AC Power

RWE Denizli-Kaklık Gas Power Plant: 775 MW

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Voltage Waveform

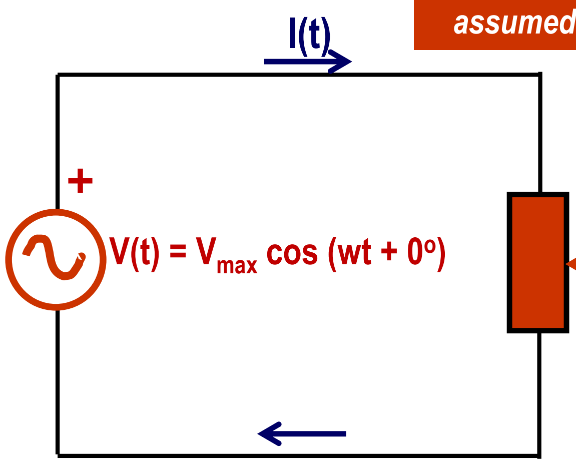
Consider the following AC circuit driven by a a source with an AC voltage waveform;

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

Voltage phasor will then be

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

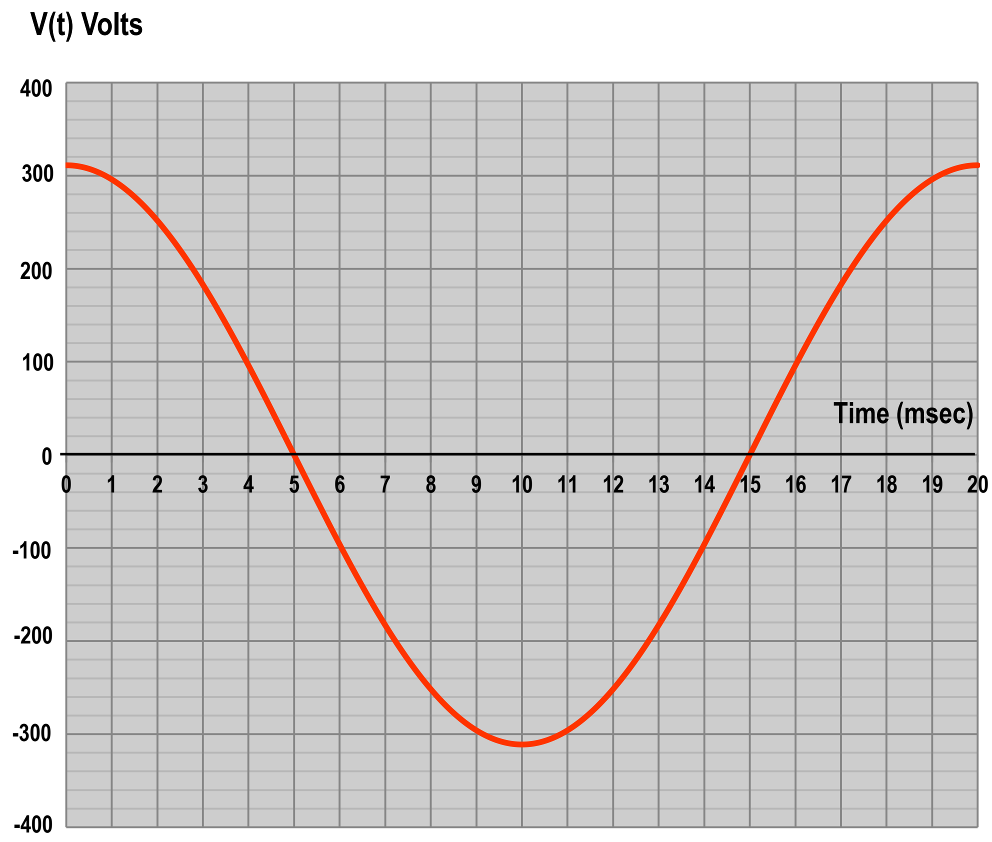
For simplicity, phase angle of the voltage waveform is assumed to be zero



Load $= R + jX$

$= Z \angle \theta$

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



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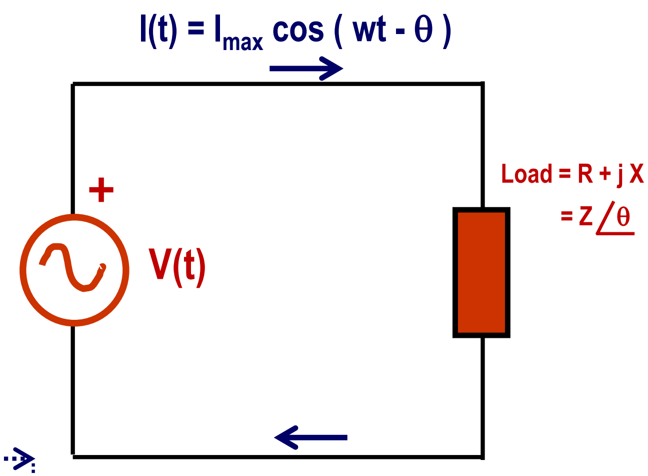
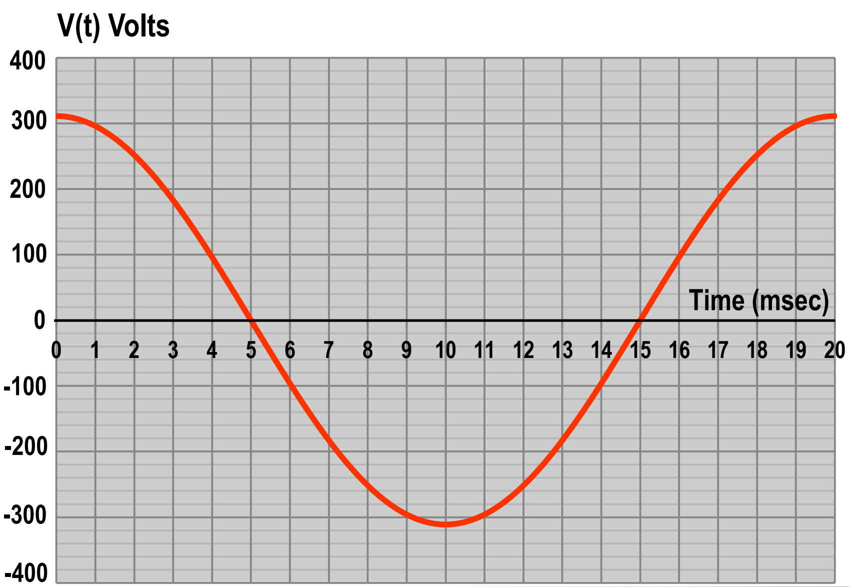
Current Waveform

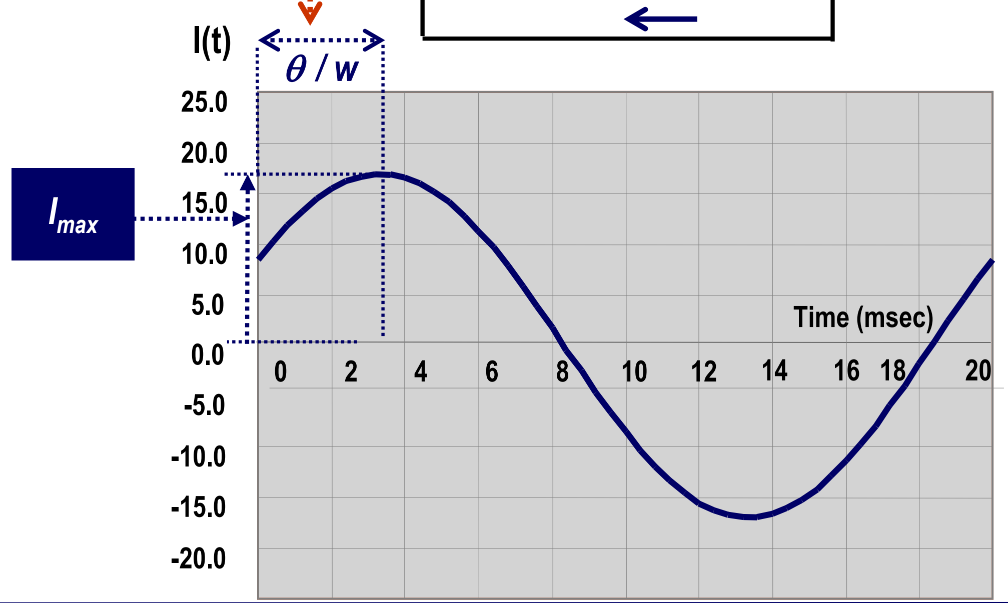
Current Phasor

$$I = \frac{V_{max} \angle 0^o}{Z \angle \theta} = I_{max} \angle -\theta$$

Phase (time) shift;
$t_1 = \theta_I / w = 3.5$ msec







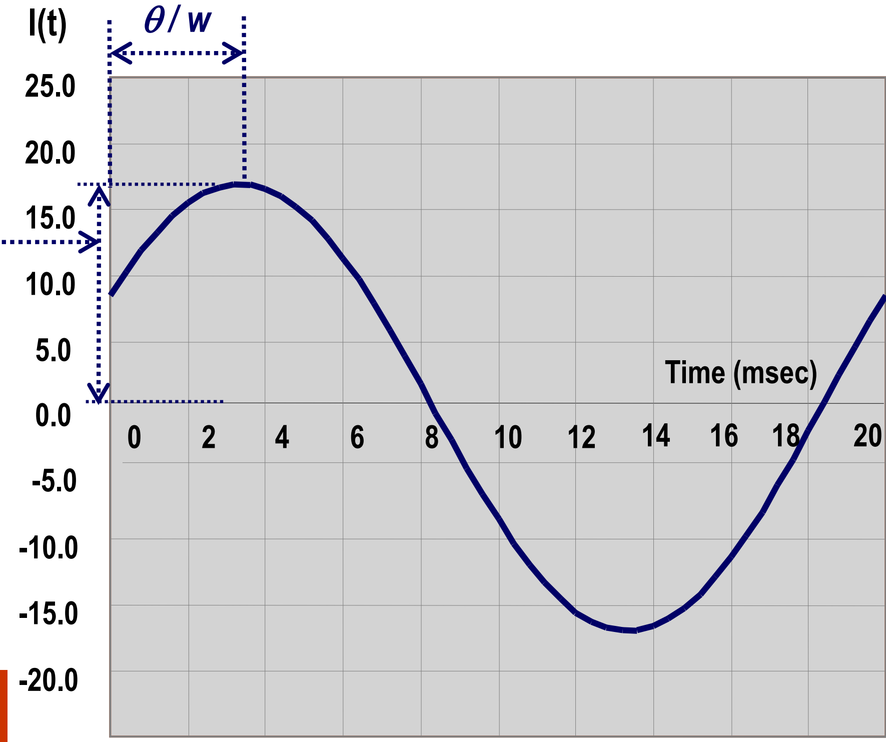
Current Waveform

Current phasor will then be

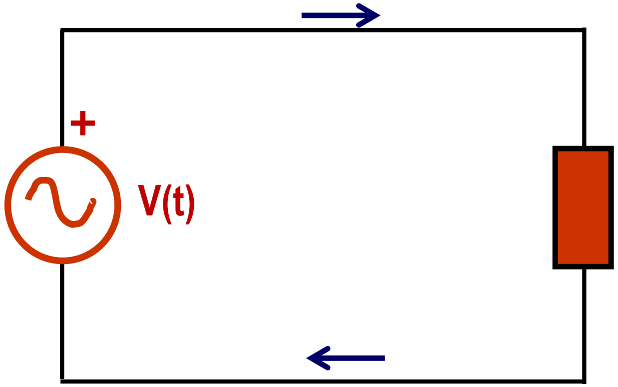
$$I_{max} \angle -\theta$$

Current waveform will then be

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



I_{max}



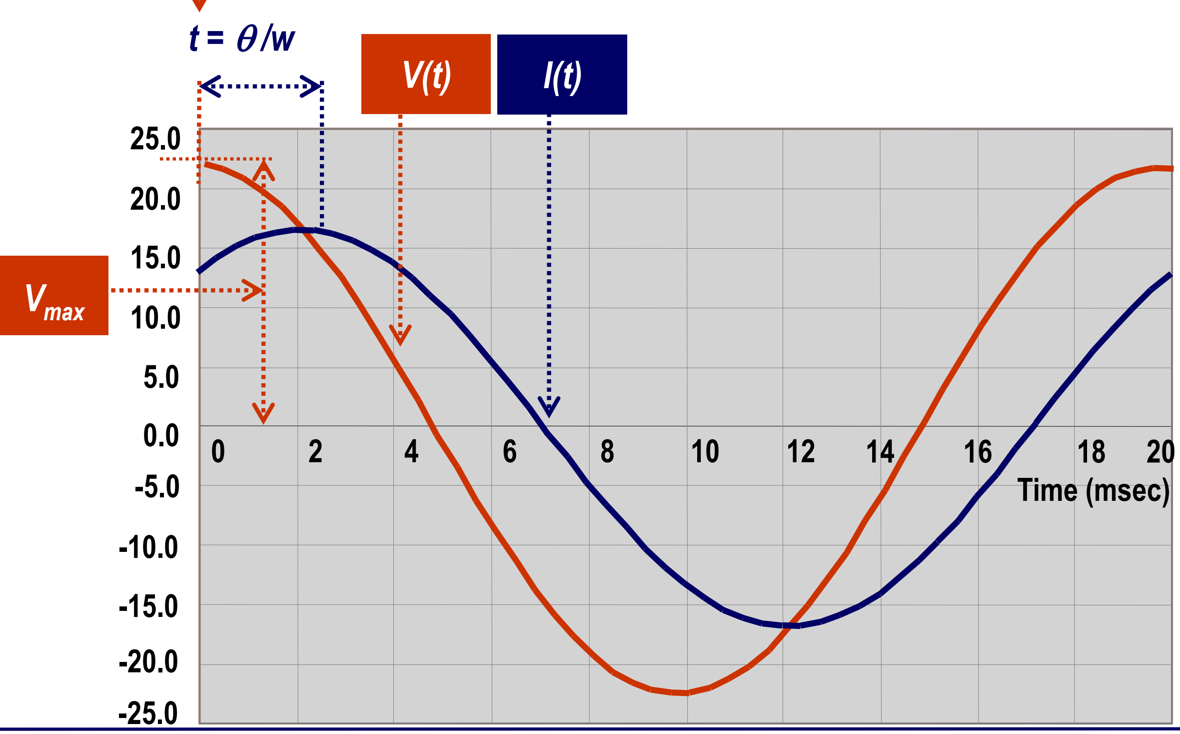
$$Load = R + j\,X = Z \angle \theta$$

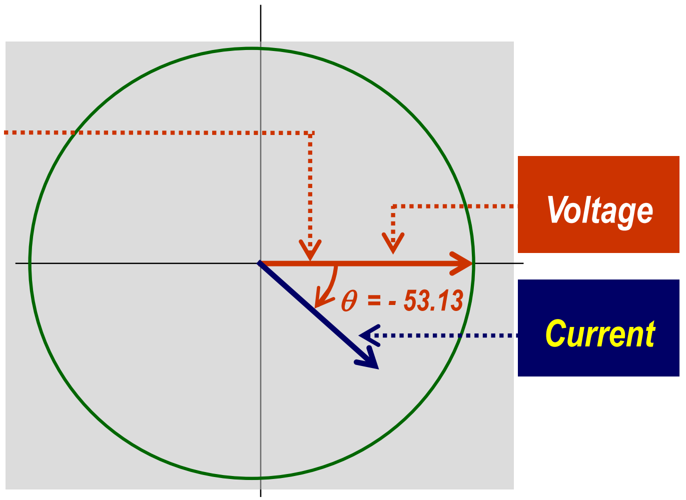
$$Z = \sqrt{R^2 + X^2}\,,\ \ \theta_I = Tan^{-1} (X / R)$$

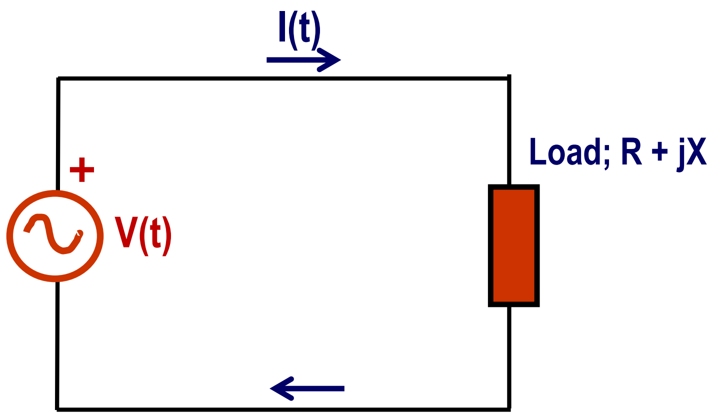
Voltage and Current Waveforms

Please note that the angle difference; θ depends only on the resistance R and reactance X of the load

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







AC Power - Power Expression

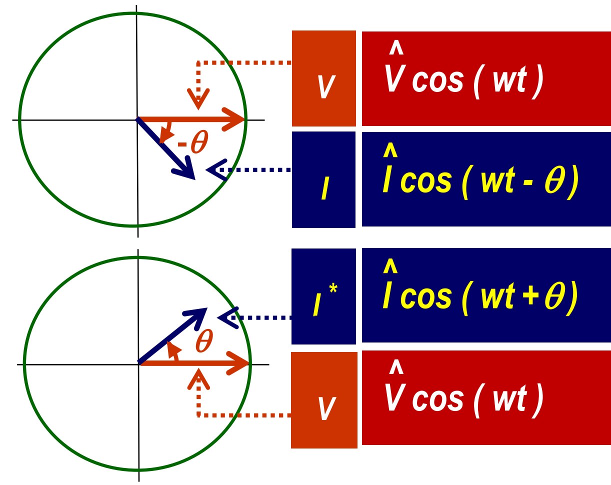
Voltage and current waveforms are

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

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

Please note that; "-" sign here should be altered to "+" due to the conjugation operator in the definition of power:

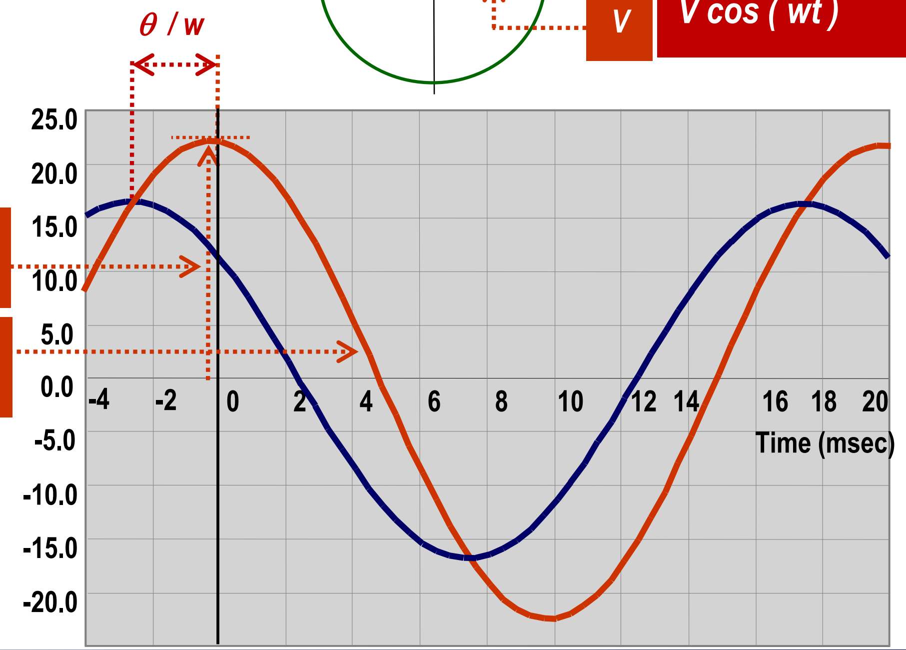
$S = V \times I^*$



Power waveform will then be

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

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



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

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

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

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

AC Power - Power Expression

Power waveform is the product of the voltage and conjugate (the phase angle with + sign) of the current waveforms

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

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

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

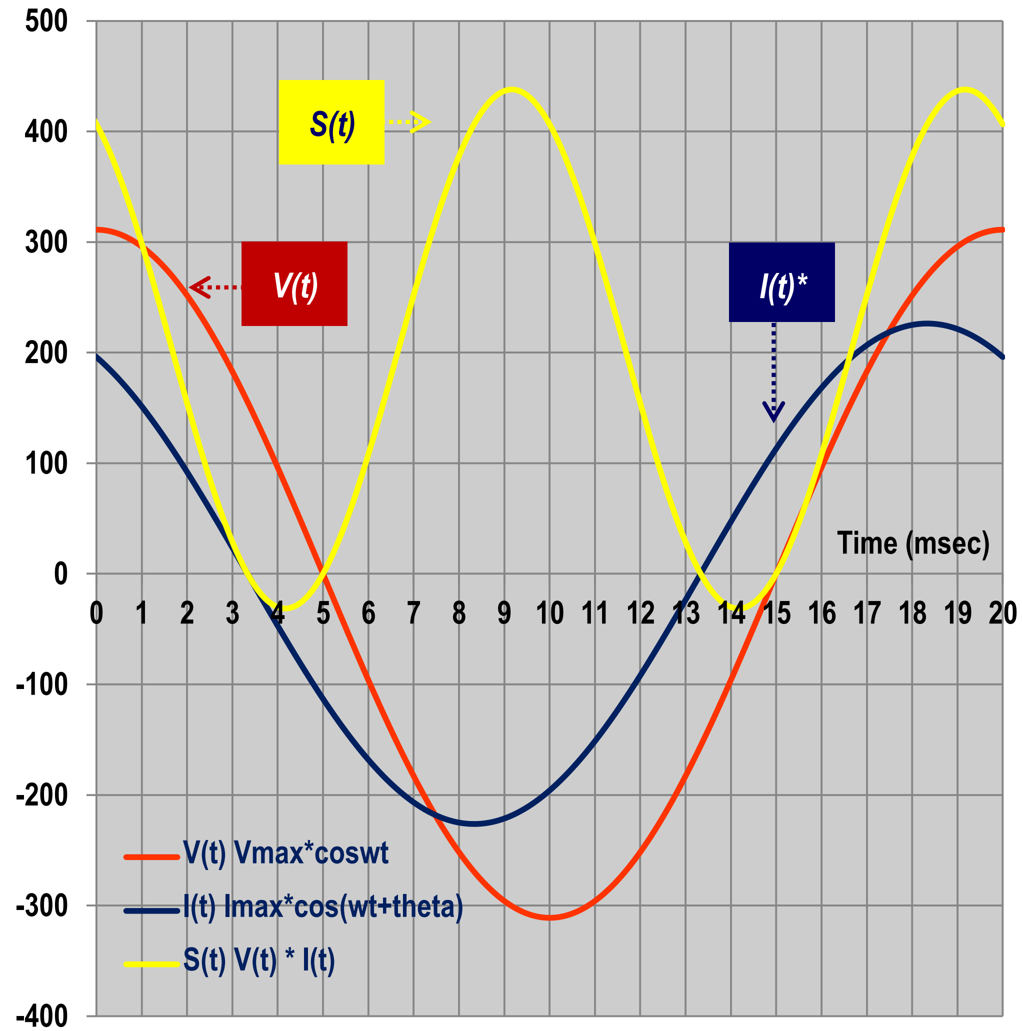
$$= ½\ V_{max} I_{max} [\cos(2wt + \theta) + \cos\theta]$$

