EE2029 Introduction to Electrical Energy Systems

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Learning Outcomes

Upon completion of this module, students should be able to :

- analyse ac circuits using phasor and impedance
- explain active, reactive, complex power, and power factor – its impact on losses and need for power factor correction.
- examine power in single-phase and three-phase balanced systems.
- model key components of power systems including generator, transmission line, transformer and induction motor load.
- analyse the working of a complete power system from generation to load.

Syllabus

1. Review of AC circuit analysis (3 hours)
   - Use of phasor and impedance in AC circuit analysis.
2. Structure of Electrical Power Systems (3 hours)
   - Introduction to power generation, transmission and distribution systems.
3. Three-Phase systems (6 hours)
   - Revise active power, reactive power and apparent power. Concept of harmonics and how it influences power factor. Introduction to phasor diagrams and complex power. Balanced three-phase systems and their single-phase equivalents. Power factor correction. Relationship between phase and line quantities Concept of regulation.
4. Generating sources (3 hours)

   Gas Turbine: basic energy conversion model, IEC symbol, and conversion efficiencies, and concept of rotating prime mover applied to other similar sources. Photovoltaic array: basic model, and conversion efficiencies.

Syllabus

4. <u>Transmission System</u> (6 hours)

   Three-phase-four-wire system, three-phase-three-wire system, and three-phase circuit analysis. Modelling and sizing of cables. Circuit breaker and its sizing. Grounding and earth followed by safety and earthing.

5. <u>Transformers</u> (6 hours)

   Ideal transformer, Magnetic circuits, magnetizing current and saturation, real transformers. Equivalent circuits with short-circuit and open circuit. Phasor diagram, regulation (applied to transformer) and efficiency. Three-phase transformer connections, including with wye and delta connections.

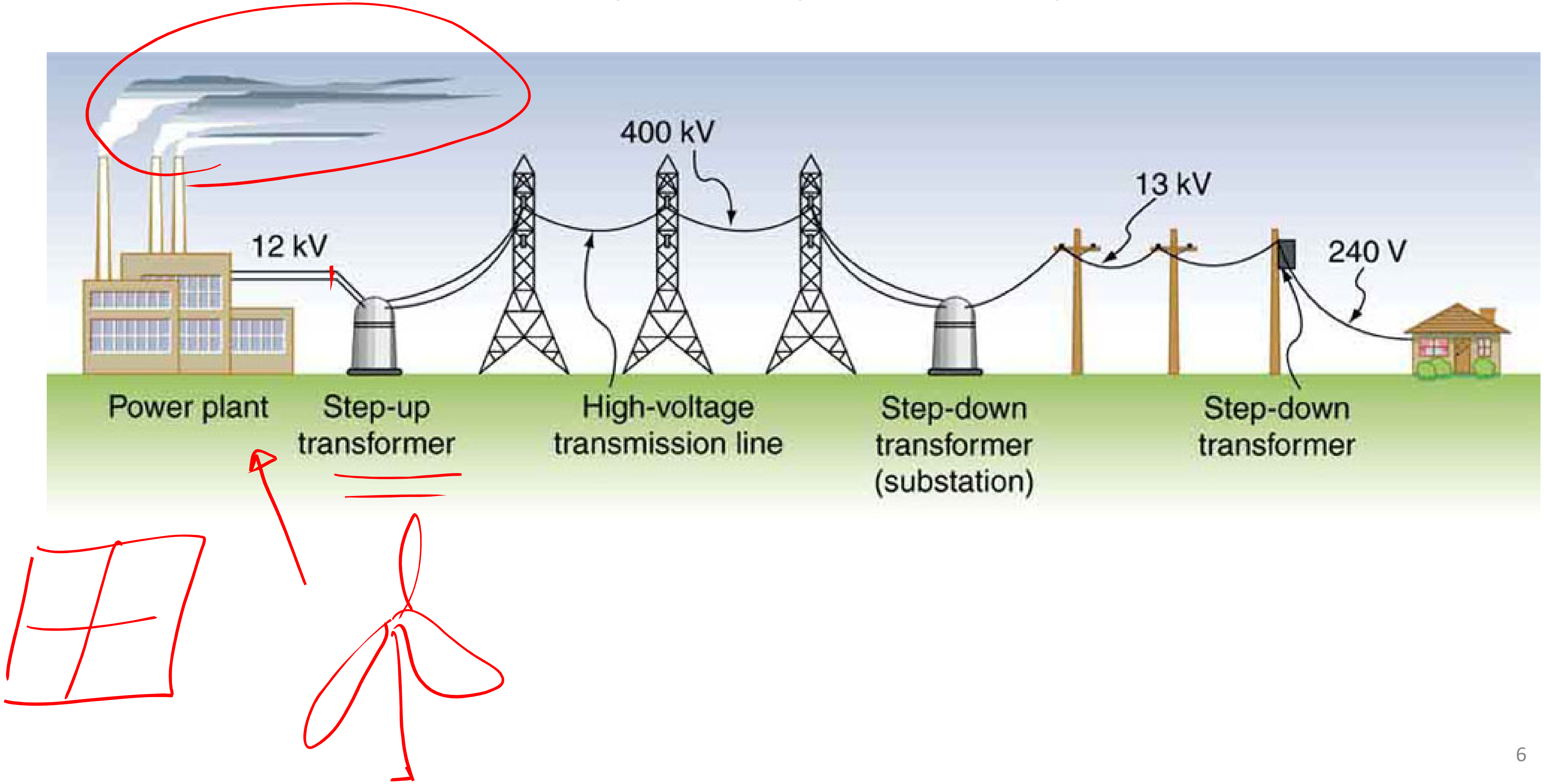
6. <u>Loads</u> (6 hours)

