11-Mavzu: O‘zgaruvchan tok zanjirlarida quvvat tahlili.

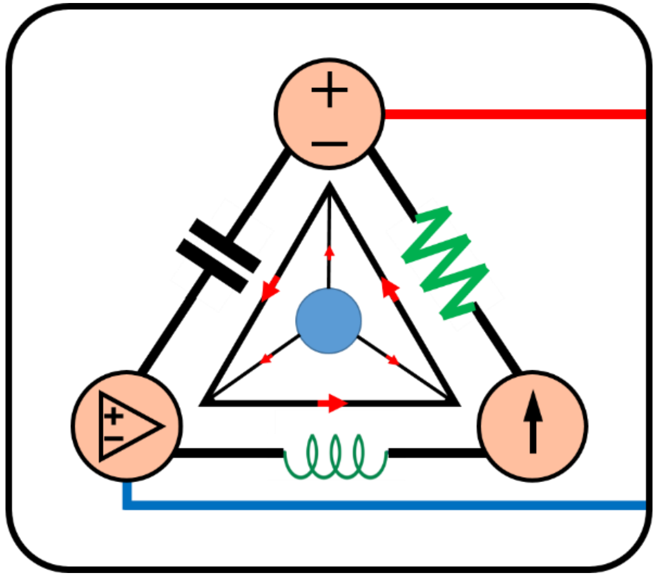
(11th Topic: AC Power Analysis.)

11-Mavzuning 1-qismi

(1st part of the 11th Topic)

14-hafta uchun

For the 14th week



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11-Mavzu: O‘zgaruvchan tok zanjirlarida quvvat tahlili.

(11th Topic: AC Power Analysis.)

O‘quv rejasi:

11.1. Umumiy tushunchalar

Photo source: [1] - https://7esl.com/wp-content/uploads/2020/12/Electronic-Devices-1.jpg

1831 yilda Maykl Faraday tomonidan o‘zgaruvchan tok generatori prinsipining kashf qilinishi muhandislikdagi katta yutuq bo‘ldi.

Biz hozirda foydalanadigan har bir elektron, elektr yoki elektromexanik qurilmada zarur bo‘lgan elektr energiyasini ishlab chiqarishning qulay usulini taqdim etdi.

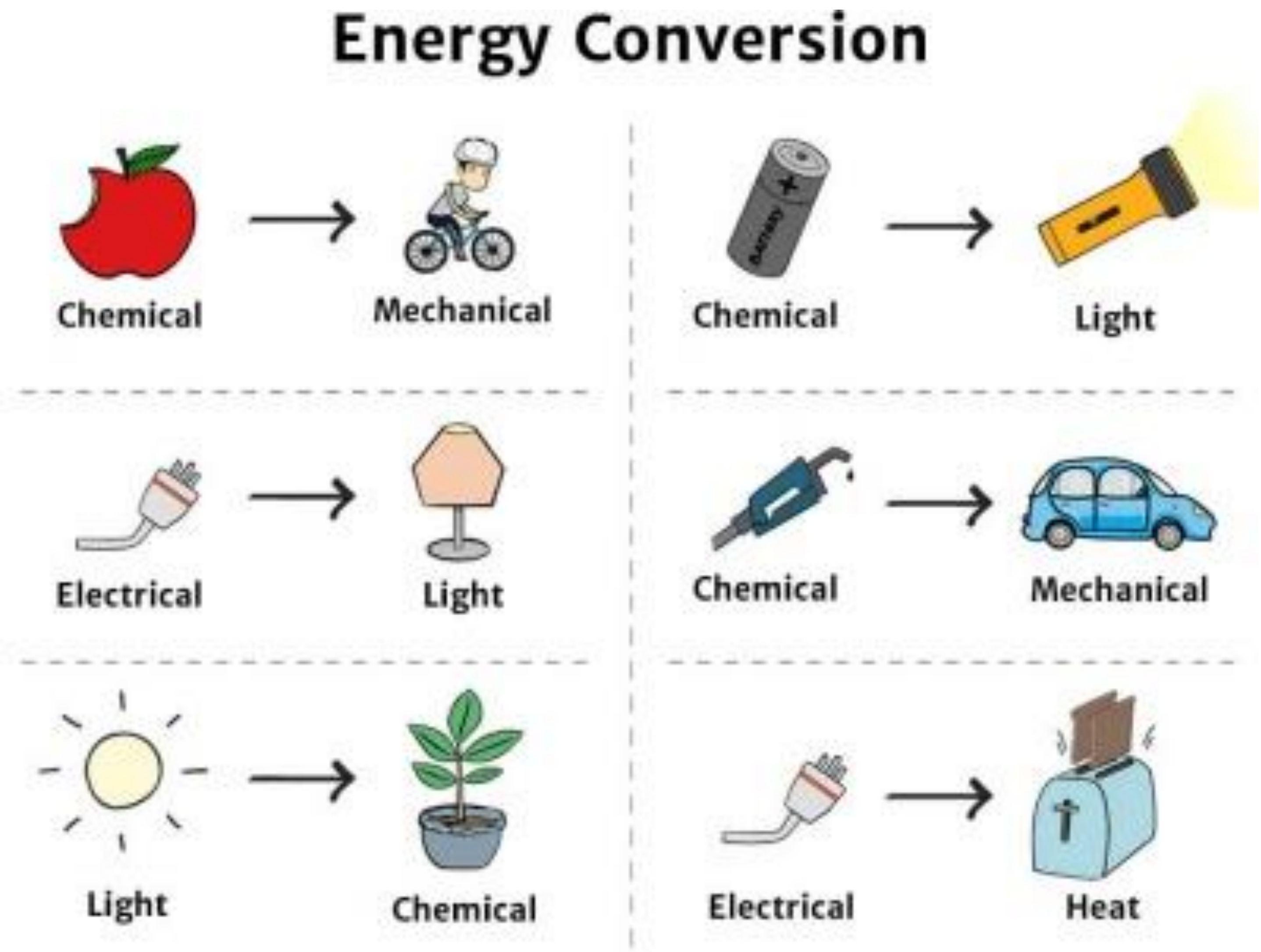


Photo source: [2] - https://www.solarschools.net/build/img/learn/energy/conversion//energy-conversion-diagram_400_resize_q95.jpg

Elektr energiyasi qazib olinadigan yoqilg‘i (gaz, neft va ko‘mir), yadro yoqilg‘isi (uran), gidroenergetika (tepadan tushadigan suv), geotermal energiya (issiq suv, bug‘), shamol energiyasi, to‘lqin energiyasi va biomassa energiyasi (chiqindilar) kabi manbalardan energiyani bir turdan boshqa turga o‘zgartirish orqali olinadi.

