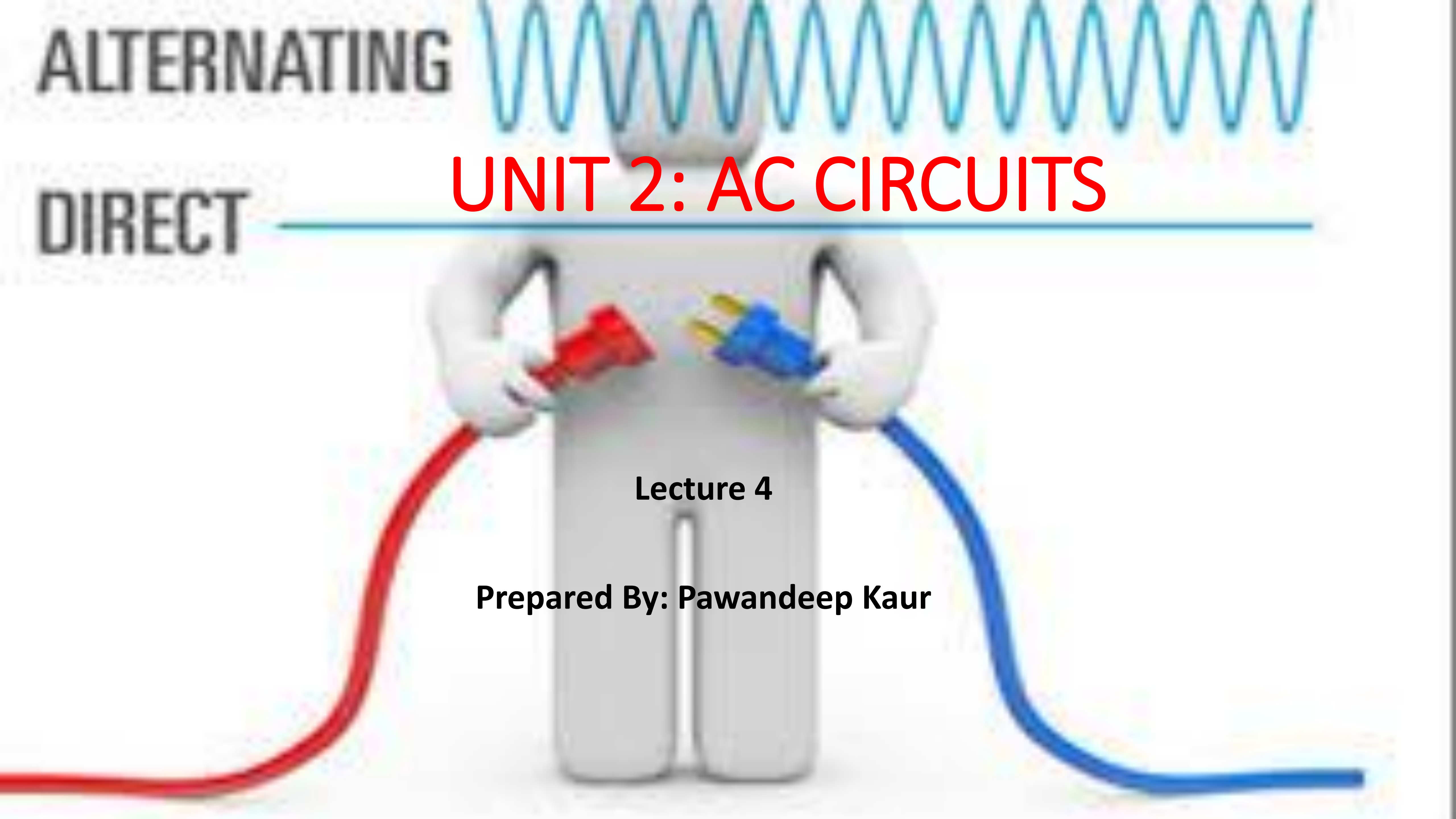


UNIT 2: AC CIRCUITS

Lecture 4

Prepared By: Pawandeep Kaur

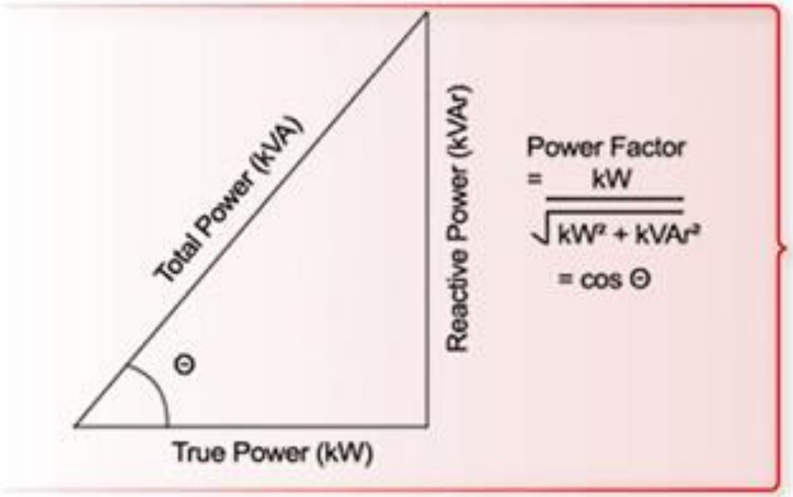
QUICK QUIZ (POLL)

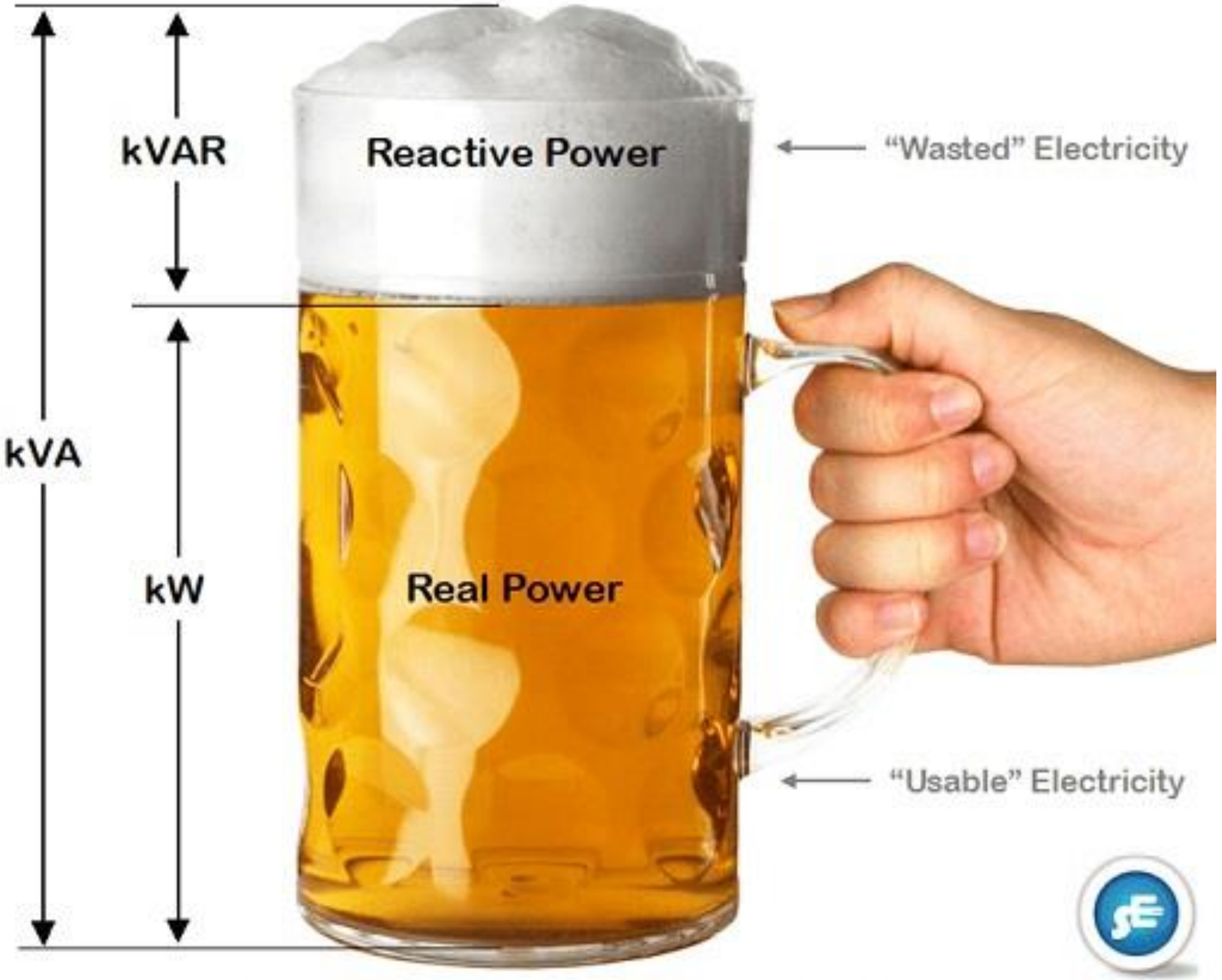
The value of power factor ranges from?

