EE2029: Introduction to Electrical Energy System

AC Fundamentals

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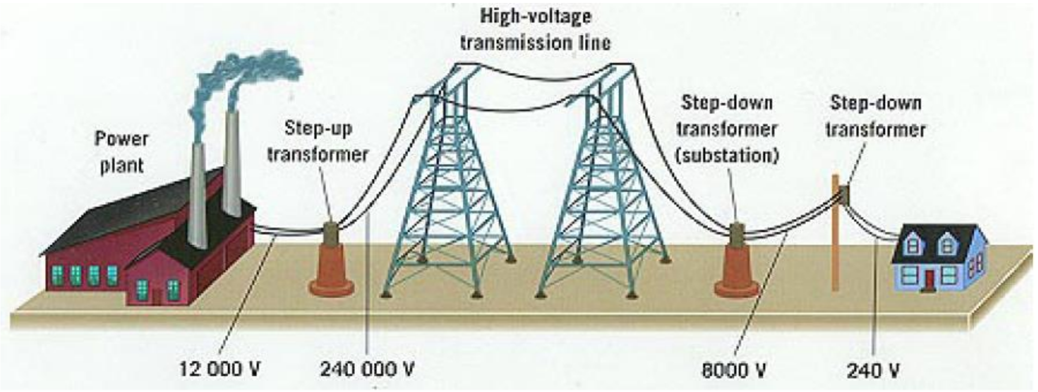
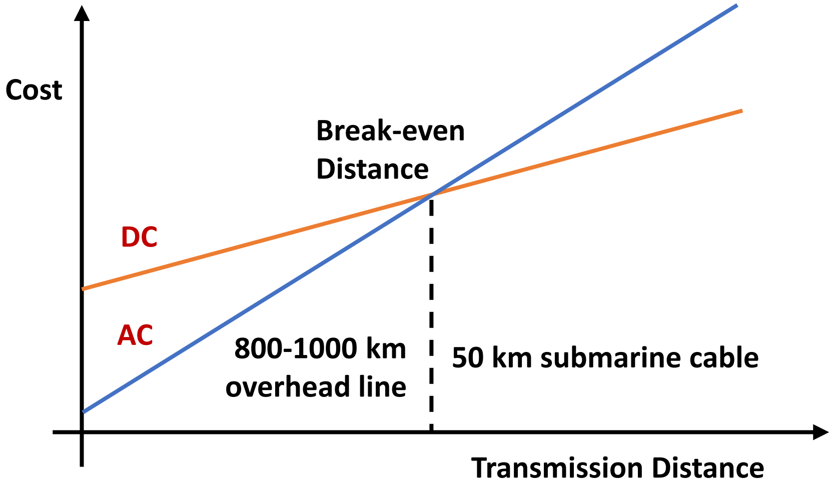
Why AC and not DC???