   Static loads: Lighting, heating, resistive, and inductive. Three-phase induction machine: Operating principle, equivalent circuits, torque-speed characteristics, losses and efficiency.

Schedule for EE2029 (First half) in Sem 1 AY2021/22

Week	Date	Time	Lecture	Topic
1	10 Aug 2021	16:00- 18:00	Lec1	Topic 1 AC Fundamentals
	13 Aug 2021	12:00-14:00	Tutorial 1	Tutorial 1 AC Fundamentals
2	17 Aug 2021	16:00- 18:00	Lec2	Topic 2 AC Power
	20 Aug 2021	12:00-14:00	Tutorial 2	Tutorial 2 AC Power
3	24 Aug 2021	16:00- 18:00	Lec3	Topic 3 Three phase analysis
	27 Aug 2021	12:00-14:00	Tutorial 3	Tutorial 3 Three phase analysis
4	31 Aug 2021	16:00- 18:00	Lec4	Topic 4 Generation
	3 Sep 2021	12:00-14:00	Tutorial 4	Tutorial 4 – Generation
5	7 Sep 2021	16:00- 18:00	Lec5	Topic 5 Renewable generation
	10 Sep 2021	12:00-14:00	Tutorial 5	Tutorial 5 – Renewable generation
6	14 Sep 2021	16:00- 18:00	Summary	Doubt clearing
	17 Sep 2021	12:00-14:00		Midterm Quiz 1

Modelling of complete power system



Key concepts and formula in AC fundamentals

time domain

Complex domain
Phasor

- $V_m \sin(\omega t + \theta) \rightarrow \frac{V_m}{\sqrt{2}} \angle \theta$
- $R \rightarrow Z_R = R$
- $L \rightarrow Z_L = j\omega L$
- $C \rightarrow Z_C = \frac{1}{j\omega C} = -j\frac{1}{\omega C}$
- Resonance frequency $\omega_0 = \frac{1}{\sqrt{Lc}} \frac{rad}{sec}$; $f_0 = \frac{\omega_0}{2\pi}$ Hz

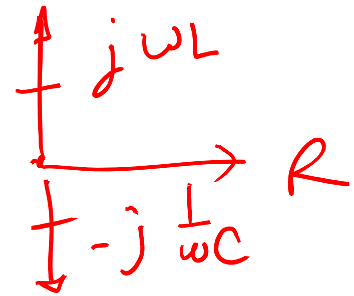
Impedance

$\omega = 2\pi f$ if

e.g. $f = 50Hz$

angular frequency (rad/sec).

