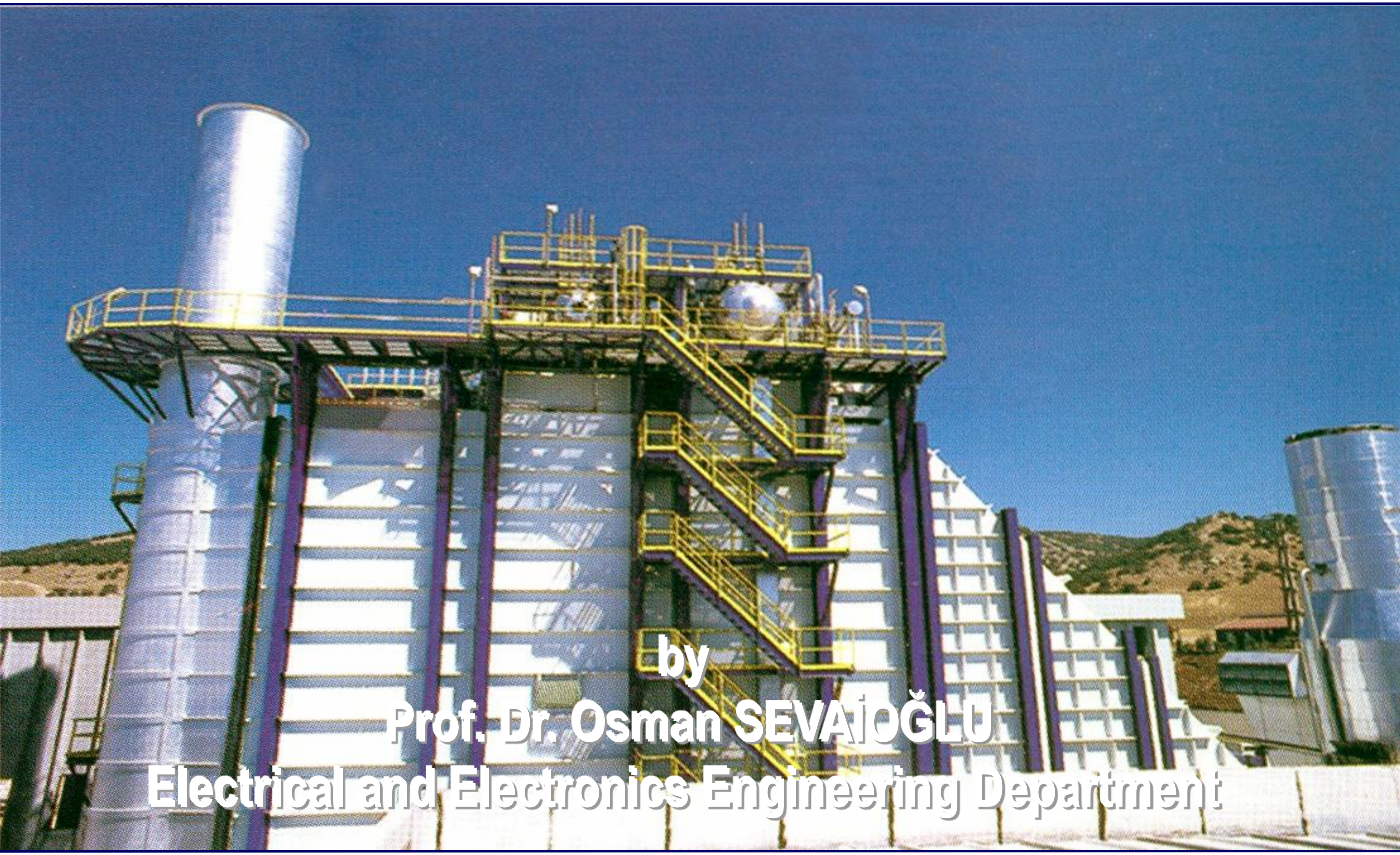
AC Power



by
Prof. Dr. Osman SEVAİOĞLU
Electrical and Electronics Engineering Department

AC Power

Voltage Waveform

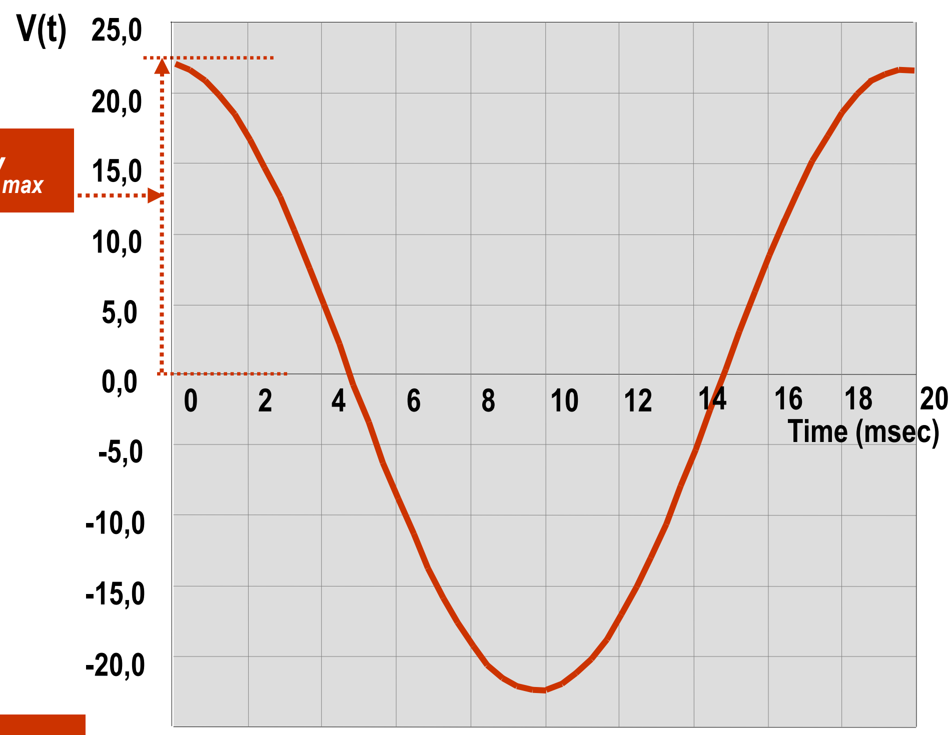
Consider the following AC circuit driven by a source with voltage waveform;

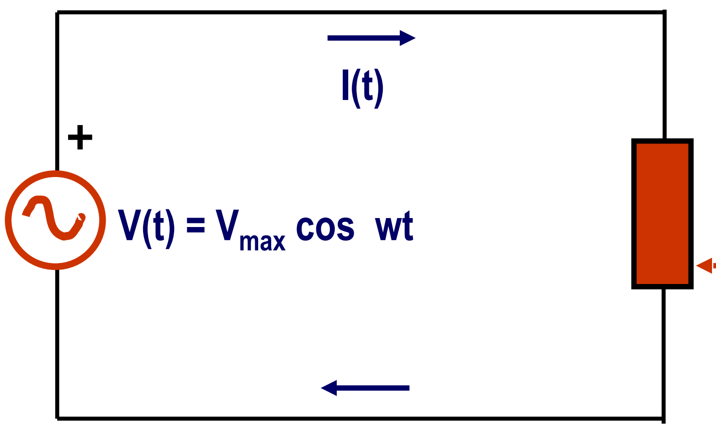
$$V(t) = V_{max} \cos \ wt$$

Phasor representation of this voltage waveform will then be

$$V_{max} \angle 0^o$$

V_{max}





$Load = R + j\,X$

$= Z \angle \theta$

$Z = \sqrt{R^2 + X^2}\,, \ \ \theta = Tan^{-1}(X / R)$

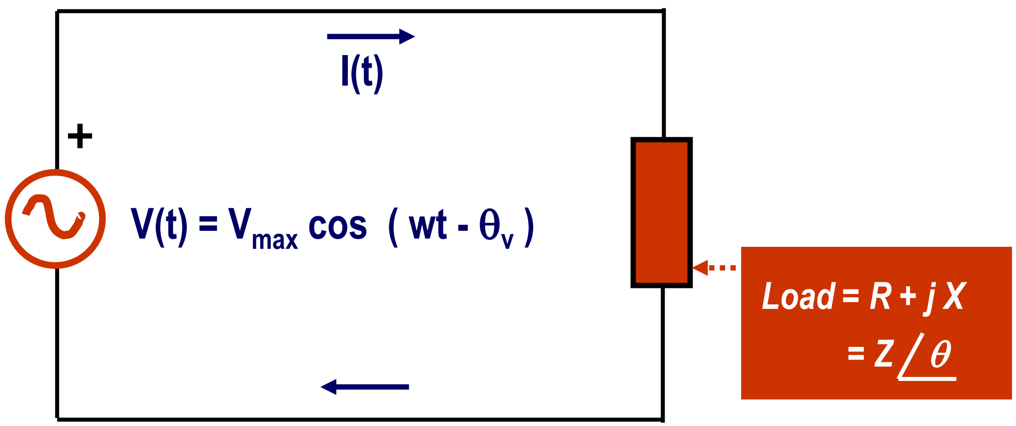
Phase Shift in Voltage Waveform

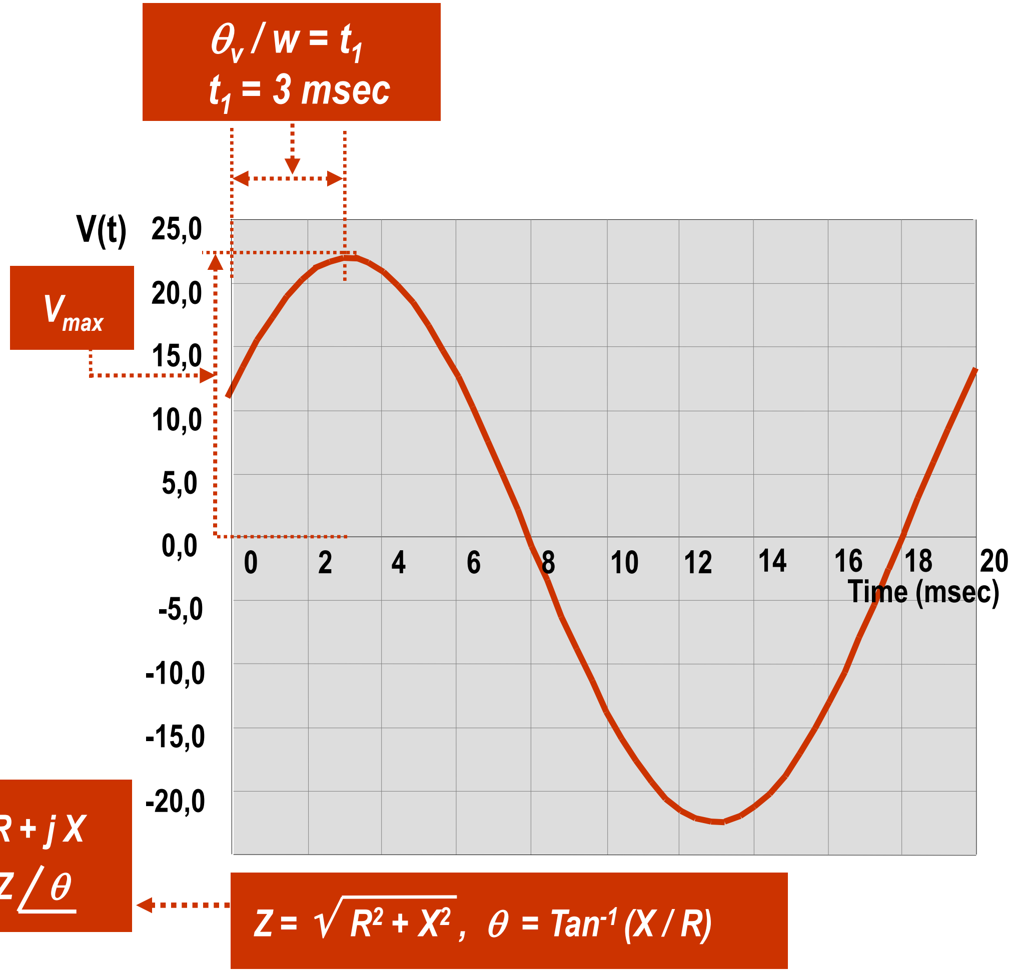
Consider now, the following AC circuit driven by a a source with an AC voltage waveform;

$$V(t) = V_{max} \cos\ (wt - \ \theta_v)$$

Phasor representation of the shifted voltage waveform will then be

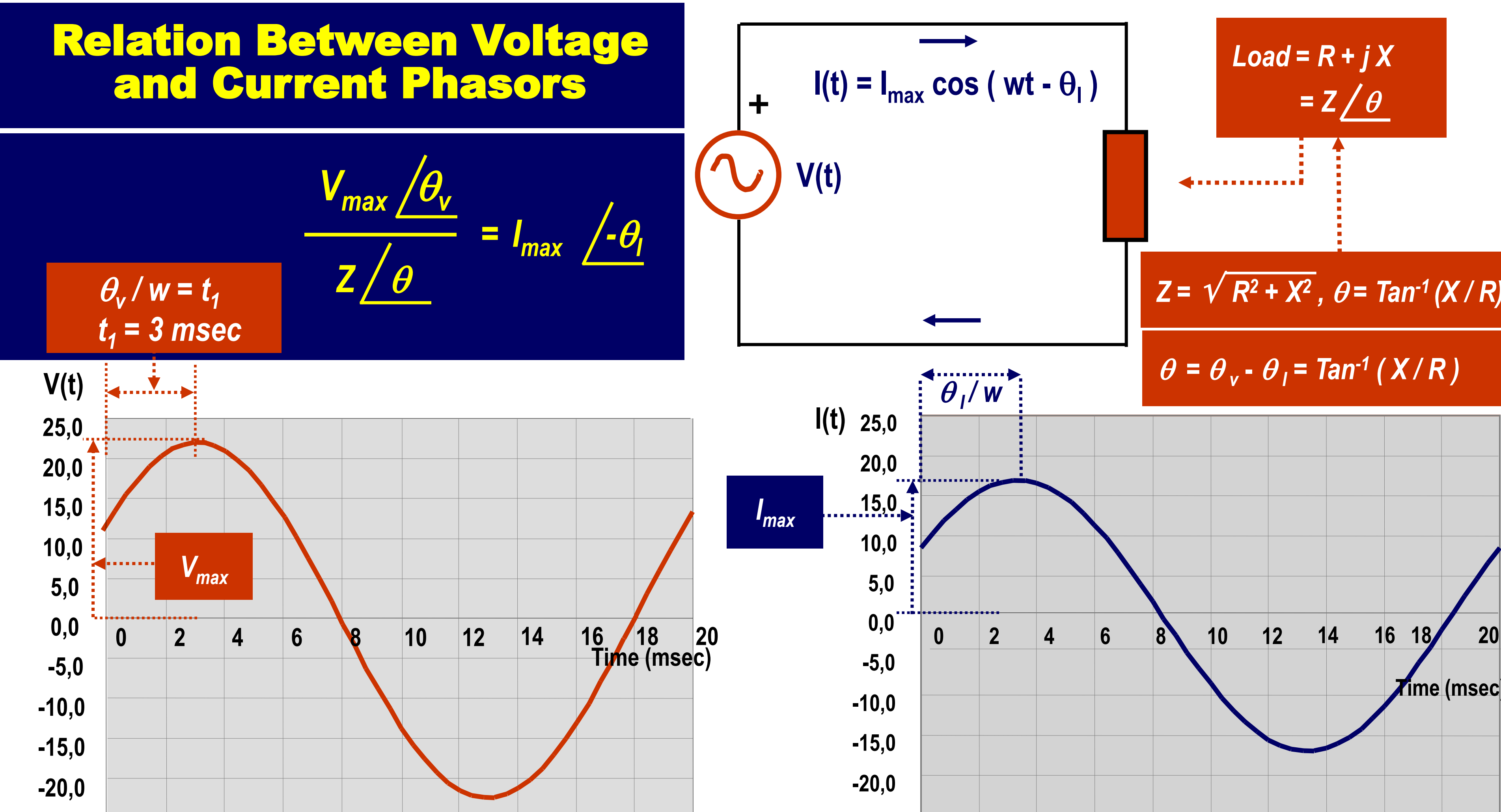
$$V_{max} \angle - \theta_v$$





AC Power

Current Waveform



AC Power

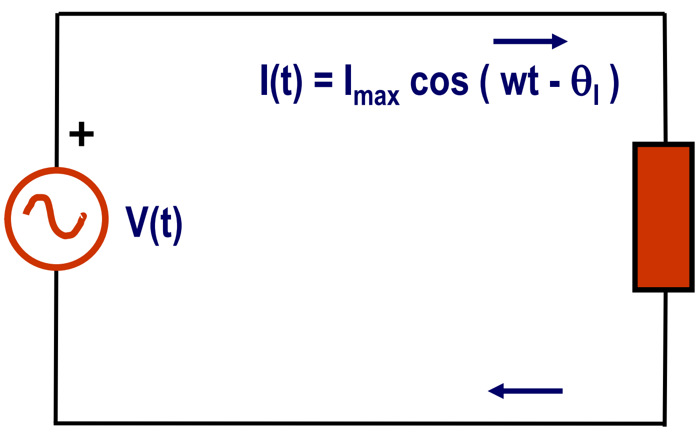
Current Waveform

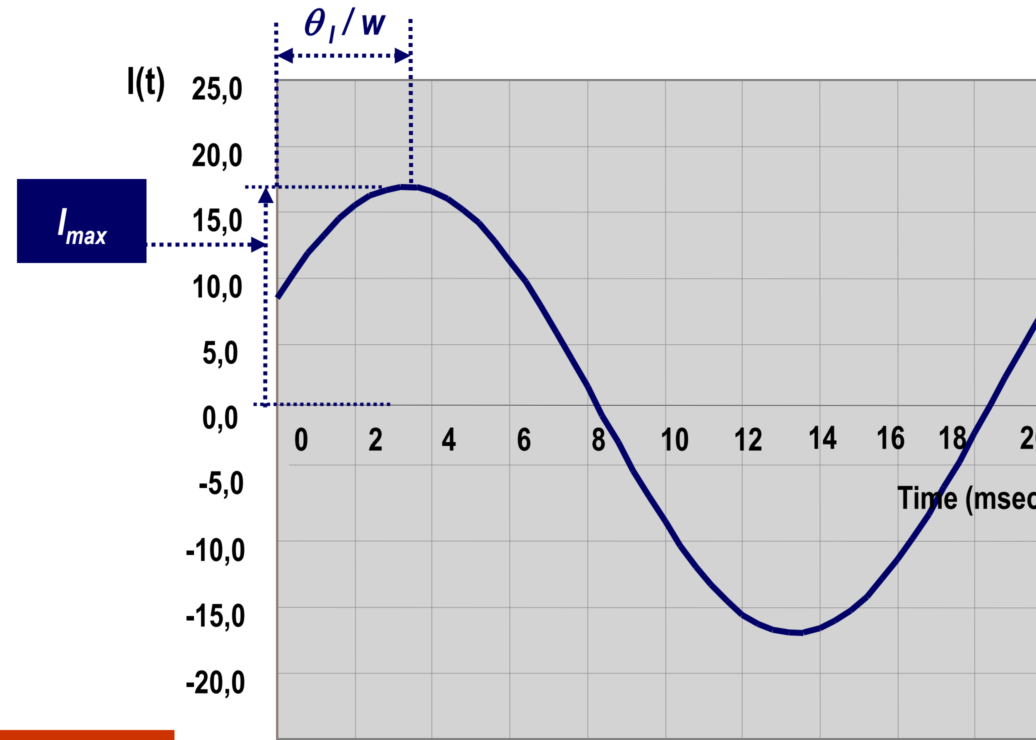
Phasor representation of this current will then be

$$I_{max} \angle -\theta_I$$

Waveform representation of this current will then be

$$I(t) = I_{max} \cos (wt - \theta_I)$$





$Load = R + j\,X$

$= Z \angle \theta$

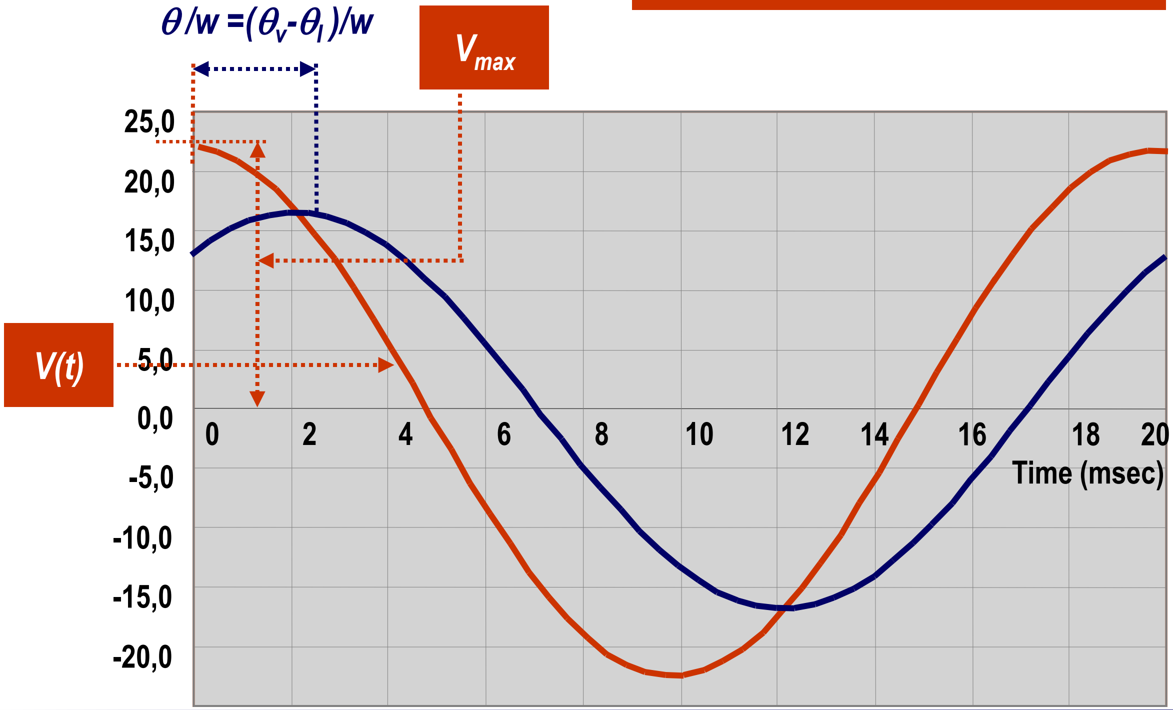
$Z = \sqrt{R^2 + X^2}\,,\ \ \theta_I = Tan^{-1} (X / R)$

