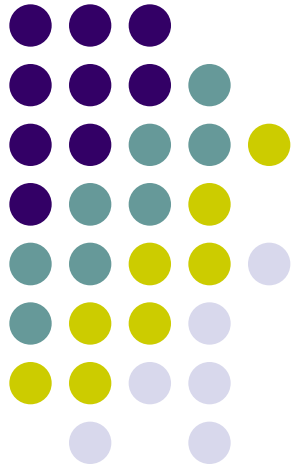
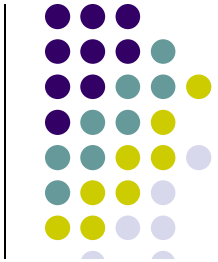
Review of 3-Phase AC Circuits

EE 340

Y. Baghzouz

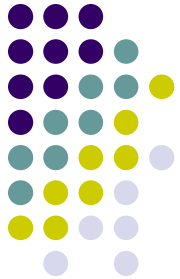


Advantages of 3-Phase Systems



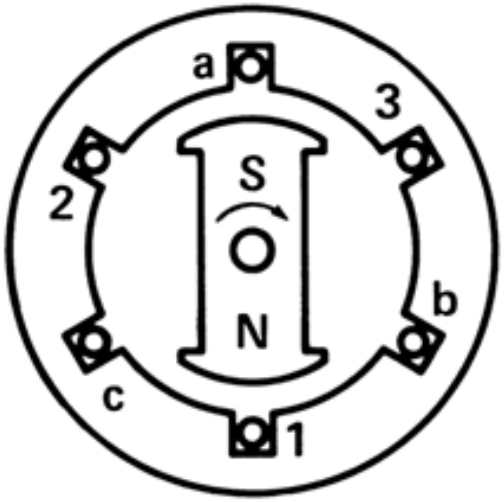
- Can transmit more power for same amount of wire (twice as much as single phase)
- Torque produced by 3ϕ machines is constant
- Three phase machines use less material for same power rating
- Three phase machines start more easily than single phase machines

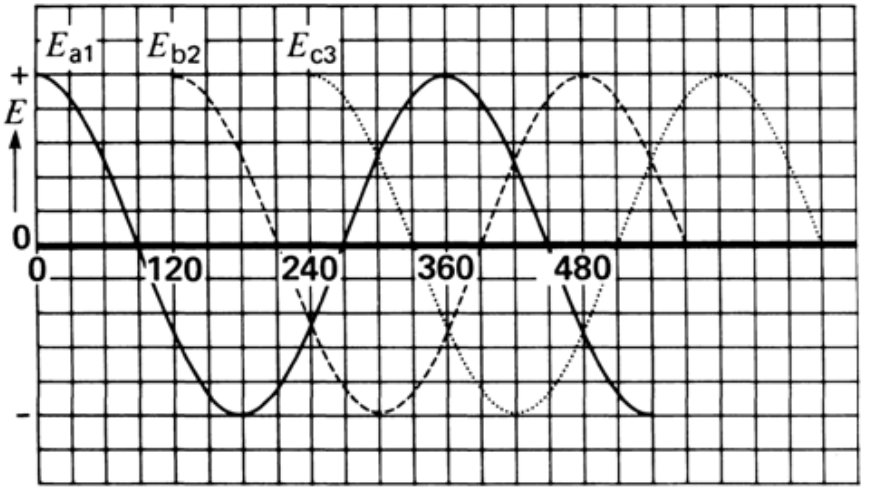
Balanced 3-Phase Systems

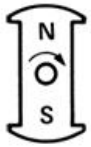


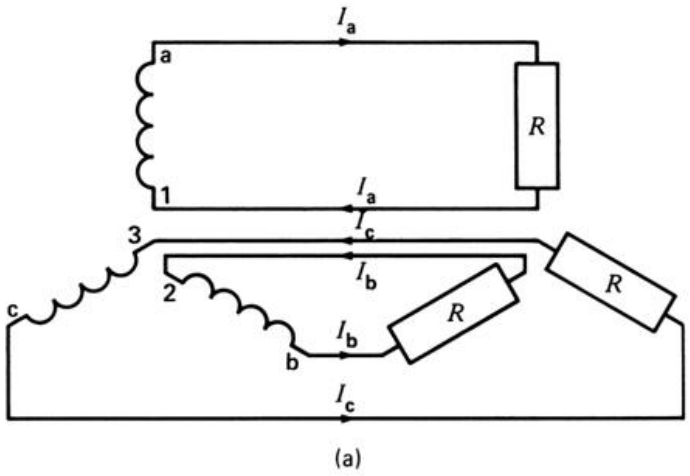
- A balanced 3 phase (ϕ) system has
  - three voltage sources with equal magnitude, but with an angle shift of 120°
  - equal loads on each phase
  - equal impedance on the lines connecting the generators to the loads
- Bulk power systems are almost exclusively 3ϕ
- Single phase is used primarily only in low voltage, low power settings, such as residential and some commercial