Elektr muhandisi elektr energiyasini **tahlil qilish**, **ishlab chiqarish**, **uzatish**, **taqsimlash** va **tannarxini yaxshi bilishi kerak**.

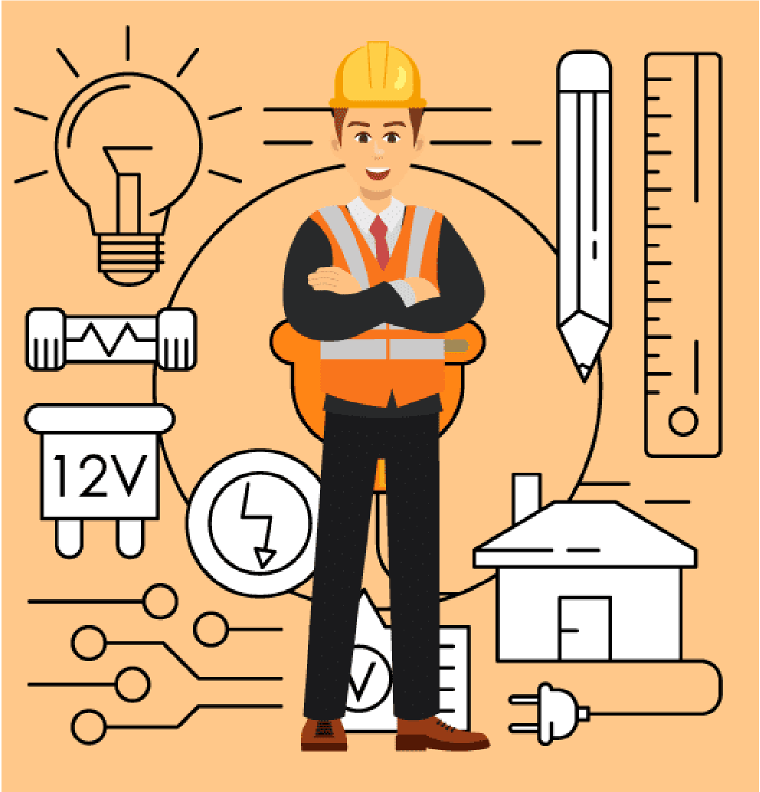


Photo source: [3] - https://leverageedublog.s3.ap-south-1.amazonaws.com/blog/wp-content/uploads/2020/01/24193801/Electrical-Engineering-Syllabus.png

Elektr energetika sanoati elektrotexnik muhandislar uchun yirik ish beruvchisi hisoblanadi.