- Transformers allow easy transformation of voltage

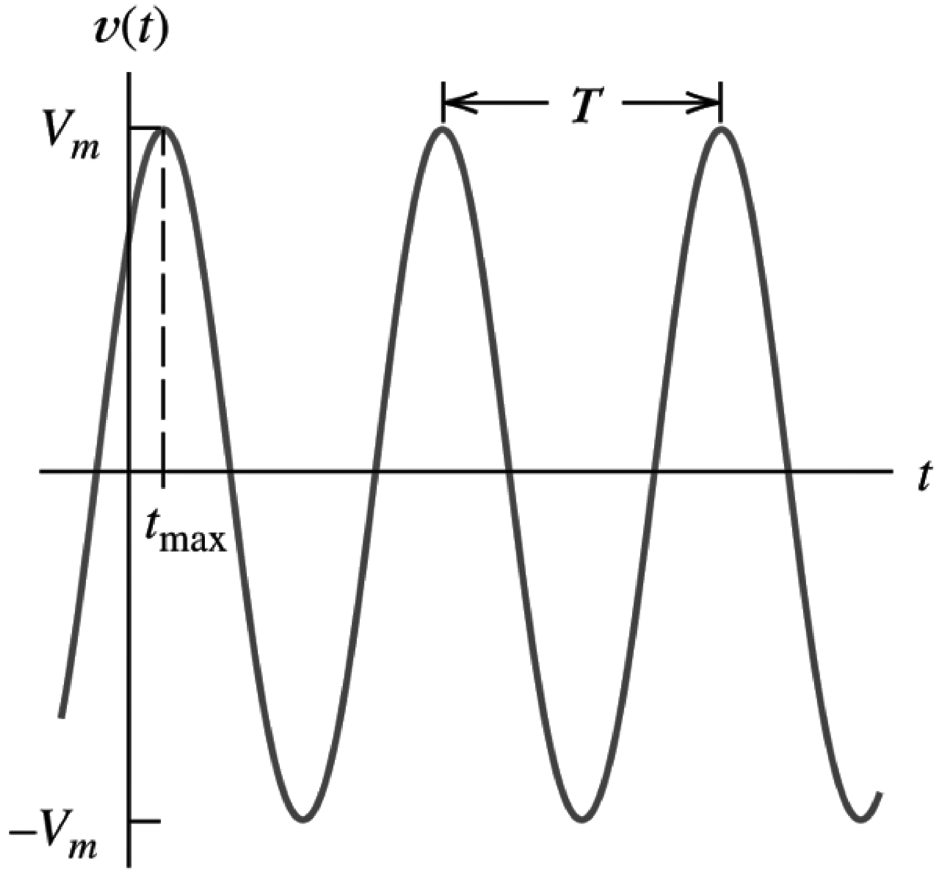


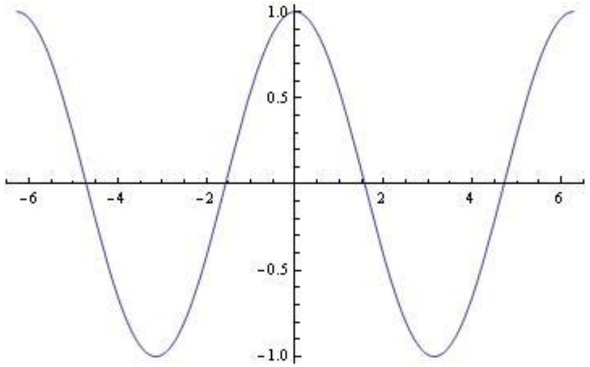
- Break-even distance for high voltage direct current (HVDC)



Why a Sinusoidal Alternating Voltage?

- Easily generated using the synchronous generator
- Basic operations: +, -, x, division, differentiation, integration
  - These operations will result in another sinusoid of same frequency and shape
  - Any signal can be represented by a linear combination of sinusoidal waveforms (remember Fourier Series!!!)

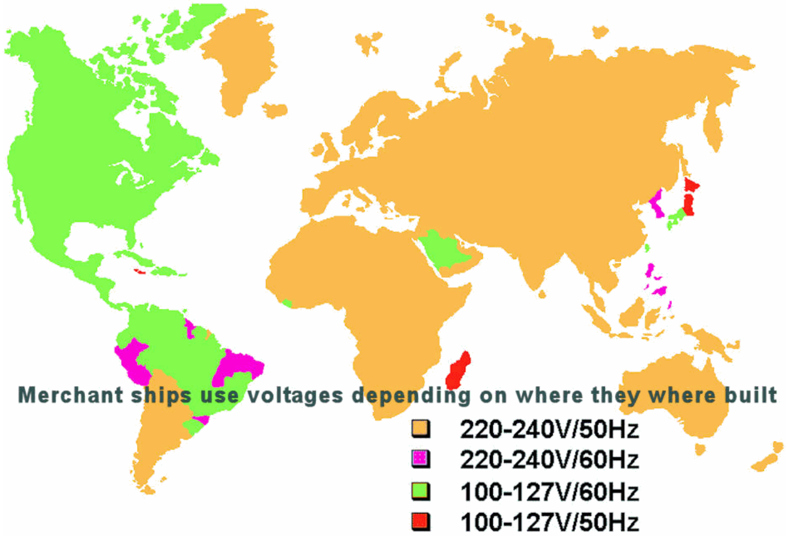




Choice of Supply Frequency

- 50 Hz and 60 Hz
- Today :
  - 60 Hz in North America, Brazil and Japan (which also uses 50 Hz!!) etc
  - 50 Hz in other countries
- Exceptions:
  - 25 Hz Railways (Amtrak)
  - $16\,\frac{2}{3}$ Hz Railways
  - 400 Hz Oil rigs, ships and airplanes

