i_{1(t)}$ va $U_{L(t)}$ aniqlansin.



Yechish.

1. Kommutatsiyagacha bo'lgan tok va kuchlanishni aniqlaymiz:

$$i_{1(0^-)} = \frac{E}{R_3 + R_1} = \frac{24}{197,4 + 8,5} = 0,116 \text{ A}$$

Sig'imdan o'zgarmas tok o'tmasligi sababli:

$$i_{2(0^-)} = 0$$

$$i_{3(0^-)} = i_{1(0^-)} = 0,116 \text{ A}$$

Sig'imdagi kuchlanish:

$$U_{C_{2(0^-)}} = \frac{E}{R_3 + R_1} R_1 = i_{1(0^-)} R_1 = 0,116 \cdot 8,5 = 1 \text{ V}$$

2. Kommutatsiyadan keyingi turg'un holatdagi tok va kuchlanish kommutatsiyagacha bo'lgan tokga teng bo'ladi:

$$i'_1 = \frac{E}{R_3 + R_1} = 0,116 \text{ A}$$

$$i'_2 = 0 \quad i'_3 = i'_1 = 0,116 \text{ A}$$

Sig'imdagi kuchlanish:

$$U'_C = i'_1 R_1 = 1 \text{ V}$$

3. O'tkinchi jarayon tok kuchlanishini aniqlash uchun Kirxgof qonuniga asosan elektr zanjir uchun differensial tenglama tuzamiz:

$$\left. \begin{aligned} -i_{1(t)} - i_{2(t)} + i_{3(t)} &= 0 \\ i_{1(t)} R_1 + L \frac{di_{1(t)}}{dt} + i_{3(t)} R_3 &= E \\ i_{2(t)} R + \frac{1}{C_2} \int i_{2(t)} dt - L \frac{di_{1(t)}}{dt} + i_{1(t)} R_1 &= 0 \end{aligned} \right\} \quad \begin{aligned} (1) \\ (2) \\ (3) \end{aligned}$$

Bunda (2) tenglamadan: $\frac{di_{1(t)}}{dt} = \frac{E - i_{1(t)} R_1 - i_{3(t)} R_3}{L}$ (4)

4. Xarakteristik tenglama ildizini aniqlash uchun $Z_{(p)} = 0$ bo'lganda:

$$Z_{(p)} = R_1 + pL_1 + \frac{R_3(R_2 + \frac{1}{pC_2})}{R_3 + R_2 + \frac{1}{pC_2}} = 0$$

$$p^2 + p \frac{R_3 R_1 + R_3 R_2 + R_2 R_1 + \frac{L}{C}}{(R_2 + R_3)L} + \frac{R_3 + R_1}{(R_2 + R_3)LC} = 0$$

Bundan: $p^2 + p46,8 \cdot 10^3 + 5972 \cdot 10^6 = 0$

yoki: $p_{1,2} = -\frac{46,8 \cdot 10^3}{2} \pm \sqrt{\left(\frac{46,8 \cdot 10^3}{2}\right)^2 - 5972 \cdot 10^6} = -23 \cdot 10^3 \pm j73 \cdot 10^3$ (5)

5. (2) differensial tenglama yechimi:

$$\left. \begin{aligned} i_{1(t)} &= i'_{1(t)} + i''_{1(t)} = i'_{1(t)} + A_1 e^{p_1 t} + A_2 e^{p_2 t} \\ \frac{di''_{1(t)}}{dt} &= A_1 p_1 e^{p_1 t} + A_2 p_2 e^{p_2 t} \end{aligned} \right\} \quad (6)$$

Integrallash koeffitsienti A_1 va A_2 boshlang'ich shartga binoan kommutatsiya birinchi qonunida, $t=0$ bo'lganda: $i_{1(0)} = 0,116 \text{ A}$

(4) tenglamadan:

$$\frac{di_{1(0)}}{dt} = \frac{E - i_{1(0)} R_1 - i_{3(0)} R_3}{L_1} = \frac{24 - 0,116 \cdot 197,4}{807 \cdot 10^{-6}} = 2,8 \cdot 10^3 \left(\frac{\text{A}}{\text{sek}} \right)$$

Ushbu qiymatni (6) tenglamaga qo'ysak ($t=0$):

$$\left. \begin{aligned} 0,116 &= 0,116 + A_1 + A_2 \\ 2,8 \cdot 10^3 &= A_1(-23 \cdot 10^3 + j73 \cdot 10^3) + A_2(-23 \cdot 10^3 - j73 \cdot 10^3) \end{aligned} \right\} \quad (7)$$

(7) tenglamani yechish natijasida:

$$A_1 = 0,058e^{-j179^\circ}; A_2 = 0,058e^{j179^\circ};$$

Aniqlangan barcha qiymatni (6) tenglamaga qo'ysak, o'tkinchi jarayondagi $i_{1(t)}$ tok ifodasi:

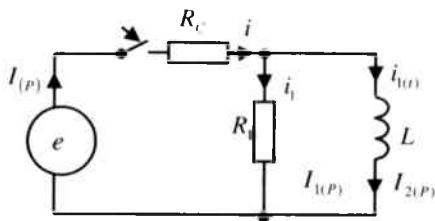
$$\begin{aligned} i_{1(t)} &= i'_{1(t)} + i''_{1(t)} = 0,116 + A_1 e^{p_1 t} + A_2 e^{p_2 t} = \\ &= 0,116 + 0,058e^{-j179^\circ} \cdot e^{(-23,4 \cdot 10^{-3} + j73,6 \cdot 10^3)t} + 0,058e^{j179^\circ} e^{(-23,4 \cdot 10^{-3} + j73,6 \cdot 10^3)t} = \\ &= 0,116 + 0,116e^{-23,4 \cdot 10^3 t} \sin(73,6 \cdot 10^3 t - 89^\circ) A \end{aligned}$$

Induktivlikdagi o'tkinchi kuchlanish:

$$\begin{aligned} U_{L(t)} &= L \frac{di_{1(t)}}{dt} = 807 \cdot 10^6 \cdot 0,058e^{-23,4 \cdot 10^3 t} \cdot \left[-23,4 \cdot 10^3 t \sin(73 \cdot 10^3 t - 89^\circ) + \right. \\ &\quad \left. + 73 \cdot 10^3 t \cos(73 \cdot 10^3 t - 89^\circ) \right] = \\ &= 3,6 \sin(73 \cdot 10^3 t + 89^\circ) \end{aligned}$$

Elektr zanjirida o'tkinchi jarayonni operator usulida hisoblash

Masala 10.12. Aktiv qarshiligi $R=R_1=50 \text{ Om}$, induktivligi $L=0,033 \text{ ГН}$ bo'lgan elektr zanjir $U_m = 200\sqrt{2} \sin(\omega t + 90^\circ)$ sinusoidal kuchlanishga ulanganda hosil bo'ladigan $i_{2(t)}$ o'tkinchi jarayondagi tok operator usulida topilsin.



Yechish.

Umumiy operator qarshiligini aniqlaymiz

$$Z_{(p)} = R + \frac{R_1 p L}{R_1 + p L} = \frac{R R_1 + p L (R + R_1)}{R_1 + p L}$$

Induktivlikdan o'tuvchi $I_{2(p)}$ tokning operator ifodasi Om qonuni-ga asosan:

$$I_{2(P)} = I_{(P)} \frac{R_1}{R_1 + PL}$$

yoki:

$$I_{2(P)} = \frac{U_{(P)}}{Z_{(P)}} \cdot \frac{R_1}{R_1 + PL} = \frac{U_{(P)}(R_1 + PL)R_1}{[RR_1 + PL(R + R_1)](R_1 + PL)} = \frac{U_{(P)}R_1}{RR_1 + PL(R + R_1)} = \frac{U_{(P)}}{Z_{2(P)}}$$

Bundan: $Z_{2(P)} = \frac{RR_1 + PL(R + R_1)}{R_1}$

Tenglama ildizi $Z_{2(P)} = 0$ asosan: $PL(R + R_1) + RR_1 = 0$

$$P = -\frac{RR_1}{L(R + R_1)} = -\frac{25}{10L} = -78,2 \frac{1}{\text{cek}}$$

$i_{2(t)}$ o'tkinchi jarayondagi tokni operator ifodasida aniqlash uchun (9.22) tenglamaga asoslanadi:

$$i_{2(t)} = M \left[\frac{U_m e^{j(\omega t + \psi)}}{Z_{2(j\omega)}} + \sum_{k=0}^n \frac{U_m e^{j\varphi} e^{P_k t}}{(P_k - j\omega)Z'_{2(P)}} \right] \quad (1)$$

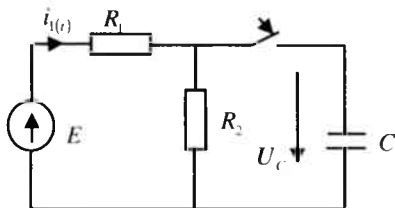
Bundan: $Z'_{2(P)} = \frac{L(R + R_1)}{R_1} = 0,064$

Aniqlangan qiymat (1) tenglamaga qo'yiladi:

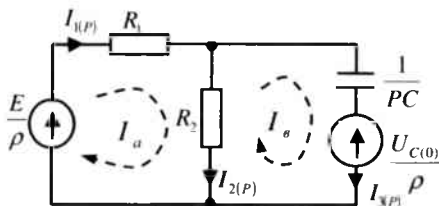
$$i_{2(t)} = \left[\frac{310e^{j(\omega t + 90^\circ)}}{20,55e^{j76^\circ}} + \frac{310e^{-90^\circ} e^{-78,2t}}{322e^{-j104^\circ} 0,064} \right] =$$

$$= 15 \sin(\omega t - 166^\circ) + 15 \sin 14^\circ e^{-78,2t} = 15 \sin(\omega t - 166^\circ) + 3,74e^{-78,2t}$$

Masala 10.13. Parametri $R_1 = R_2 = 10 \text{ Om}$, $C = 1 \text{ mkF}$ bo'lgan elektr zanjirning o'zgarmas manbai $E = 10 \text{ V}$ bo'lib, sig'im ulanganda hosil bo'ladigan $i_1(t)$ o'tkinchi jarayon tok operator usuliga asosan aniqlansin.



Yechish. Kommutatsiyadan keyingi operator sxemasini tuzamiz:



Konturli tok usuliga asosan tenglama yozamiz:

$$\begin{cases} I_{a(p)}(R_1 + R_2) - I_{b(p)}R_2 = \frac{E}{p} \\ -I_{a(p)}R_2 + I_{b(p)}(R_2 + \frac{1}{PC}) = -\frac{U_{C(0)}}{p} \end{cases}$$

Son qiymatini qo'yamiz:

$$\begin{cases} I_{a(p)}20 - 10I_{b(p)} = \frac{10}{p} \\ -I_{a(p)}10 + (\frac{10^6}{p} + 10)I_{b(p)} = -\frac{U_{C(0)}}{p} \end{cases}$$

Bundan:

$$I_{a(p)} = I_{1(p)} = \frac{10^7 + 100P - U_{C(0)}10P}{100P^2 + 2 \cdot 10^7 P} = \frac{10P - U_{C(0)}10P + 10^6}{10P(P + 2 \cdot 10^5)} = \frac{F_1(p)}{F_2(p)}$$

Tenglamadan ildiz P ni topamiz: $Z(p) = 0$

$$Z(p) = P + 2 \cdot 10^5 = 0; P = -2 \cdot 10^5 \cdot \left(\frac{1}{sek}\right)$$

Yoyish teoremasiga asosan ushbu operator tenglamani kasr tenglamalar yig'indisi ko'rinishida yozamiz:

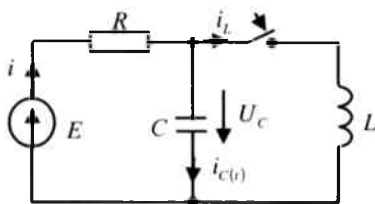
$$\begin{aligned} I_{1(p)} &= \frac{10P}{10P(P + 2 \cdot 10^5)} - \frac{U_{C(0)}P \cdot 10}{10P(P + 2 \cdot 10^5)} + \frac{10^6}{10P(P + 2 \cdot 10^5)} = \\ &= \frac{1}{P + 2 \cdot 10^5} - \frac{U_{C(0)}}{P + 2 \cdot 10^5} + \frac{10^5}{P(P + 2 \cdot 10^5)} \end{aligned}$$

O'tkinchi jarayondagi tok $i_1(t)$ haqiqiy ifodasini aniqlashda o'tish jadvalidan foydalanamiz.

Bunda:

$$i_1(t) = e^{-2 \cdot 10^5 t} - \frac{U_{C(0)}}{10} e^{-2 \cdot 10^5 t} + \frac{1}{2}(1 - e^{-2 \cdot 10^5 t}) = \frac{1}{2}(1 + e^{-2 \cdot 10^5 t}) - \frac{U_{C(0)}}{10} e^{-2 \cdot 10^5 t}$$

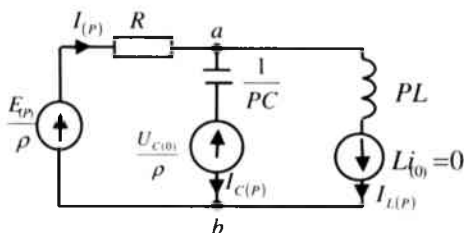
Masala 10.14. Elektr zanjir parametri $R = 10 \Omega$, $C = 100 \mu F$, $L = 29,4 mH$ bo'lib, o'zgarmas $E = 100V$ manbaga ulangan. Zanjirga induktivlik ulanganda sig'imdan o'tuvchi $i_C(t)$ o'tkimchi jarayondagi tok operator usulda aniqlansin.



Yechish.

Operator sxemasini tuzamiz:

Bunda: $U_{C(0)} = 100 (V)$ bo'lib, induktivlikdagi tok kommutatsiya birinchi qonuniga asosan $t = 0$ $i_{(0^-)} = i_{(0^+)} = i_{(0)} = 0$, yoki $Li_{(0)} = 0$



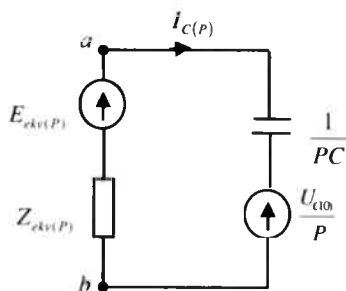
$I_{C(p)}$ tokni topish uchun ushbu sxemani ekvivalent sxemaga almashtiramiz:

Bunda:

$$U_{ab} = E_{ekv(p)} = \frac{\frac{E_{(p)}}{p} Y_1 - Li_{(0)} Y_2}{Y_1 + Y_2} = \frac{\frac{E_{(3)}}{p} \cdot \frac{1}{R} - Li_{(0)} \frac{1}{RL}}{\frac{1}{R} + \frac{1}{pL}} = \frac{10 \cdot 10P \cdot 29,4}{P(P29,4 + 10^4)} = \frac{29,4}{p2,94 + 10}$$

Bunda: $Z_{ekv} = \frac{1}{Y_{ekv}} = \frac{29,4}{2,94P + 10^3}$

Ekvivalent sxema tuzamiz:



Bundan:

$$I_{C(P)} = \frac{E_{ekv(P)} - \frac{U_{C(0)}}{P}}{Z_{ekv(P)} + \frac{1}{PC}} = \frac{294P - 294P - 10^5}{29,4P^2 + 10^4 \cdot 2,94P + 10^7} = \frac{-10^5}{29,4P^2 + 29,4 \cdot 10^3 P + 10^7} = \frac{F_1(P)}{F_2(P)}$$

Umumiy operator qarshilikdan $Z_{ekv} = 0 (F_2(P) = 0)$ ildizni aniqlaymiz: $29,4P^2 + 29,4 \cdot 10^3 P + 10^7 = 0$ yoki:

$$P_{1,2} = \frac{-29,4 \cdot 10^3 \pm \sqrt{(29,4)^2 \cdot 10^6 - 4 \cdot 29,4 \cdot 10^7}}{58,8} = \frac{-29,4 \cdot 10^3 \pm 17,8 \cdot 10^3}{58,8}$$

$$P_1 = (-500 + j300) \frac{1}{sek}; P_2 = (-500 - j300) \frac{1}{sek}$$

Yoyish teoremasiga asosan operator ifodadan haqiqiy tok $i_{C(t)}$

o'tish formulasidan: $i_{C(t)} = 2 \operatorname{Re} \sum_{k=1}^n \frac{F_1(P_k)}{F_2(P_k)} \cdot e^{P_k t}$

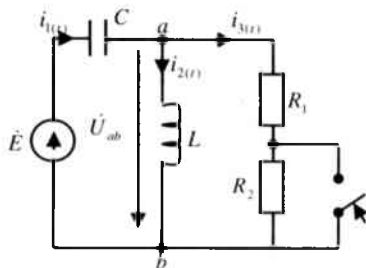
Bundan: $F_1(P_k) = -10^5$

$$F_2(P_k) = (58,8P + 29,4 \cdot 10^3) = 58,8(-500 + j300) + 29,4 \cdot 10^3 = -29,4 \cdot 10^3 + 17,6 \cdot 10^3 j + 29,4 \cdot 10^3 = j17,6 \cdot 10^3$$

Aniqlangan son qiymatini yoyish tenglamasiga qo'yib $i_{C(t)}$ o'tkinchi jarayondagi tokni aniqlaymiz:

$$\begin{aligned} i_C(t) &\doteq 2 \operatorname{Re} \left[\frac{-10^5}{j17,6} e^{-500t} e^{j300t} \right] = 2 \operatorname{Re} \left[\frac{-10^5}{j17,6 \cdot 10^3} e^{-500t} (\cos 300t + j \sin 300t) \right] = \\ &= 2 \operatorname{Re} \left[\frac{-10^2}{j17,6} \cos 300t + \frac{j \sin 300t (-10^2)}{j17,6} \right] e^{-500t} = 2(-5,6 \sin 300t \cdot e^{-500t}) = \\ &= 11,3 e^{-500t} \sin 300t \end{aligned}$$

Masala 10.15. Elektr zanjir parametri: $I_1 = R_1 = 5 \text{ Om}$, $L = 4 \cdot 10^{-2} \text{ GN}$, $C = 2 \cdot 10^{-4}$ bo'lib, $e = 100 \sin(1000t + 120^\circ)$ sinusoidal kuchlanishga ulangan. R_2 qarshilik kalit uzilgan holatda o'tkinchi jarayondagi tok $i_3(t)$ klassik va operator usulga asosan yechilsin.