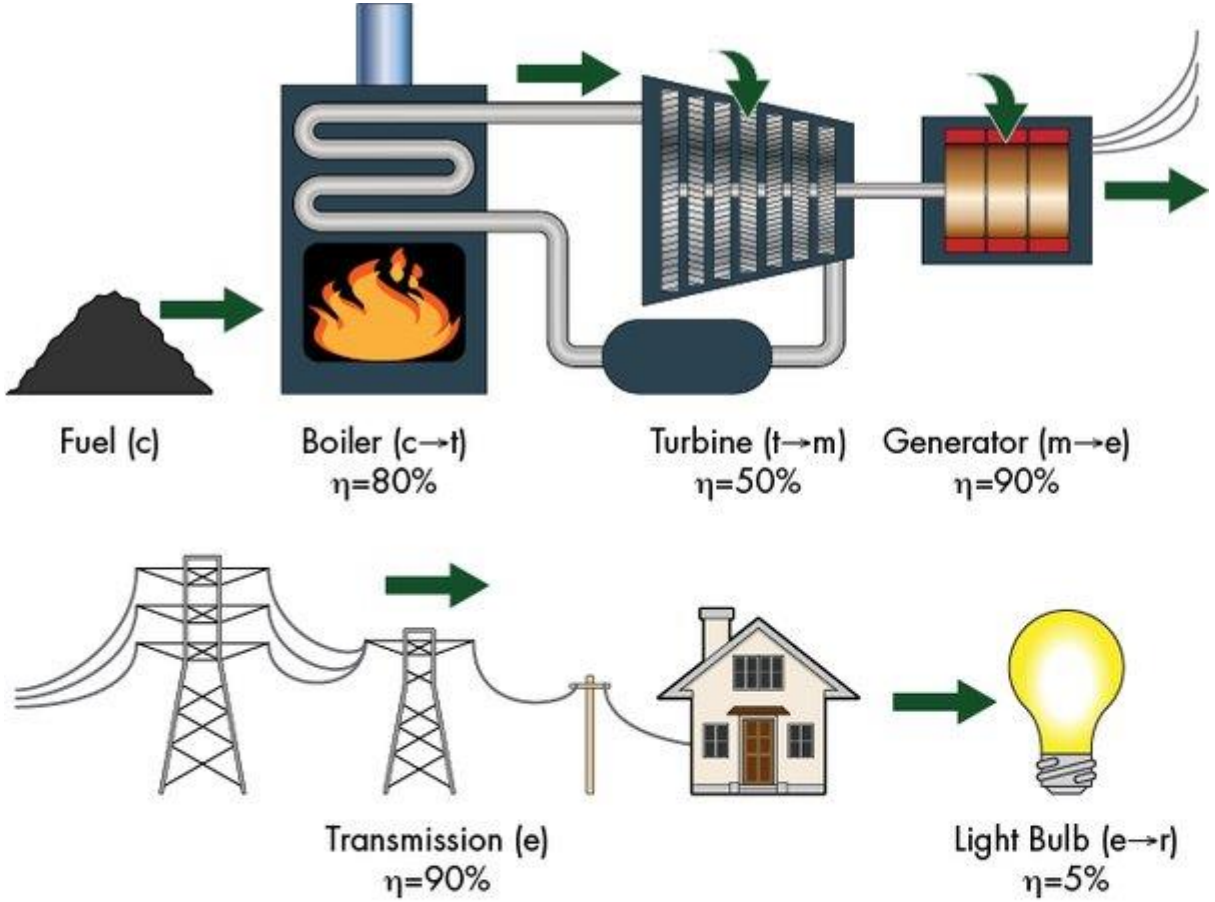


Photo source: [4] - https://qph.cf2.quoracdn.net/main-qimg-fbac0d06e06c0942a3c8d88512c3ca05-pjlq

Energetika sanoatining murakkabligi tufayli sanoatning turli sohalarida ko‘plab elektrotexnika ishlari mavjud: **elektr stansiyasi**, **uzatish** va **tarqatish**, **texnik xizmat ko‘rsatish**, **tadqiqot**, **ma’lumotlarni yig‘ish** va **tok yo‘nalishlarini boshqarish** va boshqaruv kabilardir.

Demak, o‘zgaruvchan tokni tahlil qilish jarayonida asosan kuchlanish va tok kuchini hisoblashga e’tibor qaratiladi.

O‘zgaruvchan tokni zanjirlarida quvvatni tahlil qilish katta ahamiyatga ega.

Quvvat elektr tarmoqlari, elektron va aloqa tizimlarida eng muhim miqdordir, chunki bunday tizimlar quvvatni bir nuqtadan ikkinchisiga uzatishni o‘z ichiga oladi.

Elektr quvvatining eng keng tarqalgan shakli o‘zgaruvchan toklarda 50 yoki 60 Hz.

Vaqt birligida bajarilgan ishga **QUVVAT** deb ataladi.

Har sekundda 1 Dj ish bajariladigan **QUVVAT** Vatt deb ataladi.

O‘zgarmas tok zanjirlarida quvvat quyidagi ifoda orqali aniqlanar edi:

$$P = \frac{A}{t} = UI = I^2R = \frac{U^2}{R} = U^2G \qquad (11.1)$$

Quvvat o‘lchov birliklari:

- *mVt* (millivatt = 10^{-3} Vt);
- *kVt* (kilovatt = 10^{3} Vt);
- *MVt* (megavatt = 10^{6} Vt).

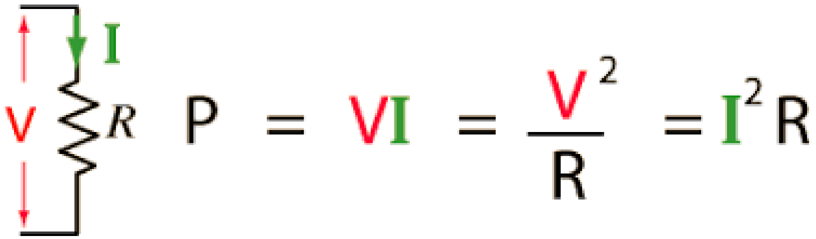


Photo source: [5] - http://hyperphysics.phy-astr.gsu.edu/hbase/electric/imgele/powr.gif

Elektr zanjir qismiga o‘zgaruvchan garmonik signal ta’sir etganda quyidagi QUVVAT turlari hosil bo‘ladi:

- **Oniy quvvat;**
- **Aktiv quvvat (quvvat);**
- **Reaktiv quvvat;**
- **To‘liq quvvat;**
- **Kompleks quvvat.**

11.2. Oniy va o‘rtacha quvvat.

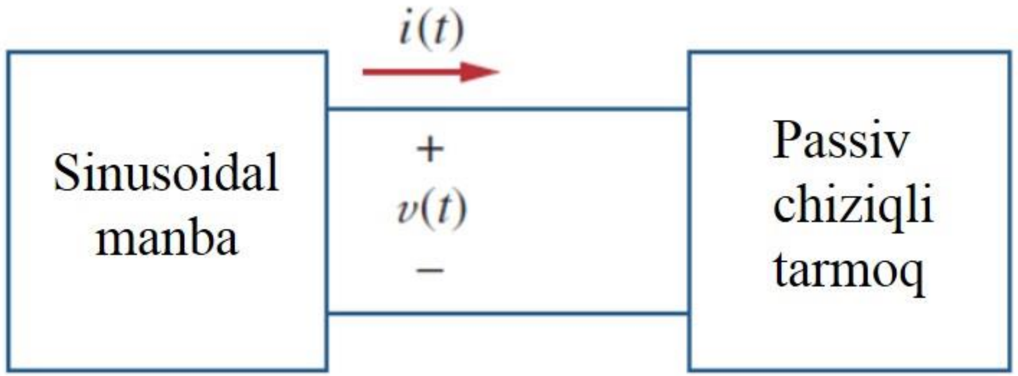
Oldingi mavzularda aytib o‘tilganidek, element tomonidan yutilgan oniy quvvat *p(t)* element bo‘ylab oniy kuchlanish *u(t)* va u orqali o‘tadigan oniy tok kuchi *i(t)* ko‘paytmasidir. Oniy quvvat o‘zgaruvchan miqdor bo‘lib quyidagi ifodaga teng bo‘ladi:

$$p(t) = u(t)i(t) \qquad (11.2)$$

Oniy quvvat (vattlarda) - har qanday vaqtdagi quvvat hisoblanadi.