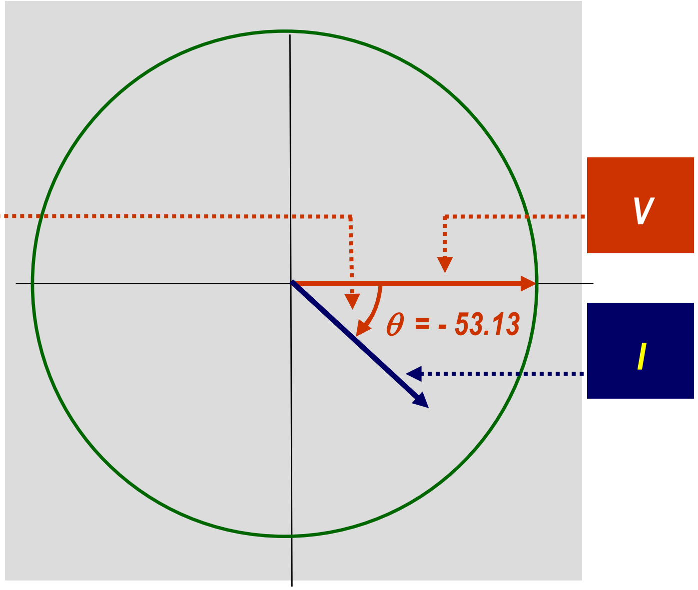
AC Power

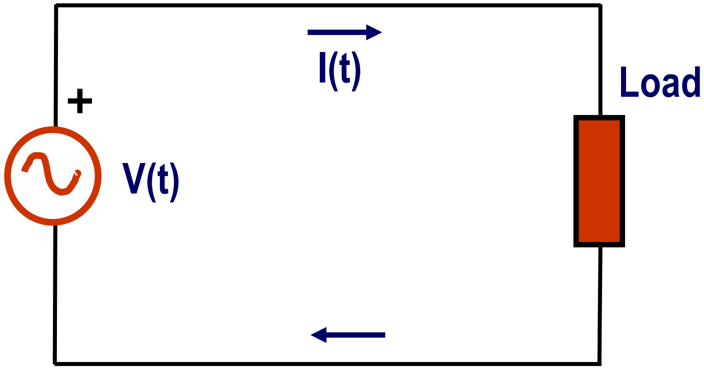
Voltage and Current Waveforms

Please note that the angle difference $\theta_V - \theta_I$ depends only on the resistance R and reactance X of the load

$$\theta = \theta_V - \theta_I = Tan^{-1}(X/R)$$







AC Power - Power Expression

Voltage and current waveforms are

$V(t) = V_{max} \cos wt$

$I(t) = I_{max} \cos (wt - \theta)$

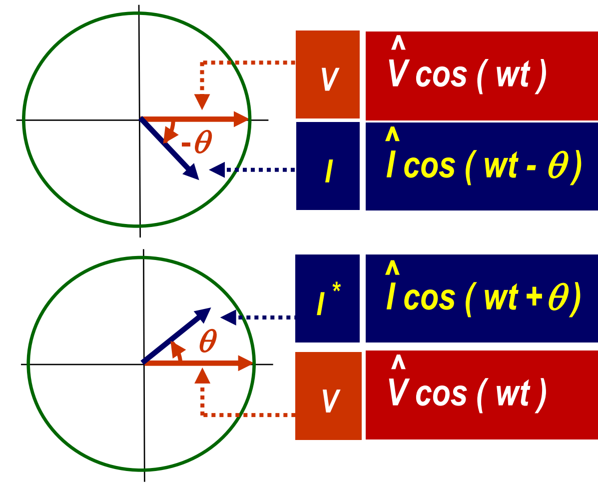
Power waveform will then be

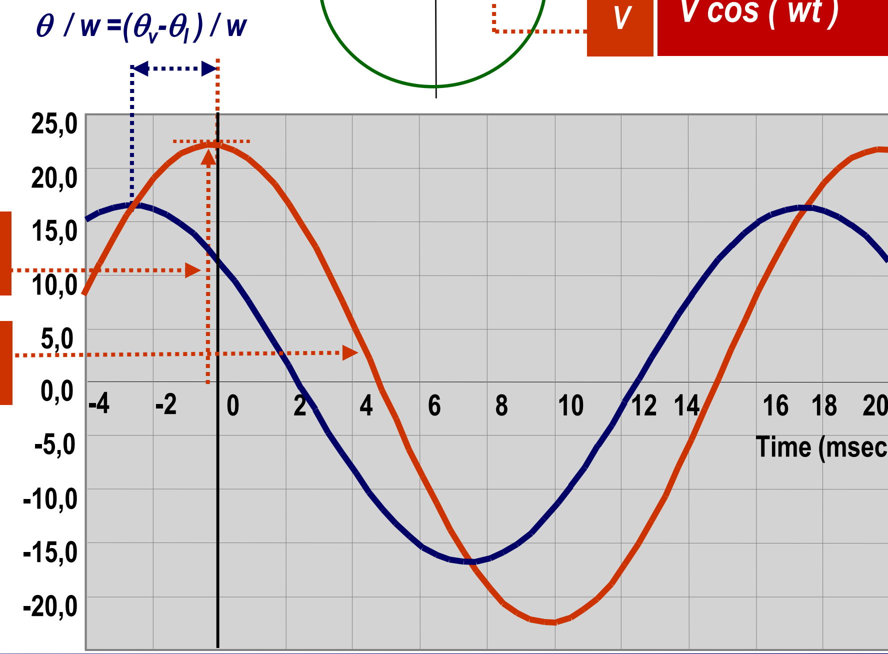
$S(t) = V(t) \times I(t)^*$

$= V_{max} \cos wt \times I_{max} \cos (wt + \theta)$

Please note that; "-" sign here has been altered due to the conjugation operation in the definition of power:

$S = V \times I^*$





$\cos (a + b) = \cos a \cos b - \sin a \sin b$	V_{max}
$\cos (a - b) = \cos a \cos b + \sin a \sin b$	$V(t)$

+

$\cos (a + b) + \cos (a - b) = 2 \cos a \cos b$

$\cos a \cos b = ½ [\cos (a + b) + \cos (a-b)]$

AC Power - Power Expression

Power waveform is the product of the voltage and conjugate of the current waveforms

$S(t) = V_{max}\ I_{max} \cos\ wt \times \cos(wt + \theta)$

$\cos a \times \cos b = ½ [\cos(a + b) + \cos(a - b)]$

$S(t) = ½\ V_{max} I_{max} [\cos(wt + wt + \theta) + \cos(wt - wt - \theta)]$

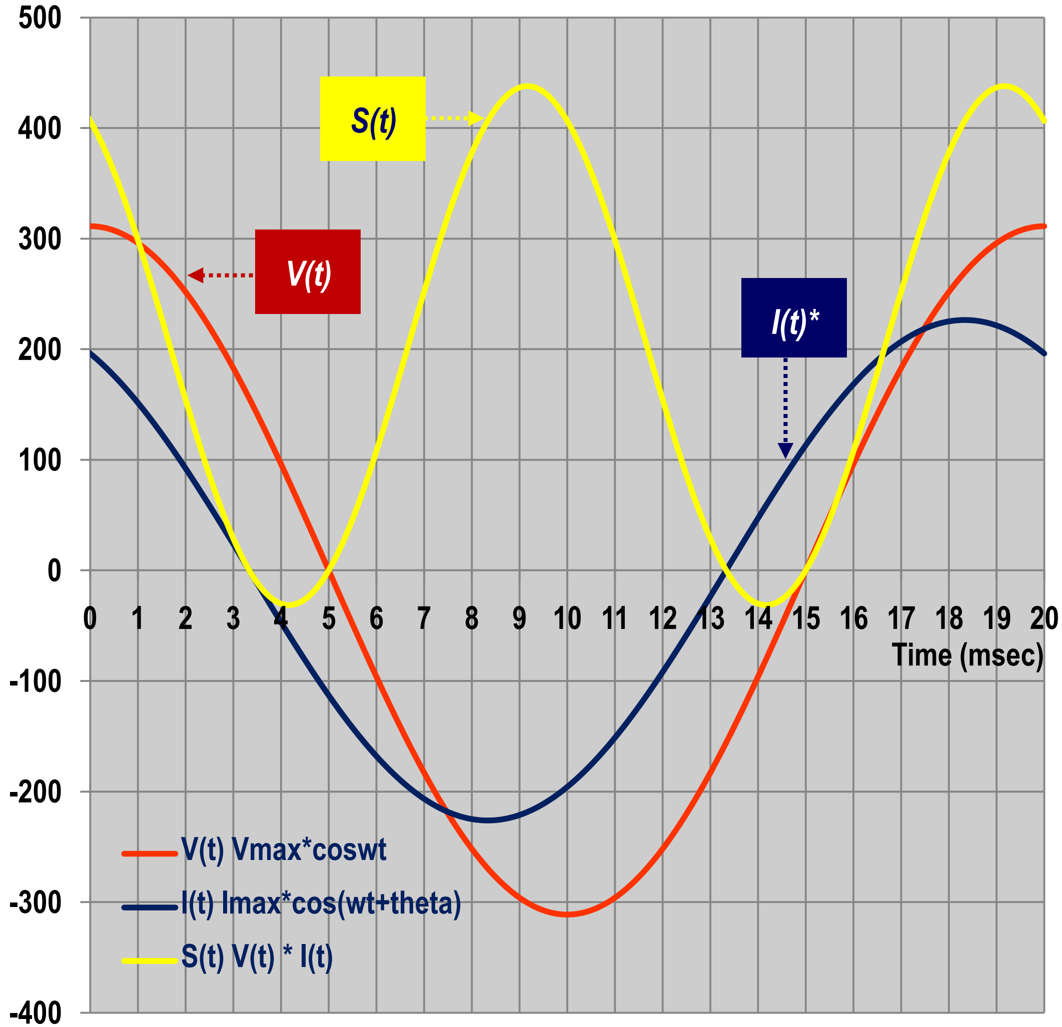
$= ½\ V_{max} I_{max} [\cos(2wt + \theta) + \cos \theta]$

$= (V_{max}/\sqrt{2})(I_{max}/\sqrt{2}) [\cos(2wt + \theta) + \cos \theta]$

$= V_{rms} I_{rms} [\cos(2wt + \theta) + \cos \theta]$

$V_{rms} = V_{max}/\sqrt{2}$

$\theta = \theta_V - \theta_I = Tan^{-1}(X/R)$

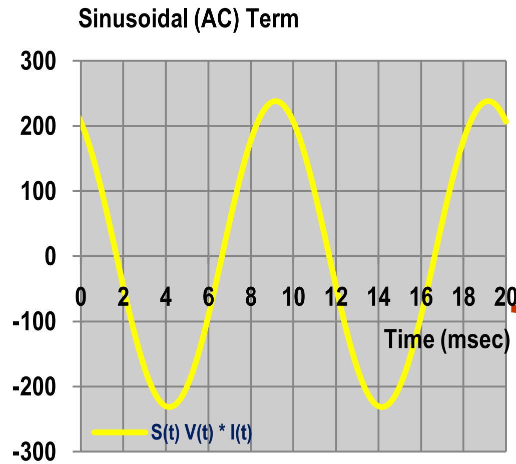


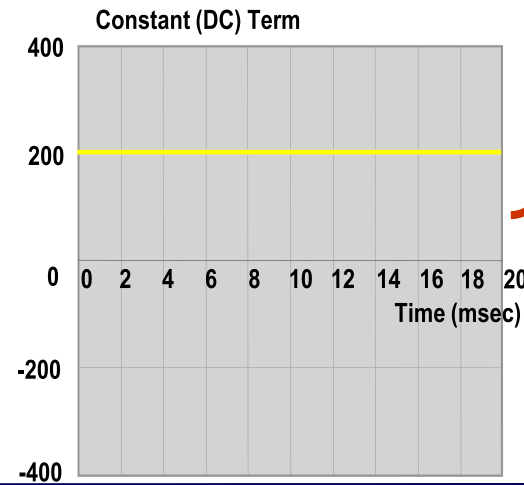
AC Power – Decomposition of Power Expression

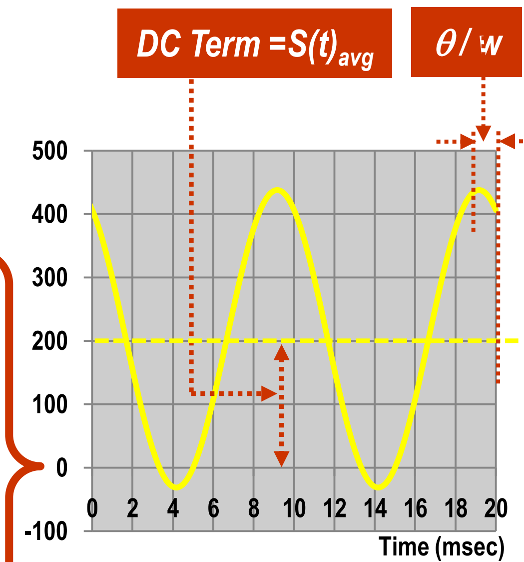
Power expression may be decomposed into two components

$$S(t) = V_{rms}\, I_{rms} \cos(\,2wt + \theta\,) + V_{rms}\, I_{rms} \cos\theta$$

Sinusoidal (AC) Term — *Constant (DC) Term*







AC Power

AC Power – Average Power Expression

Average Power

$S(t) = V_{rms} \, I_{rms} \, [\cos(2wt + \theta) + \cos\theta]$

$S(t)_{avg} = (1/T) \int_0^T S(t)\, dt$

$S(t)_{avg} = (1/T) \int P(t)\, dt$

$= (1/T) \int V_{rms} \, I_{rms} \, [\cos(2wt + \theta) + \cos\theta]\, dt$

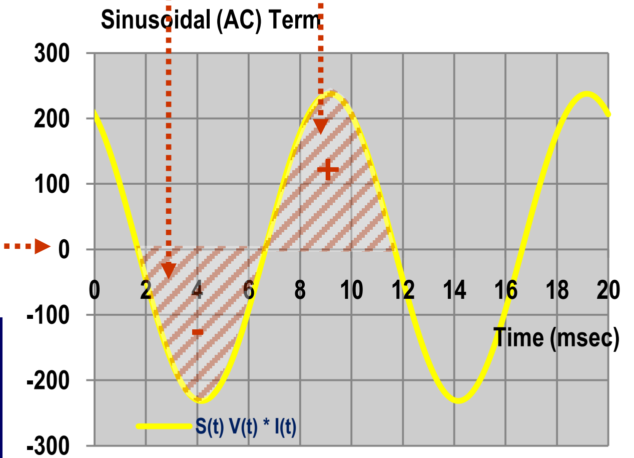
$= (1/T) \int V_{rms} \, I_{rms} \cos(2wt + \theta)\, dt + (1/T) \int V_{rms} \, I_{rms} \cos\theta\, dt$

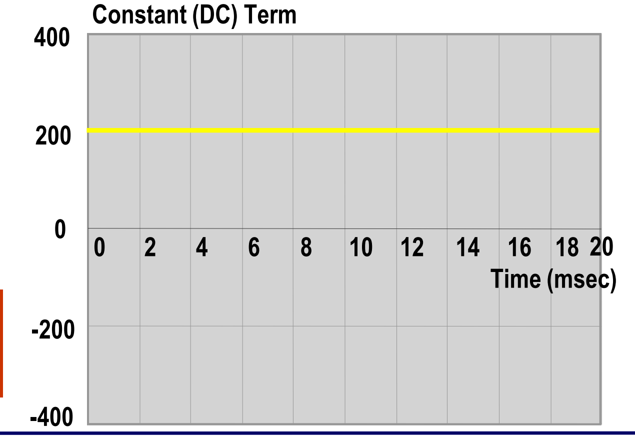
zero

Constant (DC) Term

Average is zero

Sum of these areas is zero





AC Power

AC Power – Average Power Expression

Average Power

$S(t)_{avg} = (1/T) \int P(t)\, dt$

$= (1/T)\ V_{rms}\, I_{rms} \int \cos\theta\, dt$

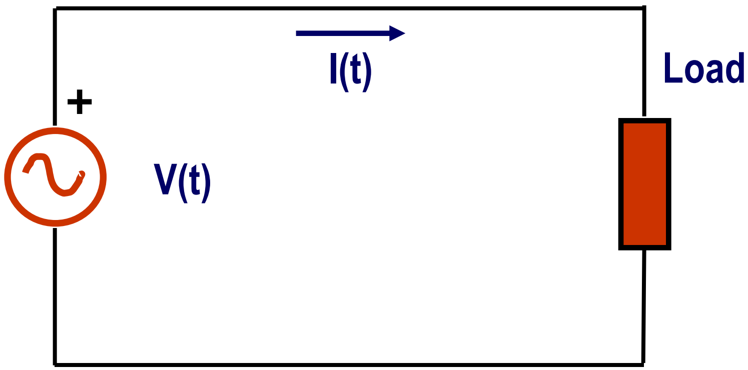
$= (1/T)\ V_{rms}\, I_{rms} \cos\theta \int dt$

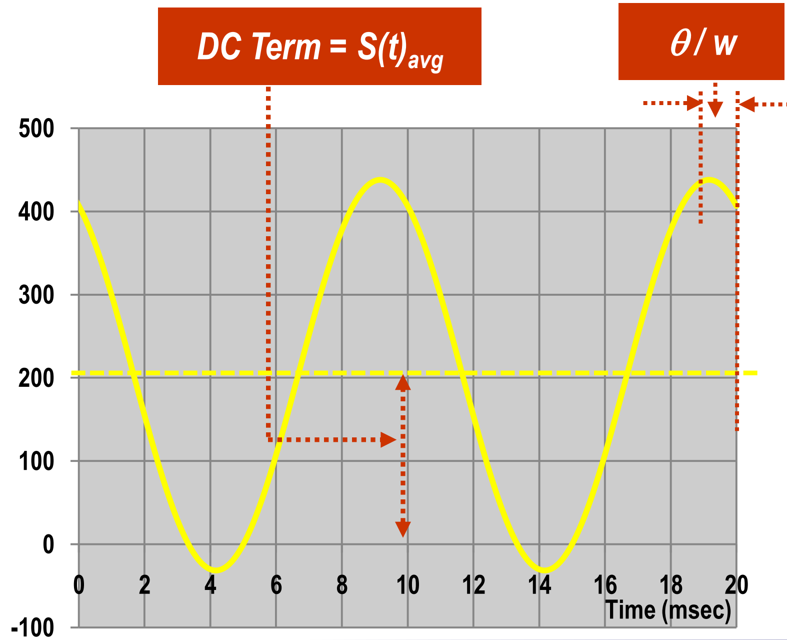
$\int_0^T dt = T$

$= (1/T)\ T\ V_{rms}\, I_{rms} \cos\theta$

$= V_{rms}\, I_{rms} \cos\theta$

$$S(t)_{avg} = V_{rms}\, I_{rms} \cos\theta$$





AC Power

Example

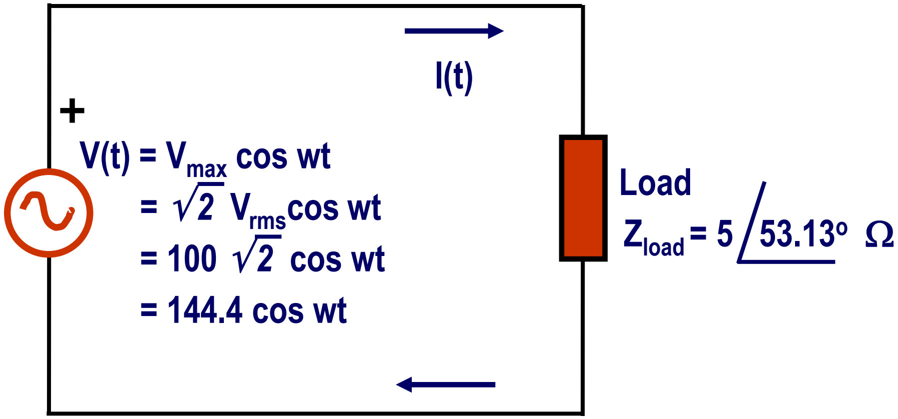
Question

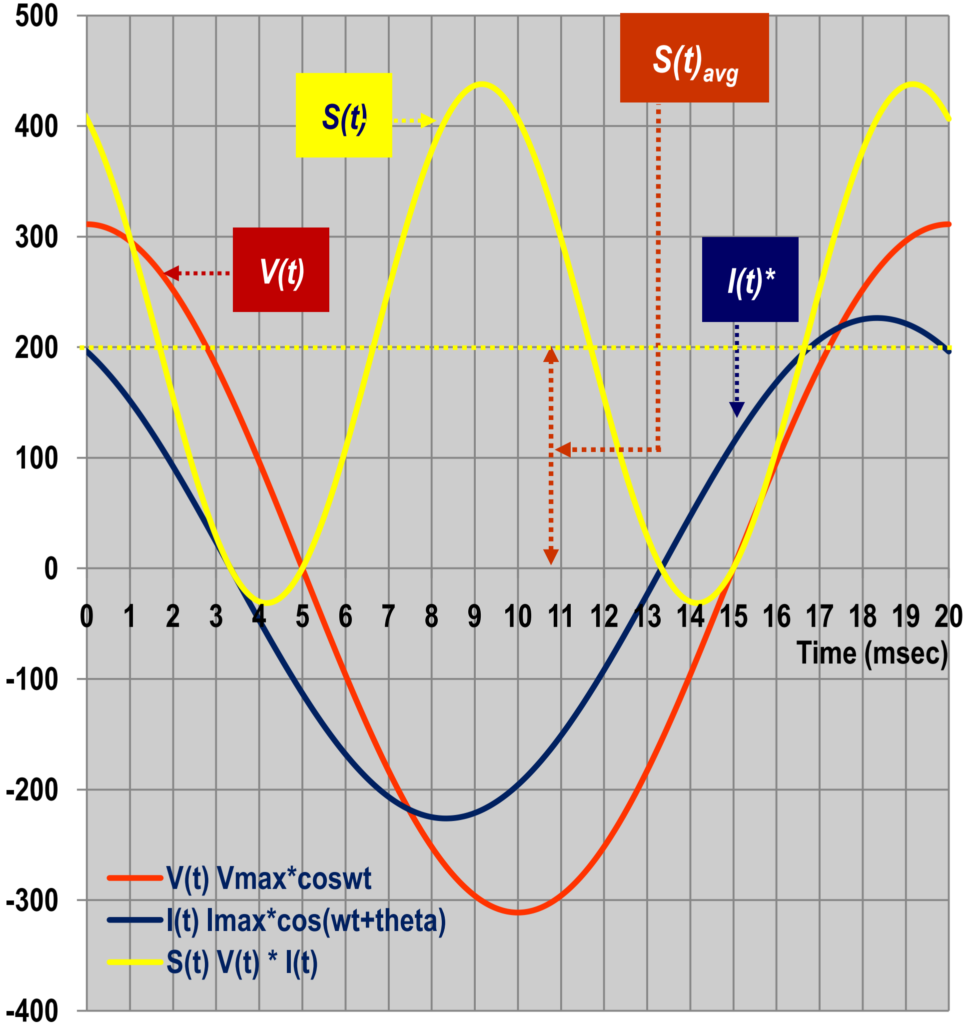
Calculate the average and instantaneous powers dissipated in the load shown below

Parameters:

V_{rms} = 100 Volts

$Z_{load} = 3 + j\,4$ Ohms $= 5\angle 53.13^o$ Ohms





AC Power

METU

Example

Solution

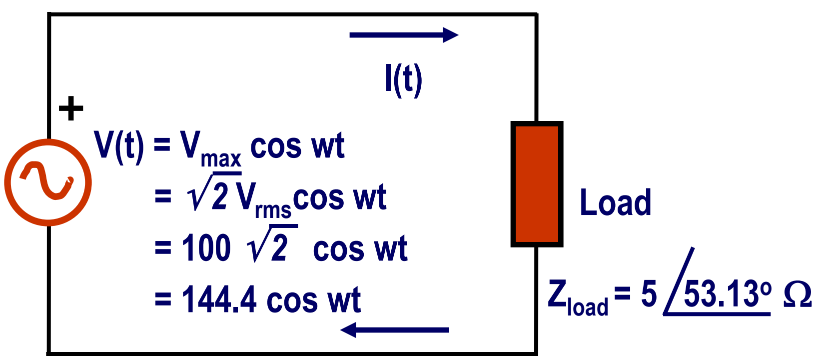
$V_{max} = 100 \times \sqrt{2} = 144.4$ Volts