A. 0 to 1
B. -1 to 1
C. -1 to 0
D. 0 to infinity

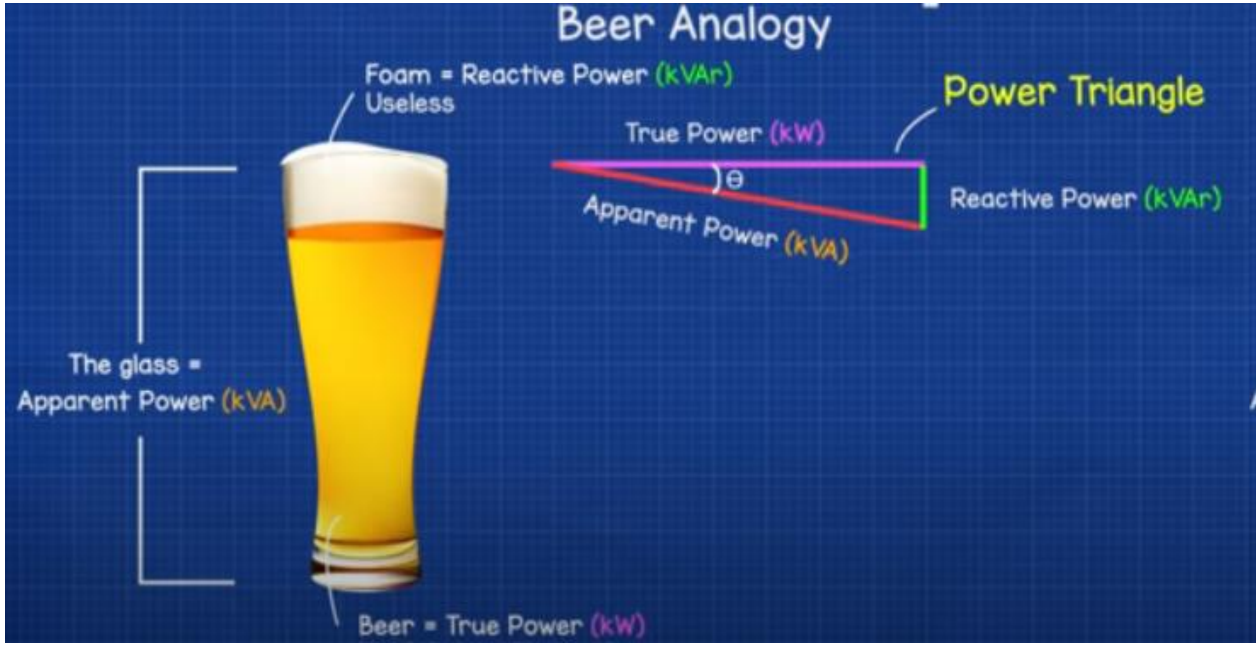
What is Power Factor?

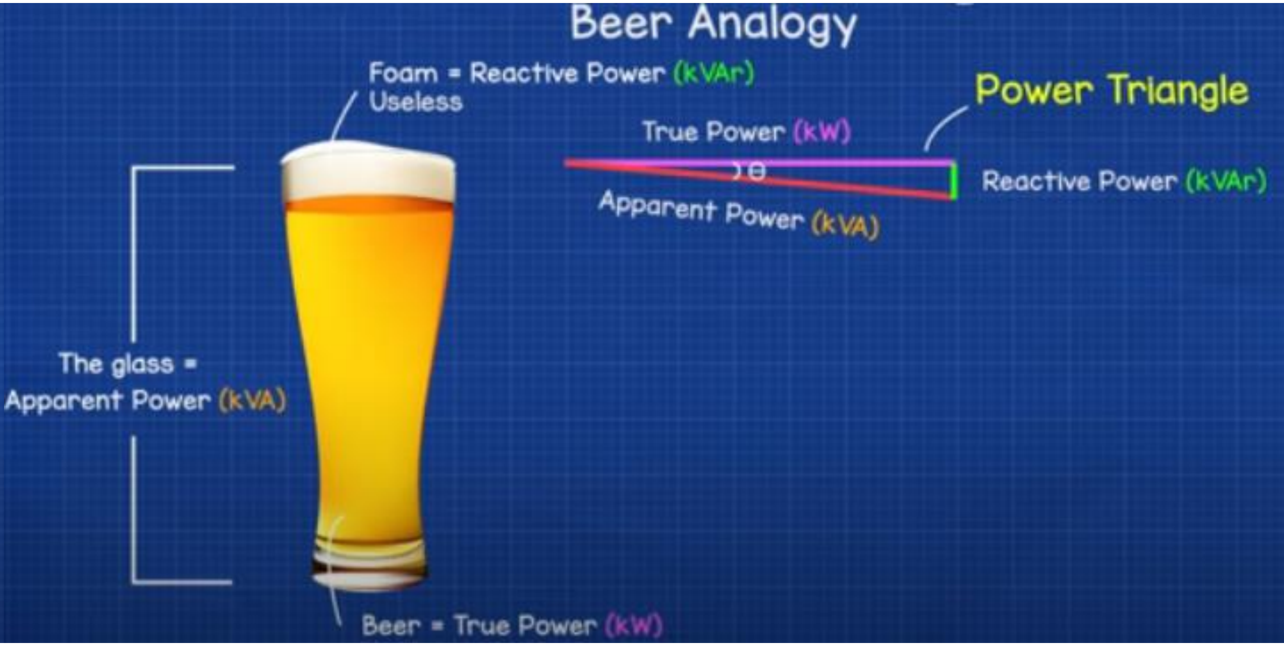
Power Factor is the percentage of apparent power that does real work. Understand Power Factor using Beer Mug Analogy.