Bundan tashqari, biz oniy quvvatni ma’lum bir vaqtning o‘zida element tomonidan so‘rilgan quvvat deb hisoblashimiz mumkin.

Oniy miqdorlar kichik harflar bilan belgilanadi.



11.1-rasm. Sinusoidal manba va passiv chiziqli zanjir.

Zanjir terminallarida ruxsat etilgan kuchlanish va tok kuchi bo‘lsin.

Misol uchun, rezistor ulangan zanjir orqali o‘tayotgan garmonik tok kuchi va kuchlanish quyidagilarga teng.

$$\boldsymbol{u(t) = U_m \cos(\omega t + \theta_u)} \quad (11.3a)$$

$$\boldsymbol{i(t) = I_m \cos(\omega t + \theta_i)} \quad (11.3b)$$

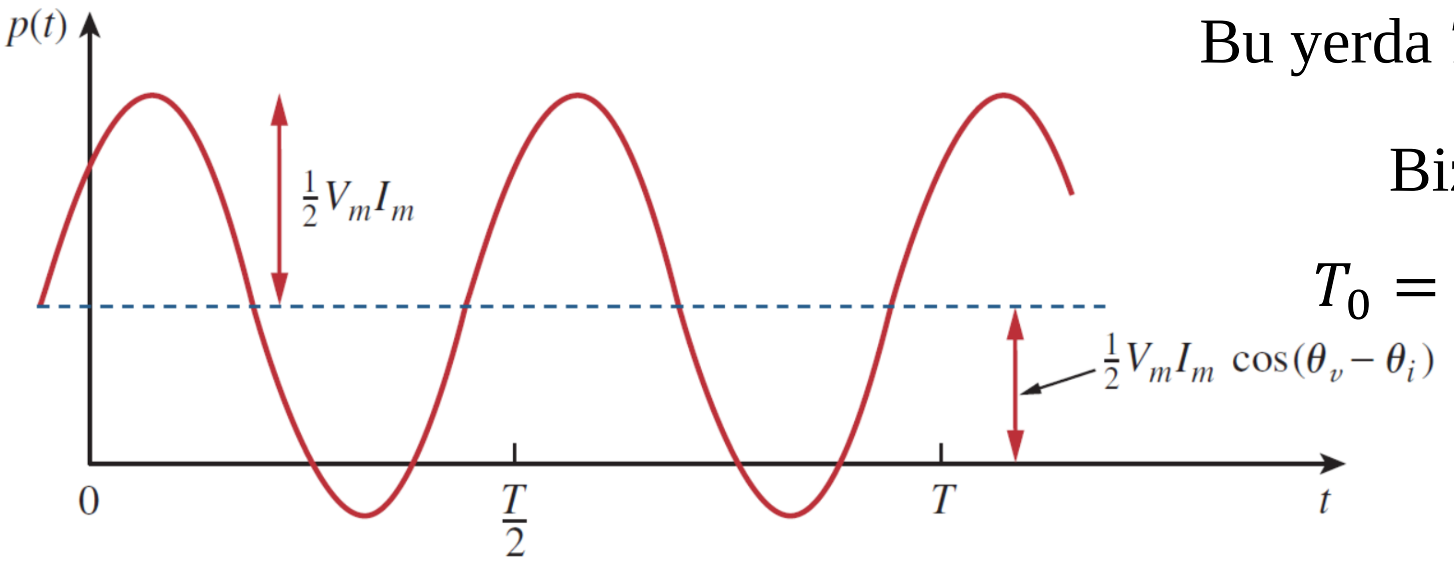
U holda, oniy quvvat quyidagi ifodaga teng bo‘ladi:

$$\boldsymbol{p(t) = u(t) i(t) = U_m I_m \cos(\omega t + \theta_u) \cos(\omega t + \theta_i)} \quad (11.4)$$

Trigonometrik ko‘rinishga o‘tkazsak, $\cos A \cos B = \frac{1}{2}[\cos(A - B) + \cos(A + B)]$ (11.5)

$$p(t) = \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i) + \frac{1}{2} U_m I_m \cos(2\omega t + \theta_u + \theta_i) \quad (11.6)$$

Bu bizga oniy quvvatning ikki qismdan iboratligini ko‘rsatadi.

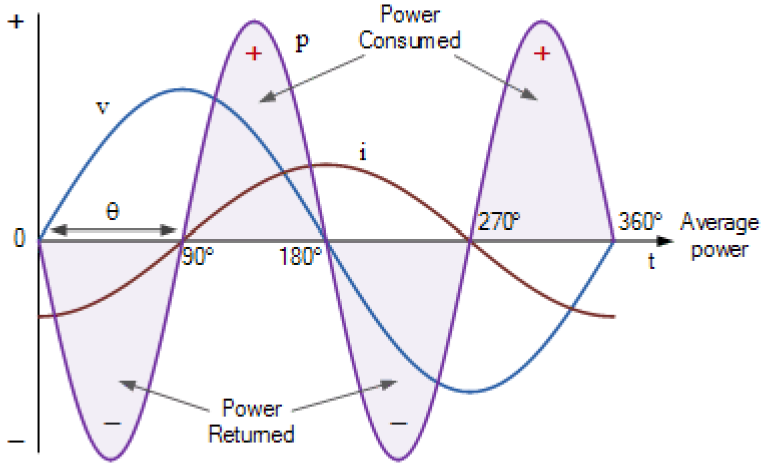


11.2-rasm. Zanjirga kiruvchi oniy quvvat *p(t)*.

Bu yerda $T=2\pi/\omega$ kuchlanish yoki tok kuchining davri.

Biz *p(t)* davriy ya'ni, $p(t) = p(t + T_0)$ va davri $T_0 = T/2$ ekanligini kuzatamiz.

p(t) har bir siklning bir qismi uchun ijobiy va siklning qolgan qismi uchun salbiy ekanligini kuzatamiz.



p(t) "+" musbat bo'lsa, elektr zanjir tomonidan so'riladi.

p(t) "-" manfiy bo'lsa, quvvat manba tomonidan so'riladi; ya'ni quvvat zanjirdan manbaga uzatiladi.