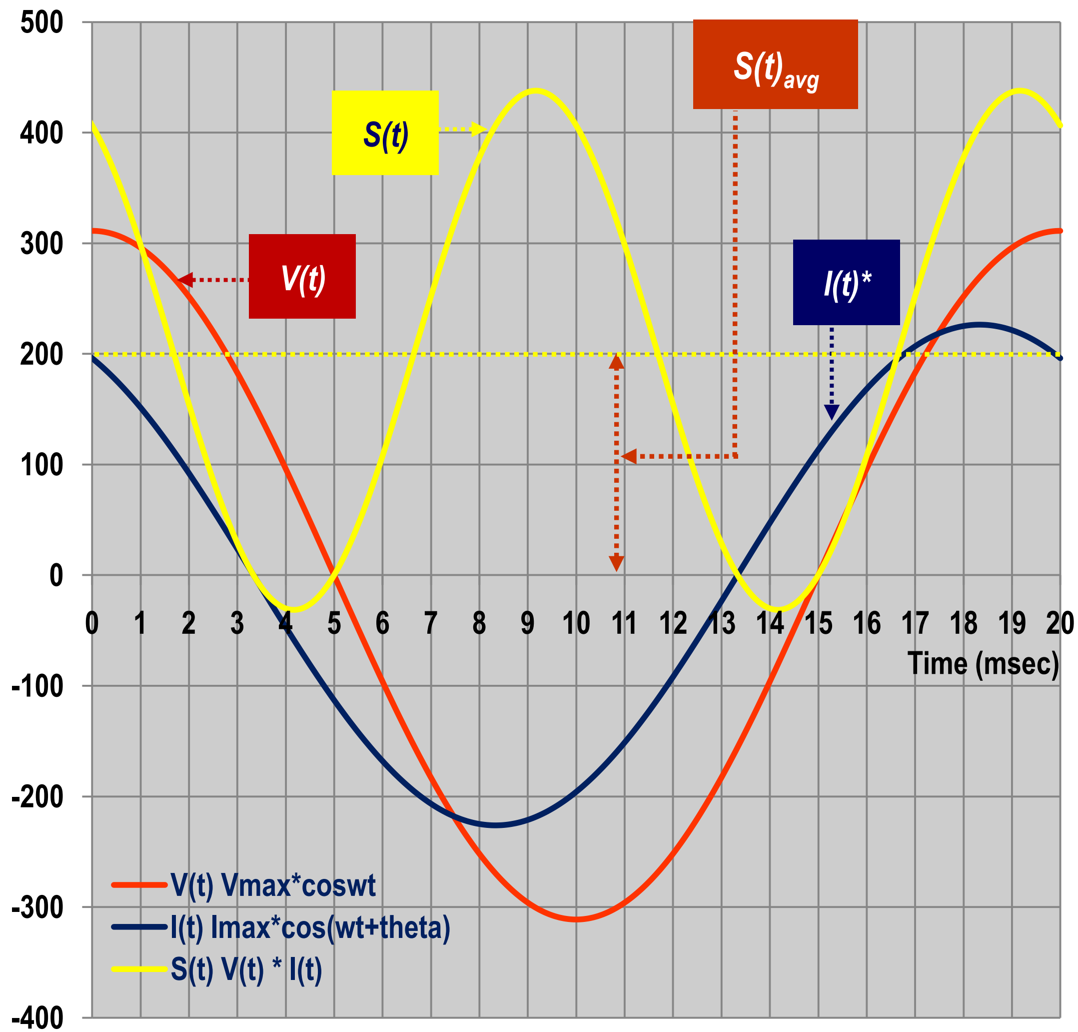
$I = V_{max} \angle 0^o \; / \; Z \angle \theta$

$= 144.4 \angle 0^o \; / \; 5 \angle 53.13^o$

$= 28.8 \angle -53.13^o$ Amp

$I_{rms} = I_{max} / \sqrt{2} = 28.8 / \sqrt{2} = 20$ Amp





AC Power

Example

Solution

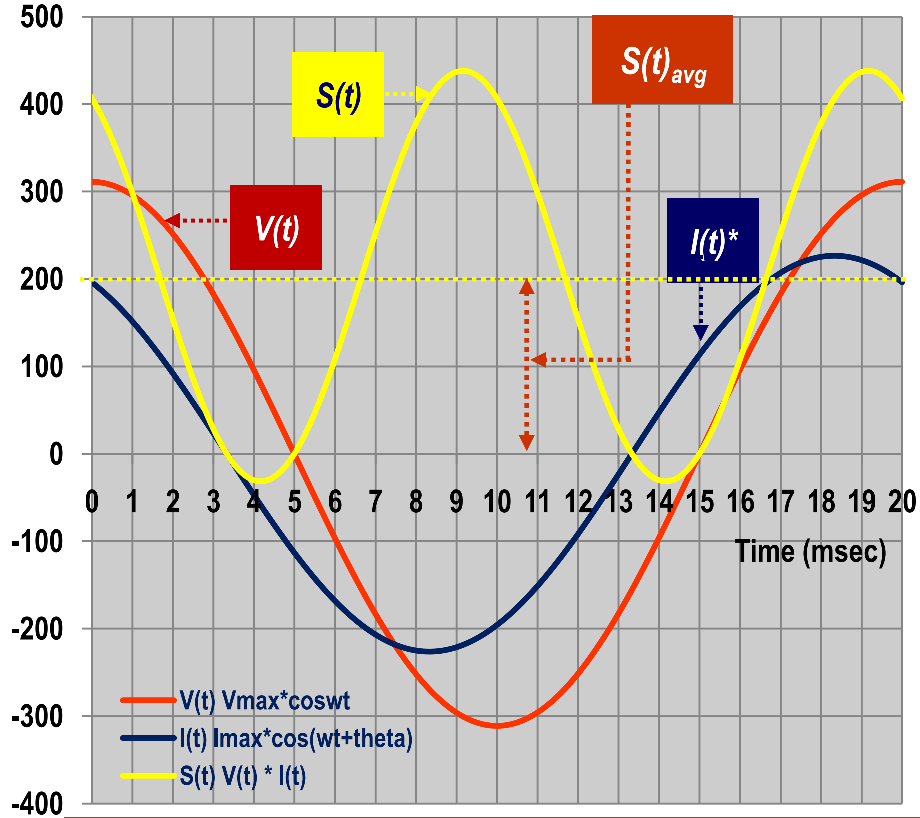
$S(t)_{avg} = V_{rms}\, I_{rms} \cos\theta$

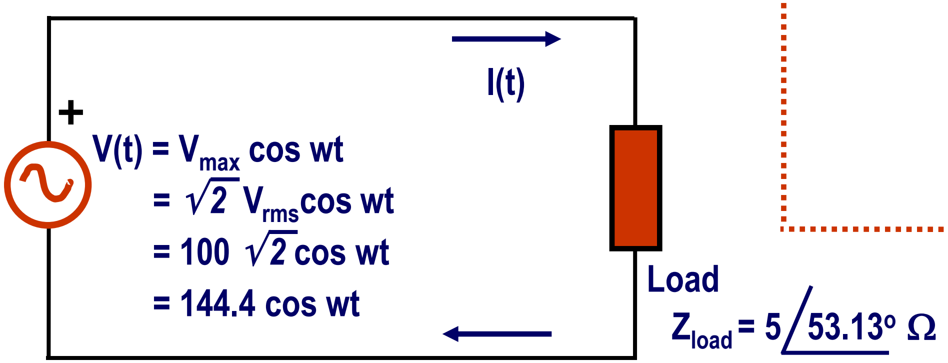
$= 100 \times 20 \cos 53.13 = 1200$ Watt

$S(t) = V(t)\, I(t)$

$= \sqrt{2} \times 100 \cos wt \times \sqrt{2} \times 20 \cos(wt + 53.13^o)$

$= 4000 \cos wt \times \cos(wt + 53.13^o)$





Please note that;
"-" sign here has been changed to "+" due to the conjugate operation in the definition of power:
$S = V \times I^*$

AC Power

Example

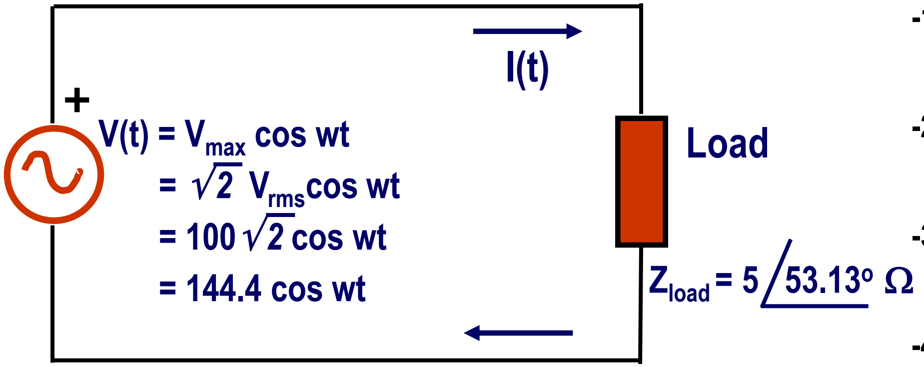
Solution

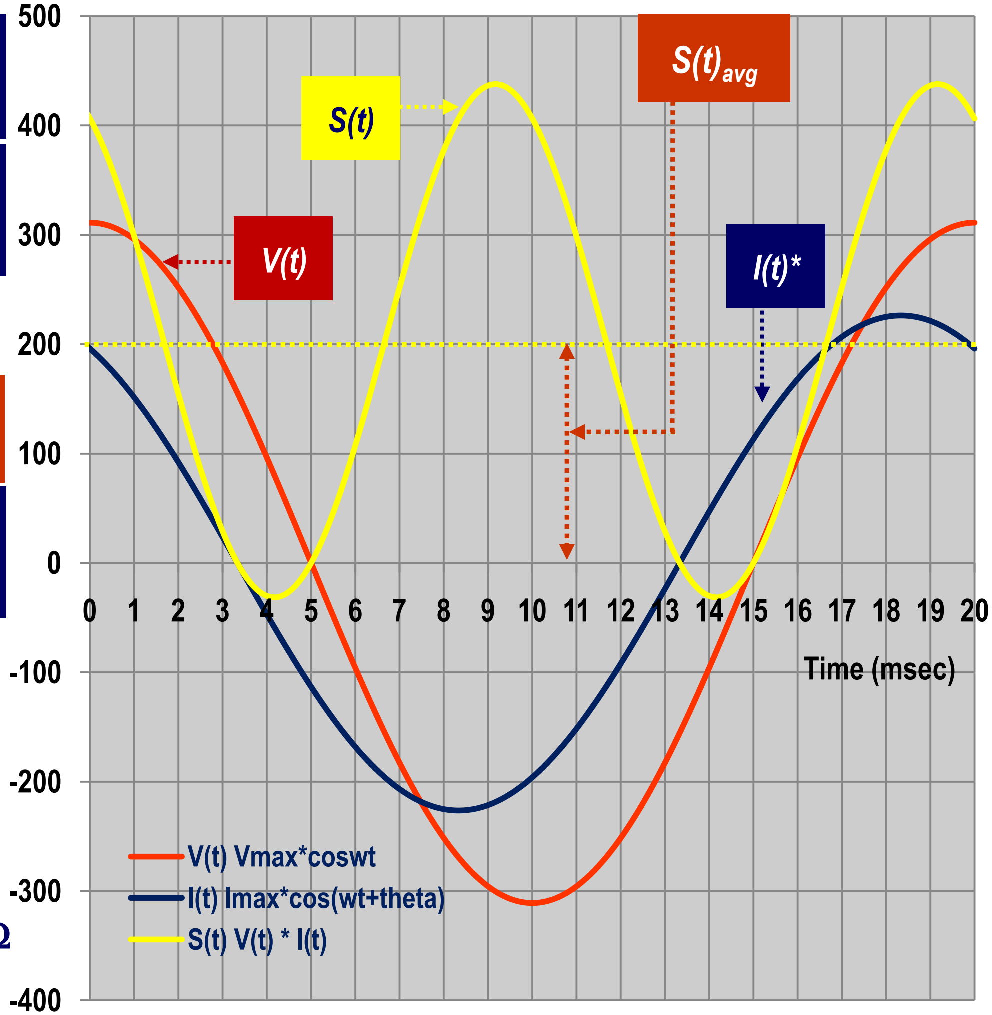
$S(t) = 4000 \cos wt \times \cos (wt + 53.13^o)$

or by using the following identity;

$\cos a \cos b = ½ [\cos (a + b) + \cos (a - b)]$

$S(t) = 2000 [\cos (2wt + 53.13^o) + \cos 53.13^o]$





Complex Power

Active Power Expression

Expanding the first term in the power expression;

$S(t) = V_{rms}\ I_{rms}\ [\cos(2wt + \theta) + \cos\theta]$

$= V_{rms}\ I_{rms}\ (\cos 2wt \cos\theta - \sin 2wt \sin\theta + \cos\theta)$

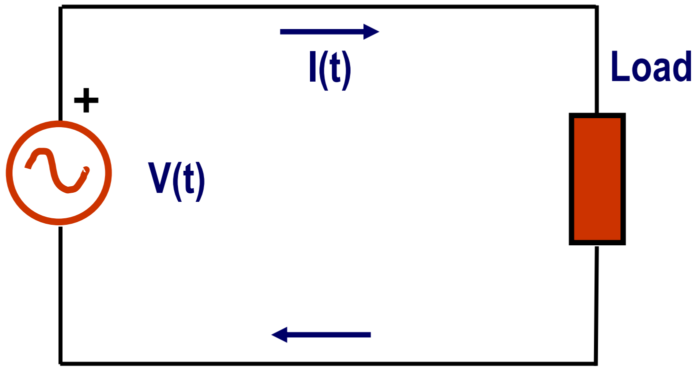
$\cos(a + b) = \cos a \cos b - \sin a \sin b$

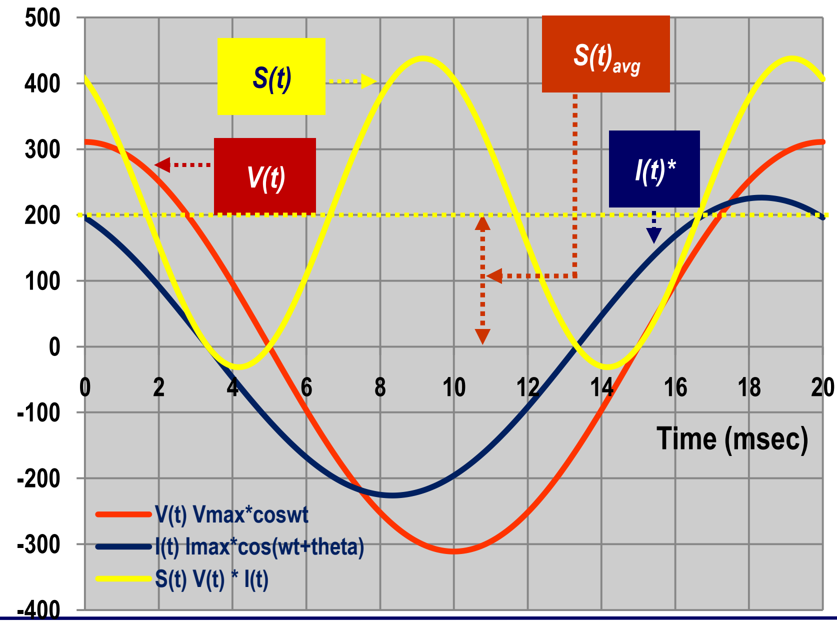
and recombining the cosine terms;

$= V_{rms}\ I_{rms}\ [\cos\theta\,(1 + \cos 2wt) - \sin 2wt\ \sin\theta\ ]$

$P(t)$ = Active power

$Q(t)$ = Reactive power





AC Power

Complex Power

$$S(t) = V_{rms}\, I_{rms}\, [\, \cos\theta\, (\, 1 + \cos 2wt\,) \; - \sin 2wt \;\; \sin\theta \,]$$

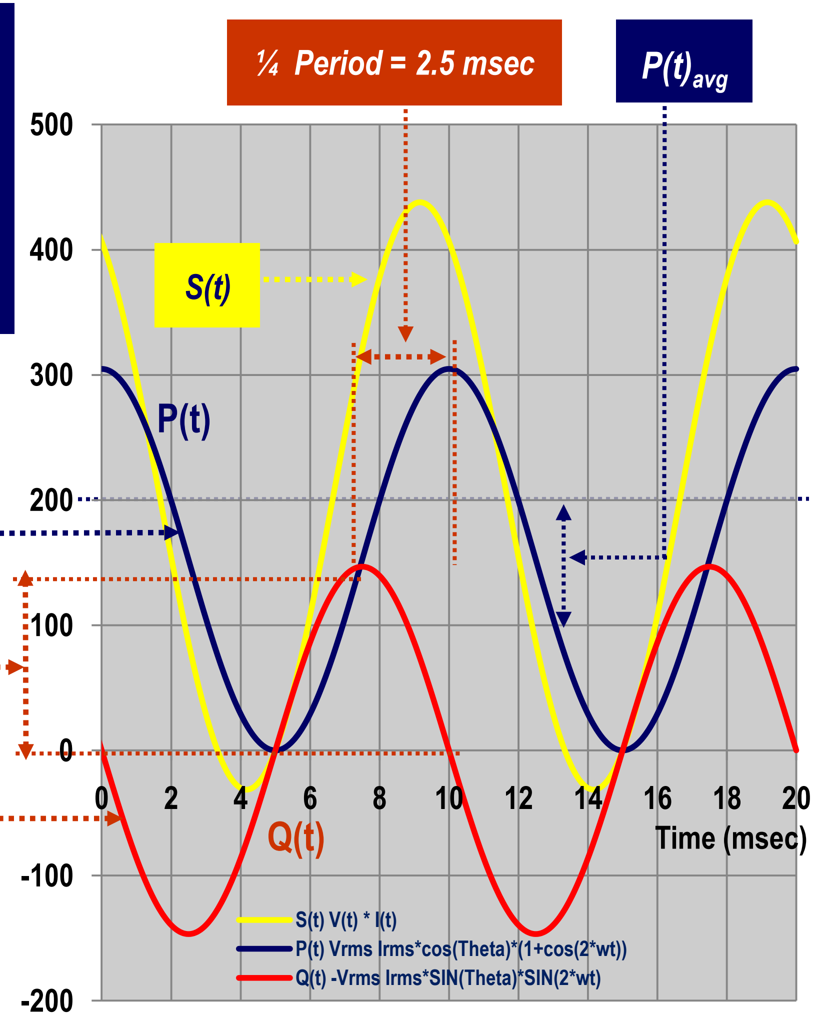
$$= V_{rms}\, I_{rms}\, \cos\theta\, (\, 1 + \cos 2wt\,) - \boxed{V_{rms}\, I_{rms}\, \sin\theta}\, \sin 2wt$$

$$= V_{rms}\, I_{rms}\, \cos\theta\, (\, 1 + \cos 2wt\,) - \; Q_{max} \;\; \sin 2wt$$

P(t) =Active power

$$Q_{max} = V_{rms}\, I_{rms}\, \sin\, \theta$$

Q(t) = Reactive power

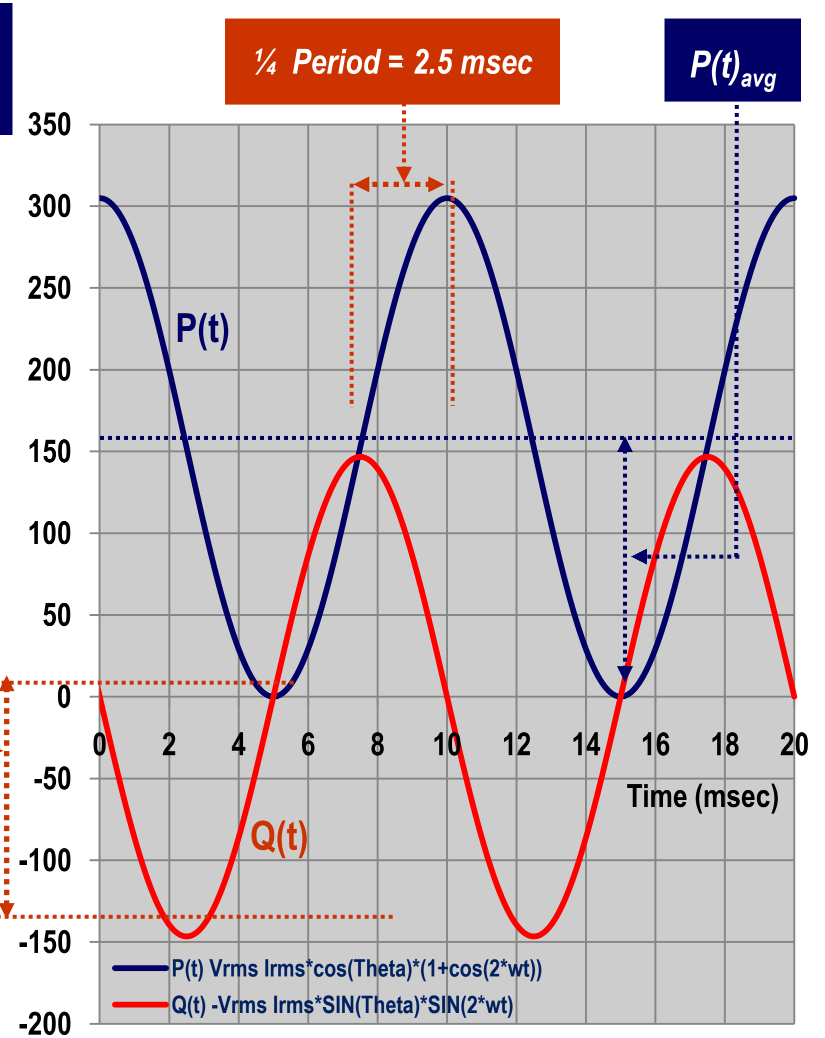


Active and Reactive Powers – Summary

$S(t) = V_{rms}\, I_{rms} \cos\theta\, (1 + \cos 2wt) - V_{rms}\, I_{rms} \sin\theta\, \sin 2wt$

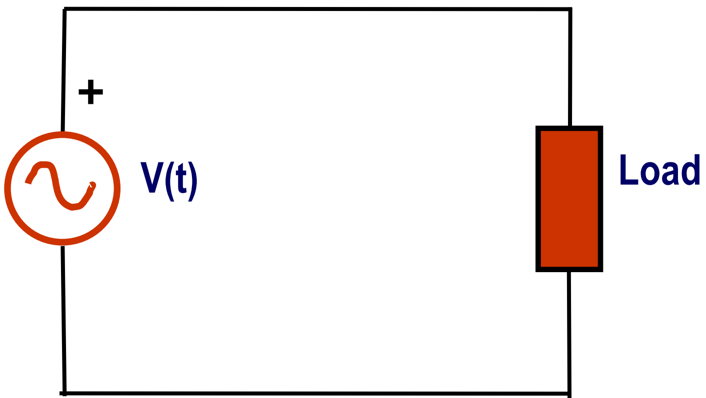
Active power	$P(t)_{avg} = V_{rms}\, I_{rms} \cos\theta$
Reactive power	$Q(t) = - Q_{max} \sin 2wt$

