YILDIZ TEKNİK ÜNİVERSİTESİ

ELEKTRİK MÜHENDİSLİĞİ BÖLÜMÜ

DEVRE TEORİSİ

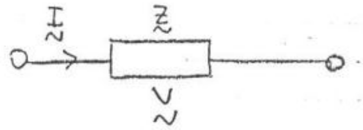
Ders Notu

- SSH'de GÜÇ ve ENERJİ
- BİR FAZLI SİSTEMLER

Doç. Dr. Recep YUMURTACI

~ SSH'de GÜÇ ve ENERJİ ~

2 uçlu elemanın gücü



$\underset{\sim}{V} = Ve^{j\theta v} = V \angle \theta_v$ **θv**: gerilimin faz açısı

$\underset{\sim}{I} = Ie^{j\theta i} = I \angle \theta i$ **θi** = Akımın faz açısı

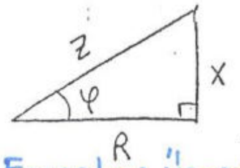
$$\boxed{\underset{\sim}{V} = \underset{\sim}{Z} \cdot \underset{\sim}{I}}$$

$$\underset{\sim}{Z} = \frac{\underset{\sim}{V}}{\underset{\sim}{I}} = \frac{V \cdot e^{j\theta v}}{Ie^{j\theta i}} = \left(\frac{V}{I}\right) \cdot e^{j(\underbrace{\theta v - \theta i}_{\varphi})}$$

$$\underset{\sim}{Z} = \underbrace{\left(\frac{V}{I}\right)}_{Z} e^{j(\theta v - \theta i)} \Rightarrow z = ze^{j\varphi} = Z \angle \varphi$$ — empedansın açısı.

φ = Empedansın açısı

$$\boxed{\varphi = \theta_v - \theta_i}$$

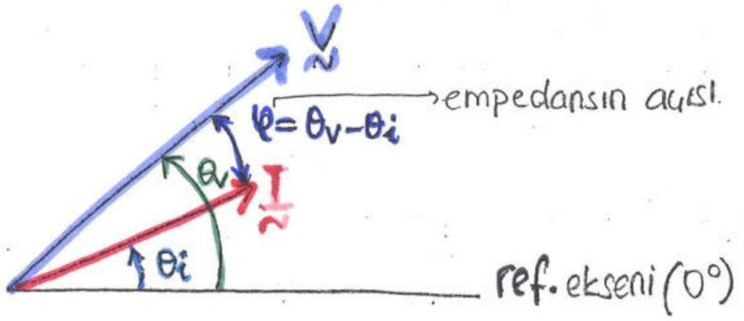


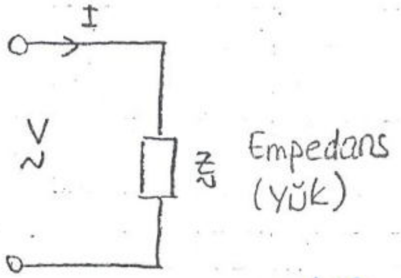
Empedans Üçgeni

$\underset{\sim}{Z} = R + jX$

$$\boxed{Z = \sqrt{R^2 + X^2}}$$

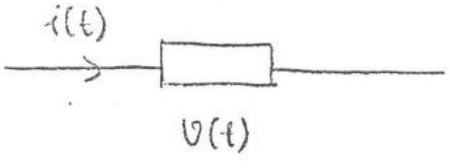
$$\boxed{\tan \varphi = \frac{X}{R}}$$





$\underset{\sim}{Z} = R + jX = Z \angle \varphi$

Ani Güç p(t)



$\underset{\sim}{V} = Ve^{j\theta v}$

$\underset{\sim}{I} = Ie^{j\theta i}$

$p(t) = v(t) \cdot i(t)$

$p(t) = \sqrt{2} \cdot V \cos(\underbrace{\omega t + \theta_v}_{a}) \cdot \sqrt{2} \cdot I \cos(\underbrace{\omega t + \theta_i}_{b})$

$$\cos a \cdot \cos b = \frac{1}{2}\left[\cos(a+b)+\cos(a-b)\right]$$

$$p(t) = \underbrace{V \cdot I \cos\varphi}_{P} + \underbrace{V I \cos\varphi}_{P} \cos 2wt + \underbrace{V I \sin\varphi}_{Q} \sin 2wt$$

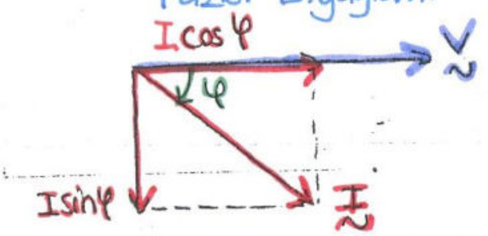
$P = V \cdot I \cos\varphi$ Aktif Güç [W] (watt)

$Q = V \cdot I \cdot \sin\varphi$ Reaktif Güç [Var] (Volt amper reaktif)

$P = V \cdot I \cos\varphi$

$Q = V \cdot I \sin\varphi$

Fazör Diyagramı



$I\cos\varphi$ · Akımın aktif bileşeni

$I \sin\varphi$ = " reaktif bil.

