SYLLABUS

Course Title:	**Elements of Electrical Engineering**		
Course Code:	**22EEE13/23**	CIE Marks	50
Course Type (Theory/Practical /Integrated)	Theory	SEE Marks	50
		Total Marks	100
Teaching Hours/Week (L:T:P: S)	2:2:0:0	Exam Hours	03
Total Hours of Pedagogy	40 hours	Credits	03

Course objectives

- To explain the basic laws used in the analysis of DC circuits, electromagnetism.
- To explain the behavior of circuit elements in single-phase circuits.
- To explain three phase circuits, balanced loads and measurement of three phase power.
- To explain the measuring techniques, measuring instruments and domestic wiring.
- To explain electricity billing, equipment and personal safety measures.

Teaching-Learning Process

These are sample Strategies, which teacher can use to accelerate the attainment of the various course outcomes and make Teaching -Learning more effective

1. Chalk and talk 2. Animated/NPTEL videos 3. Cut sections 4. PPTs

Module-1 (08 Hrs)

DC circuits: Ohm's law and Kirchhoff's laws, analysis of series, parallel and series-parallel circuits. Power and energy.
Electromagnetism: Faraday's Laws of Electromagnetic Induction, Lenz's Law, Flemings rules, statically and dynamically induced EMF; concepts of self and mutual inductance. Coefficient of Coupling. Energy stored in magnetic field. Simple Numerical.

Module-2 (08 Hrs)

Single-phase AC circuits: Generation of sinusoidal voltage, frequency of generated voltage, average value, RMS value, form factor and peak factor of sinusoidal voltage and currents.
Phasor representation of alternating quantities. Analysis of R, L, C, R-L, R-C and R-L-C circuits with phasor diagrams, Real power, reactive power, apparent power, and Power factor. Series, Parallel and Series-Parallel circuits. Simple Numerical.

Module-3(08 Hrs)

Three-phase AC circuits: Necessity and advantage of 3-phase system. Generation of 3-phase power. Definition of phase sequence. Balanced supply and balanced load. Relationship between line and phase values of balanced star and delta connections. Power in balanced 3-phase circuits. Measurement of 3-phase power by 2-wattmeter method. Simple Numerical.

Module-4(08 Hrs)

Measuring instruments: construction and working principle of whetstone's bridge, Kelvin's double bridge, Megger, Maxwel's bridge for inductance, Schering's bridge for capacitance, concepts of current transformer and potential transformer.
Domestic Wiring: Requirements, Types of wiring: casing, capping. Two way and three way control of load.

Module-5 (08 Hrs)

Electricity bill: Power rating of household appliances including air conditioners, PCs, laptops, printers, etc. Definition of "unit" used for consumption of electrical energy, two-part electricity tariff, calculation of electricity bill for domestic consumers.
Equipment Safety measures: Working principle of Fuse and Miniature circuit breaker (MCB), merits and demerits.
Personal safety measures: Electric Shock, Earthing and its types, Safety Precautions to avoid shock, and Residual Current Circuit Breaker (RCCB) and Earth Leakage Circuit Breaker (ELCB).

Course outcome (Course Skill Set)

At the end of the course the student will be able to:

CO1	Understand the concepts of DC circuits and Electromagnetism.
CO2	Understand the concepts of single phase and Three phase AC circuits.
CO3	Apply the basic Electrical laws to solve circuits.
CO4	Understand the concepts of measurements and measuring Instruments
CO5	Explain the concepts of domestic wiring, electricity billing, circuit protective devices and personal safety measures.

Assessment Details (both CIE and SEE)

The weightage of Continuous Internal Evaluation (CIE) is 50% and for Semester End Exam (SEE) is 50%. The minimum passing mark for the CIE is 40% of the maximum marks (20 marks out of 50). The minimum passing mark for the SEE is 35% of the maximum marks (18 marks out of 50). A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to each subject/ course if the student secures not less than 35% (18 Marks out of 50) in the semester-end examination(SEE), and a minimum of 40% (40 marks out of 100) in the sum total of the CIE (Continuous Internal Evaluation) and SEE (Semester End Examination) taken together.

