5.0 THREE PHASE SYSTEM

ET 201

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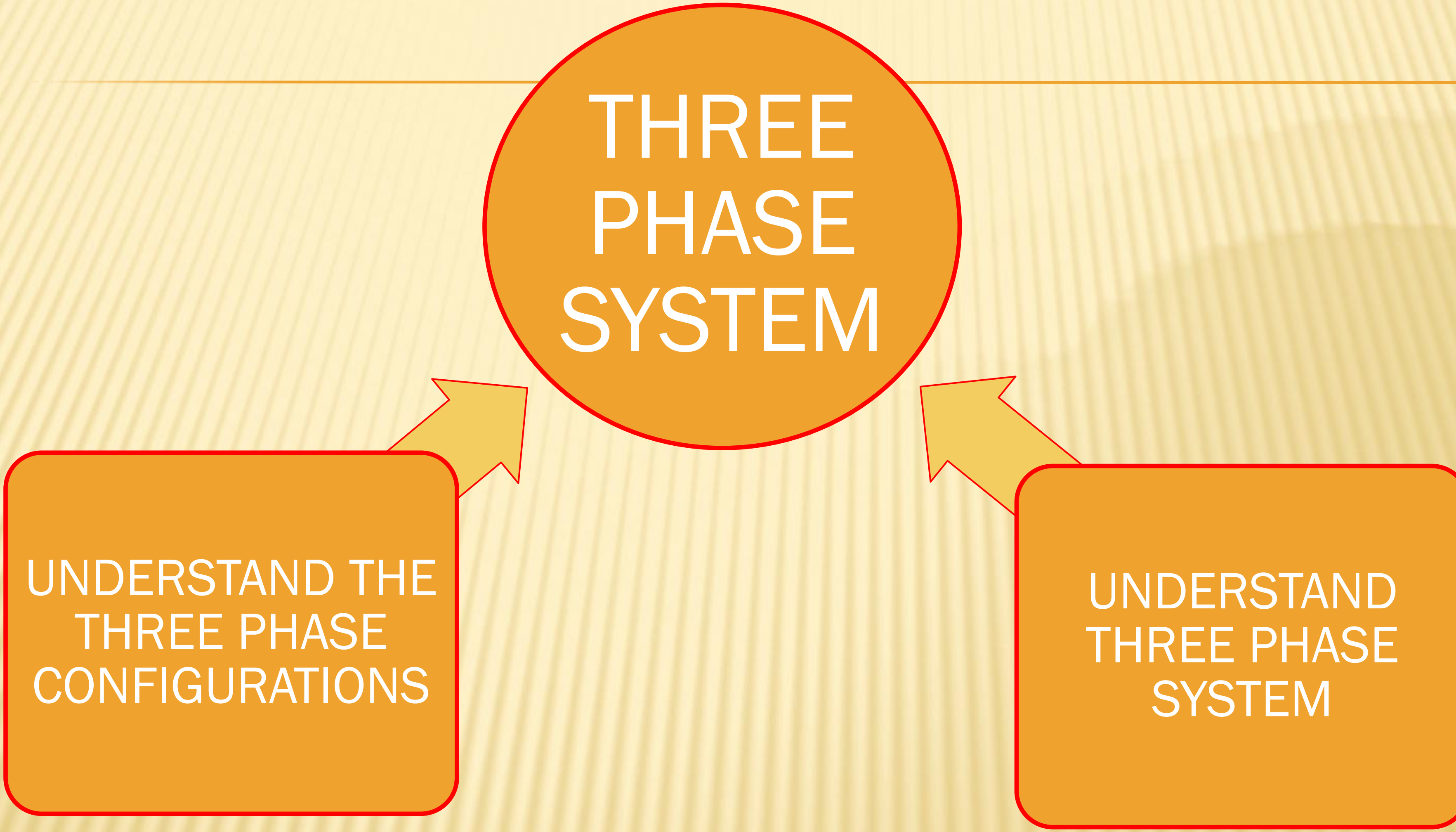
COURSE LEARNING OUTCOME

1. Explain AC circuit concept and their analysis using AC circuit law.
2. Apply the knowledge of AC circuit in solving problem related to AC electrical circuit.