$$p(t) = \underbrace{V \cdot I \cos\varphi}_{P} + \underbrace{V I \cos\varphi}_{P} \cos 2wt + \underbrace{V \cdot I \sin\varphi}_{Q} \sin 2wt$$

$$\boxed{p(t) = P.(1+\cos 2wt) + Q \sin 2wt}$$

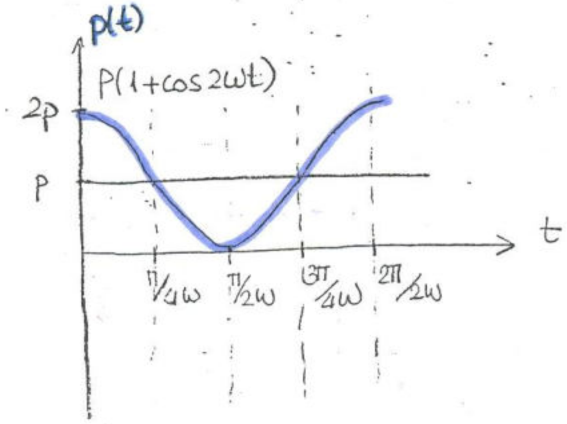
$2wt = 0$ için $t = 0$

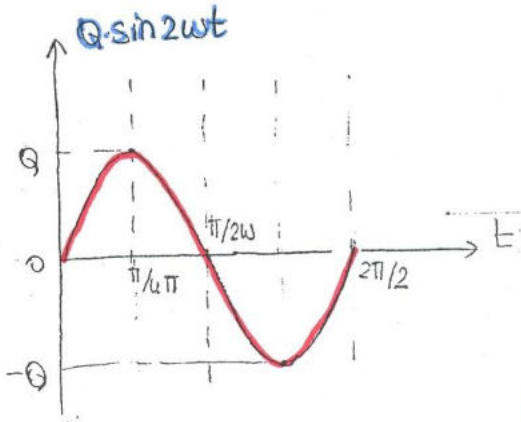
$2wt = \pi/2$ " $t = \frac{\pi}{4w}$

$2wt = \pi$ " $t = \frac{\pi}{2w}$

$2wt = 3\pi/2$ " $t = \frac{3\pi}{4w}$

$2wt = 2\pi$ " $t = \frac{2\pi}{2w}$





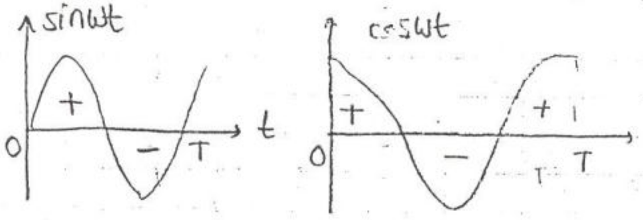
= Ortalama GÜÇ =

- SSH'de ani gücün ortalaması aktif güce (P) eşittir.

$$P_{ort} = \frac{1}{T}\int_0^T P(\tau)d\tau$$

$$P_{ort} = \frac{1}{T}\Big[\int_0^T Pdt + \overbrace{\int_0^T P\cos 2wt dt}^{0} + \overbrace{\int_0^T Q\sin 2wt dt}^{0} = \frac{1}{T}\int_0^T Pdt$$

sinüsoidal fonk'un her bir periyod (0-T) boyunca ortalaması 0'dır.



$$\boxed{P_{ort} = P = V\cdot I\cdot \cos\varphi}$$

$$P = V\cdot I\cdot \cos\varphi$$

$\downarrow$

$\cos\varphi$ {
Güç katsayısı
Güç faktörü
Güç çarpanı

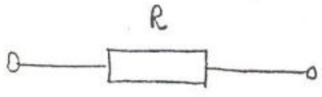
$\cos\varphi$: [0-1] arasında değişir.

$P = VI\cos\varphi$, $Q = V\cdot I\sin\varphi$ } $\cos\varphi = 0$ ise $P = 0$, $(\sin\varphi = 1)$ $Q = V\cdot I$ } Aktif güç çekilmez, sadece reaktif güç vardır.

$\cos\varphi = 1$ ise $P = V\cdot I$, $(\sin\varphi = 0)$ $Q = 0$ } sadece aktif güç çekilir.

Özel Haller

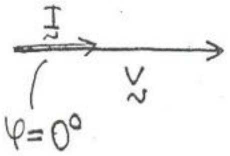
① $\underset{\sim}{Z} = R$ olsun. (DİRENÇ)



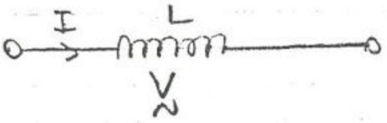
$$P_R = VI\overbrace{\cos\varphi}^{\cos 0° = 1} \rightarrow \boxed{P_R = V\cdot I}$$

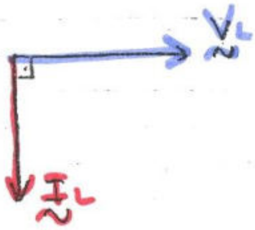
$$Q_R = V\cdot I\underbrace{\sin\varphi}_{\sin 0 = 0} \qquad \boxed{Q_P = 0}$$

} direnç sadece aktif güç çeker.



② $\underset{\sim}{Z} = j\omega L$ (Endüktans) olması halinde güç





$$\boxed{\underset{\sim}{V_L} = j\omega L \cdot \underset{\sim}{I_L}}$$

$1\angle 90^\circ = e^{j\pi/2}$

saf

$$\underset{\sim}{Z} = \overset{\uparrow}{j}\omega L = \omega L \angle 90^\circ = z \angle \varphi \Rightarrow \varphi = 90^\circ \text{ (endüktans için)}$$

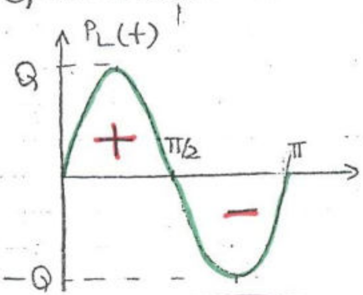
$\varphi = 90^\circ \Rightarrow \cos\varphi = 0$

$\sin\varphi = 1$

$$\left.\begin{aligned} P_L &= VI\cos\varphi = 0 \\ Q_L &= VI\cdot\underbrace{\sin\varphi}_{1} = VI \end{aligned}\right\}$$ Endüktans aktif güç çekmez.