3-Phase Voltage Source

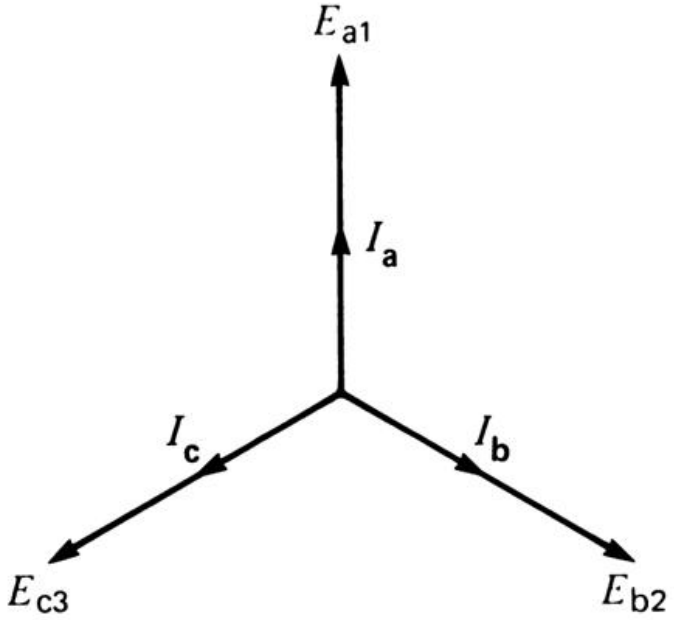




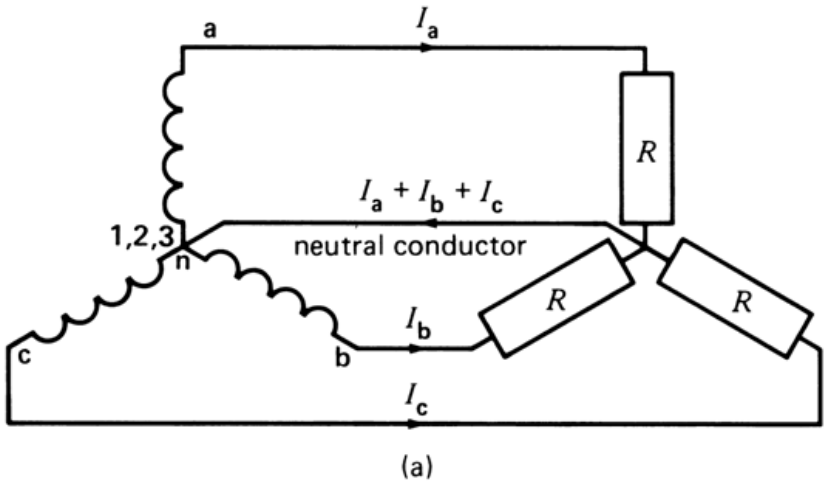




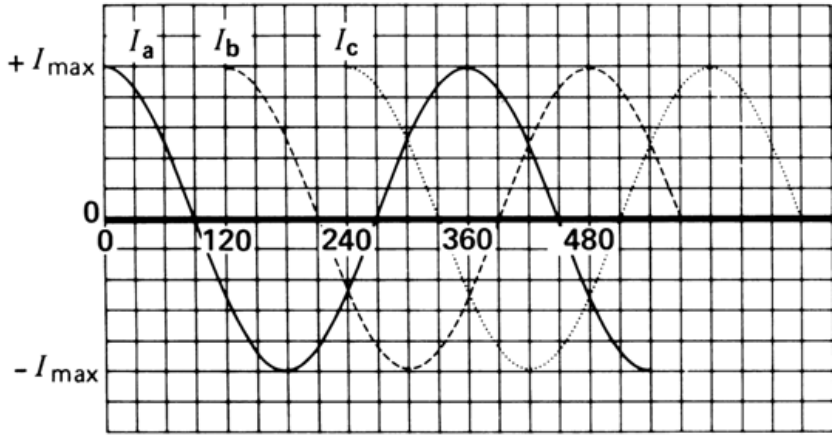
(a)



Neutral Wire Sharing

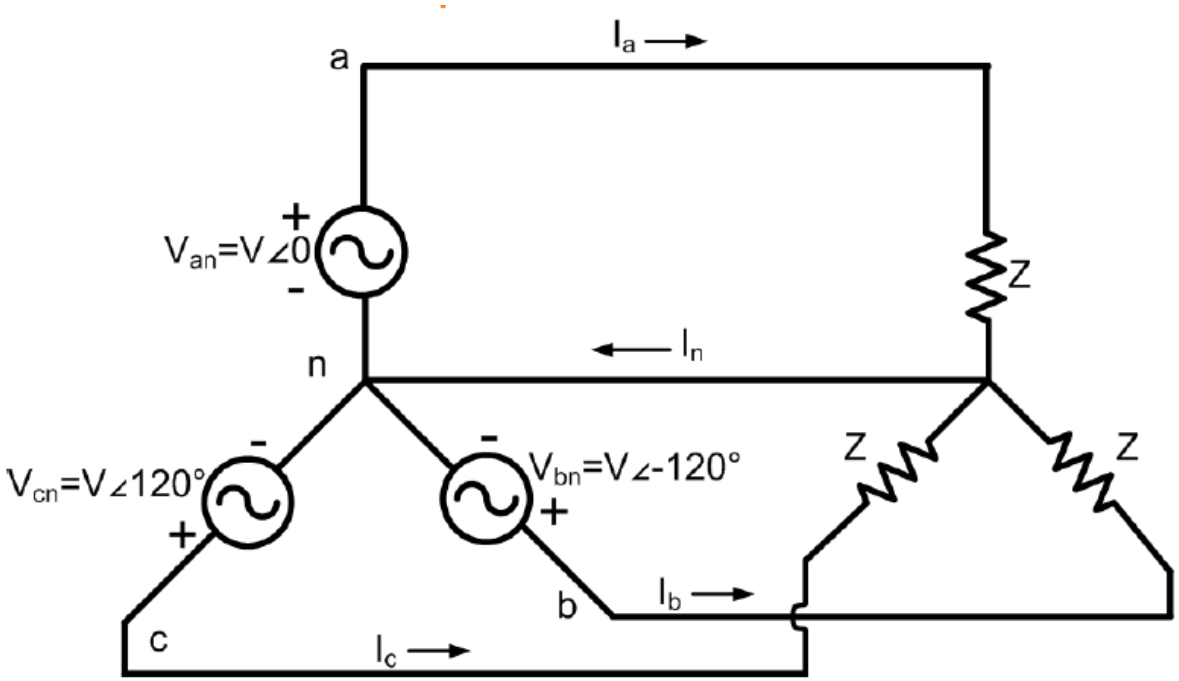


(a)