Marmara, Unimar Power Plant 470 MW



AC Power
Active and Reactive Power Waveforms

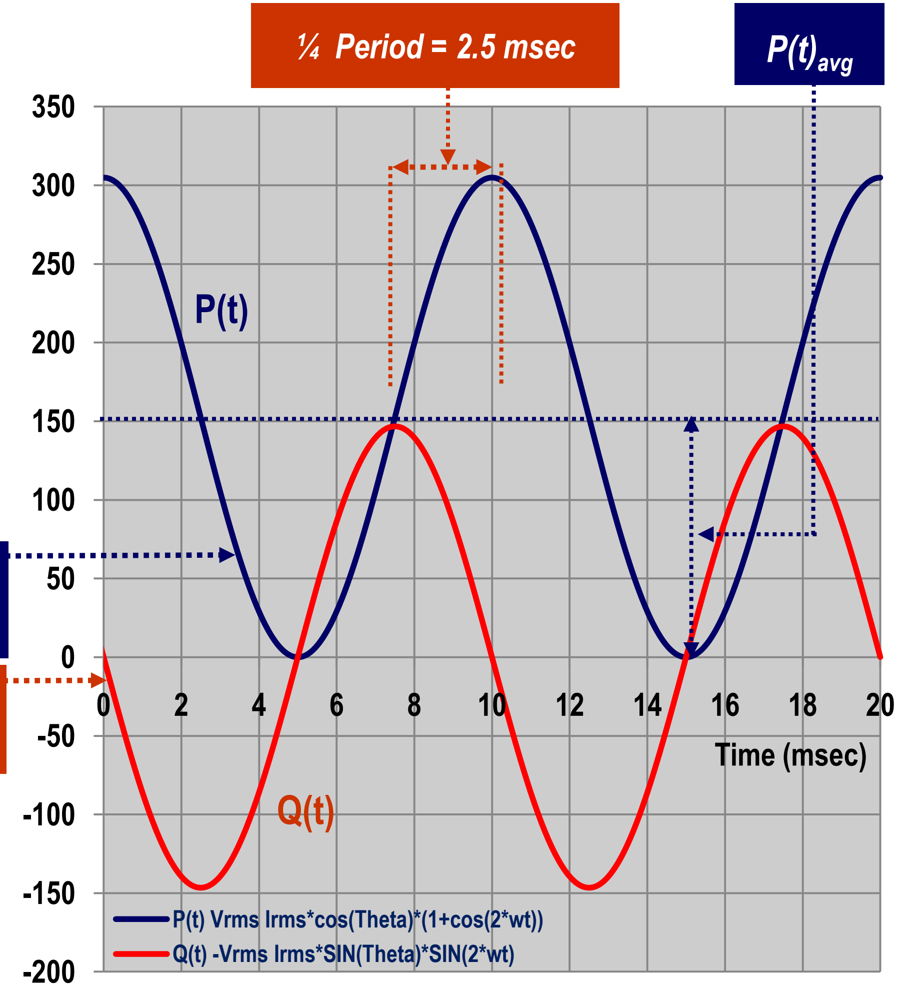
Power (P, Q) ⟶



Full period = 10 msec
¼ period = 2.5 msec
¼ period = 360° / 4 = 90°

P(t) = Active power

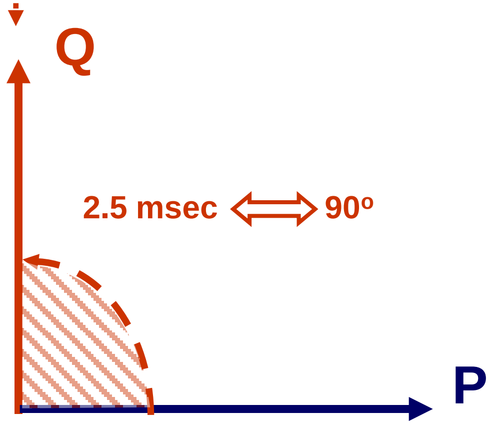
Q(t) =Reactive power



AC Power
Active and Reactive Power Waveforms

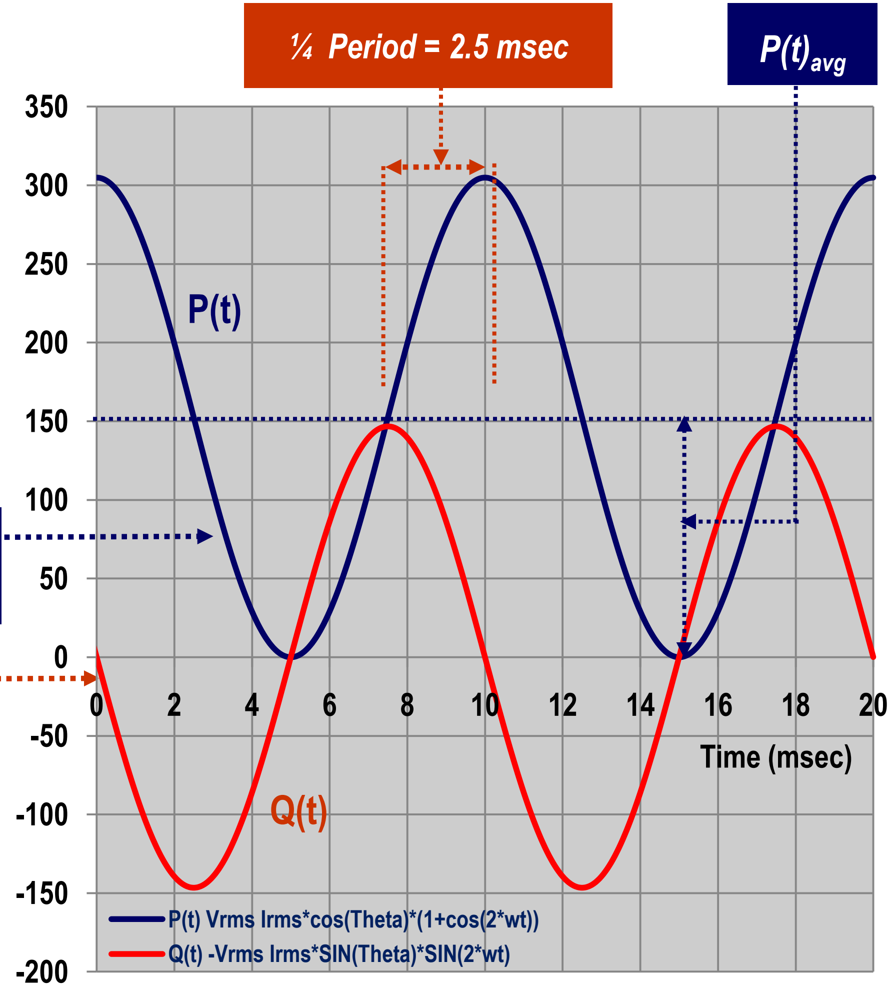
One revolution = 10 msec
Hence,
2.5 msec = 360º / 4 = 90º

Please note that Q leads P by 90º



P(t) = Active power

Q(t) =Reactive power

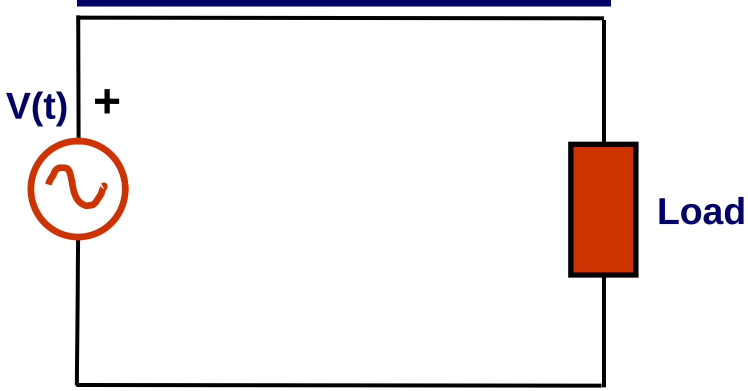


AC Power
Active Power Waveform

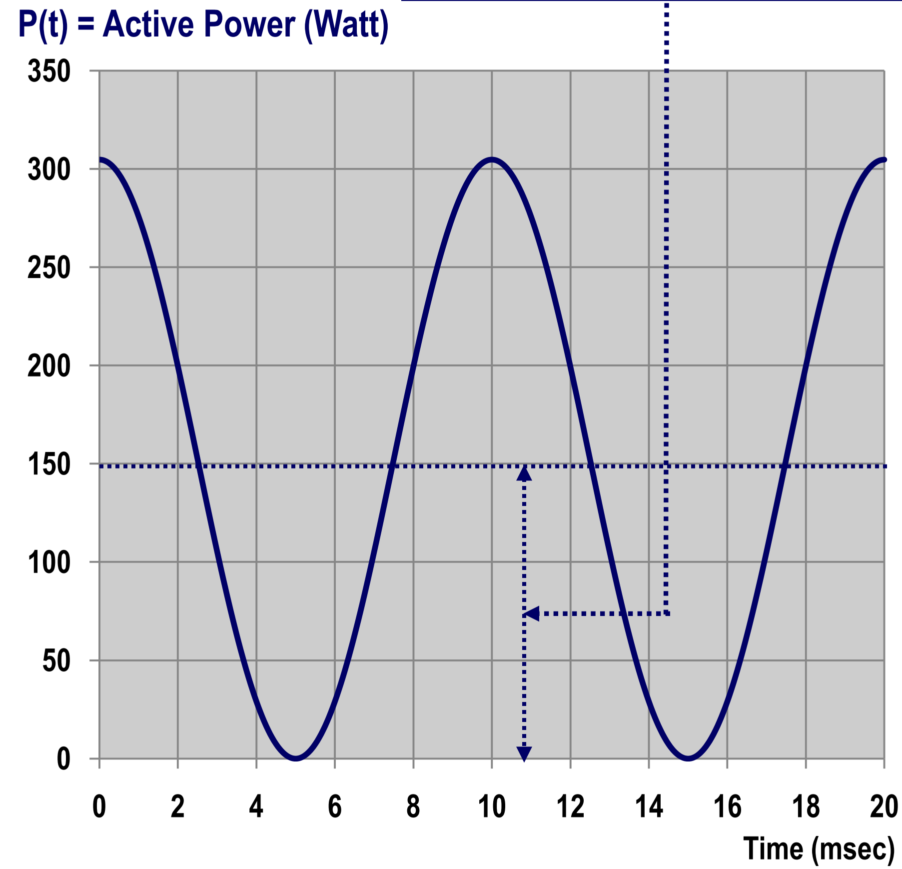
$$P(t) = V_{rms}\, I_{rms}\, \cos\theta\,(1 + \cos 2wt)$$
$$= V_{rms}\, I_{rms}\, \cos\theta + V_{rms}\, I_{rms}\, \cos\theta\, \cos 2wt$$

$P(t)_{avg}$ $P(t)_{sinusoidal}$

Active Power (P) →



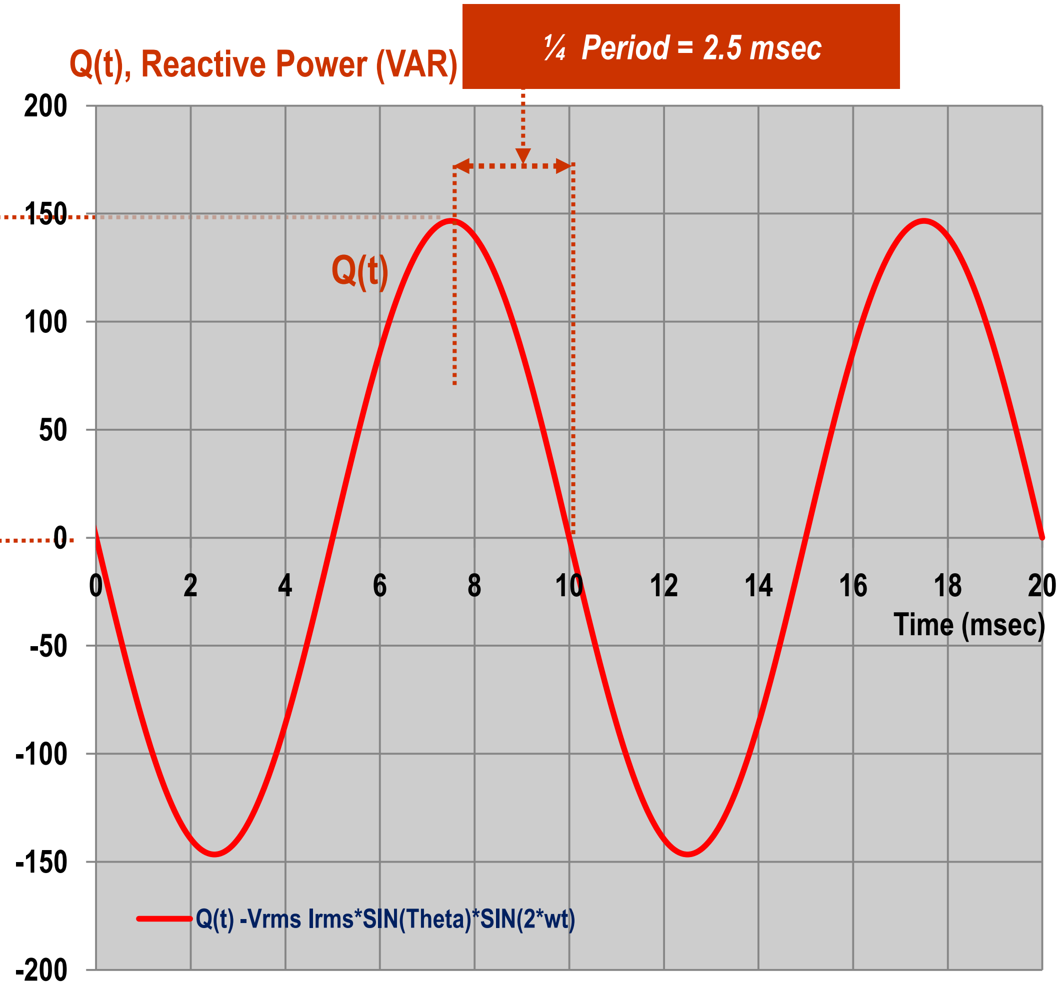
$P(t)_{avg} = 150\ W$



AC Power
Reactive Power Waveform

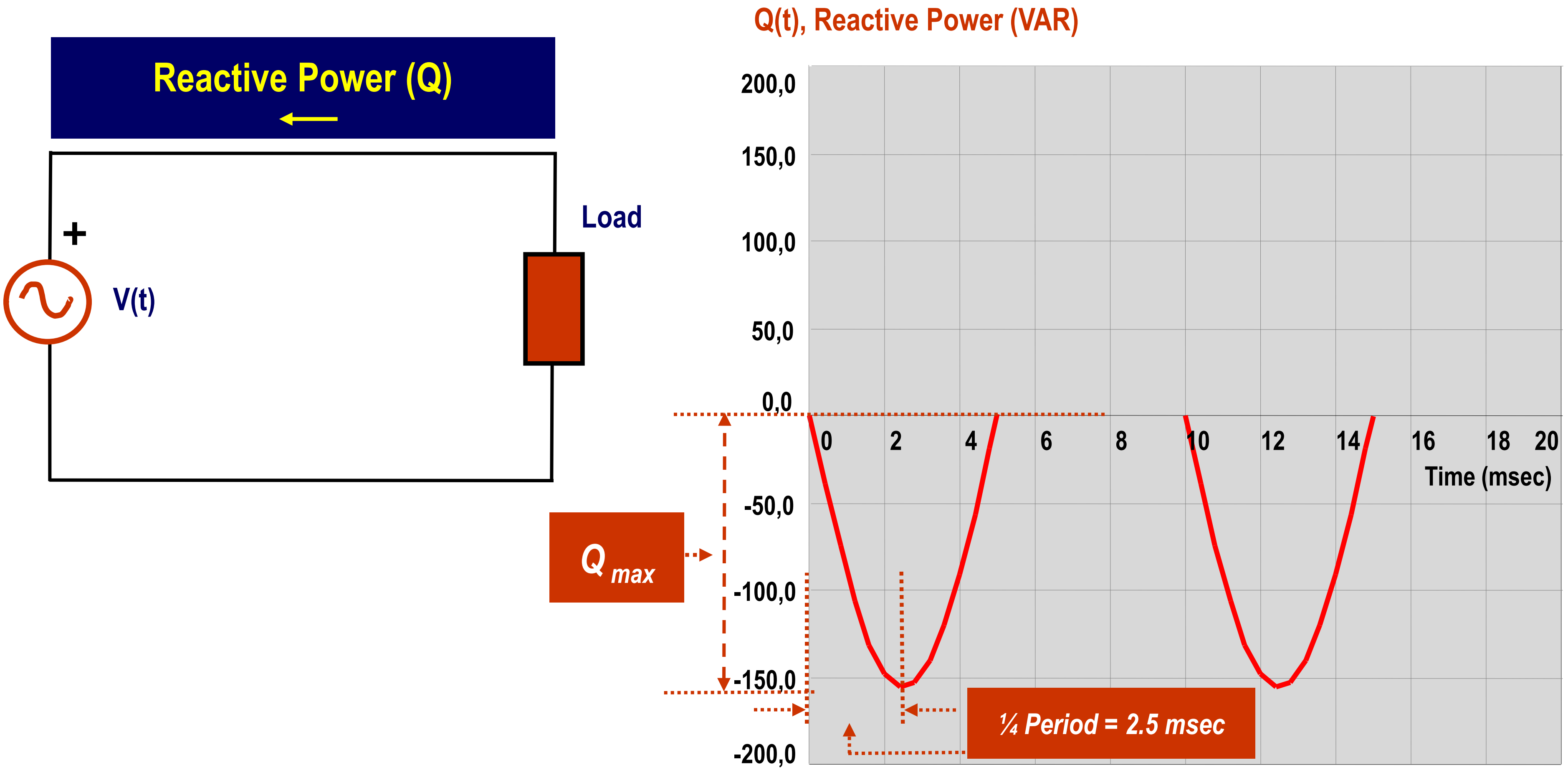
$$Q(t) = V_{rms}\, I_{rms} \sin\theta \ \mathrm{x} \ \sin 2wt$$
$$= Q_{max} \ \sin 2wt$$

$Q(t)_{\ sinusoidal}$ | $Q_{\ max}$

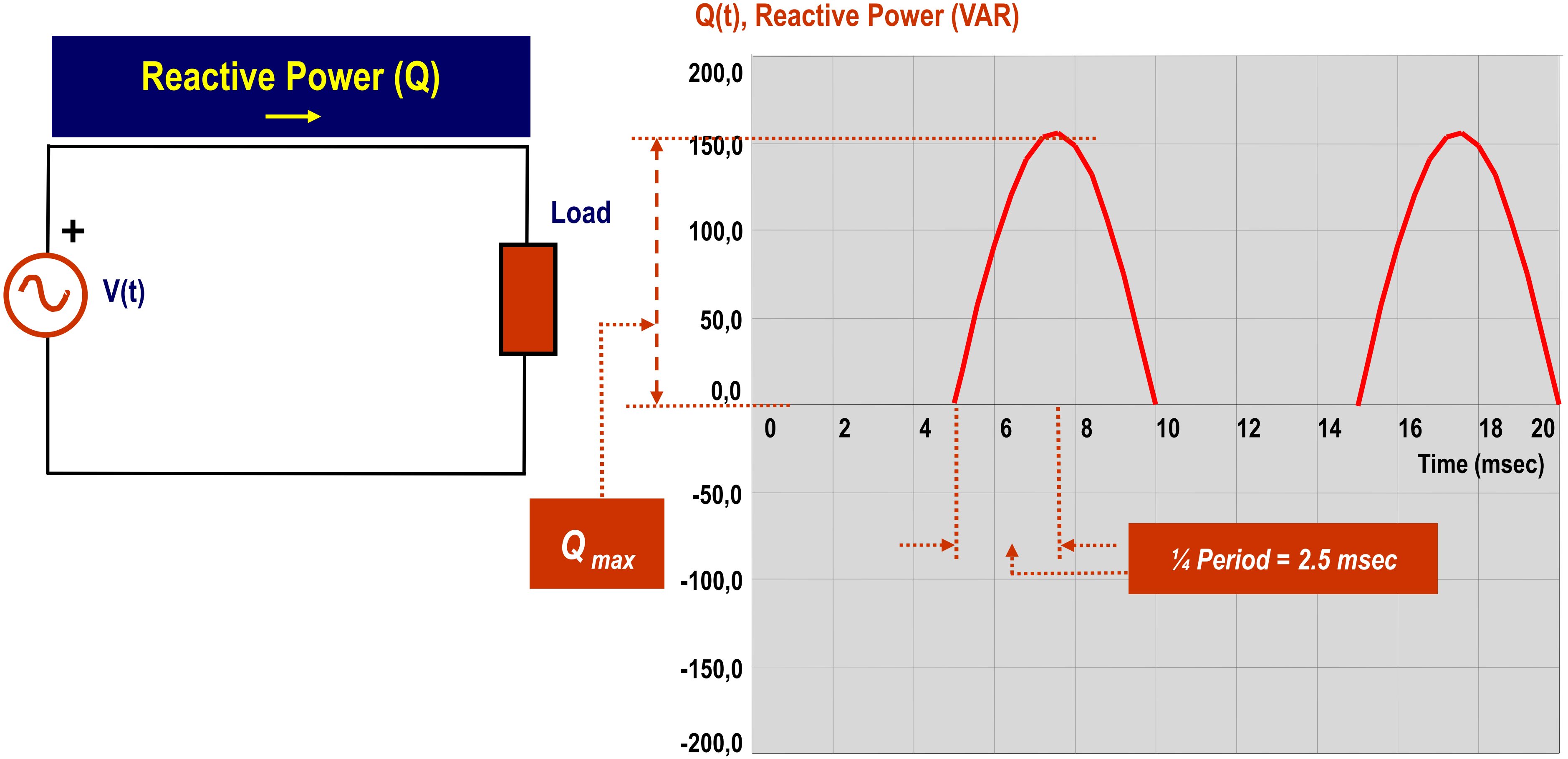


Reactive Power (Q)

AC Power
Reactive Power Waveform
(During the first 5 mseconds)



AC Power
Reactive Power Waveform
(During the next 5 mseconds)