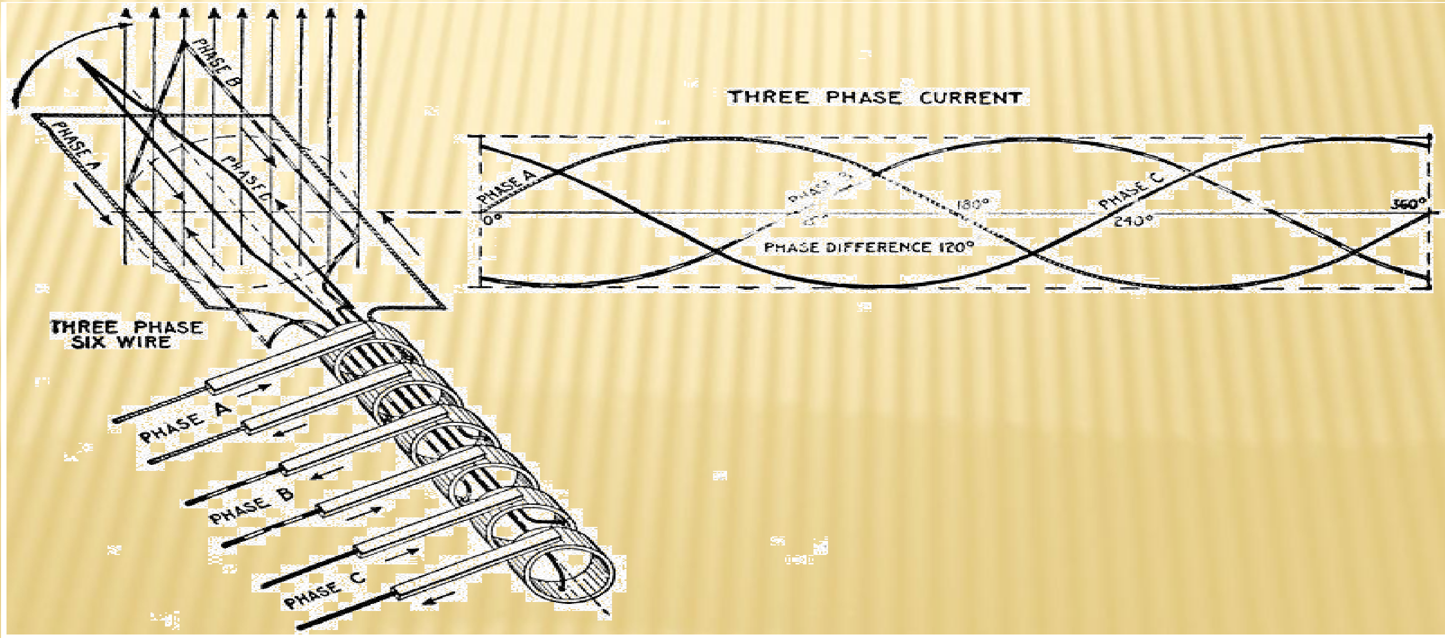

THREE PHASE SYSTEM
UNDERSTAND THE THREE PHASE CONFIGURATIONS
UNDERSTAND THREE PHASE SYSTEM

5.1 UNDERSTAND THREE PHASE SYSTEM

5.1.1 EXPLAIN THE BASIC PRINCIPLES OF A THREE PHASE SYSTEM

- 3 phase supply is generated when 3 coils are placed 120° apart and the whole rotated in a uniform magnetic field.

- The result is three independence supplies of equal voltages which are each displaced by 120°.



- The convention adopted to identify each of the phase voltages is :

  R-red, Y-yellow and B-blue.

- The phase sequence is given by the sequence in which the conductors pass the point initially taken by the red conductor.

- The national standard phase sequence is R,Y,B.

- 2 ways to interconnect the three phases:

  (a) Star connection

  (b) Delta connection

5.2 UNDERSTAND THREE PHASE SYSTEM CONFIGURATIONS

5.2.1 LIST THE ADVANTAGES AND APPLICATION OF THREE PHASE SYSTEM COMPARED TO SINGLE PHASE SYSTEM

APPLICATIONS:

- Two voltage are available (star & delta connection):

  (a) Star connection: domestic user

  (b) Delta connection: industrials user

ADVANTAGES:

CRITERIA	3 PHASE	SINGLE PHASE
COST- Cheap	The size of conductor in 3 phase is **75%** only the size of conductors in a single phase with the same rating of power.	For a given amount of power transmitted through a system, the single phase system requires conductors with a **bigger cross sectional area.**
	Three phase system requires conductors with **a smaller cross sectional area.** This means a saving of copper (or aluminum) and thus the original installation **costs are less.**	This means use more copper so the **cost will increase.**
POWER RANGE & SIZE	Also **available in a range of sizes** (1horse-power to many thousands of horse-power) and they usually have only one moving part. Generally smaller	A single phase motor **power is limited.** Bigger size,

ADVANTAGES:

CRITERIA	3 PHASE	SINGLE PHASE
POWER	There is never a time when all the voltage go to 0, the power stays constant throughout the whole cycle. This give the **vibration free drive.**	Voltage drops to 0 every half-cycle. Therefore the amount of power not constant over time. This will **cause a vibration** in a large motor application.
MAINTENANCE	Three phase motors are very robust, relatively **cheap,** provide steadier output and require little maintenance compared with single phase motors.	**Expensive**, unsteady output and need high maintenance.
SELF-STARTING	Three phase motors can have a **high starting torque** and the rotating magnetic field in very smooth.	Do **not have good starting torque** and they have a complex starting switch in some cases.

5.2.2 EXPLAIN THE THREE PHASE E.M.F GENERATION

- Three-phase generators have three coils fixed at 120° to each other with the same amplitude and frequency.

- The phases are normally called red (R), yellow (Y) and blue (B).

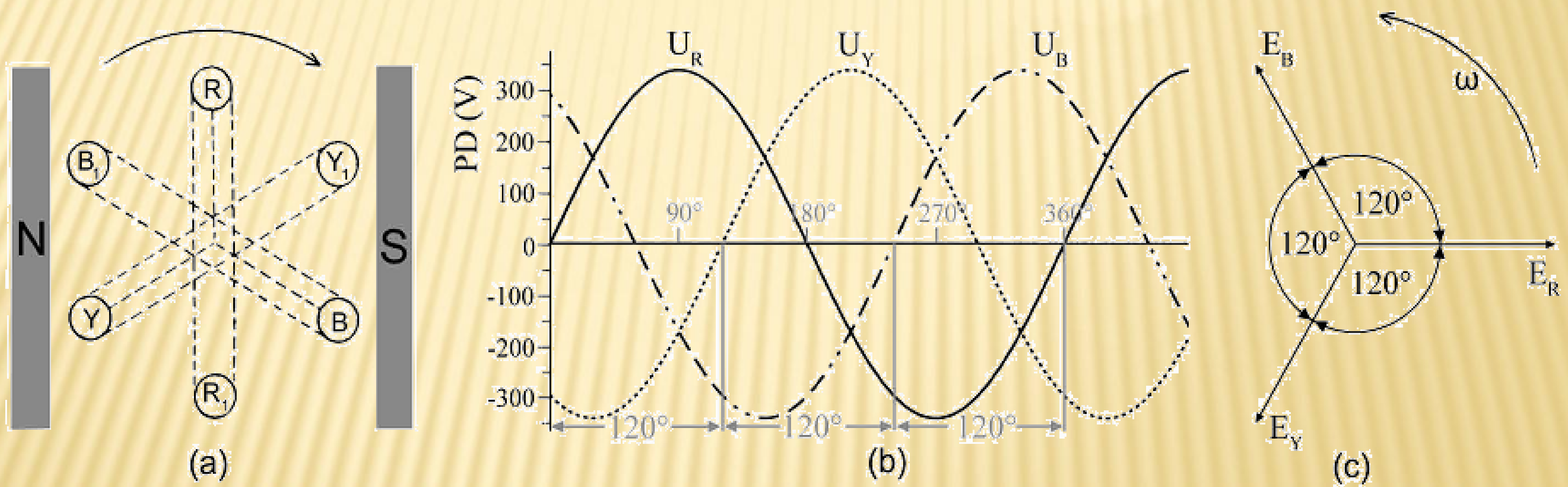


Figure 14.1: A three-phase AC supply with 240V RMS generated in each coil: (a) generation; (b) wave diagram; (c) phasor diagram.

