EEEN313/ECEN405

3 Phase Power

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Three phase Power

- We always are used to using single wires for all our applications. So they are called ‘single phase’ systems; one generator, two conductors/wires, a load.
- Now we going to do the same thing but in ‘threes’ –hence called three phase systems.
- For this course, we will just focus on what we call as ‘balanced’ three-phase systems – i.e. they are all same but just -120 and -240 degrees apart.
- Everything you know about single phase AC still relevant ☺

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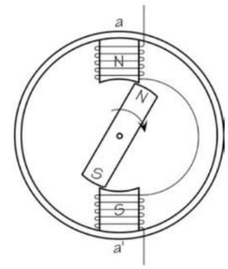
So where do we start?



- Single phase generator of course!
- Basically a magnet spinning between two pole pieces.
- So if it spins at 3000 rpm, our frequency will be 50Hz
- So what is the voltage of this? $v_a(t) = V_p \cos(\omega t)$
- Did you observe the wastage of space in the generator?
- If we put more magnets along the stator, we can get the following:

$$v_a(t) = V_p \cos(\omega t)$$
$$v_b(t) = V_p \cos(\omega t - 120°)$$
$$v_c(t) = V_p \cos(\omega t - 240°)$$

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3 Phase Power

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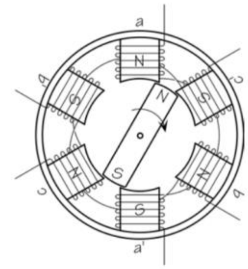
Three phase Systems



$$v_a(t) = V_p \cos(\omega t)$$
$$v_b(t) = V_p \cos(\omega t - 120°)$$
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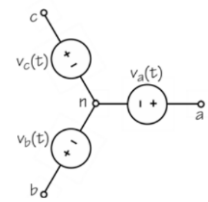

They all have the ‘same’ peak voltage but differ in phases by 120 degrees

This is the heart of moving almost everything in the world – from Power generation to Electric Cars and your washing machines (and all the servos in your robots and uavs)

As I said in the class before, if it generators power – Generator; if it consumes power - Motor

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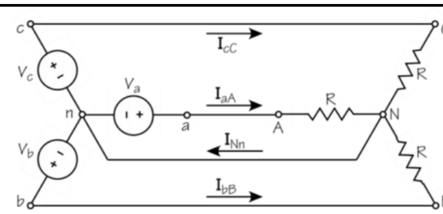
Three Phases



- A three phase system consists of a three phase generator and a load that has three distinct sections
- The load in this sense is ‘balanced’ – all have same R
- There are ‘four’ wires – three phase wires and one neutral wire.
- Neutral wire connects to common node of the generator and the load.

$$V_a = V\angle 0°$$
$$V_b = V\angle -120°$$
$$V_c = V\angle -240°$$

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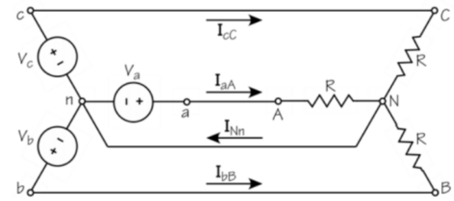
Current through the wires



$$I_{aA} = \frac{V}{R}\angle 0° = \frac{V}{R} + j0$$

$$I_{bB} = \frac{V}{R}\angle -120° = \frac{V}{R}\cos(-120°) + j\frac{V}{R}\sin(-120°)$$

$$= -0.5\frac{V}{R} - j0.866\frac{V}{R}$$

$$I_{cC} = \frac{V}{R}\angle -240° = \cos(-240°) + j\frac{V}{R}\sin(-240°)$$

$$= -0.5 + j0.866\frac{V}{R}$$

$$V_a = V\angle 0°$$
$$V_b = V\angle -120°$$
$$V_c = V\angle -240°$$

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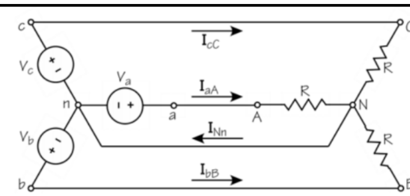
Neutral Current



- At the load side, all three currents converge at the neutral node N.
- So KCL states that neutral current is sum of all the three line currents.

$$I_{Nn} = I_{aA} + I_{bB} + I_{cC}$$
$$= \frac{V}{R} - 0.5\frac{V}{R} - j0.866\frac{V}{R} - 0.5 + j0.866\frac{V}{R}$$
$$= 0$$

$$V_a = V\angle 0°$$
$$V_b = V\angle -120°$$
$$V_c = V\angle -240°$$

- Neutral currents in a balanced system equals to zero (no neutral current).
- So if the currents all balance out to zero, so why the need for a wire?