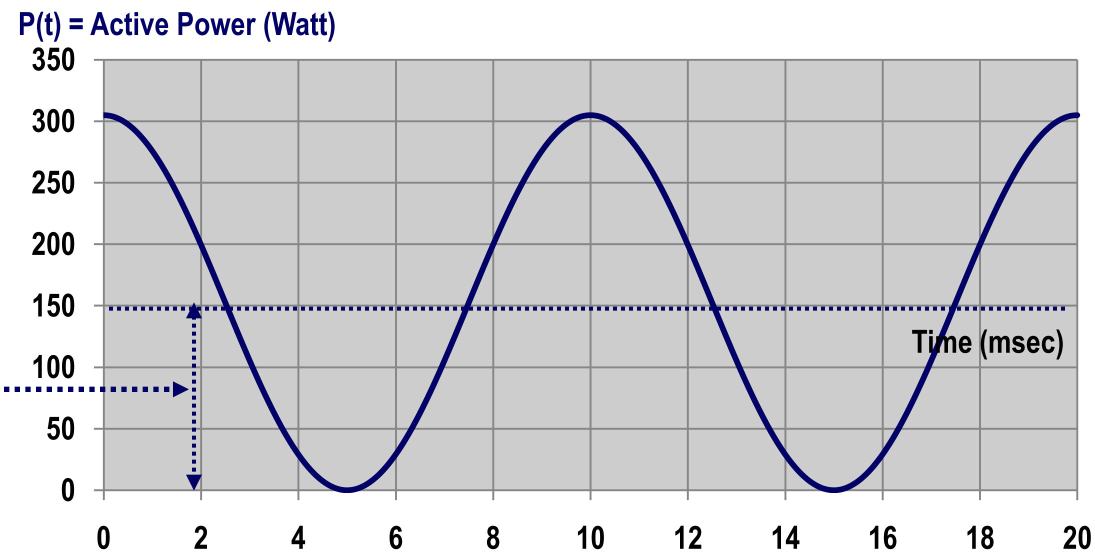


AC Power

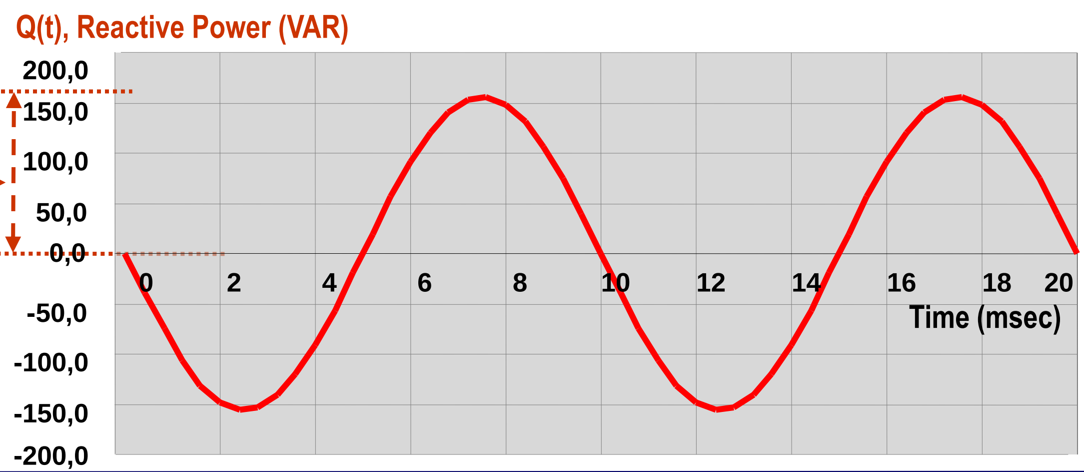
Phosors Representation of Active and Reactive Powers

Mean of P(t) is called active power
Peak of Q(t) is called reactive power

$P(t)_{avg}$ = 150 W



Q_{max} = 160 VAR



Phosors Representation of Active and Reactive Powers

Voltage and Current

Angular speed: w = 2π f
= 2 x 3.14 x 50 = 314 rad/sec

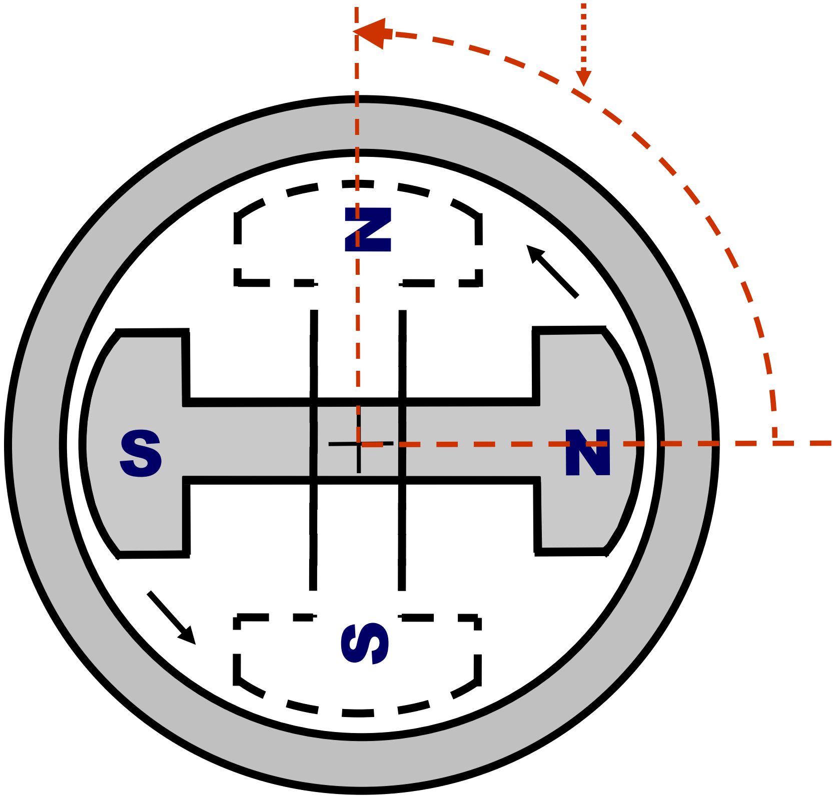
Time for one revolution = 1/f = 1/ 50 = 0.020 sec
= 20 msec

Hence,
Angle for ¼ revolution = 360° / 4 = 90°
Time for ¼ revolution = 20 msec / 4 = 5 msec

Active and Reactive Power

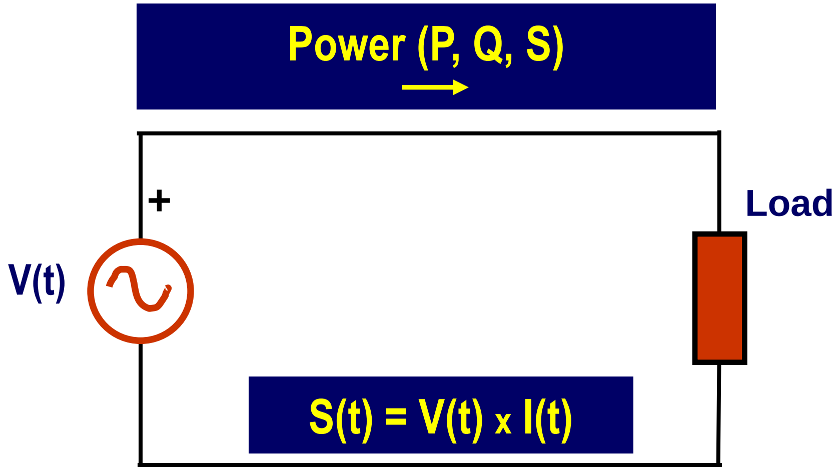
Angular speed: w' = 2 w = 4π f
= 2 x314 = 628 rad/sec
Time for one revolution = 10 msec
Time for ¼ revolution = 10 msec / 4 = 2.5 msec

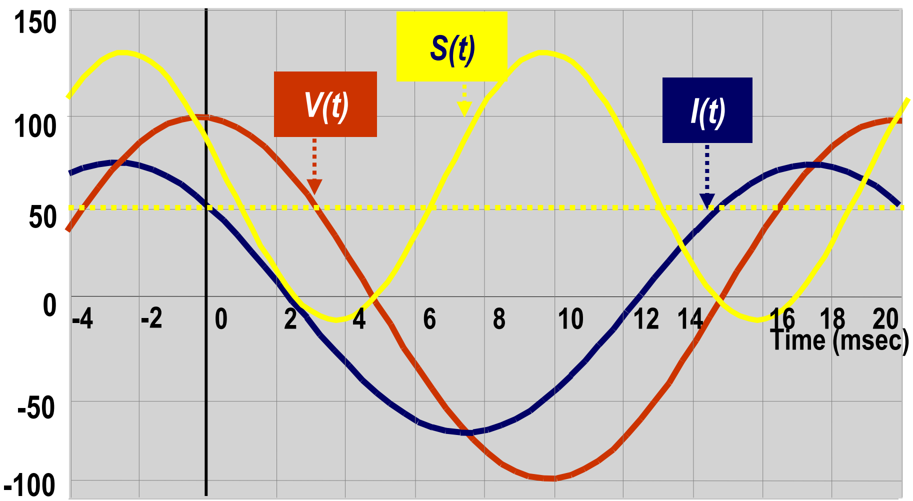
Angle = 90°, Time for ¼ revolution = 20/4 =5 msec

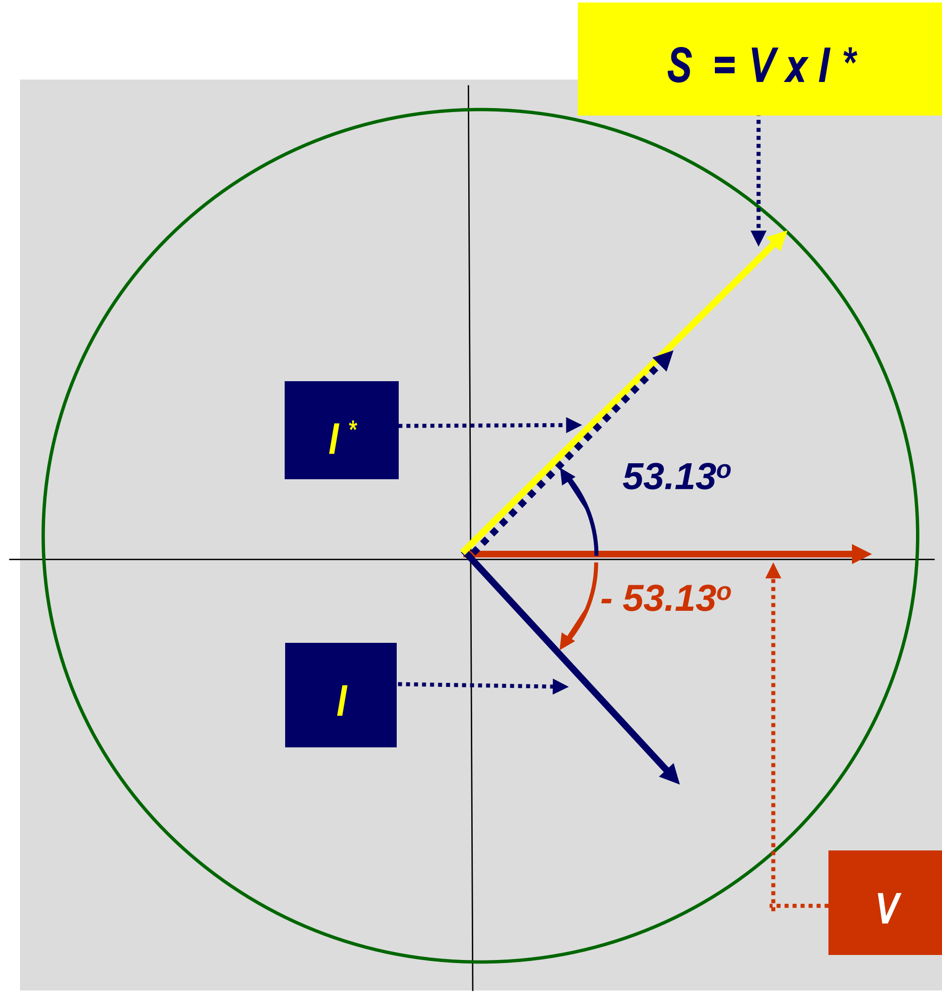


AC Power

Phosors Representation of Active and Reactive Powers



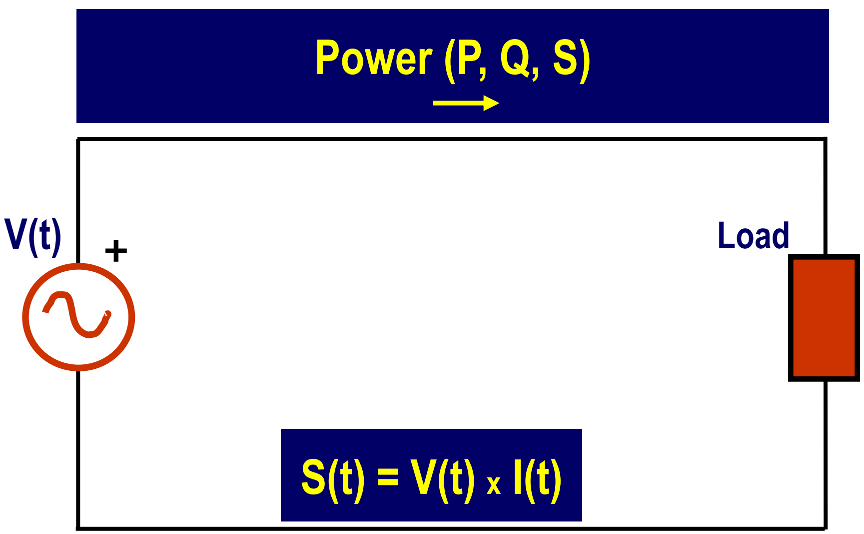


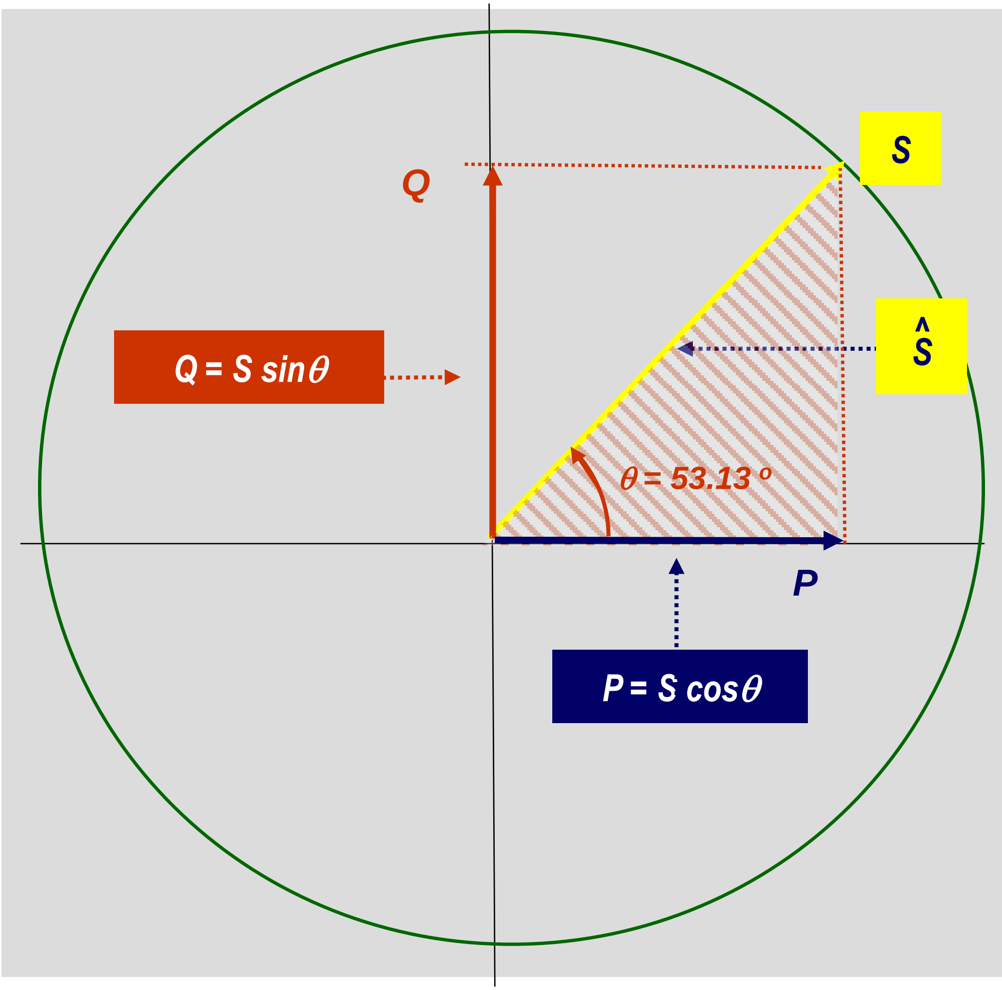


AC Power

Phosors Representation of Active and Reactive Powers

Total power	$\lvert S \rvert = V_{rms} \, I_{rms}$
	$\lvert S \rvert = \sqrt{P^2 + Q^2}$
Active power	$\lvert P \rvert = V_{rms} \, I_{rms} \cos \theta$
Reactive power	$\lvert Q \rvert = V_{rms} \, I_{rms} \sin \theta$





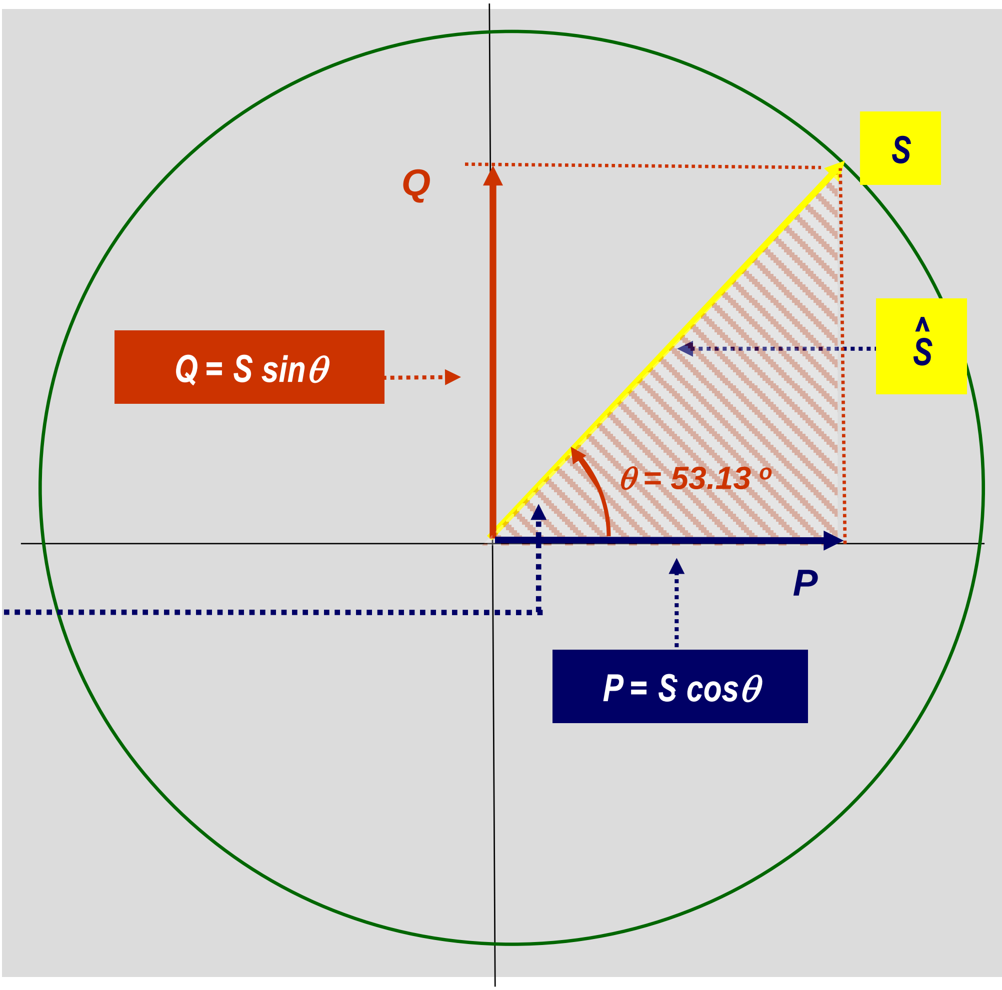
AC Power

Phosors Representation of Active and Reactive Powers

S - Total power	(k) VA (kVA)
P- Active power	(k) Watt (kW)
Q - Reactive power	(k) VAR (kVAR)

Please note that this angle depends only on the resistance R and reactance X of the load, i.e.

$$\theta = Tan^{-1}\, X / R$$
$$= Tan^{-1}\, Q / P$$



AC Power

Basic Conversions

Polar Representation

$S \angle \theta$

Rectangular Representation

$P + jQ$

$P = S\cos\theta, \quad Q = S\sin\theta$

$S = \sqrt{P^2 + Q^2}, \quad \theta = Tan^{-1}(Q/P)$

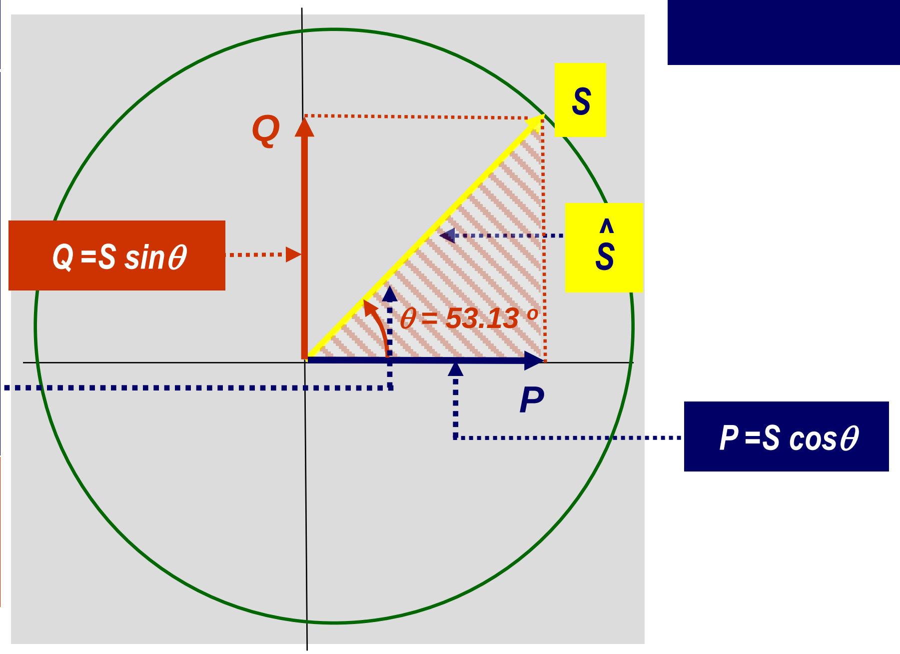
Please note that this angle depends only on the resistance R and reactance X of the load