(b)

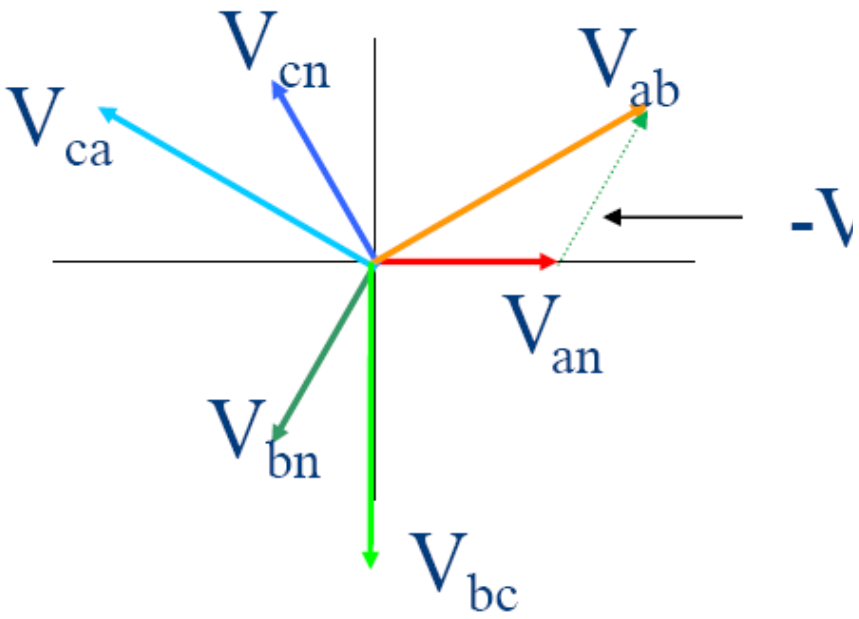
Neutral Current



$$I_n = I_a + I_b + I_c$$

$$I_n = \frac{V}{Z}(1\angle 0° + 1\angle -120° + 1\angle 120°) = 0$$

Phase and Line Voltages



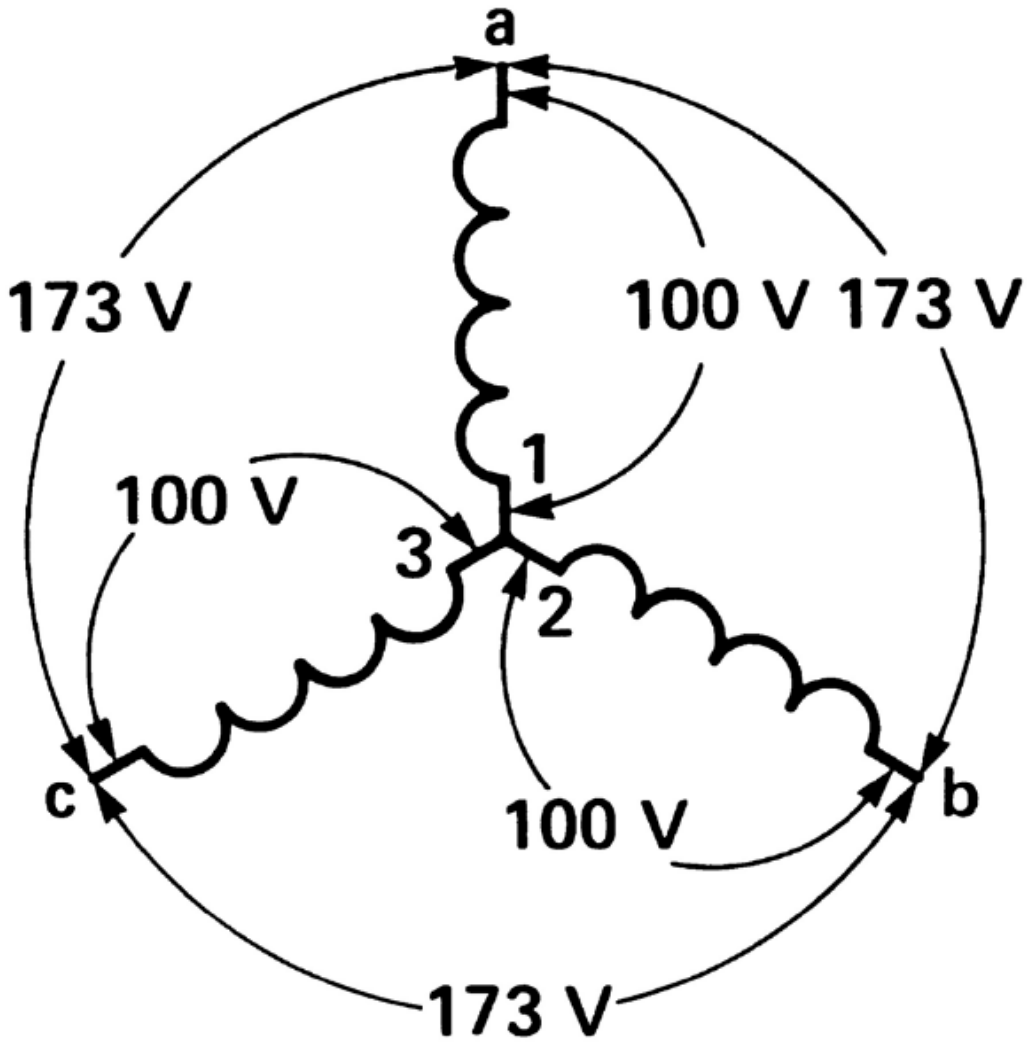
$$V_{an} = |V| \angle \alpha^\circ$$
$$V_{bn} = |V| \angle \alpha^\circ - 120^\circ$$
$$V_{cn} = |V| \angle \alpha^\circ + 120^\circ$$