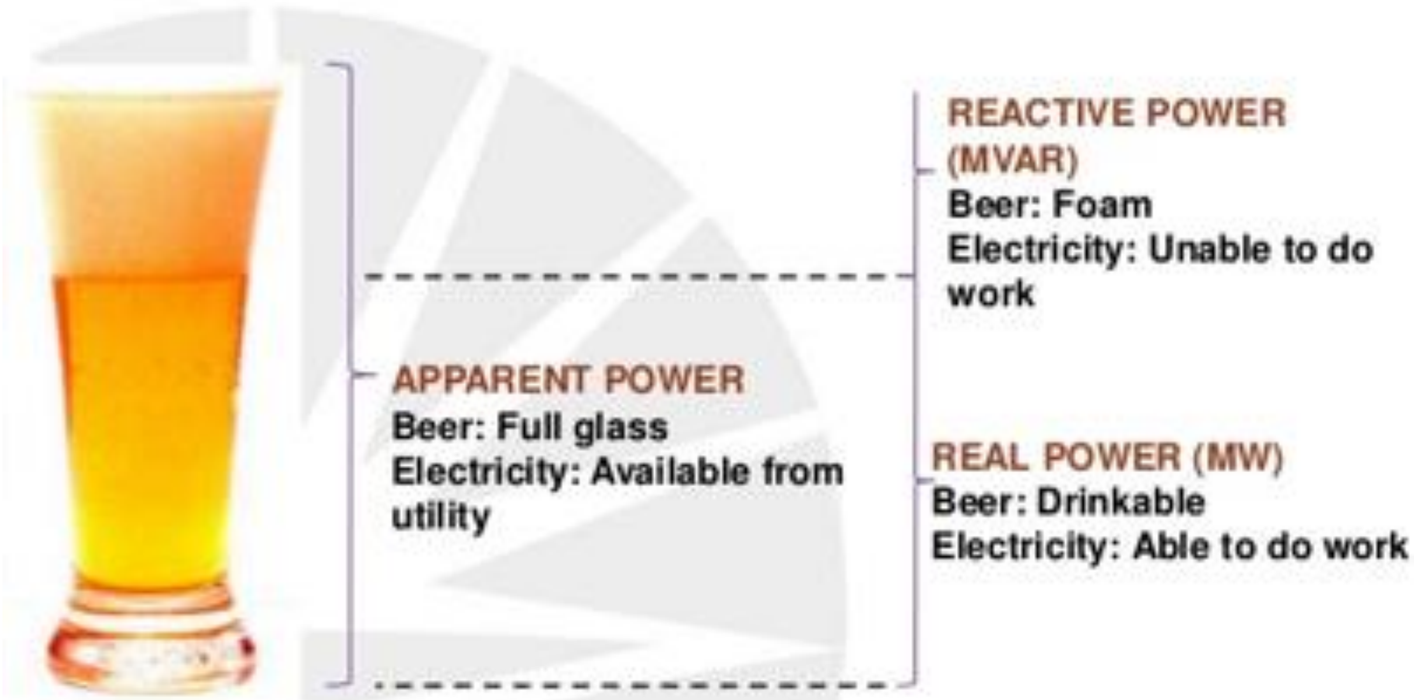




Power Factor Comparison







It is the Active Power that contributes to the energy consumed, or transmitted. Reactive Power does not contribute to the energy. It is an inherent part of the "total power" which is often referred as "Useless Power".

$$\text{Power Factor} = \frac{\text{True Power (kW)}}{\text{Apparent Power (kVA)}}$$

Or

$$\text{Power Factor} = \frac{\text{How much beer (kW)}}{\text{Per Glass we buy (kVA)}}$$

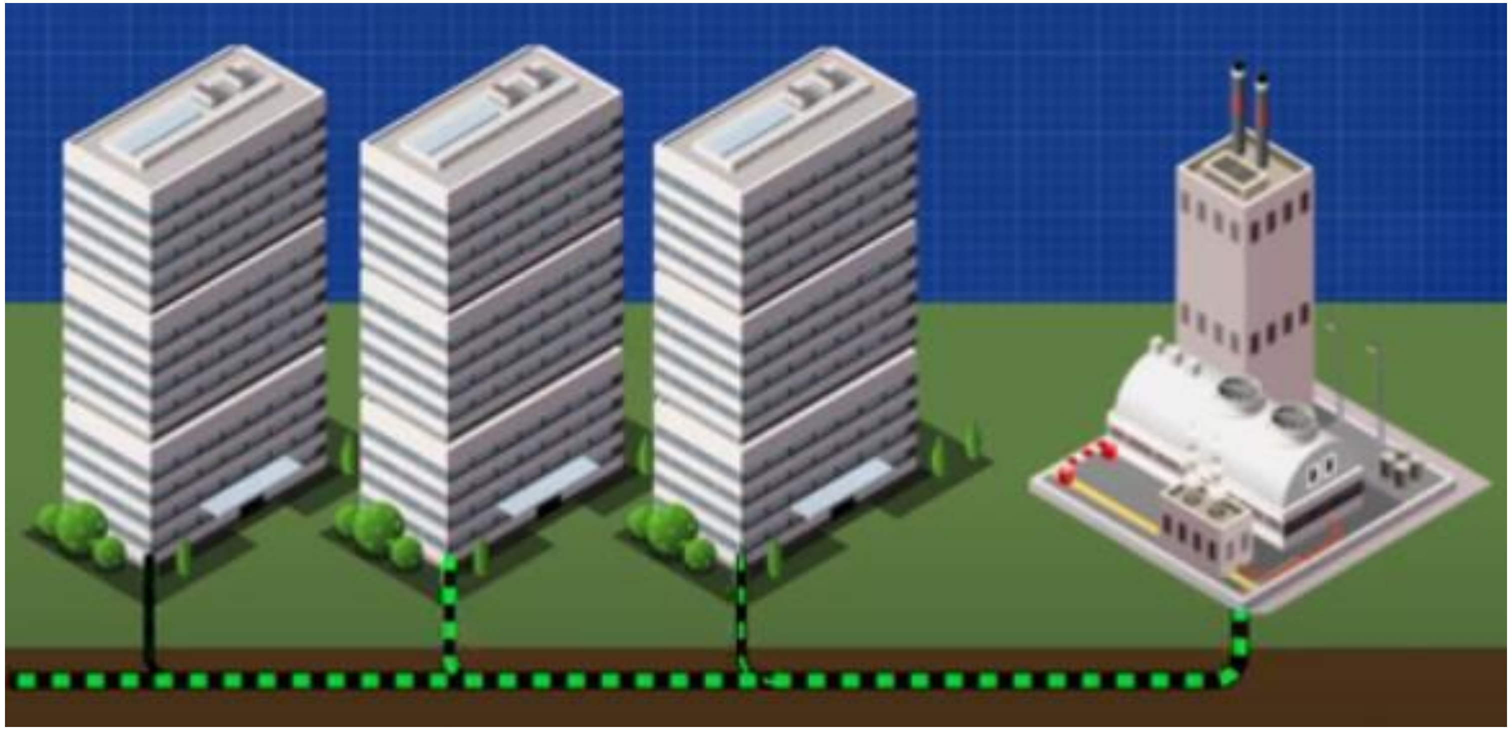
Power Factor Correction

Why is it required?

Power Factor Correction

Why is it required?

Reactive Power Charges

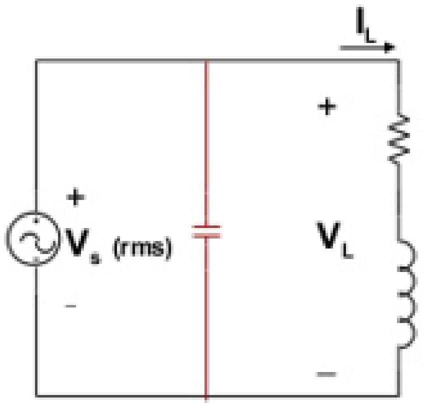


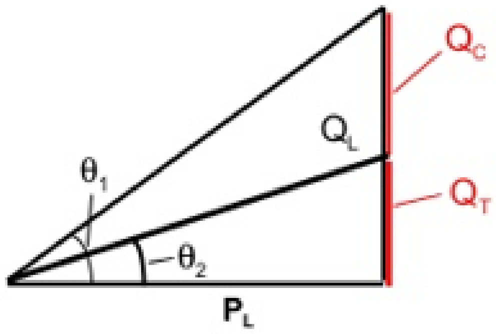
Power Factor Correction

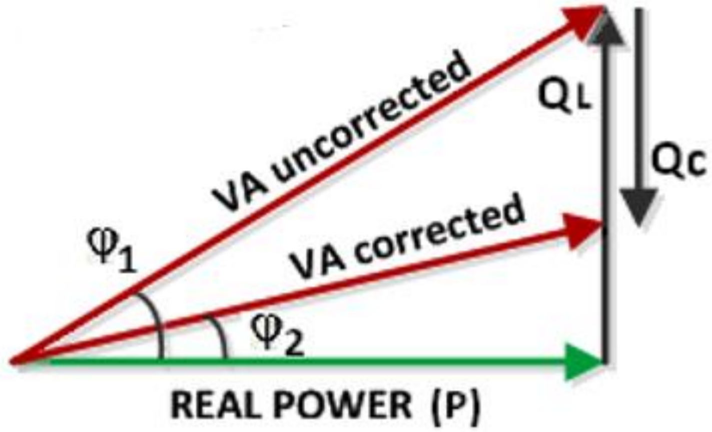
Why is it required?

