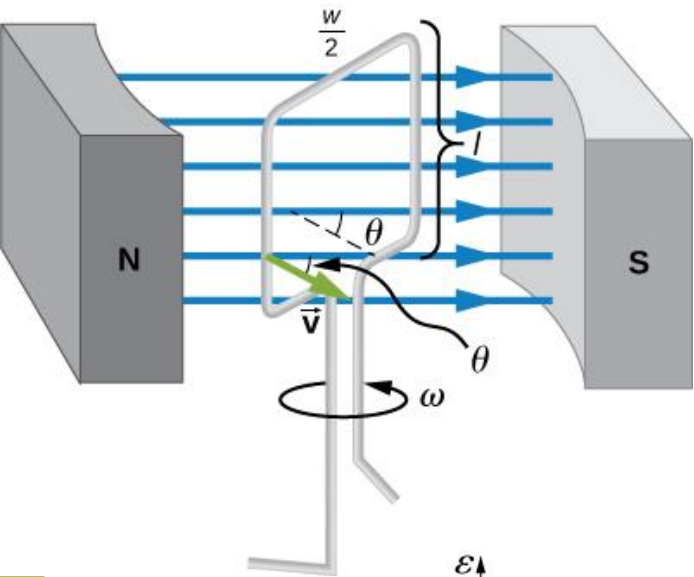




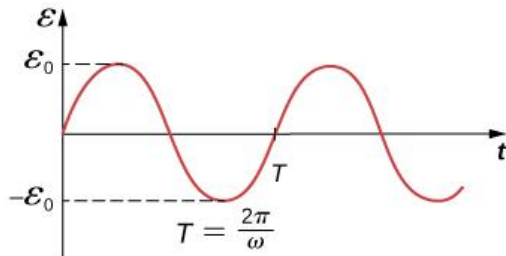
IZMJENIČNA STRUJA

Dobivanje izmjeničnih napona

- ▶ Izmjenični naponi proizvode se u sinkronim generatorima u elektranama.
- ▶ Generatori rade na principu elektromagnetske indukcije: promjenom magnetskog toka kroz vodič u obliku zavojnice, na krajevima zavojnice inducira se EMS.



$$\omega = 2\pi f$$



- Magnetski tok kroz petlju površine S koja se rotira kutnom brzinom ω u homogenom magnetskom polju indukcije B :

$$\Phi = \vec{B} \cdot \vec{S} = BS \cos \theta = BS \cos \omega t$$

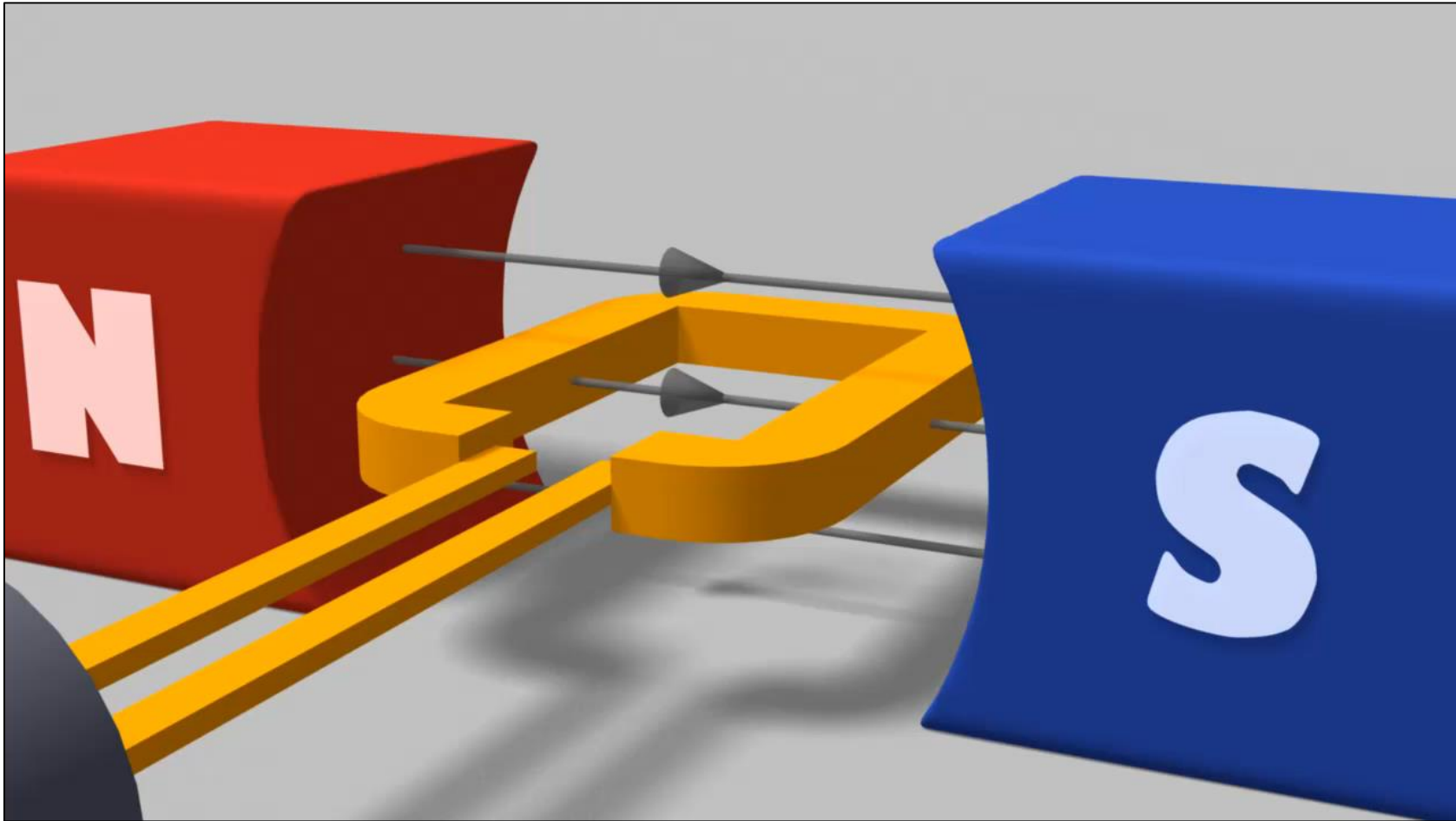
- Pri tome se inducira elektromotorna sila:

$$\varepsilon = -\frac{d\Phi}{dt} = BS\omega \sin \omega t = \varepsilon_m \sin \omega t$$