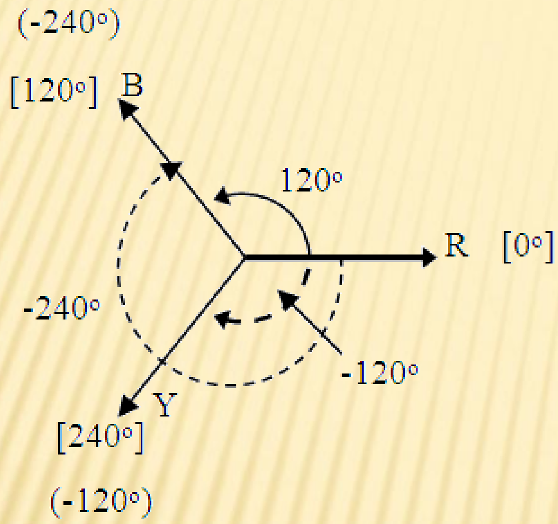
- The loops are being rotated anti-clockwise and each loop is producing exactly the same emf with the same amplitude and frequency but the loop Y Lags loop R by 120^0 and the loop B lags loop Y by 120^0.

- This is the same for the associated loop Y_1, B_1, and R_1 . At any moment the e.m.f generated in the three loops are as follows .

- $e_R = E_m \sin(\theta)$
  $e_Y = E_m \sin(\theta - 120^0)$
  $e_B = E_m \sin(\theta - 240^0)$

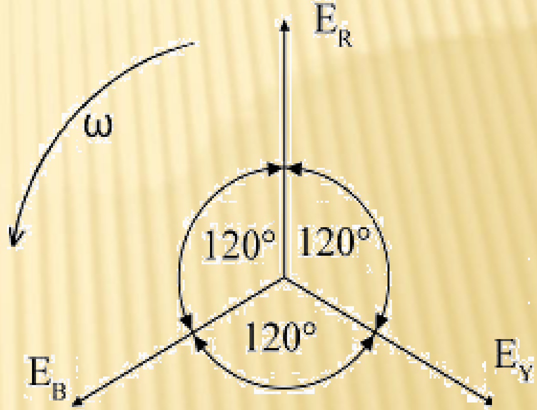
– 2 ways to generate 3 phase:
- Rotate the coil in the constant magnetic field.
- Rotate the magnetic field around the static coils.

Three phase e.m.f vector diagram (geometry)



- Select 1 phase as reference.
- Show the concept of leading & lagging.

Three phase e.m.f vector diagram (conversional)

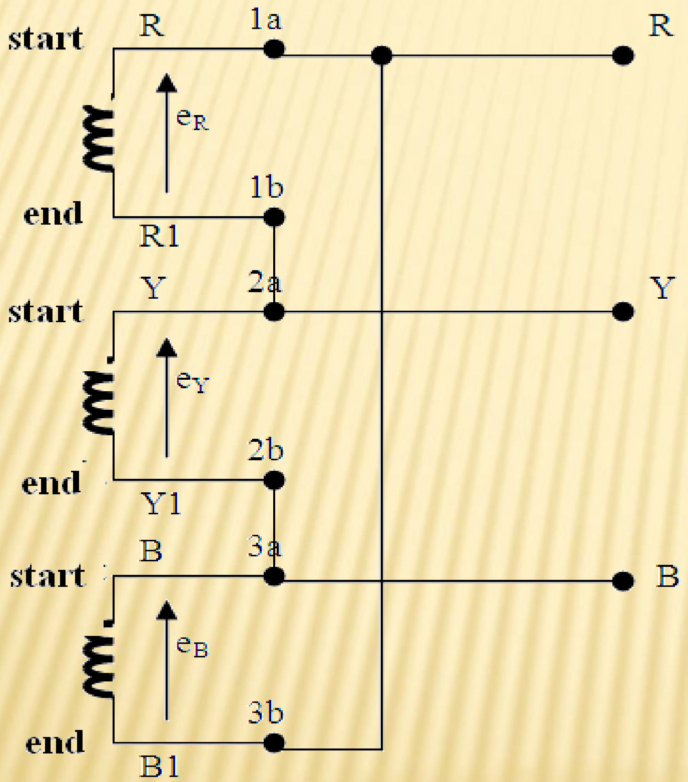


- Show that each phase have difference 120°.