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

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

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

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



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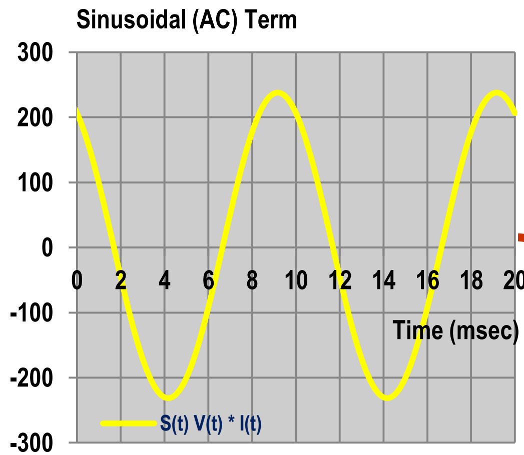
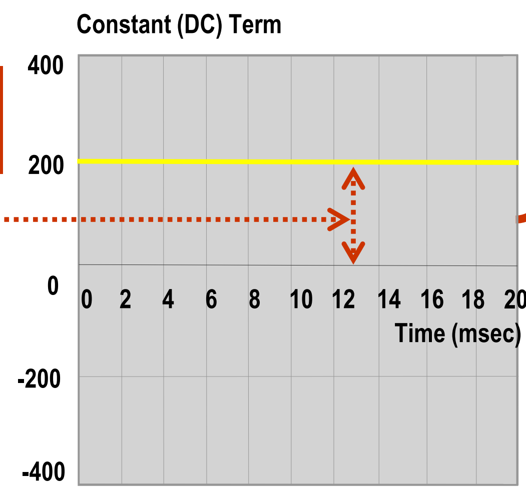
AC Power – Decomposition of Power Expression

Power given in the above expression may be decomposed into two components;

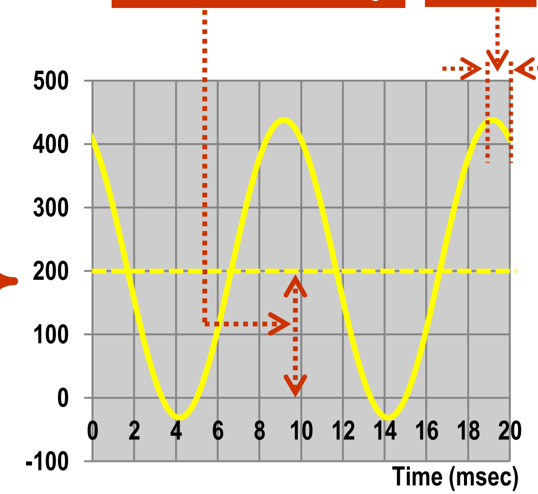
$$S(t) = \underbrace{V_{rms}\, I_{rms} \cos(\, 2wt + \theta\,)}_{\text{Sinusoidal (AC) Term}} + \underbrace{V_{rms}\, I_{rms} \cos \theta}_{\text{Constant (DC) Term}}$$





DC Term = $S(t)_{avg}$

θ / w



AC Power

AC Power – Average Power Expression

Average Power

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

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

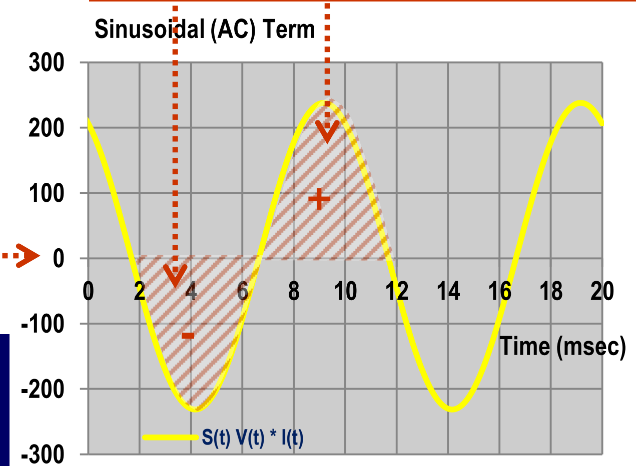
$$S(t)_{avg} = (1/T)\int P(t)\,dt$$

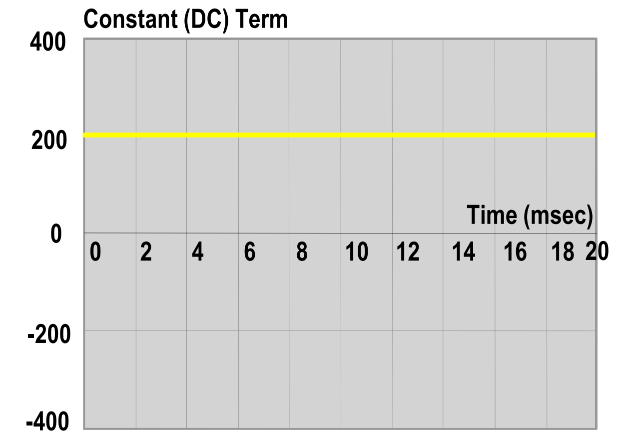
$$= (1/T)\int V_{rms}\ I_{rms}\ [\cos(2wt + \theta) + \cos\theta]\,dt$$

$$= \underbrace{(1/T)\int V_{rms}\ I_{rms}\cos(2wt + \theta)\,dt}_{= 0} + \underbrace{(1/T)\int V_{rms}\ I_{rms}\cos\theta\,dt}_{\text{Constant (DC) Term}}$$

Average is zero

Sum of these areas is zero





AC Power – Average Power Expression

Average Power

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

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

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

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

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

$$\int_0^T dt = T$$

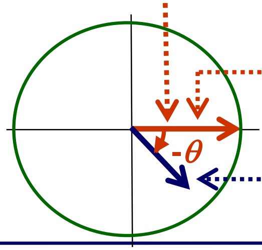
$$S(t)_{avg} = V_{rms}\, I_{rms} \cos\theta$$

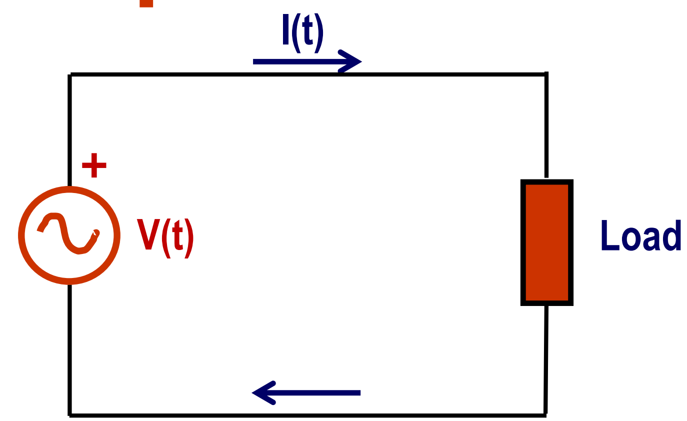
Please note that θ is constant

Most of the students forget to put this multipler term in their formula, during the examinations. Please be careful !

$$V = \hat{V} \cos(wt)$$

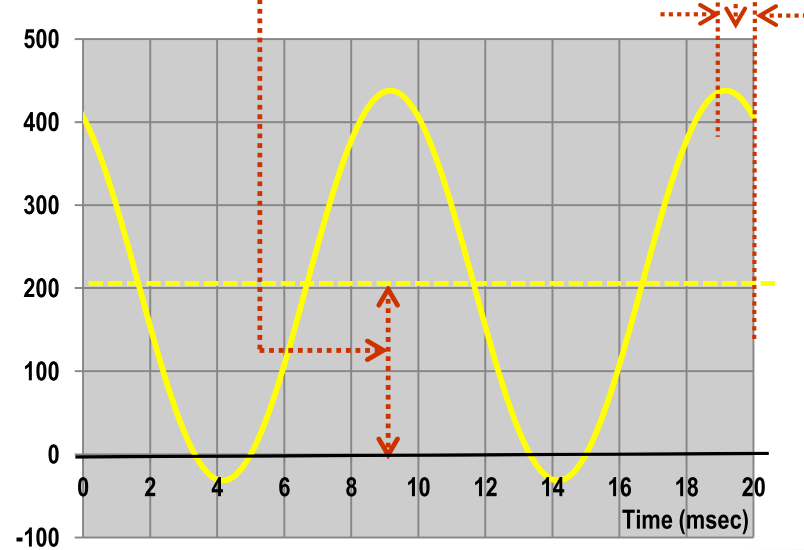
$$I = \hat{I} \cos(wt - \theta)$$





DC Term = $S(t)_{avg}$

θ / w



AC Power

Example

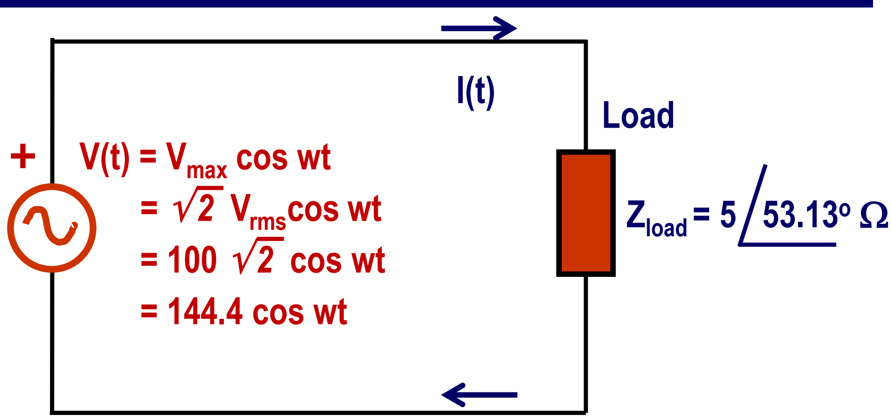
Question

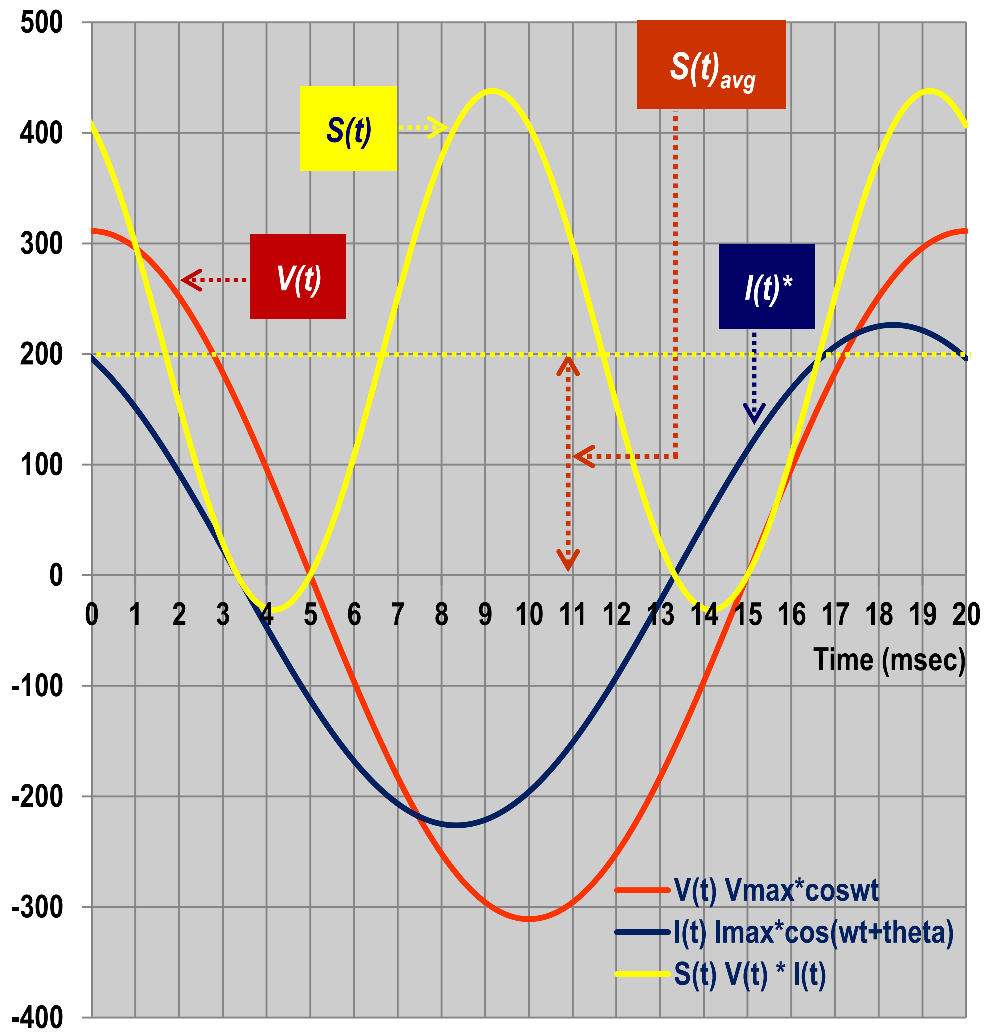
Calculate the average and instantaneous powers dissipated in the load shown in the following circuit;

System Parameters:

V_{rms} = 100 Volts

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





AC Power

Example

Solution

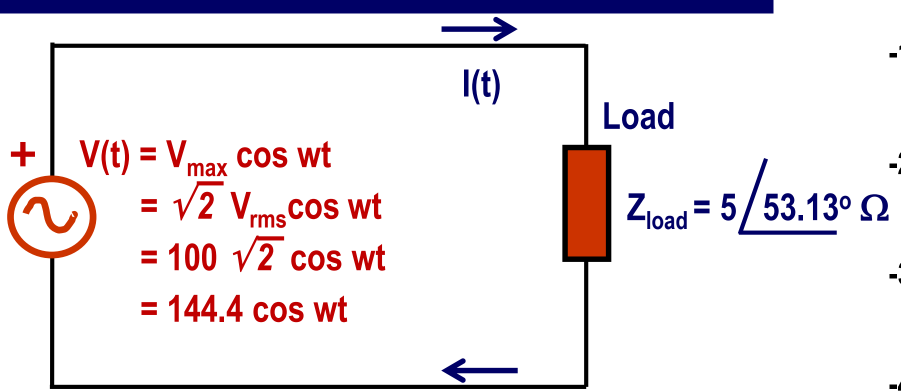
$V_{max} = 100 \times \sqrt{2} = 144.4$ Volts

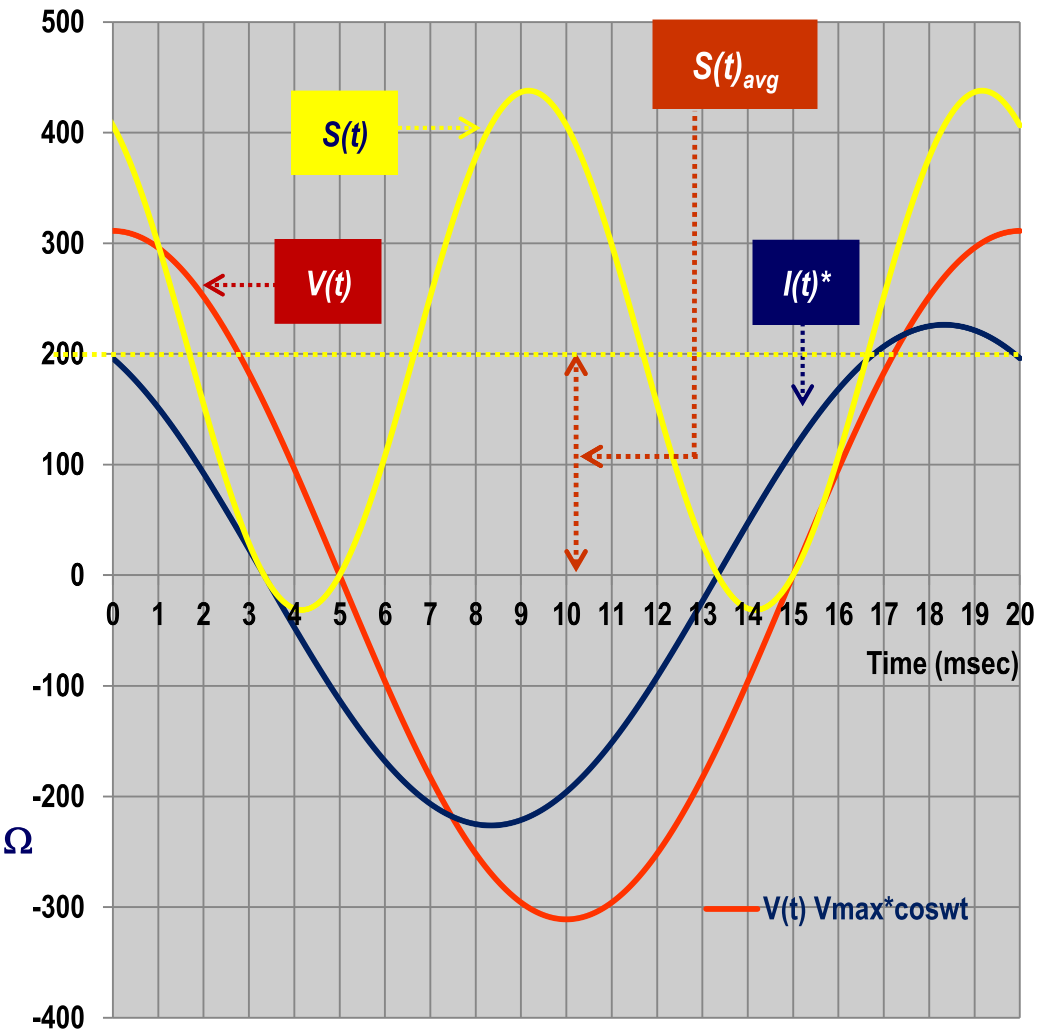
$$I = V_{max}\angle 0^o \; / \; Z\angle\theta$$

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

$$= 28.8\angle -53.13^o \text{ Amp}$$

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





Example

Solution

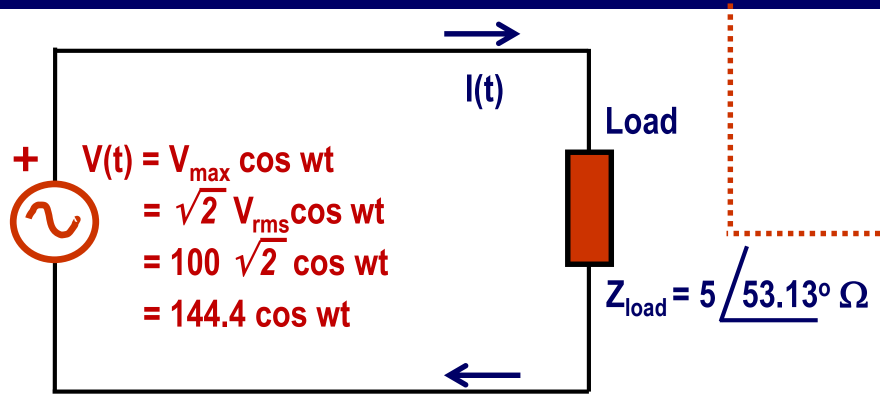
$S(t)_{avg} = V_{rms}\, I_{rms}\, \cos\theta$

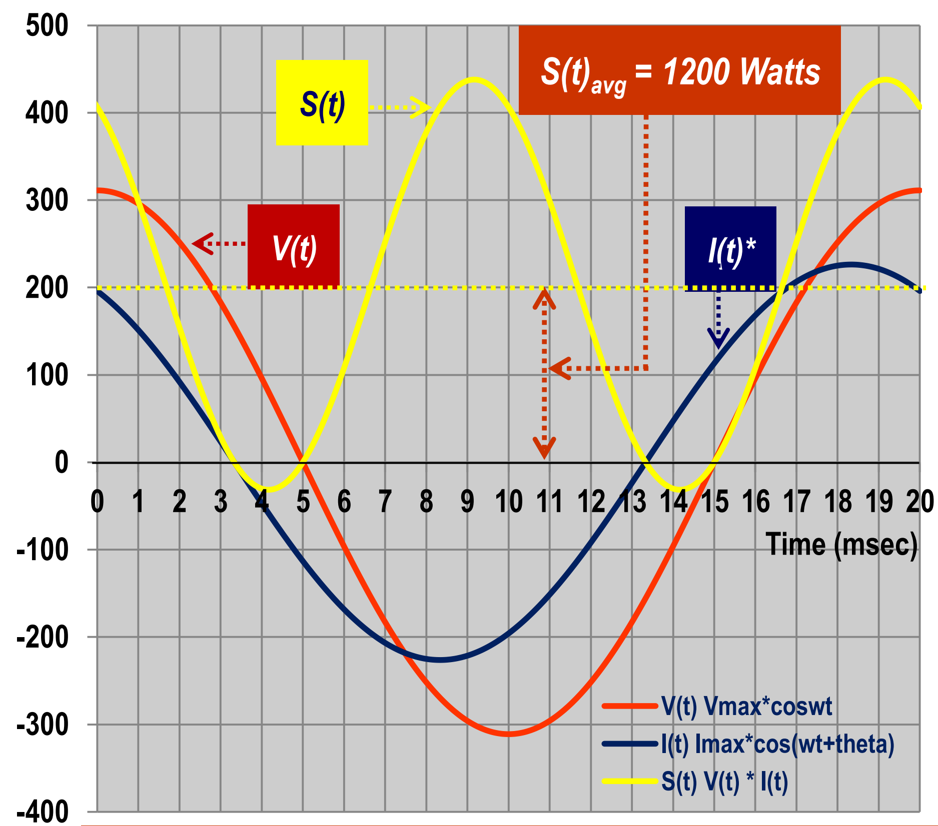
$= 100 \times 20 \cos 53.13 = 1200$ Watts