($\alpha = 0$ in this case)

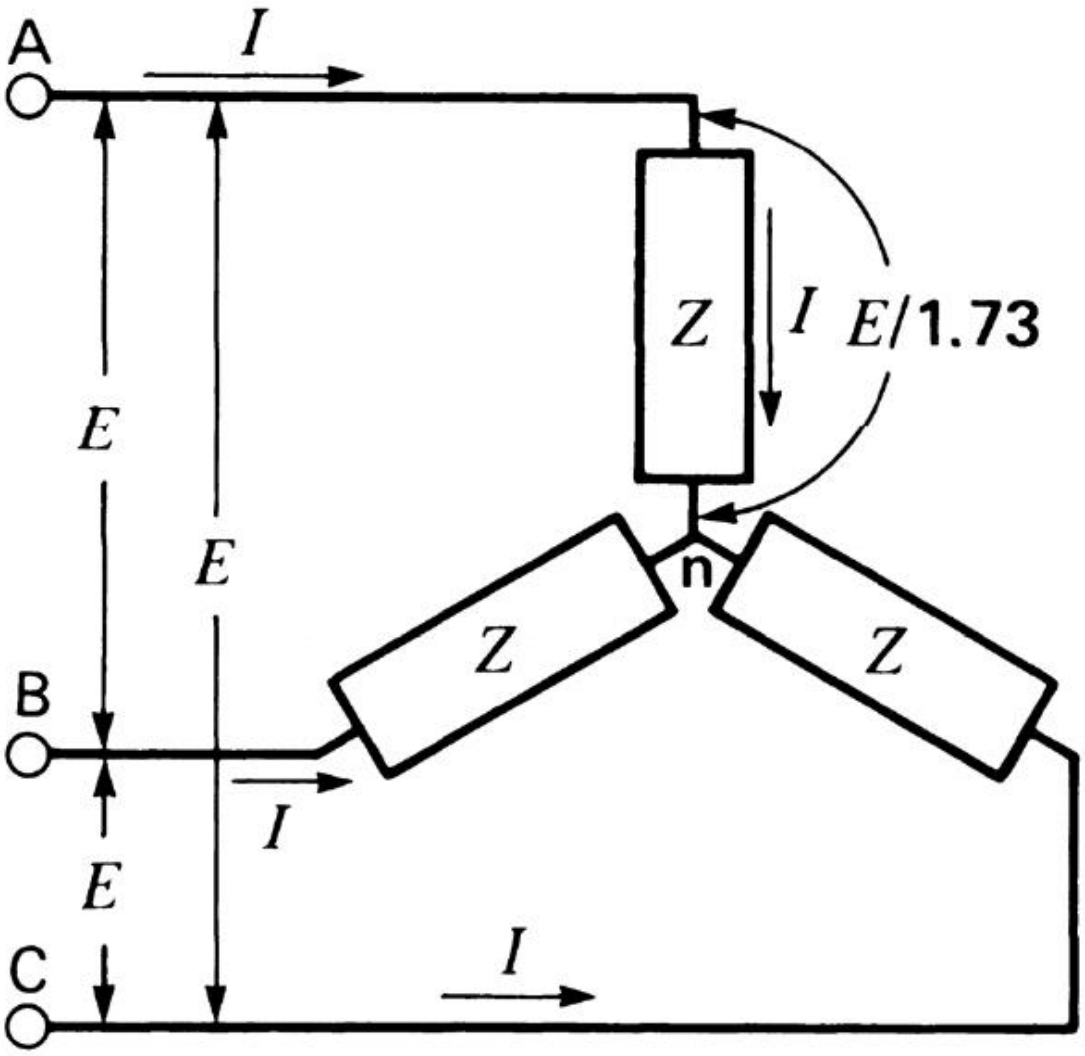
$$V_{ab} = V_{an} - V_{bn} = |V|(1\angle\alpha - 1\angle\alpha + 120^\circ)$$
$$= \sqrt{3}\,|V| \angle \alpha + 30^\circ$$
$$V_{bc} = \sqrt{3}\,|V| \angle \alpha - 90^\circ$$
$$V_{ca} = \sqrt{3}\,|V| \angle \alpha + 150^\circ$$