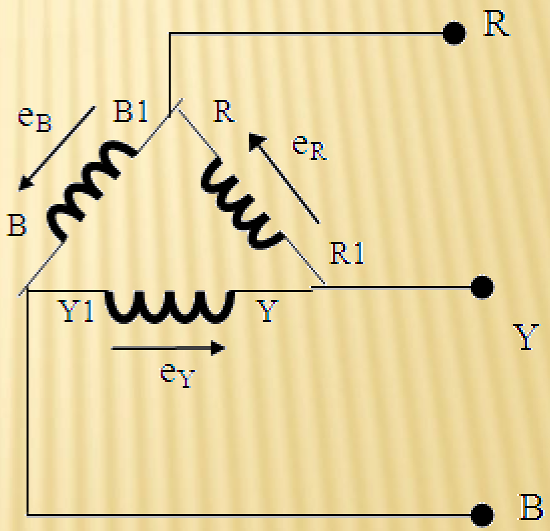
5.2.3 IDENTIFY CONNECTION AND VECTOR/PHASE DIAGRAM FOR:

(a) Delta system

Connection diagram

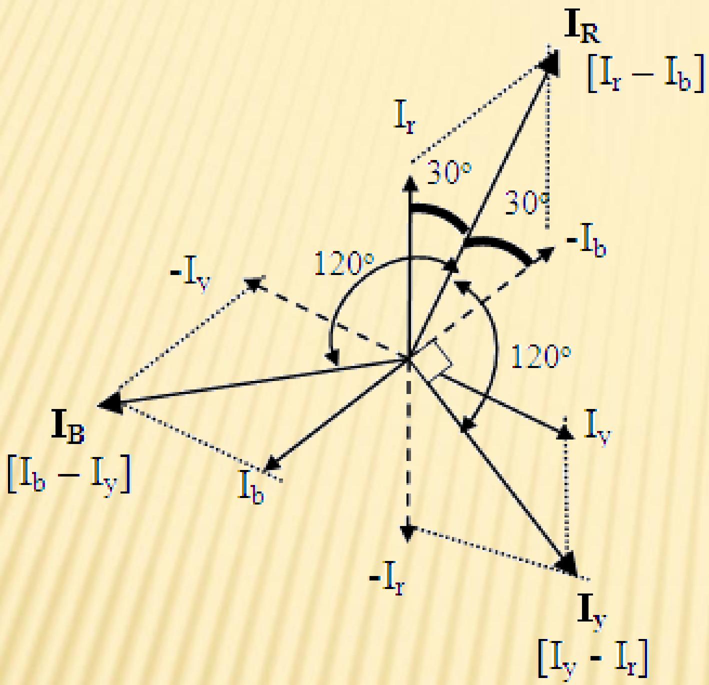


Physical connection



Conversional connection

Vector diagram



Persamaan vector:

$\vec{I_R} = \vec{I_r} - \vec{I_b}$

$\vec{I_Y} = \vec{I_y} - \vec{I_r}$

$\vec{I_B} = \vec{I_b} - \vec{I_y}$

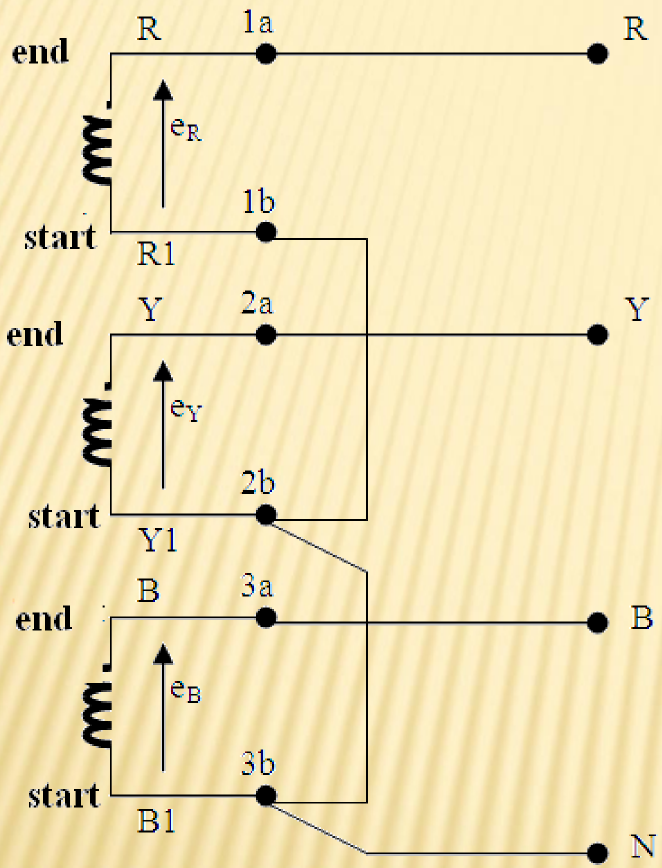
$\overrightarrow{\mathbf{I_R}} = \overrightarrow{\mathbf{I_r}} - \overrightarrow{\mathbf{I_b}}$ (Arus talian R disumbangkan oleh arus fasa *R* dan *B*)

$\overrightarrow{\mathbf{I_Y}} = \overrightarrow{\mathbf{I_y}} - \overrightarrow{\mathbf{I_r}}$ (Arus talian Y disumbangkan oleh arus fasa *Y* dan *R*)

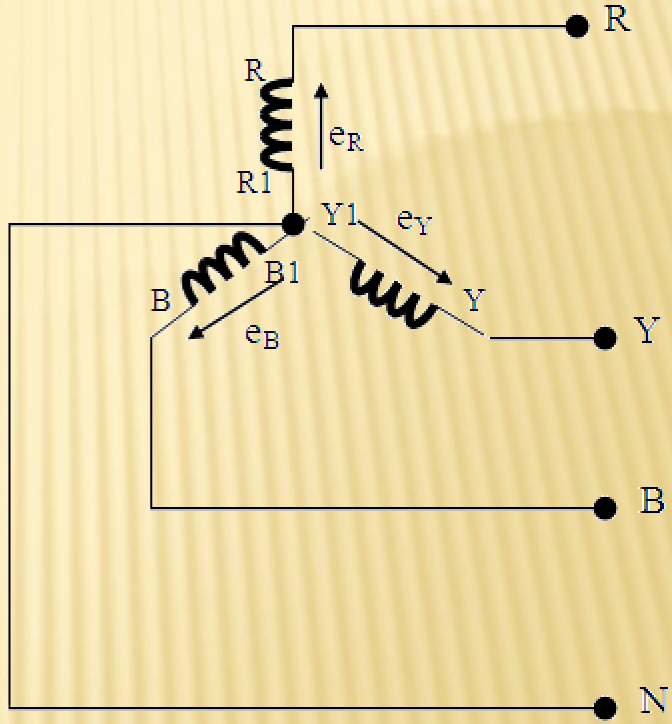
$\overrightarrow{\mathbf{I_B}} = \overrightarrow{\mathbf{I_b}} - \overrightarrow{\mathbf{I_y}}$ (Arus talian B disumbangkan oleh arus fasa *B* dan *Y*)