$S = V \times I^*$

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

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





Please note that;
"-" sign here should be altered to "+" due to the conjugate operator in the definition of power:
$S = V \times I^*$

AC Power

Example

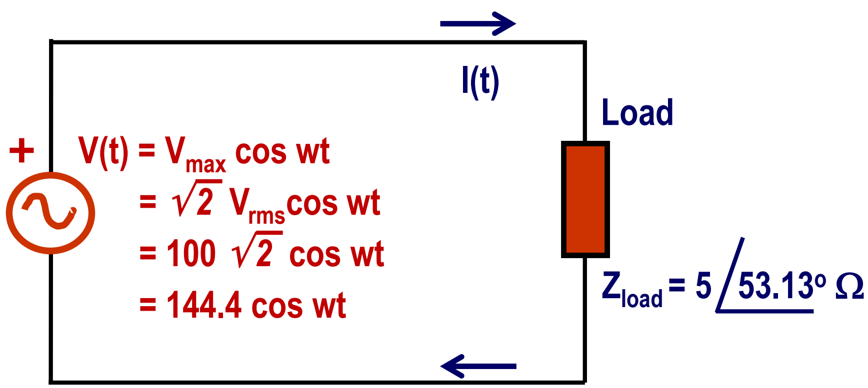
Solution

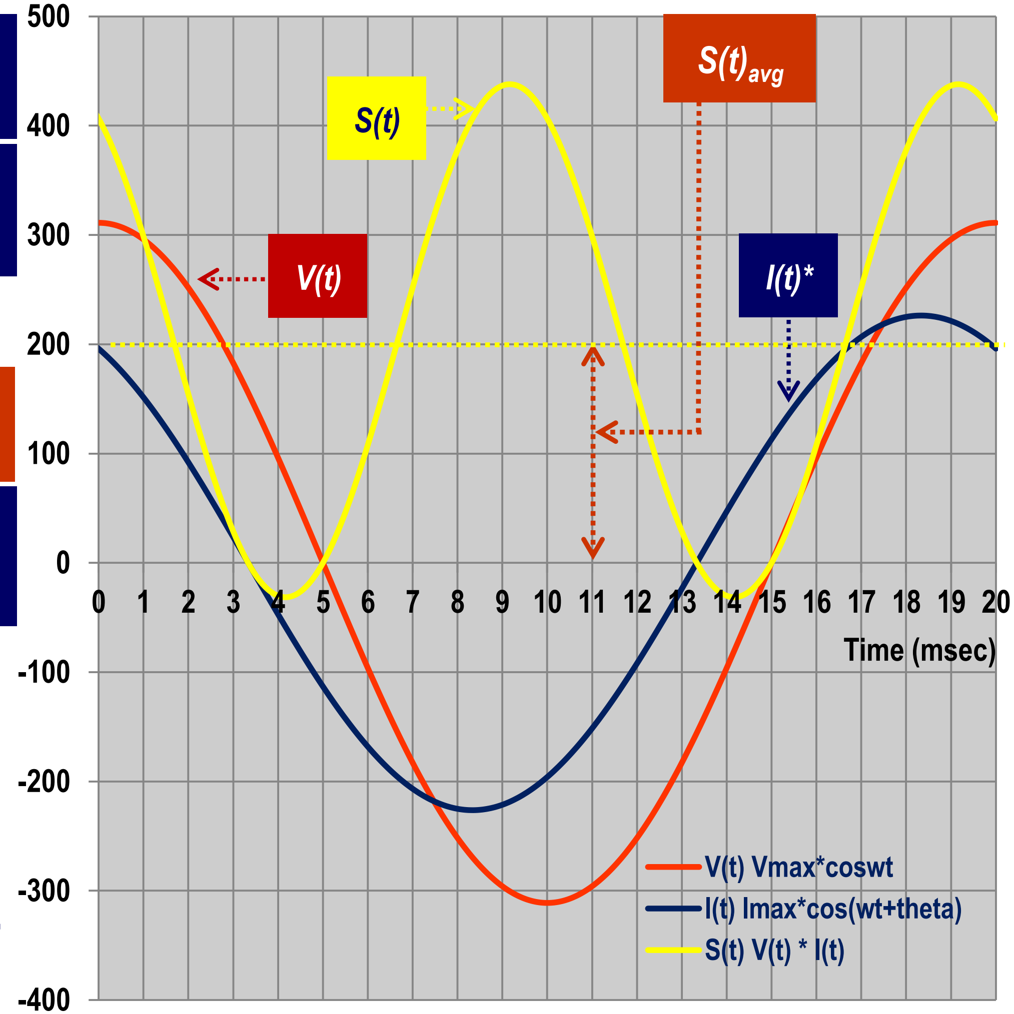
S(t) = 4000 cos wt x cos (wt + 53.13°)

or by using the following identity;

cosa cos b = ½ [cos (a + b) + cos (a - b)]

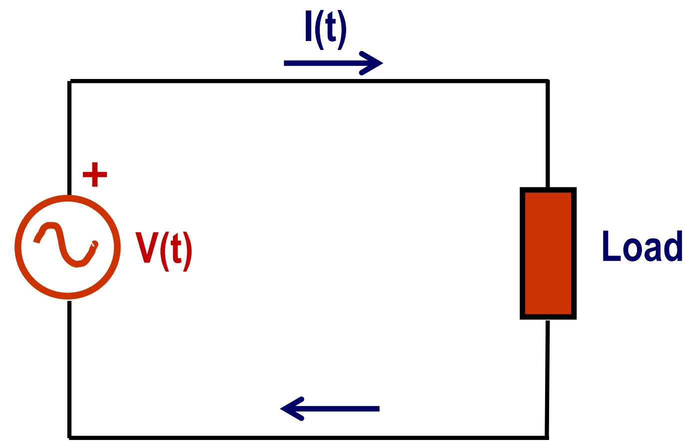
S(t) = 2000 [cos (2wt + 53.13°) + cos 53.13°]





AC Power

Complex Power



Active Power Expression

Expanding the first term in the power expression;

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

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

Expanding the first term in the power expression;

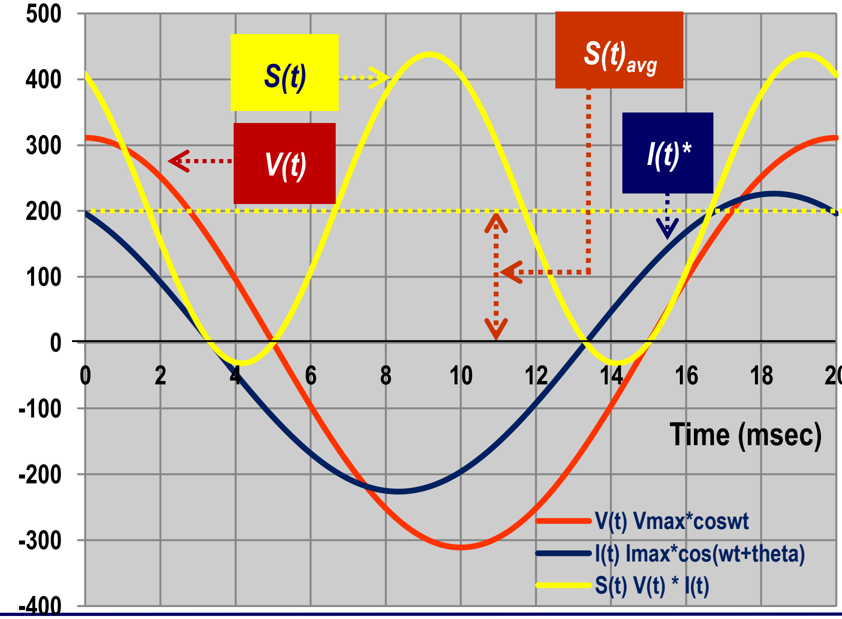
$S(t) = V_{rms}\ I_{rms}\ (\cos 2wt \cos\theta - \sin 2wt \sin\theta + \cos\theta)$

and recombining the cosine terms;

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

P(t) = Active power

Q(t) = Reactive power



AC Power

Complex Power

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

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

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

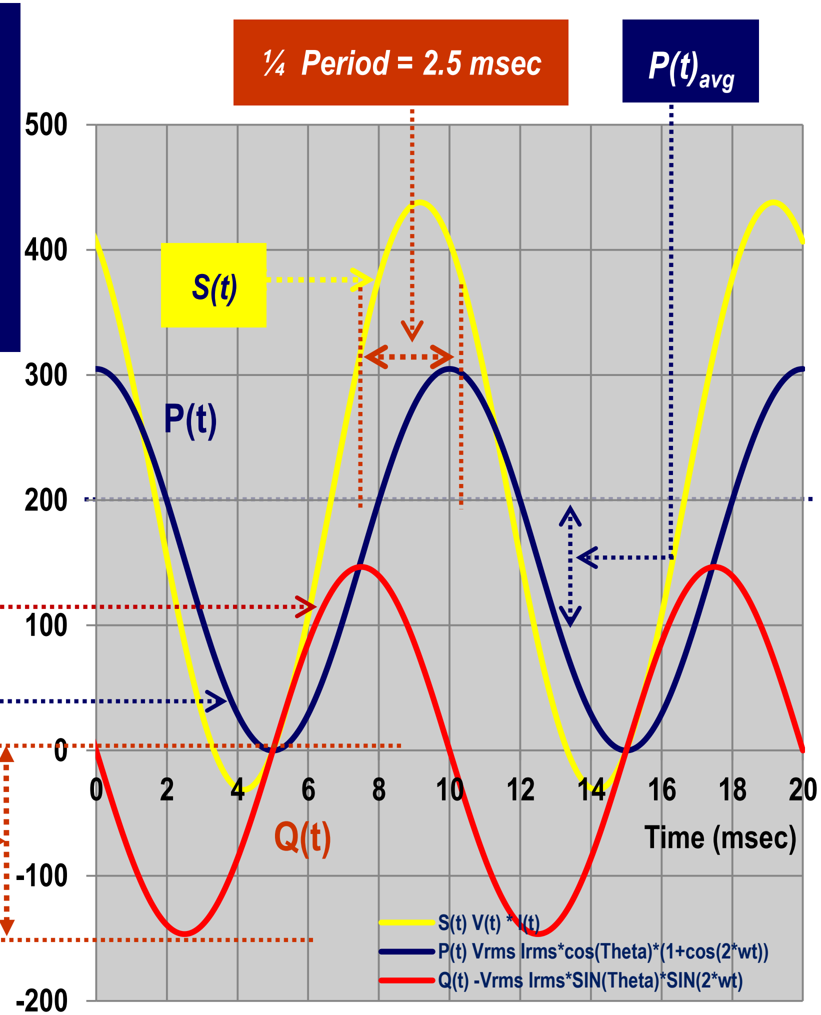
P(t) =Active power

Please note that P(t) is nonnegative

Q(t) = Reactive power

Please note that Q(t) has zero mean

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

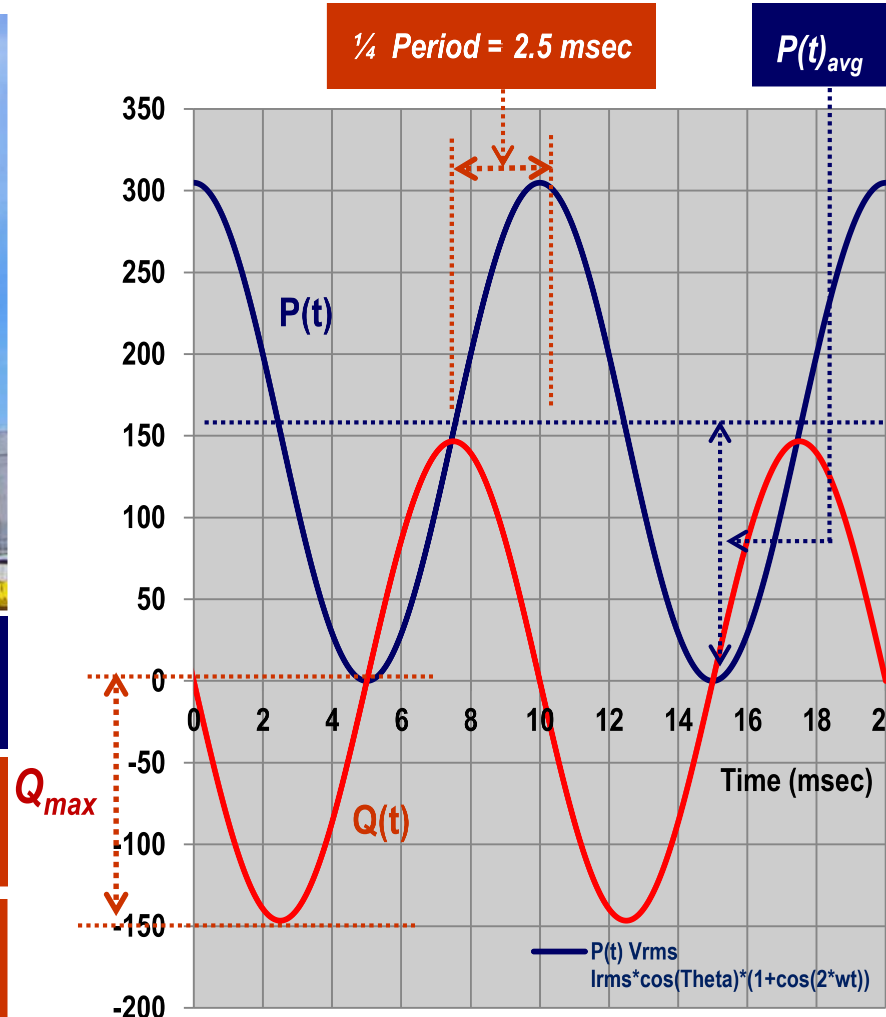


Active and Reactive Power Waveforms – Summary

Marmara, Unimar Power Plant (470 MW)

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

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



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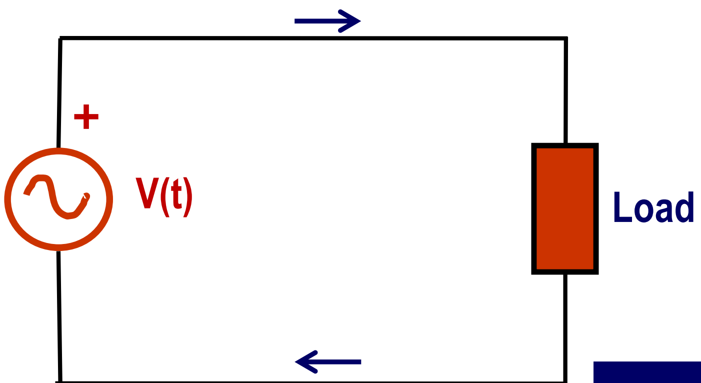
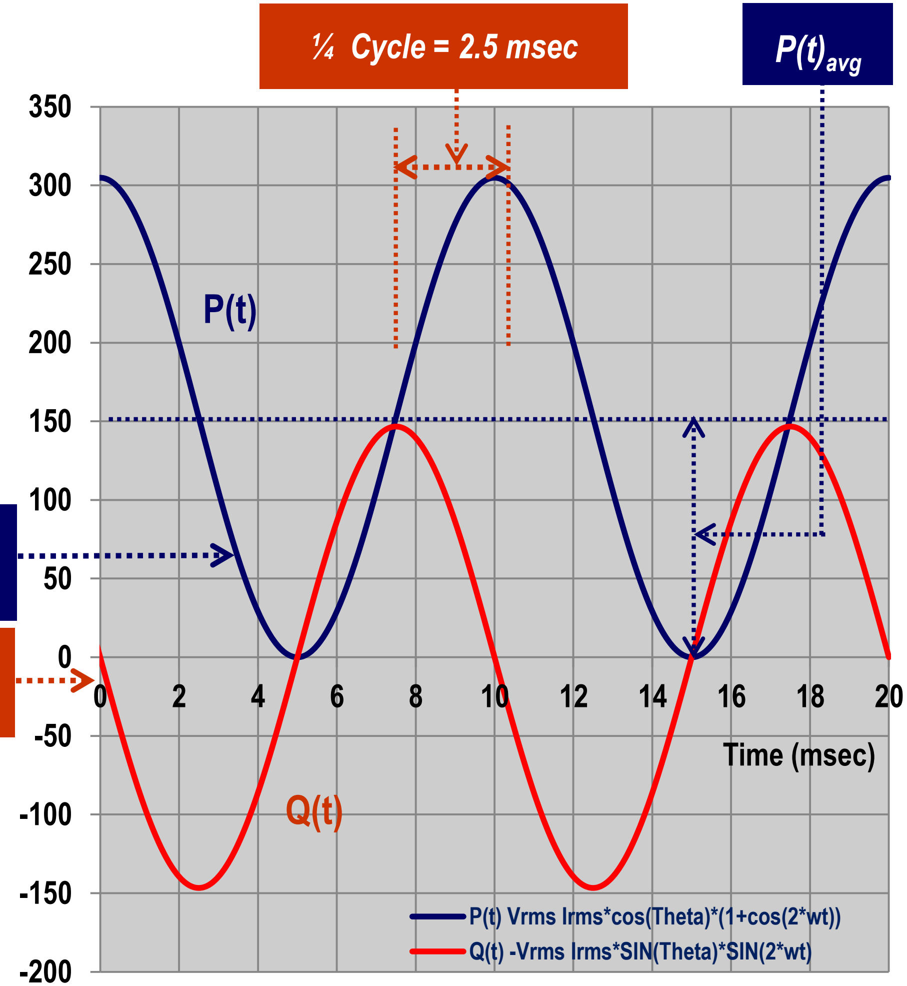
Active and Reactive Power Waveforms

Power (P, Q)