- A too low frequency like 10 Hz or 20 Hz causes flicker
- A too high frequency
  - Increases cable and line impedance
  - Increases the hysteresis losses
  - Increases eddy current losses



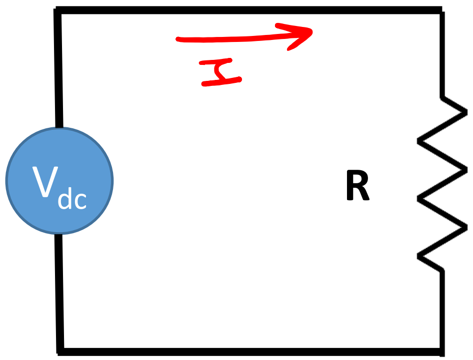
Plot the following curves

- $20 \cos(\omega t - 45°)$
- $35 \sin(\omega t - 135°)$
- $141.2 \cos(\omega t + 45°)$
- $12 \sin(\omega t + 135°)$

How do we represent AC Signals?

SINUSOID - NO SINGLE VALUE

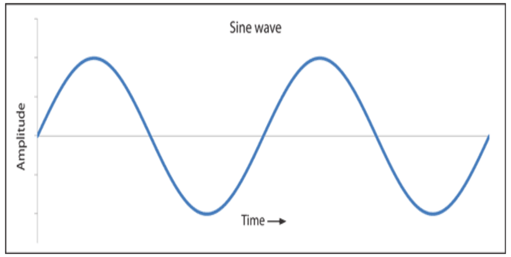
- It is desirable to have same form of equation for power in both a.c. and d.c. circuits mainly because of
  - Convenience
  - Consistence
- For a DC Circuit with a resistance R and voltage source V

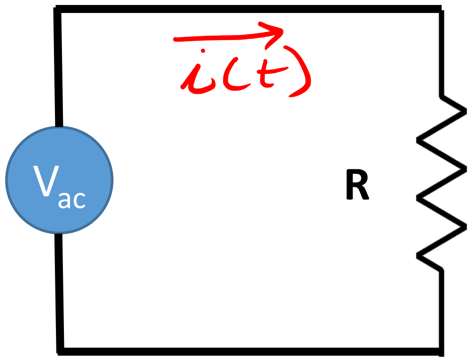


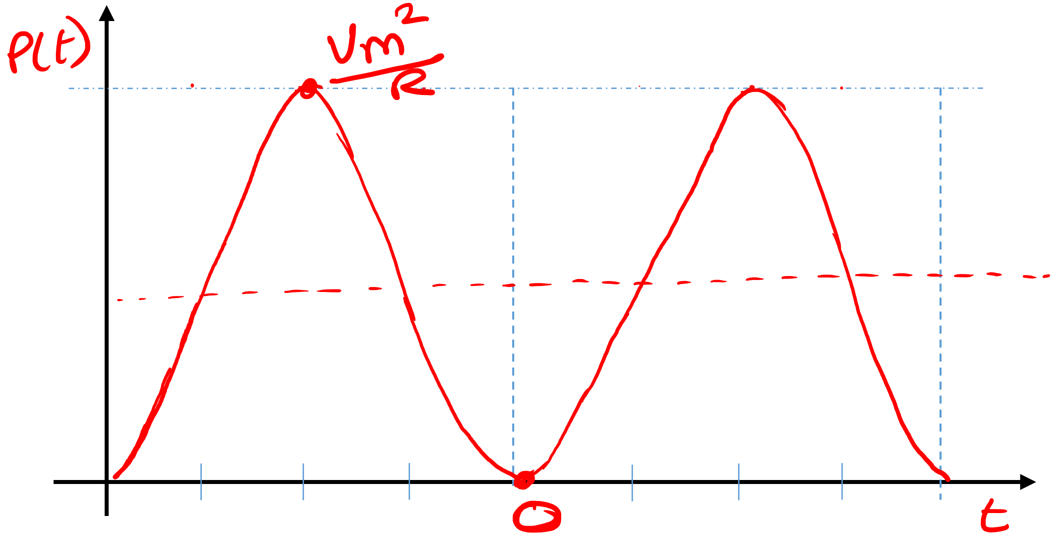
$$I_{dc} = \frac{V_{dc}}{R} \quad - \text{①}$$

$$P_{dc} = V_{dc} \cdot I_{dc} \Rightarrow P_{dc} = \frac{(V_{dc})^2}{R} \quad - \text{②}$$

How do we represent AC Signals?