$$u = U_m \sin \omega t$$

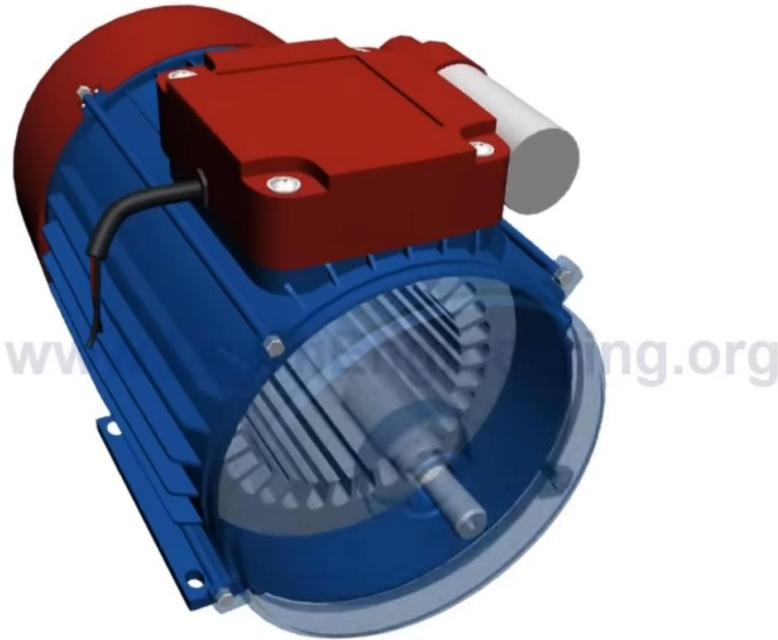


$$i = I_m \sin \omega t$$



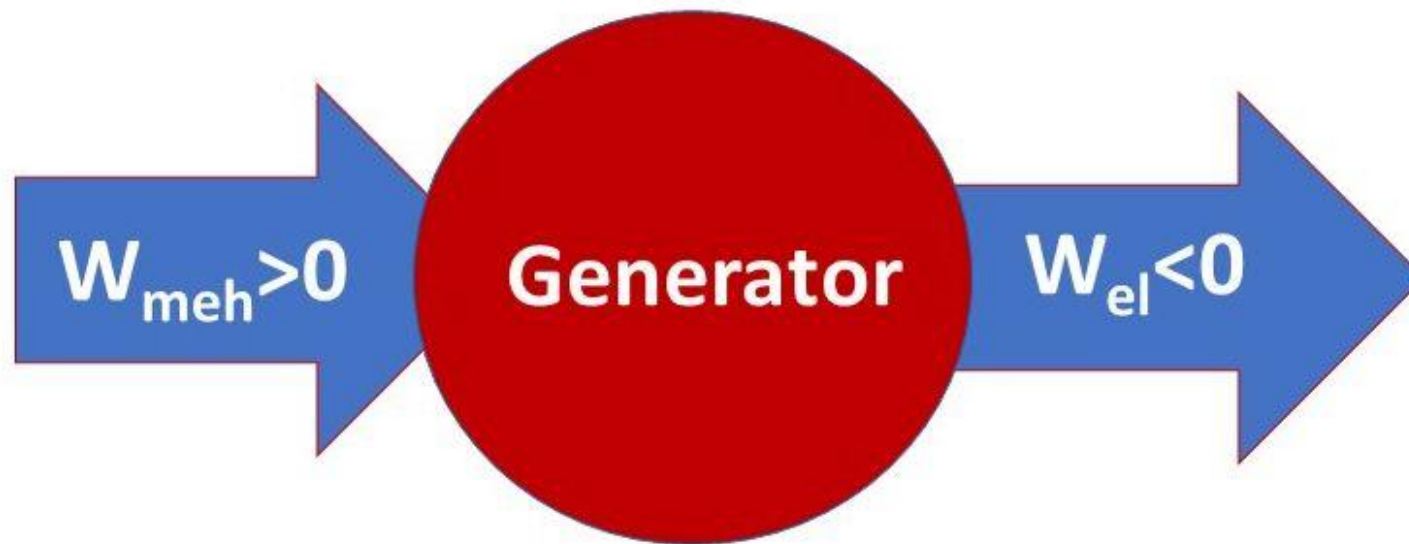
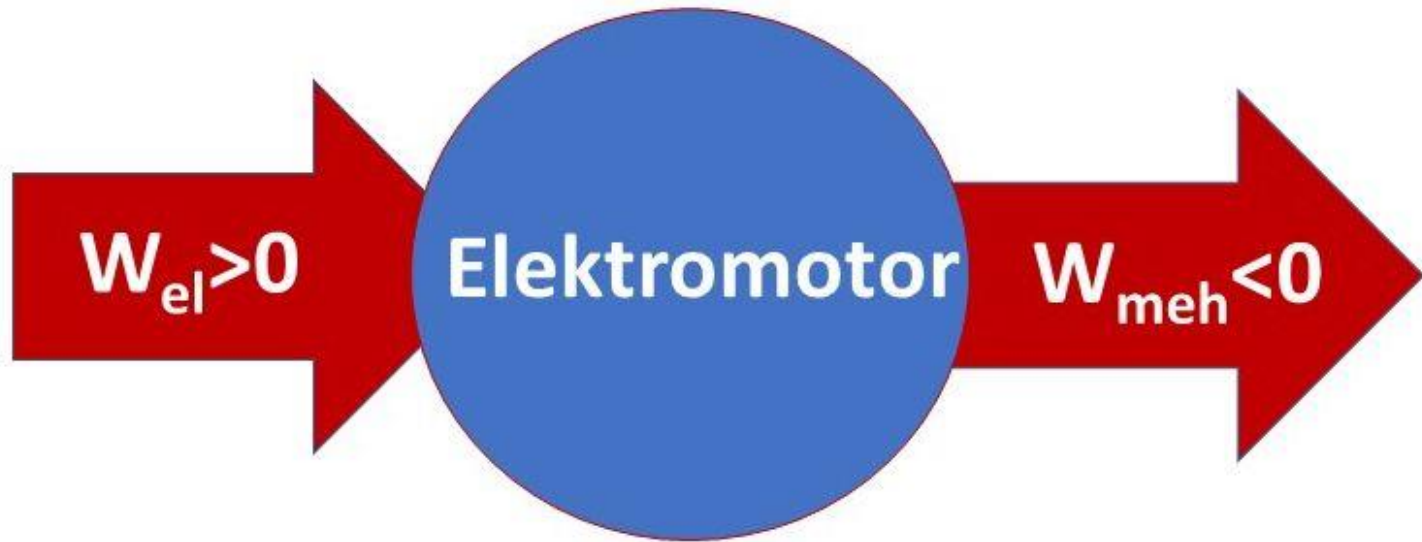
Elektromotor - izmjenična struja

ROTATING MAGNETIC FIELD

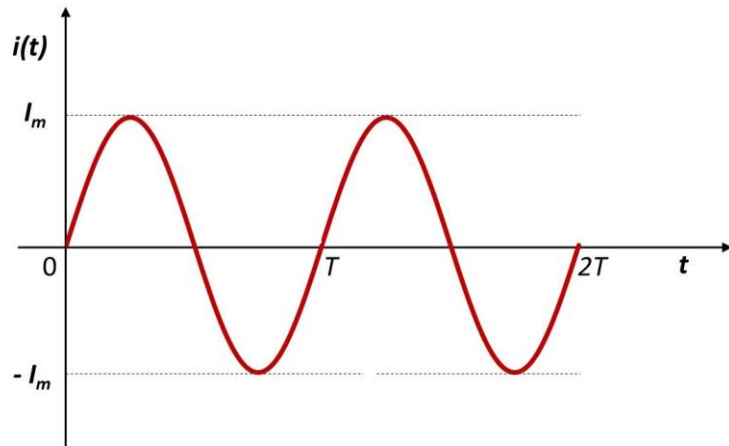
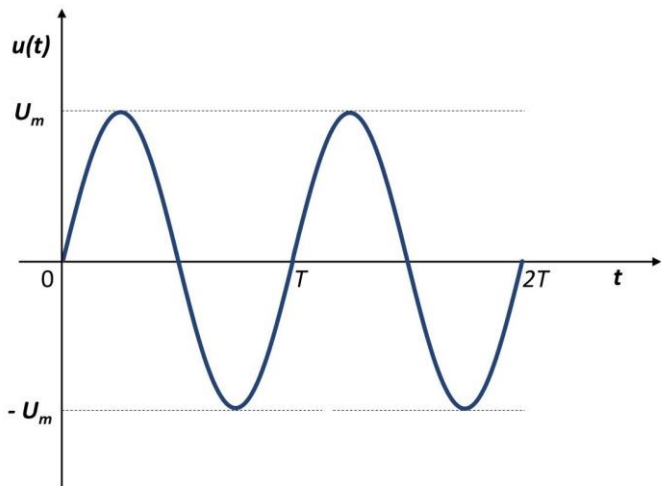