P(t) = Active power

Q(t) =Reactive power



One cycle ⟺ 10 msec
Hence,
1/4 cycle = 360º / 4 = 90º ⟺ 2.5 msec

AC Power

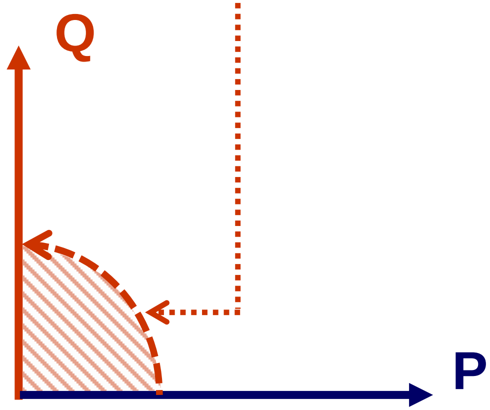
Active and Reactive Power Waveforms

One cycle ⟺ 10 msec

Hence,

1/4 cycle = 360° / 4 = 90° ⟺ 2.5 msec

Please note that Q leads P by 90°

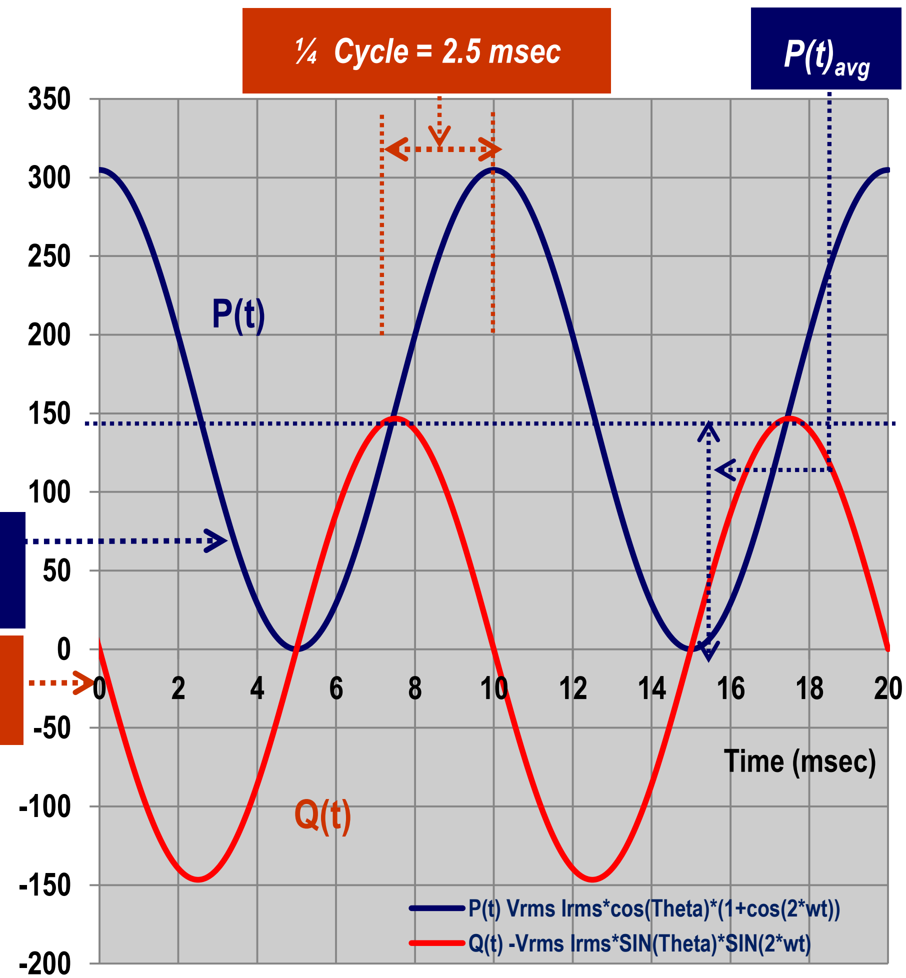


10 msec ⟺ 360°

2.5 msec ⟺ 90°

P(t) = Active power

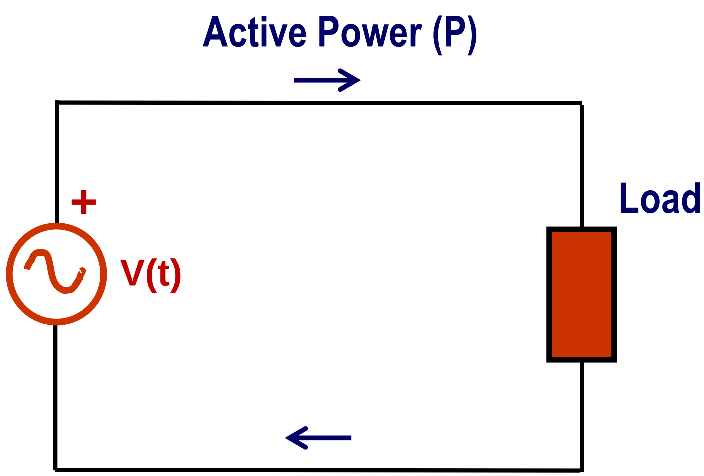
Q(t) =Reactive power



AC Power

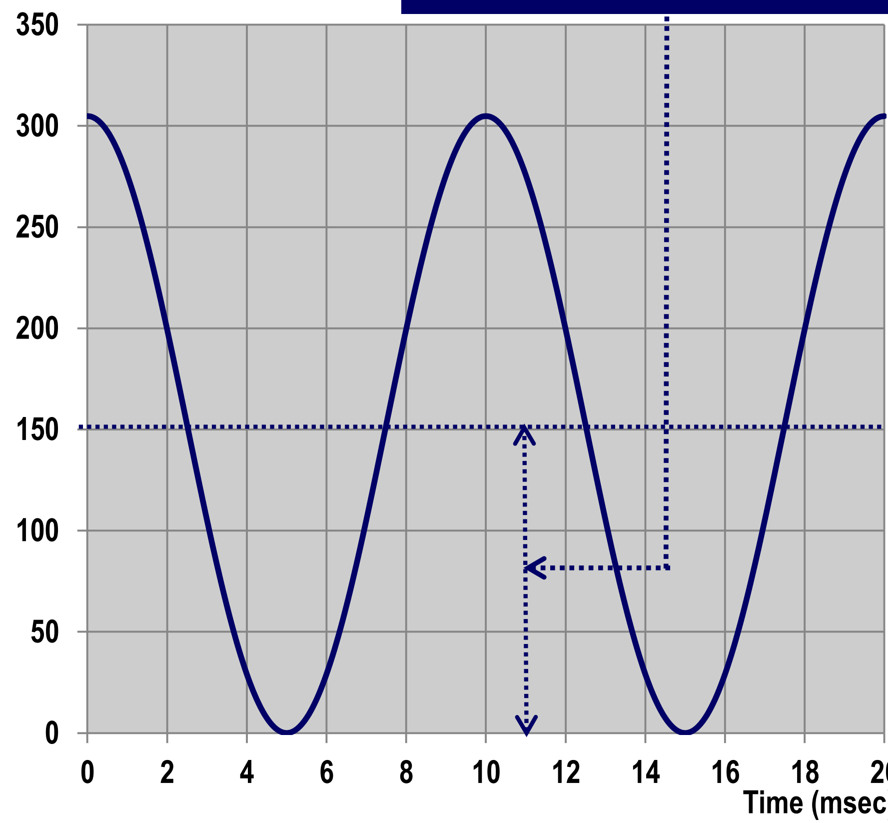
Active Power Waveform

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



$P(t)_{avg} = V_{rms}\, I_{rms}\, \cos\theta$
$= 150\ W$

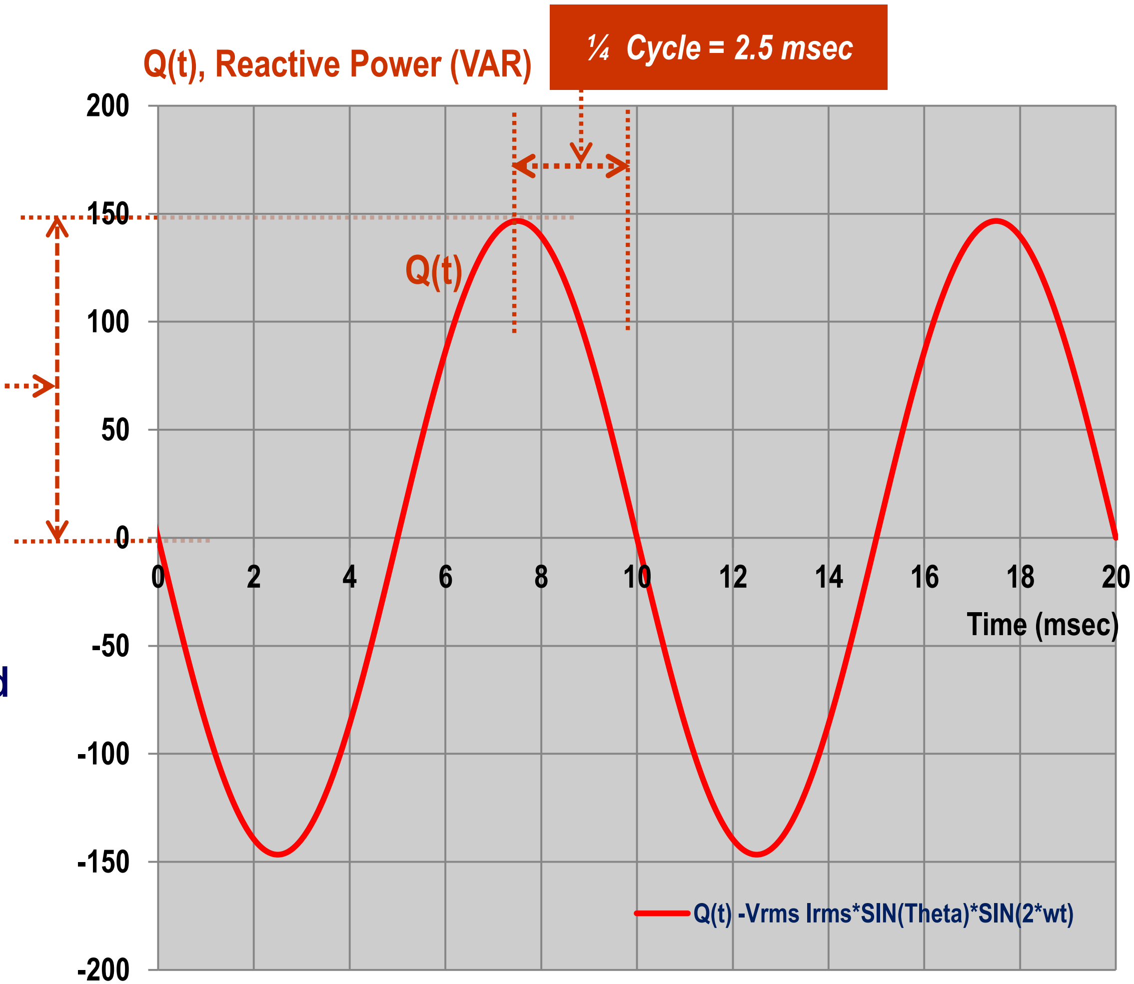
P(t) = Active Power (Watt)

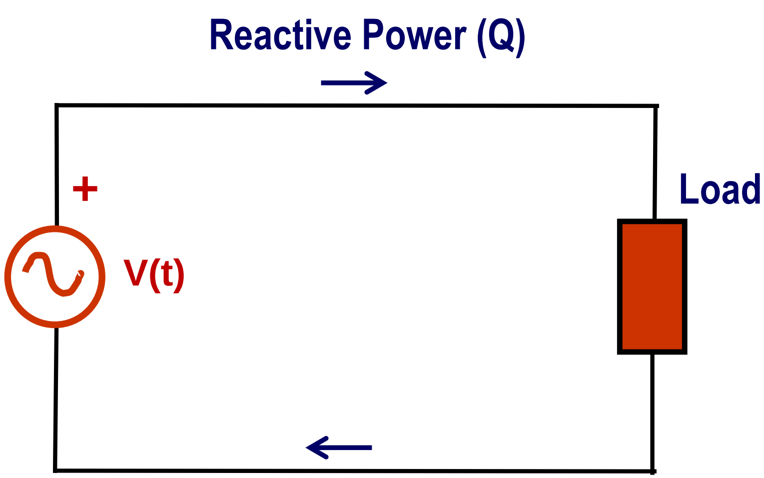


Reactive Power Waveform

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

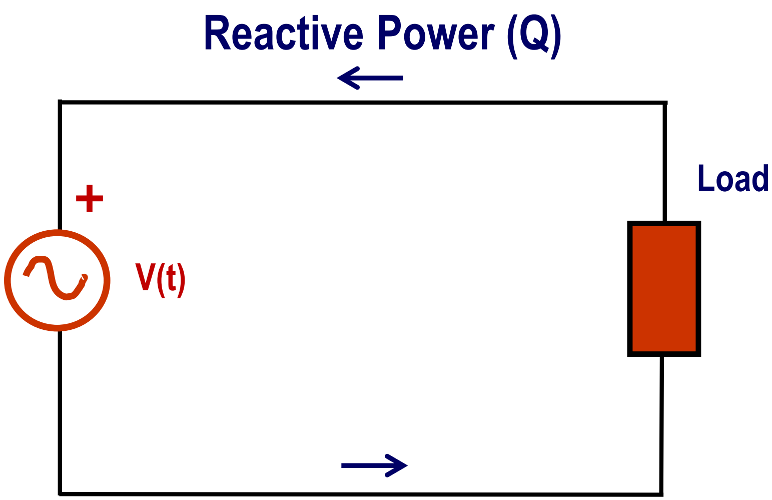
$Q(t)_{\ sinusoidal}$ | $Q_{\ max}$

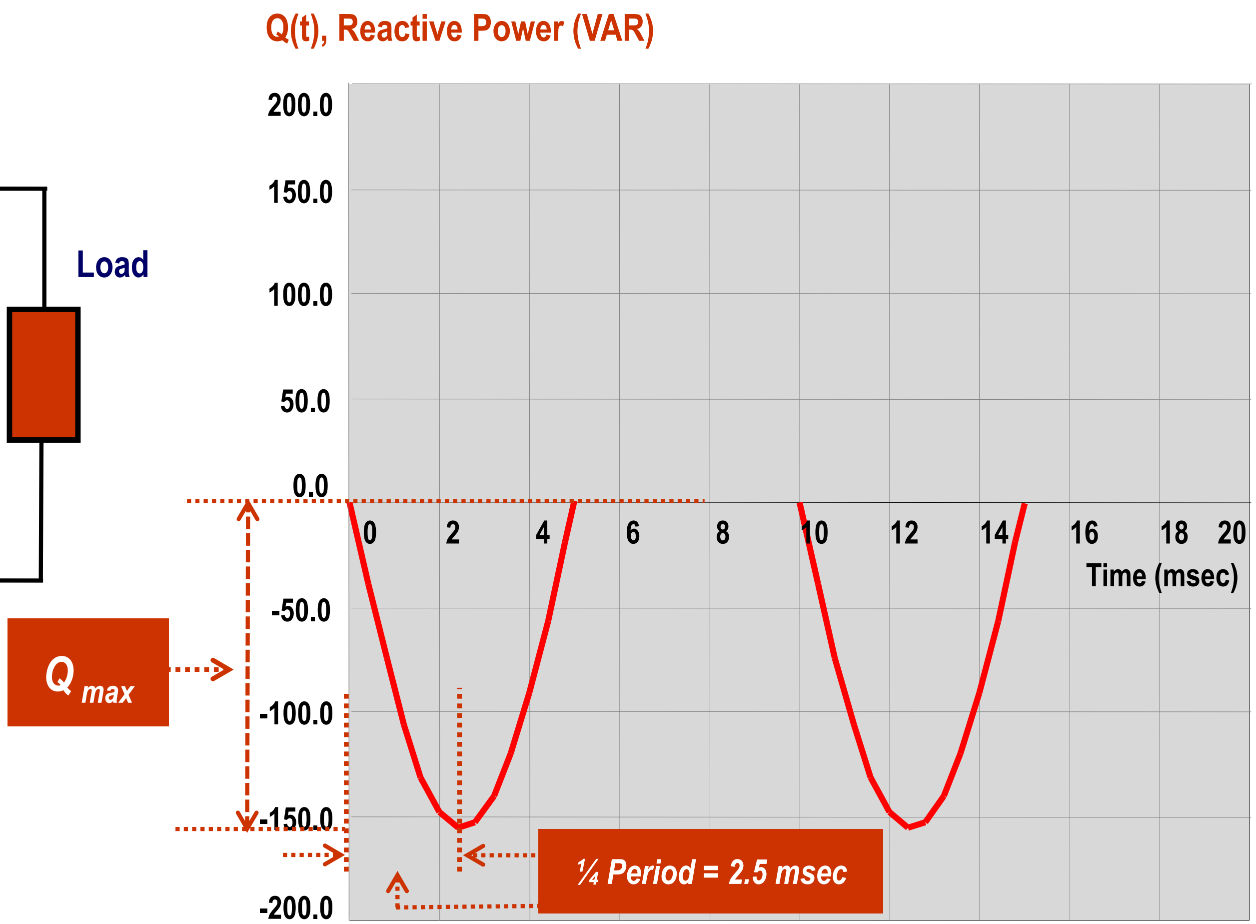




AC Power

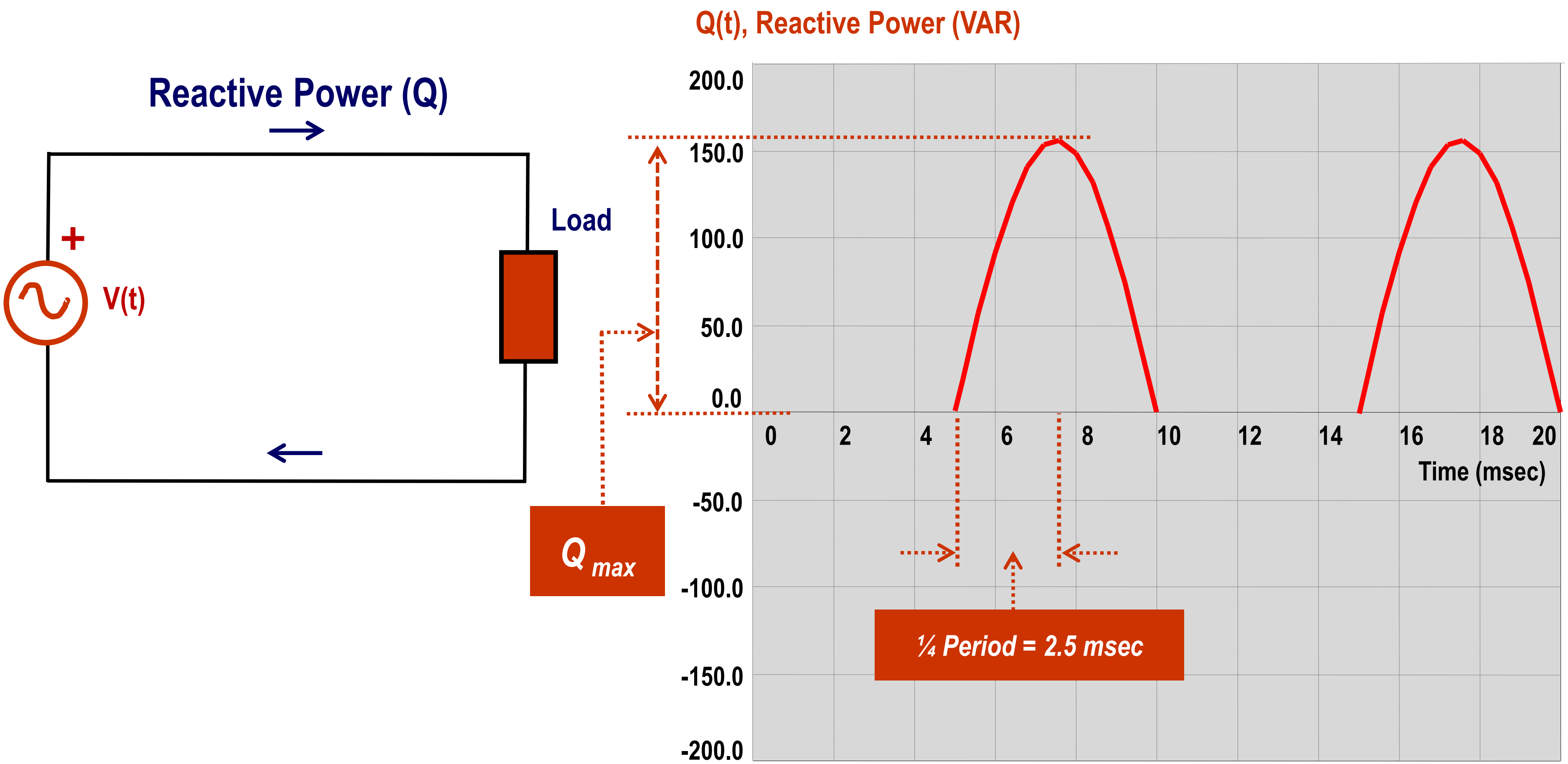
Reactive Power Waveform (During the first 5 mseconds)





AC Power

Reactive Power Waveform (During the next 5 mseconds)

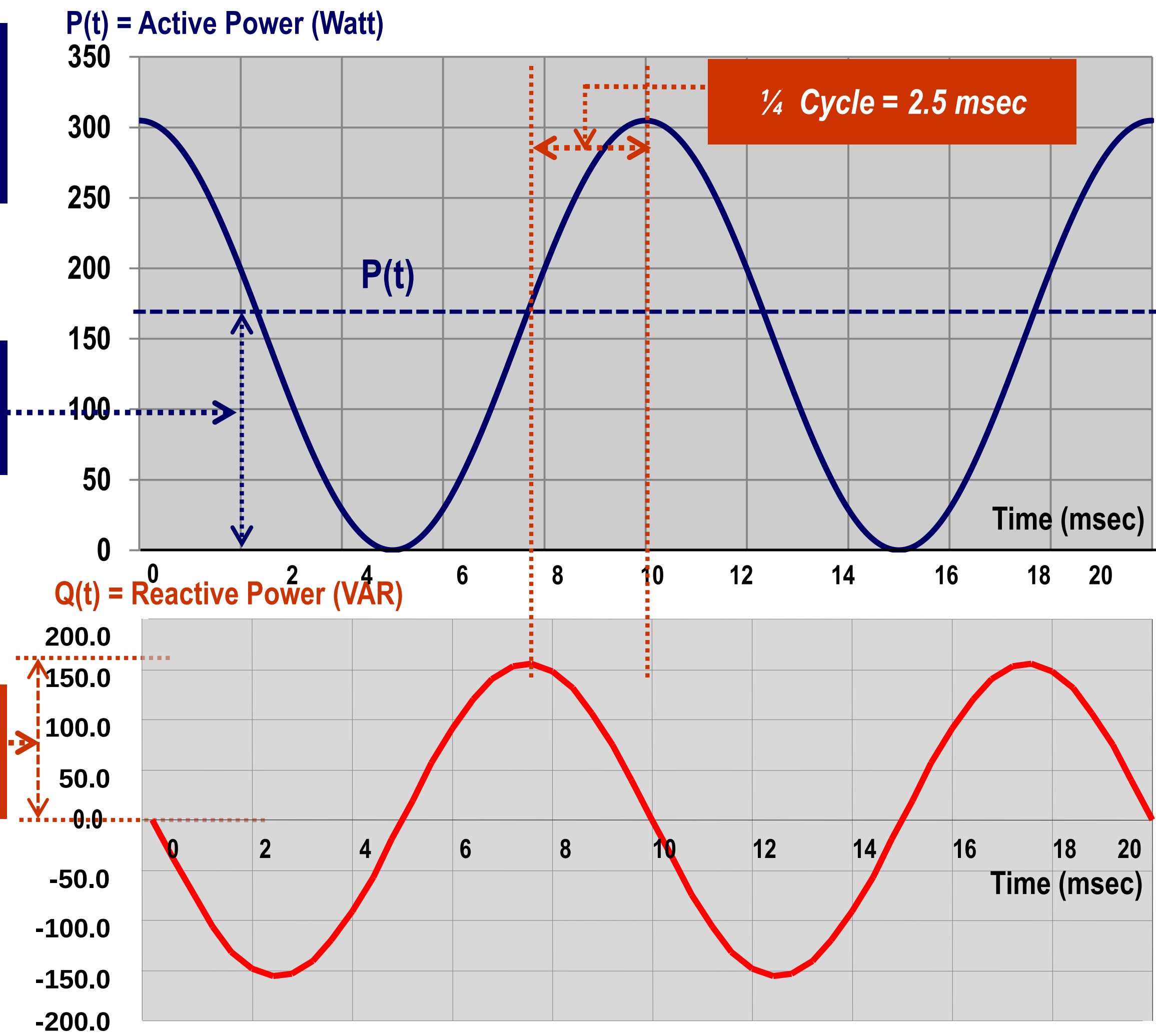


Active and Reactive Power Waveforms

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

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

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



Period of Active and Reactive Power Waveforms

Period of Voltage and Current Waveforms

Angular speed: $w = 2\pi f$

$= 2 \times 3.1415 \times 50 = 314$ rad/sec

Time duration (period) of one revolution $= 1/f = 1/50$

$= 0.020$ sec $= 20$ msec

Hence,

Angle for ¼ revolution $= 360^o / 4 = 90^o$

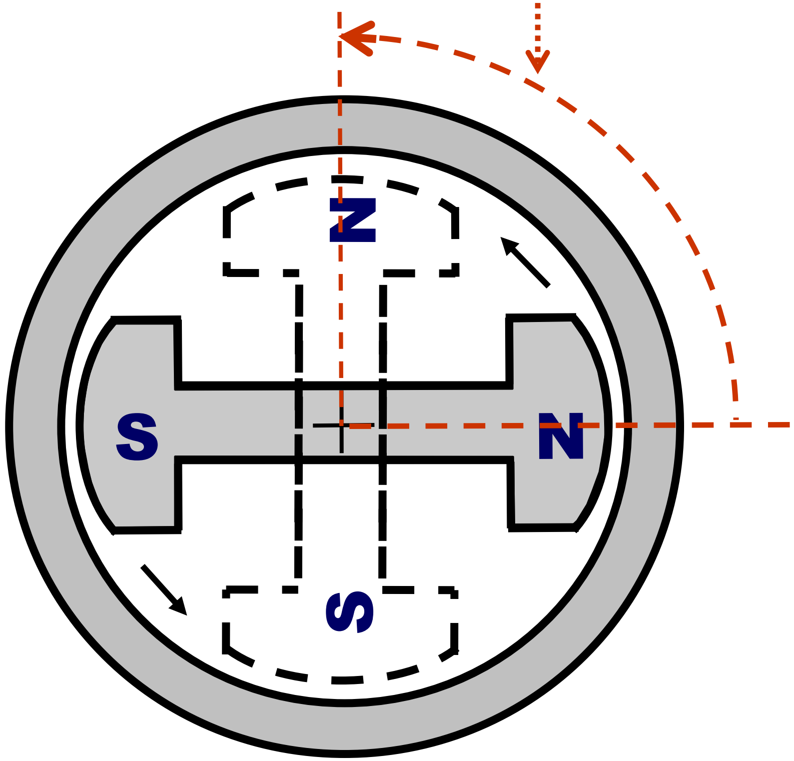
Time duration (period) of ¼ revolution $= 20$ msec $/ 4$