Bu zanjirdagi saqlash elementlari (kondensatorlar va induktorlar) bo'lishi mumkin.

Photo source: [6] - https://www.electronics-tutorials.ws/wp-content/uploads/2016/07/acp292.gif

Oniy quvvat vaqt o‘tishi bilan o‘zgaradi va shuning uchun uni o‘lchash qiyin.

O‘rtacha quvvatni o‘lchash uchun qulayroqdir u quyidagicha yoziladi.

$T_0 = T/2$ bo‘lgan $\rightarrow$ $$P = \frac{1}{2}\int_0^T p(t)\ dt \qquad (11.7)$$

(11.6) tenglamadagi *p(t)* ni (11.7) tenglamaga almashtirsak,

$$P = \frac{1}{T}\int_0^T \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i)\, dt + \frac{1}{T}\int_0^T \frac{1}{2} U_m I_m \cos(2\omega t + \theta_u + \theta_i)\, dt =$$

$$= \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i) \frac{1}{T}\int_0^T dt + \frac{1}{2} U_m I_m \frac{1}{T}\int_0^T \cos(2\omega t + \theta_u + \theta_i)\, dt \qquad (11.8)$$

Birinchi integratsiya o‘zgarmas, o‘rtachasi ham bir xil o‘zgarmasdir. Ikkinchi integrasiya sinusoiddir.

Sinusoidning davri bo‘yicha o‘rtacha ko‘rsatkichi nolga teng

$$\boldsymbol{P = \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i)} \qquad (11.9)$$

$\cos(\theta_u - \theta_i) = \cos(\theta_i - \theta_u)$ bo‘lgani uchun kuchlanish va tok kuchi fazalaridagi farq muhim ahamiyatga ega.

p(t) vaqt bo‘yicha o‘zgaradi.

P esa vaqtga bog‘liq emas.

p(t) = ? *u(t)* va *i(t)* vaqt sohasi bo‘lishi kerak.

$$U = U_m \angle \theta_u$$

$$I = I_m \angle \theta_i$$

P tenglama (11.9) yoki *U* va *I* fazalar yordamida hisoblanadi.

$$\frac{1}{2} U I^* = \frac{1}{2} U_m I_m \angle \theta_u - \theta_i = \frac{1}{2} U_m I_m [\cos(\theta_u - \theta_i) + j\, sin(\theta_u - \theta_i)] \qquad (11.10)$$

$$P = \frac{1}{2} Re[U I^*] = \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i) \qquad (11.11)$$

$$P = \frac{1}{2} U_m I_m = \frac{1}{2} I_m^2 R = \frac{1}{2} |I|^2 R \qquad (11.12)$$

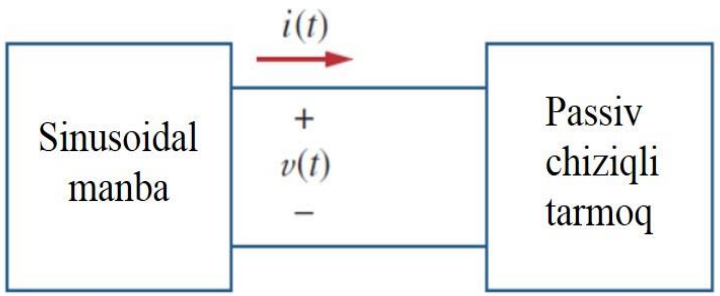
Agar $\theta_u - \theta_i = \pm 90°$ bo‘lsa, bizda sof reaktiv zanjir mavjud.

$$P = \frac{1}{2} U_m I_m \cos 90° = 0 \qquad (11.13)$$

Sof reaktiv zanjirda o‘rtacha quvvatni sarf bo‘lishini ko‘rsatadi.

Demak, qisqacha xulosa qilsak, qarshilik yuklamasi (*R*) har doim quvvatni yutadi, reaktiv yuklama (*L* yoki *C*) esa o‘rtacha nol quvvatni yutadi.

11.2.1-masala: 11.1-rasmdagi passiv chiziqli tarmoq tomonidan sarflangan oniy quvvat va o‘rtacha quvvatni toping. $u(t) = 120\cos(377t + 45°)$ va $i(t) = 10\cos(377t - 10°)$ berilgan bo‘lsin.



11.1-rasm.

Yechish:

Oniy quvvatni topamiz.

$$p = ui = 1200\cos(377t + 45°)\cos(377t - 10°)$$

Trigonometrik identifikatsiyani qo‘llaymiz.

$$\cos A\cos B = \frac{1}{2}[\cos(A - B) + \cos(A + B)]$$

$$p = ui = 600\ [\cos(754t + 35°) + \cos(55°)$$

$$= 344{,}2 + 600\cos(754t + 35°)\,W$$

O‘rtacha quvvat,

$$P = \frac{1}{2}U_m I_m\cos(\theta_u - \theta_i) = \frac{1}{2}120(10)\cos[45° - (-10°) =$$

$$= 600\cos 55° = 344{,}2\ W$$

11.3. Maksimal o‘rtacha quvvatni uzatish.

Elektr zanjirini Tevenin ekvivalenti bilan ifodalab, agar yuklama qarshiligi Tevenin qarshiligi $R_L = R_{Th}$ ga teng bo‘lsa, maksimal quvvat yuklamaga yetkazilishini isbotladik.

O‘zgaruvchan tok zanjiri Z_L yuklamaga ulangan va uning Tevenin ekvivalenti bilan ifodalanadi.

Yuklama odatda impidens bilan ifodalanadi, u elektr motorini, antennani, televizorni va boshqalarni modellashtirishi mumkin.