Line to line voltages are also balanced

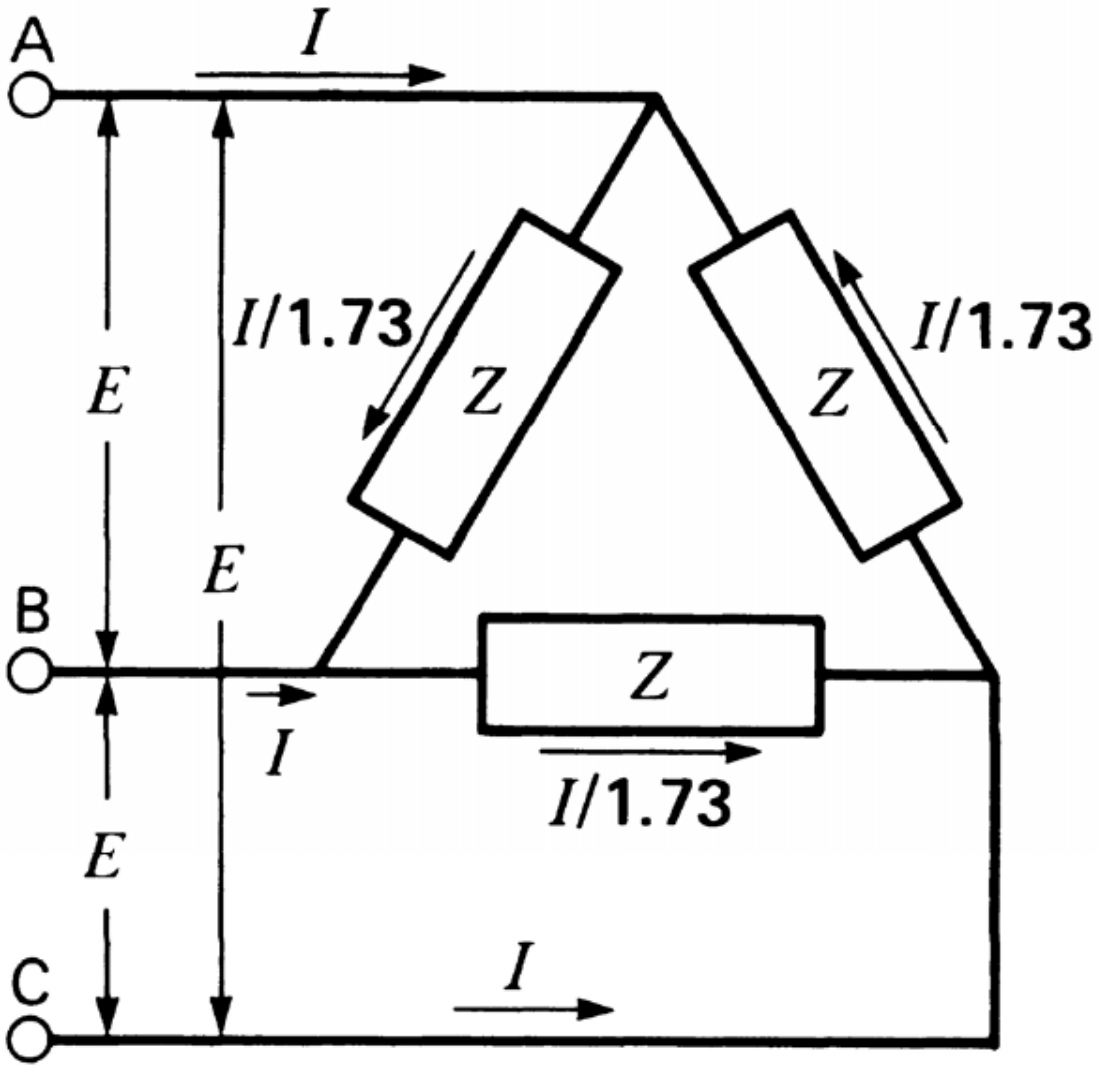
Example of Phase and Line Voltages



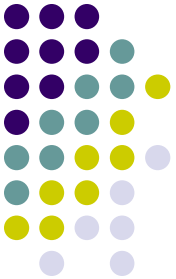
Y-Connected Load



Δ-Connected Load



Power in Balanced 3-Phase Circuits



- The real power, reactive power, apparent power, complex power and power factor are the same in each phase.

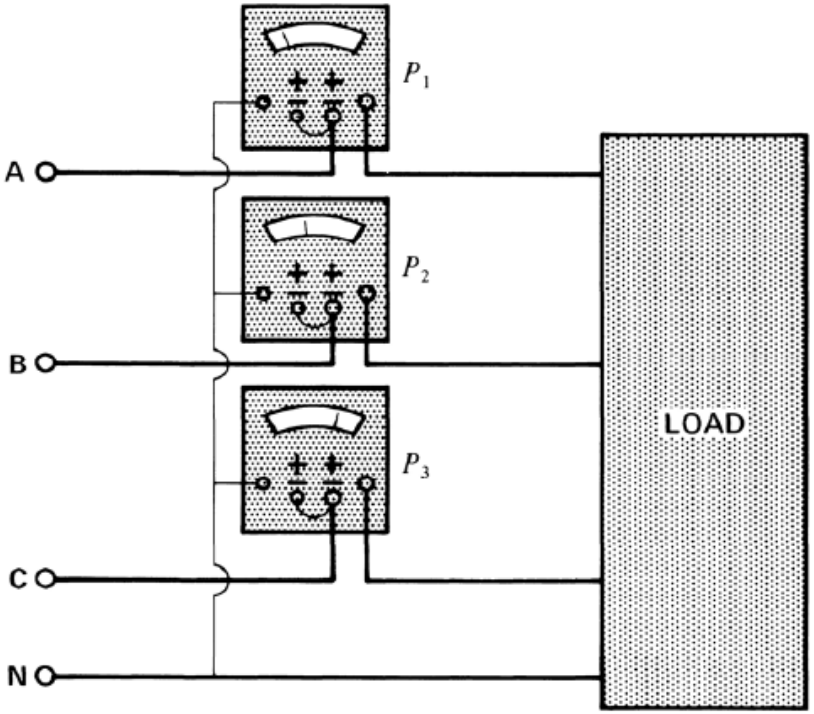
$$P = 3V_p I\cos(\theta) = \sqrt{3}V_L I\cos(\theta)$$