$= 5$ msec

Angle $= 90^o$,

Time duration (Period) of ¼ revolution $= 20/4$ sec

$= 5$ msec



Period of Active and Reactive Power Waveforms

Period of Active and Reactive Power Waveforms

Angular speed: $w' = 2\,w = 4\pi f$

$= 2 \times 31415 = 628$ rad/sec

Hence,

Time duration (period) of one revolution = 10 msec

Time duration (period) of ¼ revolution = 10 msec / 4

= 2.5 msec

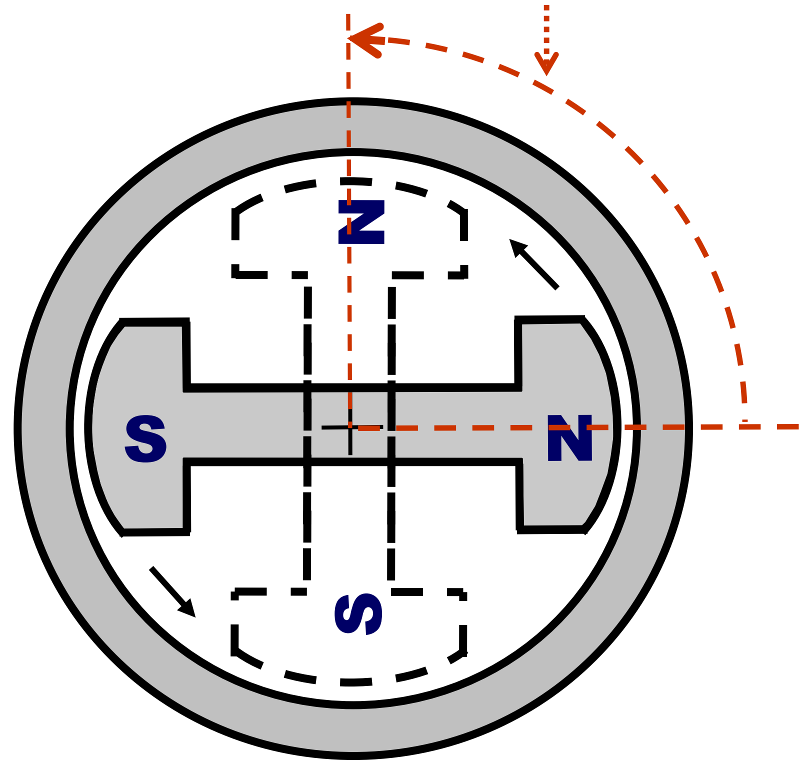
Conclusion;

Time duration (period) of active and reactive power waveforms is half of those of voltage and current

Angle = 90°,

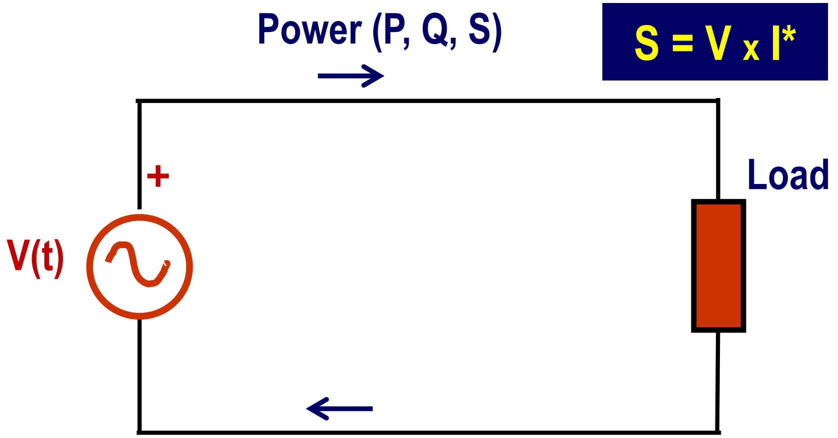
Time duration (Period) of ¼ revolution = 20/4 sec

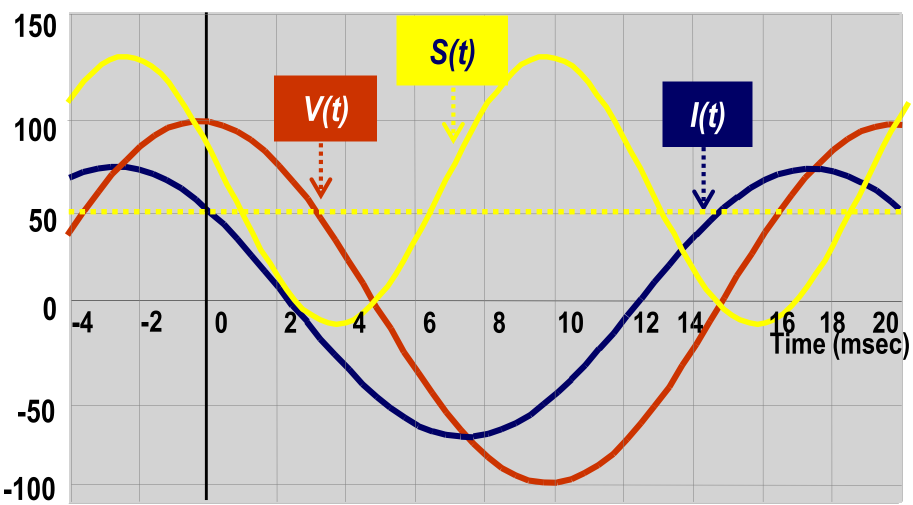
= 5 msec

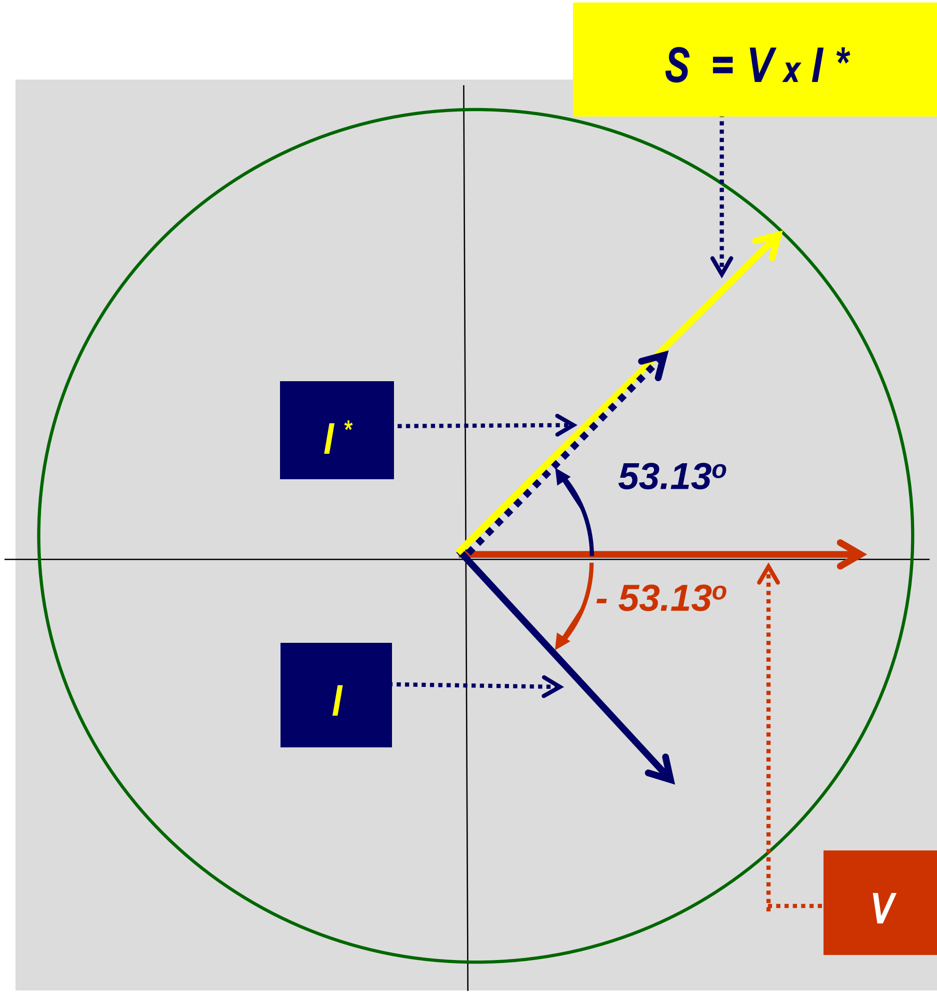


AC Power

Active and Reactive Power Phasors



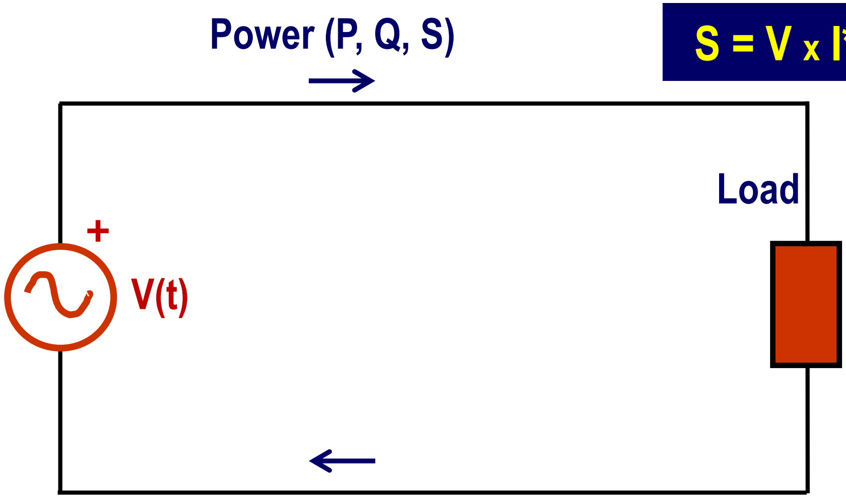


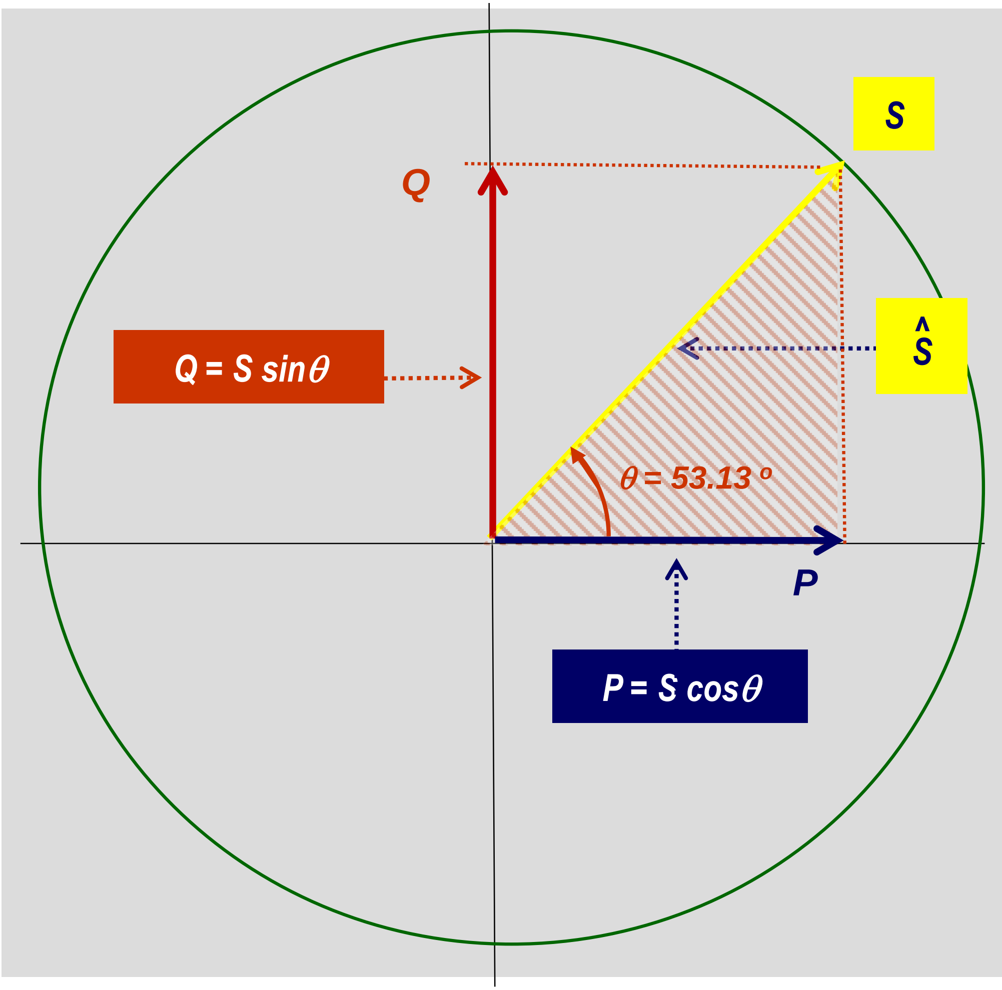


Active and Reactive Power Phasors

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

$S = V \times I^*$





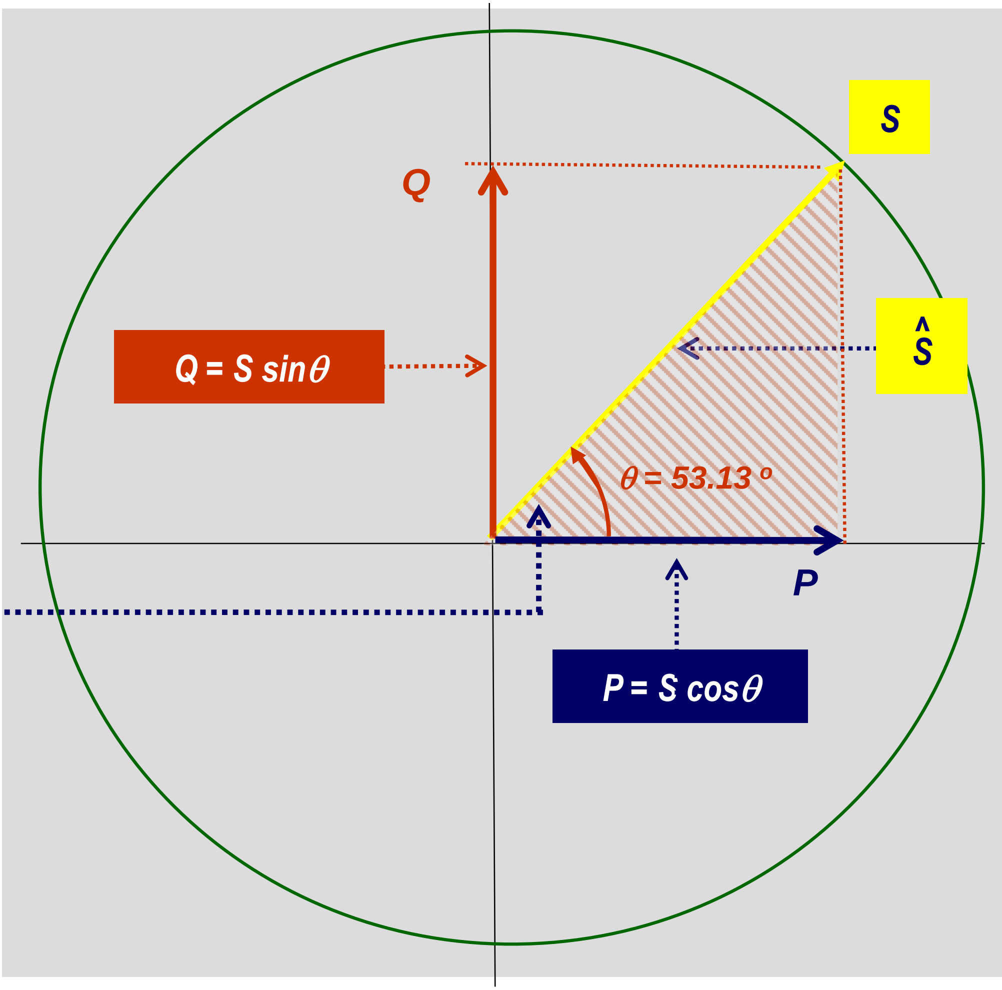
AC Power

Active and Reactive Power Phasors

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

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

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



METU

AC Power

Basic Conversions

Polar Representation

$$S \angle \theta$$

Rectangular Representation

$$P + j\,Q$$

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

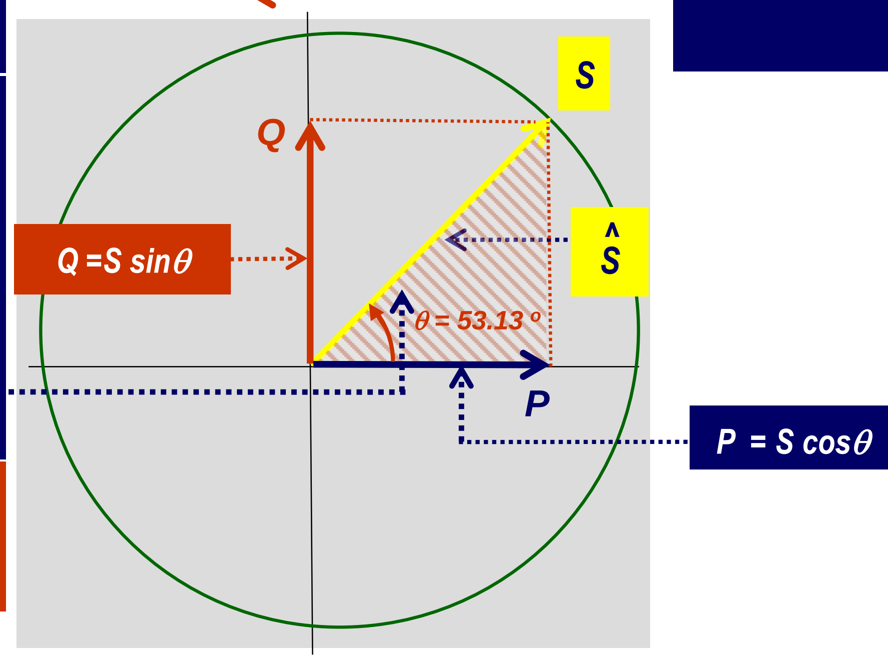
$S = \sqrt{P^2 + Q^2}, \quad \theta = Tan^{-1}(Q / P)$