Yechish.

1. Klassik usul.

a) xarakteristik tenglama ildizini topamiz:

$$z_p = \frac{1}{PC} + \frac{PL(R_1 + R_2)}{PL + R_1 + R_2} = \frac{PL + R_1 + R_2 + PC[PL(R_1 + R_2)]}{PC(PL + R_1 + R_2)} = 0$$

$$\text{Bundan: } PL + R_1 + R_2 + PC[PL(R_1 + R_2)] = 0$$

$$\text{yoki: } 8 \cdot 10^{-5} P^2 + 4 \cdot 10^{-2} + 10 = 0$$

Tenglama yechimi:

$$\begin{aligned} P_{12} &= \frac{-4 \cdot 10^{-2} \pm \sqrt{16 \cdot 10^{-4} - 4 \cdot 80 \cdot 10^{-6} \cdot 10}}{2 \cdot 80 \cdot 10^{-6}} = \frac{-4 \cdot 10^{-2} \pm j4 \cdot 10^{-2}}{160 \cdot 10^{-6}} = \\ &= \frac{5.65 e^{j135}}{160 \cdot 10^{-4}} = 0.0354 \cdot 10^{-4} e^{j135} \end{aligned}$$

$$\text{Ildizini aniqlaymiz: } P_1 = -250 + j250; P_2 = -250 - j250$$

Demak, ildiz kompleks son bo'lganligi uchun, o'tkinchi jarayondagi tok quyidagicha ifodalanadi:

$$i^* = A e^{-t} \sin(\omega_0 t + \gamma) = e^{+250t} \sin(250t - 8)$$

$$\text{yoki; } \left. \begin{aligned} &t = 0 \text{ bo'lganligi } e_{(0)}^* = A \sin \gamma \end{aligned} \right\}$$

$$\text{Hosilasi: } \left. \frac{di^*}{dt} \Big|_{t=0} = -\delta A \sin \gamma + \omega_0 A \cos \gamma \quad (*) \right\}$$

b) kommutatsiyagacha bo'lgan tok va sig'imdagi kuchlanish qiymatini topish uchun ikkita tugun potentsiallar usulidan foydalanamiz:

$$\begin{aligned}\dot{U}_{ab} &= \frac{\dot{E}y_1}{y_1 + y_2 + y_3} = \frac{71e^{j120^\circ} \cdot 0,2e^{j90^\circ}}{j0,2 - j0,025 + 0,2} = \frac{14,2e^{j210^\circ}}{0,2 + j0,175} = \\ &= \frac{14,2e^{j210^\circ}}{0,260e^{j40^\circ}} = 53,4e^{j168^\circ} = -52,3 + j10,3V\end{aligned}$$

Om qonuniga asosan tarmoqdagi tokni topamiz:

$$\dot{I}_1 = \frac{\dot{I} - \dot{U}_{ab}}{x_c} = \frac{16,7 + j51,2}{5e^{-j90^\circ}} = \frac{54 \cdot e^{j72^\circ}}{5e^{-j90^\circ}} = 10,8e^{j162^\circ} = -10,25 + j3,34A$$

$$\dot{I}_2 = \frac{\dot{U}_{ab}}{x_L} = \frac{53,4e^{j168^\circ}}{40e^{-j90^\circ}} = 1,33e^{j78^\circ} = 0,258 + j1,3A$$

$$\dot{I}_3 = \frac{\dot{U}_{ab}}{R_1} = \frac{53,4e^{j168^\circ}}{5} = 10,7e^{j168^\circ} = -10,5 + j2,07A$$

Oniy qiymat:

$$i_1 = 10,8\sqrt{2} \sin(\omega t + 162^\circ) = 15,2 \sin(\omega t + 162^\circ)$$

$$t = 0 \text{ bo'lganda } i_{1(0^-)} = 4,7A$$

$$i_2 = 1,33\sqrt{2} \sin(\omega t + 78^\circ) = 1,87 \sin(\omega t + 78^\circ)A$$

$$t = 0 \text{ bo'lganda } i_{2(0^-)} = 1,83A$$

$$i_3 = 10,7\sqrt{2} \sin(\omega t + 168^\circ) = 15,1 \sin(\omega t + 168^\circ)$$

$$t = 0 \text{ bo'lganda } i_{3(0^-)} = 1,8A$$

Sig'imdagi kuchlanish:

$$\dot{U}_c = \dot{I}_1(-jx_c) = 10,8e^{j162^\circ} \cdot 5e^{j90^\circ} = 54e^{j72^\circ}$$

Oniy qiymati: $U_c = \sqrt{2}54 \sin(\omega t + 72^\circ) = 76 \sin(\omega t + 72^\circ)$

$$t = 0 \text{ bo'lganda } U_{c(0^-)} = 72V$$

d) kommutatsiyadan keyingi turg'un holatdagi tokni topamiz:

$$\dot{U}_{ab} = \frac{E_1 Y_1}{y_1 + y_2 + y_3} = \frac{14,2e^{j120^\circ}}{0,1 + j0,175} = 67,5e^{j149^\circ} = -58,4 + j34V$$

Tokning kompleks ifodasi:

$$i_1 = \frac{\dot{E}_1 \dot{U}_{ab}}{x_s} = \frac{22,9 + j27,5}{5e^{-j90^\circ}} = \frac{36e^{j50^\circ}}{5e^{-90^\circ}} = 7,2e^{j140^\circ} = -55 + j4,65A$$

$$i_2 = \frac{\dot{U}_{ab}}{x_L} = \frac{67,5e^{j149^\circ}}{40e^{-j90^\circ}} = 1,7e^{j60^\circ} = 0,85 + j1,46A$$

$$i_3 = \frac{\dot{U}_{ab}}{R_1 + R_2} = \frac{67,5e^{j149^\circ}}{10} = 6,75e^{j149^\circ} = -5,85 + j3,4$$

Oniy qiymat: $i_1 = 7,2\sqrt{2} \sin(\omega t + 140^\circ) = 10,1 \sin(\omega t + 140^\circ)$.

Bunda: $t = 0; i_{1(0^+)} = 6,5A$

$$i_2 = 1,7\sqrt{2} \sin(\omega t + 60^\circ) = 2,38 \sin(\omega t + 60^\circ) A \quad t = 0; i_{2(0^+)} = 2,06A$$

$$i_3 = 6,75\sqrt{2} \sin(\omega t + 149^\circ) = 9,5 \sin(\omega t + 149^\circ) A \quad t = 0; i_{3(0^+)} = 4,75A$$

Sig'im kuchlanishi:

$$\dot{U}_c = \dot{I}_1(-jx_c) = 72e^{j140^\circ} \cdot 5e^{-j90^\circ} = 36e^{j50^\circ}.$$

Oniy qiymati: $U_c = 50,7 \sin(\omega t + 50^\circ); t = 0; U_{c(0^+)} = 38,8V$

e) kommutatsiya qonunini hisobga olgan holda o'tkinchi jarayon, ya'ni erkin holatdagi tok va sig'imdagi kuchlanishni topamiz:

$$\dot{i}_1 = i_{1(0^-)} - i_{1(0^+)} = 4,7 - 6,5 = -1,8A$$

$$\dot{i}_2 = i_{2(0^-)} - i_{2(0^+)} = 1,83 - 2,06 = -0,23A$$

$$\dot{U}_c = U_{c(0^-)} - U_{c(0^+)} = 33,2V$$

O'tkinchi jarayondagi i_3'' tokni topish uchun tenglama tuzamiz:

$$\begin{cases} \dot{i}_{1(0)} - \dot{i}_{2(0)} - \dot{i}_{3(0)} = 0 & (1) \end{cases}$$

$$\begin{cases} \frac{1}{C} \int \dot{i}_{1(0)} dt + \dot{i}_{3(0)} (R_1 + R_2) = 0 & (2) \end{cases}$$

$$\begin{cases} \frac{1}{C} \dot{i}_{1(0)} dt + L \frac{d\dot{i}_{2(0)}}{dt} = 0 & (3) \end{cases}$$

O'tkinchi jarayon uchun hisoblab topilgan tok va sig'imdagi kuchlanish qiymatiga (2) tenglamadan i_3'' tokni topamiz:

$$t=0 \quad U_{c(0)} + i_{3(0)}(R_1 + R_2) = 0; \text{ ya'ni } i_{3(0)} = \frac{U_{c(0)}}{R_1 + R_2} = \frac{-33,2}{10} = -3,32 \text{ A}$$

$t=0$ bo'lganda hosilasi:

$$\begin{aligned} \frac{di_{3(0)}}{dt} \Big|_{t=0} &= -\frac{i_{1(0)}}{C(R_1 + R_2)} = -\frac{(i_{2(0)} + i_{3(0)})}{C(R_1 + R_2)} = -\frac{-0,23 - 3,32}{2 \cdot 10^{-4} \cdot 10} = \\ &= \frac{3,55}{2} \cdot 10^3 = 1,77 \cdot 10^3 \text{ A / sek} \end{aligned}$$

f) Integrallash koeffitsientini topish uchun aniqlangan tok qiymatini (*) tenglamaga qo'yamiz:

$$\begin{cases} -3,32 = A \sin \gamma \\ 1,77 \cdot 10^3 = -250 A \sin \gamma + 250 A \cos \gamma \end{cases}$$

Tenglamani yechish uchun:

$$940 = 250 A \cos \gamma \quad \text{yoki: } A \cos \gamma = 3,76$$

$$\operatorname{tg} \gamma = -\frac{3,32}{3,76} = -0,885; \quad \text{yoki } \gamma = -42^\circ 50'$$

$$\sin(\gamma) = -0,676$$

$$\text{yoki: } A = \frac{3,32}{0,676} = 4,92$$

$$\text{Demak: } i_3 = 4,92 e^{-250t} \sin(250t - 42^\circ 30');$$

O'tkinchi jarayondagi tok:

$$i_{3(t)} = i_3 + i_{3(0)} = 9,5 \sin(\omega t + 149^\circ) + 4,92 e^{-j250t} \sin(250t - 42^\circ 30');$$

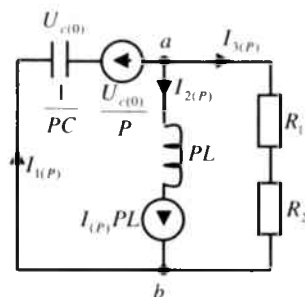
2. Operator usul.

Ekvivalent operator sxemasini chizamiz. Bunda: $U_{c(0)} = 33,2 \text{ V}$

$$i_{2(0)} \cdot L = -0,23 \cdot 4 \cdot 10^2 = -0,92 \cdot 10^2$$

Yechish.

Ikki tugun potensiallar usuliga asosan:



$$\begin{aligned}
 U_{ab(p)} &= \frac{-\frac{U_{c(0)}}{P} PC - i_{2(0)} L \frac{1}{P}}{PC + \frac{1}{PL} + \frac{1}{R}} = \frac{[-U_{c(0)} PC + (-i_{2(0)})] PLR}{P(P^2 LCR + R + PL)} = \\
 &= \frac{[-U_{c(0)} PC - i_{2(0)}] \frac{LR}{RLC}}{P^2 + \frac{R}{RLC} + \frac{PL}{PLC}} = \frac{-U_{c(0)} P - \frac{i_{2(0)}}{C}}{P^2 + \frac{1}{4 \cdot 10^{-2} \cdot 2 \cdot 10^{-4}} + \frac{P}{10 \cdot 2 \cdot 10^{-4}}} = \\
 &= \frac{-33,2P + 1150}{P^2 + 500P + 12,5 \cdot 10^4} \\
 I_{3(0)} &= \frac{U_{ab(p)}}{R} = \frac{-33,2 + 1150}{(P^2 + 500P + 12,5 \cdot 10^4)R} = \frac{-33,2P + 1150}{P^2 + 500P + 12,5 \cdot 10^4};
 \end{aligned}$$

Yoyish teoremasiga asosan operator ifodadan haqiqiy tokga o'tish formulasi: $i_{3(t)} \cong 2 \operatorname{Re} \sum_{k=1}^n \frac{F_1(P_k)}{F'_2(P_k)} e^{P_k t}$ (*)

Bundan:

$$F_{1(j)} = -3,32(-250 + j250) + 115 = 830 - j650 + 115 = 945 - j830;$$

$$F_{2(j)} = 2(-250 + j250) + 500 = j500;$$

Aniqlangan qiymatni (*) tenglamaga qo'yamiz:

$$\begin{aligned}
 i_{3(t)} &= 2 \operatorname{Re} \sum \frac{945 - j830}{j500} e^{-250t} \cdot e^{j250t} = 2 \operatorname{Re}(1,66 - j1,89) e^{-250t} \cdot e^{j250t} = \\
 &= 2 \cdot 2,46 e^{-250t} \operatorname{Re}[e^{j(250t - 227^\circ)}] = 4,92 e^{-j250t} \sin(250t - 47^\circ)
 \end{aligned}$$

$i_{3(t)}$ o'tkinchi jarayondagi tok ifodasi:

$$i_{3(t)} = i_3 + i_3^* = 9,5 \sin \sin(\omega t + 149^\circ 50') + 4,93 e^{j250t} \sin(250t - 47^\circ)$$

Elektr zanjirda o'tkinchi jarayonini Dyumel integrali usulida hisoblash

Masala 10.16. Ketma-ket ulangan R, L zanjir parametri $R=100\text{Om}$, $L=40\text{ MGn}$ bo'lib, eksponentsial funksiyasi $U_{(t)} = Ue^{-\gamma t}$ bo'lgan kuchlanishga ulanganda o'tkinchi jarayondagi tok $i_{(t)}$ Dyumel integrali usuliga asosan aniqlansin ($U=100\text{(V)}$ $\gamma = 500\left(\frac{1}{\text{sek}}\right)$)

Yechish. Aktiv va induktiv zanjirni o'zgarmas tokga ulaganda o'tkinchi jarayondagi tok (9.12) tenglamaga asosan yechiladi:

$$i_{(t)} = \frac{U}{R} (1 - e^{-\frac{t}{\tau}})$$

Yoki o'tkinchi o'tkazuvchanlik ifodasi bo'yicha:

$$y_{(t)} = \frac{1}{R} (1 - e^{-\frac{t}{\tau}}) = \frac{1}{R} (1 - e^{-\delta t})$$

$$\text{Bunda: } \delta = \frac{R}{L} = \frac{10}{40 \cdot 10^{-3}} = 250 \left(\frac{1}{\text{sek}} \right)$$