$$Q = 3V_p I\sin(\theta) = \sqrt{3}V_L I\sin(\theta)$$

$$S = 3V_p I = \sqrt{3}V_L$$

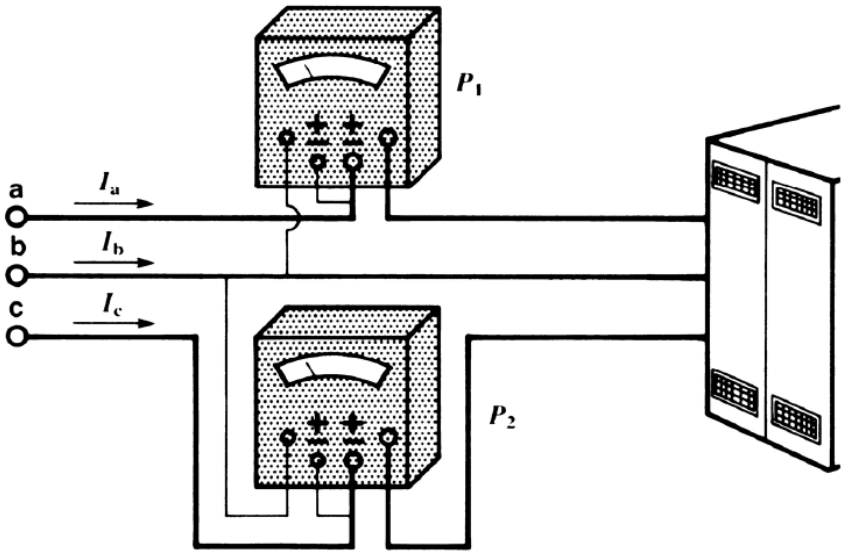
Power measurement in 3-phase 4-wire circuit

- If the load is balanced, then $P_1 = P_2 = P_3$, hence, $P_T = 3P_1$
- If the load is unbalanced, $P_1 \neq P_2 \neq P_3$, hence, $P_T = P_1 + P_2 + P_3$

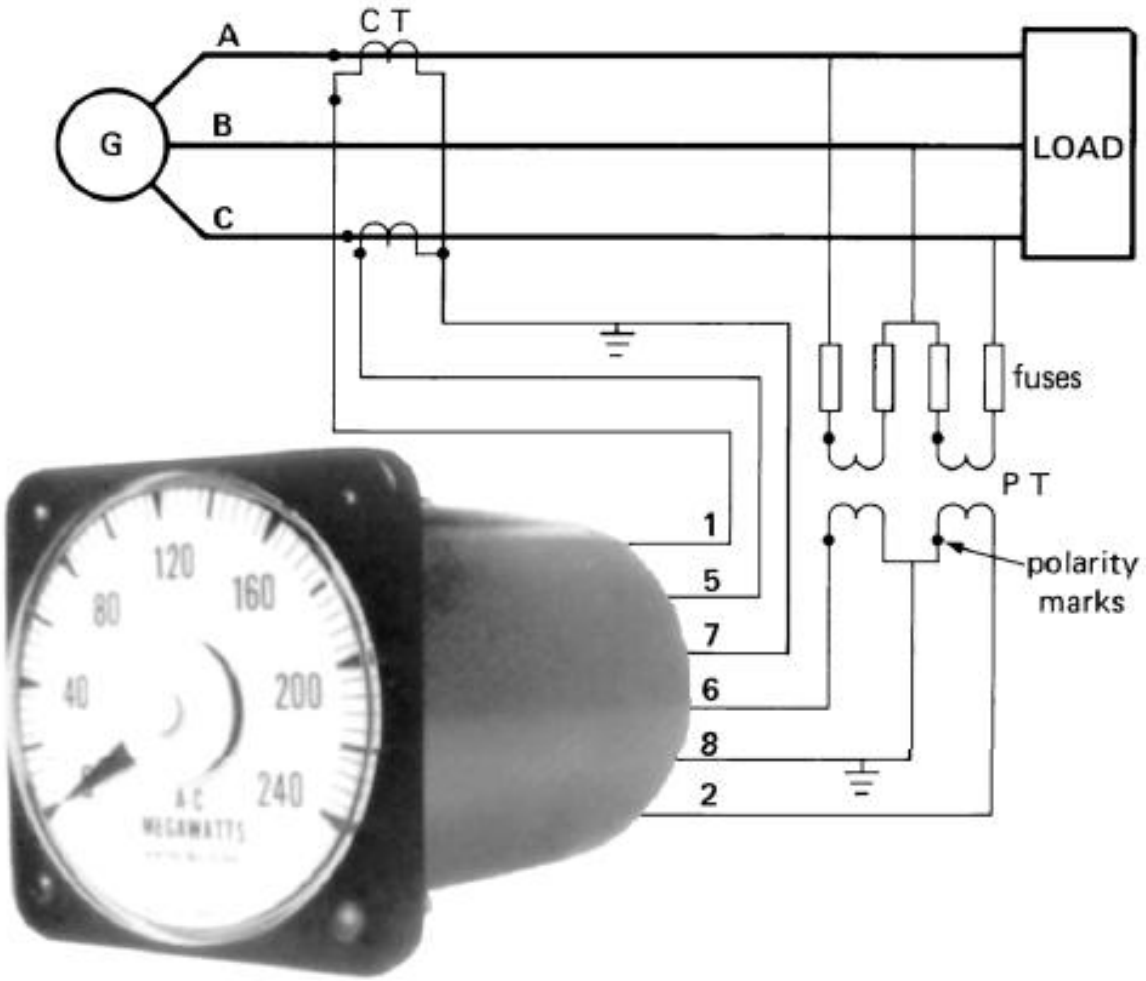


Power measurement in 3-phase 3-wire circuit: the 2-wattmeter method

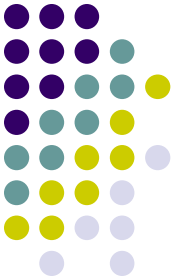
- $P_T = P_1 + P_2$
- The load can be Y-connected, Δ-connected, balanced, or unbalanced.
- Any one of the 3 phases can be used as a reference.
- If the load is balanced, then $P_1 = P_2$, hence, $P_T = 2P_1$