Continuous Internal Evaluation(CIE):

Two Unit Tests each of30 Marks (duration 01 hour)

- First test after the completion of 30-40 % of the syllabus
- Second test after completion of 80-90% of the syllabus

One Improvement test before the closing of the academic term may be conducted if necessary. However best two tests out of three shall be taken into consideration

Two assignments each of 20 Marks

The teacher has to plan the assignments and get them completed by the students well before the closing of the term so that marks entry in the examination portal shall be done in time.Formative (Successive) Assessments include Assignments/Quizzes/Seminars/ Course projects/Field surveys/ Case studies/ Hands-on practice (experiments)/Group Discussions/ others.. The Teachers shall choose the types of assignments depending on the requirement of the course and plan to attain the Cos and POs. (to have a less stressed CIE, the portion of the syllabus should not be common /repeated for any of the methods of the CIE. Each method of CIE should have a different syllabus portion of the course). CIE methods /test question paper is designed to attain the different levels of Bloom's taxonomy as per the outcome defined for the course.

The sum of two tests, two assignments, will be out of 100 marks and will be scaled down to 50 marks

Semester End Examination(SEE):

Theory SEE will be conducted by University as per the scheduled timetable, with common question papers for the subject (**duration 03 hours)**

- The question paper shall be set for 100 marks. The medium of the question paper shall be English/Kannada). The duration of SEE is 03 hours.
- The question paper will have 10 questions. Two questions per module. Each question is set for 20 marks.The students have to answer 5 full questions, selecting one full question from each module. The student has to answer for 100 marks and **marks scored out of 100 shall be proportionally reduced to 50 marks**.
- There will be 2 questions from each module. Each of the two questions under a module (with a maximum of 3 sub-questions), **should have a mix of topics** under that module.

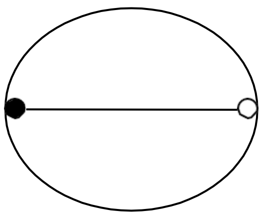
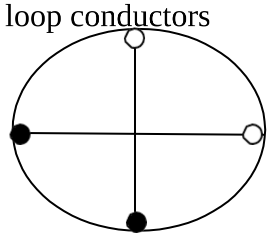
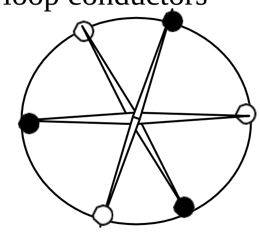
Suggested Learning Resources:

Books (Title of the Book/Name of the author/Name of the publisher/Edition and Year)

Text Books:

1. Basic Electrical Engineering by D C Kulshreshtha, Tata McGraw Hill, First Edition 2019.
2. A text book of Electrical Technology by B.L. Theraja, S Chand and Company, reprint edition 2014.

MODULE 3
Three -Phase AC Circuits

	For single phase generation, single loop conductor 	For Two phase generation, two single loop conductors  Two loop conductors are placed such that they are displaced by 90°	For three phase generation, three single loop conductors  Three loop conductor placed such that they are displaced by 120° each i.e. (360°/3)

Phase- An alternating voltage or current changes in magnitude and direction at every instant. So, it's necessary to know the condition of alternating quantity at a particular instant. The location of the condition of the alternating quantity at any particular instant is called ***phase.*** Its defined as an alternating quantity at any particular instant as the fractional part of a period or cycle through which the quantity has advanced from the selected origin.

FOR TWO PHASE GENERATION

For single phase generation we had one single loop conductor in Rotor cutting uniform magnetic field at a constant speed. For two phase generation, the rotor should have two conductor such that they are perpendicular to each other i.e. 90° phase difference between them as shown below.