(b) Star System

<u>Connection diagram</u>

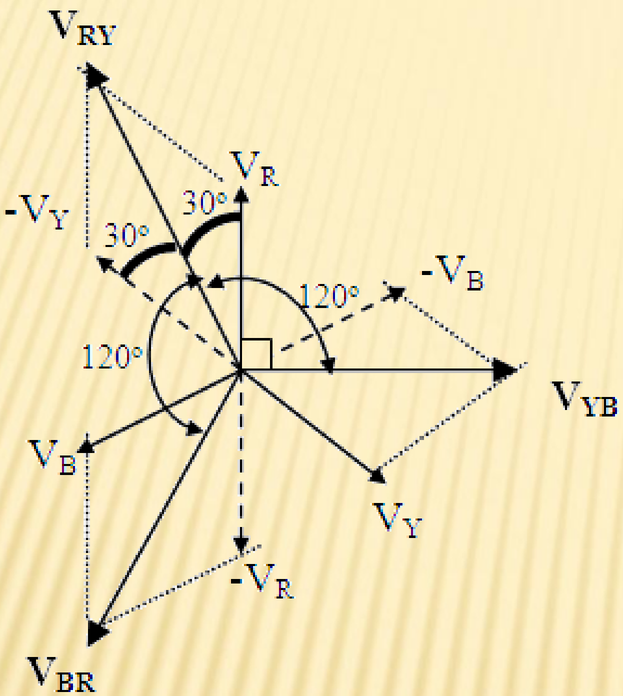


Physical connection



Conversional connection

Vector diagram



Vector equation:

$$\overrightarrow{V_{RY}} = \overrightarrow{V_R} + (\overrightarrow{-V_Y})$$

$$= \overrightarrow{V_R} - \overrightarrow{V_Y}$$

$$\overrightarrow{V_{YB}} = \overrightarrow{V_Y} - \overrightarrow{V_B}$$

$$\overrightarrow{V_{BR}} = \overrightarrow{V_B} - \overrightarrow{V_R}$$

5.2.4 DETERMINE THE PHASE VOLTAGE, PHASE CURRENT, LINE VOLTAGE AND LINE CURRENT FOR DELTA AND STAR SYSTEMS

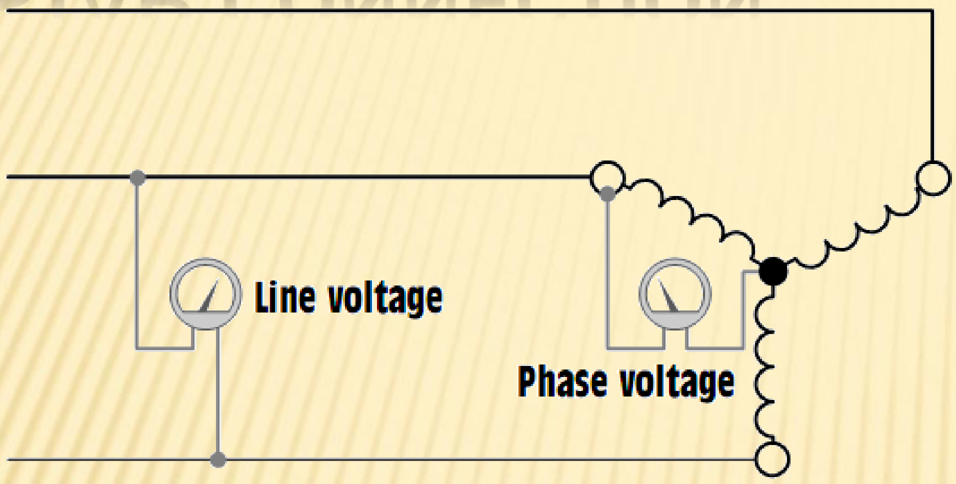
Phase voltage (Vph): Voltage induce in each coil

Phase current (Iph) : Current induce in each coil

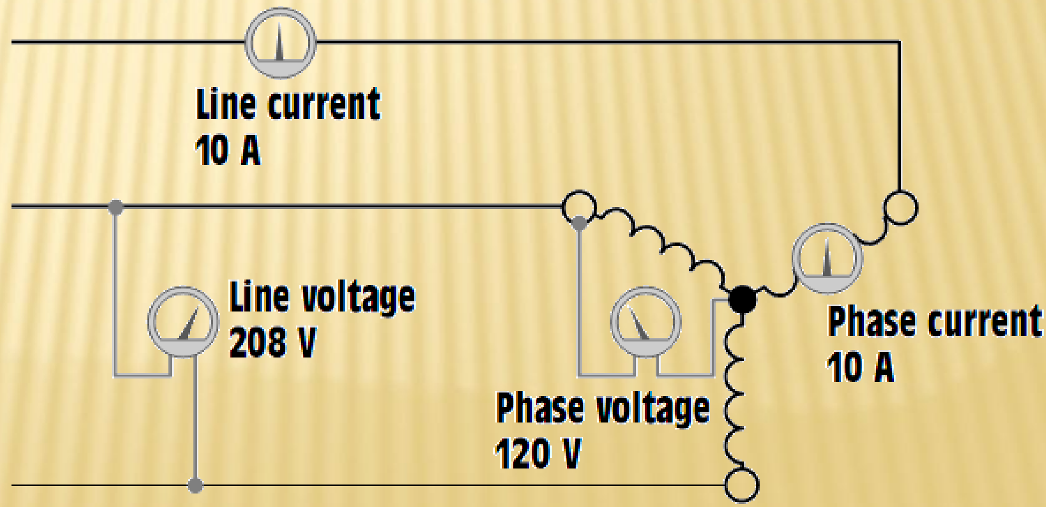
Line voltage (V_L) : Voltage across any two life terminal.