Measuring active power in a high power circuit



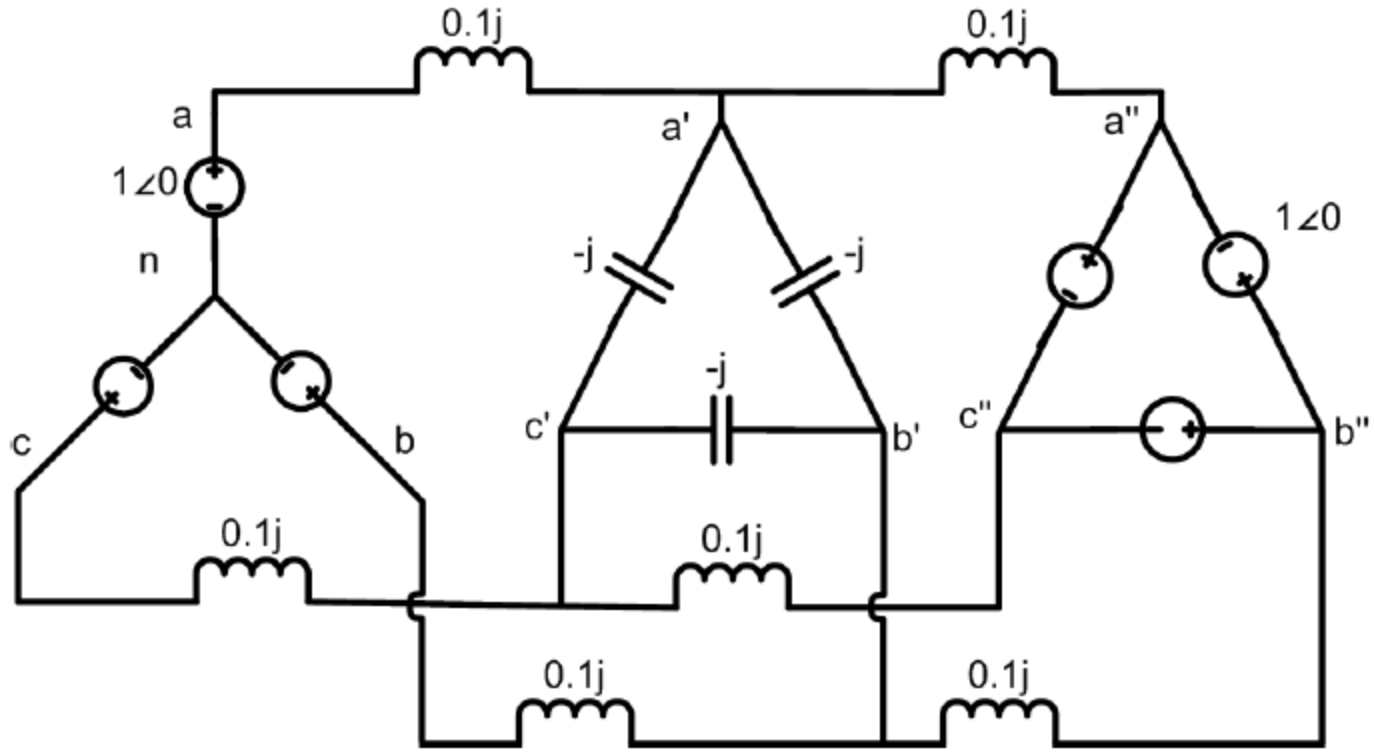
Per-Phase Analysis in Balanced 3-Phase Circuits



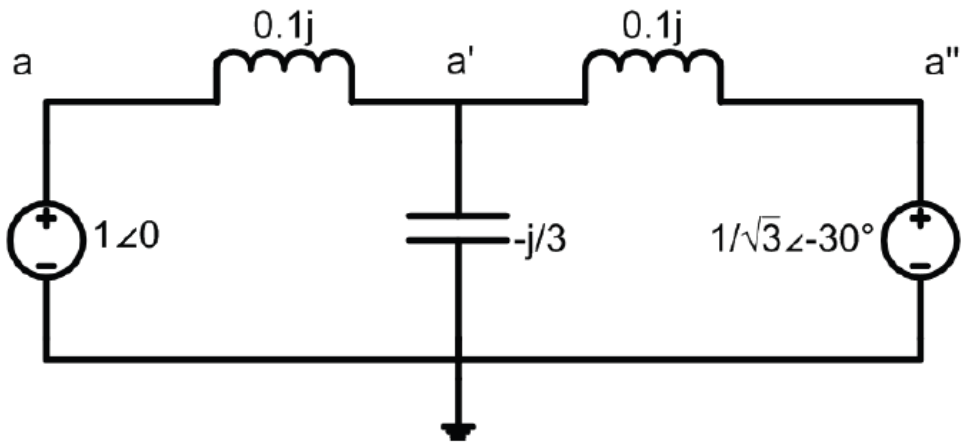
- Per phase analysis allows analysis of balanced 3ϕ systems with the same effort as for a single phase system
- **To do per phase analysis**
  1. Convert all 3ϕ load/sources to equivalent Y's
  2. Solve phase "a" independent of the other phases
  3. Total system power $S = 3\ V_a\ I_a^*$
  4. If desired, phase "b" and "c" values can be determined by inspection (i.e., ±120° degree phase shifts)
  5. If necessary, go back to original circuit to determine line-line values or internal 3ϕ values.