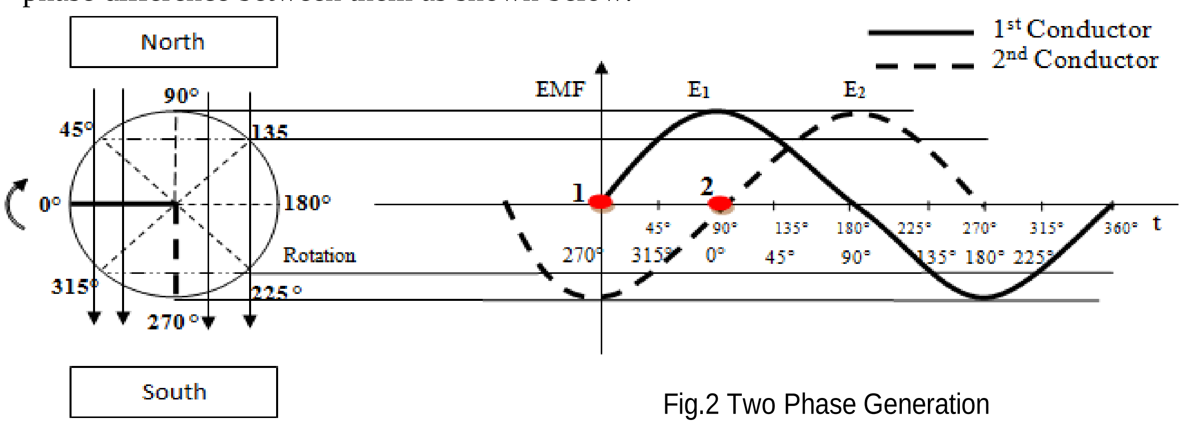


Fig.2 Two Phase Generation

From above fig.2 it can be observed that, one conductor moves, such that the force experienced by the conductor is parallel to the flux line, i.e. conductor 1 which produced emf E_1=0V, at *position 1* in waveform. The second conductor moves, such that it experiences force perpendicular to field line, thus maximum emf is produced according to faradays law electromagnetic induction, i.e. E_2=Em, but in negative cycle, at *position 1* in waveform.

As the second conductor reaches 0°, the force experienced by conductor is parallel thus E_2 at this *position 2* is 0V. The first conductor ant position 2, conductor experiences a perpendicular force wrt to field line, thus E_1= Em

- At position 1, 1st conductor produces an emf E_1=0V and 2nd conductor produces emf, E_2 = -Em volts
- At position 2, 1st conductor produces an emf E_1=Em V and 2nd conductor produces emf, E_2 = 0 V

When the rotor conductor rotates both these conductor rotates and emf is induced such that they are 90° apart from each other as it can be seen in above waveform.

We know for a single loop conductor the emf induced in the conductor is, $E = E_m$ Sin wt
Thus for taking first conductor as reference we can write the emf induced in it as,
$E_1 = E_m$ Sin wt
Thus, as the second conductor in rotor is placed 90° away from the first conductor. The emf induced in the second conductor is
$E_2 = E_m$ Sin (wt - 90°) (as at position 1, 1st conductor is zero but of 2nd conductor is maximum but negative)

FOR THREE-PHASE GENERATION

For three phase generation, rotor should have three single loop conductors such that each conductor should be placed 120° from each other. To obtain equal magnitude in each phases, their impedances should be same, i.e. $Z_R=Z_Y=Z_B$=Z. Conventionally the three phases are designated as red-R, yellow-Y and blue-B phases.

- Here let us consider Phase R as reference phase. As we rotate the conductors in clockwise, phase RBY stars to rotate and induced emf in conductor R reaches from 0v, when force experienced by conductors are parallel to flux lines to maximum volts at 90° cutting perpendicular to flux lines as shown in fig.3.
- One can say phase B reaches reference point after 120° i.e. it is delayed by 120° seen from phase R. its waveform is as shown below.
- It can be said that phase Y reaches reference point after 240° seen from phase R side. Thus conductor Y mover above reference point after 240° as shown in above fig.3.
- In the presence of constant magnetic field, as the conductors rotate and cut the magnetic field with constant speed.
- EMF is induced in each conductor such that they are 120° apart from each other.
- If all three phase (RBY) have same number of conductor, the emf induced in each conductor has same value E_{M}.

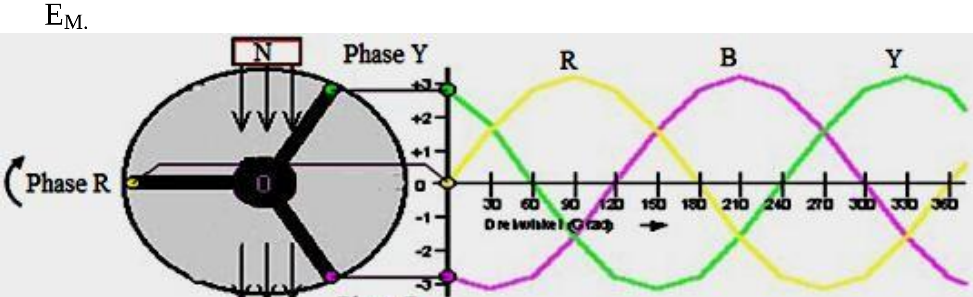


Fig.3. Three phase generation

Phase Sequence here is RBY
V_{RN}= Vm Sin wt
V_{BN}= Vm Sin (wt - 120°)
V_{YN}= Vm Sin (wt - 240°)
For Phase Sequence RYB
V_{RN}= Vm Sin wt
V_{YN}= Vm Sin (wt - 120°)
V_{BN}= Vm Sin (wt - 240°)

Balanced Supply, Balanced Load & Phase Sequence

Balance Supply:
The generation system is delta connected.
Three windings, with equal number of turns, i.e. each phase conductor (R,Y & B) having same impedance, Z per phase ($Z_R = Z_Y = Z_B$ = Z). By this one can obtain equal voltage magnitude in all phases.
These three windings should be displaced by 120° (electrical angle) from each other, thus their voltages are also displaced by 120° from each other.