$\omega L = \frac{1}{\omega C}$



Key concepts and formula in AC power

active power

- Average power (real power) in resistor $R \rightarrow P_{avg} = V_{rms} I_{rms} = I_{rms}^2 R = \frac{V_{rms}^2}{R}$
- Average power (real power)i n inductor $L \rightarrow P_{avg} = 0$
- Average power(real power) in capacitor $C \rightarrow P_{avg} = 0$
- Power in general AC load $Z = R + jX \rightarrow P = VI\cos\theta\,, Q = VIsin\theta$
  - where V, I are RMS values for voltage and current; θ is the impedance angle $\theta = tan^{-1}\left(\frac{X}{R}\right)$

L: $I = \frac{V}{Z} = \frac{V}{j\omega L}$

$= -j(\ )$

$I = I_L + I_R$

$= 3 - j2$

$= \sqrt{13}\angle$

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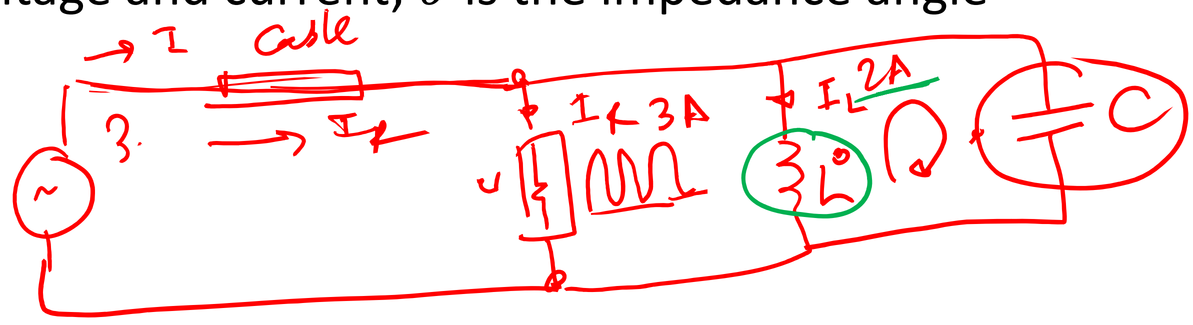
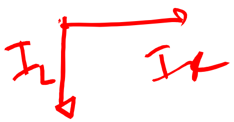
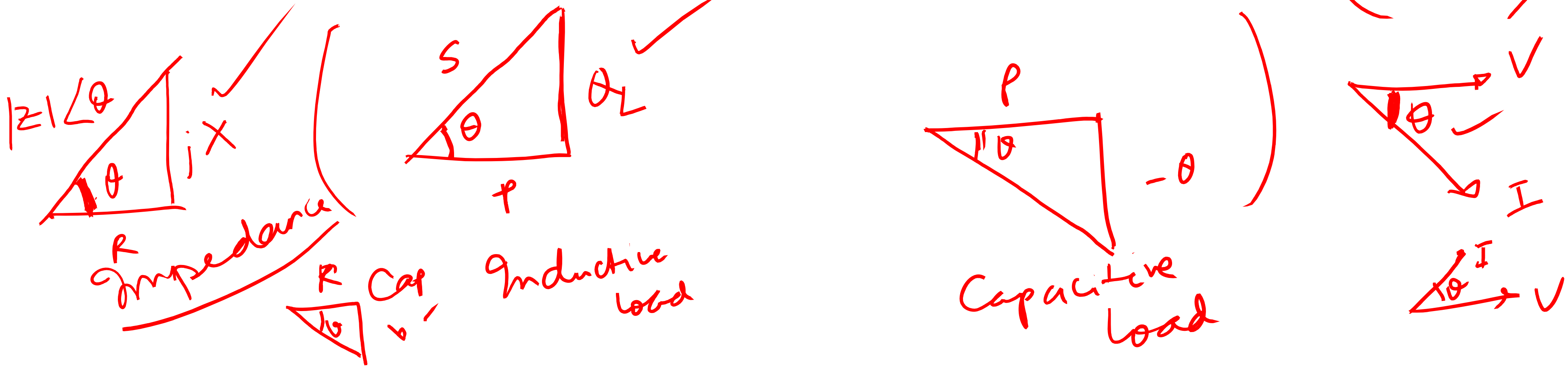