$$P_L(t) = \overset{0}{\cancel{P}}(1 + 2\cos 2\omega t) + Q\sin 2\omega t$$

$$P_L(t) = Q\sin 2\omega t \implies$$



Endüktans bir yarı periyotta aldığı gücü diğer yarı periyotta geri verir

$P_{ort} = 0$

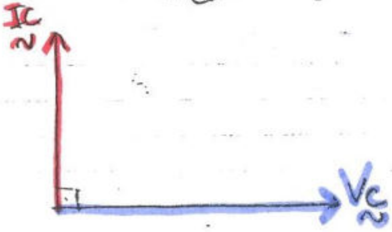
③ $\underset{\sim}{Z} = \frac{1}{j\omega C}$ olması durumu (KONDANSATÖR)

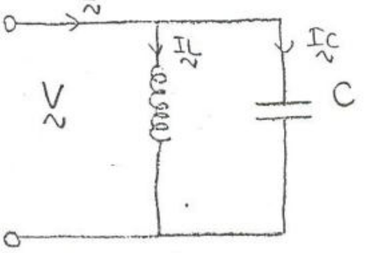
$$\underset{\sim}{Z} = \frac{1}{j\omega C} = -j\frac{1}{\omega C} = \frac{1}{\omega C}\angle -90^\circ \quad \varphi_C = -90^\circ$$

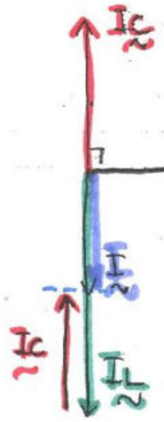
$$\left.\begin{aligned} P_C &= VI\cos\underset{\searrow 0}{\varphi_C} = 0 \\ Q_C &= VI\sin\varphi_C = VI\sin(-90^\circ) = -VI \end{aligned}\right\} \begin{aligned} &P_C = 0 \\ &Q_C = -VI \end{aligned}$$

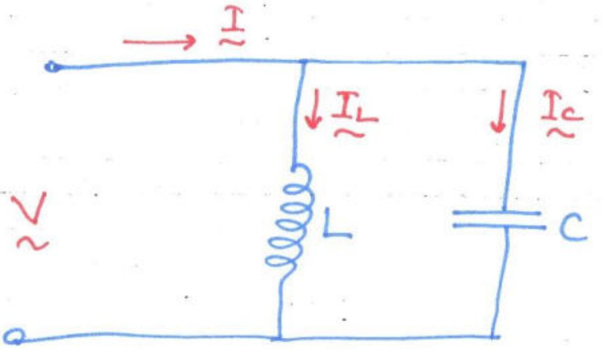
Kondansatör aktif güç çekmez.

$$\boxed{\underset{\sim}{I_C} = \underset{\downarrow 1\angle 90^\circ}{j}\omega C\, \underset{\sim}{V_C}}$$









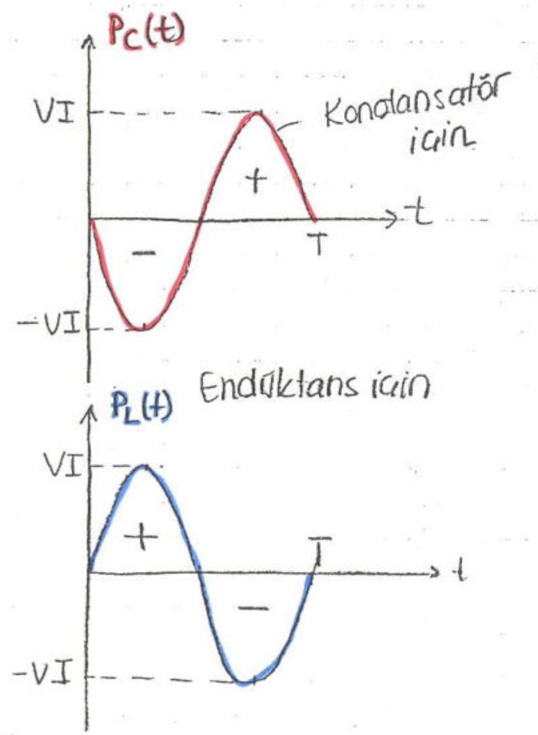
$\underset{\sim}{I} = \underset{\sim}{I_C} + \underset{\sim}{I_L}$

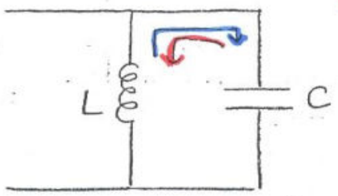
$I = |\underset{\sim}{I}| = |\underset{\sim}{I_L} - \underset{\sim}{I_C}|$

$I_C = I_L \Rightarrow I = 0$ olur.

$$P_C(t) = \cancel{P_C}^{\,0} \cdot (1+\cos 2\omega t) + \underset{\underset{-V\cdot I}{\downarrow}}{Q_C} (\sin 2\omega t)$$