Example of per-phase analysis

- Find the complex power supplied by each of the two sources.



Solution



To solve the circuit, write the KCL equation at a'

$$(V_a' - 1\angle 0)(-10j) + V_a'(3j) + (V_a' - \frac{1}{\sqrt{3}}\angle -30°)(-10j) = 0$$

$$(10j + \frac{10}{\sqrt{3}}\angle 60°) = V_a'(10j - 3j + 10j)$$

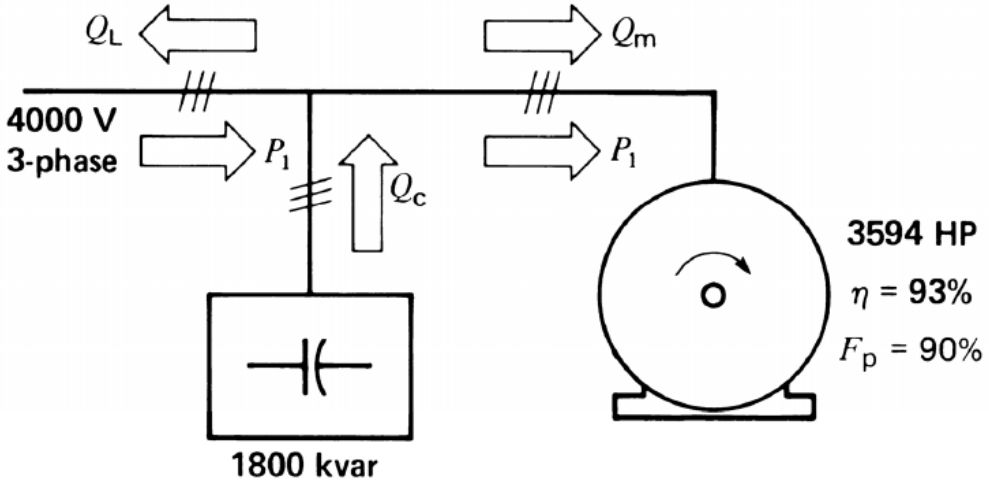
$V_a' = 0.9\angle -10.9°$ volts $\quad V_b' = 0.9\angle -130.9°$ volts

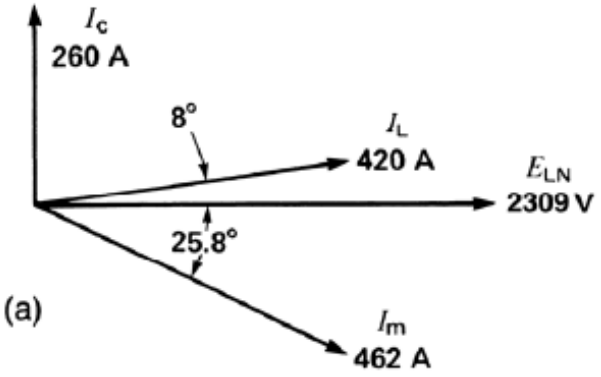
$V_c' = 0.9\angle 109.1°$ volts $\quad V_{ab}' = 1.56\angle 19.1°$ volts

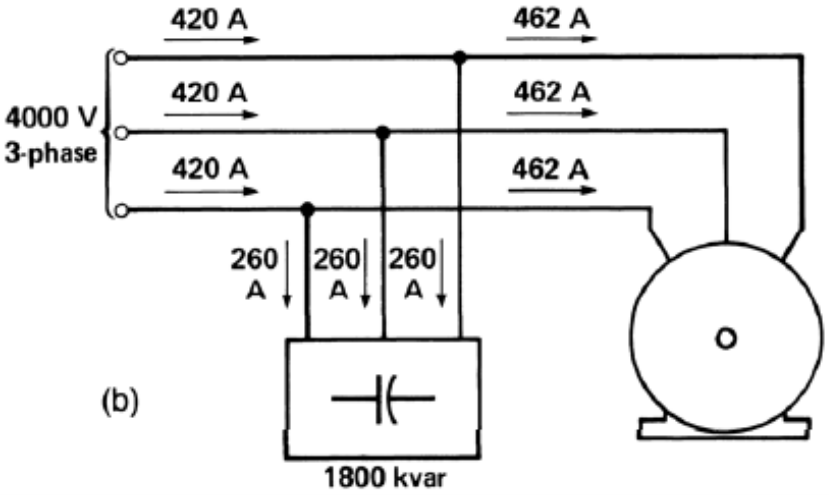
$$S_{Ygen} = 3V_a I_a^* = V_a\left(\frac{V_a - V_a'}{j0.1}\right)^* = 5.1 + j3.5 \text{ VA}$$

$$S_{\Delta gen} = 3V_a''\left(\frac{V_a'' - V_a'}{j0.1}\right)^* = -5.1 - j4.7 \text{ VA}$$

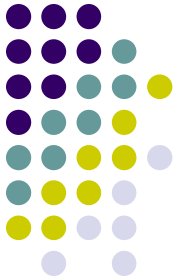
Example of 3-phase balanced circuit







Problems from Chap 2:



1, 2, 3, 4, 5, 6.