$\theta = Tan^{-1} X/R$

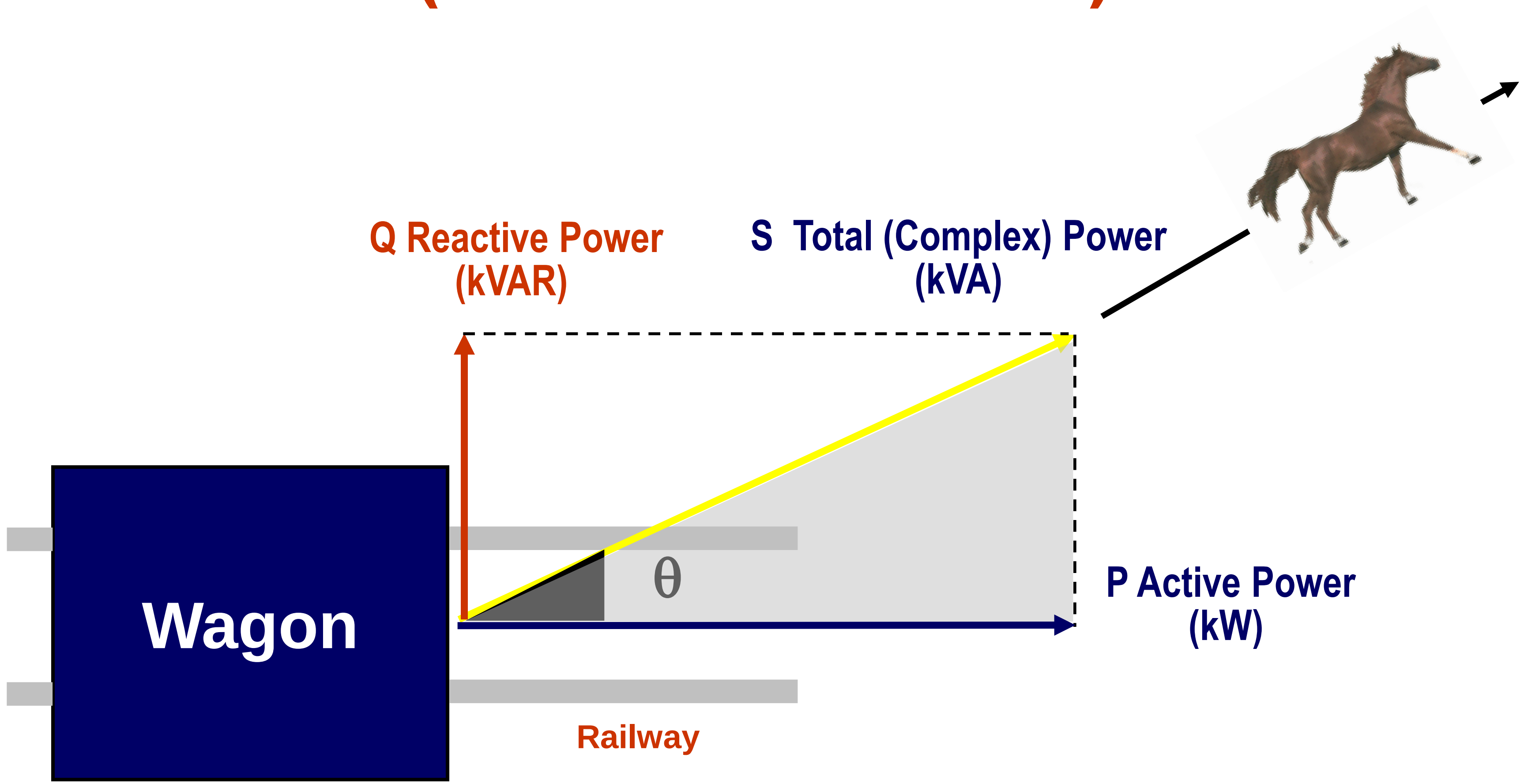
$= Tan^{-1} Q/P$

$X/R = Q/P$

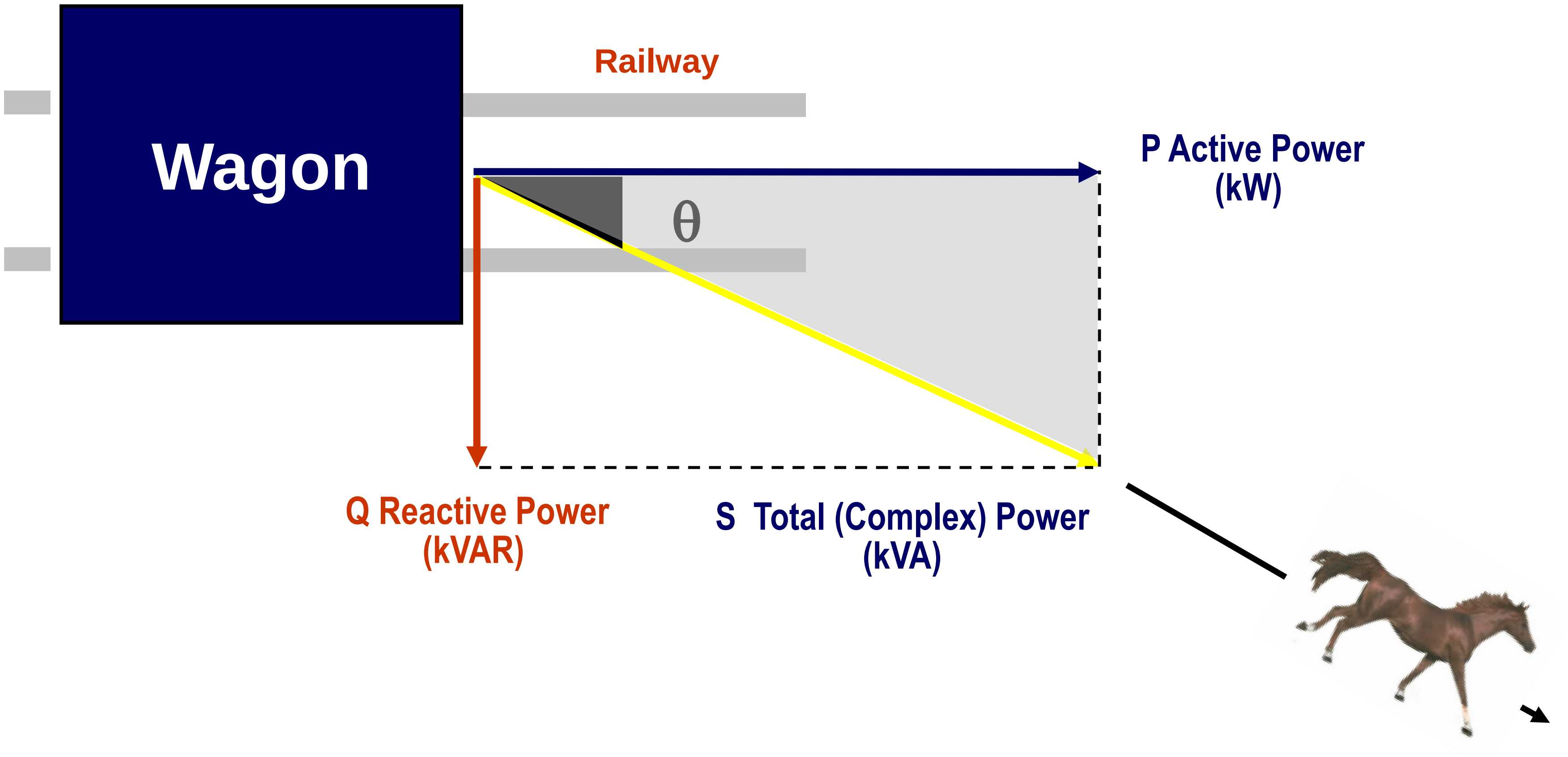
i.e. if $X = 0 \rightarrow Q = 0$



AC Power
Active Reactive Powers
(in the first 5 mseconds)

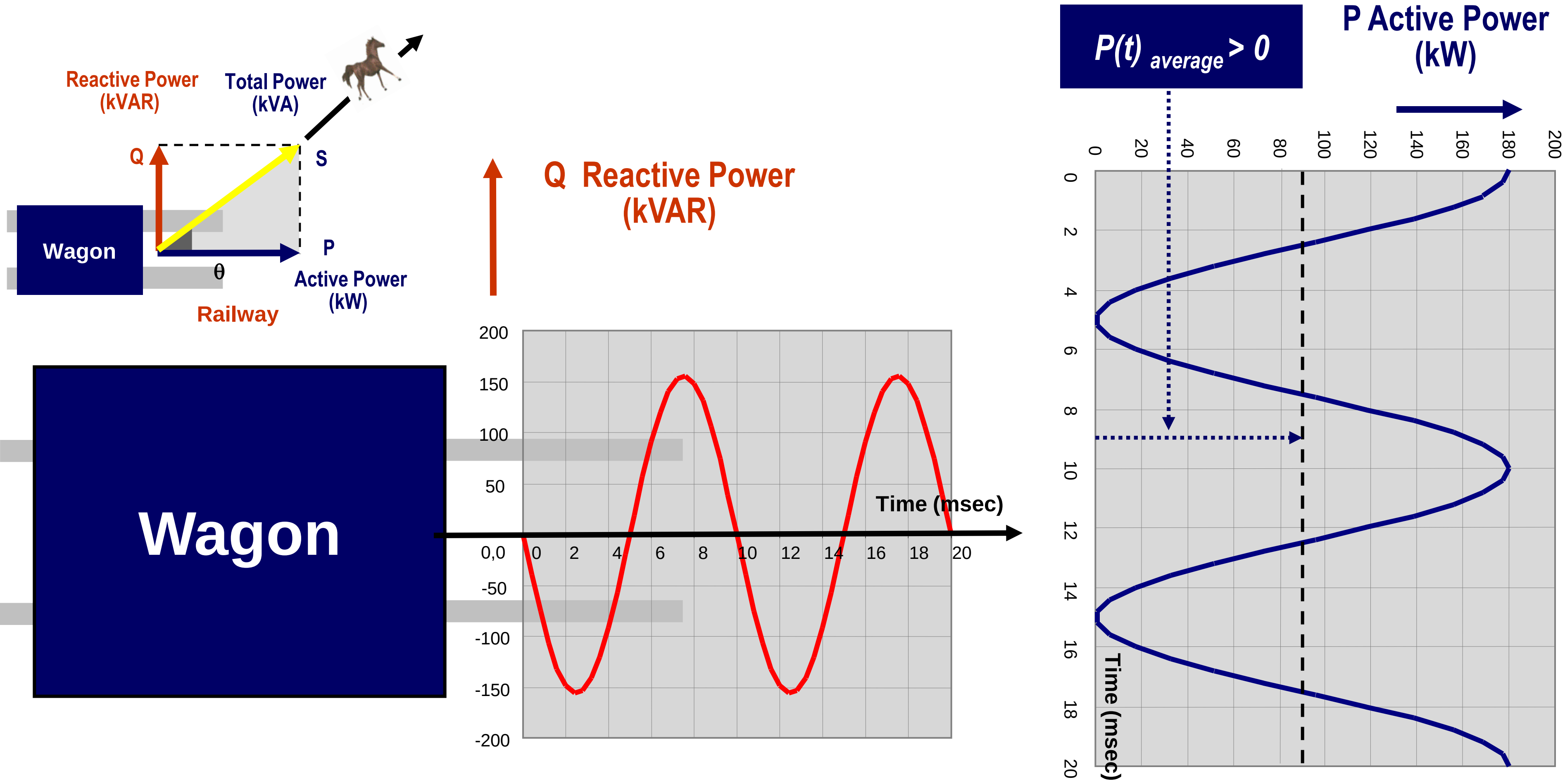


AC Power
Active Reactive Powers
(in the next 5 mseconds)



AC Power

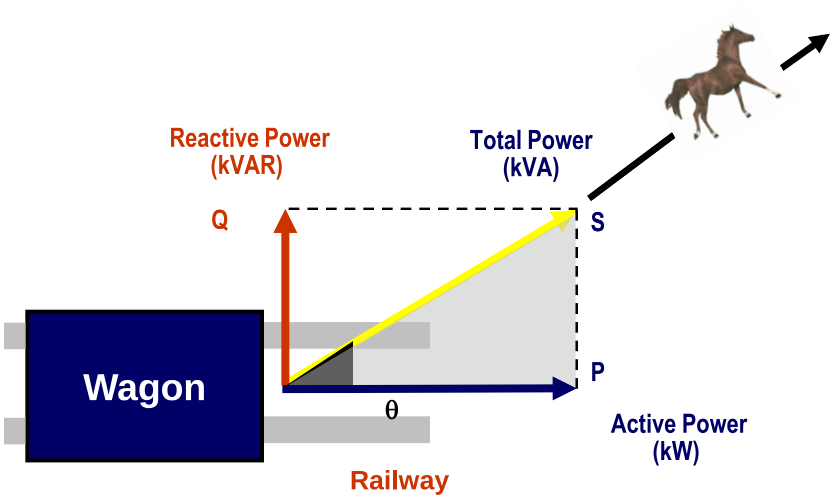
AC Power
Active Reactive Powers

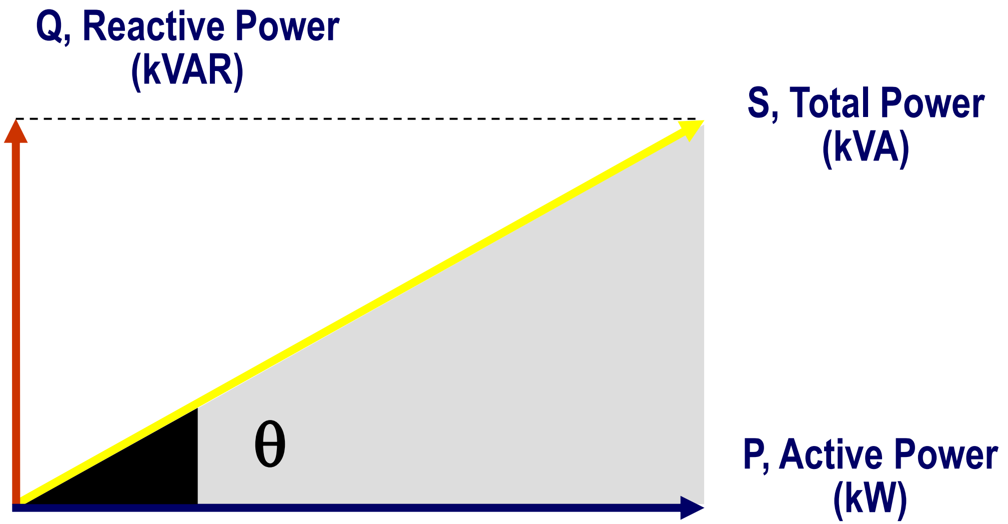


AC Power

Active-Reactive Powers

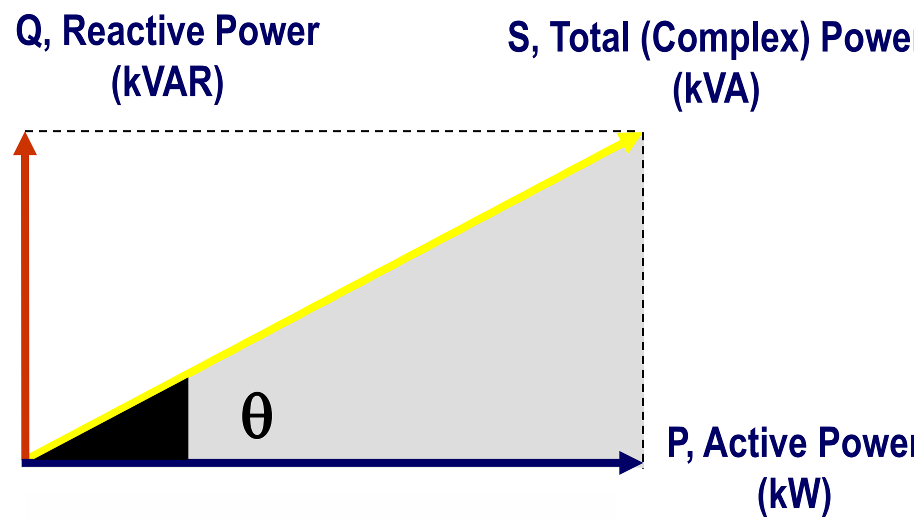
Polar Representation		Rectangular Representation
	$P = S \cos \theta, \quad Q = S \sin \theta$	
$S \angle \theta$	$S = \sqrt{P^2 + Q^2}, \quad \theta = Tan^{-1}(Q/P)$	$P + jQ$

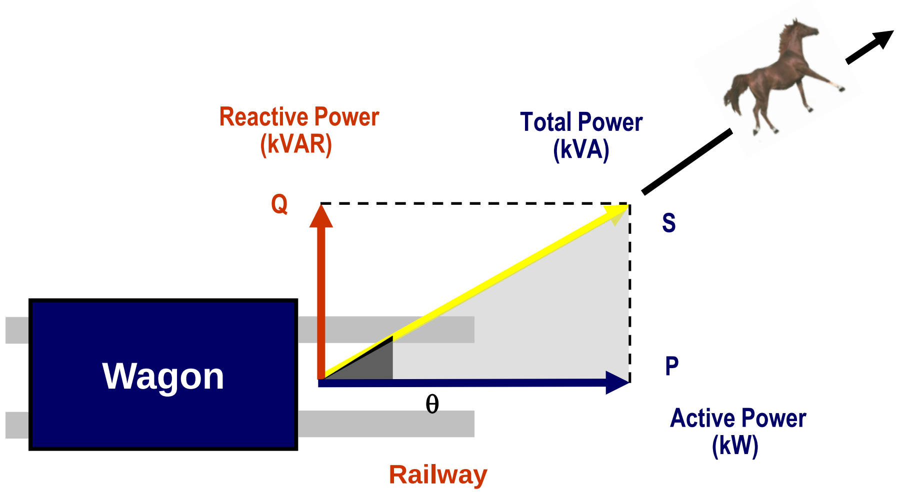


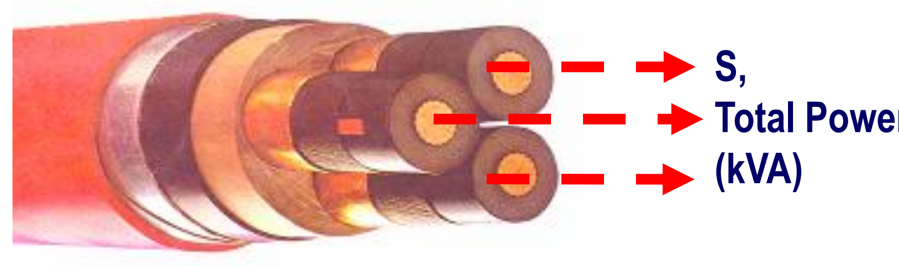


Active-Reactive Powers

Total power	$\lvert S \rvert = V_{rms}\, I_{rms}$
	$\lvert S \rvert = \sqrt{P^2 + Q^2}$
Active power	$\lvert P \rvert = V_{rms}\, I_{rms} \cos\theta$
Reactive power	$\lvert Q \rvert = V_{rms}\, I_{rms} \sin\theta$







AC Power

Power Meters

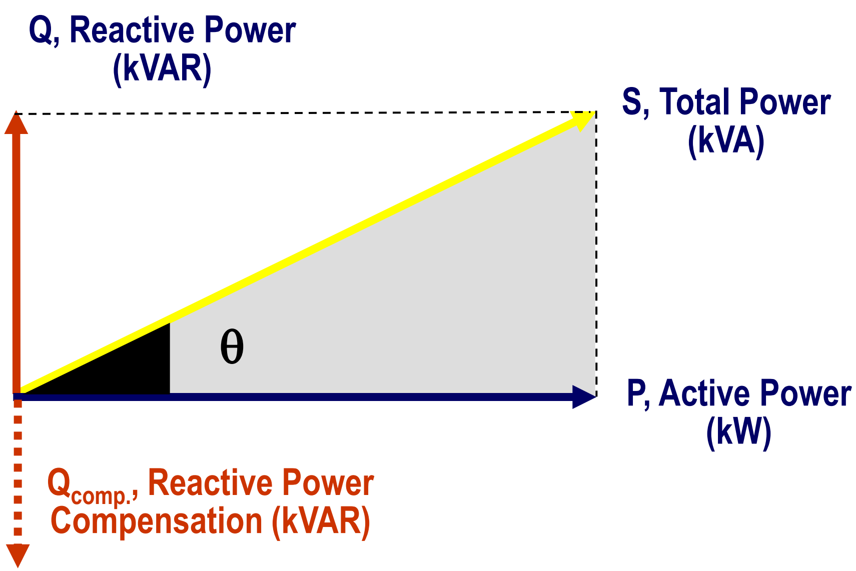
Analog	Digital	Power Analyzer

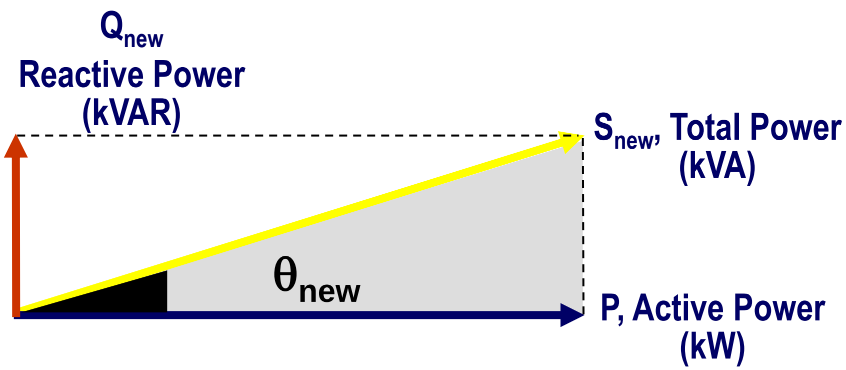
Clamp Type Current Transformers

Reactive Power Compensation

Definition

Reactive power compensation is partial or full cancellation of the reactive component of complex power by introducing a negative (compensation) component





AC Power

Power Factor

Definition

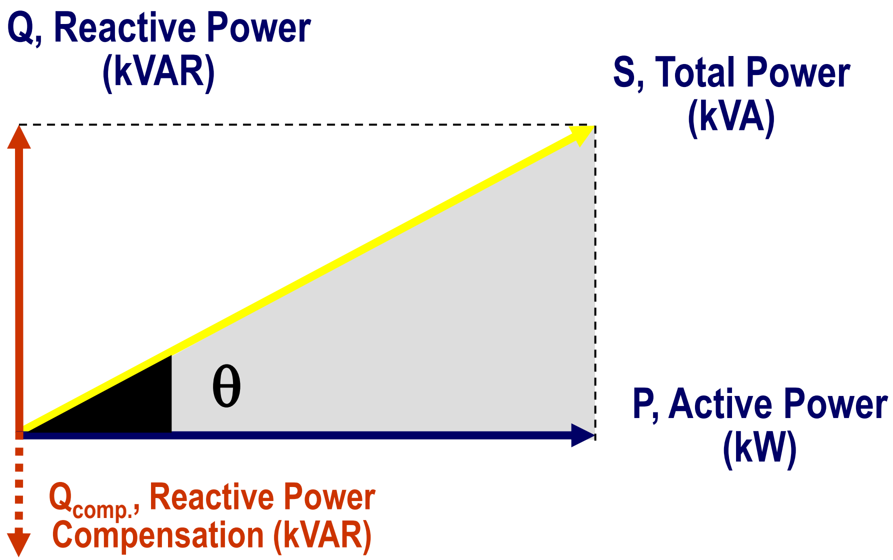
Cosine of the angle between S and P is called Power Factor of the load

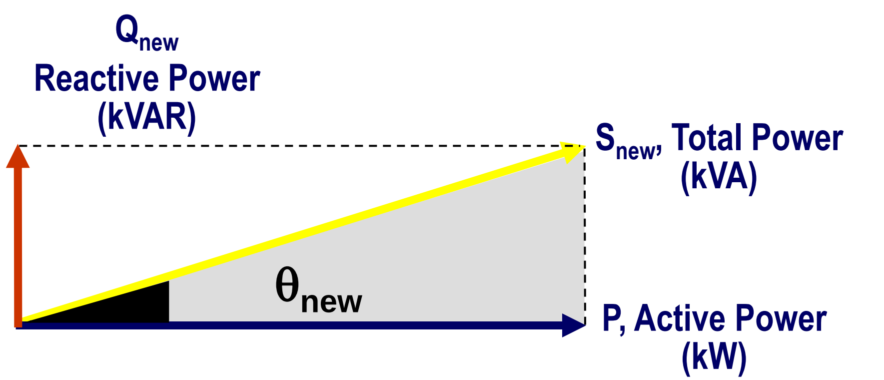
Power Factor $= p.f. = \cos\theta$

$= \cos(\tan^{-1} Q/P)$

Please note that reducing Q means reducing the angle θ, and hence increasing power factor

Hence, reactive power compensation is sometimes called as "Power Factor Correction", i.e. correcting power factor to a value near unity