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

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

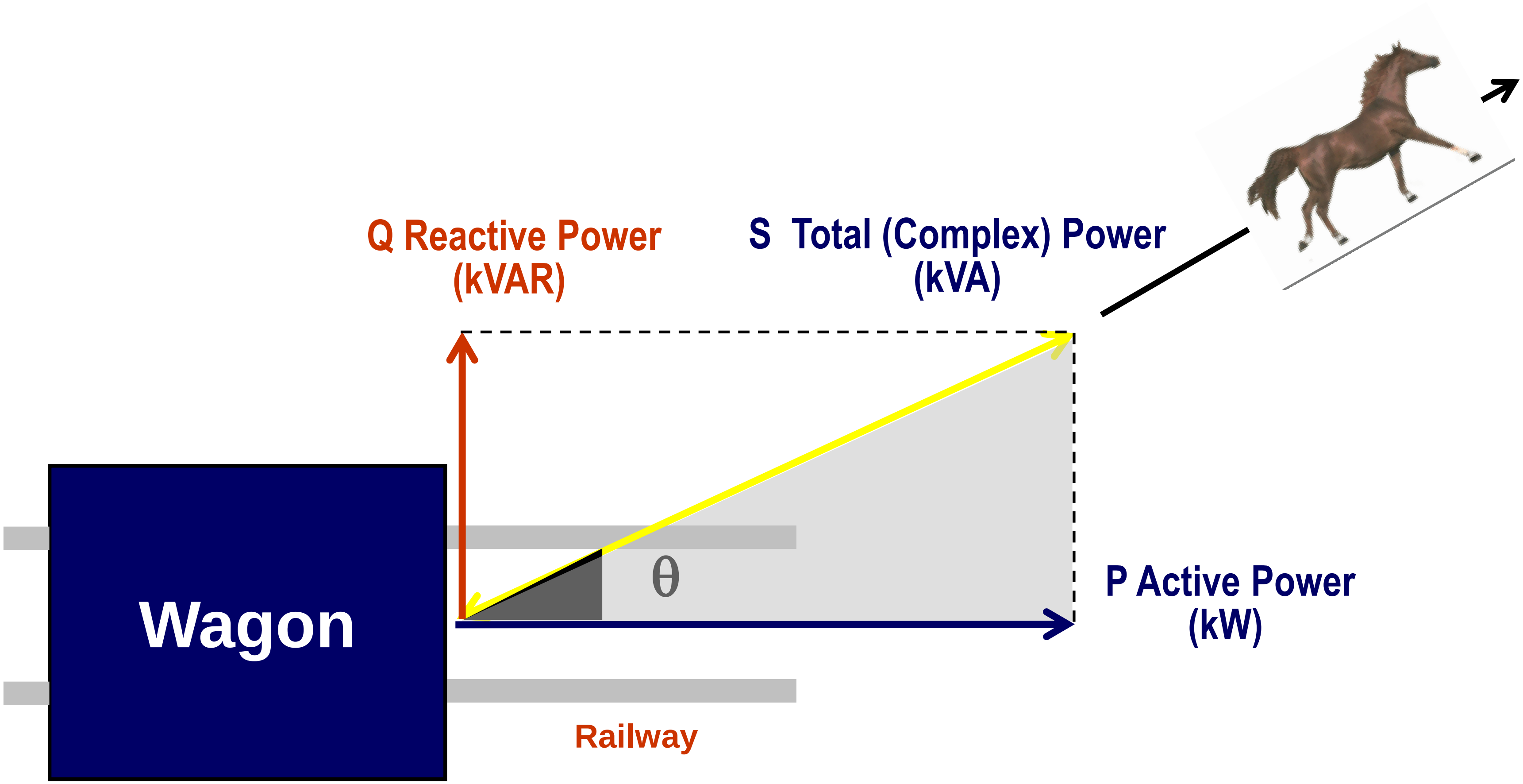
$X / R = Q / P$

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

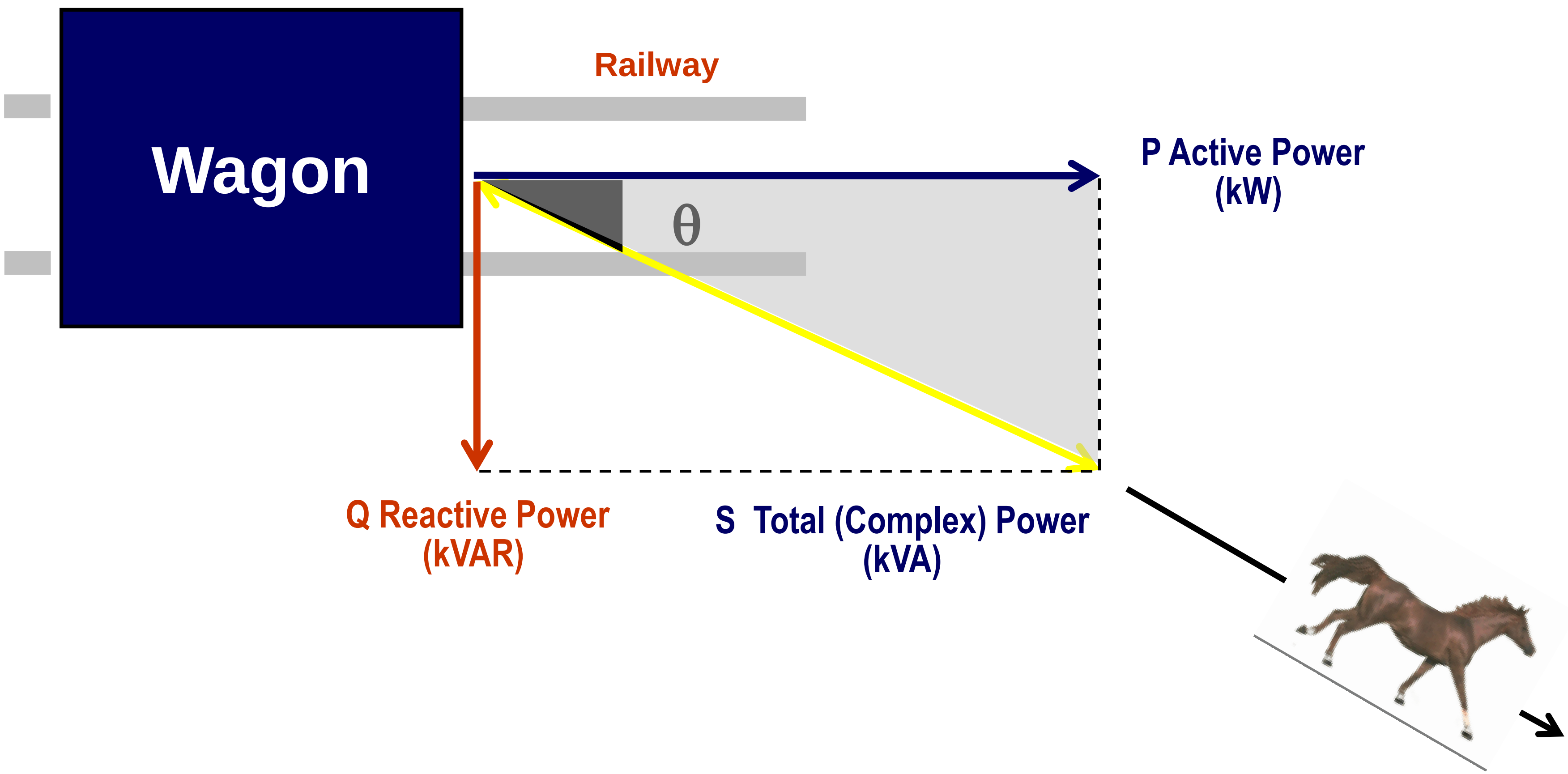


AC Power

Active and Reactive Powers (in the first 5 mseconds)

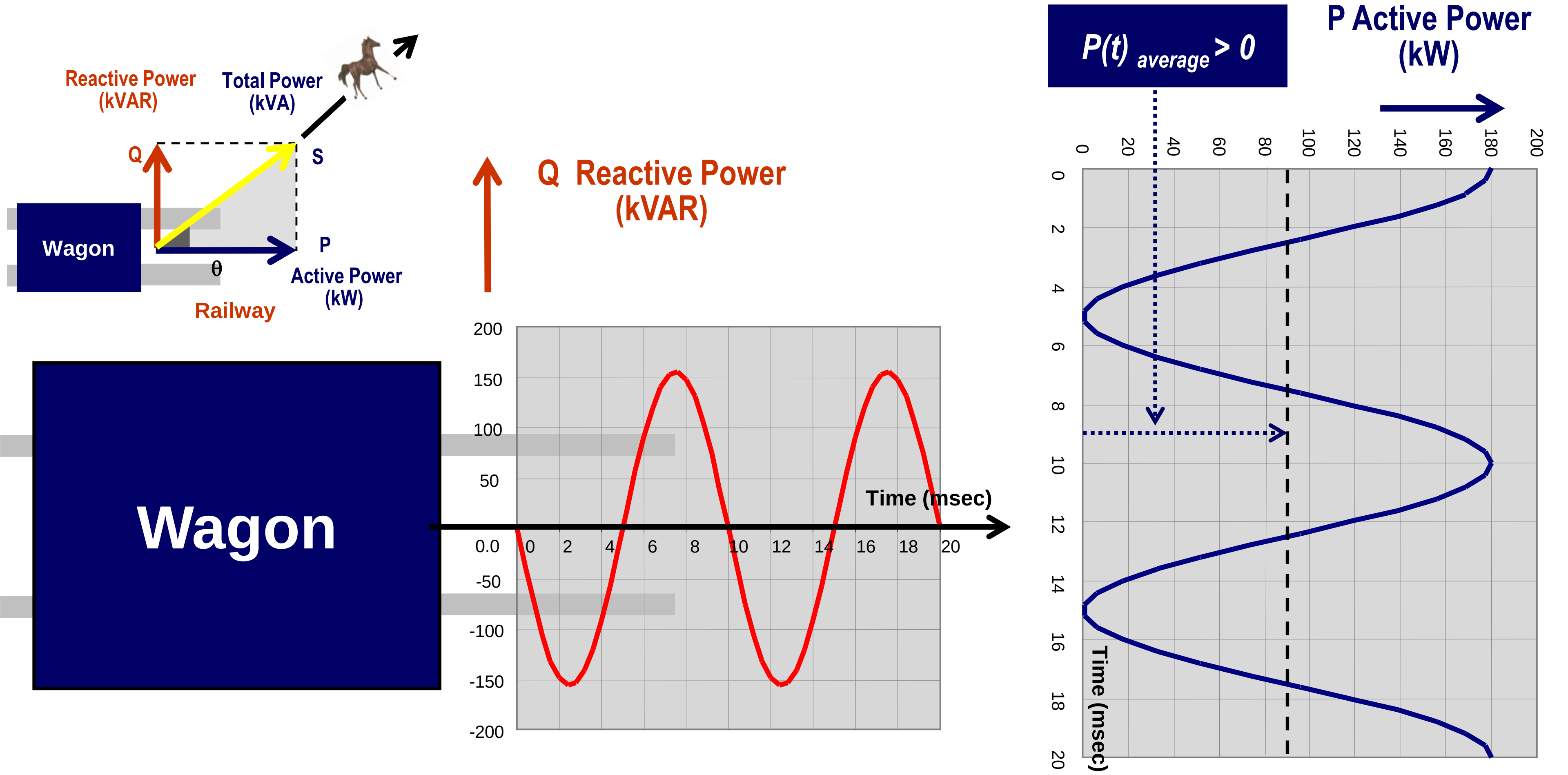


Active and Reactive Powers (in the next 5 mseconds)



AC Power

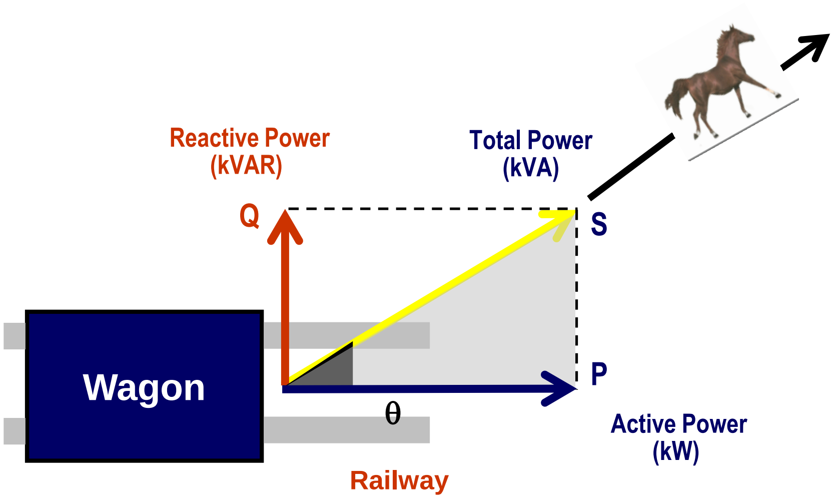
Active and Reactive Powers

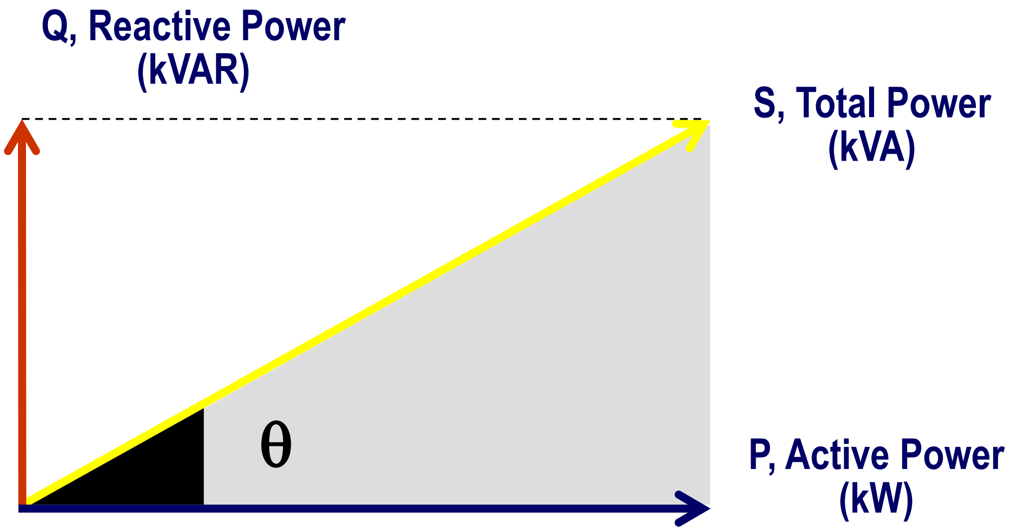


AC Power

Active and Reactive Powers

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

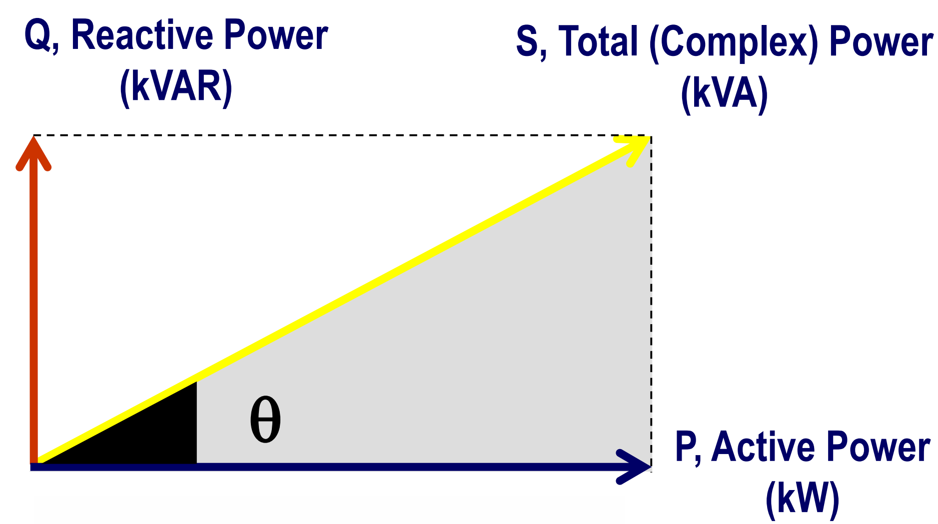


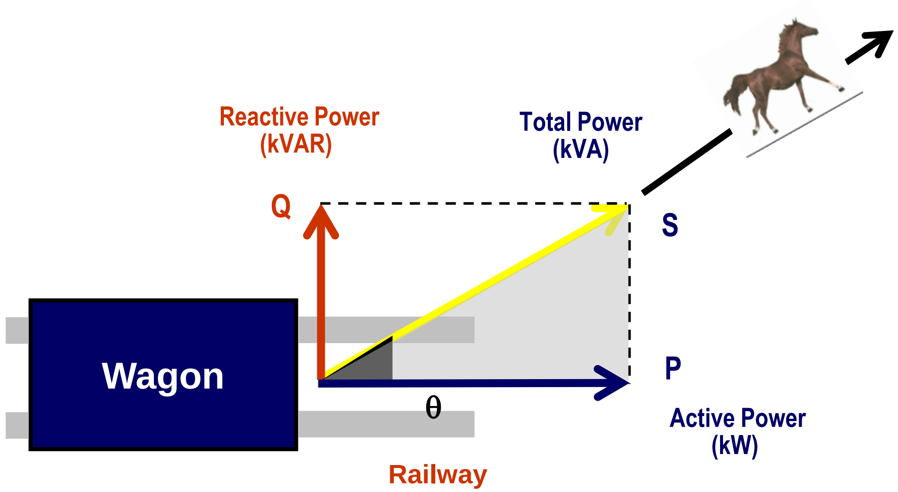


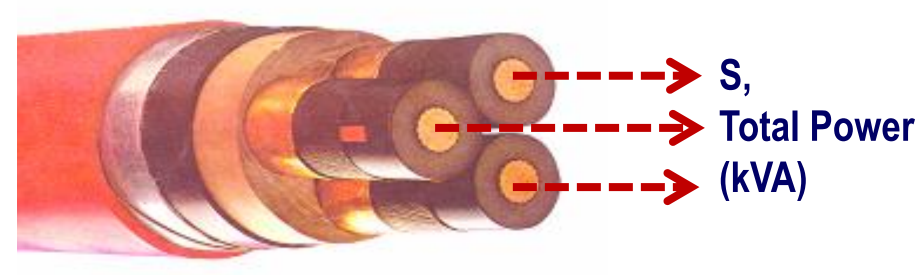
AC Power

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

Power Meters

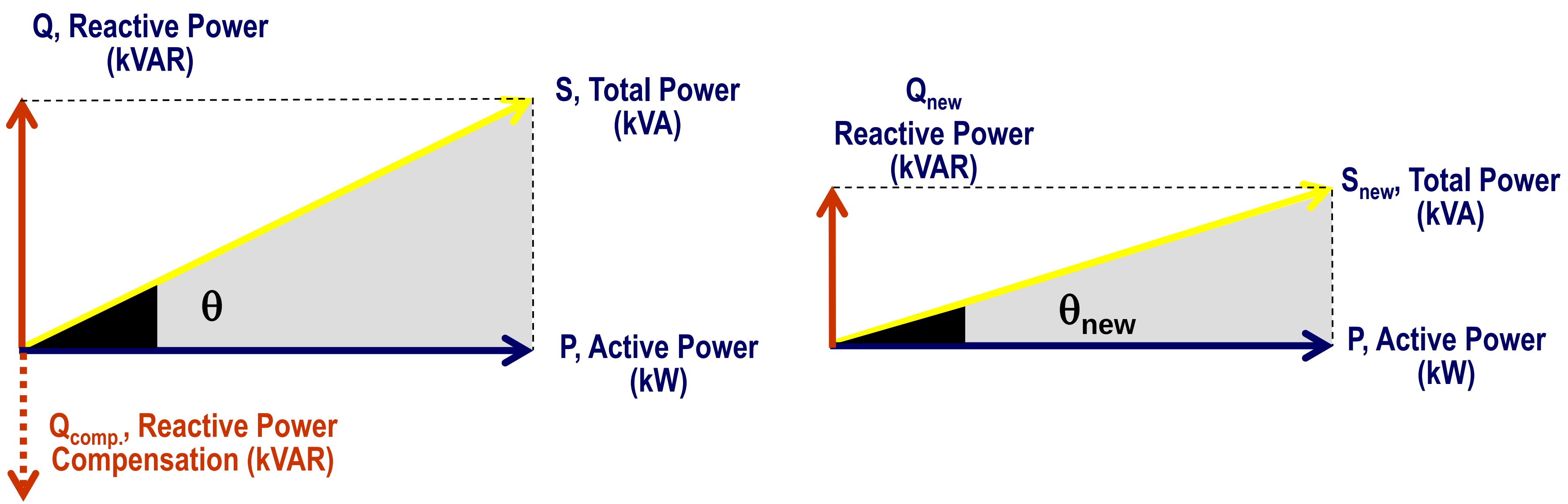
Analog	Digital	Power Analyzer

Clamp Type Current Transformers

Reactive Power Compensation

Definition

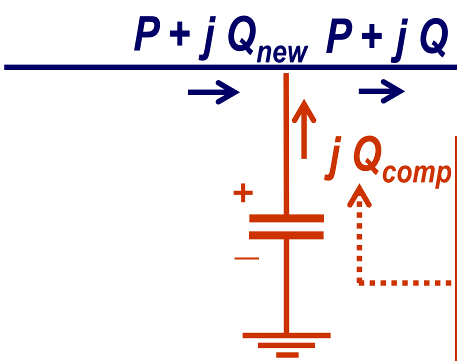
Reactive power compensation is partial or full cancellation of the reactive component of complex power by introducing a negative (compensation) component



Reactive Power Compensation

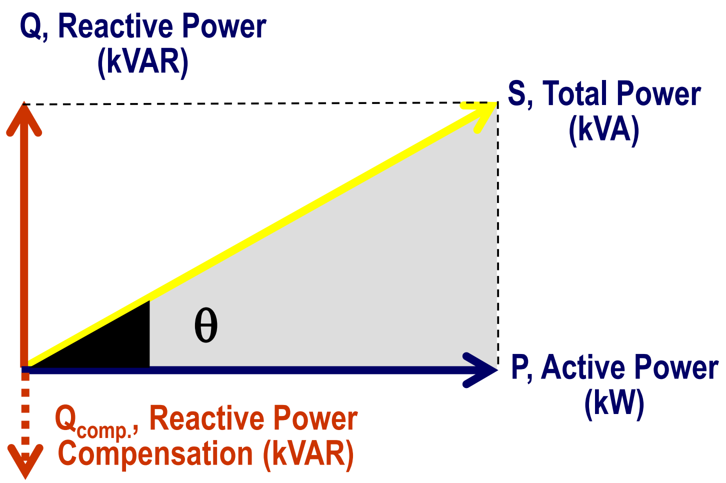
How is it Realized ?

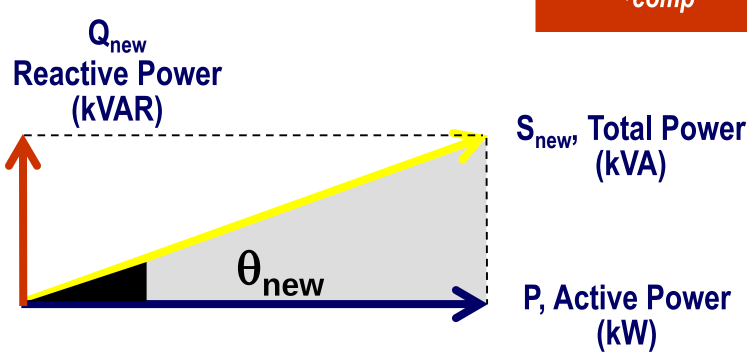
Reactive power compensation is realized by connecting a capacitor bank in parallel with the load, satisfying the reactive power need of the load.