$$P_C(t) = -V\cdot I \sin 2\omega t$$

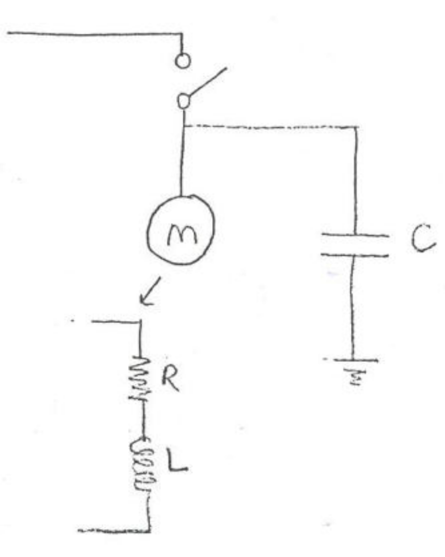




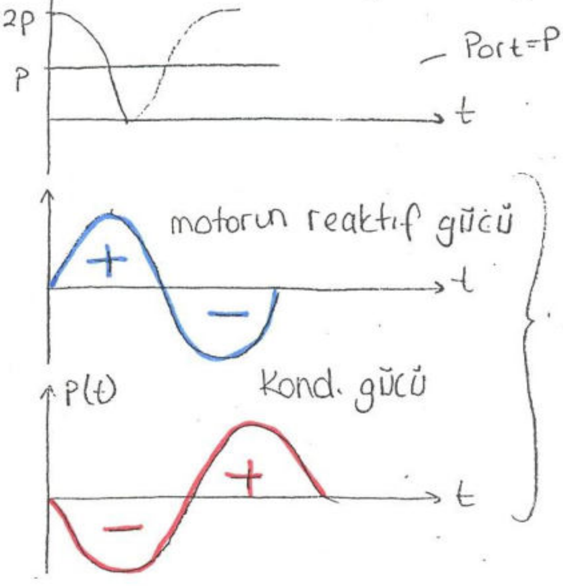
Yandaki şekillere göre, ilk yarı periyotta L enerji alıyor, C enerji veriyor. 2. yarı periyotta ise C enerji alıyor, L enerji veriyor. Bu olay periyodik olarak bu şekilde devam eder

Bu devrede direnç olmadığı için enerji harcanmaz ($P=0$)

Örn:



motorun çektiği ani güç



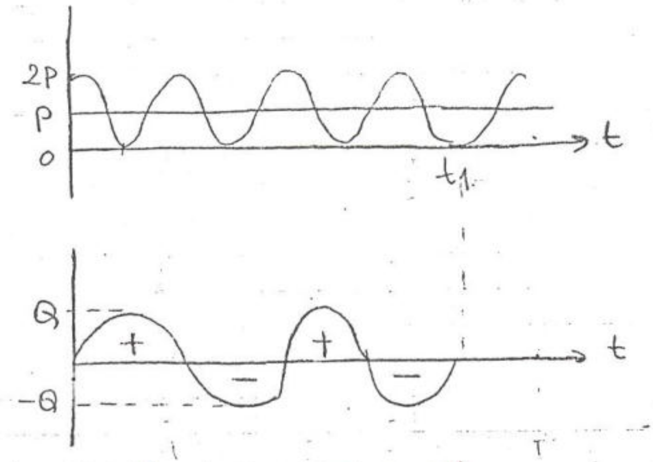
$Q_C = Q_L$ için

sadece

$\boxed{P = VI\cos\varphi}$

SH'de Enerji

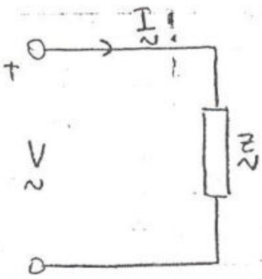
$$E(t)=\int_{0}^{t_1} P(\tau)d\tau$$



$E=P\cdot t_1$ · **Aktif enerji kwh**

$Q\,t_1=$ **Reaktif " kVArh**

SSH'de KOMPLEKS GÜÇ



$$\left.\begin{array}{l}\underset{\sim}{V}=Ve^{j\theta_v}\\ \underset{\sim}{I}=Ie^{j\theta_i}\end{array}\right\}$$

Kompleks güç: eşlenik

$$\boxed{\underset{\sim}{S}=\underset{\sim}{V}\cdot\overline{\underset{\sim}{I}}}\quad \text{veya}\quad \boxed{\underset{\sim}{S}=\underset{\sim}{V}\cdot\underset{\sim}{I}^{*}}$$

$$S=Ve^{j\theta_v}\cdot Ie^{-j\theta_i}$$

$$\underset{\sim}{S}=VIe^{j\underbrace{(\theta_v-\theta_i)}_{\varphi}}$$

Kompleks güç

$$\boxed{\underset{\sim}{S}=\underbrace{V.I}_{S}.e^{j\varphi}=S.e^{j\varphi}}$$

Kompleks güç $(\underset{\sim}{S})$

Görünen güç [VA] $(S=V.I)$

$$\underset{\sim}{S}=VIe^{j\varphi}=VI\angle\varphi$$

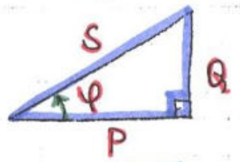
$$\underset{\sim}{S}=\underbrace{VI\cos\varphi}_{P}+j\underbrace{VI\sin\varphi}_{Q}$$

$$\underset{\sim}{S}=P+jQ$$

↓ aktif güç ↓ reaktif güç

$\underset{\sim}{S} = P + jQ$

Güç üçgeni

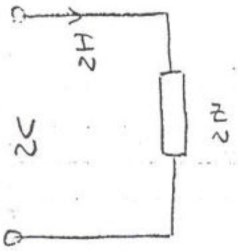


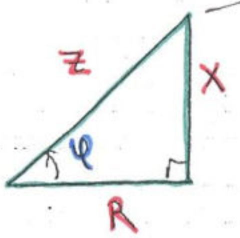
$\boxed{S = \sqrt{P^2+Q^2}}$ $P = S\cos\varphi = VI\cos\varphi$

$S = V \cdot I$ $Q = S\sin\varphi = VI\sin\varphi$

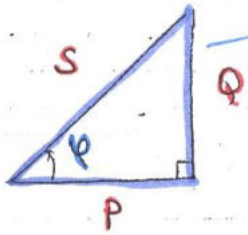
$\boxed{\tan\varphi = \frac{Q}{P}} \Rightarrow \boxed{Q = P \cdot \tan\varphi}$

* φ nedir?