(9.3) tenglama Dyumel integrali birinchi ifodasidan foydalanamiz:

$$i_{(t)} = U_{(0)} y_{(t)} + \int_0^t y(t-x) U'_{(x)} dx \quad (1)$$

Bunda $t = 0$ bo'lganda; $U_{(0)} = U = 100 \text{ V}$

$$y_{(t-x)} = \frac{1}{R} (1 - e^{-\delta(t-x)}) = \frac{1}{R} (1 - e^{-\delta t} e^{\delta x});$$

$$U'_{(x)} = \frac{dU}{dt} \bigg|_{t=x} = -\gamma U e^{-\gamma x}$$

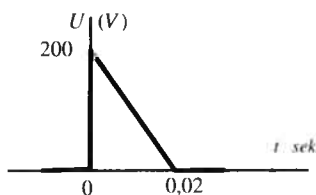
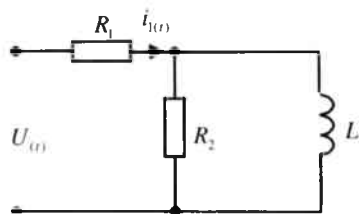
Aniqlangan qiymatni (1) tenglamaga qo'yib integrallaymiz:

$$\begin{aligned} i_{(t)} &= \frac{U}{R} (1 - e^{-\delta(t)}) + \int_{x=0}^{x=t} \frac{1}{R} (1 - e^{-\delta t} e^{\delta x}) (-\gamma U) e^{-\gamma x} dx = \\ &= \frac{U}{R} (1 - e^{-\delta(t)}) - \frac{\gamma U}{R} \int_{x=0}^{x=t} (e^{-\gamma x} - e^{-\delta x} e^{(\delta-\gamma)x}) dx \\ i_{(t)} &= \frac{U}{R} (1 - e^{-\delta(t)}) - \frac{\gamma U}{R} \left(-\frac{1}{\gamma} \right) e^{-\gamma x} \bigg|_0^t + \frac{\gamma U}{R} e^{-\delta x} \frac{1}{\delta - \gamma} e^{(\delta-\gamma)x} \bigg|_0^t = \\ &= \frac{U}{\delta - \gamma} (e^{-\gamma t} - e^{-\delta t}) \end{aligned}$$

Aniqlangan qiymatni tenglamaga qo'yamiz:

$$i_{(t)} = \frac{250}{250 - 500} \frac{100}{10} (e^{-500t} - e^{-250t}) = 10(e^{-250t} - e^{-500t}) \text{ A}$$

Masala 10.17. Parametri: $R_1=5 \text{ Om}$, $R_2=10 \text{ Om}$, $L=100 \text{ MGn}$ bo'lgan elektr zanjir arrasimon impulsli kuchlanishga ulanganda $i_{1(t)}$ o'tkinchi jarayondagi tok Dyumel integraliga asosan aniqlansin.



Yechish.

Kuchlanish analitik ifodasi:

$U = 10^4 (0,02 - t) \text{ (V)}$ bo'lib: $t=0$ $U = 200 \text{ (V)}$ va $t = 0,02 \text{ (sek)}$ $U=0$.
Demak $t=0$ bo'lganda: $U_{(0)}=200 \text{ (V)}$ $U'_{(0)} = -10^4 \text{ (V)}$

O'tkinchi jarayondagi tok:

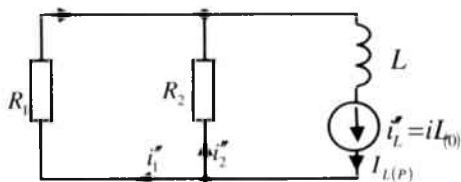
$$i_{(t)} = U \cdot y_{(t)} \text{ agar } U = 1; \quad i_{(t)} = y_{(t)}$$

Umumiy $i_{1(t)}$ o'tkinchi jarayondagi tok:

$i_{1(t)} = i'_1 + i''_1$, bo'lib, qiymatini aniqlaymiz:

Bunda
$$i' = \frac{U}{R_1} = \frac{1}{5} = 0,2 \text{ A}$$

i'' – o'tkinchi erkin hisoblanadi, tokni topish uchun operator usulidan foydalanamiz. Buning uchun operator sxemasini chizamiz:



Kirxgof qonuniga asosan tenglama tuzamiz:
$$\left. \begin{aligned} R_2 i''_2 &= R_1 i''_1, \\ i''_1 + i''_2 &= 0,2 \end{aligned} \right\}$$

Bundan: $i''_2 = 0,2 - i''_1$ yoki: $10(0,2 - i''_1) = 5 \cdot i''_1$; $i''_1 = \frac{2}{15} = 0,13 \text{ A}$

Om qonuni operator ifodasiga asosan:

$$I_{1(P)}^{\bullet} = \frac{(i_1 L) R_2}{R_1 \cdot R_2 + R_1 PL + R_2 PL} = \frac{0,02 \cdot 10}{50 + 50P0,1 + 10P0,1} = \frac{0,2}{50 + 1,5P}$$

$$\text{Bundan: } 50 + 1,5P = 0; P = -\frac{50}{1,5} = -33 \left(\frac{1}{\text{sek}} \right)$$

Operator ifodasining o'tish teoremasiga asosan:

$$i_{1(t)}^{\bullet} = \frac{F_{(P)}}{F_{2(P)}} e^{Pt} = \frac{0,2}{1,5} e^{-33t} = 0,13e^{-33t}$$

$$i_{1(t)}^{\bullet} = 0,13e^{-33t}$$

O'tkinchi o'tkazuvchanlik ifodasi:

$$y_{(t)} = 0,2 + 0,13e^{-33t}$$

$$y_{(t-x)} = 0,2 + 0,13e^{-33(t-x)}$$

$0 < t < t_1$ Interval uchun Dyumel integrali ifodasidan $i_{(t)}$ o'tkinchi tok:

$$i_t = U_{(0)} y_{(t)} + \int_0^t U'_{(x)} y(t-x) dx = 200(0,2 + 0,13e^{-33t} +$$

$$+ \int_0^t -10^4(0,2 + 0,13e^{-33(t-x)}) dx = 40 + 26e^{-33t} - 10^4 \int_0^t (0,2 + 0,13e^{-33x} \cdot e^{-33t}) dx =$$

$$= 40 + 26e^{-33t} - 10^4 \left[(0,2x) \Big|_0^t + \frac{0,13e^{-33x}}{33} e^{-33t} \Big|_0^t \right] =$$

$$= 40 + 26e^{-33t} - 10^4 \left[(0,2t - 0) - \frac{0,13e^0}{33} - \frac{0,13}{33} e^{-33t} \right] = 80 + 66e^{-33t} - 2000t$$

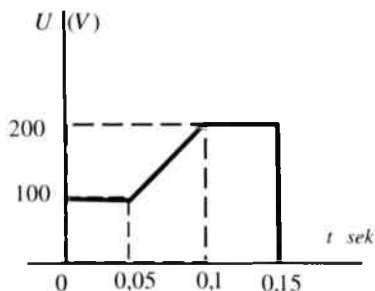
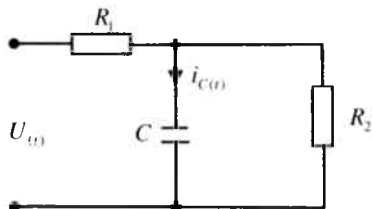
$t > t_1$ intervalda o'tkinchi jarayondagi tokni aniqlaymiz:

$$i_{(t)} = U_{(0)} y_{(t)} + \int_0^t U'_{(x)} y(t-x) dx - U_{(t_1)} y(t-t_1) =$$

$$= 200(0,2 + 0,13e^{-33t}) + \int_0^t -10^4(0,2 + 0,13e^{-33(t-x)}) dx =$$

$$= 40 + 26e^{-33t} - 2000t_1 + 40 + 40e^{-33t} = 11,2e^{-33,4t}$$

Masala 10.18. Parametri $R_1=R_2=2 \cdot 10^3 \text{ Om}$, $C=10^{-4} \text{ F}$ bo'lgan elektr zanjir $U_{(t)}$ grafikda keltirilgan impulsli kuchlanishga ulanganda, $i_{c(t)}$ o'tkinchi jarayondagi tok Dyumel integrali usuliga asosan aniqlansin.



Yechish.

$i_{c(t)}$ tokni $0 < t < 0,05$, $0,05 < t < 0,1$, $0,1 < t < 0,15$ va $t > 0,5$ sek intervalllarda aniqlaymiz:

Kalitga ulanganda o'tkinchi jarayondagi o'zgaruvchanlik:

$$y_{(t)} = \frac{1}{R} e^{-Pt}$$

$$\text{Bundan: } P = -\frac{R_1 + R_2}{R_1 R_2 C} = -\frac{4 \cdot 10^3}{4 \cdot 10^6 \cdot 10^{-4}} = -10 \left(\frac{1}{\text{sek}} \right)$$

O'tkinchi jarayondagi tok $i_{c(t)}$: $0 < t < 0,05$ intervalda:

$$\text{a) } i_{2(t)} = U_{(0)} y_{(t)} = 100 \left(\frac{1}{2 \cdot 10^3} e^{-10t} \right) = 0,05 e^{-10t}$$

$$i_{2(t)} = 0,05 e^{-10t} + \int_{0,05}^t y(t-x) U'_{(x)} dx = 0,05 e^{-10t} +$$

$$\text{b) } + \int_0^t 2000 \left(\frac{1}{2 \cdot 10^3} e^{-10(t-x)} \right) dx = 0,05 e^{-10t} + \frac{1}{10} e^{-10t} e^{-10x} \Big|_{0,05}^t =$$

$$= 0,05 e^{-10t} + 0,1 - 0,1 e^{(0,5-10t)} = 0,1 + 0,05 e^{-10t} + 0,1 e^{-5t}$$

d) interval: $t = 0,1 \div 0,15$ (sek)

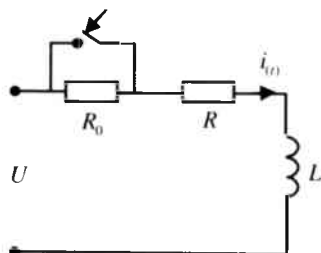
$$i_{2(t)} = 0,05 e^{-10t} + \int_{0,05}^t 2000 e^{-10(t-x)} dx + 0 = 0,05 e^{-10t} + 0,1 e^{-10(t-0,1)} - 0,1 e^{-10(t-0,05)}$$

e) interval: $t > 0,15$ (sek)

$$\begin{aligned} i_{2(t)} &= 0,05e^{-10t} + 0,1e^{-10(t-0,1)} - 0,1e^{-10(t-0,05)} + U'_{(t_3)} y(t-t_3) = \\ &= 0,05e^{-10t} + 0,1e^{-10(t-0,1)} - 0,1e^{-10(t-0,05)} - 200 \frac{1}{210^3} e^{-10(t-0,15)} = \\ &= 0,05e^{-10t} - 0,1e^{-10(t-0,15)} + 0,1e^{-10(t-0,1)} - 0,1e^{-10(t-0,05)} \end{aligned}$$

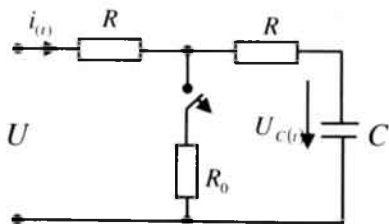
10.3. Mustaqil yechish uchun masalalar

Masala 10.1. Ketma-ket ulangan elektr zanjir parametri: $R_0=30 \text{ Om}$, $R=100 \text{ Om}$, $L=100 \text{ MGn}$ bo'lib, $U=120 \text{ V}$ o'zgarmas kuchlanishga ulangan. R_0 qisqa tutashtirilganda (kalit ulanganda) o'tkinchi jarayondagi $i_{(t)}$ tok klassik va operator usulda aniqlansin va grafigi chizilsin:



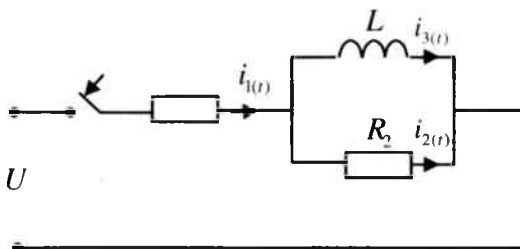
Javob: $i_{(t)} = (12 - 9e^{-100t}) \text{ A}$

Masala 10.2. Parametri: $R_0=2 \text{ Om}$, $R=20 \text{ Om}$, $C=10^{-2} \text{ F}$ bo'lgan elektr zanjiri $U=220 \text{ V}$ o'zgarmas tok kuchlanishga ulangan bo'lib, R_0 qarshilik ulangan tarmoq uzilganda sig'imda hosil bo'lgan o'tkinchi jarayondagi $U_{C(t)}$ kuchlanish aniqlansin.



Javob: $U_{C(t)} = 220 - 200e^{-\frac{t}{2RC}} \text{ (V)}$

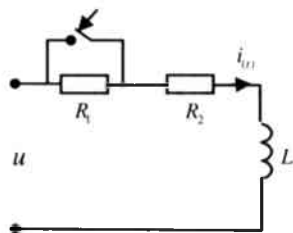
Masala 10.3. Parametri: $R_1=4 \text{ Om}$, $R_2=2 \text{ Om}$, $L=100 \text{ MGn}$ bo'lgan elektr zanjir $U=100 \text{ V}$ o'zgarmas kuchlanishga ulanganda hosil bo'ladigan o'tkinchi jarayondagi tok: $i_{1(t)}$, $i_{2(t)}$, $i_{3(t)}$ klassik va operator usulda aniqlansin.



Javob:

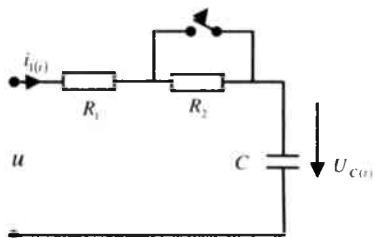
$$i_{1(t)} = 25(1 - \frac{1}{3}e^{-\frac{t}{0.1}}) \text{ (A)}, \quad i_{2(t)} = \frac{32}{3}e^{-\frac{t}{0.1}} \text{ (A)}, \quad i_{3(t)} = 25(1 - e^{-\frac{t}{0.1}}) \text{ (A)}$$

Masala 10.4. Ketma-ket sxemada ulangan elektr zanjir parametri: $R_1 = R_2 = 2 \text{ Om}$, $\omega L = 3 \text{ Om}$ bo'lib, $f = 50 \text{ Gs}$, $u = 127 \sin(\omega t - 50^\circ)$ V sinusoidal o'zgarma kuchlanishga ulangan. R_1 qarshilik qisqa tutashtirilganda o'tkimchi jarayondagi tok $i_{(t)}$ klassik va operator usulida aniqlansin.



Javob: $i_{(t)} = 35 \sin(314 - 106^\circ) + 8,5e^{-210t} \text{ A}$

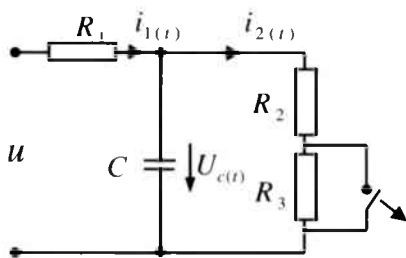
Masala 10.5. Parametri: $R_0 = 20 \text{ Om}$, $R = 20 \text{ Om}$, $C = 10^{-2} \text{ F}$ bo'lgan elektr zanjir sinusoidal kuchlanish $u = 1000 \sqrt{2} \sin(314t + 82^\circ) \text{ V}$ ga ulangan o'tkinchi jarayondagi $i_{(t)}$ tok va sig'imdagi $U_{C(t)}$ kuchlanish aniqlansin.



Javob: $i_{(t)} = (314t + 90^\circ) - 0,3e^{-\frac{t}{0.025}} \text{ (A)}$

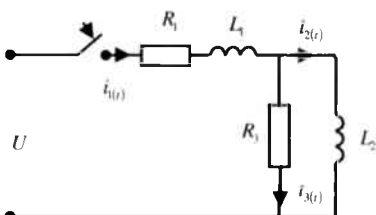
$$u_{C(t)} = 178 \sin 314t + 77e^{-\frac{t}{0.025}} \text{ (V)}$$

Masala 10.6. Parametri: $R_1=50\text{ Om}$, $R_2=30\text{ Om}$, $R_3=20\text{ Om}$, $C=10\text{ mkF}$ bo'lgan elektr zanjir $U=80\text{ V}$ o'zgaras kuchlanishga ulangan. R_3 qarshilik qisqa tutash-tirilganda hosil bo'ladigan o'tkinchi jarayondagi $i_{2(t)}$ tok va sig'imdagi $U_{C(t)}$ kuchlanish ifodasi klassik va operator usulda aniqlansin.