Balanced Load:
The load can be star or delta connected system.
Three windings of the system should have same impedance, Z per phase ($Z_R = Z_Y = Z_B$ = Z)
where Z_R, Z_Y & Z_B are per phase impedance values of their respected impedances.
These three phase should have an electrical angle 120° between each other.

Phase Sequence:

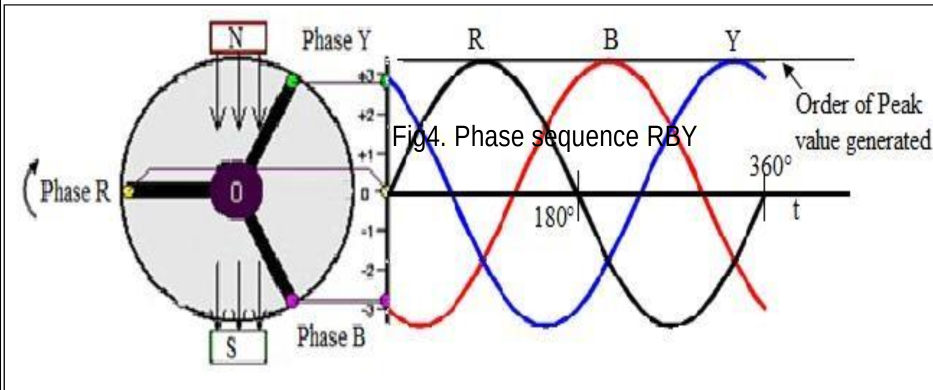


Fig4. Phase sequence RBY

As the rotor conductors rotate clockwise direction. The maximum emf (positive ***E<u>m</u>***) are induced in respected conductors when the force experienced by the conductors are perpendicular to lines of flux. In this fig one can notice the first phase that induces E_m is phase **R**, following it phase **B** and phase **Y**. For this system, we can say ***phase sequence as RBY***

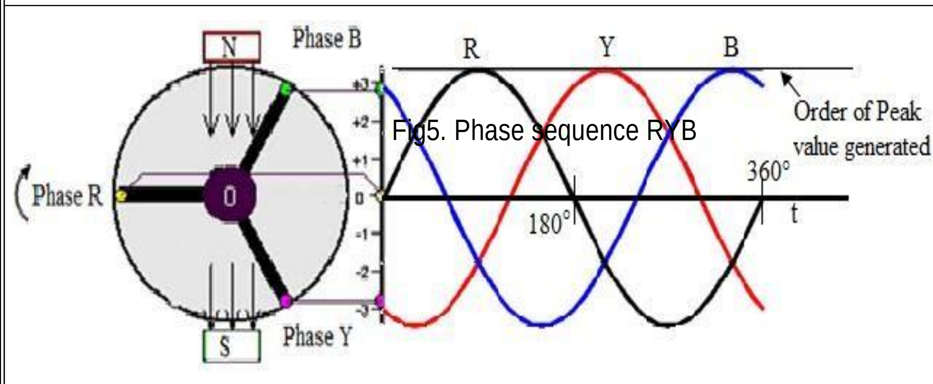


Fig5. Phase sequence RYB

As the rotor conductors rotate clockwise direction. The maximum emf (positive ***E<u>m</u>***) are induced in respected conductors when the force experienced by the conductors are perpendicular to lines of flux. In this fig one can notice the first phase that induces E_m is phase **R**, following it phase **Y** and phase **B**. For this system, we can say ***phase sequence as RYB***