Izmjenični napon i struja



$$\omega = 2\pi f$$

- Gradska mreža (Europa):

$$f = 50 \text{ Hz}$$

$$U = 220 \text{ V}$$

$$u = U_m \sin \omega t$$

Trenutna
vrijednost

$$i = I_m \sin \omega t$$

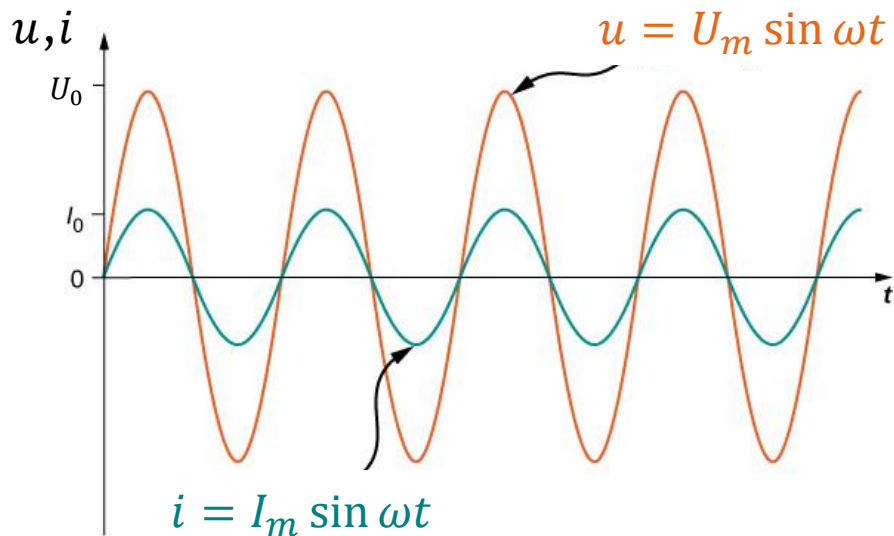
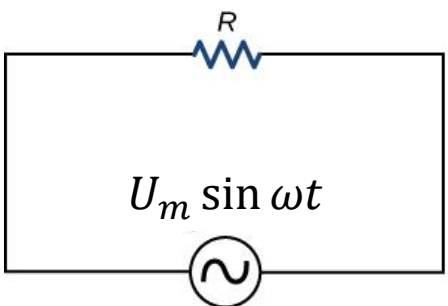
Maksimalna
vrijednost

Efektivna vrijednost izmjenične struje definira se kao vrijednost koju bi imala ona istosmjerna struja stalne jakosti koja bi u određenom vodiču proizvela jednaki toplinski učinak kao i ta izmjenična struja.

$$I = \frac{I_m}{\sqrt{2}} \quad U = \frac{U_m}{\sqrt{2}}$$

Otpori u krugu izmjenične struje - omski otpor

$$V_0 = U_0 = U_m$$

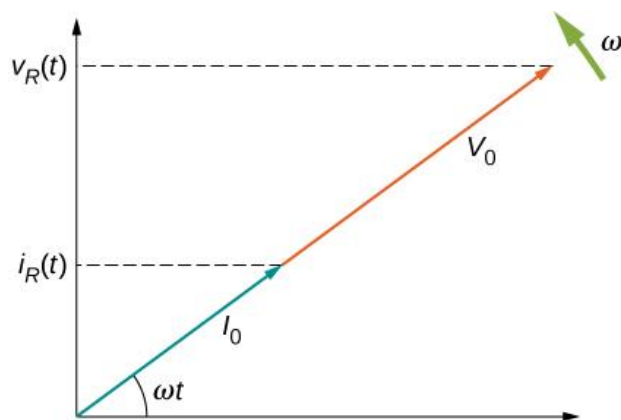
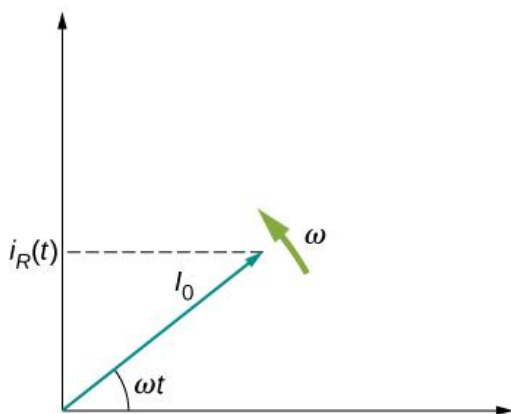


- Struja kroz otpornik (Ohmov zakon):

$$i = \frac{u}{R} = \frac{U_m}{R} \sin \omega t = I_m \sin \omega t$$

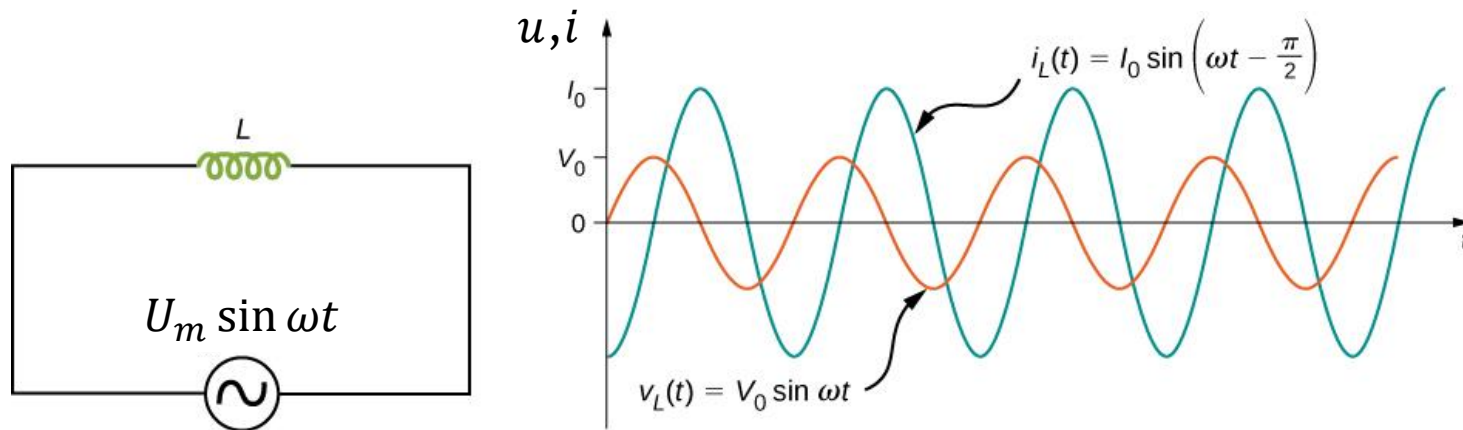
- → struja i napon su u fazi! (Matematički : $\varphi = 0$)

Fazorski dijagram:
Rotirajući vektori



Otpori u krugu izmjenične struje - induktivni otpor

- Zavojnica u strujnom krugu izmjenične struje pruža određeni otpor (R_L - induktivni otpor). Otpor je uzrokovan samoindukcijom u zavojnici (zbog stalne promjene struje).



- Ako se struja mijenja po zakonu $i = I_m \sin \omega t$ tada je

$$u = L \frac{di}{dt} = L\omega I_m \cos \omega t = L\omega I_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

U_m

- Ohmov zakon za induktivni otpor:

$$I = \frac{U}{L\omega} = \frac{U}{R_L}$$

$$R_L = L\omega$$

- EMS samoindukcije:

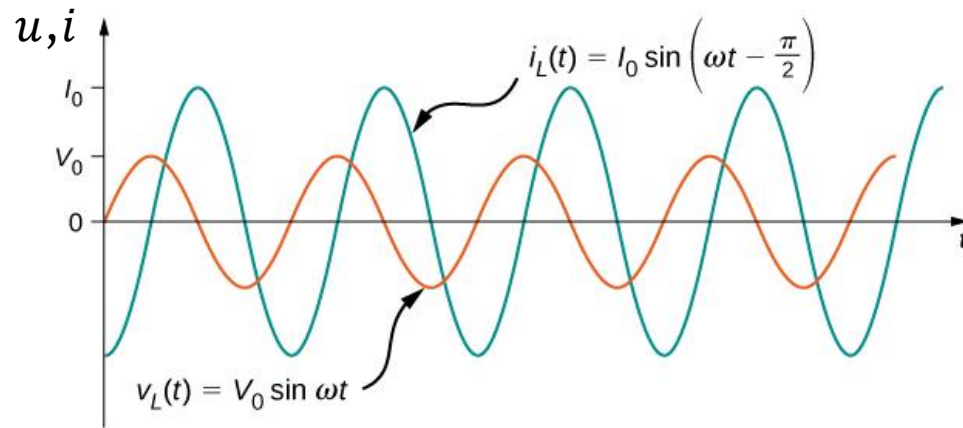
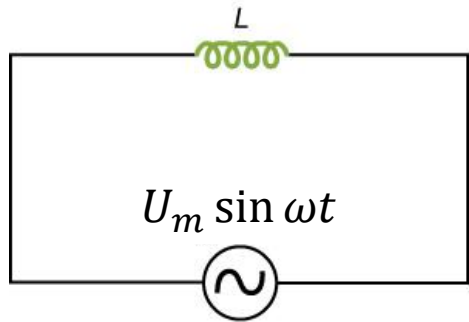
$$\varepsilon_L = -L \frac{di}{dt}$$