AVERAGE VALUE = 0

$$i(t) = \frac{V_{ac}}{R}$$

$$V_{ac} = V_m \sin\omega t$$

$$\Rightarrow i(t) = \frac{V_m \sin\omega t}{R}$$

$$= \left(\frac{V_m}{R}\right)\sin\omega t \quad \text{— (3)}$$

$$P_{ac} = V_{ac} \cdot i(t) = \frac{V_m^2}{R}\sin^2\omega t \quad \text{— (4)}$$

$$P_{avg} = \left(\frac{V_m^2}{R} + 0\right)/2 = \frac{V_m^2}{2R}$$

$$P_{avg} = \frac{V_m}{\sqrt{2}} \cdot \frac{V_m}{\sqrt{2}R} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

ROOT MEAN SQUARE OF A SINUSOID

$$\Rightarrow \boxed{P_{ac} = V_{rms} \cdot I_{rms}}$$

RMS values in AC circuits

- The use of the RMS value gives us the DC equivalent AC power equation i.e.

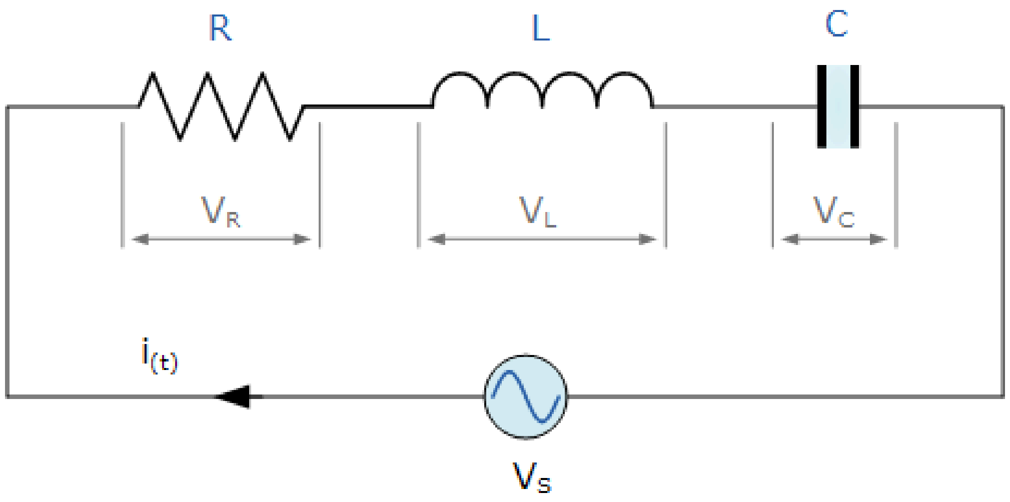
$$P_{ac} = V_{rms} \cdot I_{rms}$$

- An AC voltage source's value is the RMS value by default
  - In Singapore, the voltage supply at households is mentioned as 230V/50Hz

$$V_{rms} = 230V$$

$$V_{max} = \sqrt{2} V_{rms} = \sqrt{2} \cdot 230$$
$$= 325V$$

A Typical AC circuit Analysis



$V_R = i \cdot R$

$V_S = V_m \cos(\omega t + \theta)$

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

$V_C = \frac{1}{C}\int i\,dt$

KVL FOR THIS CIRCUIT

$V_S = V_R + V_L + V_C$

$V_m \cos(\omega t + \theta) = iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt$

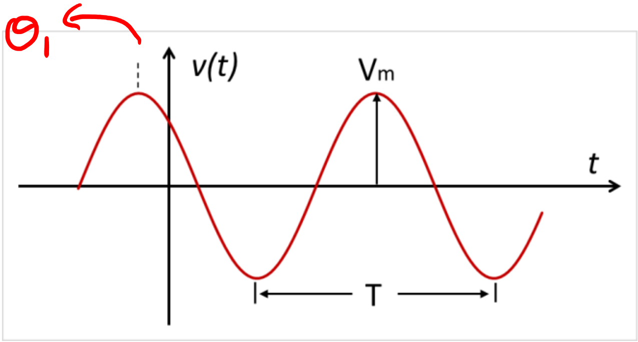
DIFFERENTIAL EQUATIONS?