Key concepts and formula

- Complex power $S = VI^* = P + jQ$,
  - *where V is voltage phasor, I^* is conjugate of current phasor*
- Apparent power $|S| = VI$ in VA
- Real power $P = Real\ part\ of\ (S)$ in Watt
- Reactive power Q $= Imaginary\ \ part\ of\ (S)$ in VAr

$I = \frac{V}{Z}$



Key concepts and formula

- Power Factor = $\frac{Real\ power}{Apparent\ power} = \frac{P}{|V||I|} = \cos\theta$
  - Where θ is the impedance angle, it is the phase difference between voltage and current phasors
- Power factor is lagging for inductive load
- Power factor is leading for capacitive load
- Low power factor leads to increased current for the same power
  - Leads to increased loss
- Capacitor can be connected across inductive load to improve power factor

Assume V is ref

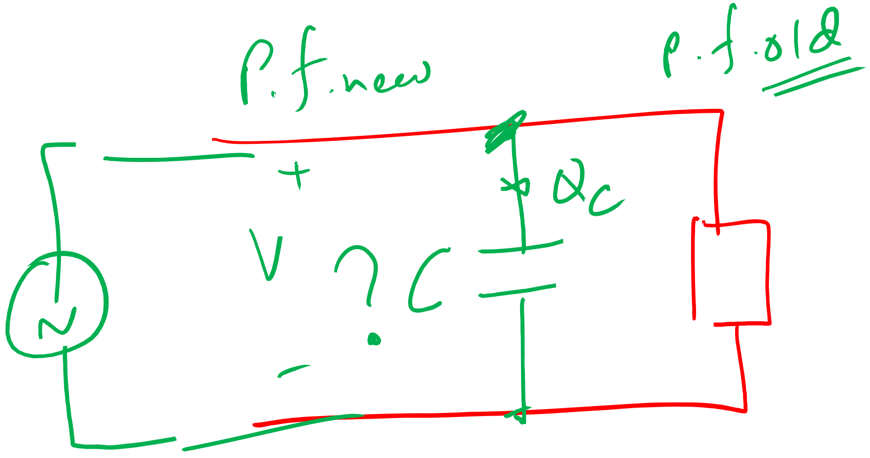
$I = \frac{P}{|V| \times p.f.} \angle -\cos^{-1}(0.8)$

1-phase AC load consumes P. 2000W at 0.8 lagging power factor at 230V.

p.f. $|V|$

$I = \frac{2500}{230} \angle +\cos^{-1} 0.8$

1 ph AC load draws |S| 2500 VA, 0.8 leading p.f. at 230V.



Old : P.f. and the load

New P.f.