To‘rtburchaklar shaklida Thevenin impidensi Z_{Th} va yuklama impidensi Z_L quyidagicha ifodalanadi.

$$Z_{Th} = R_{Th} + jX_{Th} \qquad (11.14a)$$

$$Z_L = R_L + jX_L \qquad (11.14b)$$

Yuklama orqali o‘tadigan tok kuchi quyidagicha aniqlanadi.

$$I = \frac{U_{Th}}{Z_{Th}+Z_L} = \frac{U_{Th}}{(R_{Th}+jX_{Th})+(R_L+jX_L)} \qquad (11.15)$$

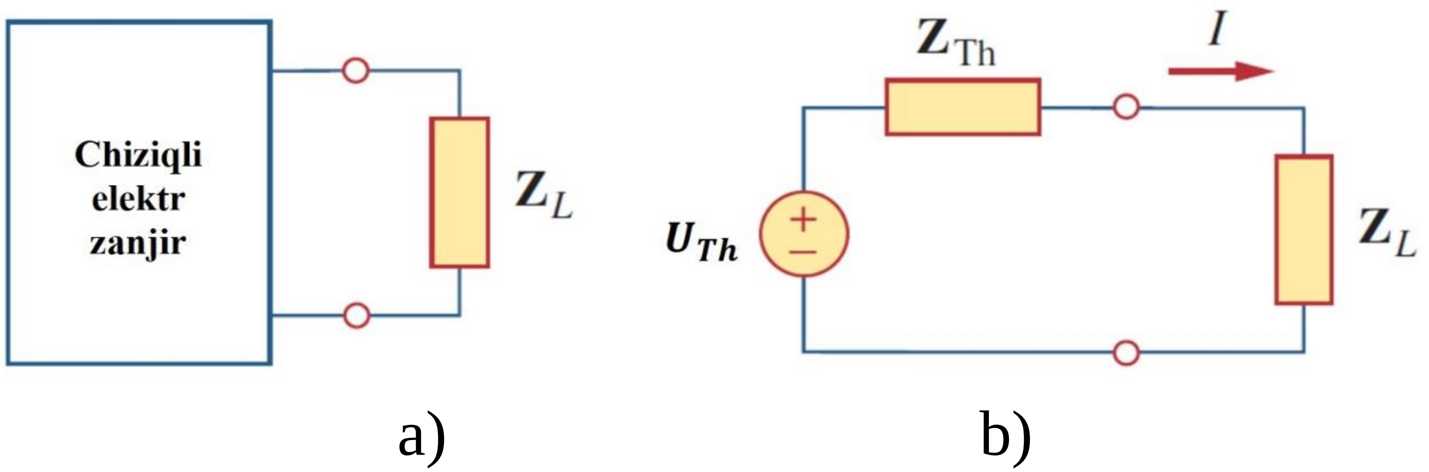
(11.12) tenglamadan yuklamaga yetkazilgan o‘rtacha quvvat

$$P = \frac{1}{2}|I|^2 R_L = \frac{|U_{Th}|^2 R_L/2}{(R_{Th}+R_L)^2+(X_{Th}+X_L)^2} \qquad (11.16)$$

R_L va X_L yuklama parametrlarini P maksimal bo‘lishi uchun $\partial P/\partial R_L$ va $\partial P/\partial X_L$ ni nolga tenglashtiramiz.

$$\frac{\partial P}{\partial X_L} = \frac{|U_{Th}|^2 R_L (X_{Th}+X_L)}{[(R_{Th}+R_L)^2+(X_{Th}+X_L)^2]^2} \qquad (11.17a)$$

$$\frac{\partial P}{\partial R_L} = \frac{|U_{Th}|^2[(R_{Th}+R_L)^2+(X_{Th}+X_L)^2-2R_L(R_{Th}+R_L)]}{2[(R_{Th}+R_L)^2+(X_{Th}+X_L)^2]^2} \qquad (11.17b)$$



11.3-rasm. Maksimal o‘rtacha quvvat uzatishni topish:

a) yuklangan zanjir; b) Tevenin ekvivalenti.

$\partial P/\partial X_L$ to‘plamni nolga tenglashtirish quyidagi ifodani beradi.

$$X_L = -X_{Th} \qquad (11.18)$$

$\partial P / \partial R_L$ to‘plamni ham nolga tenglashtirish natijasida quyidagi ifodani beradi.

$$R_L = \sqrt{R_{Th}^2 + (X_{Th} + X_L)^2} \quad (11.19)$$

(11.18) va (11.19) tenglamalarni birlashtirib, maksimal o‘rtacha quvvat uzatish uchun Z_L ni $X_L = -X_{Th}$ va $R_L = R_{Th}$ ni tanlash kerak, degan xulosaga kelamiz. Ya’ni,

$$\boldsymbol{Z_L = R_L + jX_L = R_{Th} - jX_{Th} = Z_{Th}^*} \quad (11.20)$$

Maksimal o‘rtacha quvvat uzatish uchun Z_L yuk impidensi Tevenin impidensi Z_{Th} kompleks konjugatiga teng bo‘lishi kerak. Agar $\boldsymbol{Z_L = Z_{Th}^*}$ bo‘lsa, yuklama manbaga mos keladi deymiz.

Ushbu natija sinusoidal barqaror holat uchun ***maksimal o‘rtacha quvvat uzatish teoremasi*** sifatida tanilgan. (11.16) tenglamada $R_L = R_{Th}$ va $X_L = -X_{Th}$ to‘plami (yoki o‘rnatilishi) bizga maksimal o‘rtacha quvvatni beradi.