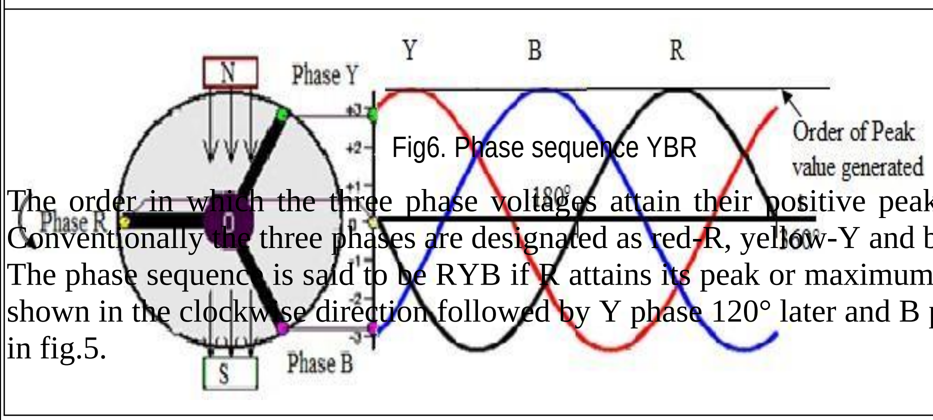


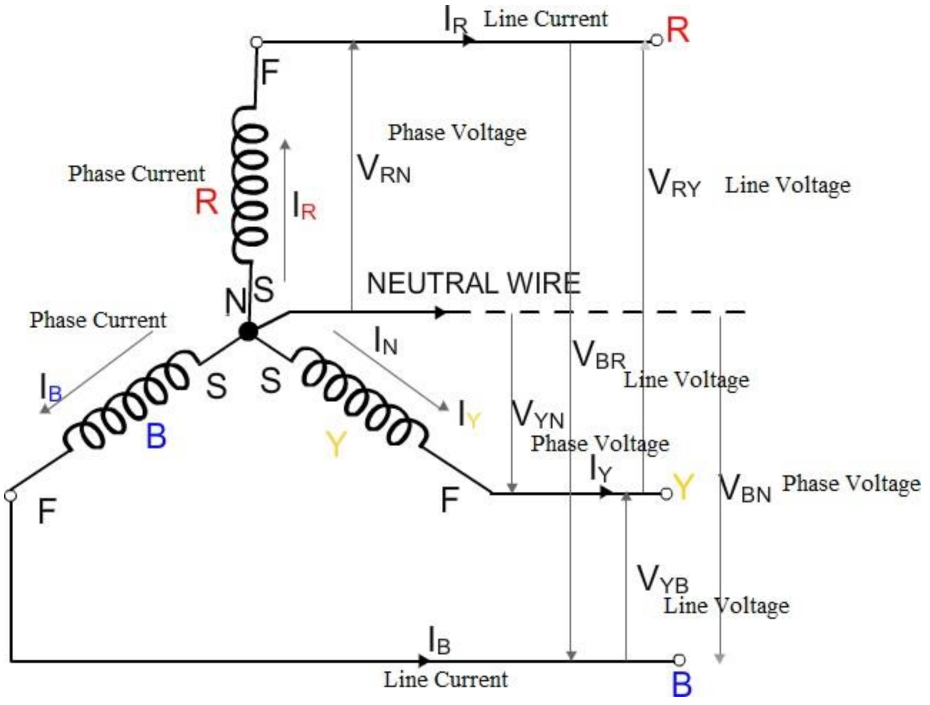
Fig6. Phase sequence YBR

As the rotor conductors rotate anticlockwise direction. The maximum emf (positive ***E<u>m</u>***) are induced in respected conductors when the force experienced by the conductors are perpendicular to lines of flux. In this fig one can notice the first phase that induces E_m is phase **Y**, following it phase **B** and phase **R**. For this system, we can say ***phase sequence as YBR***

The order in which the three phase voltages attain their positive peak values is known as the phase sequence. Conventionally the three phases are designated as red-R, yellow-Y and blue-B phases.

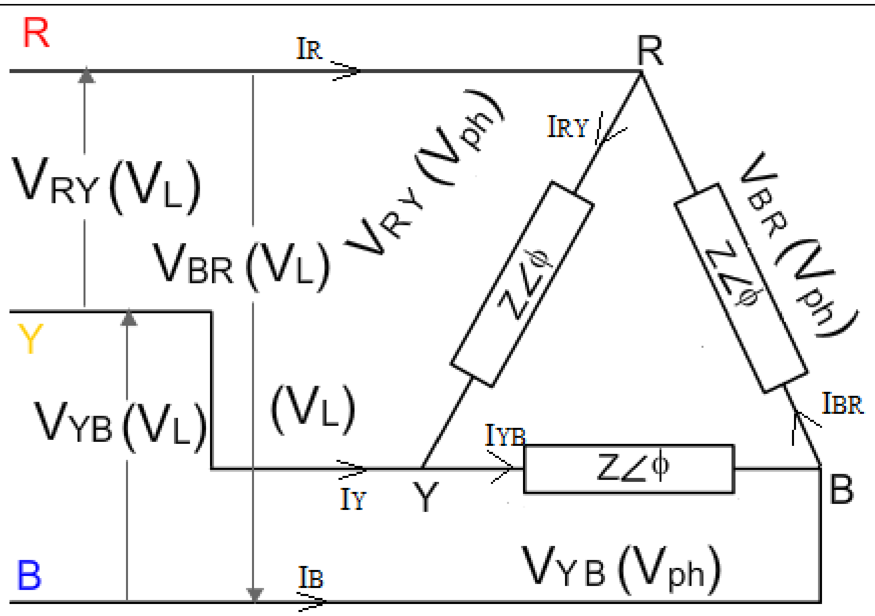
The phase sequence is said to be RYB if R attains its peak or maximum value first with respect to the reference as shown in the clockwise direction followed by Y phase 120° later and B phase 240° later than the R phase as shown in fig.5.