Line current (I_L) : Current across any life terminal

STAR CONNECTION

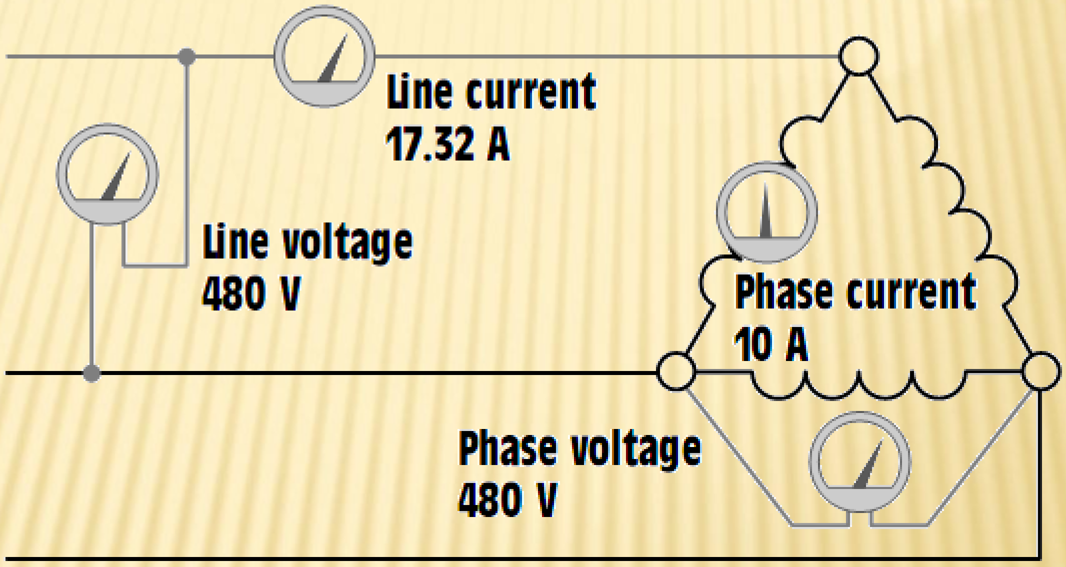


Line and phase voltages are different in a wye connection.



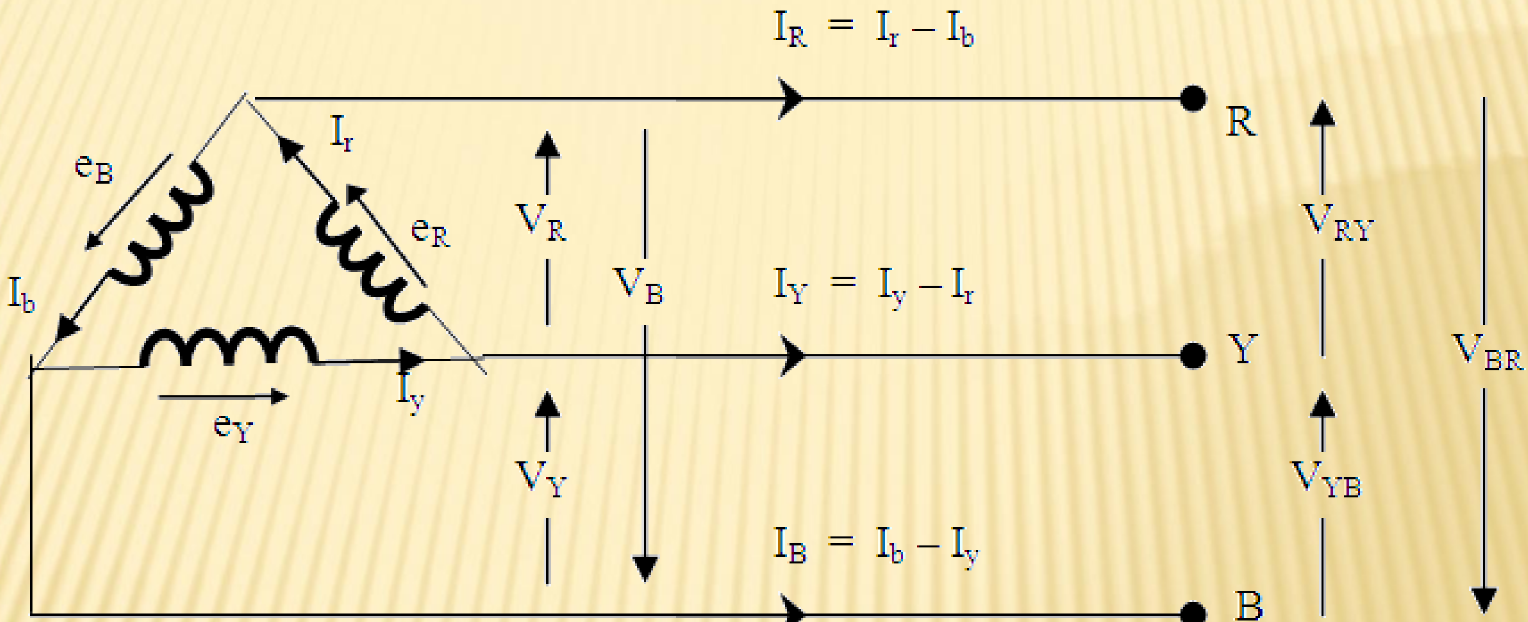
Line current and phase current are the same in a wye connection.

DELTA CONNECTION



Voltage and current relationships in a delta connection.