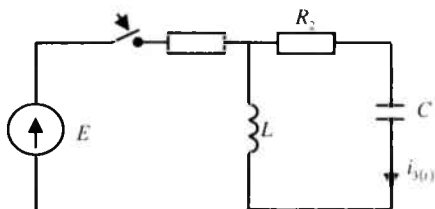
Javob: $i_{2(t)} = 0,8 + 0,2e^{-4 \cdot 10^4 t}\text{ A}$, $U_{C(t)} = 0,8 + 0,2e^{-4 \cdot 10^4 t}\text{ (V)}$

Masala 10.7. Parametri $R_1=160\text{ Om}$, $R_3=90\text{ Om}$, $L=100\text{ MGn}$, $L_2=36\text{ MGn}$ bo'lgan elektr zanjir $U=48\text{ V}$ o'zgaras kuchlanishga ulanganda $i_{2(t)}$ o'tkinchi jarayondagi tok klassik va operator usulga asosan aniqlansin.



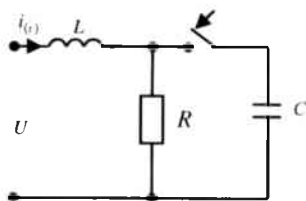
Javob: $i_{2(t)} = 0,3 - 0,4e^{-1000t} + 0,1e^{-4000t}\text{ A}$,

Masala 10.8. Parametri $R_1=R_2=10\text{ Om}$, $L=1\text{ Gn}$, $C=1000\text{ mkF}$ bo'lgan elektr zanjir $E=100\text{ V}$ o'zgaras manbaga ulanganda $i_{3(t)}$ o'tkinchi jarayondagi tok klassik va operator usulida aniqlansin.



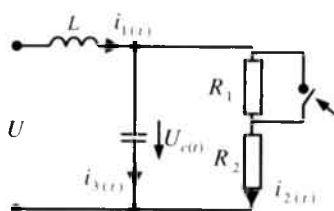
Javob: $i_{3(t)} = 6,81e^{-43t} - 1,81e^{-11t}\text{ A}$

Masala 10.9. Ketma-ket ulangan elektr zanjiri parametrlari $R=100\text{ Om}$, $L=0,32\text{ Gn}$ bo'lib, $U=2000\sin(314t+90^\circ)\text{ V}$ o'zgaruvchan kuchlanishga ulangan zanjirga $C=16\text{ mkF}$ bo'lgan sig'in ulanganda hosil bo'ladigan o'tkinchi jarayon tok $i_{(t)}$ aniqlansin.



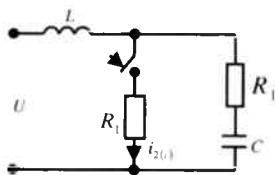
Javob: $i_{(t)} = 20\sin(314t + 58^\circ) + 2\sqrt{10}e^{-314t} \cdot \sin(314t - 71^\circ)\text{ A}$

Masala 10.10. Parametri $R_1=R_2=10\text{ Om}$, $L=0,04\text{ MGn}$, $C=55\text{ mkF}$ bo'lgan elektr zanjirga $U=100\sin(1000t+30^\circ)$ sinusoidal o'zgaruvchan kuchlanish ulangan. R_1 qarshilkni qisqa tutashtirilganda hosil bo'ladigan o'tkinchi jarayondagi tok $i_{3(t)}$ va $U_{C(t)}$ klassik va operator usulida aniqlansin va grafigi chizilsin.



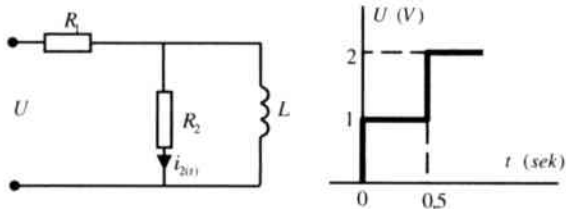
Javob: $i_{3(t)} = 1,825e^{-1500t} - 0,04e^{-300t} + 1,32\sin(1000t + 13^\circ)$

Masala 10.11. Parametri $R_1=25\text{ Om}$, $R_2=50\text{ Om}$, $L=0,25\text{ Gn}$, $C=400\text{ mkF}$ bo'lgan elektr zanjir $U = 400\sqrt{2}(314t - 90^\circ)$ ulangan. Zanjirga R_2 qarshilik ulanganda hosil bo'ladigan o'tkinchi jarayondagi tok $i_{2(t)}$ klassik va operator usulga asosan aniqlansin.



Javob: $i_{2(t)} = 1,81\sin(314t - 179^\circ) - 0,326e^{-50t}\sin(64,6t + 4^\circ)\text{ A}$

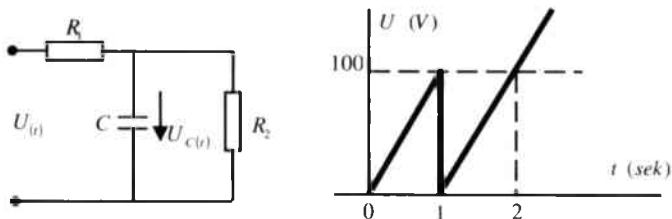
Masala 10.12. Elektr zanjir parametri $R_1=R_2=10\text{ Om}$, $L=5\text{ MGn}$, bo'lib, bosqichma-bosqich o'suvchi impulsi kuchlanishga ulangan. Dyumel intervalidan foydalanib $i_{2(t)}$ o'tkinchi jarayondagi tok aniqlansin.



Javob: interval $0 < t < 0,5$ msek $i_{2(t)} = 0,05e^{-10^3 t}$ (mA)

interval $t > 0,5$ msek $i_{2(t)} = 0,132e^{-10^3 t}$ (mA)

Masala 10.13. Elektr zanjir parametri $R_1 = R_2 = 10$ Om, $C = 200$ mkF bo'lib, grafik berilgan $U_{(t)}$ kuchlanishga ulangan. Dyuamel integraliga asosan $U_{C(t)}$ o'tkinchi jarayondagi tok aniqlansim.



Javob: interval $0 < t < 1$ msek $U_{C(t)} = 50(t - 1 + e^{-t})$ (V)

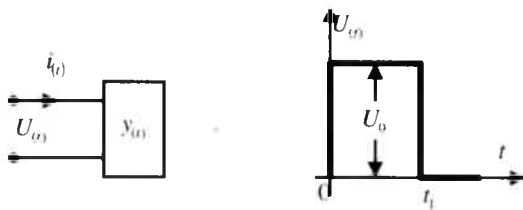
interval $t > 1$ msek $U_{C(t)} = 50t - 100 + 186e^{-t}$ (V)

10.4. Nazorat savollari

1. Elektr zanjirda hosil bo'ladigan o'tkinchi jarayon deganda nimani tushunasiz?
2. Qachon va nima sababdan elektr zanjirlarda o'tkinchi jarayon hosil bo'ladi?
3. Nima uchun induktivlikdagi tok yoki sig'imdagi kuchlanish sakrab o'zgara olmaydi?
4. Kommutatsiya qonunining fizik ma'nosini tushuntirib bering.
5. O'tkinchi jarayon, turg'un holatdagi tok va kuchlanishning fizik ma'nosini bilasizmi?

6. Nima uchun o'tkinchi jarayondagi tok, turg'un holat va o'tkinchi tok yig'indisi ko'rinishida ifodalanadi va chiziqli elektr zanjir uchun ishlatiladi?
7. O'tkinchi jarayon vaqti nima, qanday ifodalanadi?
8. RL, RC zanjir uchun o'tkinchi jarayon vaqti nimaga teng?
9. O'tkinchi jarayon integrallash koeffitsienti qanday aniqlanadi?
10. O'tkinchi jarayon boshlang'ich sharti deganda nimani tushunasiz va qanday aniqlanadi?
11. O'tkinchi jarayon vaqtida elektr va magnit maydon energiyalari qanday o'zgaradi?
12. Elektr zanjir manbaga ulanganda uzilish, qisqa tutashuv holatlarida nima uchun uchqun chiqadi?
13. Kondensator razryadlanganda elektr energiyasi qayerda sarflanadi?
14. R, L C zanjirning differensial tenglamasiga asosan xarakteristik tenglamasini yozing va ildizlarini aniqlang.
15. R, L C zanjirida o'tkinchi jarayon tok yoki kuchlanish tebranuvchan, so'nuvchan (aperiodik) hamda kritik holatda o'zgarishiga sabab nima?
16. Qaysi vaqtda induktiv g'altak sinusoidal o'zgaruvchan elektr zanjiriga ulanganda o'tkinchi jarayon hosil bo'lmaydi va aksincha?
17. O'tkinchi jarayondagi tok yoki kuchlanish grafigidan o'tkinchi jarayon vaqti τ qanday aniqlanadi?
18. Ketma-ket ulangan R, L zanjirning o'zgarmas tok manbai U dan uzilgan holatdagi o'tkinchi jarayondagi $i_{(t)}$ tok ifodasini yozing.
19. Ketma-ket R, C zanjirining o'zgaruvchan $U_{(t)}$ kuchlanishga ulanganda $U_{C(t)}$ o'tkinchi jarayon tenglamasini yozing.
20. O'tkinchi jarayondagi tokni operator usulida hisoblash qanday amalga oshiriladi?
21. Elektr zanjirda o'tkinchi jarayondagi tokni hisoblashda ekvivalent operator sxemasi qanday tuziladi?
22. Om va Kirxgof qonuni operator ifodasini yozing.
23. Operator formadan originaliga o'tish formulasini ifodalab bering.
24. O'tkinchi jarayondagi tokni Dyumel integraliga asosan hisoblash qanday amalga oshiriladi?
25. Dyumel integrallash formulasini yozing.

26. Passiv ikki qutbli zanjirga o'tkinchi jarayon o'tqazuvchanligi $y_{(t)}$ ga impulsli formada $U_{(t)}$ kuchlanish ulangan $0 \leq t \leq t_1$ intervalda $i_{(t)}$ o'tkinchi jarayondagi tok ifodasini aniqlang.



Javob: $i_{(t)} = U_0 y_{(t)}$

XI. TARQOQ PARAMETRLI ELEKTR ZANJIR

11.1. Asosiy nazariy tushunchalar

1. Bir jinsli tarqoq parametrlı elektr zanjirning asosiy tenglamasi.

Bunday elektr zanjirning nisbiy uzunlikdagi birlamchi parametri: aktiv R_0 , induktiv L_0 , aktiv o'tqazuvchanligi g_0 va sig'im C_0 bo'ladi.

Ikkilamchi parametri: to'liq qarshiligi $\underline{Z}_C$ va doimiy tarqalish koeffitsienti γ .

Bir jinsli liniyaning **to'liqin** yoki **tavsifiy qarshiligi** quyidagicha ifodalandi.

$$\underline{Z}_C = \sqrt{\frac{R_0 + j\omega L_0}{g_0 + j\omega C_0}} = \underline{Z}_C e^{j\theta} \quad (11.1)$$

Liniyaning **tarqalish koeffitsienti**:

$$\underline{\gamma} = \sqrt{(R_0 + j\omega L_0)(g_0 + j\omega C_0)} = \alpha + j\beta \quad (11.2)$$

Bunda α – **so'nish koeffitsienti**; β – **faza koeffitsienti**.

Odatda liniya birlamchi parametri berilgan bo'lib (11.2) tenglamadan α va β ni aniqlashda doimiy kompleks ifodasidan foydalaniladi.

$$\left. \begin{aligned} \alpha &= \operatorname{Re}(\gamma) \\ \beta &= \operatorname{Im}(\gamma) \end{aligned} \right\} \quad (11.3)$$

$$\text{Elektromagnit to'liqin tarqalish tezligi: } \theta = \frac{\omega}{\beta} \quad (10.4)$$

ω – tok va kuchlanish burchiak chastotasi.

$$\text{To'liqin uzunligi: } \lambda = \frac{v}{f} = \frac{2\pi}{\beta} \quad (11.5)$$

Liniyadagi tok va kuchlanish qaytish to'liqini quyidagicha ifodalanadi:

$$K_U = -K_I = \frac{\underline{Z}_2 + \underline{Z}_C}{\underline{Z}_2 - \underline{Z}_C} \quad (11.6)$$

$\underline{Z}_2$ – liniyaning oxiriga ulangan kompleks qarshiligi.

Bu yerda: $\underline{Z}_2 = \underline{Z}_c$ bo'lganda to'liqin qaytmaydi.

Liniyaning salt ishlash holatida $\underline{Z}_2 = \infty$ bo'lib to'liqin qaytish koefitsienti yoki kuchlanishning tushuvchi to'liqin koefitsienti:

$$K_U = \frac{1 - \underline{Z}_2 \underline{Z}_c}{1 - \underline{Z}_2 \underline{Z}_{yuk}} = 1 \quad \text{va} \quad K_I = K_U = -1 \quad (11.7)$$

Biror-bir (x) masofadagi liniya boshidan hisobga olinsa tok va kuchlanish effektiv kompleks ifodasi:

$$\left. \begin{aligned} \dot{U}_x &= \dot{U}_1 ch\gamma X - \dot{I}_1 \underline{Z}_c sh\gamma X \\ \dot{I}_x &= \dot{I}_1 ch\gamma X - \frac{\dot{U}_1}{\underline{Z}_c} sh\gamma X \end{aligned} \right\} \quad (11.8)$$

$\dot{U}_1$ va $\dot{I}_1$ – liniya boshidagi tok va kuchlanish.

Agar liniya oxiridagi tok va kuchlanish qiymati berilgan bo'lsa, biror (x) masofadagi liniya oxiriga nisbatan tenglama:

$$\left. \begin{aligned} \dot{U}_x &= \dot{U}_2 ch\gamma X - \dot{I}_2 \underline{Z}_c sh\gamma X \\ \dot{I}_x &= \dot{I}_2 ch\gamma X - \frac{\dot{U}_2}{\underline{Z}_c} sh\gamma X \end{aligned} \right\} \quad (11.9)$$

Demak, liniyaning boshi va oxiridagi tok va kuchlanish bog'lanish tenglamasi quyidagicha ifodalanadi:

$$\left. \begin{aligned} \dot{U}_1 &= \dot{U}_2 ch\gamma X - \dot{I}_2 \underline{Z}_c sh\gamma X \\ \dot{I}_1 &= \dot{I}_2 ch\gamma X - \frac{\dot{U}_2}{\underline{Z}_c} sh\gamma X \end{aligned} \right\} \quad (11.10)$$

Liniya boshidagi kompleks qarshilik $\underline{Z}_1 = \frac{\dot{U}_1}{\dot{I}_1}$ desak, (11.10)

tenglamadan biror ixtiyoriy qarshilik ulangan holatdagi kompleks qarshilik:

$$\underline{Z}'_2 = \underline{Z}_c \frac{\underline{Z}_2 + \underline{Z}_c th\gamma l}{\underline{Z}_2 th\gamma l + \underline{Z}_c} \quad (11.11)$$

Liniya qarshiligi salt ishlash holatda $\underline{Z}_2 = \infty$ ($\underline{Z}_\infty$ bilan belgilaymiz) va qisqa tutashtirilganda $\underline{Z}_0 = 0$ bo'lib ($\underline{Z}_0$ bilan belgilaymiz) (11.11) tenglamaga asosan:

$$\left. \begin{aligned} \underline{Z}_\infty &= \underline{Z}_c \text{cthy}l \\ \underline{Z}_0 &= \underline{Z}_c \text{thyl} \end{aligned} \right\} \quad (11.12)$$

2. Bir jinsli liniya xususiy holatdagi ikkilamchi parametri.

a) yuqori chastotali liniya parametri:

Agar bir jinsli liniya chastotasi $\frac{\omega L_0}{R_0} \geq 5$; $\frac{\omega L_0}{g_0} \geq 5$ bo'lsa, liniya parametri quyidagi tenglama ko'rinishida ifodalanadi:

$$\underline{Z}_c = \sqrt{\frac{L_0}{C_0}}; \quad \beta = \omega \sqrt{L_0 C_0}; \quad \alpha = \frac{R_0}{2} \sqrt{\frac{C_0}{L_0}} + \frac{g_0}{2} \sqrt{\frac{L_0}{C_0}} \quad (11.13)$$

b) signal shaklini buzmaydigan liniya parametri:

uzun liniyaning eng muhim parametri uzun liniya bo'ylab energiya uzatishni ta'minlovchi elektromagnit to'lqinlarning miqdor va sifatdash o'zgarishini tavsiflovchi so'nish koeffitsienti – α , faza koeffitsienti – β va tavsifiy qarshiligi $\underline{Z}_c$ deb belgilanadi. Bular bir jinsli liniyaning ikkilamchi parametri yoki tavsifi deyiladi.