$P = 3000$ kW
p.f. $= 0.65$
$\theta = 49.46^o$ (lag)
$Q = 3507$ kVAR

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





AC Power

Power Factor

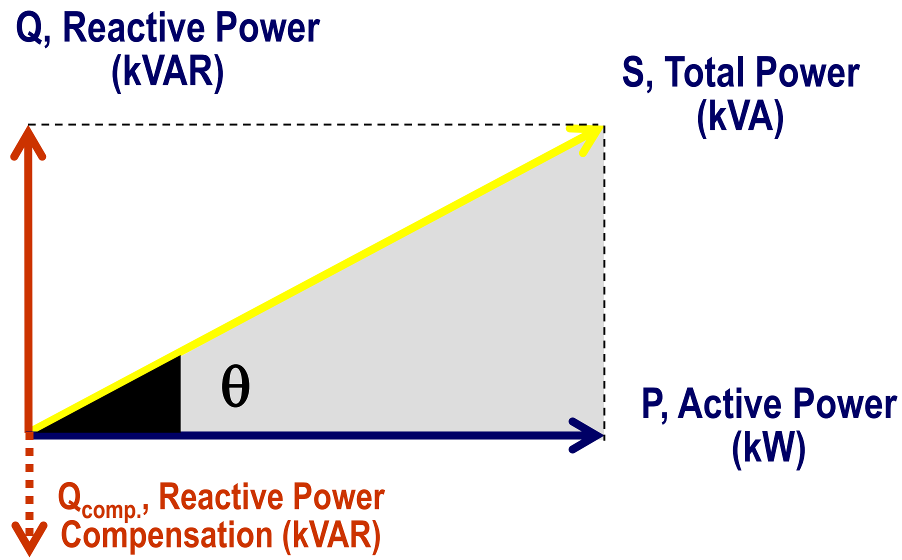
Definition

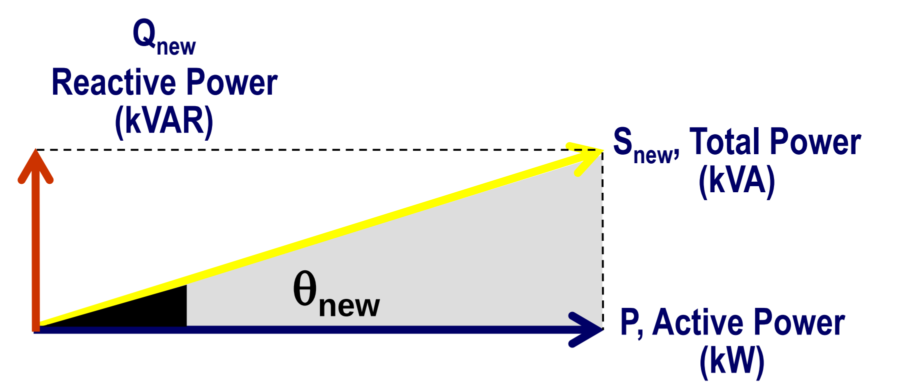
Cosine of the angle between S and P is called Power Factor of the load

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





AC Power

Full or Partial Compensation

Full Compensation

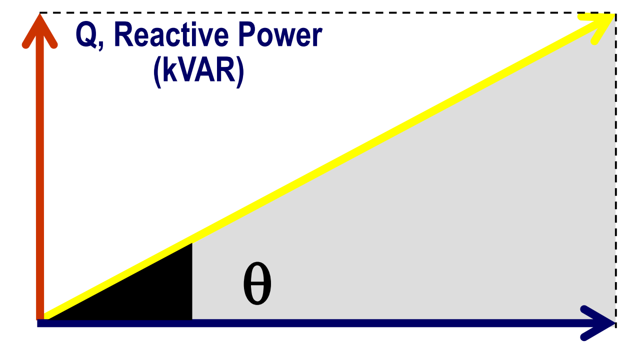
Full compensation is the case, where Power Factor is unity

Power Factor$_{new}$ = *p.f.*$_{new}$ = $\cos\theta_{new}$
= $\cos(\tan^{-1} 0 / P) = 1$

Partial Compensation

Partial compensation is the case, where Power Factor is raised to a level below unity

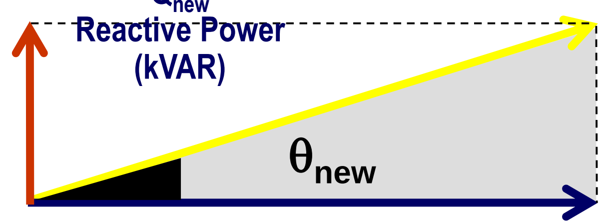
Power Factor$_{new}$ = *p.f.*$_{new}$ = $\cos\theta_{new}$
= $\cos(\tan^{-1} Q_{new} / P)$



Full Compensation

$Q_{new} = 0$ $\theta_{new} = 0$ $S_{new} = P$

Partial Compensation



AC Power

Charging Principle Applied by TEDAS

If

$$\left| Q / P \right| > 1/3$$

Then, reactive power is charged

If

$$\left| Q / P \right| < 1/3$$

Then, reactive power is free

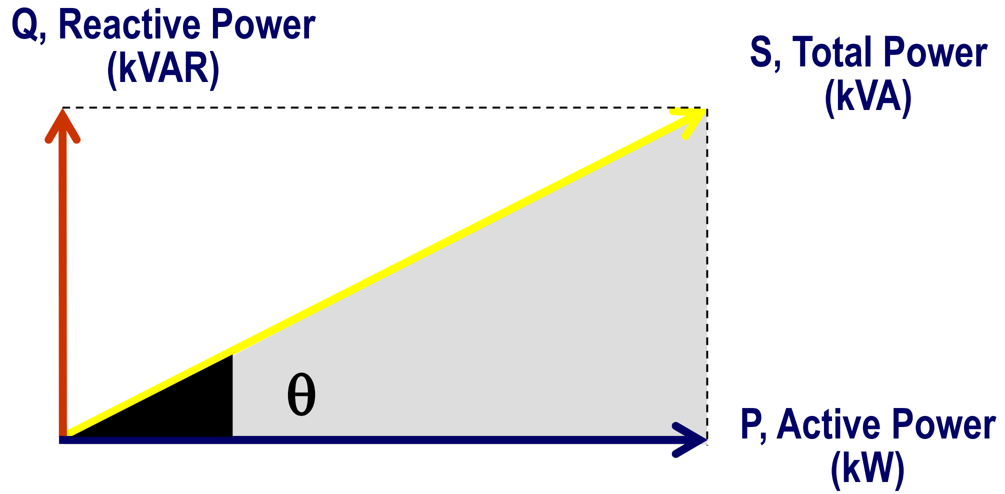
Please note that

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

means;

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

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



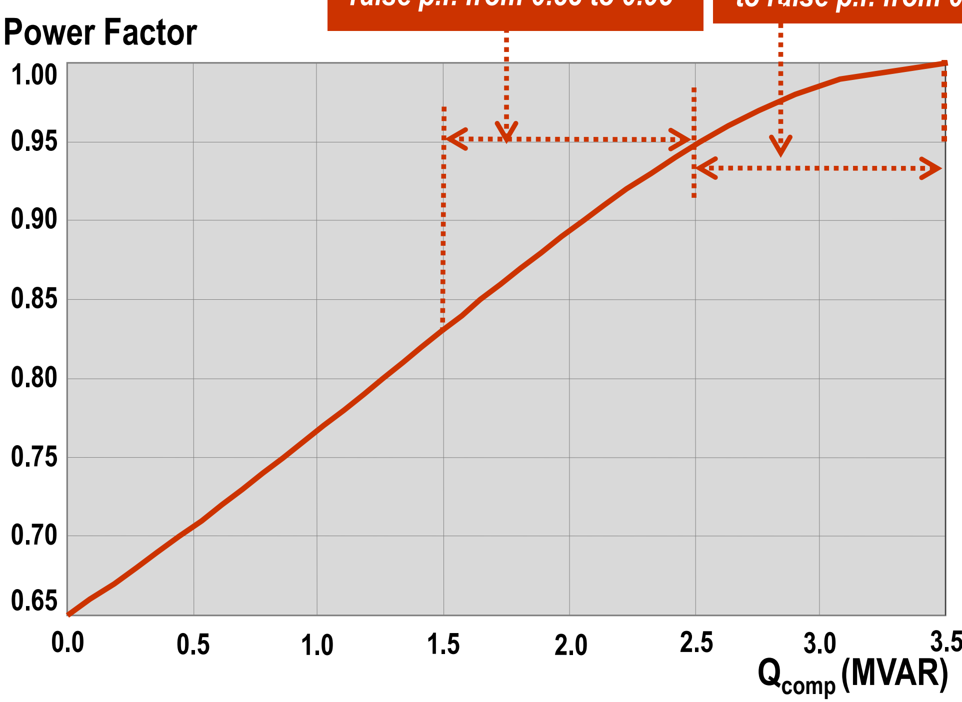
Why Full Compensation is not Worthwhile ?

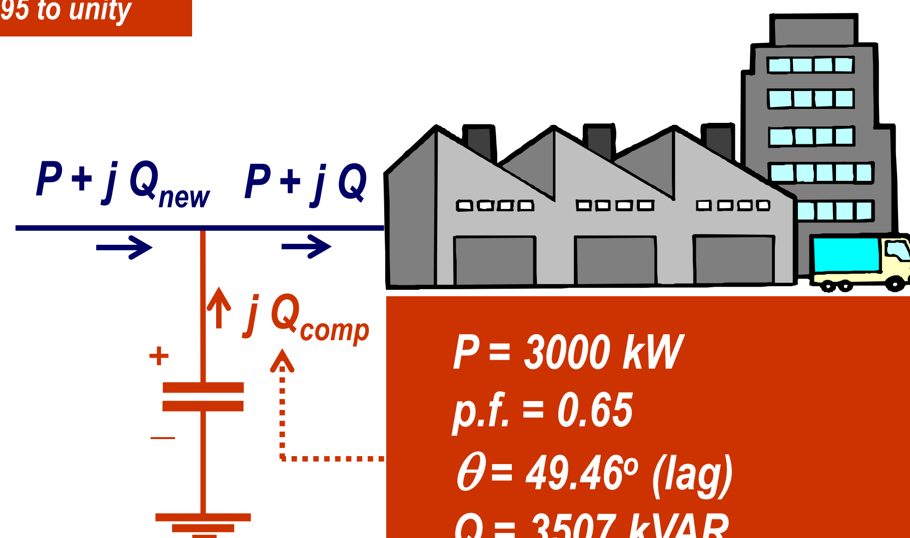
Full compensation is not worhwhile, since compensation beyond 0.95 p.f. requires unnecessarily large and expensive capacitive banks.

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

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

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

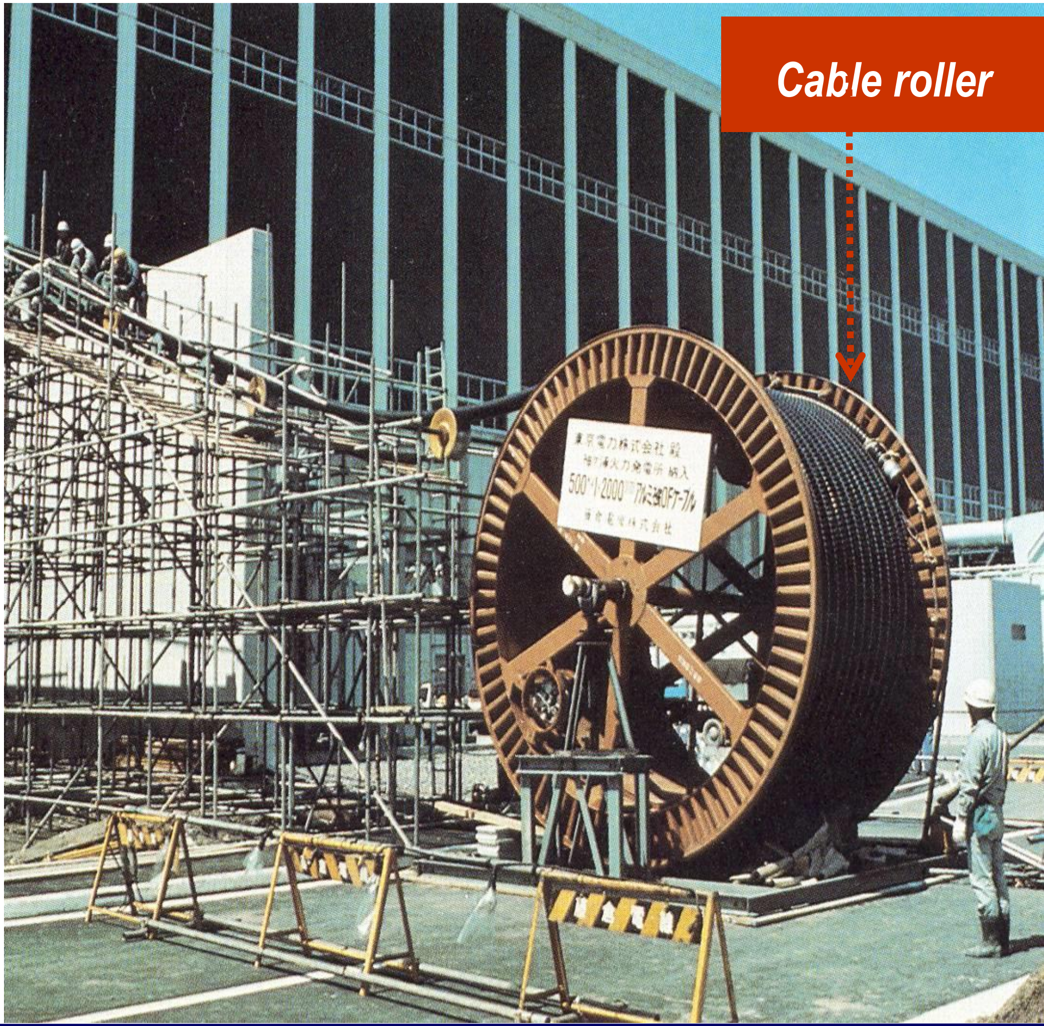
Cross Section (mm^2)	Current Capacity (Amp)
1.0	12.0
1.5	16.0
2.5	21.0
4.0	27.0
6.0	35.0
10.0	48.0
16.0	65.0
25.0	88.0
35.0	110.0
50.0	140.0
70.0	175.0
95.0	215.0
120.0	225.0

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



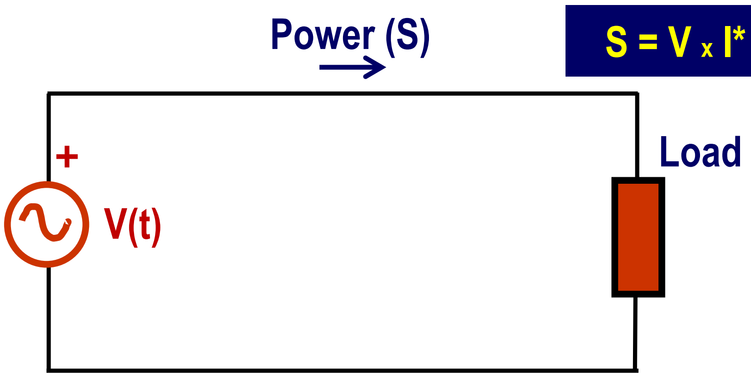
Application of Reactive Power Compensation

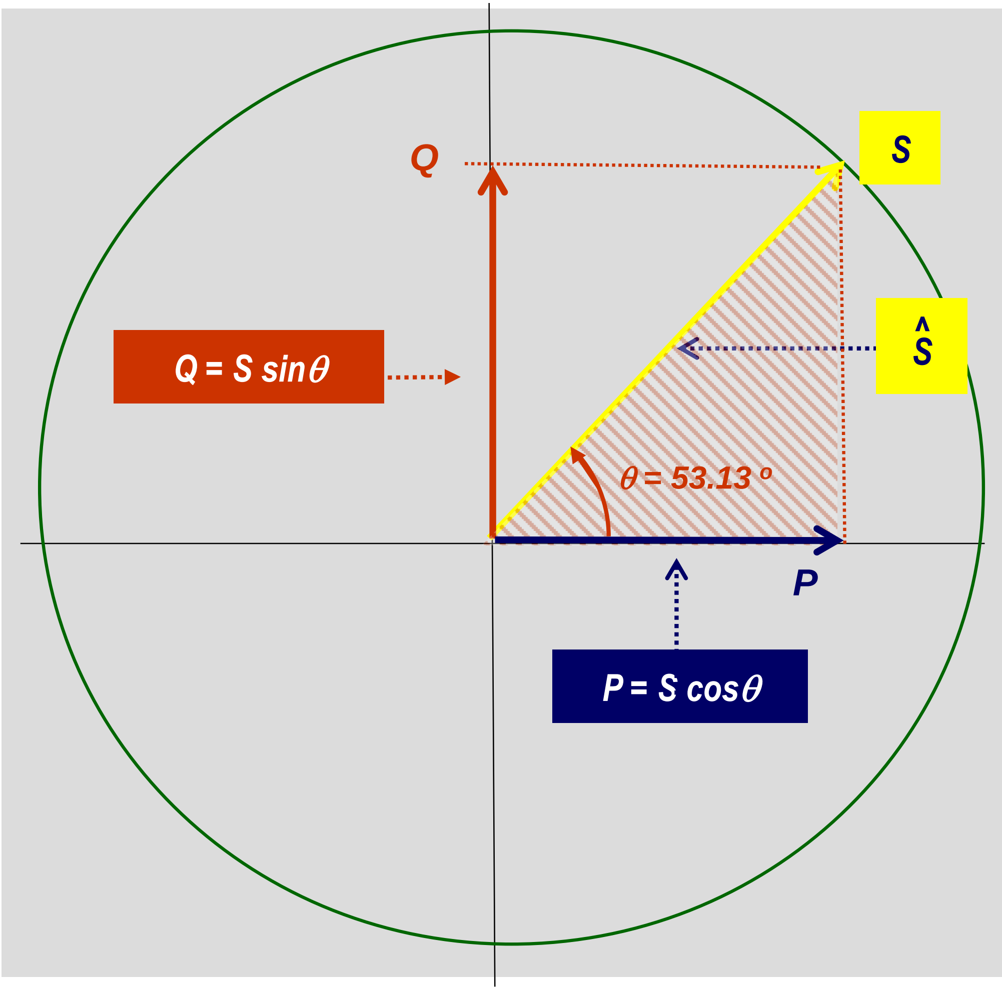
Reduction of Equipment Loading

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

$S = V \times I^*$



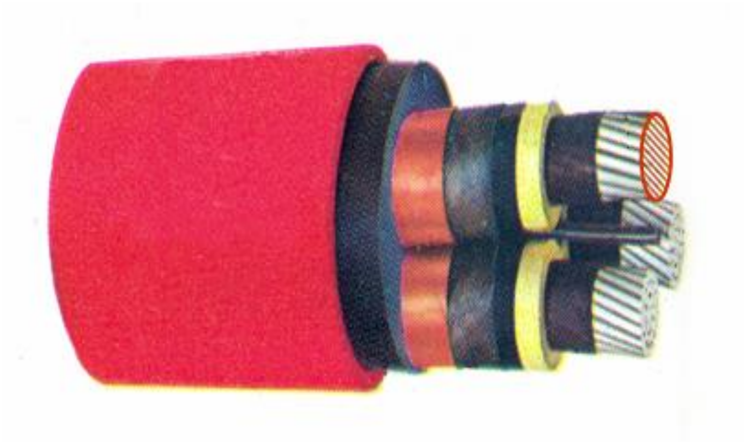


Alternative Ways of Reducing S (kVA)

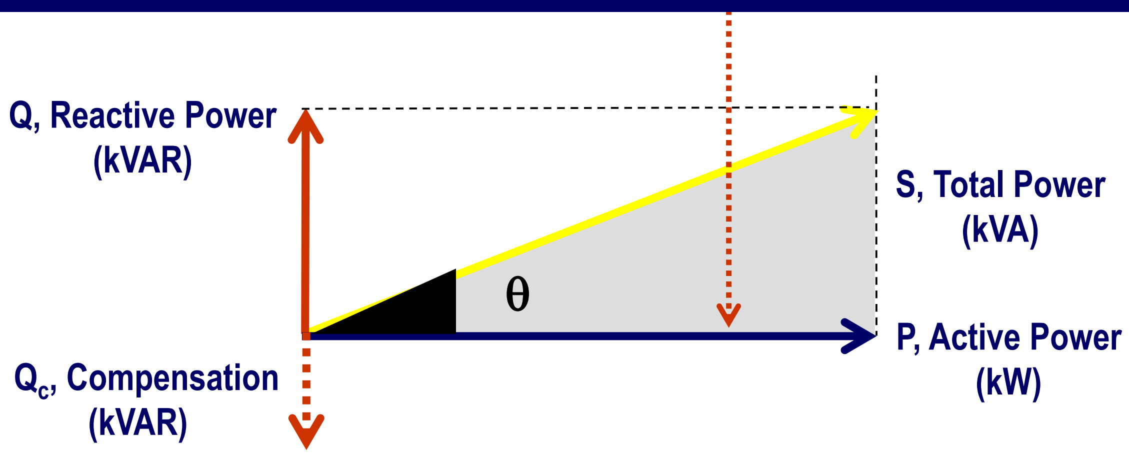
Alternative Ways of Reducing S (kVA)