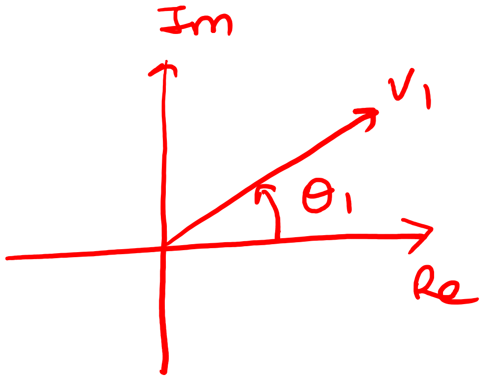
COMMON PARAMETER – FREQUENCY

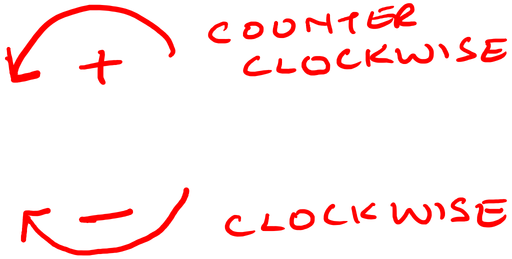
PHASE AND AMPLITUDE CHANGE

Phasor Representation of a Sinusoid

- Time Function: $v_1(t) = V_m\cos(\omega t + \theta_1)$
- Phasor: $\mathbf{V_1} = V_1 \angle \theta_1$, here V_1 is the RMS value of the voltage







- Rotating Vector with
  - Length representing the rms value of the waveform
  - Angle representing the phase of the waveform
- The phasor for a sinusoid is a snapshot of the corresponding rotating vector at t=0 with its rms values
- Time domain signal is expressed as cosine function