Delta connection:



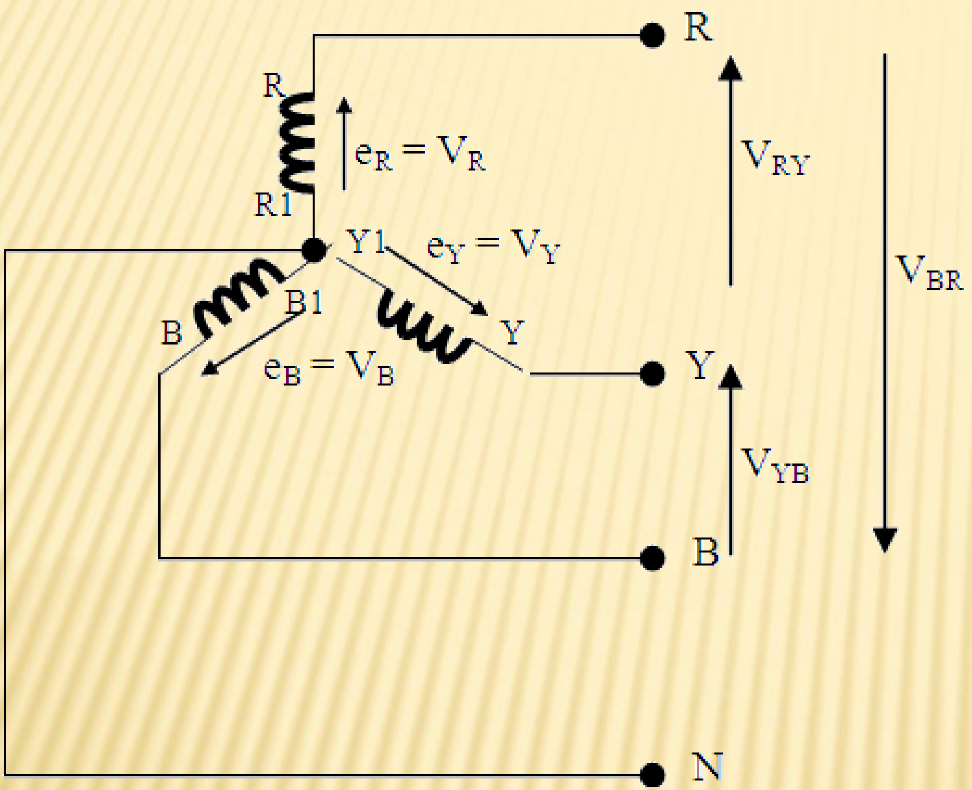
phase voltage (V_{PH}) : V_R, V_Y, V_B

phase current (I_{PH}) : I_r, I_y, I_b

Line voltage (V_L) : V_{RY}, V_{YB}, V_{BR}

Line current (I_L) : I_R, I_Y, I_B

Star connection:



Phase voltage (V_{PH}) : V_R, V_Y, V_B

or V_{RN}, V_{YN}, V_{BN}

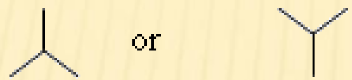
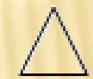
Phase current (I_{PH}) : I_r, I_y, I_b

Line voltage (V_L) : V_{RY}, V_{YB}, V_{BR}

Line current (I_L) : I_R, I_Y, I_B

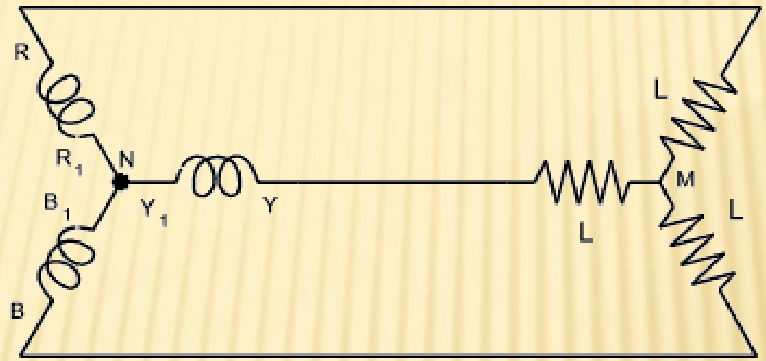
$I_N = I_R+I_Y+I_B$

(a) COMPARE THE DELTA AND STAR QUANTITIES

Quantities	Start connection	Delta connection
Symbol :		
Voltage :	$V_L = \sqrt{3}\ V_{PH}$	$V_L = V_{PH}$
Current :	$I_L = I_{PH}$	$I_L = \sqrt{3}\ I_{PH}$
Balance condition :	$I_N = I_R + I_Y + I_B = 0$	$V_{close\ circuit} = V_{RY} + V_{YB} + V_{BR} = 0$

5.2.5 DEFINE BALANCED LOAD IN A THREE PHASE SYSTEM

- Hence with balanced loads there is no load in the neutral line at any instant and the neutral line can be removed resulting in the three wire star system as shown below.



- It can be proved that at every instant, for balanced loads the algebraic sum of the currents flowing in the three conductors is zero

5.2.6 CALCULATE TOTAL POWER FOR 3 PHASE SYSTEM USING FORMULA P = $\sqrt{3} V_L I_L \cos\theta$

Single phase power	:		
Each phase	:	$V_{PH} \cdot I_{PH} \cdot \text{kos}\ \varphi$	$V_{PH} \cdot I_{PH} \cdot \text{kos}\ \varphi$
3 phase power	:		
Phase element	:	$3 \cdot V_{PH} \cdot I_{PH} \cdot \text{kos}\ \varphi$	$3 \cdot V_{PH} \cdot I_{PH} \cdot \text{kos}\ \varphi$
Line element	:	$\sqrt{3} \cdot V_L \cdot I_L \cdot \text{kos}\ \varphi$	$\sqrt{3} \cdot V_L \cdot I_L \cdot \text{kos}\ \varphi$

Real power (P) : - Also call true power
- Measure in watt (W)
- $\sqrt{3}\, V_L I_L \cos\theta = 3\, V_p I_p \cos\theta$