- ❖Poor Power factor means that more power is drawn.
- ❖Requires larger cables
- ❖Reactive Power penalty fee
- ❖Losses in a transformer
- ❖Voltage drops

Example: Power Factor Correction







Before C added, $S = P_L + jQ_L$ p.f. $= \cos\theta_1$

After C added, $S = P_L + j(Q_L - Q_C)$ p.f. $= \cos\theta_2$ i.e. increased

(voltage and current to original load retained)

Concept of Phasors

$$z = x + jy \qquad \text{Rectangular form}$$
$$z = r\angle\phi \qquad \text{Polar form}$$
$$z = re^{j\phi} \qquad \text{Exponential form}$$

$$r = \sqrt{x^2 + y^2}, \qquad \phi = \tan^{-1}\frac{y}{x}$$

On the other hand, if we know r and ϕ, we can obtain x and y as

$$x = r\cos\phi, \qquad y = r\sin\phi$$

Thus, z may be written as

$$\boxed{z = x + jy = r\angle\phi = r(\cos\phi + j\sin\phi)}$$

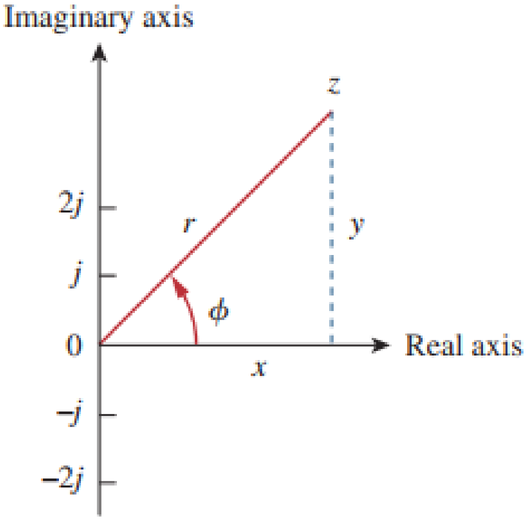


Figure
Representation of a complex number $z = x + jy = r\angle\phi$.

$$v(t) = V_m \cos(\omega t + \phi) \quad \Leftrightarrow \quad \mathbf{V} = V_m \angle \phi$$

(Time-domain representation) (Phasor-domain representation)

Practice Problem

Evaluate the following complex number?

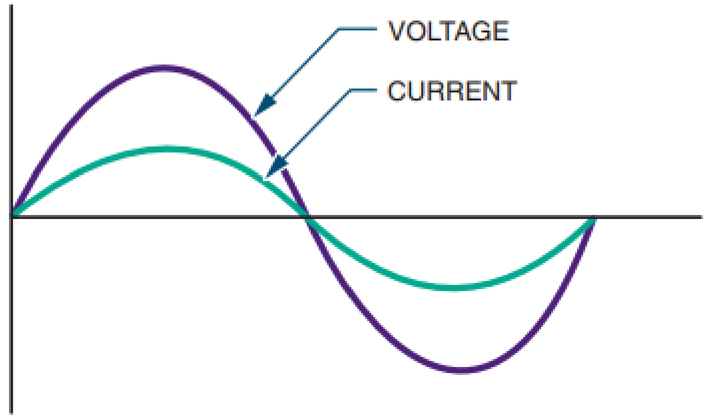
(a) $(40\angle 50^\circ + 20\angle -30^\circ)^{1/2}$

Behavior of R, L and C in AC Circuits

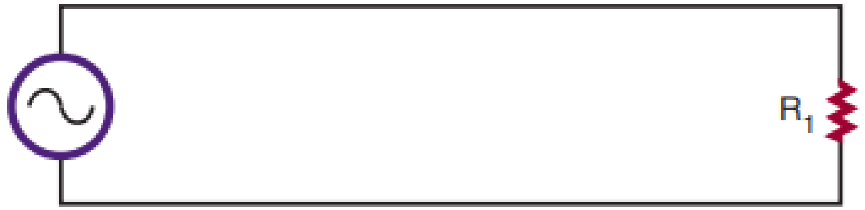
1. Purely Resistive Circuit

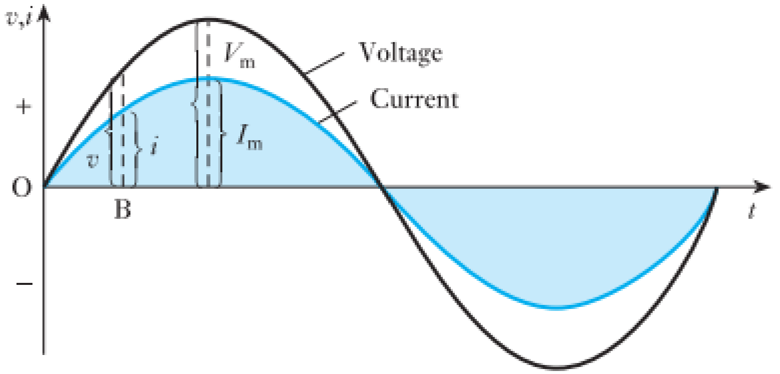
When an AC voltage is applied to the resistive load, the AC current's amplitude and direction vary in the same manner as those of the applied voltage. When the applied voltage changes polarity, the current also changes. They are said to be **in phase**.

The voltage and current are in phase in a pure resistive circuit.



1. Purely Resistive Circuit





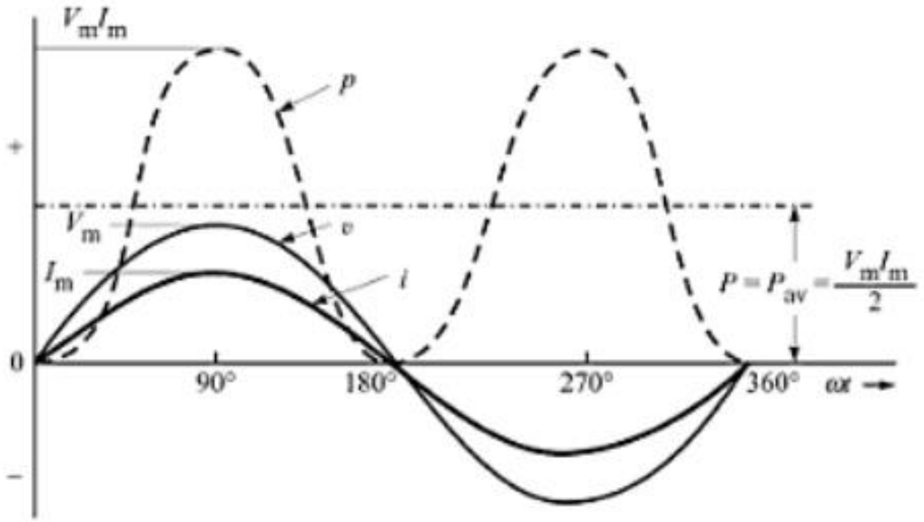
Power Waveform in purely resistive circuit

- Current and voltage are in phase.
- The instantaneous power fluctuates (sinusoidaly).

$$P = P_{av} = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} = VI$$

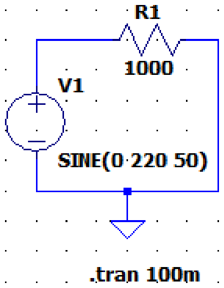
$$P_r = VI\cos\theta = VI\cos 0° = VI = \text{Apparent power}$$