So'nish koeffitsienti – α , to'lqin qarshiligi – $\underline{Z}_c$ va to'lqin fazoviy tarqalish tezligi – $\theta = \frac{\omega}{\beta}$ ning burchak chastotasi – ω ga teng bo'lmasligi uchun birlamchi parametri quyidagi nisbatda tanlanishi lozim:

$$\frac{R_0}{L_0} = \frac{g_0}{C_0}$$

Signal shaklini buzmaydigan liniyada to'lqin qarshiligi $\underline{Z}_B$ va faza koeffitsienti β (11.1), (11.2), (11.13) tenglama asosida aniqlanadi.

So'nish koeffitsienti esa (11.2) dan:

$$\alpha = \frac{g_0}{C_0} \sqrt{L_0 C_0} = \frac{R_0}{L_0} \sqrt{L_0 C_0} = \sqrt{R_0 g_0} \quad (11.14)$$

Barcha yuqori chastotalar ushbu turdagi liniyada to'lqin tarqalish tezligi quyidagicha ifodalanadi:

$$v = \frac{1}{\sqrt{L_0 C_0}} \quad (11.15)$$

Uzatish liniyasida to'liqin tarqalish tezligi: $v = 3 \cdot 10^5 \text{ km / sek}$

b) isrofsiz liniya parametri.

Radiotexnikada foydalaniladigan chastotasi yuqori bo'lgan liniyalarda aktiv qarshilik parametri $R_0 \ll \omega L_0$ dan va aktiv o'tkazuvchanlik $g_0 \ll \omega C_0$ juda ham kichik bo'lganligi uchun hisobga olinmaydi, shu sababli bu turdagi liniyaga isrofsiz liniya deyiladi. Bunday liniya ikkilamchi parametrli (11.13) tenglamadan aniqlanadi. Bu yerda koeffitsient $\alpha = 0$.

3. Bir jinsli liniyaning turli holatda ishlashi.

a) bir jinsli liniyaga $\underline{Z}_2$ to'la qarshilik ulangan bo'lib, to'liqin qarshiligiga teng: $\underline{Z}_2 = \underline{Z}_C$

Bunda (11.10) tenglamaga asosan tok $\dot{U}_2$ va $\dot{I}_2$ giperbolik funksiyasidan kompleks formada quyidagi tenglik bilan ifoda qilinadi:

$$\dot{U}_2 = \dot{U}_1 e^{-\gamma l}; \quad \dot{I}_2 = \dot{I}_1 e^{-\gamma l}; \quad (11.16)$$

Bularning nisbati:

$$\frac{\dot{U}_2}{\dot{U}_1} = \frac{\dot{I}_2}{\dot{I}_1} = e^{-\gamma l} = \varphi_{U_1} - \varphi_{U_2} = \varphi_{I_1} - \varphi_{I_2} = \beta l \quad (11.17)$$

(11.11) yoki (11.12) tenglamaga asosan lihiyaga kiruvchi qarshilik:

$$\bar{Z}_{kir} = \bar{Z}_C \quad (11.18)$$

(11.17) tenglamaga asosan liniya foydali ish koeffitsienti quyidagi tenglamadan aniqlanadi:

$$h = \frac{P_2}{P_1} = e^{-2\gamma l}$$

b) liniya rostlashgan holatida maksimal quvvat uzatish mumkin bo'ladi:

$$P_{2\max} = I_H^2 \rho = \frac{U_H^2}{\rho} \quad (11.19)$$

Limya juda uzun bo'lganda ($2l \geq 1,5$) va $\underline{Z}_2 \neq \underline{Z}_C$.

Bu holatda yuqorida keltirilgan tenglamadan zarur bo'lgan miqdorning barchasi hisoblab topiladi.

d) isrofsiz liniya. Isrofsiz liniya uchun (10.8) tenglamani quyidagicha yozamiz:

$$\left. \begin{aligned} \dot{U}_x &= \dot{U}_1 \cos \beta X - j \dot{I}_1 \underline{Z}_c \sin \beta X \\ \dot{I}_x &= \dot{I}_1 \cos \beta X - j \frac{\dot{U}_1}{\underline{Z}_c} \sin \beta X \end{aligned} \right\} \quad (11.20)$$

Shunga o'xshash (10.10) tenglamani ham quyidagicha belgilab olamiz:

$$\left. \begin{aligned} \dot{U}_x &= \dot{U}_2 \cos \beta X - j \dot{I}_2 \underline{Z}_c \sin \beta X \\ \dot{I}_x &= \dot{I}_2 \cos \beta X - j \frac{\dot{U}_2}{\underline{Z}_c} \sin \beta X \end{aligned} \right\} \quad (11.21)$$

Agar liniya masofasi x oxiridan hisoblansa (11.11) va (11.5) tenglamaga binoan:

$$\underline{Z}_{kir} = \underline{Z}_c \frac{\underline{Z}_2 - j \underline{Z}_c \operatorname{tg} \frac{2\pi}{\lambda} l}{j \underline{Z}_c \operatorname{tg} \frac{2\pi}{\lambda} \underline{Z}_c} \quad (11.22)$$

4. Turg'un (qo'zg'almas) to'lqinlar.

Odatda turg'un to'lqinlar isrofsiz liniyada salt va qisqa tutashuv holatlarida yuzaga kelib, to'g'ri va teskari to'lqinlarning amplitudalari bir xil bo'lganda, ya'ni ikkita kiruvchi to'lqinni ushlashdan iborat. Bundan tashqari, liniyaga ulangan iste'molchida aktiv, reaktiv quvvat sarf bo'lmasligi kerak.

a) (11.21) tenglamaga asosan liniya salt ishlash holati:

$$\begin{aligned} \dot{I}_2 &= 0, \quad \underline{Z}_2 = \infty \\ \dot{U}_x &= \dot{U}_c \cos \beta X, \quad \dot{I}_x = j \frac{\dot{U}_x}{\underline{Z}_c} \sin \beta X \end{aligned} \quad (11.23)$$

Liniya qanday masofa va vaqtiga bog'liq bo'lmagan holda:

$$X = k \frac{\pi}{\beta} = k \frac{\lambda}{2}$$

Haqiqatan ham $X=0, \lambda/2, \lambda, 3\lambda/2$ va hokazo hollarda $\cos \beta X = \pm 1$ bo'lib, $X=\lambda/4, 3\lambda/4, 5\lambda/4$ va hokazo bo'lganda $\cos \beta X = 0$

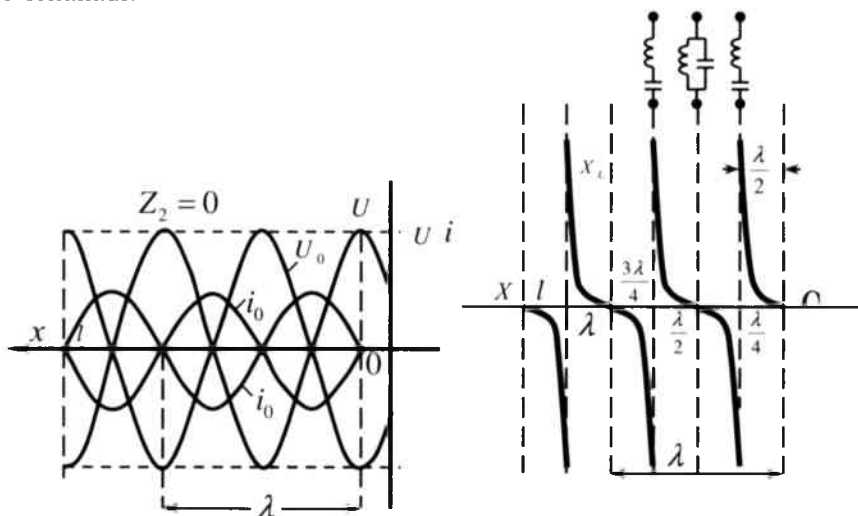
X masofada kuchlanish ham xuddi shunday qonuniyat bilan o'zgarib $\cos \beta X = \pm 1$ da kuchlanishlar «**bo'rtiq**»larini, $\cos \beta X = 0$ bo'lganda kuchlanish «**tugun**» larini hosil qiladi.

Isrofsiz liniya salt ishlaganda (11.22) formulaga binoan uning kirish qarshiligi:

$$\underline{Z}_0 = \frac{\dot{U}_{10}}{\dot{I}_{10}} = \frac{\underline{Z}_c}{j \operatorname{tg} \beta l} = -j \underline{Z}_c \operatorname{ctg} \beta l = j X l \quad (11.24)$$

Bunda Xl liniya tavsifiy qarshiligi, «**moduli**» shu sababli $\theta = 0$, $\underline{Z}_c = X_c$

Liniyaga kiruvchi qarshilik sof reaktiv qarshilik bo'lib, uning qiymati, ishorasi liniyaning uzunligi X va manba kuchlanishi bilan o'lchanadi.



Agar liniya uzunligi $l = k \frac{\lambda}{2}$ bo'lsa, kirish qarshiligi induktivlik xususiyatiga ega bo'lib, o'zini xuddi tok rezonansi rejimida ideal parallel konturdek tutadi.

Agar liniya uzunligi $l = (2k+1) \frac{\lambda}{4}$ bo'lganda, uning kirish qarshiligi sig'im xususiyatiga ega bo'lib, o'zini xuddi kuchlanish rezonansi rejimidagi ideal ketma-ket tebranish konturidek tutadi.

b) isrofsiz liniyada qisqa tutashuv $\underline{Z}_2 = 0$ va $\dot{U}_2 = 0$. Bunday liniyaning kirish qarshiligi (11.22) tenglamaga asosan quyidagicha ifodalanadi:

$$\underline{Z}_K = \frac{\dot{U}_{1K}}{\dot{I}_{1K}} = j\underline{Z}_C \quad \operatorname{tg} \beta l = jXl \quad (11.25)$$

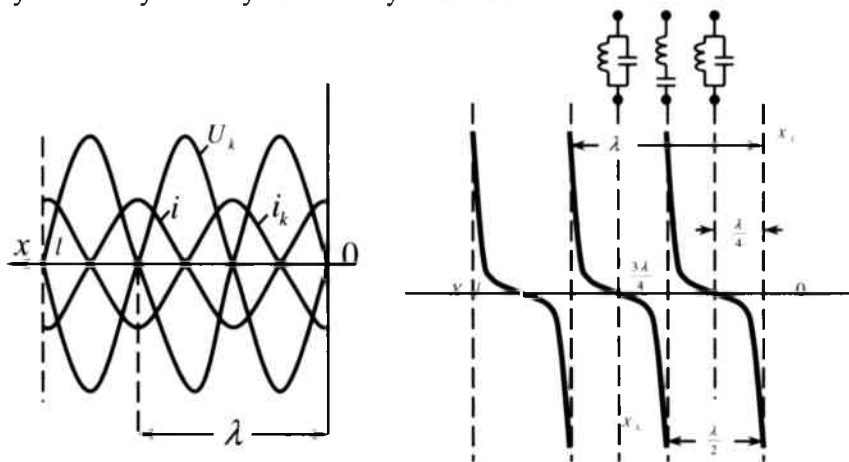
liniyaning har qanday nuqtasida tok va kuchlanish quyidagicha aniqlanadi:

$$\dot{U}_K = j\dot{I}_{2K}\underline{Z}_C \sin \beta X, \quad \dot{I}_K = \dot{I}_{2K} \cos \beta X \quad (11.26)$$

Qisqa tutashuvda hosil bo'ladigan turg'un to'liqin hududi salt ishlash holatidek faqat fazalari jihatidan $\lambda/4$ inasofaga siljigan. Liniyaning uzunligi $l=0, \lambda/2, \lambda$ va hokazo bo'lganda, liniyadagi tok bo'rtiqlari va kuchlanish tugunlarining liniya oxiridan $l= \lambda/4, 3\lambda/4, 5\lambda/4$ va h.k. masofalardagi nuqtalarda esa kuchlanish bo'rtiqlari $\dot{U}_K$ va tok tugunlari $\dot{I}_K$ ning hosil bo'lishi kuzatiladi. Uzunligi $l=\lambda/2, \lambda, 3\lambda/2$ va h.k bo'lib, oxirida qisqa tutashgan liniyaning kirish qarshiligi $\underline{Z}_2 = 0$ va bunday liniya o'zini xuddi kuchlanish rezonansi zanjiriday tutadi.

Uzunligi $l= \lambda/4, 3\lambda/4, 5\lambda/4$ va h.k. bo'lgan liniyaning kirish qarshiligi $\underline{Z}_K = \infty$ o'zini xuddi toklar rezonansi zanjiriday tutadi.

Bunday isrofsiz liniyaning yuqori chastotali qurilmalar uchun sof tayanch izolyatorlar yasashda foydalaniladi.



11.2. Masalalar yechish va uslubiy ko'rsatmalar

Masala 11.1. Bir jinsli liniyaning boshlang'ich parametri: $R_0=2.25 \text{ Om/km}$, $L_0=2 \cdot 10^{-3} \text{ Gn/km}$, $C_0=6 \cdot 10^{-9} \text{ F/km}$, $g_0=10^{-6} \frac{1}{\text{Om} \cdot \text{km}}$ uzunligi $l=100 \text{ km}$ chastota $f=800 \text{ Gs}$ ga teng, to'liq qarshiligi $-Z_C$, doimiy tarqalish koeffitsienti $-\gamma$, to'liq tarqalish tezligi $-V$ va uzunligi $-\lambda$ hamda $\frac{I_{2m}}{I_{1m}} = \frac{U_{2m}}{U_{1m}}$ nisbat aniqlansin.

Yechish.

Mis simdan tortilgan havo liniyasining to'liq qarshiligi:

$$Z_C = \sqrt{\frac{R_0 + j\omega L_0}{g_0 + j\omega C_0}} = \sqrt{\frac{2.25 + j10}{10^{-6}(1 + j30)}} = 585 \cdot e^{-j6^\circ} \text{ Om};$$

Doimiy tarqalish koeffitsienti:

$$\gamma = \sqrt{(R_0 + j\omega L_0)(g_0 + j\omega C_0)} = (\gamma)e^{j\omega} = 17.6 \cdot 10^{-3} e^{j83^\circ} \left(\frac{1}{\text{km}} \right)$$

So'nish koeffitsienti: $\beta = |\gamma| \sin 82^\circ = 2.44 \cdot 10^{-3} \left(\frac{1}{\text{km}} \right)$

Faza koeffitsienti: $\alpha = |\gamma| \cos 82^\circ = 17.4 \cdot 10^{-3} \left(\frac{1}{\text{km}} \right)$

Liniya bo'ylab to'liq tarqalish tezligi:

$$v = \frac{\omega}{\alpha} = \frac{2\pi \cdot 800}{17.4 \cdot 10^{-3}} = 289000 \left(\frac{\text{km}}{\text{sek}} \right)$$

To'liq uzunligi: $\lambda = \frac{2\pi}{\alpha} = \frac{2 \cdot 3.14}{17.4 \cdot 10^{-3}} = 360 \text{ km}$

Liniyaning boshi va oxirida so'nuvchi to'liq tok va kuchlanishlar amplituda nisbati:

$$\frac{I_{2m}}{I_{1m}} = \frac{U_{2m}}{U_{1m}} = e^{\beta l} = \frac{1}{e^{2.44 \cdot 10^{-3} \cdot 100}} = 0.785$$

Masala 11.2. Uzunligi $l=200 \text{ m}$ va boshlang'ich parametrlari $L_0 = 2 \cdot 10^{-6} \text{ Gn/km}$, $C_0 = 5.55 \cdot 10^{-6} \text{ mkF/m}$ bo'lgan isrofsiz liniyada to'liq uzunligi $\lambda=60 \text{ m}$ ga teng. Liniya oxiriga $L=0.01 \text{ mGn}$ induktivlik ulangan.

a) to'liqin qarshiligi; b) liniyada bo'rtiq to'liqlar tok va kuchlanish hosil bo'lishini isbotlash; d) liniya oxiridan qanday X masofada tok va kuchlanish bo'rtig'i hosil bo'ladi; e) tok va kuchlanishlar uchun liniya oxiridan bo'rtiq amplituda nisbatlari; f) tok va kuchlanish uchun liniya boshida bo'rtiq amplituda nisbati; g) liniyaga kirish qarshiligi aniqlansin.