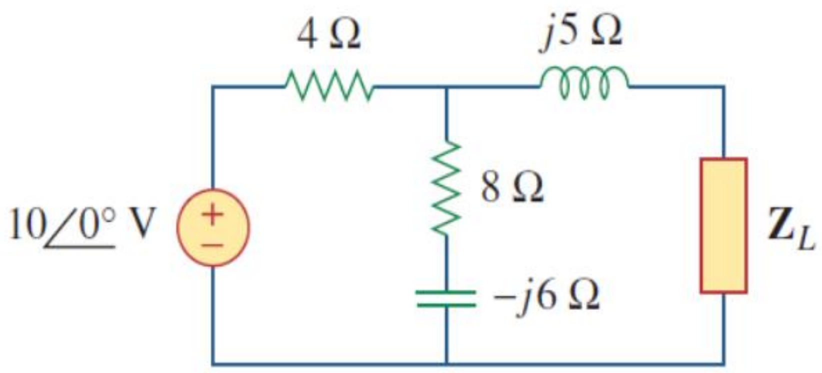
$$P_{max} = \frac{|U_{Th}|^2}{8R_{Th}} \qquad (11.21)$$

Yuklama sof haqiqiy bo‘lgan vaziyatda maksimal quvvat uzatish sharti (11.19) tenglamadan $X_L = 0$ ni belgilash orqali olinadi. Demak,

$$R_L = \sqrt{R_{Th}^2 + X_{Th}^2} = |Z_{Th}| \qquad (11.22)$$

Maksimal o‘rtacha quvvatni faqat qarshilik yuklamasiga o‘tkazish uchun yuklama impidensi (*yoki qarshilik*) Tevenin impidensining kattaligiga teng bo‘ladi.

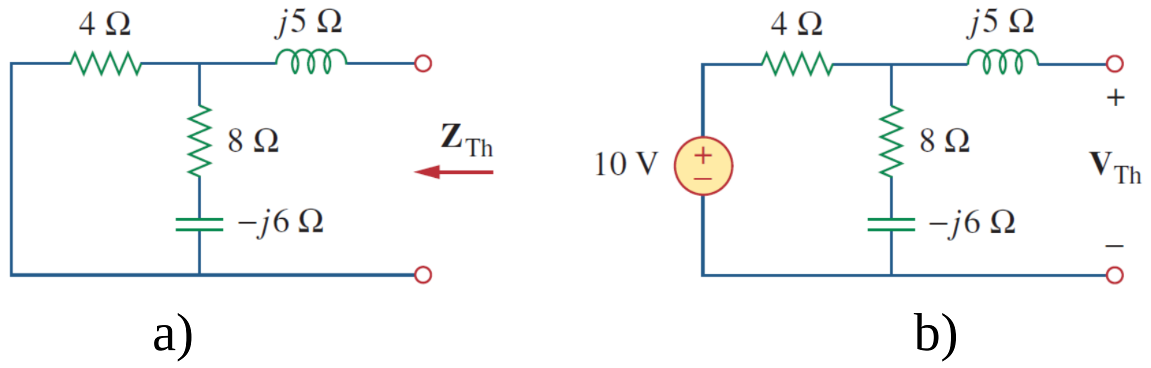
11.3.1-masala: 11.4-rasmdagi zanjir bo‘yicha olingan o‘rtacha quvvatni maksimal darajaga ko‘taradigan yuklama empedansini Z aniqlang. Maksimal o‘rtacha quvvat qancha?



11.4-rasm.

Yechish:

$$Z_{Th} = j5 + 4||(8 - j6) = j5 + \frac{4(8-j6)}{4+8-j6} = 2{,}933 + j4{,}467\ \Omega$$



11.5-rasm.

$$Z_L = Z_{Th}^* = 2{,}933 - j4{,}467\ \Omega$$

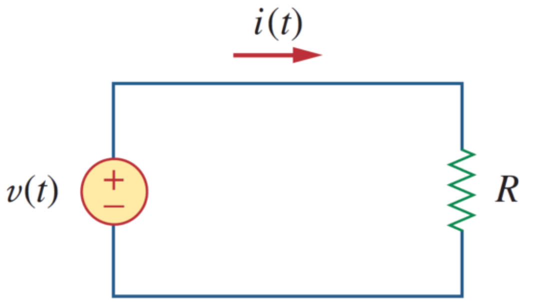
$$U_{Th} = \frac{8-j6}{4+8-j6}(10) = 7{,}454\angle - 10{,}3°\ V$$

$$P_{max} = \frac{|U_{Th}|^2}{8R_{Th}} = \frac{(7,454)^2}{8(2,933)} = 2,368\ W$$

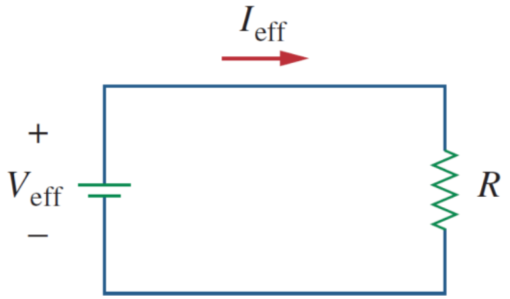
11.4. Effektiv yoki o‘rtacha kvadrat ildiz qiymati.

Effektiv qiymat g‘oyasi quvvatni qarshilik yuklamasiga yetkazib berishda kuchlanish yoki tok kuchi manbasining effektivligini o‘lchash zaruratidan kelib chiqadi.

Davriy tok kuchining effektiv qiymati - bu davriy tok bilan bir xil o‘rtacha quvvatni qarshilikka yetkazib beradigan doimiy tokdir.



a) o‘zgaruvchan tok zanjiri;



b) o‘zgarmas tok zanjiri.

11.6-rasm. Samarali tokni topish:

Sinusoid i bilan bir xil quvvatni R rezistoriga o‘tkazadigan I_{eff} ni topish uchun quyidagilarni aniqlash zarur.