Suprotna je naponu u pa je:

$$u = L \frac{di}{dt}$$

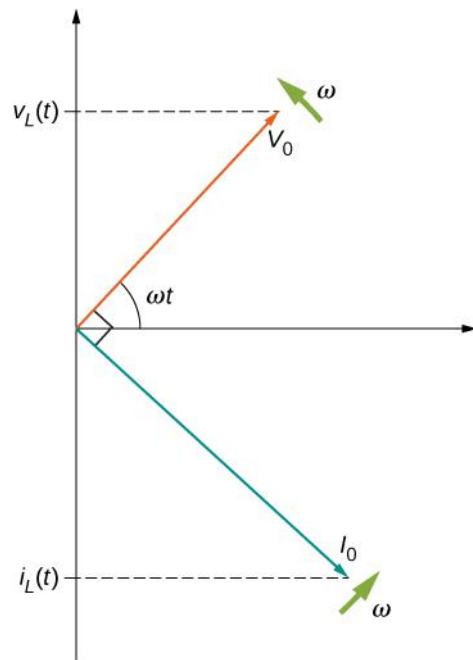
induktivni otpor
(induktivna reaktancija)
OVISI O FREKVENCiji

Otpori u krugu izmjenične struje - induktivni otpor



$$R_L = L\omega$$

Fazorski
dijagram:
Rotirajući
vektori



$$i = I_m \sin \omega t$$

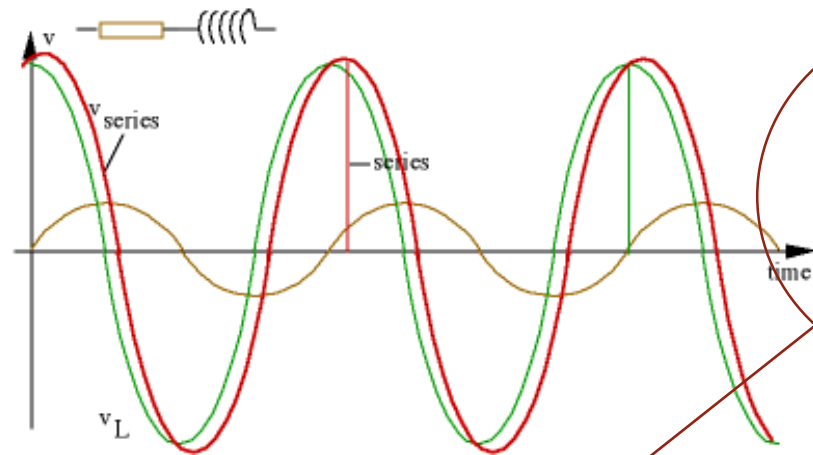
$$u = U_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

→ struja kasni za naponom za $\frac{\pi}{2}$!

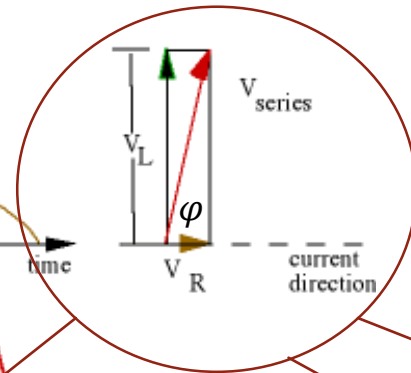
$$\varphi = \frac{\pi}{2} = 90^\circ$$

Otpori u krugu izmjenične struje - induktivni i omski otpor

- Ako se uz induktivni, u strujnom krugu nalazi i omski otpor R :



Fazorski dijagram:



$$u = u_R + u_L = iR + L \frac{di}{dt}$$

$$i = I_m \sin \omega t$$

$$u = RI_m \sin \omega t + L\omega I_m \cos \omega t$$

$$u = RI_m \sin \omega t + L\omega I_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

$$u = U_m \sin(\omega t + \varphi)$$

$$u = \sqrt{R^2 + L^2 \omega^2} I_m \sin(\omega t + \varphi)$$

→ struja kasni za naponom za φ !

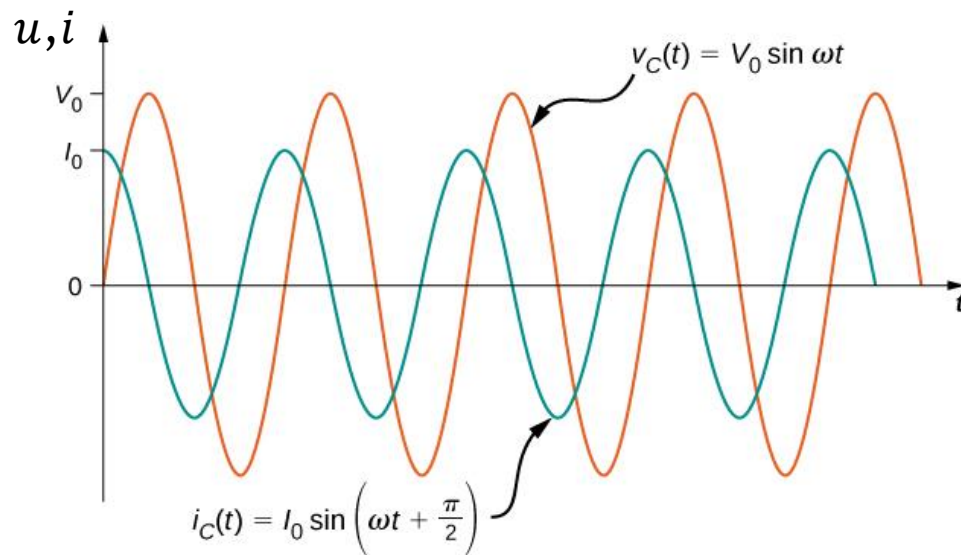
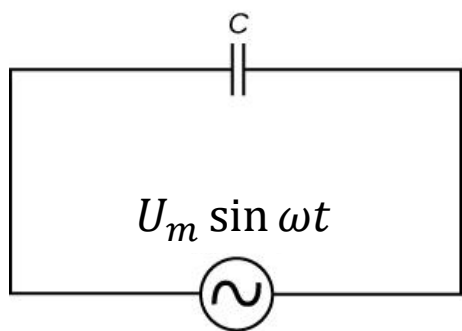
$$\tan \varphi = \frac{R_L}{R} = \frac{L\omega}{R}$$

Impedancija:
(ukupni otpor)

$$Z = \sqrt{R^2 + L^2 \omega^2}$$

Otpori u krugu izmjenične struje - kapacitivni otpor

- Kondenzator se u strujnom krugu izmjenične struje naizmjenično puni i prazni, tako da u krugu teče izmjenična struja.