Empedans üçgeni



Güç üçgeni

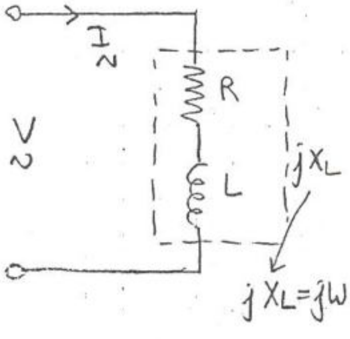
$\tan\varphi = \frac{X}{R}$ $\boxed{\underset{\sim}{Z} = \sqrt{R^2+X^2}\angle\varphi}$

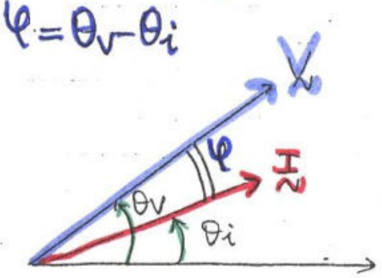
$\tan\varphi = \frac{Q}{P}$ $\boxed{\underset{\sim}{S} = \sqrt{P^2+Q^2}\angle\varphi}$

φ, hem empedans üçgeninin hem de güç üçgeninin açısıdır.

Endüktif Yükler için Güç Üçgeni

$\varphi = \theta_V - \theta_i$



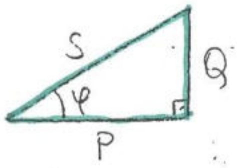


End. yük için $\theta_V > \theta_i$

$\varphi > 0°$

$\underset{\sim}{S} = VI\cos\varphi + jVI\sin\varphi = P + jQ$

φ>0° olduğu için Q>0



endüktif yükler için Q (+) işaretli

Kapasitif yükler için güç üçgeni

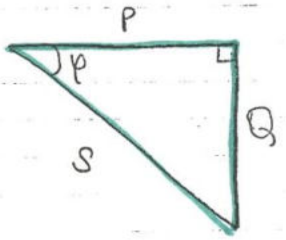
$\varphi = \theta_V - \theta_i$

$\theta_i > \theta_V \quad \varphi < 0° \Rightarrow Q < 0$

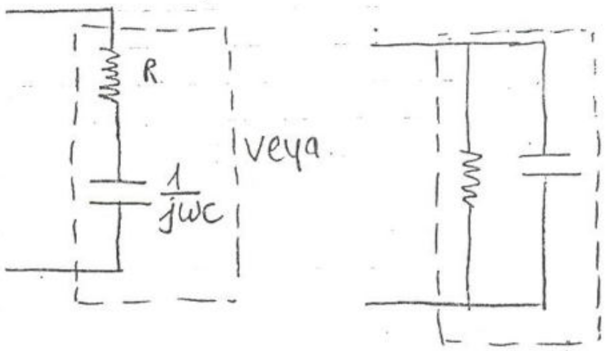
$\underset{\sim}{S} = P + jQ = V \cdot I\cos\varphi + jVI\sin\varphi$

φ<0 olduğu için sin φ (−)

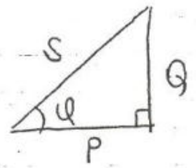
Kapasitif yükün reaktif gücü (–) işaretlidir



Kapasitif yük



Alternatif akımda güçler

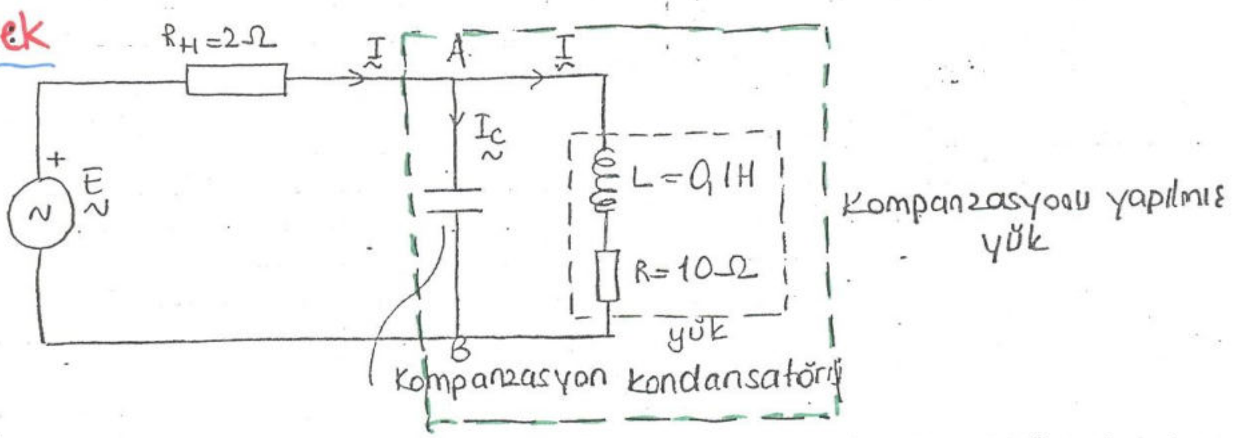


$P = V \cdot I \cos\varphi$ Aktif güç [W]

$Q = V I \sin\varphi$ Reaktif 〃 [VAr]

$S = V I$ Görünen güç [VA]

Örnek



ⓐ Şekildeki devre kabaca bir güç sistemini temsil etmektedir. A-B uçları arasında $V_{ef} = 100V$ ise R, L elemanlarından oluşan yükün çektiği gücü ve R_H hat direncindeki gücü bulunuz (Kond. yokken)

ⓑ Bu devrede A-B uçlarına paralel olarak bir C kond. bağlanıyor. Elde edilen yükün güç katsayısının 1 olması sağlanıyor. (Tam kompanzasyon yapılıyor) C kapasitesinin değeri ? Yükün aktif gücünü ve R_H'daki gücü bulunuz. $f = 50Hz$, $\omega = 314$ rd/s

NOT: A-B uçlarına kond. bağlandıktan sonrada 100 V'luk gerilimin değişmediği kabul edilecek.