Find and draw the phasors of the following curves

- $20 \cos(\omega t - 45°)$
- $35 \sin(\omega t - 135°)$
- $141.2 \cos(\omega t + 45°)$
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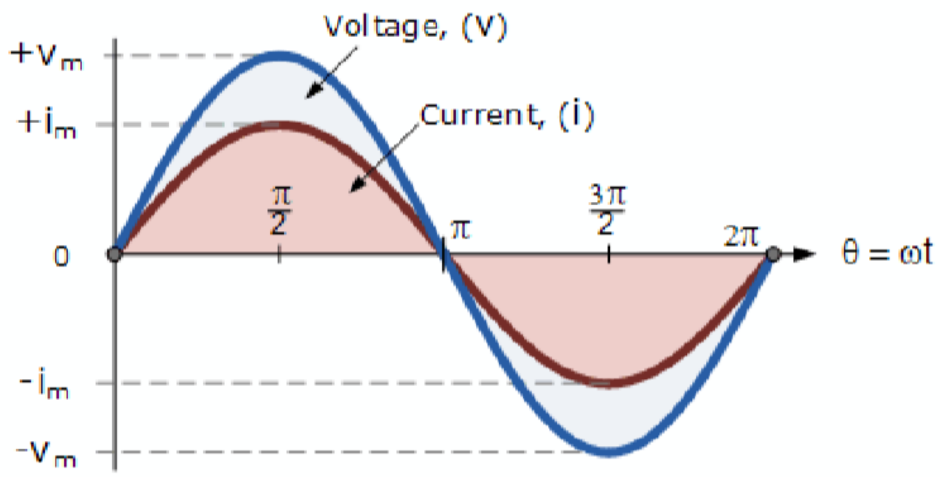
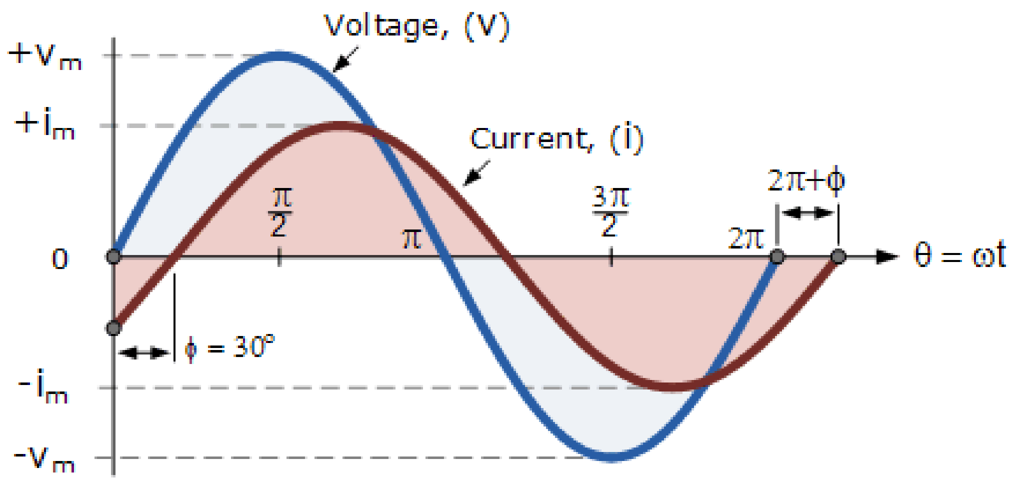
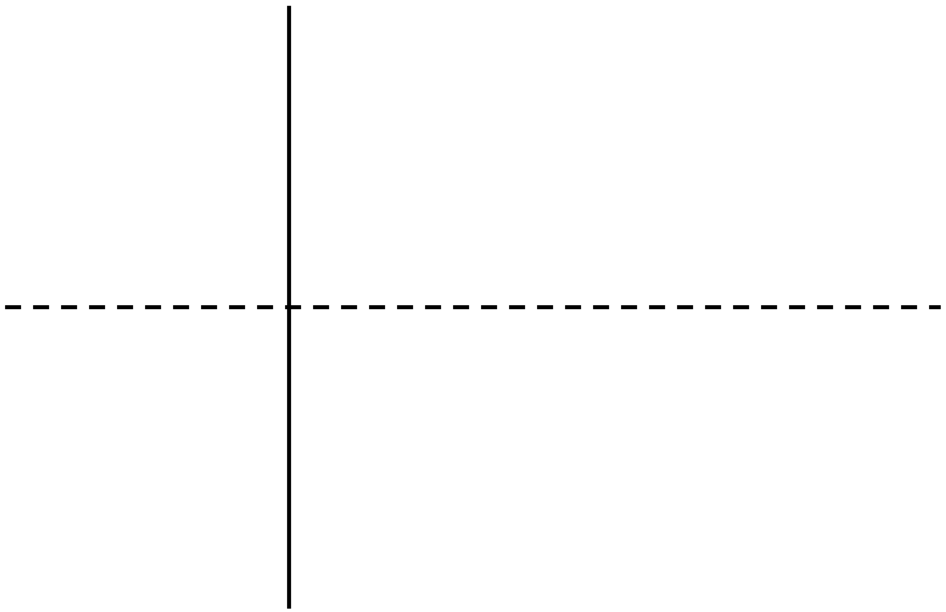
Phase Relationships between Sinusoids



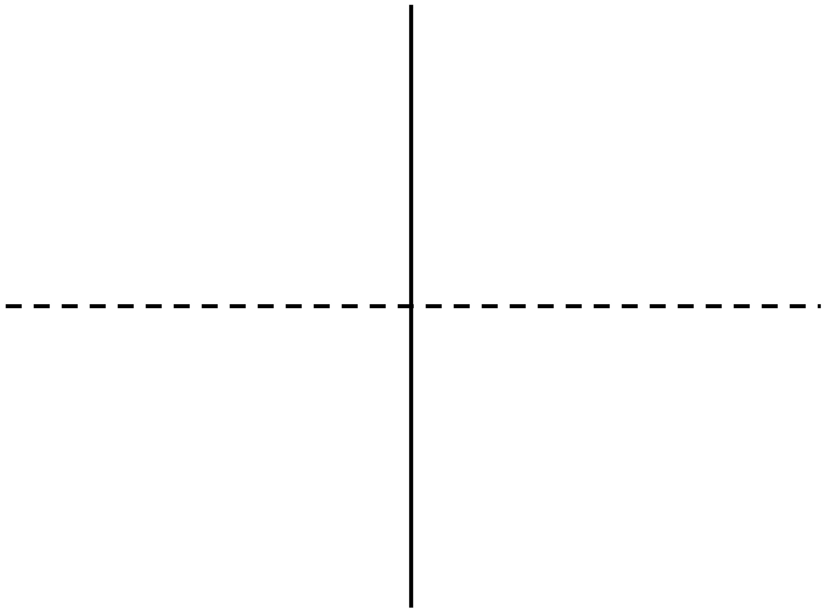


Find and draw the time domain and the phasor of the 141.2 cos(ωt-90°), 70.7 sin(ωt-30°) &100 cos(ωt+30°) curves on the same axis!!!