Yechish.

$$\text{To'liqin qarshiligi: } \underline{Z}_C = \sqrt{\frac{L_0}{C_0}} = 600 \text{ Om}.$$

$$\text{Faza koeffitsienti: } \alpha = \frac{2\pi}{\lambda} = \frac{6 \cdot 28}{60} = 0,105 \left(\frac{1}{\text{m}} \right)$$

(10.20) va (10.21) liniyaning kompleks tenglamasiga binoan hamda masalaning shartiga ko'ra: $\underline{Z}_{kir} = \underline{Z}_C$, $\gamma = j\alpha$ va tok $\dot{I}_2 = \frac{\dot{U}_2}{\underline{Z}_2}$ yoki: $\underline{Z}_2 = X_L = j\omega L = 2\pi fL = 314 \text{ Om}$ bo'lib, quyidagi bir jinsli liniya kompleks tenglamasini yozamiz:

$$\left. \begin{aligned} \dot{U}_x &= \dot{U}_2 \left(\cos \alpha X - \frac{\underline{Z}_C}{\underline{Z}_2} \sin \alpha X \right) = \frac{\dot{U}_2}{\cos \delta} \cos(\alpha X - \delta) \\ \dot{I}_x &= \dot{I}_2 \left(\cos \alpha X - \frac{\underline{Z}_2}{\underline{Z}_C} \sin \alpha X \right) = \frac{\dot{I}_2}{\sin \delta} \sin(\alpha X - \delta) \end{aligned} \right\}$$

$$\text{Bunda } \delta = \arctg \frac{\underline{Z}_C}{\underline{Z}_2} = \arctg \frac{600}{314} = 63^\circ 20' = 1,1 \text{ rad}.$$

Kuchlanish boshlang'ich fazasi $\varphi_U = 0$ ekanligi inobatga olinib, tok va kuchlanishni oniy qiymat orqali ifodalaymiz:

$$\left. \begin{aligned} U_x &= \frac{\sqrt{2}U_2}{\cos \delta} \cos(\alpha X - \delta) \sin \omega t = U_{2m} \cos(\alpha X - \delta) \sin \omega t \\ I_x &= \frac{\sqrt{2}I_2}{\sin \delta} \sin(\alpha X - \delta) \cos \omega t = I_{2m} \sin(\alpha X - \delta) \cos \omega t \end{aligned} \right\}$$

Keltirilgan tenglamaga asosan liniyada turg'un holatdagi tok yuzaga kelishi mumkin. Liniya oxiridagi bo'rtiq kuchlanish $(\cos \alpha X_{l-\delta}) = 1$

Bundan: $\alpha X_1 - \delta = 0$ $X_1 = \frac{\delta}{\alpha} = \frac{1,09}{0,1} = 10,5 \text{ m}$

Liniya oxirida hosil bo'lgan bo'rtiq tok masofasi:

$$X_2 = X_1 + \frac{\lambda}{4} = 10,5 + \frac{60}{4} = 25,5 \text{ m}$$

Liniya oxiridagi bo'rtiq tok va kuchlanish amplituda nisbati:

$$\frac{U_2}{\cos \delta} : U_2 = \frac{1}{\cos \delta} = 2,15 \text{ va } \frac{I_2}{\sin \delta} : I_2 = \frac{1}{\sin \delta} = 1,13$$

Liniya boshida bo'rtiq tok va kuchlanish amplituda nisbati:

$$\frac{U_2}{\cos \delta} : \frac{U_2}{\cos \delta} \cos(\alpha l - \delta) = \frac{1}{\cos(1047 \cdot 10^{-4} \cdot 200 - 1,09)} = \frac{1}{\cos 57^{\circ} 30'} = 1,86$$

$$\text{Tok uchun: } \frac{I_2}{\sin \delta} : \frac{I_2}{\sin \delta} \sin(\alpha l - \delta) = \frac{1}{\sin 57^{\circ} 30'} = 1,19$$

Masala 11.3 Uzunligi $l=2 \text{ km}$ ga teng bir jinsli isrofsiz liniyaga

$\dot{U}_2 = 120 \sin 30000t$ bo'lgan o'zgaruvchan kuchlanish ulangan. Iste'molchi qarshiligi bilan to'lqim qarshiligi: $\underline{Z}_2 = \underline{Z}_C$ va $\underline{Z}_2 = 2\underline{Z}_C$ bo'lgan holat uchun liniya kirish qismidagi (boshidagi)

$\dot{U}_1$ kuchlanish, $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda to'lqin qaytish hamda yuguruvchi koeffitsient aniqlansin.

Yechish.

Isrofsiz liniyada to'lqim tarqalish tezligi: $v = 3 \cdot 10^8 \left(\frac{\text{km}}{\text{sek}} \right)$. Shu

sababli (11.17) tenglamaga binoan liniya oxiridagi kuchlanish U_2 ga nisbatan boshidagi U_1 kuchlanishga hisbatan fazadagi farq:

$$\Delta \varphi = \beta l = \frac{\omega t}{v} = \frac{3 \cdot 10^4 \cdot 2}{3 \cdot 10^5} = 0,2 \text{ rad}$$

(11.17) tenglamaga asosan $\underline{Z}_2 = \underline{Z}_C$ bo'lsa:

$$U_1 = 120 \sin(30000t + 0,2) = 120 \sin(30000t + 12^{\circ}) \text{ (V)}$$

Iste'molchi $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda liniya kirish qismidagi kuchlanishni (11.21) tenglamaga binoan quyidagicha yozamiz:

$$\dot{U}_1 = \dot{U}_2 \left(\cos \beta l + \frac{1}{2} j \sin \beta l \right). \text{ Demak: } \varphi = \varphi_{U1} - \varphi_{U2} = \arctg \frac{1}{2} \operatorname{tg} \beta l$$

Tangens kichik burchagi o'zining burchagiga teng bo'lib:
 $\Delta\varphi = 0,1 \text{ rad} = 6^\circ$

U_{1m} kuchlanish amplitudasi U_{2m} dan kichik bo'lib:

$$\begin{aligned} U_{1m} &= U_{2m} \cos \beta l \sqrt{1 + \left(\frac{1}{2} \operatorname{tg} \beta l \right)^2} = U_{2m} \cos 0,2 \sqrt{1 + 0,1^2} = \\ &= U_{2m} 0,98(1 + 0,005) = 0,985 U_{2m} \end{aligned}$$

Liniya boshidagi kuchlanish oniy qiymati:

$$U_1 = 1200,985 \sin(30000t + 6^\circ) = 118 \sin(30000t + 6^\circ) \text{ V}$$

Iste'molchi qarshiligi $\underline{Z}_2 = 2\underline{Z}_C$ bo'lganda (11.6) tenglamaga asosan

$$\text{to'liqin qaytish koeffitsienti: } K_U = \frac{\underline{Z}_2 - \underline{Z}_C}{\underline{Z}_2 + \underline{Z}_C} = \frac{2 - 1}{2 + 1} = \frac{1}{3}$$

$$\text{Yuguruvchi to'liqin koeffitsienti: } K = \frac{1 - K_U}{1 + K_U} = \frac{1 - \frac{1}{3}}{1 + \frac{1}{3}} = 0,5$$

Masala 11.4. Uzunligi $l = 900 \text{ km}$, uch fazali liniya chastotasi $f = 50 \text{ Gs}$, to'liqin tarqalish umumiy koeffitsienti $\underline{\gamma} = (0,1 + j1,07)10^{-3} \left(\frac{1}{\text{km}} \right)$

va to'liqin qarshiligi $\underline{Z}_C = 400e^{-j6^\circ} \text{ Om}$, liniya oxiridagi kuchlanishi $U_{x2} = \sqrt{3}220 \text{ kV}$ ga teng. Liniya boshidagi U_{1L} kuchlanish, liniya boshidagi va oxiridagi tok $\dot{I}_1$, $\dot{I}_2$, liniyadagi tok quvvati va foydali ish koeffitsienti aniqlansin.

Yechish.

Liniya sof quvvati $\underline{Z}_\phi = \underline{Z}_C$ bo'lganda liniya oxiridagi quvvat qiymati hisoblanadi:

$$P_2 = 3 \frac{(220 \cdot 10^3)^2}{400} \cos 6^\circ = 363 \cdot 10^6 \text{ Vt} = 363 \text{ MVt}$$

(11.16) tenglamaga asosan:

$$\dot{U}_{1L} = \dot{U}_2 e^{j\gamma l} = \dot{U}_2 e^{\alpha l} \cdot e^{j\beta l} = 220 e^{0,09} \cdot e^{j0,963} = 220 \cdot 1,094 e^{j55^\circ} = 241 e^{j55^\circ} \text{ kV}$$

yoki: $U_{1L} = 241\sqrt{3} = 417 \text{ (kV)}$

Liniya boshidagi kiruvchi tok:

$$\dot{I}_1 = \frac{\dot{U}_{1L}}{Z_c} = \frac{241 e^{j55^\circ} 10^3}{400 e^{-j6^\circ}} = 602,5 e^{j61^\circ} \text{ (A)}$$

Liniya oxiridagi tok: $\dot{I}_2 = \frac{\dot{U}_{2L}}{Z_c} = \frac{220 \cdot 10^{-3}}{400 e^{-j6^\circ}} = 550 e^{j6^\circ} \text{ (A)}$

Liniya foydali ish ko'effitsienti tenglamasiga binoan:

$$\eta = e^{-2\alpha l} = e^{-0,18} \approx 0,83$$

Masala 11.5. Bir necha jinsli uch fazali liniya uzunligi $l=200 \text{ km}$, to'liq tarqalish ko'effitsienti $\gamma = (0,59 + j1,21)10^{-3} \left(\frac{1}{\text{km}}\right)$, to'liq qarshi-

ligi $Z_c = 475 e^{-j26^\circ} \text{ (Om)}$ ga teng. Liniya oxiridagi liniya kuchlanishi $U_L=100 \text{ kV}$, $\cos \varphi = 0,8$ bo'lgan iste'molchi quvvati $P=10 \text{ MW}$ ni mstansiyaga ulangan.

Liniya boshidagi kuchlanish $\dot{U}_{1L}$ va liniya oxiridagi kuchlanish $\dot{U}_{2L}$ va ular orasidagi fazadagi farq aniqlansin.

Yechish.

Uch fazali liniyada iste'molchi qarshiligi simmetrik bo'lganligi uchun: $\varphi = \arccos 0,8 = 37^\circ$ fazadagi qarshilik:

$$Z_\varphi = \frac{U^2}{P} \cos \varphi = \frac{10^{10}}{10^7} 0,8 = 800 \text{ Om}$$

yoki: $Z_\varphi = Z_\varphi e^{j\varphi} = 800 e^{j37^\circ} = (640 + j480) \text{ Om}$

(11.10) tenglamadan foydalanamiz: $\dot{U}_1 = \dot{U}_2 (ch \gamma l + \frac{Z_c}{Z_\varphi} sh \gamma l)$

Giperbolik funksiya argumentini kompleks ifoda orqali yozamiz:

$$sh \gamma l = \frac{1}{2}(e^{\gamma l} - e^{-\gamma l}) \quad ch \gamma l = \frac{1}{2}(e^{\gamma l} + e^{-\gamma l})$$

Bunda: $\gamma l = (0,59 + j1,21) \cdot 10^{-3} \cdot 200 = 0,118 + j0,242$

Giperbolik funksiya kompleks ifodasidan haqiqiy argumentga o'tishda tablitsadan foydalaniladi:

$$\begin{aligned} sh\gamma l &= \frac{1}{2}(e^{0,118} \cdot e^{-j0,242} - e^{-0,118} \cdot e^{-0,242}) = \\ &= \frac{1}{2}[1,125(\cos 0,242 + j \sin 0,242) - 0,89(\cos 0,242 + j \sin 0,242)] = \\ &= 0,114 + j0,242 \end{aligned}$$

Ikkinchi giperbolik funksiya ifodasi:

$$ch\gamma l = (0,118 + j0,242) = 0,98 + j0,028$$

Aniqlangan kompleks qiymatni kuchlanish tenglamasiga qo'yamiz:

$$\begin{aligned} \dot{U}_1 &= \dot{U}_2[(0,98 + j0,028) + \frac{475e^{-j26^\circ}}{800e^{j37^\circ}}(0,114 + j0,242)] = \\ &= \dot{U}_2[0,98 + j0,028 + 0,6e^{-j63^\circ}(0,114 + j0,242)] = \dot{U}_2(1,14 + j0,035) \end{aligned}$$

$$\text{Liniya boshidagi: } \dot{U}_1 = 1,14\dot{U}_2 = 114 \text{ kV}$$

Liniya boshidagi va oxiridagi kuchlanish orasidagi fazadagi farq kompleks mavhum ifodadagi haqiqiy songa nisbati bilan aniqlanadi:

$$tg\varphi_U = \frac{0,035}{1,14} = 0,0306$$

Tangens burchak juda ham kichik bo'lsa, uning argumenti o'ziga teng bo'ladi

$$\text{yoki: } \varphi_U \approx 0,0306 = 1,75^\circ$$

Masala 11.6. Isrofsiz liniya parametri $L = 2,25 \frac{mGn}{km}$,

$C = 4,6 \frac{mkF}{km}$ bo'lib, uzunligi $l = 200 \text{ km}$ ga teng. Liniya oxirida chastota: $f = 50 \text{ Gs}$ va $U_2 = 100 \text{ kV}$ kuchlanishga ulangan. Iste'molchi qarshiligi liniya xarakteristik tenglamasiga teng $Z_2 = Z_C$.

Liniya boshidagi tok I_1 va kuchlanish $\dot{U}_1$ qiymati va fazadagi farq aniqlansin.

Yechish.

Isrofsiz liniya tavsifiy qarshiligi sof aktiv qarshiligi bo'lib:

$$Z = R = \sqrt{\frac{L}{C}} = \sqrt{\frac{2,25 \cdot 10^{-3}}{4,6 \cdot 10^{-9}}} = 1000 \cdot 0,7 = 700 \text{ Om}$$

$$\text{Liniya oxiridagi tok: } I_2 = \frac{U_2}{Z_H} = \frac{U_2}{Z} = \frac{100000}{700} = 143 \text{ A}$$

Liniya boshi va oxiridagi kuchlanish $\dot{U}_1$ va $\dot{U}_2$ muvozanati:

$$\dot{U}_1 = \dot{U}_2 e^{j\beta l} = \dot{U}_2 e^{j\alpha l}$$

Bunda isrofsiz liniya bo'lganligi uchun faza koeffitsienti $\beta = 0$:

Xuddi shunga o'xshash tok tenglamasi: $\dot{I}_1 = \dot{I}_2 e^{j\alpha l}$

Faza koeffitsientini aniqlaymiz:

$$\alpha = \omega \sqrt{LC} = 314 \sqrt{2,25 \cdot 4,6 \cdot 10^{-3} \cdot 10^{-9}} = 1,02 \cdot 10^{-3} \frac{1}{\text{km}}$$

To'liq uzunligi:

$$\lambda = vT = \frac{1}{\sqrt{LC} \cdot f} = \frac{2\pi}{\omega \sqrt{LC}} = \frac{2\pi}{\alpha} = \frac{2\pi \cdot 10^{-3}}{1,02} = 6160 \text{ (km)}$$

$$\text{yoki: } \alpha l = 2\pi \frac{l}{\lambda} = 2\pi \frac{200}{6160} = 0,204$$

$\dot{U}_2$ kuchlanish haqiqiy son ekanligini hisobga olganda liniya boshidagi kuchlanish: $\dot{U}_1 = 100 e^{j11,7^\circ} \text{ (kV)}$

$$\text{Tok esa: } \dot{I}_1 = 143 e^{j11,7^\circ} \text{ (A)}$$

Masala 11.7. Signal shakli o'zgarmas bir jinsli liniyaning parametri: $L = 1 \frac{\text{mGn}}{\text{km}}$, $C = 11,2 \cdot 10^{-3} \frac{\text{mkF}}{\text{km}}$ va $R = 8 \text{ Om/km}$ bo'lib, liniya oxiriga $R_H = 100 \text{ Om}$ aktiv qarshilik ulangan. Liniya uzunligi $l = 40 \text{ km}$, chastotasi $f = 10^4 \text{ Gs}$, liniya oxiridagi kuchlanish $U_2 = 1000$ bo'lganda, liniya boshidagi kuchlanish aniqlansin.