$$u = \frac{q}{C} = \frac{\int i dt}{C}$$

$$i = I_m \sin \omega t$$

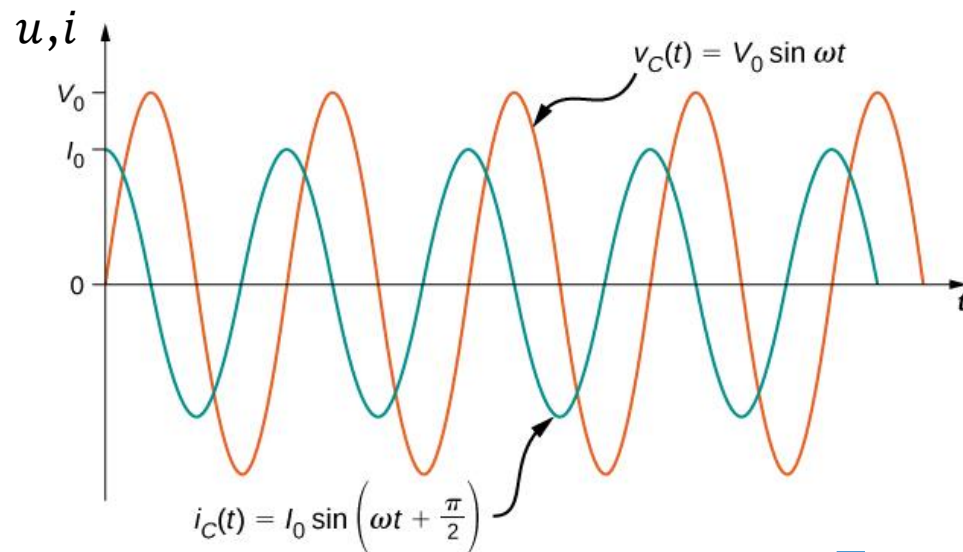
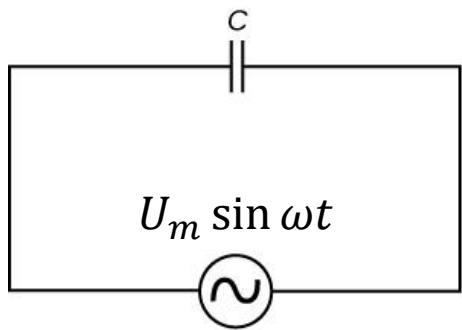
$$u = \frac{1}{C} \int I_m \sin \omega t dt = -\frac{I_m}{C\omega} \cos \omega t$$

$$u = \frac{I_m}{C\omega} \sin\left(\omega t - \frac{\pi}{2}\right)$$

kapacitivni otpor
(kapacitivna reaktancija) -
OVISI O FREKVENCiji

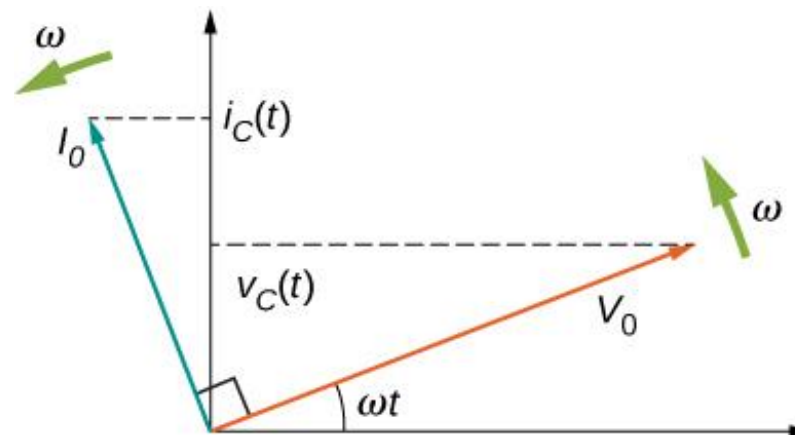
$$R_C = \frac{1}{C\omega}$$

Otpori u krugu izmjenične struje - kapacitivni otpor



$$R_C = \frac{1}{C\omega}$$

Fazorski dijagram:
Rotirajući vektori



$$i = I_m \sin \omega t$$

$$u = U_m \sin \left(\omega t - \frac{\pi}{2} \right)$$

→ struja prethodi naponu za $\frac{\pi}{2}$!

$$\varphi = -\frac{\pi}{2} = -90^\circ$$

Otpori u krugu izmjenične struje

Otpornik



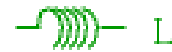
R

Kondenzator



C

Zavojnica



L

Resistance

$$V_R/I = R$$

V and I in phase

Capacitive reactance

$$V_C/I = X_C = \frac{1}{\omega C}$$

V lags I by $\pi/2$

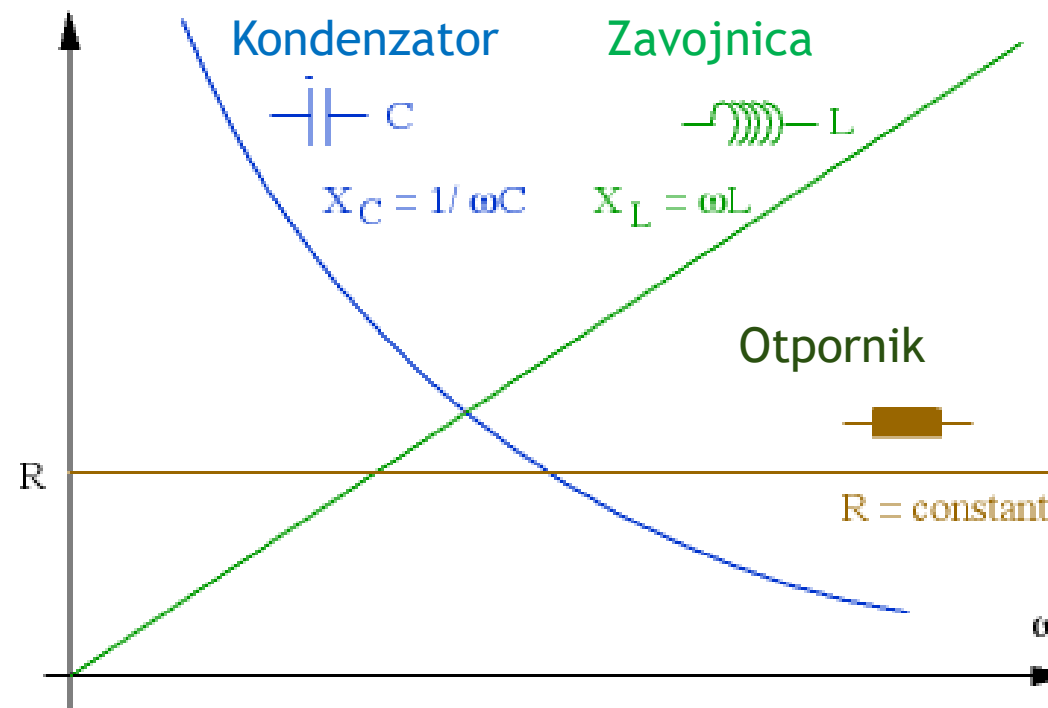
Inductive reactance

$$V_L/I = X_L = \omega L$$

V leads I by $\pi/2$

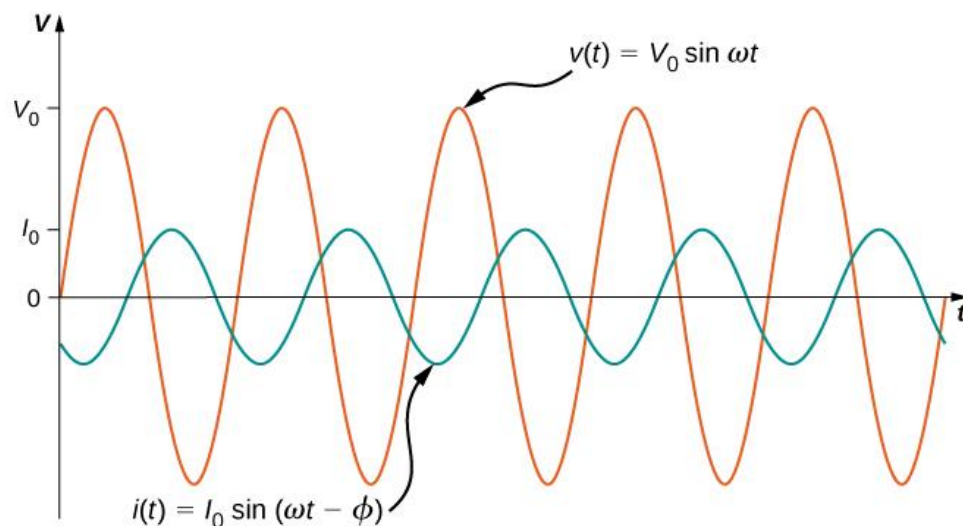
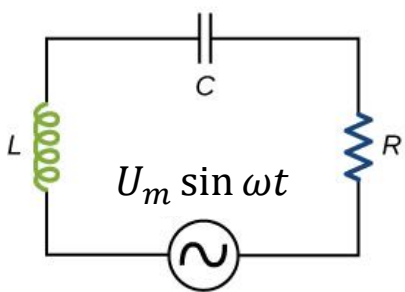
Impedancija