- **Time domain**



- **Phasors!!!**

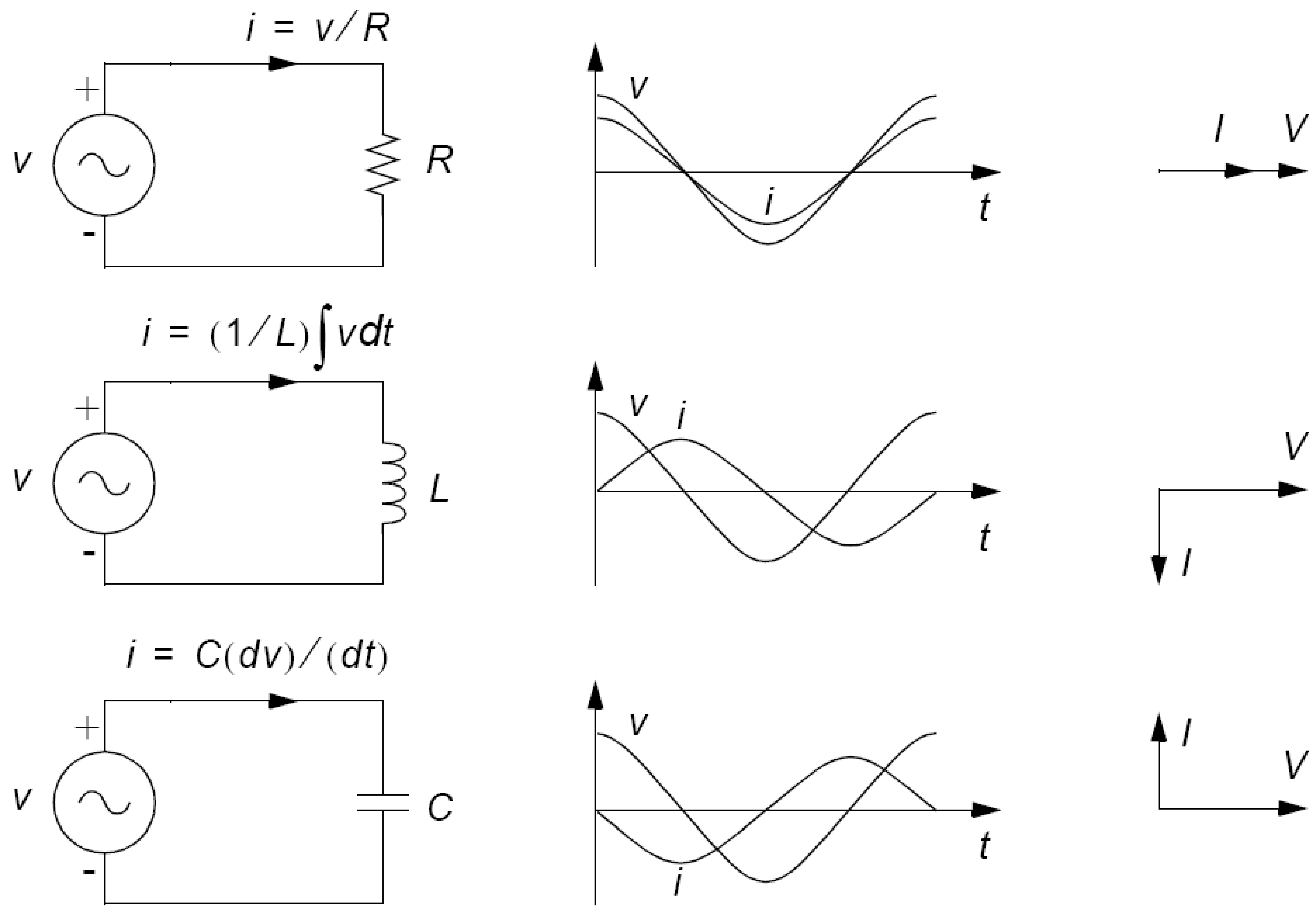


Impedance ➔ Complex Resistance

- $DC:\ Resistance\ (R) \ = \dfrac{Voltage\ (V)}{Current\ (I)}$

- $AC: Impedance\ (Z) \ = \dfrac{Voltage\ Phasor(V)}{Current\ Phasor(I)}$

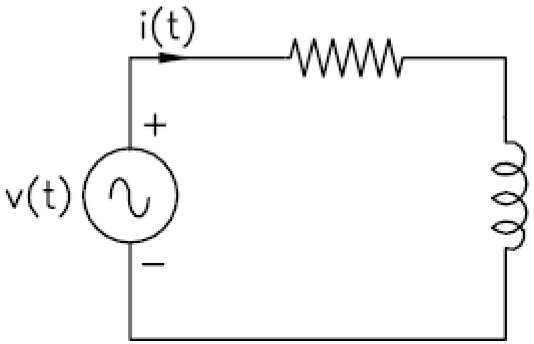
Time $\Longleftrightarrow$ Phasor



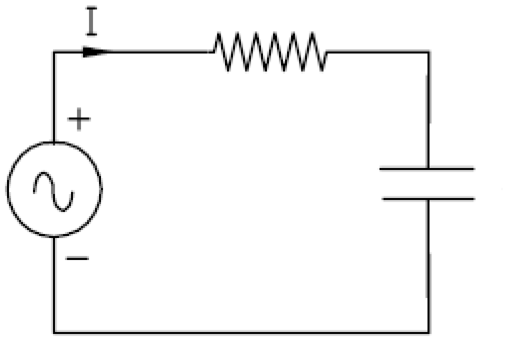