ⓐ $R = 10\,\Omega$

$$\left.\begin{array}{l} R = 10\,\Omega \\ X_L = \omega L = 314 \cdot 0{,}1 = 31{,}4\,\Omega \end{array}\right\} \quad \begin{array}{l} z = R + j\omega L = 10 + j31{,}4 \\ \underset{\sim}{z} = 33{,}2 \angle 72{,}5^\circ\,\Omega \end{array}$$

$\underset{\sim}{V}_{AB} = 100\, e^{j0^\circ} = 100 \angle 0^\circ = 100\ \text{V}$ (ref alındı)

$\underset{\sim}{I} = \dfrac{\underset{\sim}{V}_{AB}}{\underset{\sim}{Z}} = \dfrac{100 \angle 0^\circ}{33{,}2 \angle 72{,}5^\circ} = 3 \angle -72{,}5^\circ\ \text{A}$ (yük endüktiftir)

R-L yükünün akımı

Hattaki kayıp güç

$\underset{\sim}{V}_H = \underset{\sim}{R}_H \cdot I$ (C bağlı değil)

$\underset{\sim}{S}_H = \underset{\sim}{V}_H \cdot \underset{\sim}{\bar{I}}$

$\underset{\sim}{S}_H = R_H \underbrace{\left(\underset{\sim}{I} \cdot \underset{\sim}{\bar{I}}\right)}_{I^2} = R_H \cdot I^2$

$\underset{\sim}{S}_H = 2 \cdot 3^2 = 18\ \text{VA}$

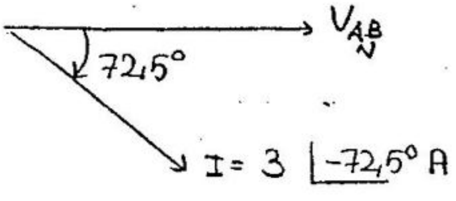
$\underset{\sim}{S}_H = P_H + jQ_H = 18 + j0$ — Reaktif güç

$\underset{\sim}{S}_H = 18$ (Sadece aktif güç)

$P_H = 18\ \text{W}$

$Q = 0\ \text{VAr}$

* Fazör diyagramı



Yükün gücü

(Eşlenik alındı)

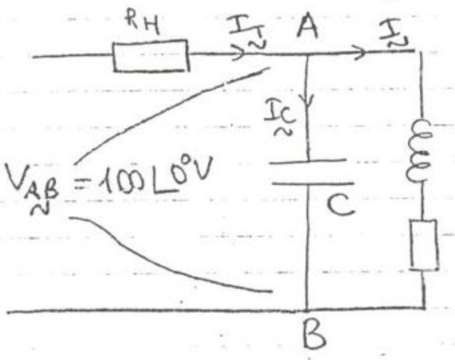
$\underset{\sim}{S}_y = \underset{\sim}{V}_{AB} \cdot \underset{\sim}{\bar{I}} = 100 \angle 0^\circ \cdot 3 \angle +72{,}5^\circ$

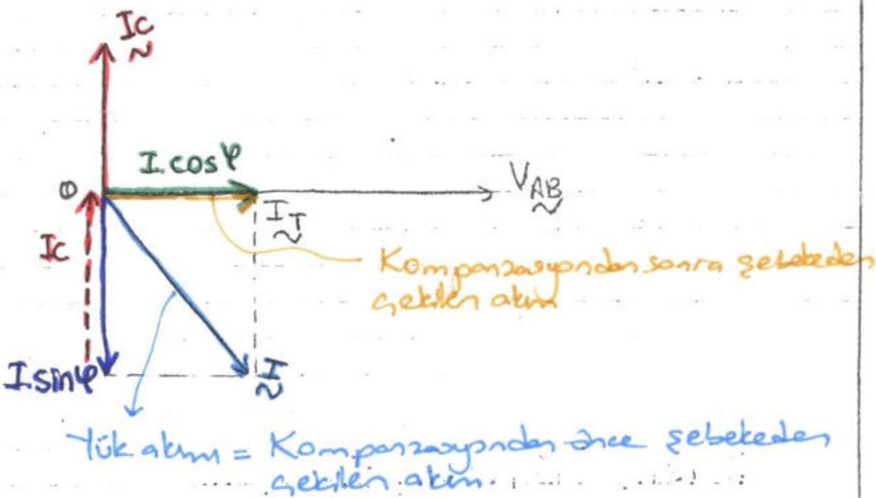
$\underset{\sim}{S}_y = 300 \angle 72{,}5^\circ = 300\left(\cos 72{,}5 + j \sin 72{,}5\right)$

$\underset{\sim}{S}_y = 90 + j286 = P_y + jQ_y$

$P_y = 90\ \text{W} \qquad Q_y = 280\ \text{VAr}$ (end.)

ⓑ C kondansatörü bağlanıyor.



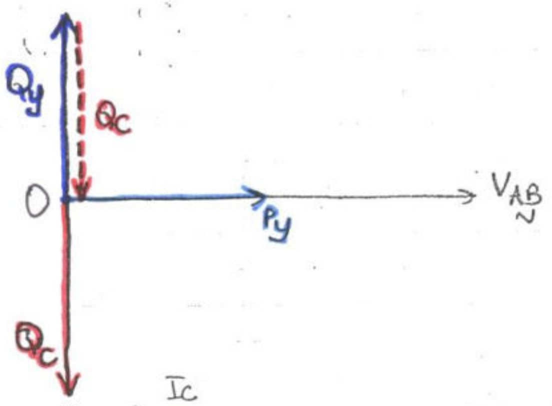


$\underset{\sim}{I_J} = \underset{\sim}{I} + \underset{\sim}{I_C}$

Tam kompanzasyondan sonra; $I_T = I \cdot \cos\varphi = I \cos 72,5 = 0,9 A$

$P_H{}' = R_H \cdot I_T{}^2 = 2 \cdot 0,9^2 = 1,62 W$

C bağlanınca $\cos\varphi = 1 \Rightarrow \varphi = 0°$ olacak

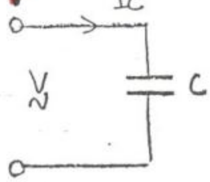


$\cos\varphi = 1 \Rightarrow \varphi = 0° \Rightarrow Q_T = 0$ olmalıdır.