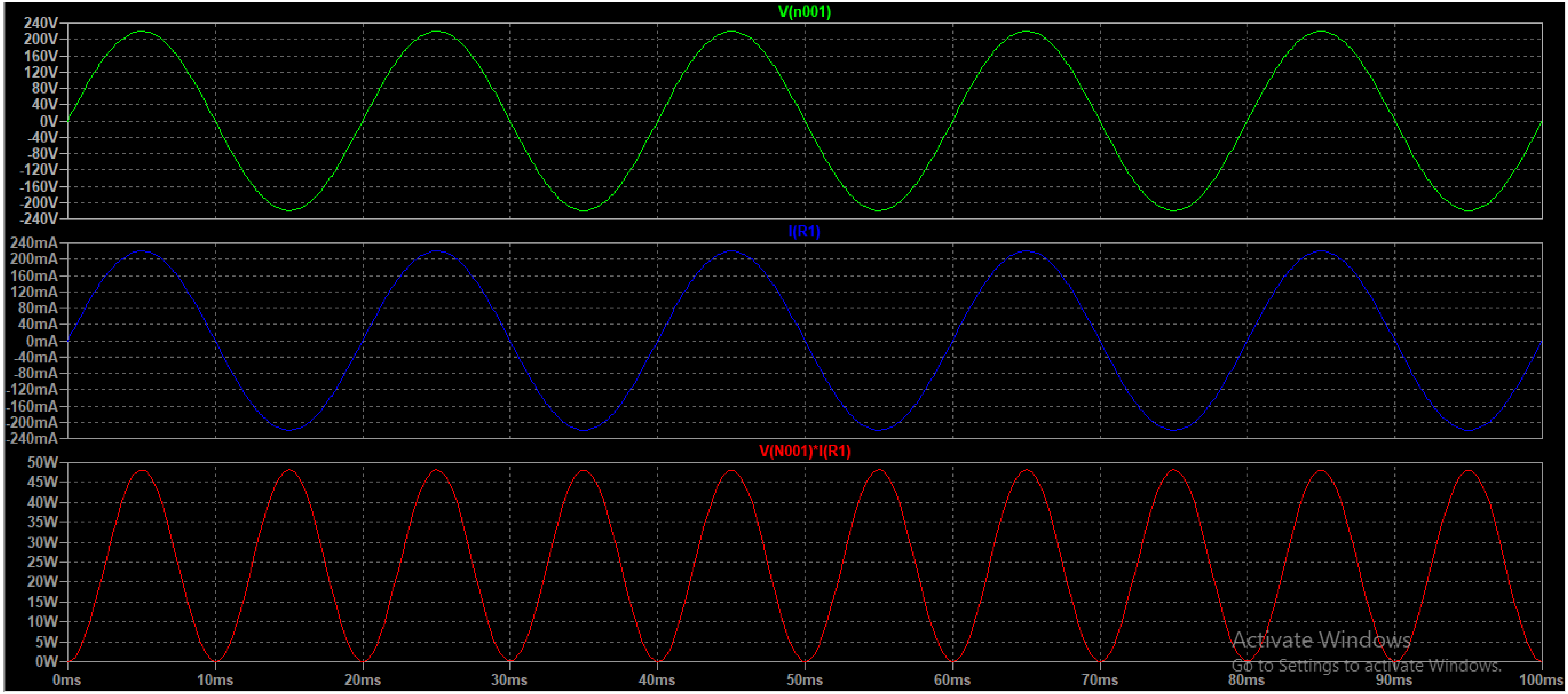
$$pf = \cos\theta = \cos 0° = 1$$



- Phasor Representation

LT Spice Simulation

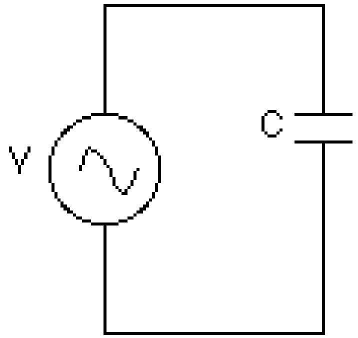


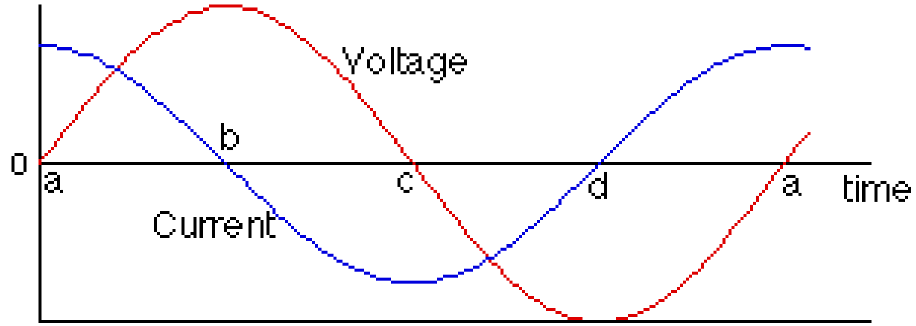


Behavior of R, L and C in AC Circuits

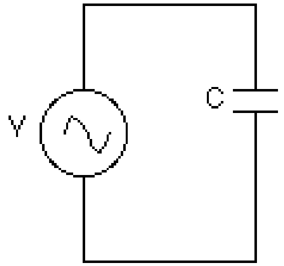
2. Purely Capacitive Circuit

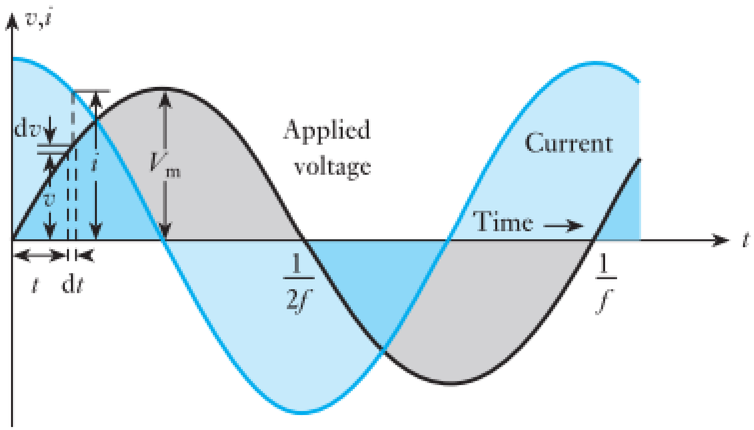
- When an AC voltage is applied to a capacitor, it gives the appearance that electrons are flowing in the circuit. However, electrons do not pass through the dielectric of the capacitor. As the applied AC voltage increases and decreases in amplitude, the capacitor charges and discharges.
- The current leads the applied voltage in a capacitive circuit.





2. Purely Capacitive Circuit





Capacitive Reactance

$$\frac{V_m}{I_m} = \frac{1}{2\pi fC}$$

Hence, if I and V are the r.m.s. values

$$\frac{V}{I} = \frac{1}{2\pi fC} = \textit{capacitive reactance}$$

The capacitive reactance is expressed in ohms and is represented by the symbol X_C. Hence

$$I = 2\pi fCV = \frac{V}{X_C}$$

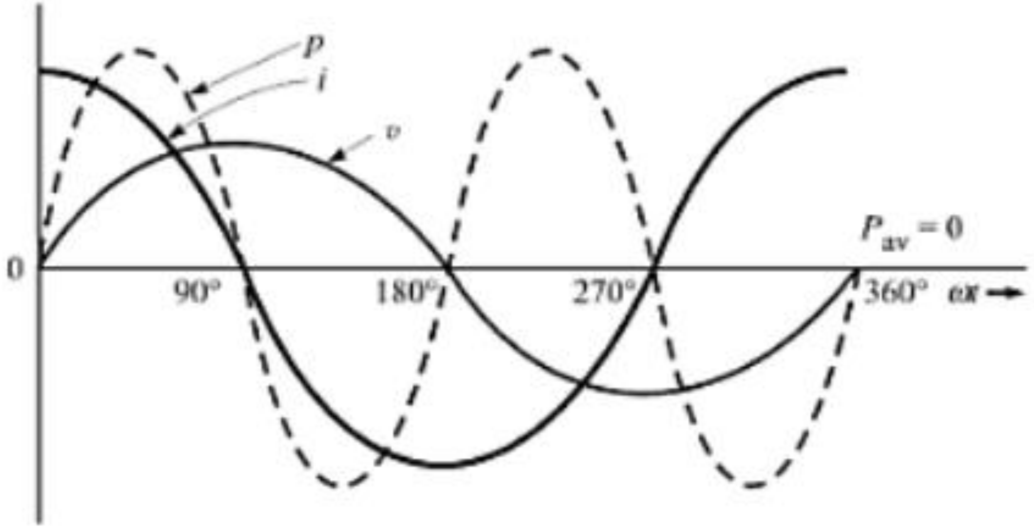
$$\therefore \qquad X_C = \frac{1}{2\pi fC}$$