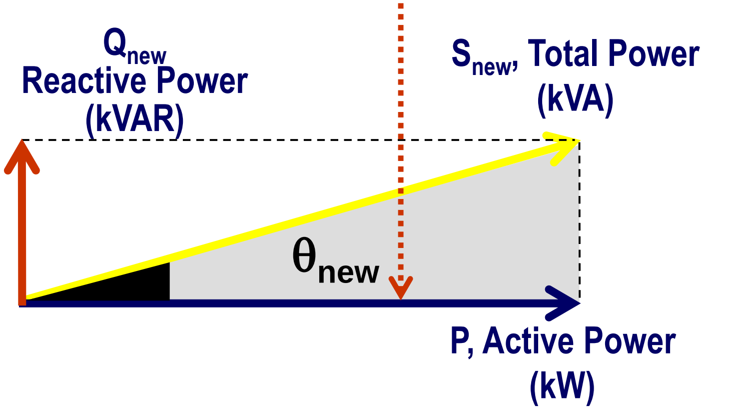
a) Reducing the overall loading;
P + jQ (kW + j kVAR) (Overall comsumption)
Unreasonable, unacceptable, since the active consumption (P) is determined only with respect to the needs of the consumer

a) Reducing only Q (kVAR) Possible, reasonable



Please note that active power remains unchanged after compensation





AC Power

Example

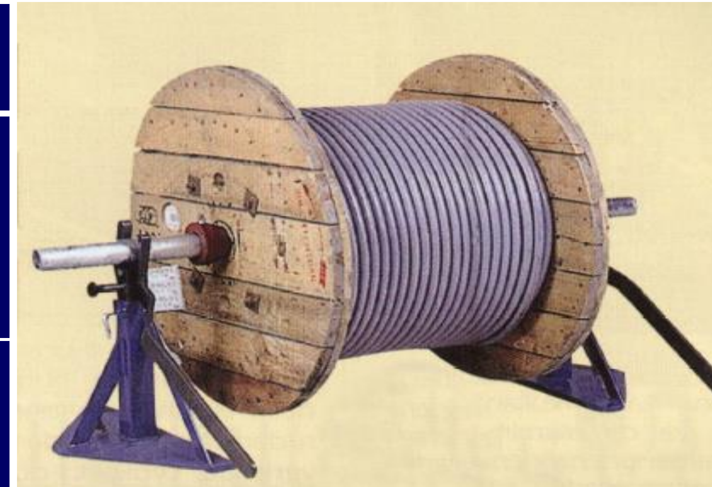
Question

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

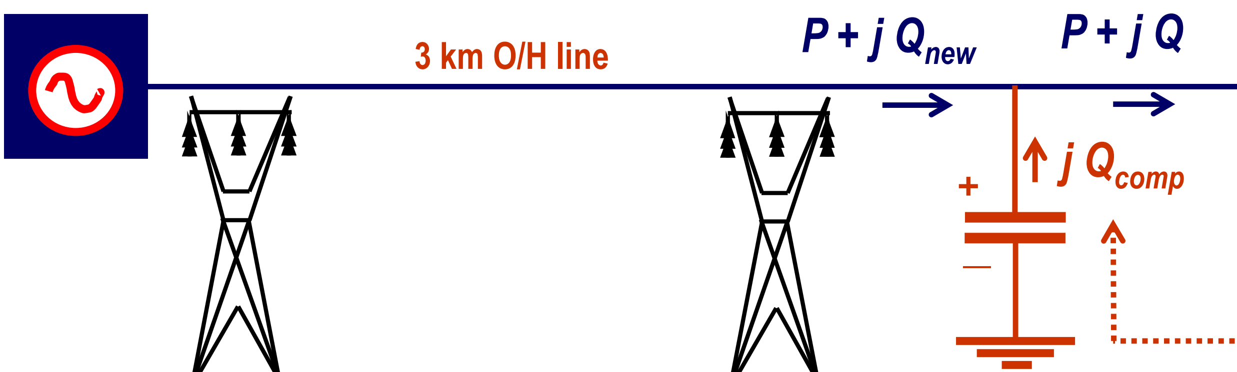
$$P + j\,Q = 120\ kW + j\ 140\ kVAR$$

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

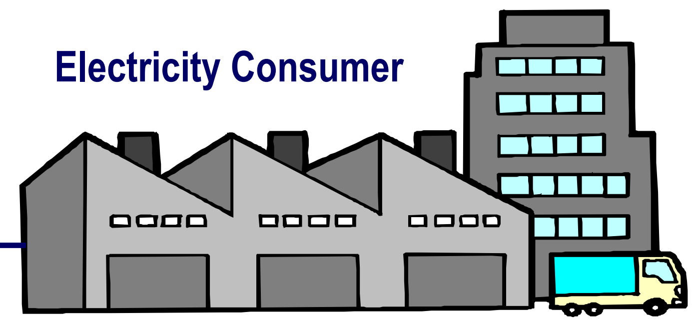
(Although the system shown on the RHS is obviously three-phase, for simplicity in solution, it is assume here, to be single-phase)



TEDAŞ 6300 V (rms) Mains



Electricity Consumer



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

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

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

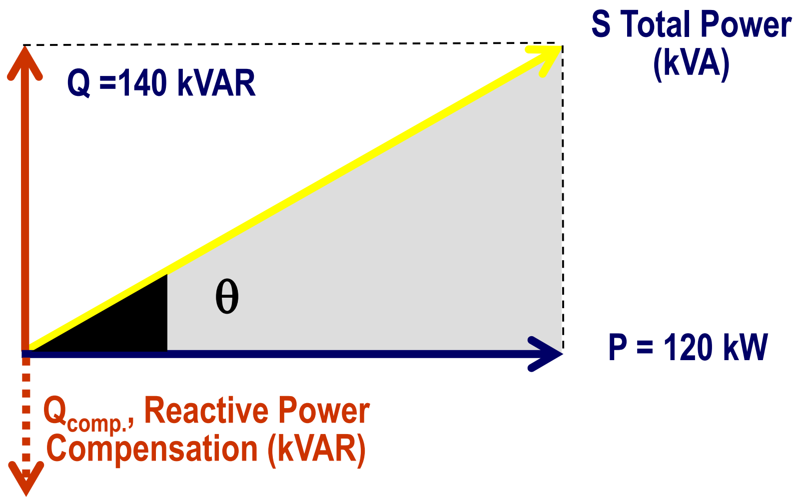
$\cos \theta_{new} = 0.95,$

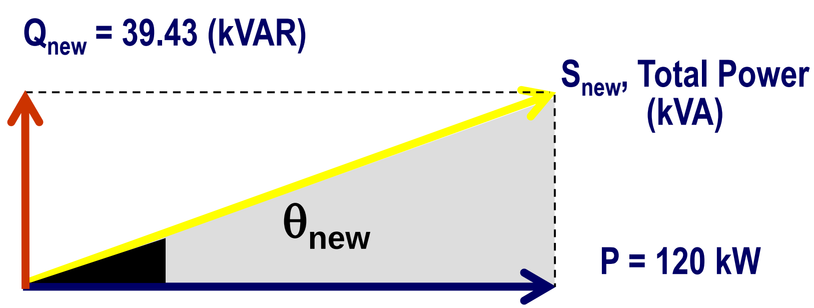
$\theta_{new} = \cos^{-1} 0.95 = 18.19^o$

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

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

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





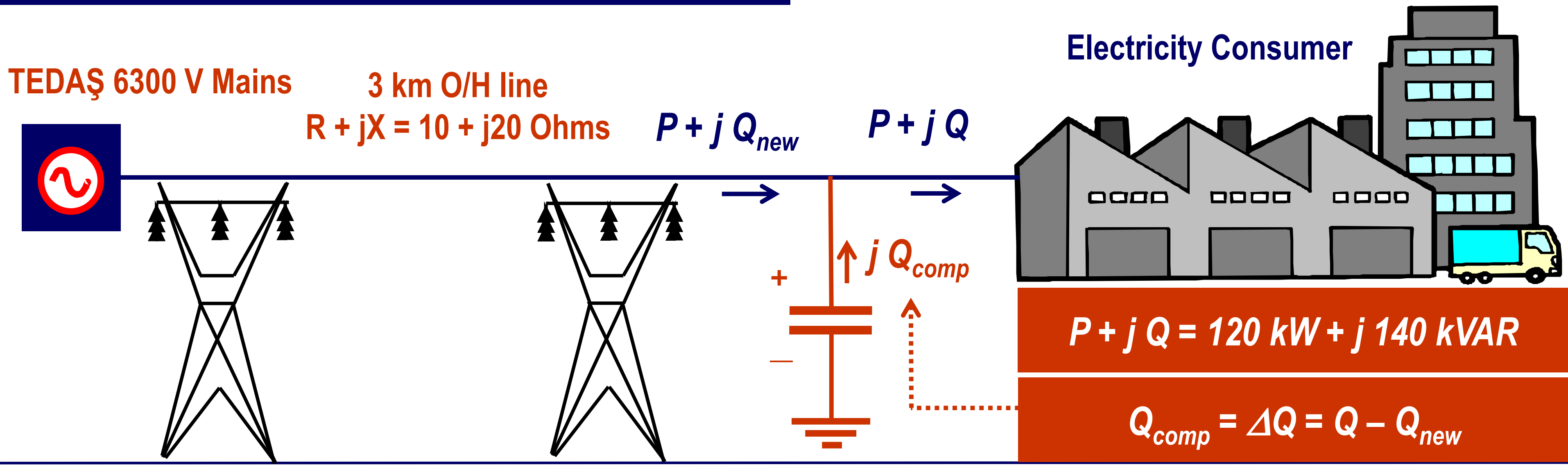
AC Power

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

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

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

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

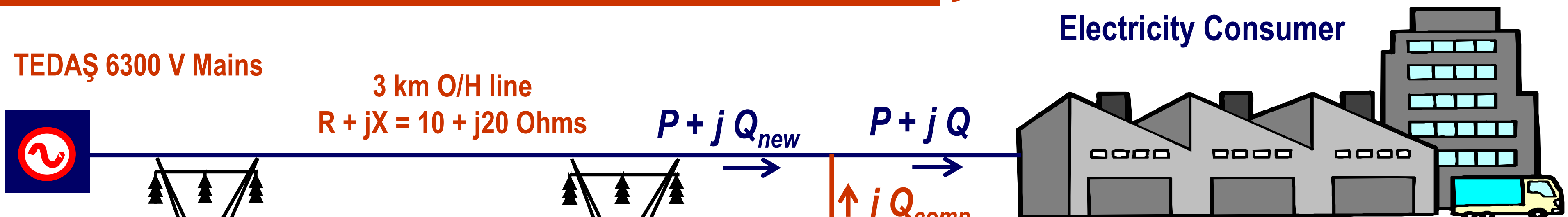
$= 126.312 \times 1000 / 6300 = 20.049 \text{ Amp}$

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

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

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

$= 4546.55 \text{ Watts}$

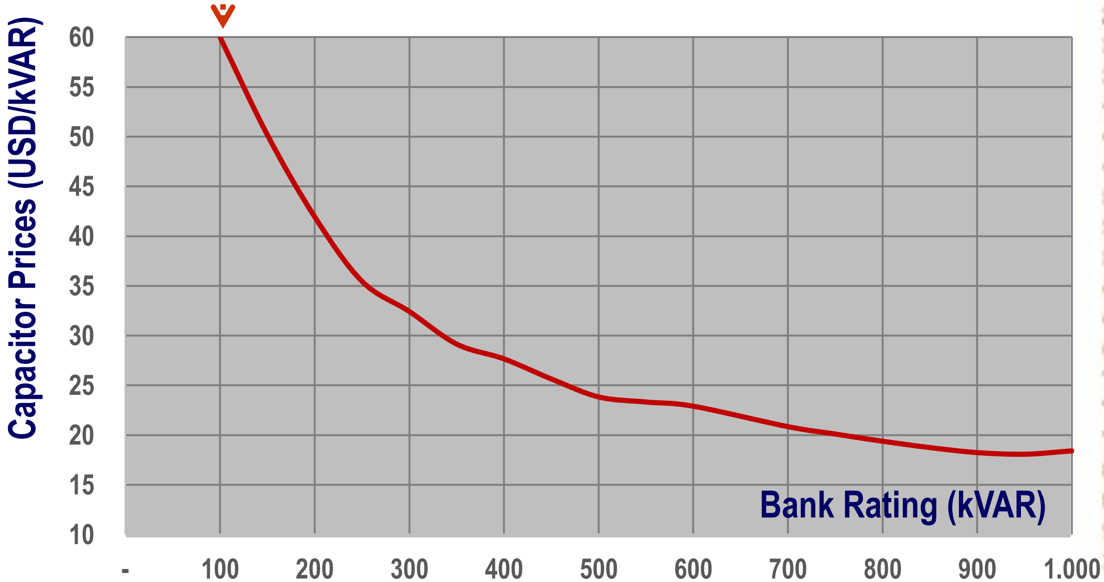


$P + j Q = 120 \text{ kW} + j\, 140 \text{ kVAR}$

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

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 US Cents/kWh and the price of capacitor is 60 USD / kVAR for a 100 kVAR bank



Capacitor Prices (USD/kVAR)

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	400LVA080F2B100	$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	600LVA48LVA8100	$13,256
600	12 X 50	600LVA48LV2B	$13,742
650	13 X 50	650LVA48LV2B	$12,280
700	7 X 100	700LVA480F2B100	$14,594
700	14 X 50	700LVA480F2B	$15,080
750	15 X 50	750LVA40LV2B	$15,506
800	8 X 100	800LVA40LV2B100	$15,933
800	16 X 50	800LVA480F2B	$16,418
900	9 X 100	900LVA480F2B100	$17,174
1000	10 X 100	1000LVA000F2B100	$18,414

Example

Calculation of the Return Rate

ΔP_{loss} = 8566.39 – 4019.84 = 4,546.55 Watts

Investment = 100.57 kVAR x 60.00 USD/kVAR

= 6.034,20 USD

Saving / hour = 4,546.55 /1000 kW x (16 / 100 USD)

= 0,7274 USD / hour

Return Rate = Investment / (Saving / hour)

= 6.034,20 / 0.7274

= 8,295.57 hours = 345.45 days

= 0.95 years

Three - Phase Compensator Bank

AC Power

Example

Question

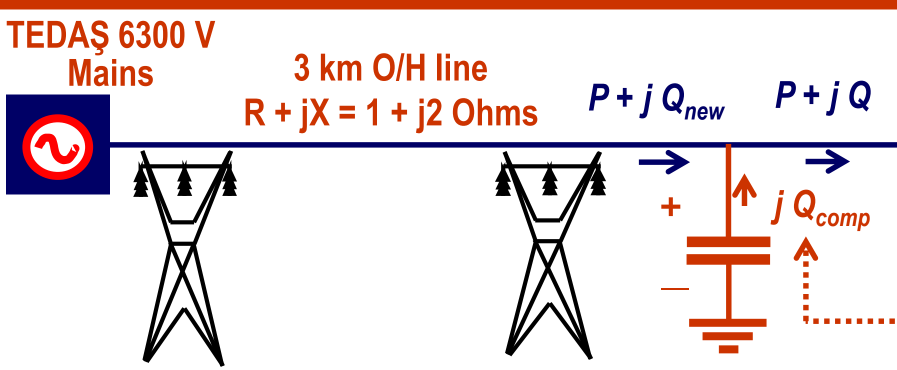
Now, for the previous problem, determine the cross sections of the line for the alternative cases, when line is compansated and uncompensated

Cheaper alternative

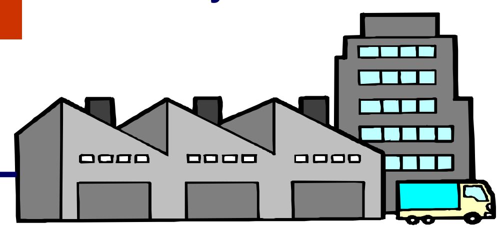
I_{new} = 20.495 Amp

$I_{initial}$ = 29.268 Amp

Cross Section (mm²)	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



Electricity Consumer



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

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

Question

Question

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

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

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

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

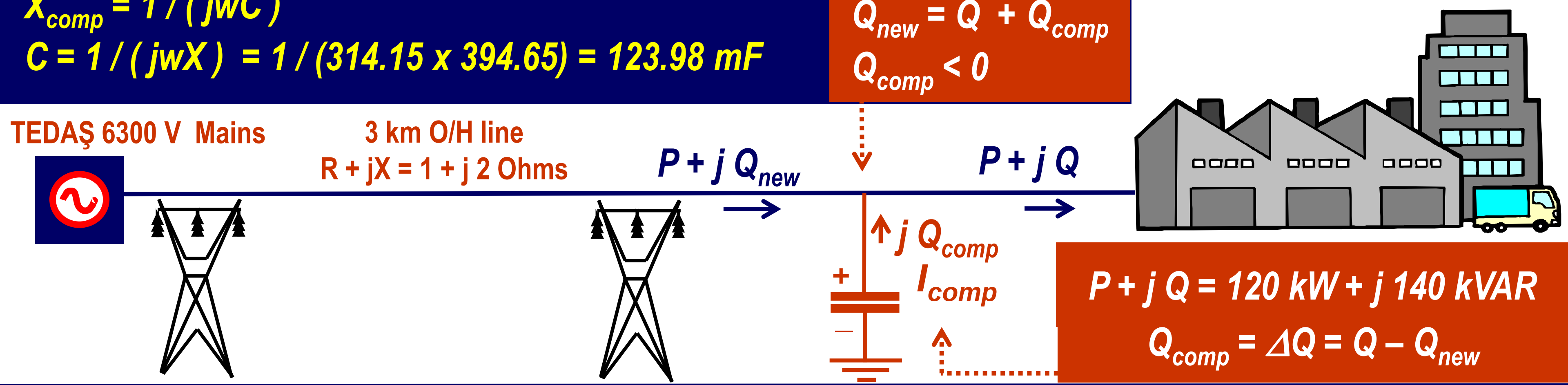
$X_{comp} = 1 / (jwC)$

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

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

$Q_{comp} < 0$

Electricity Consumer



Medium Voltage Capacitor Banks

Shunt connection of large capacity capacitors in power systems

Installation of MV Capacitor Banks

LV (Low Voltage) Capacitor Banks

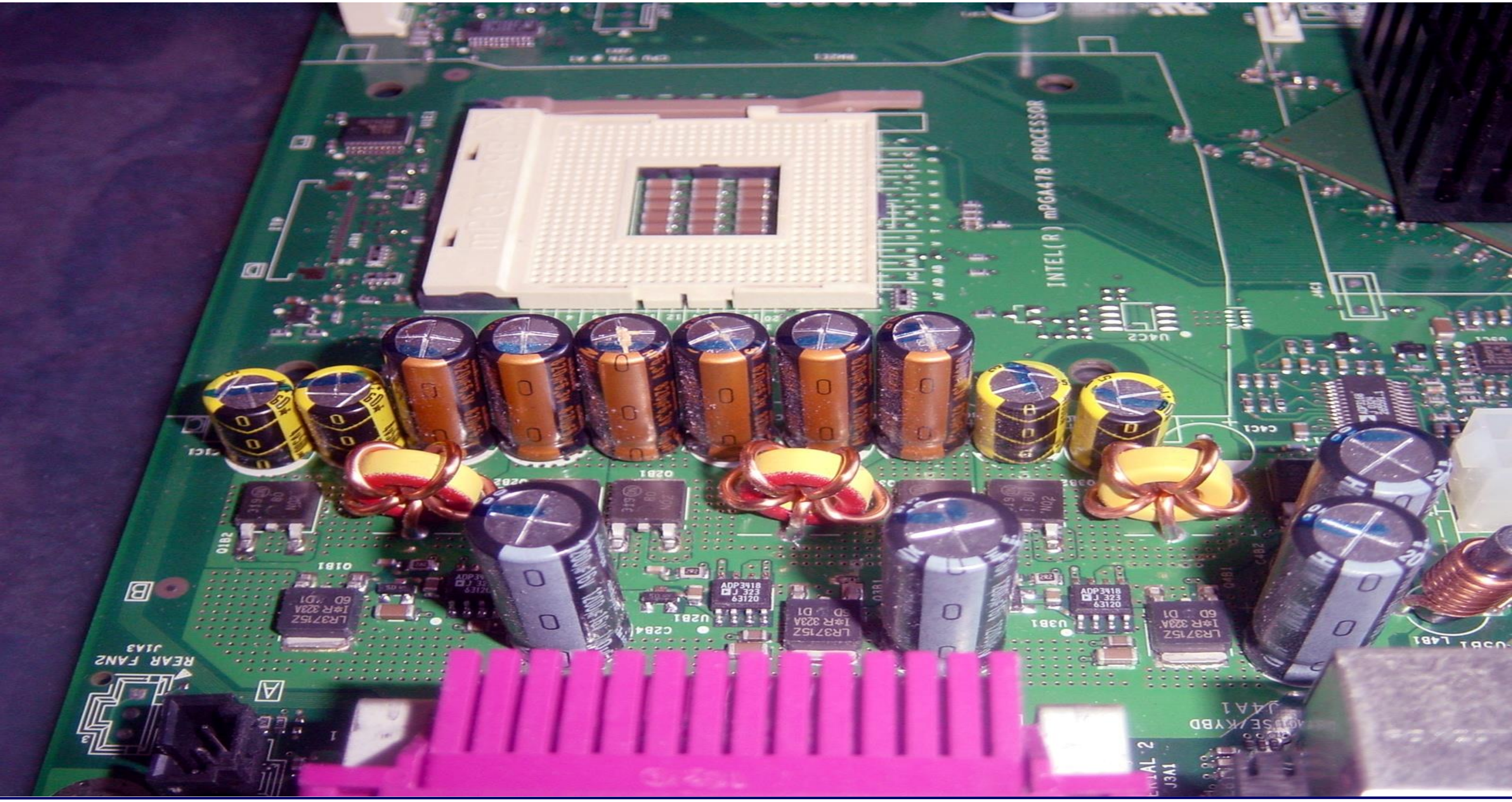
Contactors

Fuses

Capacitor Bank

AC Power

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.

AC Power

Another Example

Unfortunately,

- 50 Hz AC has greater losses and is not as efficient as 60 HZ.
- 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

Another Example

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.

Another Example

U.S. stays at 110 V, 60Hz

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 ?