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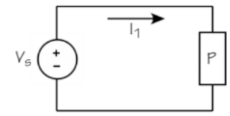
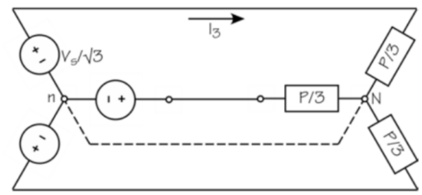
Conductors and Wires



- Single phase system requires two wires.
- Three phase system requires 3 wires minimum – so more power with just one extra wire.
- In reality, based on power transferred, 3 phase uses only 86.6% of metal to deliver the same power (details not included).



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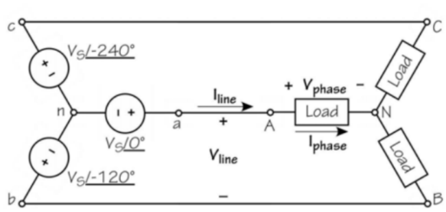
Other terminology

- Line currents and voltages
  - Always refers to the wires of the three phase system
- Phase currents and voltages
  - Always refers to the load in the three phase system



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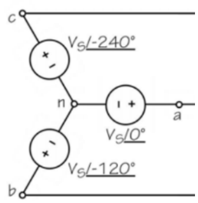
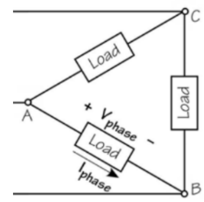
Y and Delta connections





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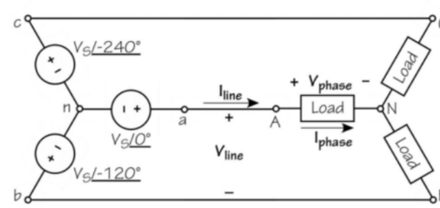
Y –Y Connection



- Both generation and load are connected in Y
- Line Current is current between a and A nodes
- Phase Current is through A phase of the load
- Line voltage is between two A and B phases
- Phase voltage is voltage across one phase of the load

$$I_{line} = I_{phase}$$

$$\begin{aligned}|V_{line}| &= |V_S\angle 0° - V_S\angle -120°| \\ &= \sqrt{3}|V_{phase}|\end{aligned}$$

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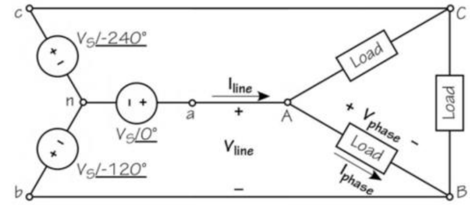
Y - Δ Connection



- Generator is Y and Load is Δ

$$V_{line} = V_{phase}$$

Y connection

$$I_{line} = I_{phase}$$

$$|V_{line}| = \sqrt{3}|V_{phase}|$$

Δ connection

$$|I_{line}| = \sqrt{3}|I_{phase}|$$

$$V_{line} = V_{phase}$$

$$\begin{aligned}|I_{line}| &= |I_{AB}\angle\theta - I_{CA}\angle\theta - 240°| \\ &= \sqrt{3}|I_{phase}|\end{aligned}$$

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P, Q and S – Power in 3 Phase

- If you understand the line and phase aspects of 3 phase – you know the secret handshake of the 3 phase community ☺
- For P,Q,S, lets take the Y-Y system:
- Power absorbed by a single phase in the system $P_{1\phi} = |V_{phase}||I_{phase}|pf$
- Since all phases have same load $P_{3\phi} = 3|V_{phase}||I_{phase}|pf$
- For Y connected

$$\begin{aligned}P_{3\phi} &= 3\left|\frac{V_{line}}{\sqrt{3}}\right||I_{line}|pf \\ &= \sqrt{3}|V_{line}||I_{line}|pf\end{aligned}$$

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P, Q and S

- For Y - Δ
- P for 3 phase will be

$$P_{3\phi} = 3|V_{line}|\left|\frac{I_{line}}{\sqrt{3}}\right| pf$$
$$= \sqrt{3}|V_{line}||I_{line}| pf$$

- So power is the same whether our system is Y connected or Δ connected provided we express our V and I in 'line' terms
- Q and S are the same too

$$P = \sqrt{3}|V_{line}||I_{line}| pf, \quad pf = \cos(\theta_v - \theta_i)$$
$$Q = \sqrt{3}|V_{line}||I_{line}| \sin(\theta_v - \theta_i)$$
$$S = \sqrt{3}V_{line}I^*_{line} = P + jQ$$

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Now you are inducted into 3 Phase Society ☺

- Summary:
  - Needs only 86% of the material to transport same energy
  - Engineer must use line and phase to refer to connecting wires and load
  - All power calculations need a $\sqrt{3}$ in their equations
  - Since our restriction is to study only balanced three phase, we can reduce any system to a single phase equivalent.

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Tomorrow –some examples

- So have some coffee before ☺