Q_{old} from the load

$$S_{old} = P_{old} + j\,Q_{old}$$

$$S_{new} = P_{old} + j\,Q_{new}$$

$$Q_{new} = Q_{old} + Q_c$$

$$Q_c = -V^2 \cdot \omega \cdot C \rightarrow C$$

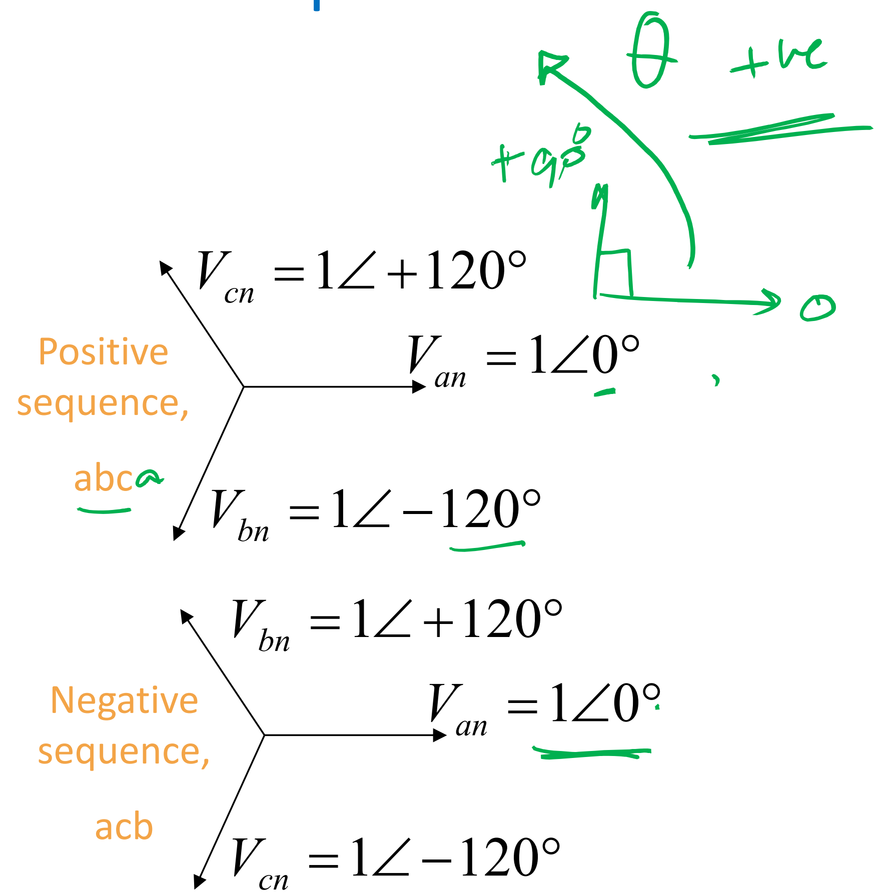
If P.f. new = 1,

$$Q_{new} = 0$$

$$Q_c = -Q_{old}$$

Key concepts and formula in Three-phase

- Balanced three-phase supply with 'abc' (positive) phase sequence
  - $v_a(t) = V_m \sin(\omega t)\,, v_b(t) = V_m \sin(\omega t - 120^o), v_c(t) = V_m \sin(\omega t + 120^o) =$
- Balanced three-phase supply with 'acb' (negative) phase sequence
  - $v_a(t) = V_m \sin(\omega t)\,, v_c(t) = V_m \sin(\omega t - 120^o), v_b(t) = V_m \sin(\omega t + 120^o)$

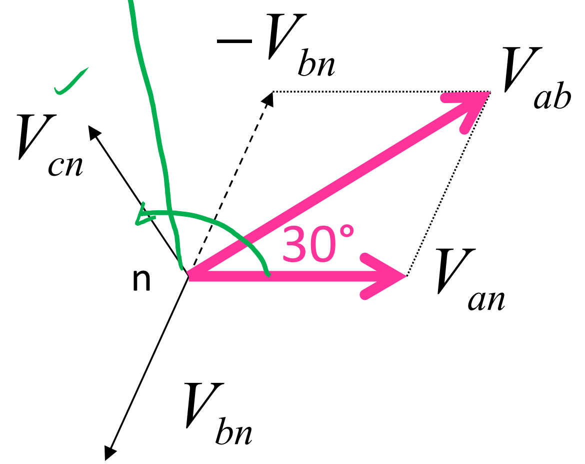


Key concepts and formula

- In a balanced three phase system
  - $V_a + V_b + V_c = 0$
  - $I_a + I_b + I_c = 0$
- For positive sequence system
  - $V_{ab} = \sqrt{3} V_{an} \angle 30^0$