Power Waveform in purely capacitive circuit and Phasor

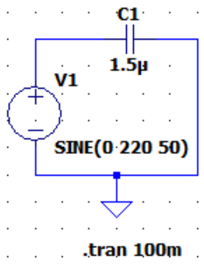
- Current leads applied voltage by 90°.
- The instantaneous power fluctuates (sinusoidally).

$$P = VI\cos\theta = VI\cos 90° = 0$$

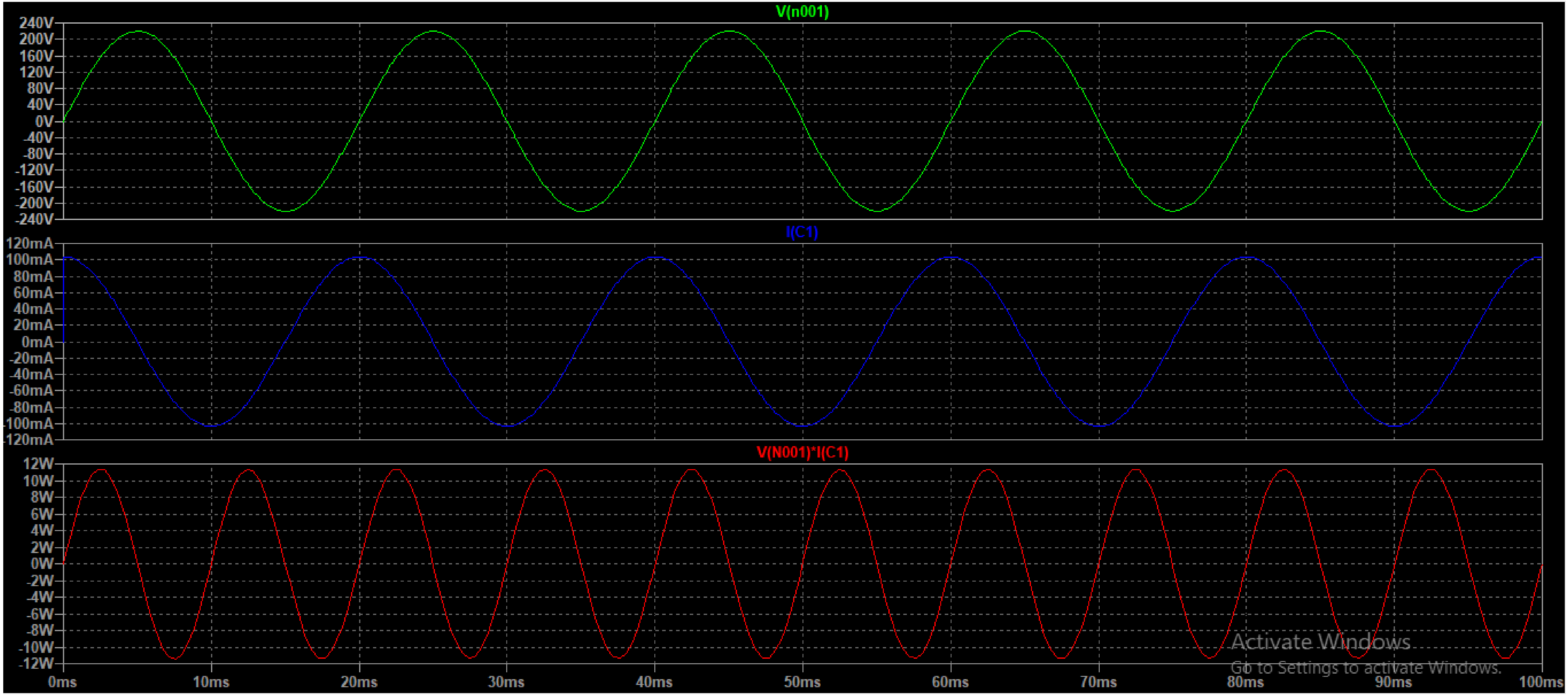
$$pf = \cos\theta = \cos 90° = 0 \text{ (leading)}$$

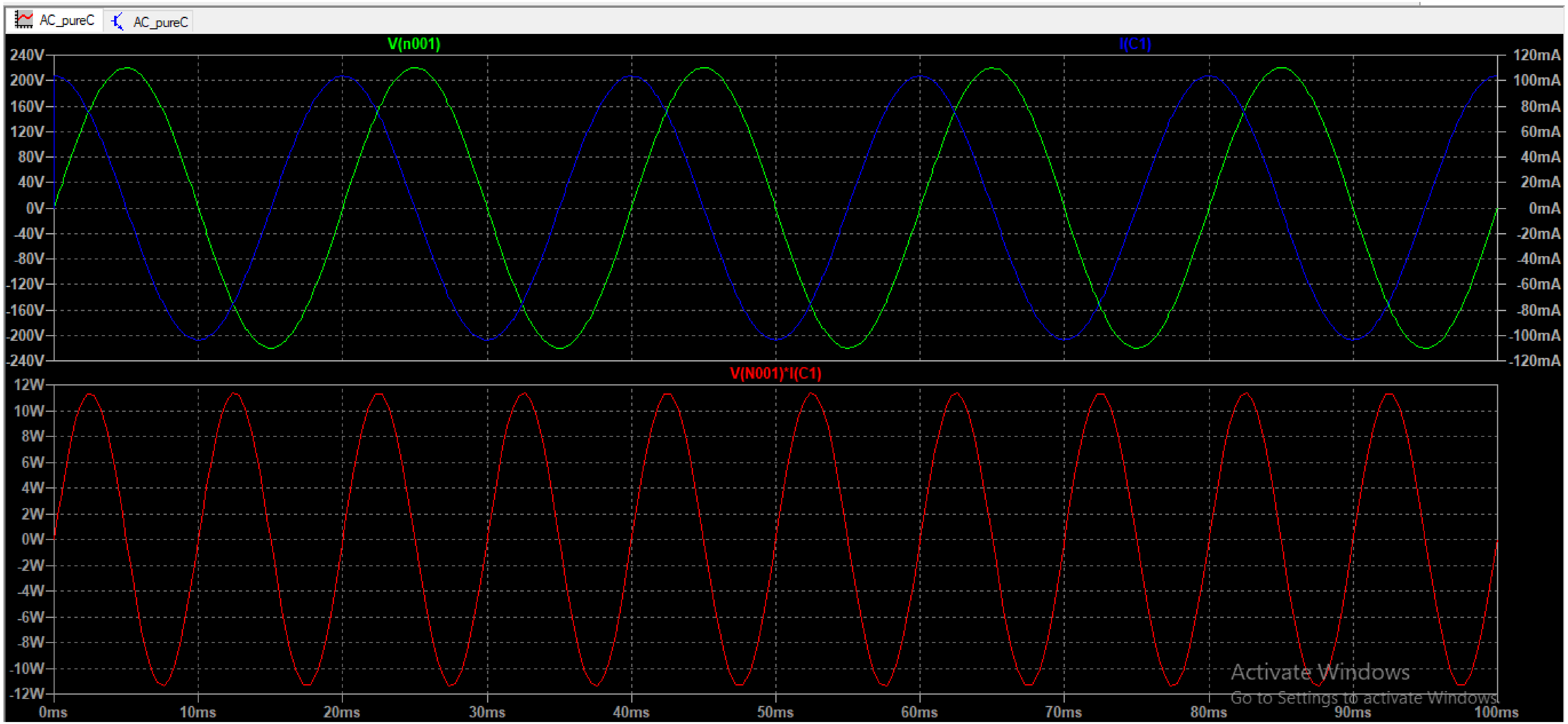


- Phasor



LT Spice Simulation




AC_pureC
AC_pureC
V(n001)
I(C1)
V(N001)*I(C1)
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms
Activate Windows
Go to Settings to activate Windows.