O‘zgaruvchan tok zanjiridagi rezistor tomonidan sarflangan o‘rtacha quvvat quyidagicha aniqlanadi.

$$P = \frac{1}{T}\int_0^T i^2 R\,dt = \frac{R}{T}\int_0^T i^2\,dt \qquad (11.23)$$

O‘zgarmas tok pallasida rezistor tomonidan so‘rilgan quvvat esa,

$$P = I_{eff}^2 R \qquad (11.24)$$

(11.23) va (11.24) tenglamalardagi ifodalarni tenglashtirib, I_{eff} ni yechish orqali hosil qilamiz.

$$I_{eff} = \sqrt{\frac{1}{T}\int_0^T i^2\,dt} \qquad (11.25)$$

Kuchlanishning samarali qiymati tok kuchi bilan bir xil tarzda topiladi.

$$U_{eff} = \sqrt{\frac{1}{T}\int_0^T u^2\,dt} \qquad (11.26)$$

Bu effektiv qiymat davriy signalning o‘rtacha kvadratining ildizi ekanligini ko‘rsatadi.

Shunday qilib, effektiv qiymat ko‘pincha o‘rtacha kvadrat ildiz (*root-mean-square*) yoki qisqacha ***rms*** deb ataladi.

$$I_{eff} = I_{rms},$$

$$U_{eff} = U_{rms} \qquad (11.27)$$

Har qanday davriy funksiya $x(t)$ uchun umumiy holda, ***rms*** qiymati bilan beriladi.

$$X_{rms} = \sqrt{\frac{1}{T}\int_0^T x^2\,dt} \qquad (11.28)$$

Sinusoid $i(t) = I_m \cos \omega t$ uchun samarali yoki ***rms*** qiymati quyidagicha yoziladi.

$$\boldsymbol{I_{rms}} = \sqrt{\frac{1}{T}\int_0^T I_m^2 \cos^2 \omega t \, dt} = \sqrt{\frac{I_m^2}{T}\int_0^T (1 + \cos^2 \omega t) \, dt} = \frac{\boldsymbol{I_m}}{\sqrt{\mathbf{2}}} \qquad (11.29)$$

$$u(t) = U_m \cos \omega t \quad \rightarrow \quad \boldsymbol{U_{rms}} = \frac{\boldsymbol{U_m}}{\sqrt{\mathbf{2}}} \qquad (11.30)$$

Bu tenglamalar faqat sinusoidal signallar uchun amal qiladi.

$\boldsymbol{P = \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i)}$ (11.9) o'rtacha quvvatni ***rms*** qiymatlari bilan yozish mumkin.

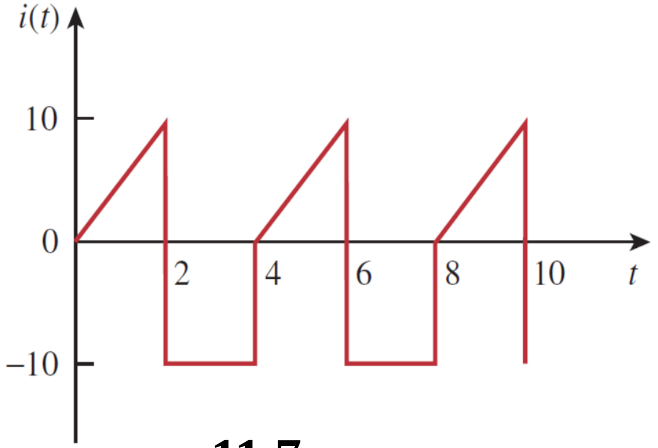
$$P = \frac{1}{2} U_m I_m \cos(\theta_u - \theta_i) = \frac{U_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos(\theta_u - \theta_i) = U_{rms} I_{rms} \cos(\theta_u - \theta_i) \qquad (11.31)$$

$\boldsymbol{P = \frac{1}{2} U_m I_m = \frac{1}{2} I_m^2 R = \frac{1}{2} |I|^2 R}$ (11.12) tenglamadagi rezistor R tomonidan sarflangan o'rtacha quvvatni quyidagicha yozish mumkin.

$$\boldsymbol{P} = I_{rms}^2 R = \frac{\boldsymbol{U_{rms}^2}}{\boldsymbol{R}} \qquad (11.32)$$

11.4.1-masala: 11.7-rasmda tok kuchi to‘lqin shaklining rms qiymatini aniqlang.

Agar tok kuchi 2 Ω rezistordan o‘tkazilsa, rezistor tomonidan sarflangan o‘rtacha quvvatni toping.



11.7-rasm.

Yechish: To‘lqin shaklining davri $T = 4$. Bir davr mobaynida biz tok kuchi to‘lqin shaklini quyidagicha yozishimiz mumkin.

$$i(t) = \begin{cases} 5t, & 0 < t < 2 \\ -10, & 2 < t < 4 \end{cases}$$

RMS qiymati,

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2\,dt} = \sqrt{\frac{1}{T}\left[\left[\int_0^2 (5t)^2 dt + \int_2^4 (-10)^2\,dt\right]\right]} = = \sqrt{\frac{1}{4}\left[\left[25\frac{t^3}{3}\Big|_0^2 + 100t\,\Big|_2^4\right]\right]} = \sqrt{\frac{1}{4}(\frac{200}{3} + 200)} = 8{,}165\ A$$

2 Ω rezistorda sarflanadigan quvvat quyidagicha aniqlanadi.

$$P = I_{rms}^2 R = (8{,}165)^2(2) = 133{,}3\ W$$

FOYDALANILGAN MANBALAR:

1. https://7esl.com/wp-content/uploads/2020/12/Electronic-Devices-1.jpg
2. https://www.solarschools.net/build/img/learn/energy/conversion//energy-conversion-diagram_400_resize_q95.jpg
3. https://leverageedublog.s3.ap-south-1.amazonaws.com/blog/wp-content/uploads/2020/01/24193801/Electrical-Engineering-Syllabus.png
4. https://qph.cf2.quoracdn.net/main-qimg-fbac0d06e06c0942a3c8d88512c3ca05-pjlq
5. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/imgele/powr.gif
6. https://www.electronics-tutorials.ws/wp-content/uploads/2016/07/acp292.gif

E’TIBORINGIZ UCHUN RAHMAT!!!