$V_{cb} = V_{cn} - V_{bn}$

$V_{cb} = \sqrt{3} \cdot V_{cn} \angle -30^0$

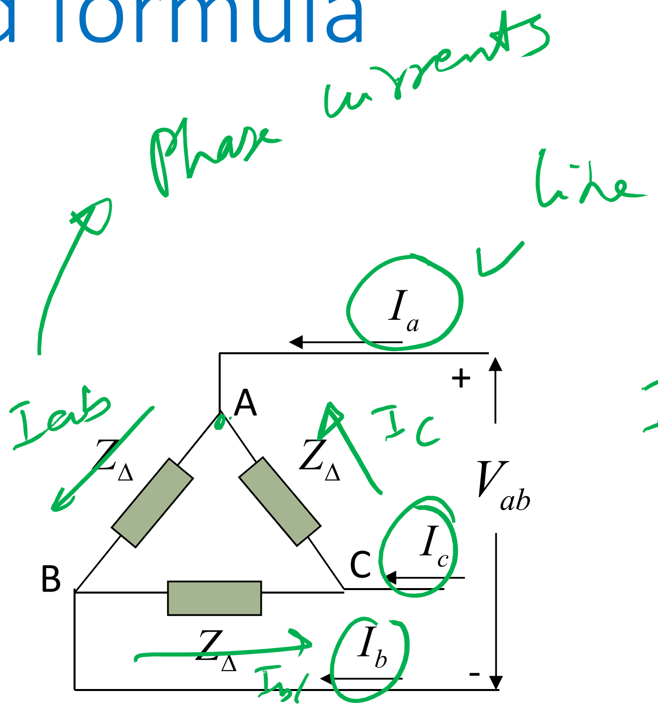


$$\left|V_{\text{Line-Line}}\right| = \sqrt{3}\left|V_{\text{Line-neutral}}\right|$$

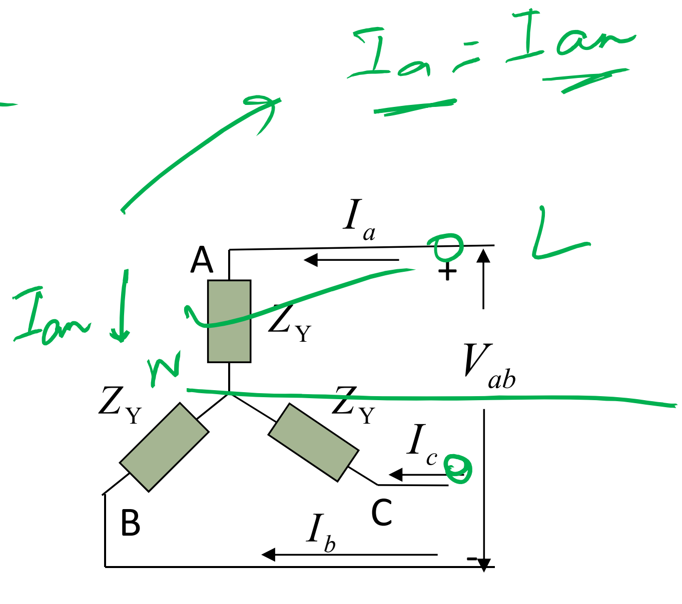
$V_{ab} = V_{an} - V_{bn}$

Key concepts and formula

- Balanced three phase load can be connected as Wye or Delta
- We can convert a Wye connected to equivalent Delta connected load
  - $Z_{\Delta} = 3\, Z_Y$
- We can convert a Delta connected to equivalent Wye connected load
  - $Z_Y = \frac{z_{\Delta}}{3}$



Delta connection



Wye (Star) connection

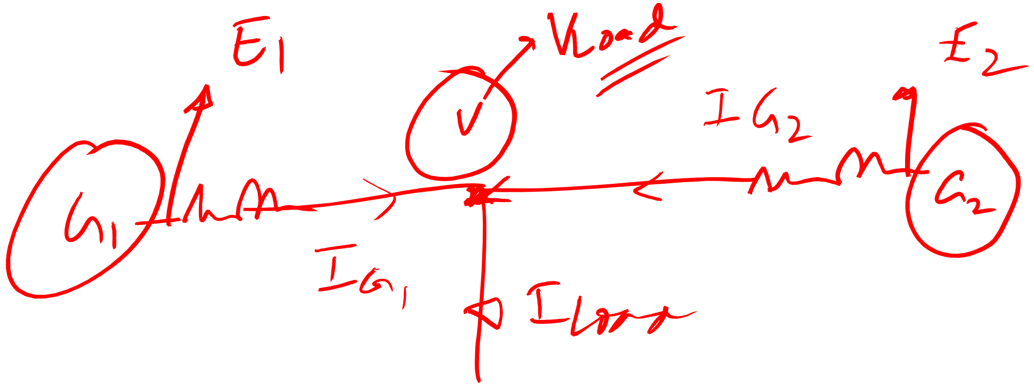
Key concepts and formula

$\sqrt{3}$, V, I

- Balanced three-phase power $s_{3\emptyset} = 3V_{an}I_{an}^{*} = \sqrt{3}V_{line-to-line}I_{line}$
- Balanced three-phase power transfer to load constant

Ask me anything

- Consultation session before midterm



$$S_{G_2} = V \cdot (I_{G_2})^*$$
$$= P_{G_2} + j\, Q_{G_2}$$