$Q_T = Q_y - Q_C = 0 \Rightarrow Q_y = Q_C$ olmalı.

$Q_y = 286$ VAr idi.

$Q_C = ?$



$Q_C = V \cdot I_C = V \cdot \frac{V}{\underset{\hookrightarrow 1/\omega C}{X_C}} = V \cdot V \cdot \omega C$

$\boxed{Q_C = \omega . C . V^2}$

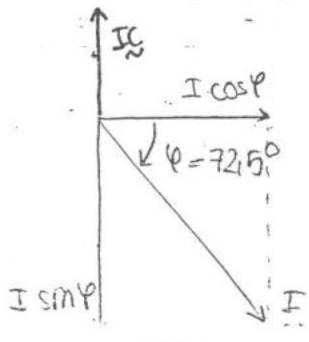
$Q_y = Q_C = 286 = \omega C V_{AB}^2$

$286 = 314 \cdot C \cdot 100^2$

$C = \frac{286}{314 \cdot 100^2} = 91 \mu F$

$1 \mu F = 10^{-6} F$
$1 nF = 10^{-9} F$
$1 pF = 10^{-12} F$

Not:
C değeri akımdan da bulunabilir.



$\cos\varphi = 1 \Rightarrow \varphi = 0°$

$|\underset{\sim}{I_C}| = |I \sin\varphi|$

$I_C = \frac{V}{X_C} = \frac{V}{\frac{1}{\omega C}} = V \omega C$

$\omega C V = I \sin\varphi$

$314\ C\ 100 = 3 \sin 72{,}5$ C= ---- bulunur

Kondansatörün akımı

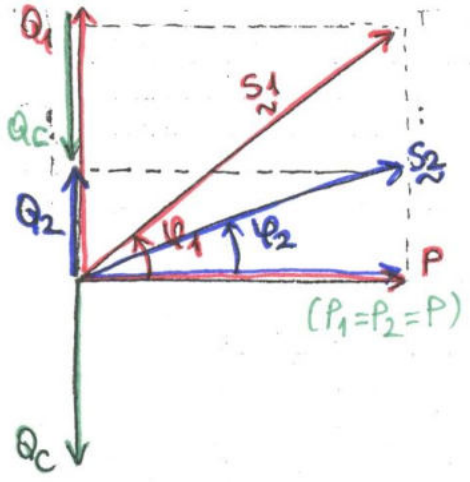
$\underset{\sim}{I_C} = j\omega C \cdot \underset{\sim}{V}$

$\underset{\sim}{I_C} = j\,314\ 91\ 10^{-6}\ 100 \angle 0^\circ$

$\underset{\sim}{I_C} = j\,2{,}86 = 2{,}86 \angle 90^\circ$. A

Reaktif Güç Kompanzasyonu (Kompanzasyonda aktif güç değişmez)

($\cos\varphi_1$'in $\cos\varphi_2$ yapılması)



Q_1: Kondansatör bağlanmadan önce çekilen reaktif güç

Q_C: Kondansatörün reaktif gücü

$Q_C = \omega C V^2$

$\boxed{Q_2 = Q_1 - Q_2}$ (C bağlandıktan sonra çekilen reaktif güç)

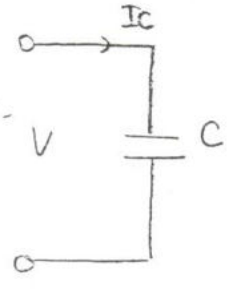
P değişmez

$\tan\varphi_1 = \frac{Q_1}{P} \Rightarrow Q_1 = P \cdot \tan\varphi_1$

$\tan\varphi_2 = \frac{Q_2}{P} \rightarrow Q_2 = P \cdot \tan\varphi_2$

$\boxed{Q_C = Q_1 - Q_2}$

$\boxed{Q_C = P.(\tan\varphi_1 - \tan\varphi_2)}$



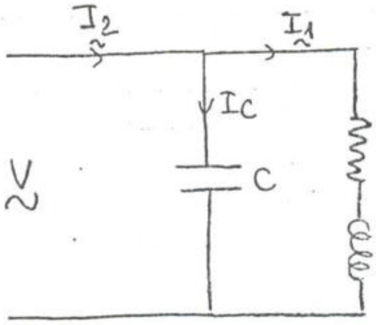
$Q_C = V_C \cdot I_C$

$Q_C = V \cdot \frac{V}{\frac{1}{\omega C}} = \omega C V^2$

$\boxed{Q_C = \omega C V^2}$

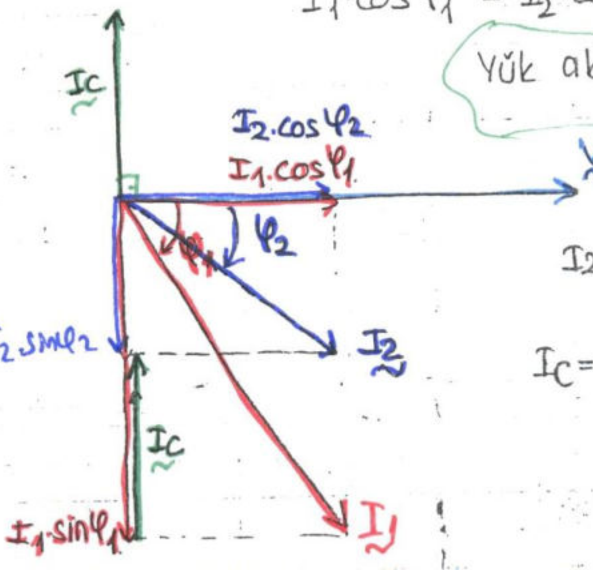
$$Q_C = P(\tan\varphi_1 - \tan\varphi_2) = \omega C V^2$$