Yechish.

Liniya birlamchi parametrini bog'lovchi tenglamadan o'tkazuvchanlik aniqlanadi:

$$\frac{R}{L} = \frac{g}{C}; \quad g = \frac{RC}{L} = \frac{8 \cdot 11,2 \cdot 10^{-9}}{10^{-3}} = 89,6 \cdot 10^{-6} \frac{1}{Om \cdot km}$$

$$\text{Faza koeffitsienti: } \beta = \sqrt{Rg} = \sqrt{89,6 \cdot 8 \cdot 10^{-6}} = 26,8 \cdot 10^{-3} \frac{1}{km}$$

So'nish koeffitsienti:

$$\alpha = \omega \sqrt{LC} = 6,28 \cdot 10^{-3} \sqrt{1 \cdot 11,2 \cdot 10^{-3} \cdot 10^{-9}} = 0,21 \frac{1}{km}$$

$$\text{To'lqin uzunligi: } \lambda = \frac{2\pi}{\alpha} = \frac{6,28}{0,21} = 30 \text{ km}$$

$$\text{To'lqin tavsifiy qarshlligi: } Z = \sqrt{\frac{L}{C}} = \sqrt{\frac{10^{-3}}{11,2 \cdot 10^{-9}}} = 300 \text{ Om}$$

$$\text{Liniya oxiridagi tok kompleks ifodasi: } \dot{I}_2 = \frac{\dot{U}_2}{R_H} = \frac{1000}{100} = 10 \text{ A}$$

(11.10) tenglamani kuchlanish $\dot{U}_2$ va tok $\dot{I}_2$ qavsdan tashqariga chiqariladi:

$$\left. \begin{aligned} \dot{U}_1 &= \dot{U}_2 \left(ch \gamma X + \frac{Z}{Z_H} sh \gamma X \right) \\ \dot{I}_1 &= \dot{I}_2 \left(ch \gamma X - \frac{Z_H}{Z} sh \gamma X \right) \end{aligned} \right\} \quad (*)$$

$$X = l = 40 \text{ km.}$$

$$\text{Bunda: } \beta l = 26,8 \cdot 10^{-3} \cdot 40 = 1,07 \quad \alpha l = 0,21 \cdot 40 = 8,4$$

yoki:

$$\begin{aligned} ch(\beta e + j\alpha e) &= ch(1,07 + j8,4) = ch1,07 \cdot \cos 8,4 + jsh1,07 \cdot \sin 8,4 = \\ &= 1,63(-0,5) + j1,29 \cdot 0,866 = -0,815 + j1,12 \end{aligned}$$

$$sh(\beta e - j\alpha e) = sh1,07 \cdot \cos 120^\circ + jch1,07 \cdot \sin 120^\circ = -0,645 + j1,41$$

$$\text{Liniyadagi qarshilik nisbati: } \frac{Z}{Z_H} = \frac{300}{100} = 3$$

Aniqlangan qiymat (*) tenglamadagi tok va kuchlanish ifodasiga qo'yiladi:

$$\begin{aligned} U_1 &= U_2 [-0,815 + j1,12 + 3(0,645 + j1,41)] = \\ &= U_2 (-2,85 + j5,35) = 1000 \cdot 6 \cdot 0,7 e^{j118^\circ} = 6070 e^{j118^\circ} \end{aligned}$$

$$\text{Kuchlanish haqiqiy qiymati: } U_1 = 6070 \text{ V}$$

$$\dot{I}_1 = \dot{I}_2 \left[-0,815 + j1,12 + \frac{1}{3}(0,645 + j1,41) \right] = \dot{I}_2(-1,03 + j1,6) = 10 \cdot 1,9 e^{j123^\circ} = 19 e^{j123^\circ}$$

tok haqiqiy qiymati: $I_1 = 19 \text{ A}$.

11.3. Mustaqil yechish uchun masalalar

Masala 11.1. Ikki simli uzatish liniyasi birlamchi parametri: $R_0 = 6 \frac{\text{Om}}{\text{km}}$, $L_0 = 1,6 \cdot 10^{-3} \frac{\text{Gn}}{\text{km}}$, $g_0 = 10^{-6} \frac{1}{\text{Om} \cdot \text{km}}$, $C_0 = 6,4 \cdot 10^{-9} \frac{\text{F}}{\text{km}}$ Liniya chastotasi $f_1 = 100 \text{ Gs}$ va $f_2 = 100 \text{ Gs}$ bo'lgan hollarda to'liq tarqalish koeffitsienti, to'liq uzunligi, to'liq qarshiligi aniqlansin.

Javob: $\underline{\gamma}_1 = 5,3 \cdot 10^{-3} e^{j44^\circ} \frac{1}{\text{km}}$, $\underline{Z}_{C1} = 1150 \cdot e^{-j34^\circ 30'} \text{Om}$,

$$\alpha_1 = 3,82 \cdot 10^{-3} \frac{1}{\text{km}}, \beta_1 = 3,65 \cdot 10^{-3} \frac{1}{\text{km}},$$

$$\nu_1 = 173 \cdot 10^3 \text{ km / sek}, \lambda_1 = 173 \text{ km}, \underline{\gamma}_2 = 22,9 \cdot 10^{-3} e^{j74^\circ} \frac{1}{\text{km}},$$

$$\underline{Z}_{C2} = 510 \cdot e^{-j15^\circ} \text{Om}, \alpha_2 = 6,4 \cdot 10^{-3} \frac{1}{\text{km}}, \beta_2 = 22 \cdot 10^{-3} \frac{1}{\text{km}},$$

$$\nu_2 = 288 \cdot 10^3 \text{ km / sek}, \lambda_2 = 288 \text{ km}$$

Masala 11.2. Koaksial kabel parametri: $R=7 \text{Om/km}$, $L=0,3 \cdot 10^{-3} \frac{\text{Gn}}{\text{km}}$, $C=0,2 \frac{\text{mkF}}{\text{km}}$, $g=0,5 \cdot 10^{-6} \frac{1}{\text{Om} \cdot \text{km}}$ bo'lib, chastotasi $f=800 \text{ Gs}$.

Kabel to'liq qarshiligi $\underline{Z}_c$, α , β koeffitsienti, to'liq tarqalish tezligi ν va to'liq uzunligi λ aniqlansin.

Javob: $\underline{Z}_c = 843 e^{-j39^\circ} \text{Om}$, $\beta = 5,36 \cdot 10^{-2} \frac{1}{\text{km}}$, $\alpha = 6,62 \cdot 10^{-2} \frac{1}{\text{km}}$,
 $\nu = 0,75 \cdot 10^5 \text{ km / sek}$, $\lambda = 95 \text{ km}$.

Masala 11.3. Isrofsiz liniya to'liq qarshiligi $\underline{Z}_c = 865 \text{Om}$, uzunligi $l=200 \text{ km}$ bo'lib, $f=1000 \text{ Gs}$ chastotali o'zgaruvchan kuchlanish $U_l = 50 \text{ V}$ ga ulangan. Liniya oxirida salt va qisqa tutashuv

tajribalariga asosan liniya boshidagi kompleks qarshilik Z_{10} va Z_{1K} qiymati aniqlansin.

Javob: $Z_{10} = -j500 \text{ Om}$, $Z_{1K} = j1500 \text{ Om}$

Masala 11.4. Shakli o'zgarmas liniya koeffitsienti $\beta = 26,8 \cdot 10^{-3} \frac{1}{\text{km}}$, $\alpha = 3,34 \cdot 10^{-6} \frac{1}{\text{km}}$ va to'liq qarshiligi $Z_C = 300 \text{ Om}$ ga teng. Liniya uzunligi $l = 100 \text{ km}$, $f = 400 \text{ Gs}$ bo'lganda salt ishlash va qisqa tutashuv holatidagi qarshilik Z_{10} va Z_{1K} aniqlansin.

Javob: $Z_{10} = 300 \text{ Om}$; $Z_{1K} = 300 \text{ Om}$.

Masala 11.5. Uzunligi $l = 100 \text{ km}$, chastotasi $f = 1600 \text{ Gs}$ bo'lgan telefon liniyasida o'tkazilgan qisqa tutashuv va uzilgan holat uchun $Z_{10} = 900e^{-j40^\circ} \text{ Om}$, $Z_{1K} = 100e^{-j40^\circ} \text{ Om}$ qarshilik qiymati aniqlangan.

Liniya to'liq qarshiligi Z_C tarqalish koeffitsienti γ , induktivlik va sig'im parametrlari aniqlansin.

Javob: $Z = 300 \text{ Om}$, $L = 10^{-8} \frac{\text{Gn}}{\text{km}}$, $C = 11,2 \cdot 10^{-3} \frac{\text{mkF}}{\text{km}}$

$$\gamma = \beta + j\alpha = (2,5 \cdot 10^{-3} + j3/35 \cdot 10^{-2}) \frac{1}{\text{km}}$$

Masala 11.6. Elektr energiya uzatish liniya uzunligi $l = 1000 \text{ km}$ ga teng bo'lib, birlamchi parametri: $R_0 = 0,035 \frac{\text{Om}}{\text{km}}$, $\omega L_0 = 0,392 \frac{\text{Om}}{\text{km}}$, $g_0 = 4,17 \cdot 10^{-8} \frac{\text{sim}}{\text{km}}$, $\omega C = 2,92 \cdot 10^{-6} \frac{\text{Om}}{\text{km}}$, liniya oxiriga ulangan iste'molchi quvvati $P_2 = 300 \text{ MW}$, kuchlanishi $U_2 = 220,3 \text{ kV}$ va $\cos \varphi = 1$ ga teng. Liniyaning ikkilamchi parametri va kirish qismidagi I_1 tok va U_2 kuchlanish qiymati aniqlansin.

Javob: $Z_1 = 367e^{-j2^\circ 15'} \text{ Om}$; $g = 1,07 \cdot 10^{-3} e^{j87^\circ} \frac{1}{\text{Om}}$;

$$U_2 = 201e^{j57^\circ} \text{ kV}; \quad I_1 = 570e^{j65^\circ 30'} \text{ A}$$

11.4. Nazorat savollari

1. Tarqoq parametrli elektr zanjiri nima? Misol keltiring.
2. Tarqoq uzunlikdagi liniyaning qaysi parametri birinchi yoki ikkinchi hisoblanadi?
3. Bir jinsli liniya to'liq yoki tavsifiy qarshiligi va liniya tarqallish koeffitsienti ifodalarini yozing.
4. Elektromagnit to'liq tarqalish va to'liq uzunligi tenglamasini yeching.
5. Bir jinsli tarqoq parametrli zanjirdagi tok ekvivalent sxemasini chizib, tenglamasini yozing.
6. Isrofsiz liniyaning salt holatdagi tok va kuchlanishi tenglamasini yozing.
7. Bir jinsli uzun liniya to'rt qutbli T va Π sxemaga ekvivalent shaklda almashtirish mumkinmi?
8. Isrofsiz liniya nima ekanligini tushuntirib bering.
9. Qanday sharoitda elektromagnit jarayon liniyada turg'un to'liq hosil qiladi?
10. Isrofsiz liniyada kuchlanish «bo'rtiq» lari va «tugun» lari qanday hosil bo'ladi?
11. To'liq uzunligi bilan tarqalish fazasi qanday bog'langan? Ifodasini yozing.
12. Isrofsiz uzatish liniyasida elektromagnit to'liq tarqalish tezligi qanchaga teng?
13. To'liq tarqallish koeffitsient ifodasida so'nish koeffitsienti va faza koeffitsienti fizik ma'nosini tushuntirib, birligini yozing.
14. Iste'molchi qarshiligi liniya bilan muvofiqlashtirilganda qanday xususiyatga ega bo'ladi?
15. Elektromagnit jarayon turg'un to'liq holatda bo'lganda energiya liniya bo'ylab tarqaladimi?

ILOVALAR

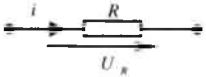
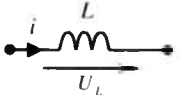
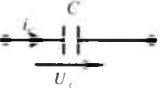
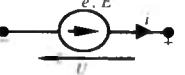
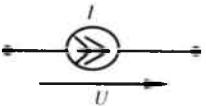
1-ilova

Elektr va magnit kattaliklarning birliklari

Elektromagnit kattaliklar nomi	Kattalik belgisi	Birligi	Birlik nomi	Birlik belgisi
1	2	3	4	5
1-umumiy elektr magnit kattaliklari				
Elektr miqdori (hajmi) zaryadi	Q, q	Amper-sekund	Kulon	K
Elektr maydon kuchlanganligi, potensial gradienti	$E, \text{grad}\phi$	Voltmetr	–	V/m
Elektr zaryad siljishi	D	Kulon taqsim metr KV.	–	Kl/m^2
Elektr doimiyligi	ϵ_0	Farada taqsim metr		F/m
Elektr sig'im	C	Kulon taqsim metr	Farada	f
Elektr yurituvchi kuch, kuchlanish potentsiali	e, U, ϕ	Volt	Volt	V
Elektr tok, elektr tokning zichligi	I, i, δ	Amper Amper taqsim metr kvadrat	Amper	A A/m^2
Elektr qarshilik	R, r	Volt amper	Om	Om
Elektr o'tkazuvchanlik	G, g	Amper volt	Simens	Sm
Elektr energiya (elektr bajargan ish)	W, A	Amper (vatt-sekund)	Joul	J
Elektr quvvat	R	Volt-amper	Vatt	Vt
Magnit oqimi	ϕ	amper Volt-sekund	Veber	Vb
Ilashgan magnit oqimi	$\psi = w\phi$	Volt-sekund	Veber	Vb
Magnit induksiya	B	Veber taqsim metr kvadrat	Tesla	Tl
Magnit maydon kuchlanganligi	H	Amper taqsim metr	–	A/m
Magnit doimiyligi	μ_0	Genri taqsim metr		G/m

Induktivlik	L	Veber taqsim amper	Genri	G
O'zaro induktivlik	M	Veber taqsim amper	Genri	G
Magnit yurituvchi kuch (magnitlovchi kuch)	$F=Hl$	Amper	Amper	A
P. O'zgaruvchan (sinusoidal) tokga oid kattaliklar				
Elektr tok: oniy	i	Amper	Amper	A
Amplitudaviy	I_m	Amper	Amper	A
Effektiv (amaliy)	$I = I_m / \sqrt{2}$	Amper	Amper	A
O'rta	I_{oT}	Amper	Amper	A
Tok davri	T	sekund	sekund	sek
Tok chastotasi	$f = 1/T$	Bir taqsim sekund	Gers	Gs
Burchak chastota	$\omega = 2\pi f$	Radian - sekund		Rad/s
Tokning (EYK ning, kuchlanishning) boshlang'ich fazasi	ψ_e, ψ_i, ψ_u	Radian (gradus)	—	—
Tok va kuchlanish o'rtasidagi fazaviy siljish	$\varphi = \psi_u - \psi_i$	Radian (gradus)	—	—
Quvvat: aktiv	$P = UI \cdot \cos \varphi$	Volt-amper	Vatt	Vt
Reaktiv	$Q = UI \sin \varphi$	Volt-amper	Volt-amper reaktiv	Var
To'la	$S = UI$	Volt-amper	Volt-amper	VA
Quvvat koeffitsienti	$\cos \varphi$	—	—	—
Rezonans chastota	$\omega = \frac{1}{\sqrt{LC}}$	Radian -sekund		rad/sek
To'lqin qarshiligi	$\rho = \sqrt{LC}$	Volt amper	Om	Om

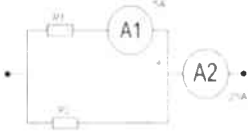
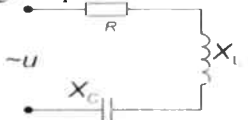
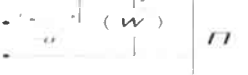
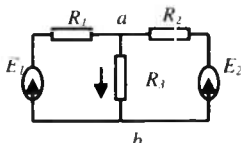
Elektr zanjir elementlarining asosiy tavsifi.