QUICK QUIZ (POLL)

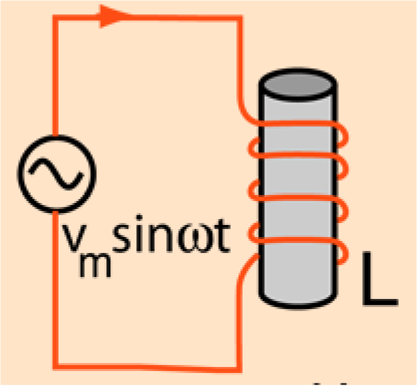
What is the reactance of a 0.5 μF capacitor at 1 kHz?

A. 5 ohm
B. 500 ohm
C. 318.3 ohm
D. 412.4 ohm

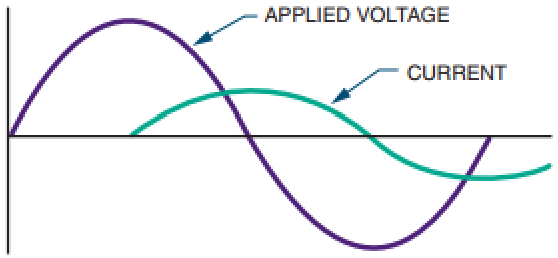
Behavior of R, L and C in AC Circuits

3. Purely Inductive Circuit

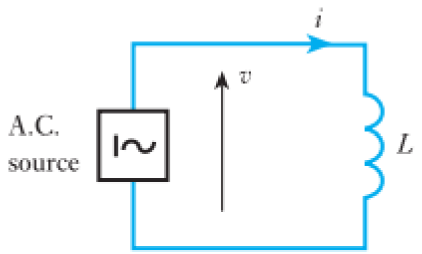
- Inductors, like capacitors, oppose current flow in AC circuits. They may also introduce a phase shift between the voltage and the current in AC circuits.
- Inductors in AC circuits offer opposition to current flow. When an AC voltage is placed across an inductor, it creates a magnetic field. As the AC voltage changes polarity, it causes the magnetic field to expand and collapse. It also induces a voltage in the inductor coil.

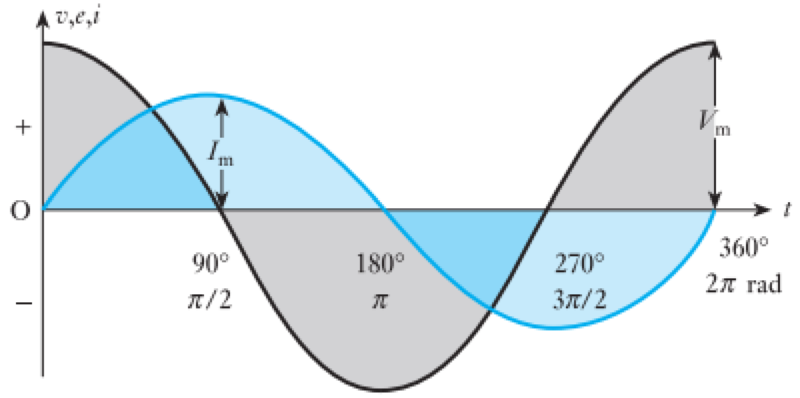


The current lags the applied voltage in an AC inductive circuit.



3. Purely Inductive Circuit





Inductive Reactance

$$V_m = 2\pi f L I_m \quad \text{so that} \quad \frac{V_m}{I_m} = 2\pi f L$$

If I and V are the r.m.s. values, then

$$\frac{V}{I} = \frac{0.707 V_m}{0.707 I_m} = 2\pi f L$$

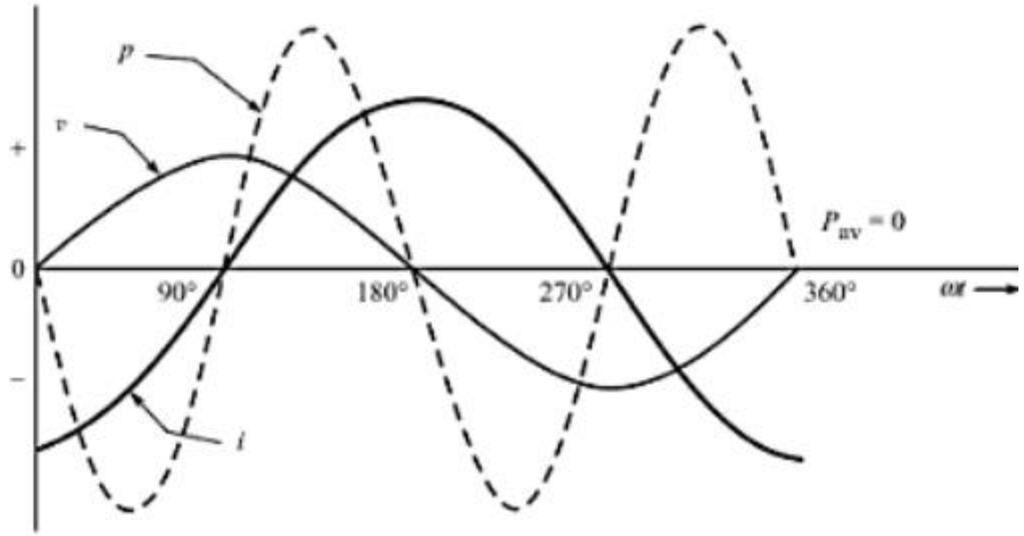
$$= \textit{inductive reactance}$$

Power Waveform in purely inductive circuit

- Applied voltage leads current by 90°.
- The instantaneous power fluctuates (sinusoidally).

$$P = VI\cos\theta = VI\cos 90^\circ = 0$$

$$pf = \cos\theta = \cos 90^\circ = 0 \text{ (lagging)}$$



QUICK QUIZ (POLL)

What is the reactance of a 4.5 mH inductor at 1 kHz?

A. 4.5 ohm
B. 20 K ohm
C. 28.27 K ohm
D. 28.27 ohm

Reactance

- Reactance is the opposition of a circuit element to the flow of current due to that element's inductance or capacitance.
- Greater reactance leads to smaller currents for the same voltage applied.
- Reactance is similar to electric resistance in this respect, but differs in that reactance does not lead to dissipation of electrical energy as heat. Instead, energy is stored in the reactance, and later returned to the circuit whereas a resistance continuously loses energy.
- Two Types

1. Inductive Reactance (XL) and is measured in Ohms
2. Capacitive Reactance (XC) and is measured in Ohms

Impedance

- This is a comprehensive expression of any and all forms of opposition to current flow, including both resistance and reactance.
- Represented as: Impedance = Resistance + Reactance
- Mathematically, $Z = R + jX$
- Perfect resistors possess resistance, but not reactance. Perfect inductors and perfect capacitors possess reactance but no resistance.
- All components possess impedance, and because of this universal quality, it makes sense to translate all component values (resistance, inductance, capacitance) into common terms of impedance as the first step in analyzing an AC circuit.

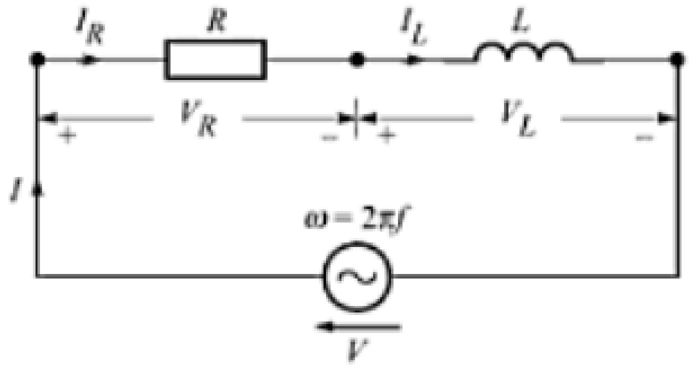
Recap Poll

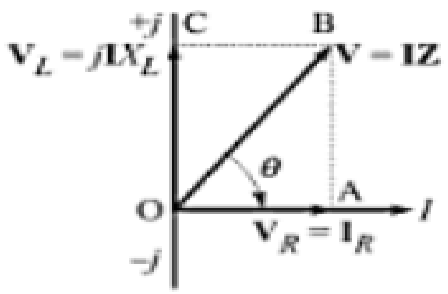
- The power consumed by a pure capacitive connected to an AC source is
- A)ZERO
- B)Very low
- C)Very high
- D) Infinite

Series Of
R----L
R----C

Series RL Circuit

V=VL+VR   can't added directly why???