$$Z = \frac{U}{I}$$



Serijski spoj radnog, induktivnog i kapacitivnog otpora

- Serijski RLC krug



Ukupni pad napona na svim otporima:

$$u = Ri + L \frac{di}{dt} + \frac{1}{C} \int i dt$$

$$i = I_m \sin \omega t$$

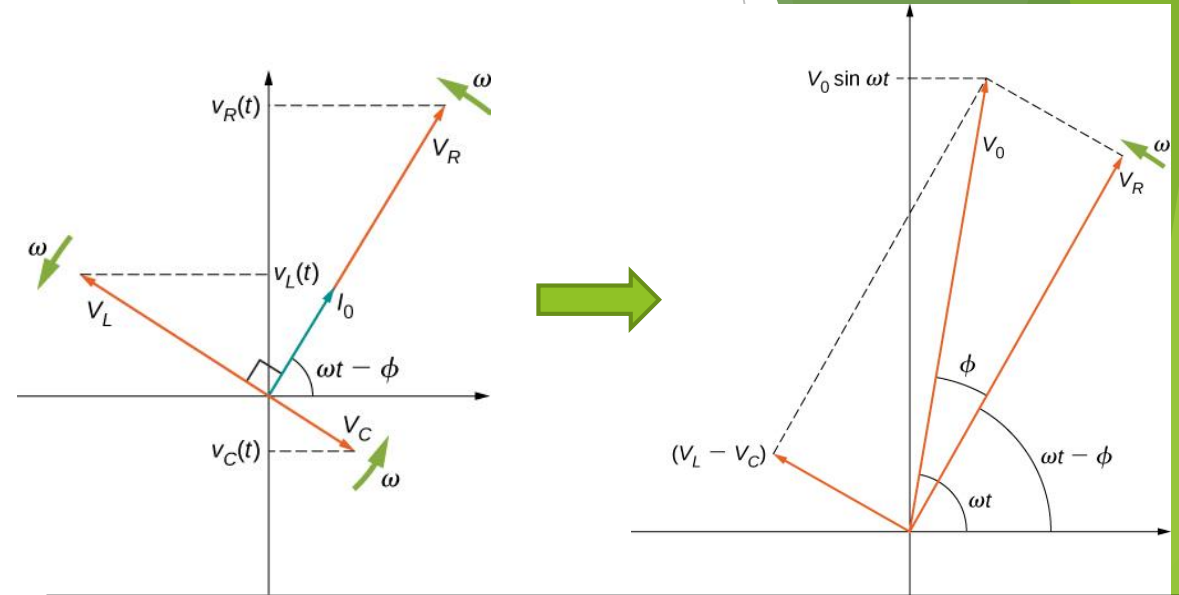
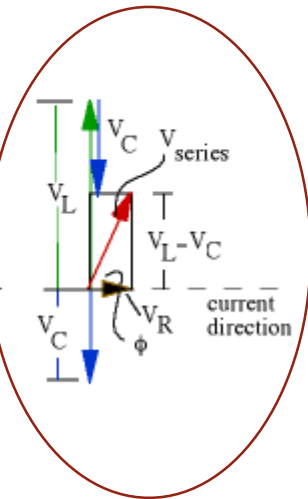
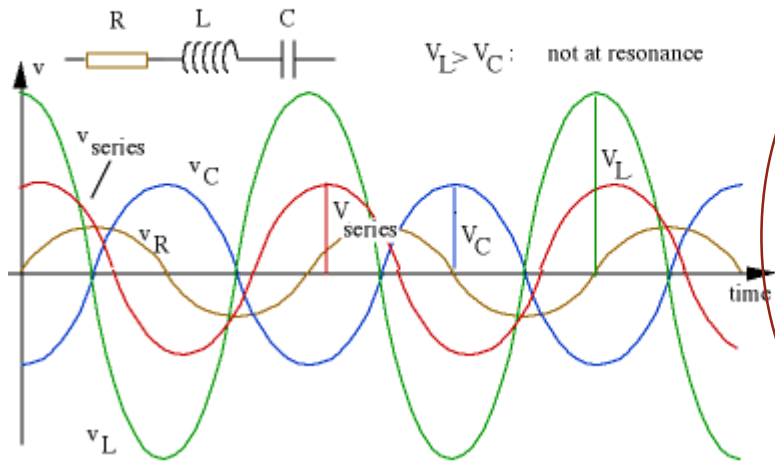
$$u = RI_m \sin \omega t + L\omega I_m \sin \left(\omega t + \frac{\pi}{2} \right) + \frac{I_m}{C\omega} \sin \left(\omega t - \frac{\pi}{2} \right)$$

Napone zbrojimo, npr. rotirajućim vektorima:

$$u = U_m \sin(\omega t + \varphi)$$

Serijski spoj radnog, induktivnog i kapacitivnog otpora

- Zbrajanje napona rotirajućim vektorima:



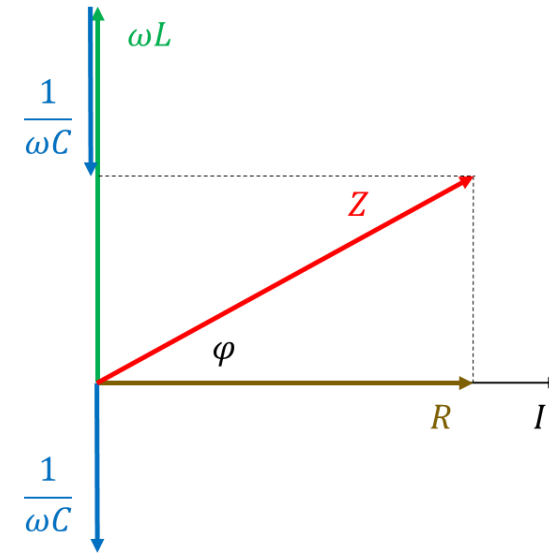
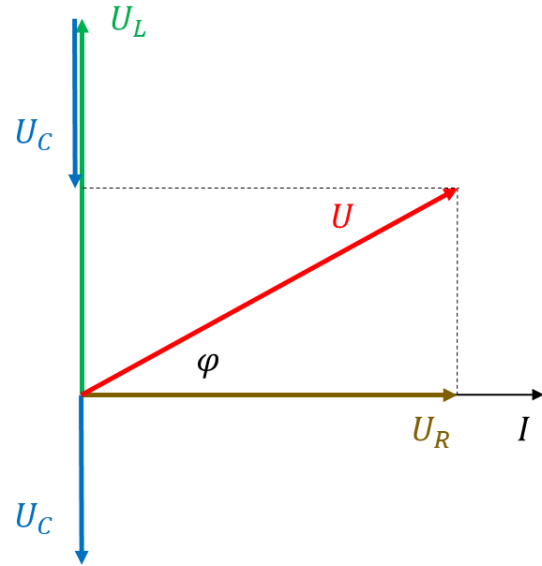
Rotirajući vektori „zamrznuti” su u nekom trenutku. → vektori se zbroje u tom trenutku.

Najpraktičniji trenutak je kad je napon na otporniku (uvijek u fazi sa strujom) na x osi.