Full or Partial Compensation

Partial Compensation

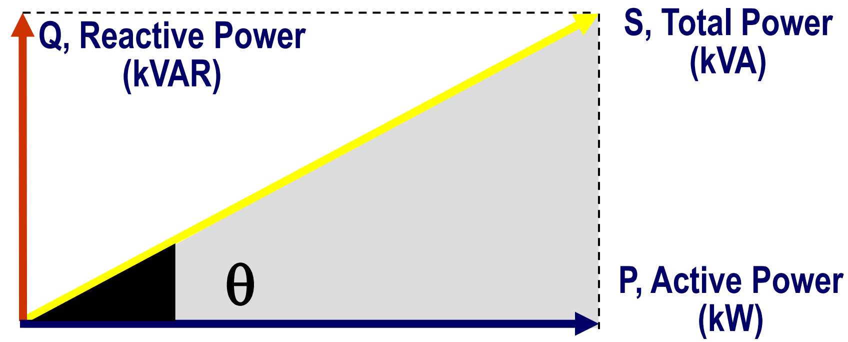
Partial compensation is the case, where Power Factor is raised to a value not reaching unity

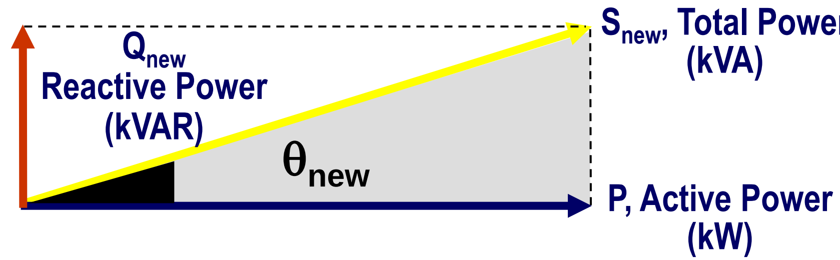
$$\textit{Power Factor}_{new} = p.f._{new} = \cos\theta_{new}$$
$$= \cos\left(Tan^{-1}\, Q_{new} / P\right)$$

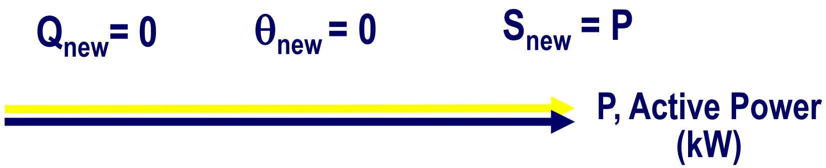
Full Compensation

Full compensation is the case, where Power Factor is unity

$$\textit{Power Factor}_{new} = p.f._{new} = \cos\theta_{new}$$
$$= \cos\left(Tan^{-1}\, 0 / P\right) = 1$$







AC Power

Charging Principle Applied by TEDAS

If

$$|Q / P| > 1/3$$

Then, reactive power is charged

If

$$|Q / P| < 1/3$$

Then, reactive power is free

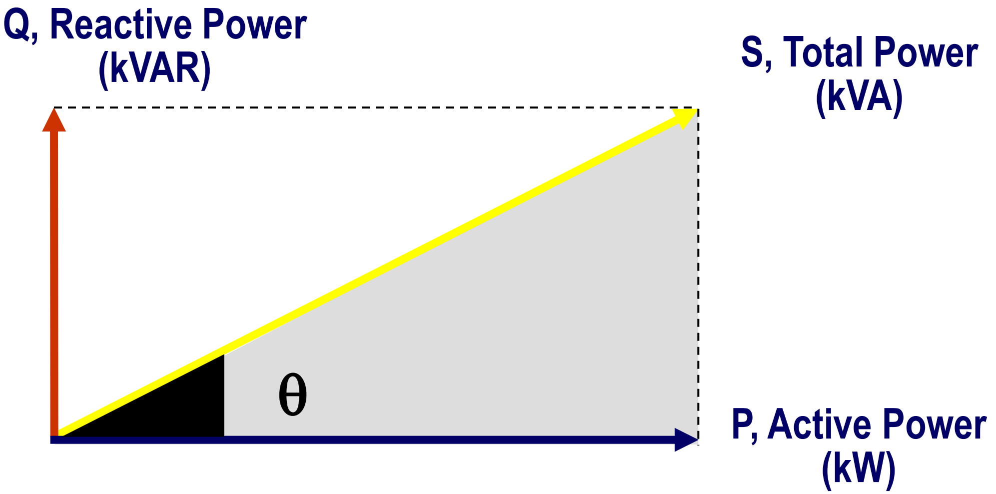
Please note that

$$|Q / P| > 1/3$$

means;

$$Tan^{-1} (1/3) = 18.435^o$$

$$\cos 18.435^o = 0.949 \cong 0.95$$



AC Power

Why Partial Compensation is Preferred ?

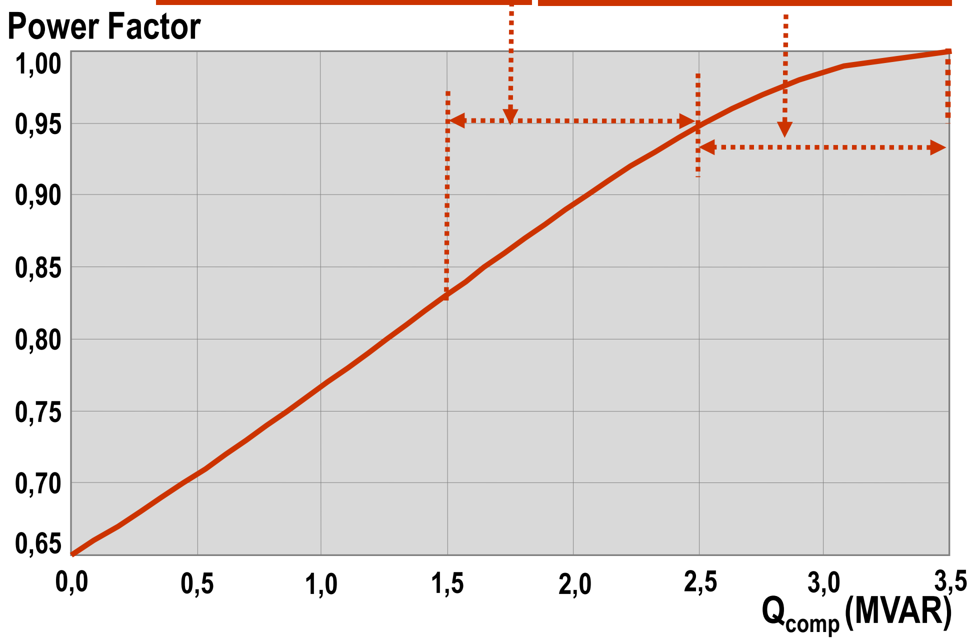
Partial Compensation

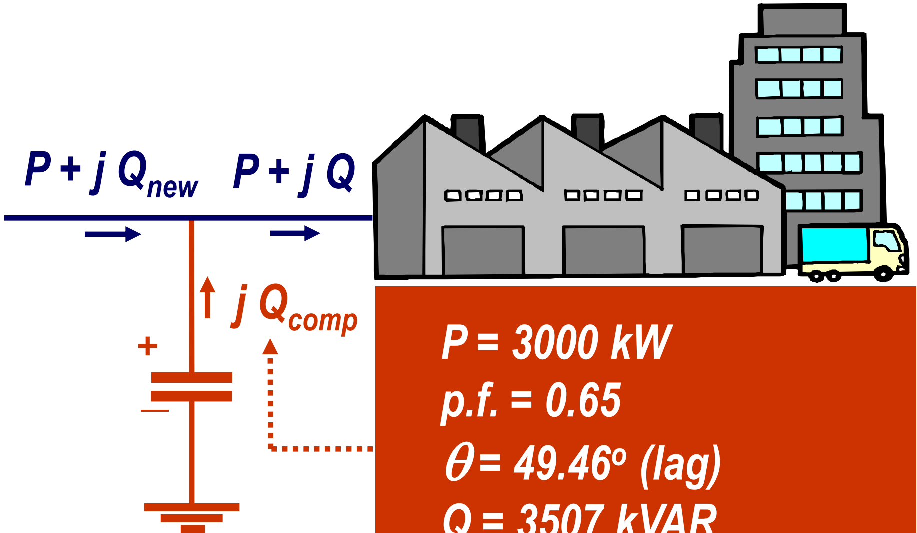
Due to economic reasons, full compensation is rarely implemented

Reactive power needed to raise p.f. from 0.95 to 1 is the same as that for raising p.f. from 0.83 to 0.95 (not worthwhile)

Reactive power needed to raise p.f. from 0.83 to 0.95

Reactive power needed to raise p.f. from 0.95 to unity





$P = 3000\ kW$

$p.f. = 0.65$

$\theta = 49.46^o$ (lag)

$Q = 3507\ kVAR$

$Q_{comp} = \Delta Q = Q - Q_{new}$

AC Power

Application of Reactive Power Compensation

Reduction of Equipment Loading

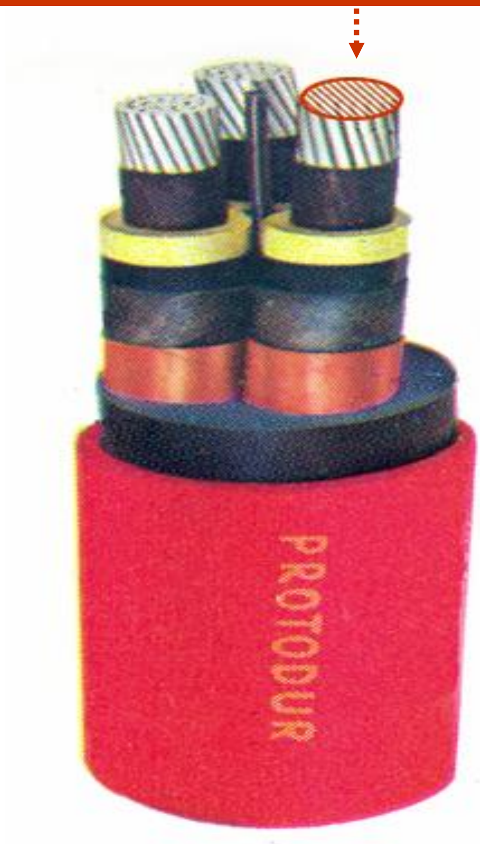
- Transformers
- Lines
- Cables

are priced with respect to the power rating (kVA)

Prices of these equipments on the other hand, are determined by the cross-section (mm^2) of the equipment

Cross Section (mm^2)	Current Capacity (Amp)
1.0	12.0
1.5	16.0
2.5	21.0
4.0	27.0
6.0	35.0
10.0	48.0
16.0	65.0
25.0	88.0
35.0	110.0
50.0	140.0
70.0	175.0
95.0	215.0
120.0	225.0

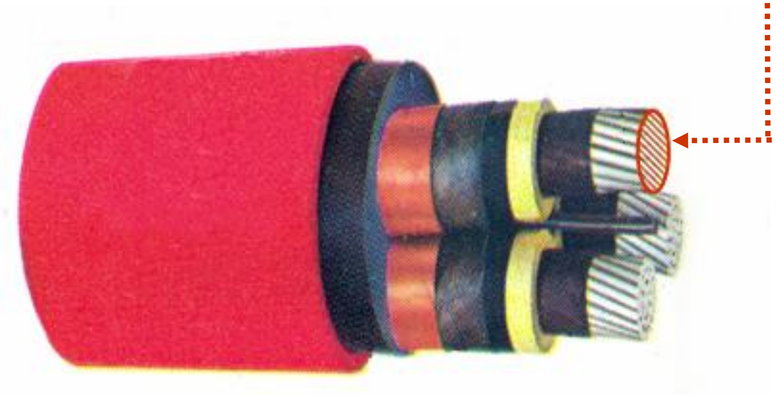
Cross section (size) of the cable (mm^2)

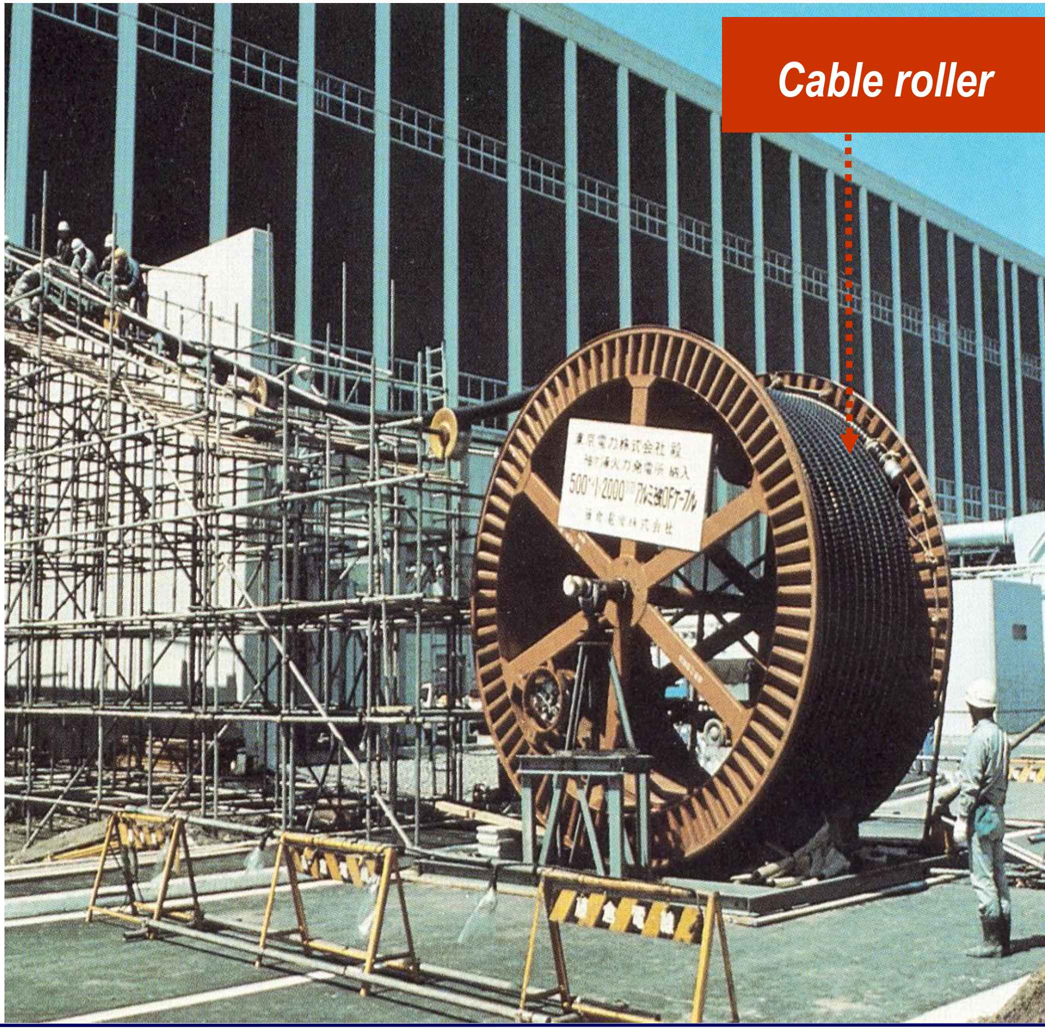


Application of Reactive Power Compensation

Reduction of Equipment Loading

Hence, the power rating S (kVA) of a cable is merely determined by the cross section, which must be minimized in order to reduce the investment to be made for the cable



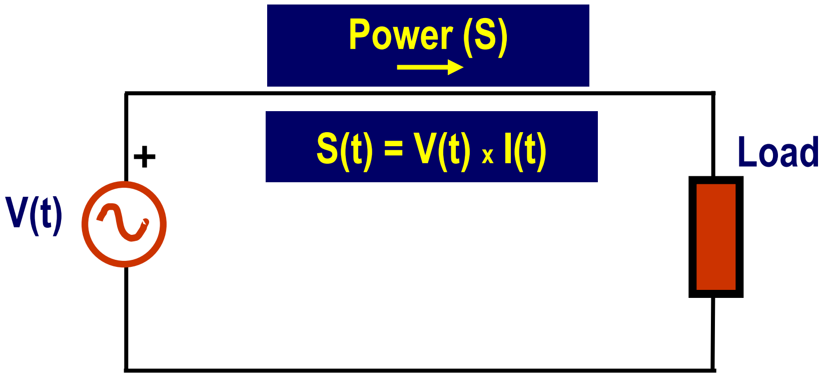


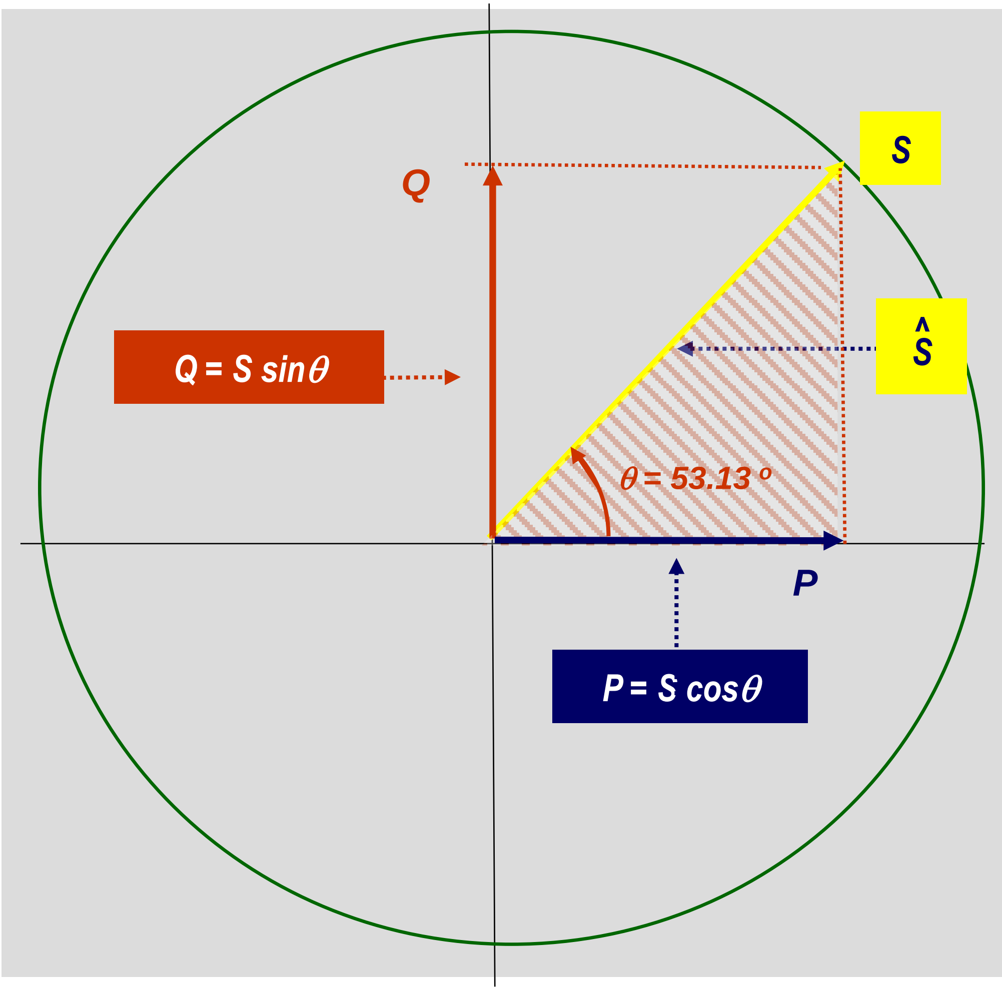
Application of Reactive Power Compensation

Reduction of Equipment Loading

Hence, the power rating S (kVA) of a cable is merely determined by the cross section, which must be minimized in order to reduce the investment to be made for the cable

Hence, S (kVA) must be minimized





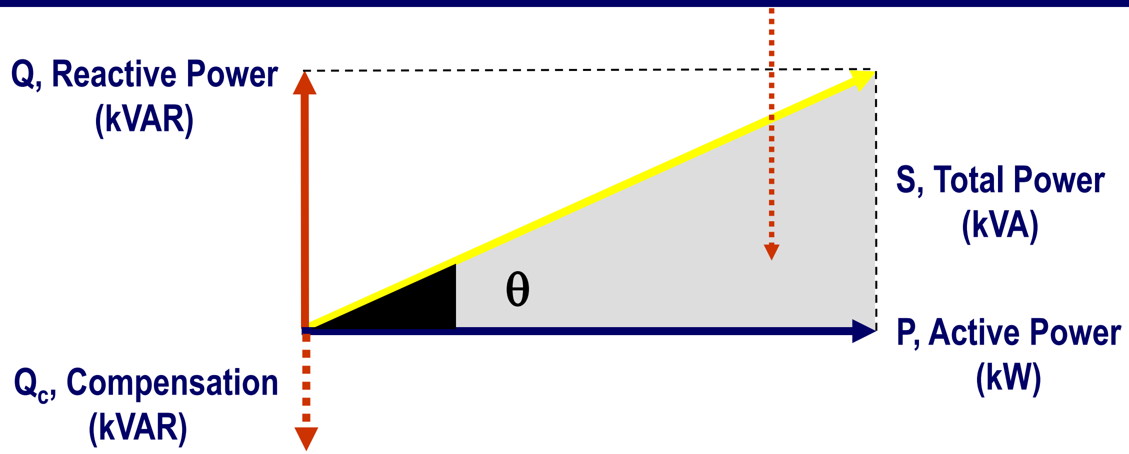
Alternative Ways of Reducing S (kVA)