Steps For phasor understanding:

1.Mark or label the current and voltage in the circuit across each element

2.Draw individual element phasor

a) Resistance: For resistance V and I are in phase thus choose reference as either current or voltage.

b)Inductor: In Inductor current lags the voltage by 90˚.Draw the voltage 90 phase difference by current as reference.

3.Superimpose the two phasors, as common current as reference ,because current is same in series connected elements. Thus IR=IL, voltage draw and phasor diagram looks like in above figure.

4.Find the phasor addition same as vector addition, by drawing parallelogram OABC, here it is rectangle. The resultant is OB is supply voltage which is equal to ……….as per KVL. Thus indicates phasor currents lags the supply voltage by θ.BOA= θ

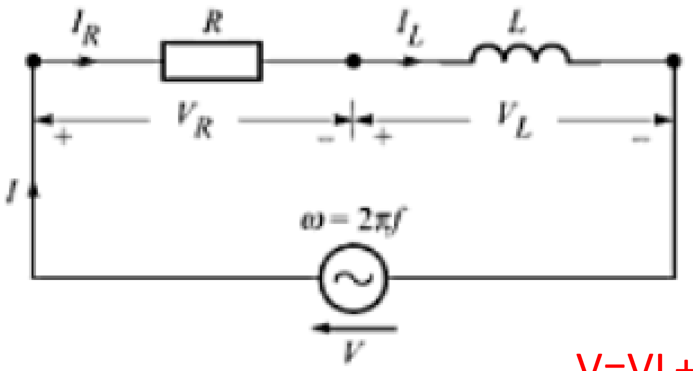
5.For Complex plane, X-axis as real and Y-axis as Imaginary. VR=IR…..Real axis

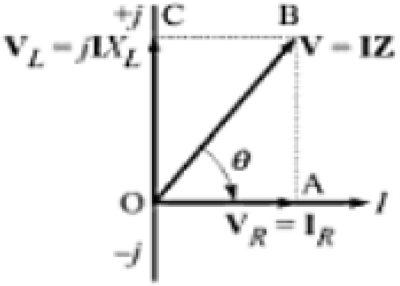
$V_L = jIX_L$,thus $V=V_L+V_R$ $=IR+jI X_L$

The resultant is OB is supply voltage which is equal to ???

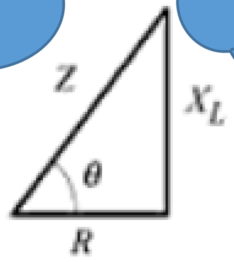
Series RL Circuit

V=VL+VR   can't added directly why???





Each side of triangle OAB divided by I gives ????



Impedance triangle in which quadrant ???

V=VL+VR   =IR+jI XL

Complex representation of total Impedance (Resistance + j Reactance) and current as reference

$$\mathbf{Z} = \frac{\mathbf{V}}{\mathbf{I}} = R + j\omega L = Z\angle\theta$$

$$Z = \sqrt{R^2 + (\omega L)^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{\omega L}{R}$$

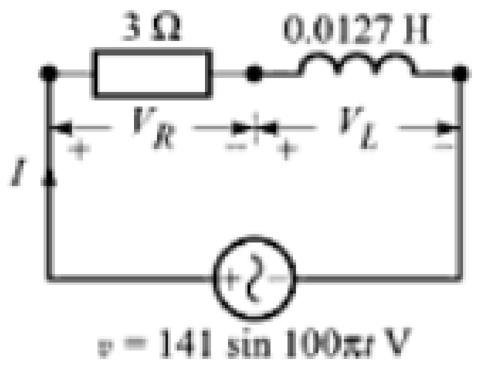
Voltage Phasor as Reference

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{Z}} = \frac{V\angle 0^\circ}{Z\angle\theta} = \frac{V}{Z}\angle -\theta$$

$$i = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \sin\{\omega t - \tan^{-1}(\omega L)/R\} \text{ amperes}$$

Practice Numerical:

(a) Calculate the rms value of the steady state current and the relative phase angle.
(b) Write the expression for the instantaneous current.
(c) Find the average power dissipated in the circuit.
(d) Determine the power factor.
(e) Draw the phasor diagram.



(a) The circuit.

Practice Numerical:

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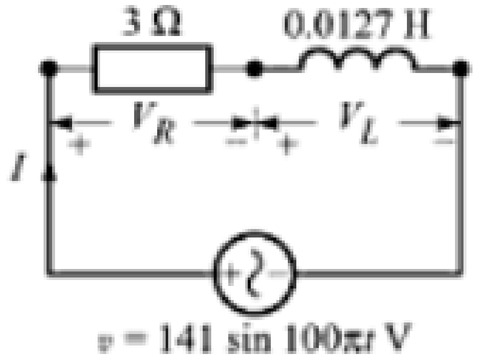
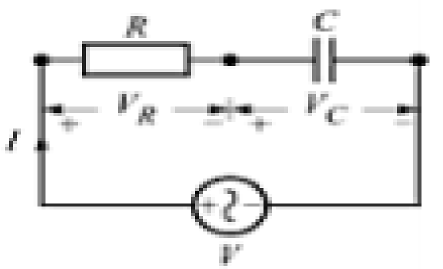
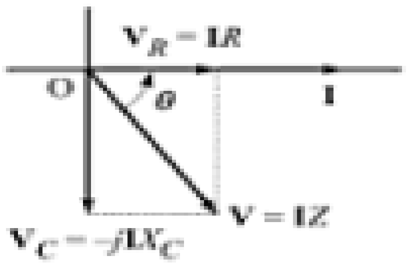


(*a*) The circuit.

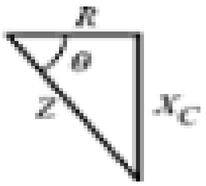
Series RC Circuit



(a) The circuit.



(b) Phasor diagram.



(c) Impedance triangle.

Impedance triangle in which quadrant ???

$\mathbf{V}_R = \mathbf{I}R$, where $\mathbf{V}_R$ is in phase with $\mathbf{I}$

$\mathbf{V}_C = \mathbf{I}X_C$, where $\mathbf{V}_C$ lags $\mathbf{I}$ by 90°

$\mathbf{V} = \mathbf{V}_R + \mathbf{V}_C$ (phasor sum)

Also $V = (V_R^2 + V_C^2)^{\frac{1}{2}}$

$= (I^2R^2 + I^2X_C^2)^{\frac{1}{2}}$

$= I(R^2 + X_C^2)^{\frac{1}{2}}$

Hence $V = IZ$

$$Z = (R^2 + X_C^2)^{\frac{1}{2}}$$

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

$$\phi = \tan^{-1}\frac{V_C}{V_R} = \tan^{-1}\frac{IX_C}{IR}$$

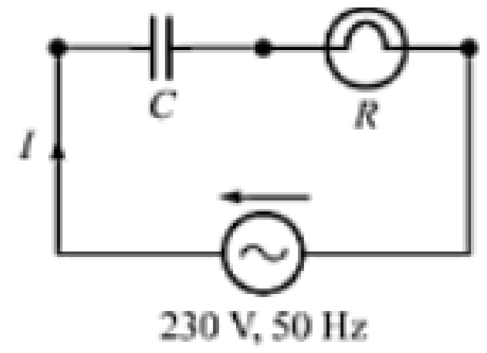
$$\phi = \tan^{-1}\frac{X_C}{R}$$

Practice Numerical:

A metal filament lamp rated at 750 W, 100V, is to be used on 230 V and 50 Hz supply by connecting a capacitor of suitable value in series?

Determine:

a. Capacitance required.
b. Phase angle
c. Power factor
d. Apparent power
e. Reactive power



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