Star and Delta System(only to understand star and delta system)



Star connected system

Line voltage:- Voltage measured between any two Phases.
Example: Voltage between phase R & Y, V_{RY}; is called line or phase to phase voltage. Similarly, V_{YB} & V_{BR} are called $\mathbf{V_L}$ Line voltages.
Phase Voltage: Voltage measure between any one phase and Neutral.
Example: voltage between phase R wrt N, V_{RN}; is called phase voltage.
Similarly, V_{YN} & V_{BN} are called $\mathbf{V_P}$ or $\mathbf{V_{Ph}}$ phase voltages
Phase and Line currents: Current flowing in respective phases are called phase currents, i.e. I_R,I_Y & I_B are all phase current which can be represented as $\mathbf{I_{Ph}}$ **or** $\mathbf{I_P}$.
Current flowing towards terminal (load) or from terminal (supply) points are called line currents, $\mathbf{I_L}$



Delta connected system

Line Voltage: Voltage measured across terminal ends of the system, V_{RY}, V_{YB} & V_{BR}, i.e. $\mathbf{V_L}$
Phase Voltage: Voltage measured across their respected phase, i.e voltage across phase R, Y & B is $\mathbf{V_{Ph}}$ **or** $\mathbf{V_P}$
Line Current: Current flowing from terminal (supply) or to terminals (load), i.e. I_R,I_Y & I_B i.e. $\mathbf{I_L}$
Phase Current: Currents flowing in respective phases, i.e. I_{RY}, I_{YB} & I_{BR}, i.e. $\mathbf{I_{Ph}}$ or $\mathbf{I_P}$

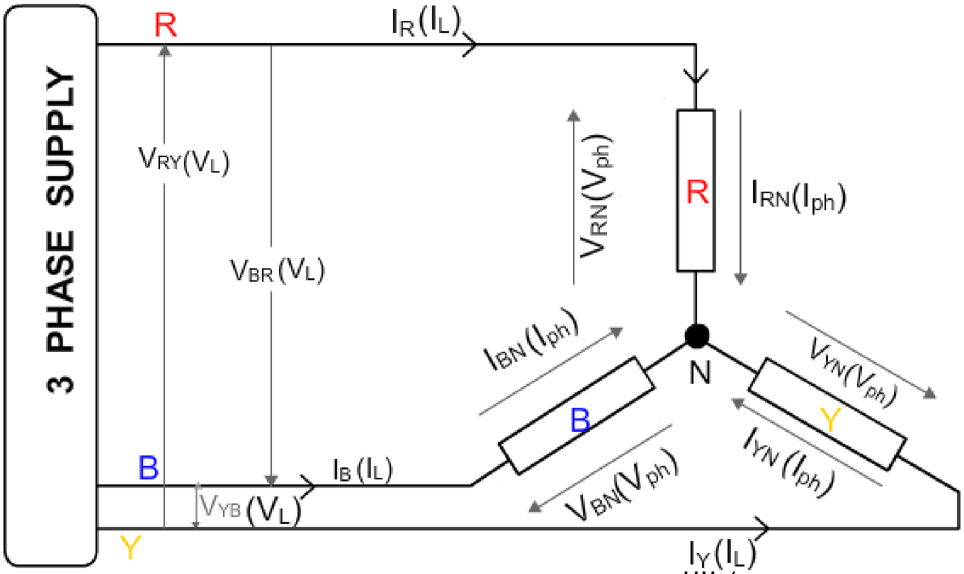


fig.7

Relationship between line and phase quantities (voltage and current) in Star connected balanced system