$$\boxed{C = \frac{P(\tan\varphi_1 - \tan\varphi_2)}{\omega V^2}}$$



$$\underset{\sim}{I_2} = \underset{\sim}{I_1} + \underset{\sim}{I_C}$$

$$\underset{\sim}{I_c} = j\omega C \underset{\sim}{V}$$



$P = V \cdot I \cdot \cos\varphi$

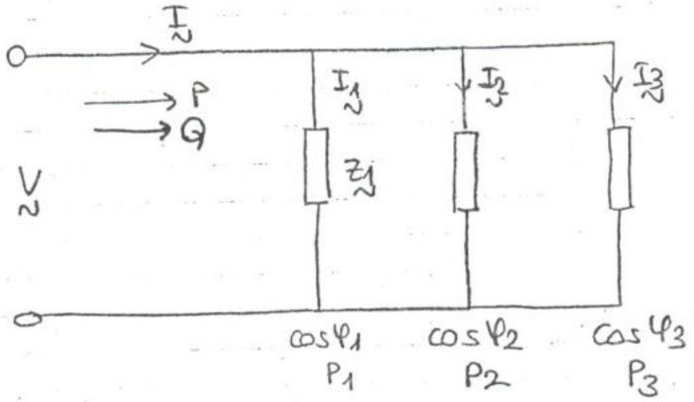
$I_1 \cdot \cos\varphi_1 = I_2 \cdot \cos\varphi_2$

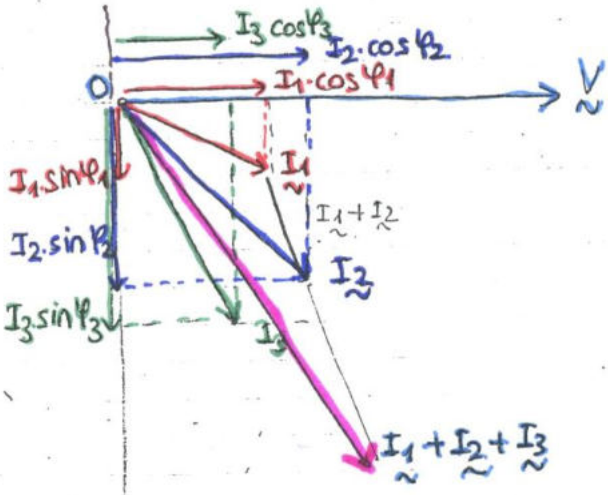
Yük akımının aktif bileşeni her iki durumda değişmez aynıdır.

$I_2 \cdot \sin\varphi_2 = I_1 \cdot \sin\varphi_1 - I_C$

$I_C = \omega C V = (I_1 \cdot \sin\varphi_1 - I_2 \cdot \sin\varphi_2)$

Değişik Güç Faktörlü Yüklerin Şebekeye Bağlanması





$$\underset{\sim}{I} = (I_1 \cdot \cos\varphi_1 + I_2 \cdot \cos\varphi_2 + I_3 \cos\varphi_3) + j(I_1 \sin\varphi_1 + I_2 \sin\varphi_2 + I_3 \cdot \sin\varphi_3)$$

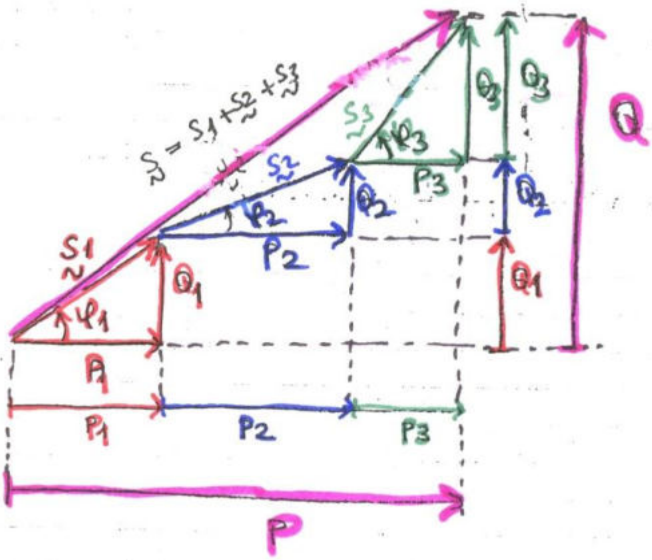
her iki tarafı V ile çarpalım.

$$\left\{ \begin{array}{l} P = P_1 + P_2 + P_3 + \dots \\ Q = Q_1 + Q_2 + Q_3 + \dots \end{array} \right\}$$

$$\boxed{\underset{\sim}{S} = (P_1 + P_2 + P_3 + \dots) + j(Q_1 + Q_2 + Q_3 + \dots)}$$

$\underset{\sim}{S} = \underset{\sim}{S_1} + \underset{\sim}{S_2} + \underset{\sim}{S_3}$ Doğru (Fazör toplam)

$S \neq S_1 + S_2 + S_3$



* Bir devreden çekilen toplam aktif güç yüklerin tek tek çektikleri aktif güçlerin toplamına eşittir.

* Bir devreden çekilen toplam reaktif güç // // // reaktif güçlerin toplamına eşittir.

Bir devreden çekilen toplam görünen güç // görünen güçlerinin toplamına eşit değildir. (Kompleks olarak toplamına eşittir.)

$S \neq S_1 + S_2 + S_3$

$$\boxed{\underset{\sim}{S} = \underset{\sim}{S_1} + \underset{\sim}{S_2} + \underset{\sim}{S_3}}$$