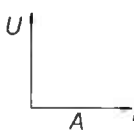
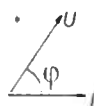
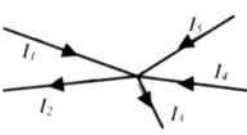
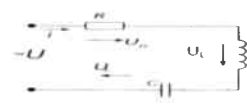
Ele- mentlar	Shartli belgilar	Elektr kuchlanish (V)	Tok (A)	Quvvat yoki energiya (Vt, KVt) (Dj)
Aktiv qarshilik (rezistor)		$U_R = iR$	$i = \frac{U_R}{R}$	$P = Ri^2$
O'tka- zuvchan- lik		$U_g = \frac{i}{g}$	$i = U_g g$	$P = gu_g^2 = \frac{I_g^2}{g}$
Induk- tivlik		$U_L = L \frac{di_L}{dt}$	$i_L = \frac{1}{L} \int U_L dt$	$W_L = \frac{Li_L^2}{2}$
Sig'im		$U_C = \frac{1}{C} \int i_C dt$	$i_C = C \frac{du_C}{dt}$	$W_C = \frac{CU_C^2}{2}$
Elektr yurituv- chi kuch		$e = -u$	i -istalgan qiymat	$P_e = ei$
Tok manbai		u -istalgan qiymat	$i = I$	$P_i = ui$

Test savollari

№	SAVOLLAR	Javob variantlari			
		A	B	C	D
1	Kuchlanish $u = 30 \sin(157t + 30^\circ)$ Ifoda uchun ω va f topilsin.	* 157 rad/s; 25 Gs;	157 rad/s; 50 Gs;	157 rad/s; 157 Gs	25 rad/s; 157 Gs.
2	$u = 141 \sin(314t + 80^\circ)$ $i = 14,1 \sin(314t + 20^\circ)$ Zanjirning aktiv quvvati aniqlansin.	* 500 Vt	616 Vt	1000 Vt	308 Vt,
3	Kuchlanish va tok bo'yicha iste'molchi- ning kompleks qarshiligi yozilsin. $u = 147 \sin(\omega t + 102^\circ 40')$ $i = 42 \sin(\omega t + 155^\circ 50') A$	* $(2,1 - j2,8)$	$(2,8 - j2,1)$	35	$(2,8 + j2,1)$
4	Tenglamalardan qaysi biri o'zgaruvchan tok zanjirining to'la qarshi- ligini ifodalaydi.	* $Z = \sqrt{R^2 + X^2}$	$Y = \sqrt{g^2 + b^2}$	$b = \frac{1}{\omega L} - \omega C$	$X = \omega L - \frac{1}{\omega C}$
5	Formulalardan qaysi biri kommutatsiyaning bi- rinchi qonunini ifoda- laydi?	* $i_L(0_-) = i_L(0_+)$	$i_L \frac{d\psi_L(0_-)}{dt} = i_L \frac{d\psi_L(0_+)}{dt}$	$u_c(0_-) = u_c(0_+)$	$\frac{dq(0_-)}{dt} = \frac{dq(0_+)}{dt}$
6	Quvvatni ifodalovchi formulalarning qaysi biri xato yozilgan?	* $P = UI \sin \varphi$	$S = UI$	$S = \sqrt{P^2 + Q^2}$	$Q = UI \sin \varphi$
7	Formulalarning qaysi biri o'zgaruvchan tok zanjirining reaktiv qar- shiligini ifodalaydi?	* $X = \omega L - \frac{1}{\omega C}$	$Y = \sqrt{g^2 + b^2}$	$b = \frac{1}{\omega L} - \omega C$	$Z = \sqrt{r^2 + x^2}$
8	Keltirilgan kompleks miqdorlarning qaysi biri trigonometrik tarzda ifodalangan?	* $\dot{A} = (\cos \alpha + j \sin \alpha)$	$\dot{A} = a_1 + ja_2$	$\dot{A} = A e^{j\alpha}$	$\dot{A} = \dot{B} + \dot{C}$

9	Transformatorning ishlash prinsipi:	*Elektromagnit induksiyasi qonuniga asoslangan	Amper qonuniga asoslangan	Lens prinsipiga asoslangan	Hech qanday qonunga asoslanmagan
10	Yulduzcha shaklida ulangan uch fazali tok zanjirida tok va kuchlanish munosabatlari qanday ifodalanadi?	$*I_1 = I_\phi$ $U_1 = \sqrt{3}U_\phi$	$U_1 = U_\phi$ $I_1 = \sqrt{3}I_\phi$	$I_1 = I_\phi$ $\sum I_0 = 0$	$U_{00} = U_\phi$ $I_1 = I_\phi$
11	Elektr zanjirining kuchlanishi $U=220$, toki $I=10A$, aktiv quvvati $P=1,1kVt$ ga teng bo'lganda, $\cos\phi$ nimaga teng?	* $\cos\phi=0,5$	$\cos\phi=1$	$\cos\phi=0$	$\cos\phi=0,75$
12	Neytral simhi uch fazali tok zanjiri qanday sxemada ulanadi?	*Yulduzcha	Uchburchak	Ketma-ket	Parallel
13	4 qutbli zanjir simmetrik bo'lganda:	* $A=D$ $A^2-BC=1$	$B=C$	$B=D$	$AD-BC=0$
14	Nosinusoidal tok R, L, C zanjiri k -yuqori garmonikadan iborat bo'lsa, to'la qarshiligi qanday ifodalanadi?	$Z_1 = \sqrt{R^2 + \left(k\omega L - \frac{1}{k\omega C}\right)^2}$	$y = \sqrt{R^2 + (b_1 - b_2)^2}$	$X = kX_L - kX_C$	$*Z_k = \sqrt{R^2 + (X_L - X_C)^2}$
15	Rezonans holatda elektromagnit maydon energiyasi qanday munosabatda bo'ladi?	* $W_3 = W_M$	$W_M \neq W_3$	$W_3 > W_M$	$W_3 < W_M$
16	Agar faza kuchlanishlari $U_A=U_B=U_C=220V$ bo'lsa va yulduzcha shaklida ulangan aktiv va reaktiv iste'molchilarning qarshiliklari $R=10\Omega$ $X_L=10\Omega$ $X_C=10\Omega$ bo'lsa, uch fazali zanjirning reaktiv quvvati qancha bo'ladi?	4840 var	14520 var	9680 var	*0

17	Agar sxemada $R_2=3\text{ Om}$ va ampermetrlar ko'rsatishi $I_1=5\text{ A}$, $I_2=25\text{ A}$ bo'lsa, R_2 qarshilik miqdori qanchaga teng? 	$*12\text{ Om}$	20 Om	15 Om	25 Om
18	Agar $R=4\text{ Om}$, $X_L=4\text{ Om}$, $X_C=4\text{ Om}$ bo'lsa, zanjirning to'la qarshiligi aniqlansin. 	$*Z=4\text{ Om}$	$Z=12\text{ Om}$	$Z=4\sqrt{2}\text{ Om}$	$Z=4/\sqrt{2}\text{ Om}$
19	Passiv ikki qutbli zanjir qismlaridagi kuchlanish va tokning kompleks amplituda qiymatlari $U_m=100e^{130t}\text{ V}$ va $I_m=10e^{130t}\text{ A}$ Vattmetrk ko'rsatishi aniqlansin. 	$*1000\text{ Vt}$	500 Vt	250 Vt	200 Vt
20	Rasmda ko'rsatilgan zanjirda $E_1=12\text{ V}$, $E_2=24\text{ V}$, $R_1=R_2=2\text{ Om}$, $R_3=1\text{ Om}$ bo'lsa, A va B tugunlari orasidagi kuchlanish U_{ab} necha voltga teng? 	$*9\text{ V}$	12 V	18 V	24 V

21	Keltirilgan vektor diagrammalarning qaysi biri sxemaga mos keladi? 				
22	Ushbu tugun uchun Kirxgof 1-qonuni asosida yozilgan qaysi tenglama to'g'ri keladi? 	$*I_1 - I_2 - I_3 + I_4 + I_5 = 0$	$I_1 + I_2 + I_3 - I_4 - I_5 = 0$	$-I_1 + I_2 - I_3 + I_4 - I_5 = 0$	$I_1 + I_2 - I_3 - I_4 + I_5 = 0$
23	Ko'rsatilgan sxemada $U=25$ B, $U_L=60$ B va $U_C=40$ B bo'lsa, rezistordagi kuchlanish qancha? 	$*15V$	$115V$	$75V$	$35V$

Test savollarini yechish namunalari

1. **2-test savol yechimi:** Aktiv quvvat ifodasidan $P = UI \cos \varphi$, kuchlanish effektiv qiymati $U = \frac{U_m}{\sqrt{2}} = \frac{141}{1,41} = 100B$. Tok effektiv qiymati

esa $I = \frac{I_m}{\sqrt{2}} = \frac{14,1}{1,41} = 10A$ bo'lib, b tok va kuchlanish orasidagi faza farqi:

$$\varphi = \varphi_u - \varphi_i = 80^\circ - 20^\circ = 60^\circ, \text{ yoki } \cos \varphi = 60^\circ = \frac{1}{2}.$$

Demak aktiv quvvat ifodasidan

$$P = UI \cos \varphi = 100 \cdot 10 \cdot 0,5 = 500Wt$$

2. **17-test savol yechimi:** Masalaning shartiga ko'ra uch fazali zanjir simmetrik bo'lib, to'la qarshilik ifodasidan:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{10^2 + (10 - 10)^2} = \sqrt{10^2 + 0}.$$

Demak, reaktiv qarshilik $x = 0$ bo'lganligi uchun reaktiv quvvat ham $Q = Q_L - Q_C = 0$.

3. **21-test savol yechimi:** Parallel sxemada ulangan zanjir, ikkita tugun potentsiallar usuliga asosan:

$$U_{ab} = \varphi_a - \varphi_b = \frac{E_1 Y_1 + E_2 Y_2}{Y_1 + Y_2 + Y_3} = \frac{12 \cdot \frac{1}{2} + 24 \cdot \frac{1}{2}}{\frac{1}{2} + \frac{1}{2} + \frac{1}{10}} = \frac{6 + 12}{1 + 1} = 9$$

4. **24-test savol yechimi:** Zanjir ketma-ket ulangan bo'lib, vektor ifodasidan umumiy kuchlanish:

$$\bar{U} = \bar{U}_R + \bar{U}_L + \bar{U}_C = \sqrt{U_R^2 + (U_L - U_C)^2}$$

Bundan rezistordagi kuchlanish:

$$U_R = \sqrt{U^2 - (U_L - U_C)^2} = \sqrt{625 - 400} = \sqrt{225} = 15B$$

ADABIYOTLAR

1. *М.Р. Шебес, М.В. Каблукова.* Задачник по теории линейных электрических цепей. Москва. 2003.
2. «Задачник по теоретическим основам электротехники». Под редакций *К.М. Поливанова.* Москва. 1997.
3. *И.А. Зайцев и А.Г. Лурье.* Задачник по «Теоретическим основам электротехники (ТОЭ)». Ленинград. 1991.
4. *Л.А. Бессонов и др.* Сборник задач по ТОЭ. Москва. 2008.
5. *М.Ю. Зайчик и др.* «Сборник учебно-контрольных задач по теории электрических цепей». Москва. 1991.
6. *О.Е. Гольдин и др.* «Программированное изучение по ТОЭ». Москва. 1998.
7. *А.С. Каримов.* «Назарий электротехника». Тошкент. 2003.
8. *В.А. Прянишников.* ТОЭ курс лекций. Санкт-Петербург. 2004.
9. *Л.Р. Нейман, К.С. Демирчян.* «ТОЭ». Москва. 2006.
10. *Г.И. Атабеков.* «ТОЭ». Москва. 1998.
11. *Г.В. Зевеке, П.А. Ионкин, А.В. Нетушил, С.В. Страхов.* «Основы теории цепей». Москва. 2003.
12. *И.А. Иванов.* «Справочник по электротехнике». Москва. 1998.

MUNDARIJA

KIRISH	3
I. O'ZGARMAS TOK ELEKTR ZANJIR.....	4
1.1. ASOSIY NAZARIY TUSHUNCHALAR	4
1.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR	10
1.3. MUSTAQIL YECHISH UCHUN MASALALAR	31
1.4. NAZORAT SAVOLLARI	40
II. SINUSOIDAL TOK ELEKTR ZANJIR.....	44
2.1. ASOSIY NAZARIY TUSHUNCHALAR.	44
2.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR	47
2.3. MUSTAQIL YECHISH UCHUN MASALALAR	69
2.4. NAZORAT SAVOLLARI	73
III. SINUSOIDAL O'ZGARUVCHAN ELEKTR ZANJIRINI KOMPLEKS (SIMVOLIK) USULDA HISOBLASH.....	76
3.1. ASOSIY NAZARIY TUSHUNCHALAR.	76
3.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	83
3.3. MUSTAQIL YECHISH UCHUN MASALALAR.	101
3.4. NAZORAT SAVOLLARI.	104
IV. O'ZARO INDUKTIV BOG'LANGAN O'ZGARUVCHAN ELEKTR ZANJIR	106
4.1. ASOSIY NAZARIY TUSHUNCHALAR.	106
4.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	110
4.3. MUSTAQIL YECHISH UCHUN MASALALAR.	120
4.4. NAZORAT SAVOLLARI	123
V. ELEKTR TOK ZANJIRDA REZONANS HODISALAR	125
5.1. ASOSIY NAZARIY TUSHUNCHALAR.	125
5.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR	130
5.3. MUSTAQIL YECHISH UCHUN MASALALAR	143
5.4. NAZORAT SAVOLLARI.....	147
VI. UCH FAZALI SINUSOIDAL O'ZGARUVCHAN ELEKTR ZANJIR	149
6.1. ASOSIY NAZARIY TUSHUNCHALAR	149
6.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	160
6.3. MUSTAQIL YECHISH UCHUN MASALALAR.	178
6.4. NAZORAT SAVOLLARI	183
VII. NOSINUSOIDAL ELEKTR ZANJIR	185
7.1. ASOSIY NAZARIY TUSHUNCHALAR	185
7.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	189
7.3. MUSTAQIL YECHISH UCHUN MASALALAR.	199
7.4. NAZORAT SAVOLLARI	203

VIII. TO'RT QUTBLI ZANJIR.....	206
8.1. ASOSIY NAZARIY TUSHUNCHALAR.....	206
8.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	210
8.3. MUSTAQIL YECHISH UCHUN MASALALAR.....	224
8.4. NAZORAT SAVOLLARI.....	228
IX. ELEKTR FILTR	230
9.1. ASOSIY NAZARIY TUSHUNCHALAR.....	230
9.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	236
9.3. MUSTAQIL YECHISH UCHUN MASALALAR.....	248
9.4. NAZORAT SAVOLLARI.....	249
X. CHIZIQLI ELEKTR ZANJIRLARDA O'TKINCHI JARAYON.....	251
10.1. ASOSIY NAZARIY TUSHUNCHALAR.....	251
10.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR (KLASSIK USUL).....	257
10.3. MUSTAQIL YECHISH UCHUN MASALALAR.....	292
10.4. NAZORAT SAVOLLARI.....	296
XI. TARQOQ PARAMETRLI ELEKTR ZANJIR	299
11.1. ASOSIY NAZARIY TUSHUNCHALAR.....	299
11.2. MASALALAR YECHISH VA USLUBIY KO'RSATMALAR.....	306
11.3. MUSTAQIL YECHISH UCHUN MASALALAR.....	314
11.4. NAZORAT SAVOLLARI.....	316
ILOVALAR.....	317
ADABIYOTLAR.....	325

O'quv nashri

MUXTORXON IBADULLAYEV

NAZARIY ELEKTROTEXNIKA ASOSLARI

Masala va mashqlar to'plami

I qism

Muharrir *S. Salohutdinova*
Badiiy muharrir *B. Zufarov*
Texnik muharrir *L. Hijova*
Kichik muharrir *D. Xolmatova*
Musahhih *M. Ishonxonova*
Kompyuterda sahifalovchi *F. Botirova*

Nashriyot litsenziyasi AI № 158.14.08.09.

Bosishga 2015-yil 9-fevralda ruxsat etildi.

Bichimi 60x84¹/₁₆. Ofset qog'oz.

«Times New Roman» garniturasida ofset usulida bosildi.

Shartli bosma tabo g'i 19,06.

Nashr tabog'i 17,19. Adadi 300 nusxa.

Buyurtma № 15-87.

O'zbekiston Matbuot va axborot agentligining «O'zbekiston» nashriyot-matbaa ijodiy uyi. 100129. Toshkent, Navoiy ko'chasi, 30.

Telefon: (371) 244-87-85, 244-87-20

Faks: (371) 244-37-81, 244-38-10

e-mail: iptduzbekistan@iptd-uzbekistan.uz

www.iptd-uzbekistan.uz