Assuming the ***phase sequence to be RYB***, three phase voltages are given by V_{RN}, V_{YN}, V_{BN}. Taking V_{RN} as reference voltage then RMS value of phase voltages can be represented as

$$V_{RN} = Vm\ Sin\ wt$$

$$V_{YN} = Vm\ Sin\ (wt - 120°)$$

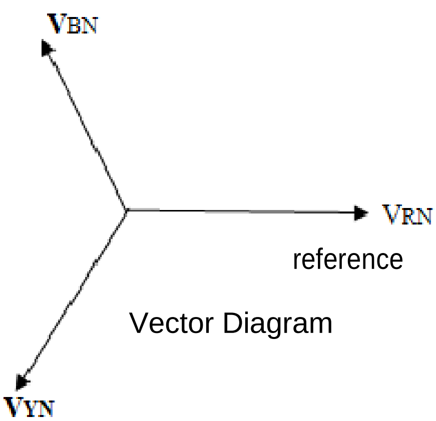
$$V_{BN} = Vm\ Sin\ (wt - 240°)$$

Their respectiveVectors in polar form

$$V_{RN} = Vm\ \angle 0$$

$$V_{YN} = Vm\ \angle -120°$$

$$V_{BN} = Vm\ \angle -240°$$



Vector Diagram

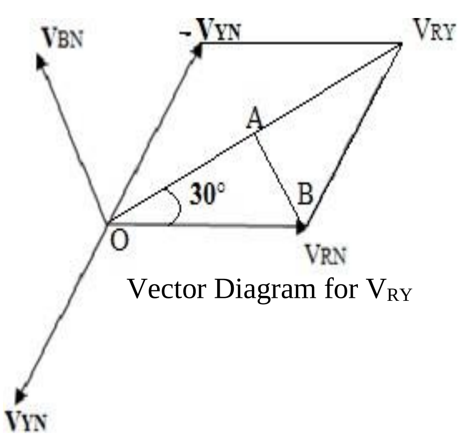
The phasor or vector diagram can be writing taking phase R as reference

$V_{RY} = V_{YB} = V_{BR}$ = Line voltages = V_L
$V_{RN} = V_{YN} = V_{BN}$ = Phase voltages
$= V_{ph}$ $I_{RN} = I_{YN} = I_{BN} = I_{ph}$ = Phase currents
$I_R = I_Y = I_B = I_L$ = Line currents
In a star connected system **$I_{ph} = I_L$---------**(1)

Because current flowing in respective phase, is the same current flowing from terminal or supply.

Applying KVL between the lines R and Y in fig.7
$- V_{RN} + V_{YN} + V_{RY} = 0$
i.e. **$V_{RY} = V_{RN} - V_{YN}$ --------** (2)

Rewriting the vector diagram for equation 2, vector diagram for **V_{RY}**



Vector Diagram for V_{RY}

Writing **$-V_{YN}$** in opposite direction to **V_{YN}**
Drawing perpendicular lines from vector **V_{BN}** & **$-V_{YN}$**
The point of their intersection gives **V_{RY}** as shown in fig.
From the triangle AOB,

$$Cos\ 30 = \frac{Base}{\text{Hypotenuse}} = \frac{OA}{OB}$$

$$\frac{\sqrt{3}}{2} = \frac{V_{RY}/2}{V_{RN}}$$

$$\sqrt{3} * V_{RN} = V_{RY}$$

$$\sqrt{3}\ V_P = V_L$$

$$V_L = \sqrt{3}\ V_P$$

Current relation: $\mathbf{I_L = I_{Ph}}$ ---------------A	Voltage relation: $\mathbf{V_L = \sqrt{\ }\ V_{Ph}}$ -------- B

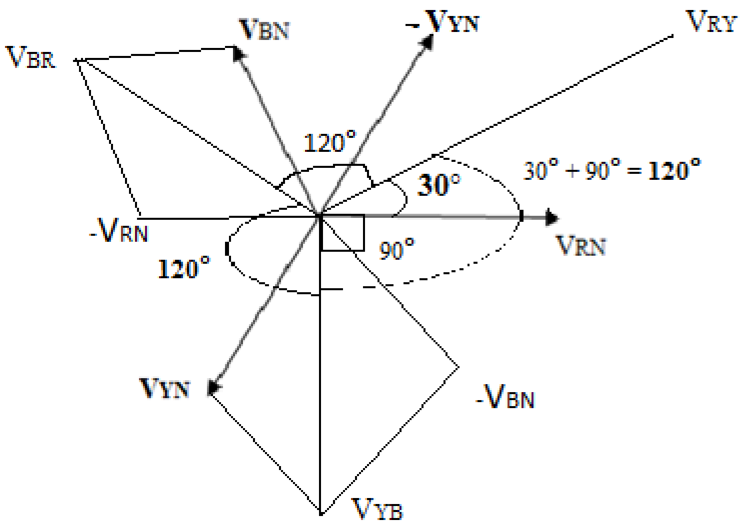


Fig.8 Vector diagram for star connected system

Power in each phase = Voltage in each phase * Current through respective phase * Cos