Reactive power (Q) : - measure in volt amperes reactive (VAR).
- $\sqrt{3}\, V_L I_L \sin\theta = 3\, V_p I_p \sin\theta$

Apparent power (S) : - measure in volt amperes (VA).
- $\sqrt{(P^2 + Q^2)} = 3\, V_p I_p$

STAR VS DELTA CONNECTION

CRITERIA	STAR CONNECTION	DELTA CONNECTION
Symbol	⅄ @ Y	△
Voltan	$V_L = \sqrt{3}\ V_{PH}$	$V_L = V_{PH}$
Current	$I_L = I_{PH}$	$I_L = \sqrt{3}\ I_{PH}$
Balance condition	$I_N = I_R + I_Y + I_B = 0$	$V_{close\ circuit} = V_{RY} + V_{YB} + V_{BR} = 0$
1 phase power in each coil	$V_{PH} . I_{PH}$. kos φ	$V_{PH} . I_{PH}$. kos φ
3 phase power: (i) Phase element: (ii) Line element:	3 .$V_{PH} . I_{PH}$. kos φ √3 .$V_L . I_L$. kos φ	3 .$V_{PH} . I_{PH}$. kos φ √3 .$V_L . I_L$. kos φ

5.2.7 SOLVE PROBLEM RELATED TO THREE PHASE SYSTEM

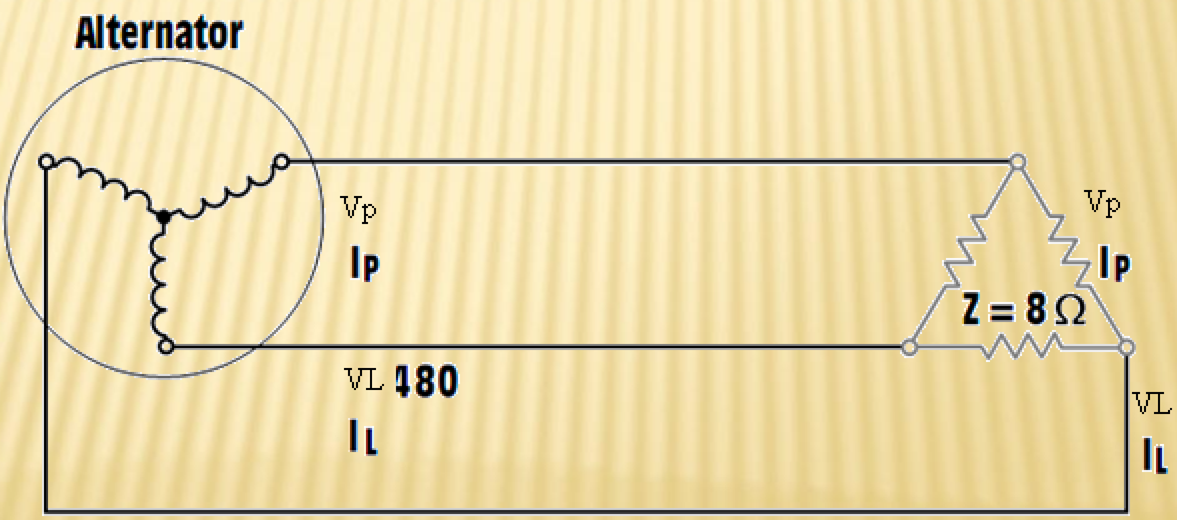
Example 1:

A wye-connected three-phase alternator supplies power to a delta-connected resistive load, Figure below. The alternator has a line voltage of 480V. Each resistor of the delta load has 8 Ω of resistance. Find the following values:

VL(Load) — line voltage of the load

VP(Load) — phase voltage of the load

IP(Load) — phase current of the load



Computing three-phase values using a wye-connected power source and a delta-connected load (Example 1 circuit).

SOLUTION:

- The load is connected directly to the alternator. Therefore, the line voltage supplied by the alternator is the line voltage of the load.

  VL(Load) = 480 V

- The three resistors of the load are connected in a delta connection. In adelta connection, the phase voltage is the same as the line voltage.

  Vp(Load) = VL(Load)

  Vp(Load) = 480 V

- Each of the three resistors in the load is one phase of the load. Now that the phase voltage is known (480 V), the amount of phase current can be computed using Ohm's Law.

$$I_{P(Load)} = \frac{V_{P(Load)}}{Z}$$

$$I_{P(Load)} = \frac{480}{8}$$

$$I_{P(Load)} = 60\ A$$

- The three load resistors are connected as a delta with 60 A of current flow in each phase. The line current supplying a delta connection must be √3 times greater than the phase current.

$$I_{L(Load)} = I_{P(Load)} \times 1.732$$

$$I_{L(Load)} = 60 \times 1.732$$

$$I_{L(Load)} = 103.92\ A$$

** note:
$\sqrt{3} = 1.732$

- The alternator must supply the line current to the load or loads to which it is connected. In this example, only one load is connected to the alternator. Therefore, the line current of the load will be the same as the line current of the alternator.

$$I_{L(Alt)} = 103.92\ A$$

- The phase windings of the alternator are connected in a wye connection. In a wye connection, the phase current and line current are equal. The phase current of the alternator will, therefore, be the same as the alternator line current.

$$I_{P(Alt)} = 103.92\ A$$

- The phase voltage of a wye connection is less than the line voltage by a factor of the square root of 3. The phase voltage of the alternator will be:

$$V_{P(Alt)} = \frac{V_{L(Alt)}}{1.732}$$

$$V_{P(Alt)} = \frac{480}{1.732}$$

$$V_{P(Alt)} = 277.13 \text{ V}$$

- In this circuit, the load is pure resistive. The voltage and current are in phase with each other, which produces a unity power factor of 1. The true power in this circuit will be computed using the formula:

$$P = 1.732 \times V_{L(Alt)} \times I_{L(Alt)} \times PF$$

$$P = 1.732 \times 480 \times 103.92 \times 1$$

$$P = 86{,}394.93 \text{ W}$$