- ukupni napon: $u = U_m \sin(\omega t + \varphi)$

Serijski spoj radnog, induktivnog i kapacitivnog otpora

- Zbrajanje napona rotirajućim vektorima:



$$\tan \varphi = \frac{L\omega - \frac{1}{\omega C}}{R}$$

- ukupni napon je: $u = U_m \sin(\omega t + \varphi)$

$$U_m = \sqrt{U_{Rm}^2 + (U_{Lm} - U_{Cm})^2} = I_m \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}$$

$$I = \frac{U}{Z}$$

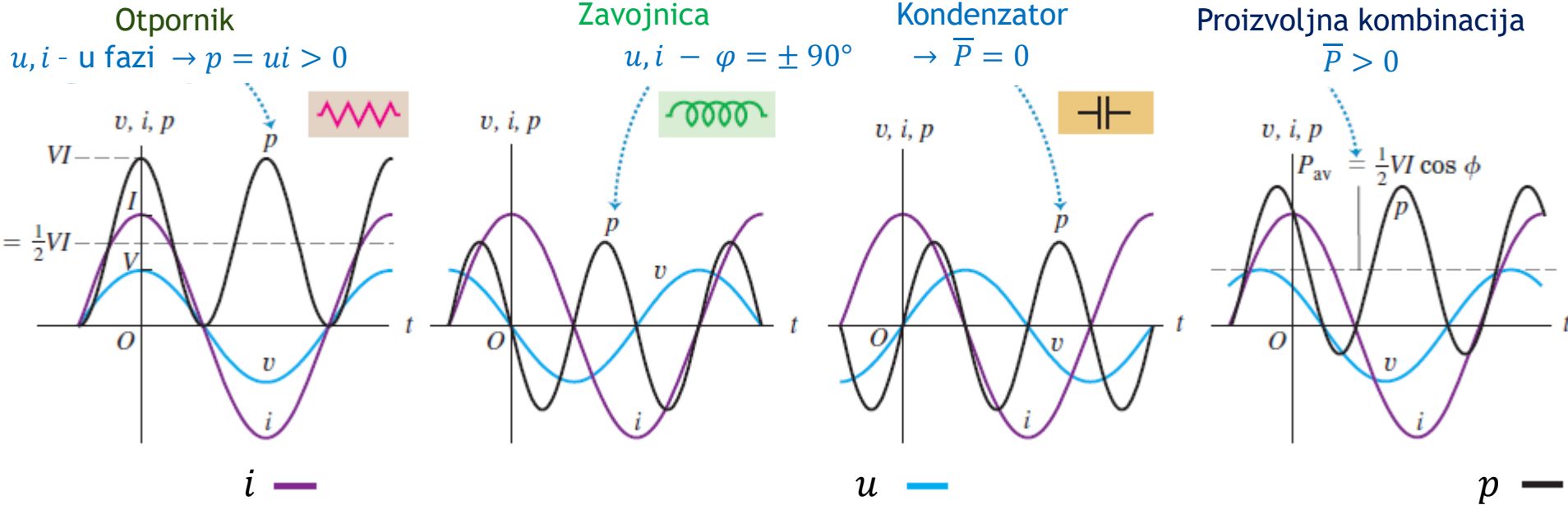


Impedancija

$$Z^2 = R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2$$

Rad i snaga izmjenične struje

- Trenutna vrijednost snage, ovisi o t : $p(t) = u(t)i(t)$



$$p(t) = U_m I_m \sin(\omega t + \varphi) \sin(\omega t)$$

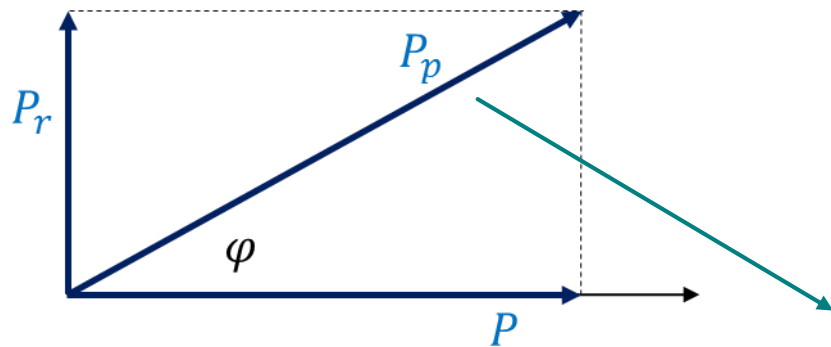
- Srednja vrijednost snage:

$$\bar{P} = \frac{1}{T} \int_0^T U_m I_m \sin(\omega t + \varphi) \sin(\omega t) dt = \frac{1}{2} U_m I_m \cos \varphi$$

Rad i snaga izmjenične struje

- Srednja vrijednost snage:

$$\bar{P} = \frac{1}{2} U_m I_m \cos \varphi = UI \cos \varphi$$



$$P_p = UI$$

Prividna snaga

$$P = P_p \cos \varphi$$

Radna snaga

$$P_r = P_p \sin \varphi$$

Reaktivna snaga

$$P_p = \sqrt{P^2 + P_r^2} = UI$$

- Faktor snage:

$$\cos \varphi = \frac{\bar{P}}{UI} = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}$$



$$\bar{P} = UI \cos \varphi = \frac{U^2 R}{Z^2} \rightarrow I^2 R$$

Ako je:
 $Z = R$

Električna rezonancija

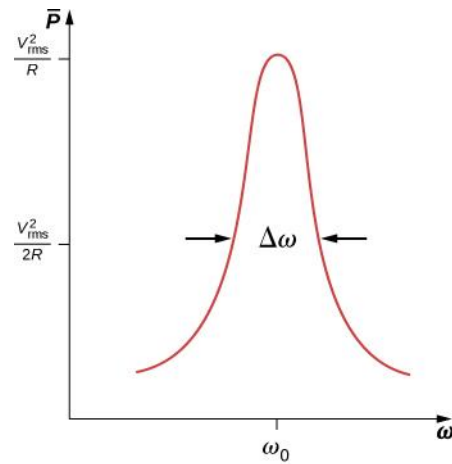
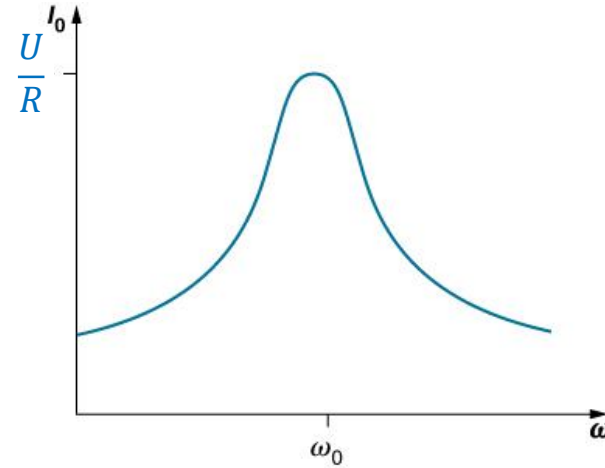
- Jakost izmjenične struje u serijskom RLC krugu:

$$I = \frac{U}{Z} = \frac{U}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}$$

- Najveća struja za $L\omega = \frac{1}{C\omega}$

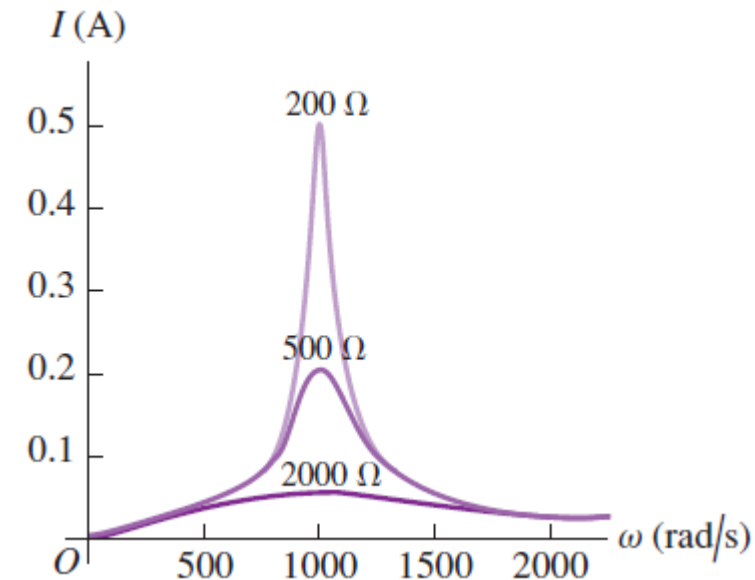
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