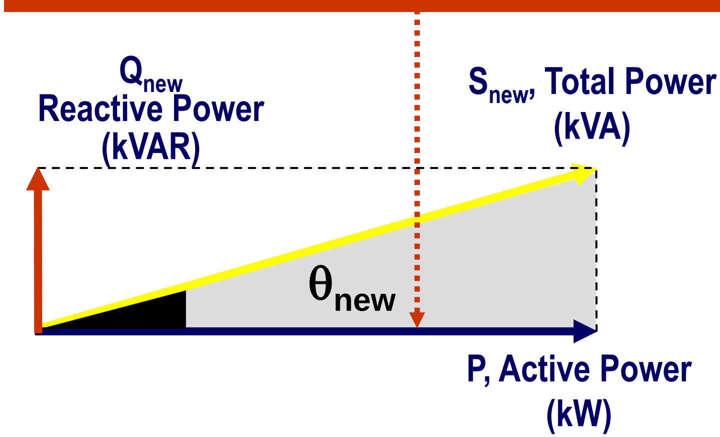
Alternative Ways of Reducing S (kVA)

a) <u>Reducing the overall loading;</u>
P + jQ (kW + j kVAR) (Overall comsumption)
<u>Unreasonable</u>, since the active consumption P is determined by the needs of the comsumer, who consumes electricity

a) <u>Reducing only Q (kVAR) Possible, reasonable</u>

Please note that active power does not change after compensation





AC Power

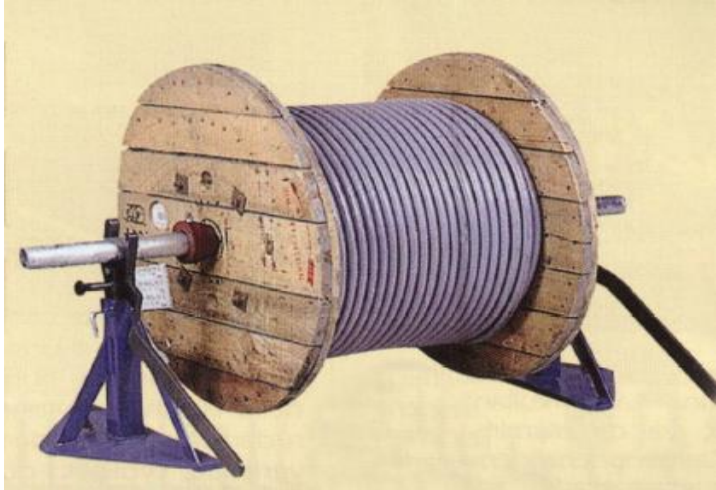
Example

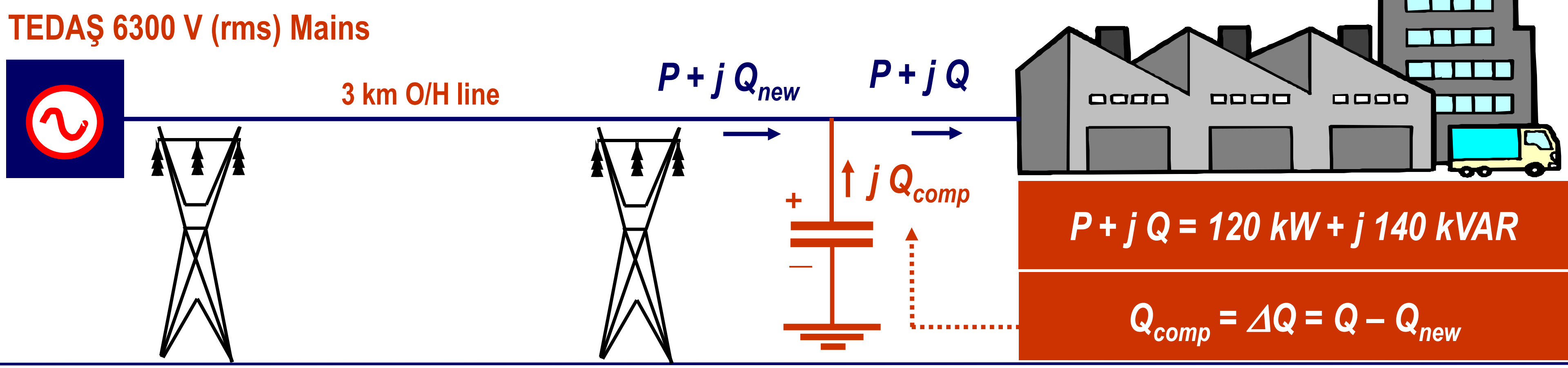
Question

The factory shown on the RHS draws a load at 6300 V nominal voltage

$$P + j\,Q = 120\ kW + j\ 140\ kVAR$$

Calculate the amount of reactive power needed in order to raise the power factor of the factory to 0.95 (Lagging)





AC Power

Example

Answer

Uncompensated (Given) Case

$\tan\theta = Q / P$
$= 140 / 120 = 1.1667$

$\theta = \tan^{-1} 1.167 = 49.40^o$

p.f.: $\cos\theta = 0.65$ (lagging)

Compensated Case

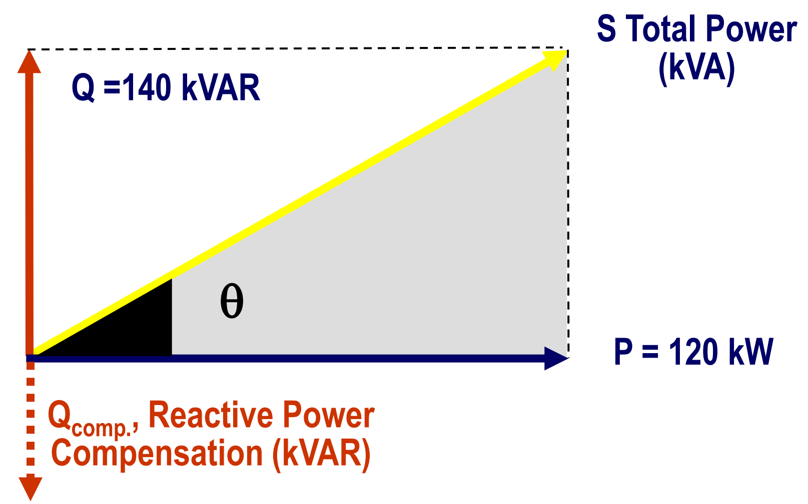
$\cos\theta_{new} = 0.95$,

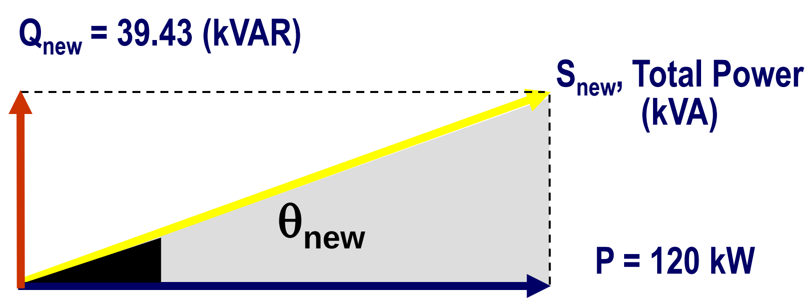
$\theta_{new} = \cos^{-1} 0.95 = 18.19^o$

$\tan\theta_{new} = \tan 18.19^o = 0.3286$

$\tan\theta_{new} = Q_{new} / P \longrightarrow Q_{new} = 0.3286 \times P$
$= 39.43$ kVAR

$Q_{comp} = \Delta Q = Q - Q_{new} = 140 - 39.43 = 100.57$ kVAR





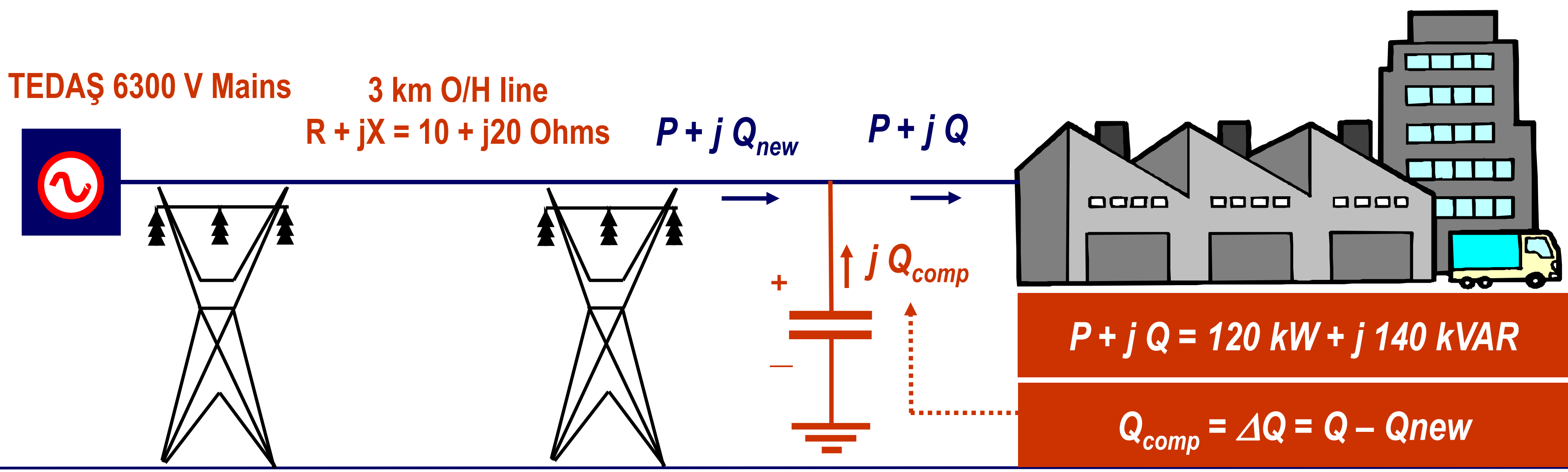
AC Power

Example

Question

Now, for the previous problem, calculate the reduction in line losses as a result of this compensation by assuming that line impedance is

$$R + jX = 10 + j\,20 \text{ Ohms}$$



AC Power

Example

$S = V I^* \rightarrow I = S / V = \sqrt{140^2 + 120^2} / 6300$

$= 184.39 \times 1000 / 6300 = 29.268 \text{ Amp}$

$S_{new} = V I_{new}^* \rightarrow I_{new} = \sqrt{39.43^2 + 120^2} / 6300$

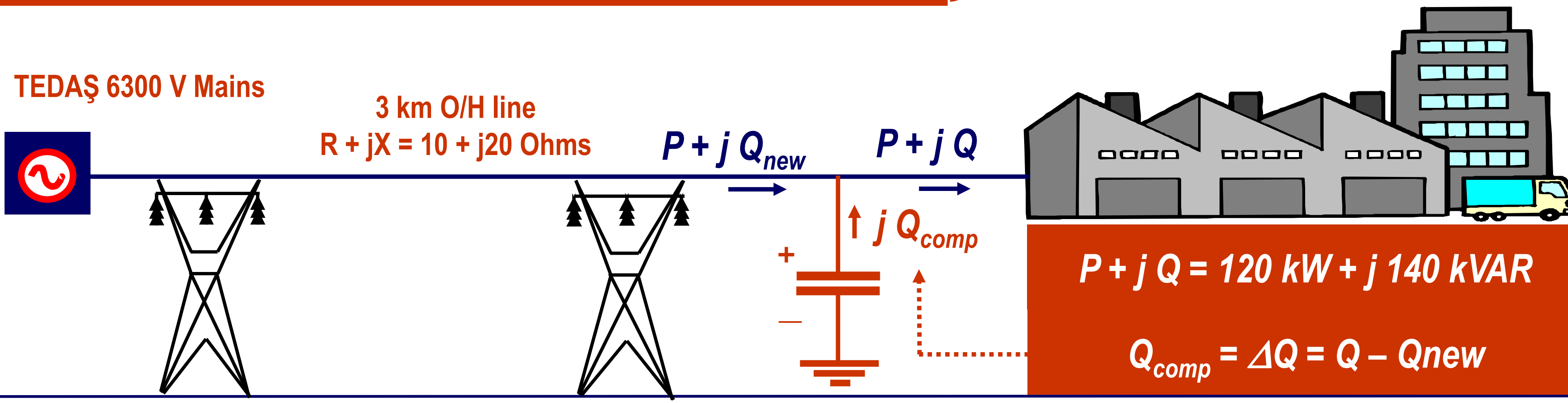
$= 126.312 \times 1000 / 6300 = 20.049 \text{ Amp}$

$P_{loss} = R I^2 = 10 \times 29.268^2 = 8566.39 \text{ Watts}$

$P_{loss\text{-}new} = R I_{new}^2 = 10 \times 20.495^2 = 4019.84 \text{ Watts}$

$\Delta P_{loss} = 8566.39 - 4019.84$

$= 4546.55 \text{ Watts}$



$P + j Q = 120 \text{ kW} + j\, 140 \text{ kVAR}$

$Q_{comp} = \Delta Q = Q - Q_{new}$

Example

Now, calculate the return rate of the investment to be made for the compensator, by assuming that the retail price of electricity is 16 Cents/kWh and price of capacitor is 184.41 USD/kVAR

ΔP_{loss} = 8566.39 – 4019.84 = 4546.55 Watts

*Investment = 100.57 kVAR * 184.41 USD/kVAR*

= 18546,11 USD

*Saving = 4546.55 / 1000 * 16 Cent/kWh/ 100*

= 0.7274 USD / hour

Return Rate = Investment / Saving

= 10057.00 / 0.7274

= 13825.9 hours = 576.8 days = 1.58 years

CORPORATE | PRODUCTS | SERVICES | TECHNICAL RESOURCES

LV-ACB™ List Price

Low Voltage Automatic Capacitor Banks

480 VOLT AUTOMATIC CAPACITOR BANKS

BANK RATING (KVAR)	STEP X KVAR	MODEL NUMBER	LIST PRICE
150	3 X 50	150LVA480F2B	$7,526
200	4 X 50	200LVA480F2B	$8,389
250	5 X 50	250LVA480F2B	$8,864
300	6 X 50	300LVA480F2B	$9,727
350	7 X 50	350LVA480F2B	$10,202
400	4 X100	400LVA480F2B100	$10,580
400	8 X 50	400LVA480F2B	$11,065
450	9 X 50	450LVA480F2B	$11,540
500	5 X 100	500LVA480F2B100	$11,918
500	10 X 50	500LVA480F2B	$12,404
550	11 X 50	550LVA480F2B	$12,830
600	6 X 100	600LVA480F2B100	$13,256
600	12 X 50	600LVA480F2B	$13,742
650	13 X 50	650LVA480F2B	$12,280
700	7 X 100	700LVA480F2B100	$14,594
700	14 X 50	700LVA480F2B	$15,080
750	15 X 50	750LVA480F2B	$15,506
800	8 X 100	800LVA480F2B100	$15,933
800	16 X 50	800LVA480F2B	$16,418
900	9 X 100	900LVA480F2B100	$17,174
1000	10 X 100	1000LVA480F2B100	$18,414

AC Power

Example

Question

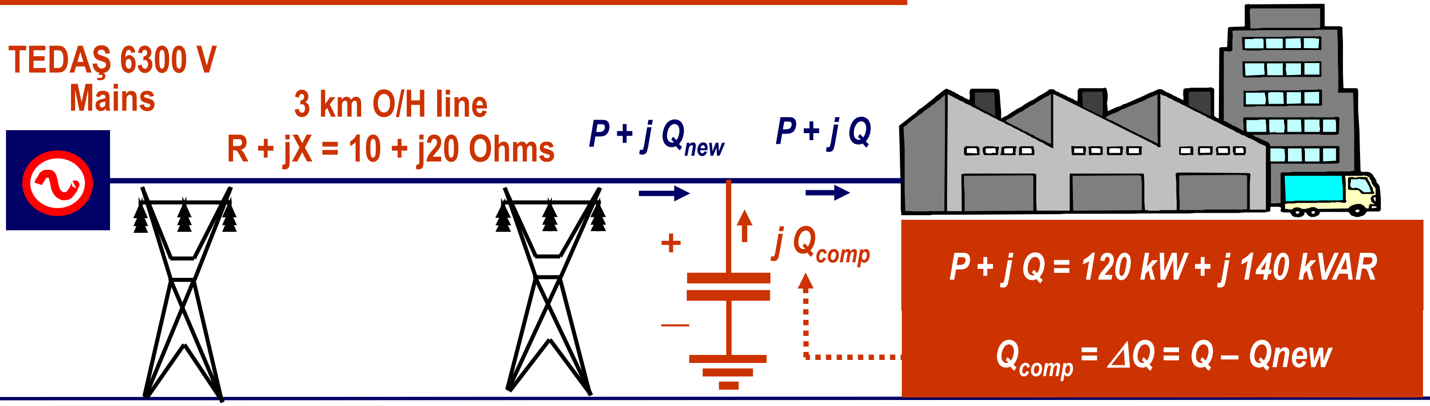
Now, for the previous problem, determine the minimum cross section of the line for the alternative cases, when line is compansated and uncompensated

The cheaper alternative

I_{new} = 20.495 Amp

$I_{initial}$ = 29.268 Amp

Cross Section (mm^2)	Current Capacity (Amp)
1.0	12,0
1.5	16,0
2.5	21,0
4.0	27,0
6.0	35,0
10.0	48,0
16.0	65,0
25.0	88,0
35.0	110,0
50.0	140,0
70.0	175,0
95.0	215,0
120.0	225,0



Question

Question

Now, for the previous problem, calculate the shunt capacitance in Farads needed for the amount of compensation found above

$Q_{comp} = \Delta Q = Q - Q_{new} = 140 - 39.43 = 100.57 \text{ kVAR}$

$Q_{comp} = V\, I_{comp}^{*} \rightarrow I_{comp} = Q_{comp} / V = 100570 \text{ VA} / 6300 \text{ V} = 15.963 \text{ Amp}$

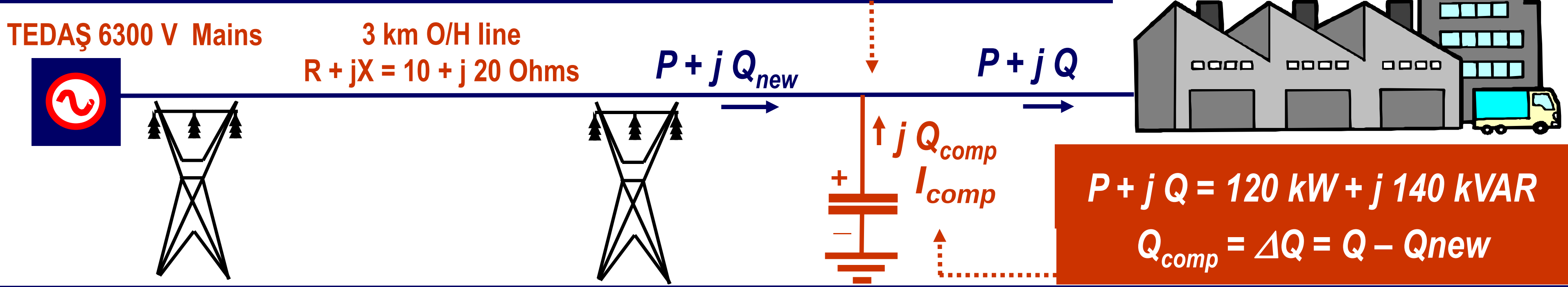
$X_{comp} = V / I_{comp} = 6300 / 15.963 = 394.65 \text{ Ohms}$

$X_{comp} = 1 / (jwC)$

$C = 1 / (jwX) = 1 / (314.15 \times 394.65) = 123.98 \text{ mF}$

$Q_{new} = Q + Q_{comp}$

$Q_{comp} < 0$

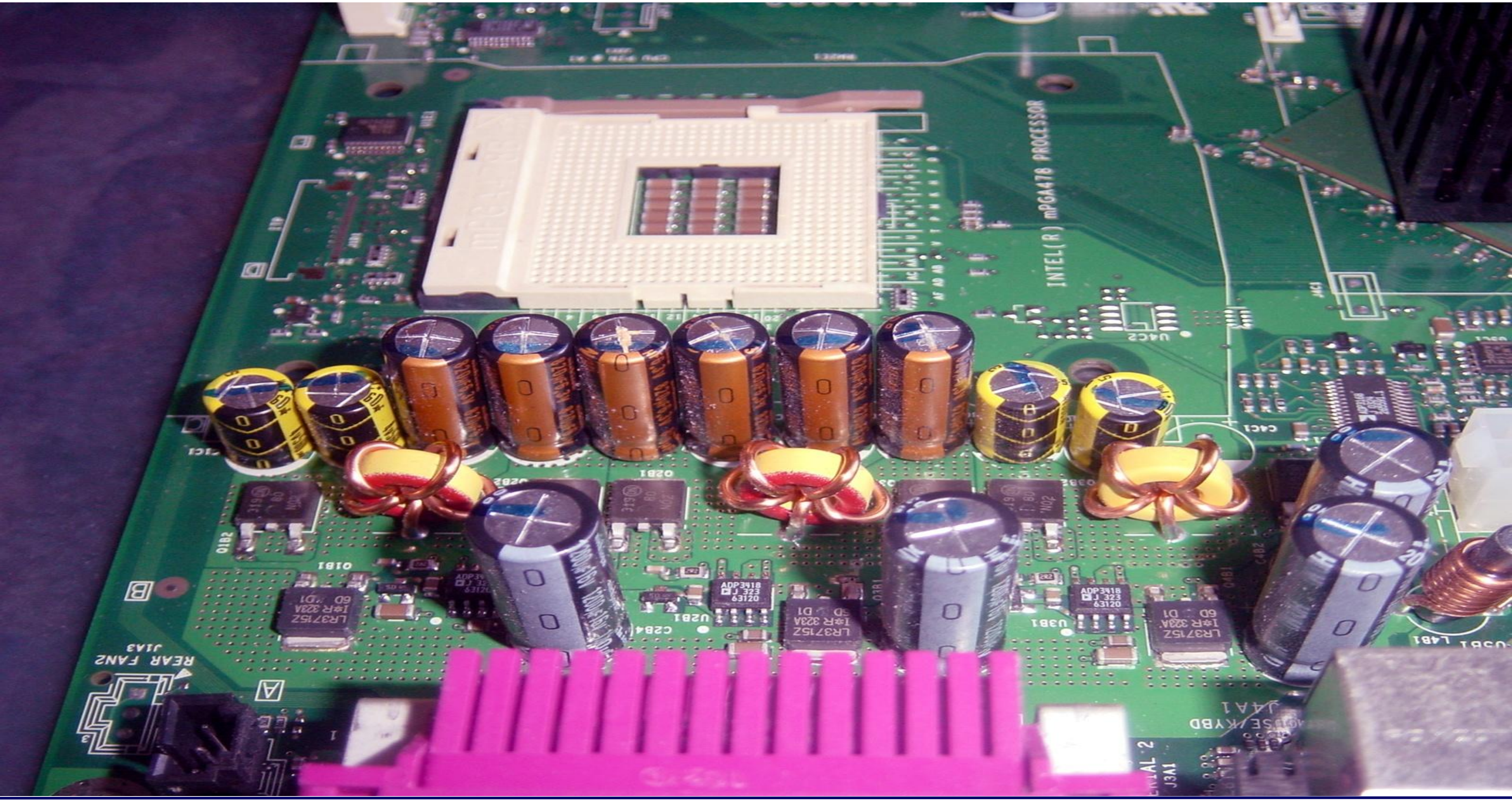


Medium Voltage Capacitor Banks

Shunt connection of large capacity capacitors in power systems

Installation of MV Capacitor Banks

Electronic Capacitors in a Motherboard



AC Power

Another Example

- Early in the history or electricity, Thomas Edison's General Electric company was distributing DC electricity at 110 volts in the United States.
- Then Nikola Tesla the devised a system of three-phase AC electricity at 240 volts. Three-phase meant that three alternating currents slightly out of phase were combined in order to even out the great variations in voltage occurring in AC electricity. He had calculated that 60 cycles per second or 60Hz was the most effective frequency. Tesla later compromised to reduce the voltage to 110 volts for safety reasons.

Another Example

- Europe goes to 50 Hz:
- With the backing of the Westinghouse Company, Tesla's AC system became the standard in the United States. Meanwhile, the German company AEG started generating electricity and became a virtual monopoly in Europe. They decided to use 50 Hz instead of 60 Hz to better fit their metric standards, but they kept the voltage at 110 V.
- Unfortunately,
- 50 Hz AC has greater losses and is not as efficient as 60 HZ.

AC Power

Another Example

- Due to the slower speed, 50Hz electrical generators are 20 % less effective than 60Hz generators. Electrical transmission at 50 Hz is about 10-15 % less efficient. 50Hz transformers require larger windings and 50 Hz electric motors are less efficient than those meant to run at 60Hz. They are more costly to make to handle the electrical losses and the extra heat generated at the lower frequency.
- Europe goes to 220 V
- Europe stayed at 110 V AC until the 1950s, just after World War II. They then switched over to 220 V for better efficiency in electrical transmission. Great Britain not only switched to 220 V, but they also changed from 60Hz to 50 Hz to follow the European lead. Since many people did not yet have electrical appliances in Europe after the war, the change-over was not that expensive for them.
- U.S. stays at 110 V, 60Hz

Another Example

- The United States also considered converting to 220 V for home use but felt it would be too costly, due to all the 110 V electrical appliances people had. A compromise was made in the U.S. in that 220 V would come into the house where it would be split to 110 V to power most appliances. Certain household appliances such as the electric stove and electric clothes dryer would be powered at 220 V.

AC Power

Did everybody follow this part carefully ?