Element	Voltage	Current	Impedance
R			
L			
C			

Complex Impedance

- RL Load

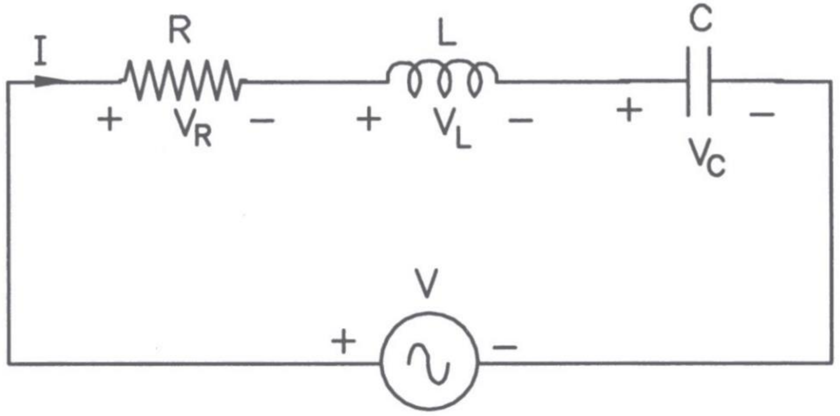


- RC Load

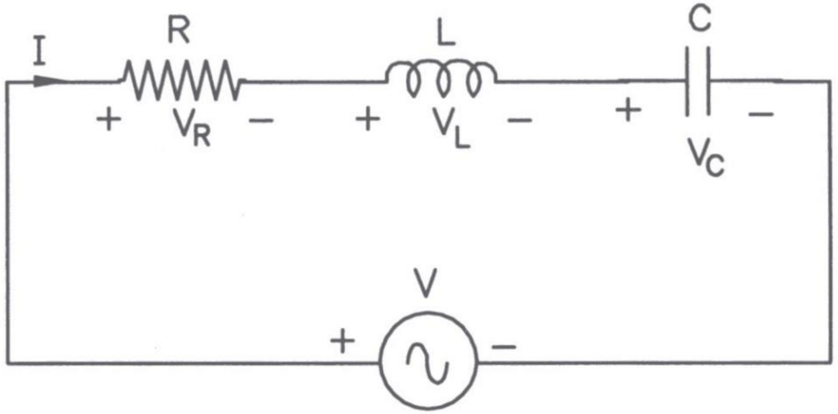


Series RLC Circuit

- Find the impedance of the following circuit. Draw the impedance diagram. What is the current if $Z_L = Z_C$?



Series RLC Circuit



Voltage Phasors and KVL