rezonancija



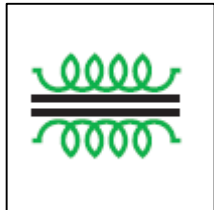
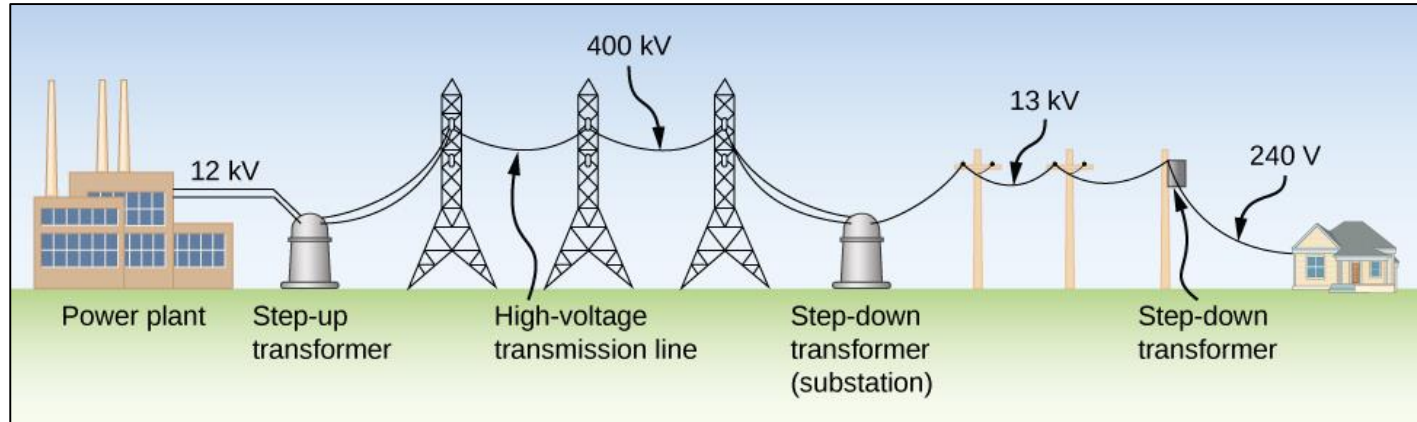
$$Q = \frac{\omega_0}{\Delta\omega} = \frac{\omega_0 L}{R}$$

Faktor
rezonantnog
kruga

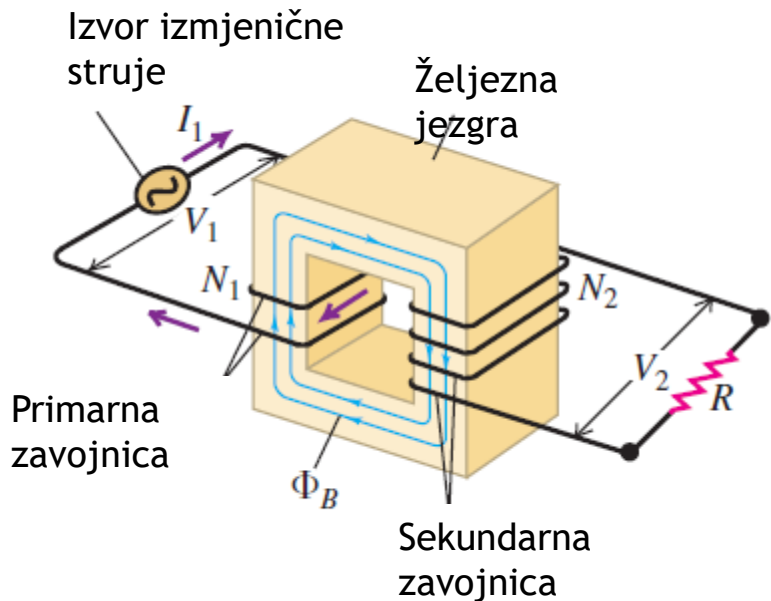


Transformatori

Transformatori - uređaji koji pretvaraju napone iz jedne vrijednosti u drugu elektromagnetskom indukcijom.



Transformatori - idealni



- Primarna zavojnica spojena je na izvor izmjeničnog napona → kroz nju teče izmjenična struja → mijenja se magnetski tok u željeznoj jezgri → inducira se ems, ε_1 .
- Čitav magnetski tok proizveden u primarnoj zavojnici prolazi i kroz sekundarnu zavojnicu i u njoj inducira ε_2 .

$$\varepsilon_1 = -N_1 \frac{d\Phi}{dt} \quad \varepsilon_2 = -N_2 \frac{d\Phi}{dt}$$

Tok kroz jedan namotaj

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{N_1}{N_2}$$

- Snaga utrošena u otporu spojenom na sekundar jednaka je snazi koja iz izvora dolazi primarnoj zavojnici:

$$U_1 I_1 = U_2 I_2$$

- Isto i za napone na krajevima zavojnica (otpor = 0 -idealno tr.)

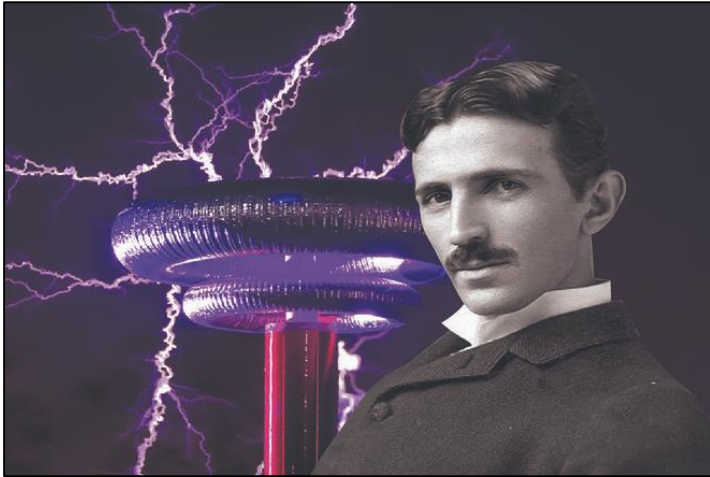
$$\frac{U_1}{U_2} = \frac{N_1}{N_2}$$

$$\frac{I_2}{I_1} = \frac{U_1}{U_2} = \frac{N_1}{N_2}$$

Realni transformator

$$\eta = \frac{U_2 I_2}{U_1 I_1}$$

Rat struja

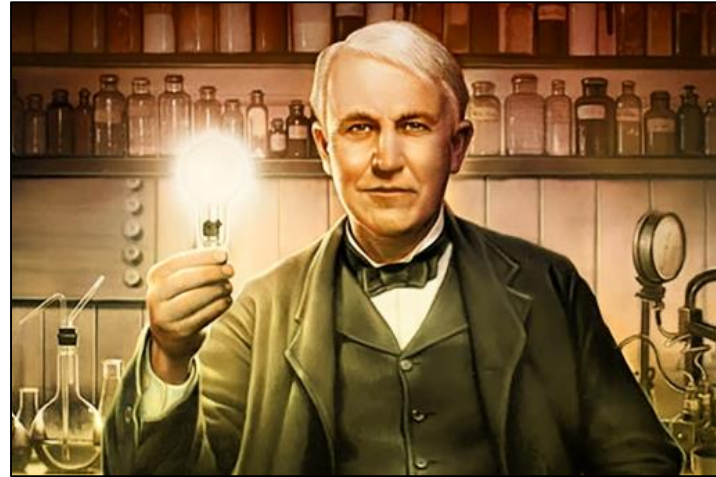


Nikola Tesla

Izmjenična struja

- Promjenjiv smjer
- Promjenjiv iznos
- Manji gubitak energije
- Opasnija

VS.



Thomas Edison

Istosmjerna struja

- Konstantan smjer
- Konstantan iznos
- Veći gubitak energije
- Sigurnija

Tko je pobijedio ?