$= V_{ph} * I_{ph} \cos\theta$

Total power in three phases = Power in Phase R + Power in phase Y + Power in Phase B

$V_{ph} * I_{ph} \cos\theta \quad + \quad V_{ph} * I_{ph} \cos\theta \quad + V_{ph} * I_{ph} \cos\theta$

$3\, V_{ph} * I_{ph} \cos\theta$; substituting for V_{ph} & I_{ph} from eq A & B we get

$\mathbf{P = \sqrt{\ }\ V_L\ I_L \cos\theta}$ in **KW** known as Active or Real power

$Q = \sqrt{\ }\ \mathbf{V_L\ I_L \sin\theta}$ in **KVAR** known as Reactive or Imaginary Power

$S = \sqrt{\ }\ \mathbf{V_L\ I_L}$ in **KVA** known as Apparent or Total power

Writing for other Line voltages such that they are 120° apart from each other we can represent them as shown in fig.8 for below equvations

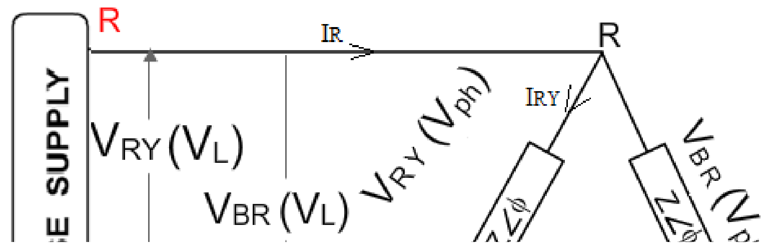
For line YB from fig7, by kvl; $-V_{BN} + V_{YN} - V_{YB} = 0$

$-V_{BN} + V_{YN} = V_{YB}$ ----3

For line BR from fig7, by kvl; $-V_{RN} + V_{BN} - V_{BR} = 0$

$-V_{RN} + V_{BN} = V_{BR}$ -- 4

Relationship between line and phase quantities (voltage and current) in Delta connected balanced system



Applying KCL at nodes R, Y and B in fig.9 we get

At node R	At node Y	At node B
$I_R + I_{BR} = I_{RY}$	$I_Y + I_{RY} = I_{YB}$	$I_B + I_{YB} = I_{BR}$
$I_R = I_{RY} - I_{BR}$	$I_Y = I_{YB} - I_{RY}$	$I_B = I_{BR} - I_{YB}$

In

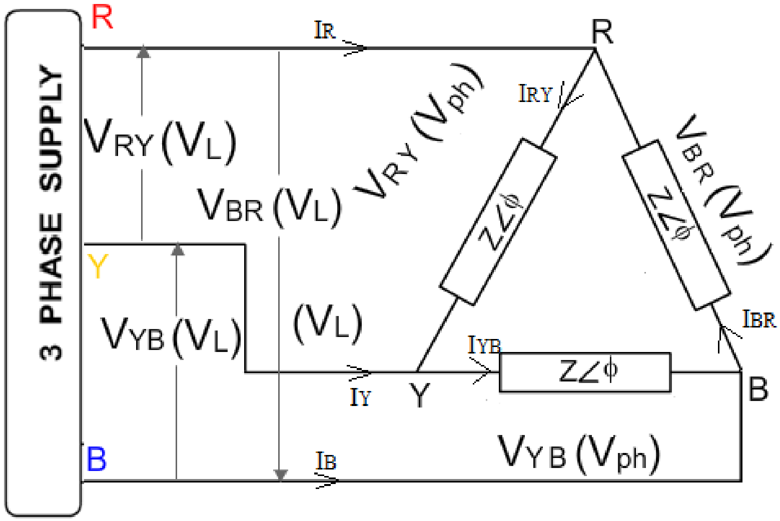


Fig.9. Delta connected system

Applying KCL at nodes R, Y and B in fig.9 we get

At node R	At node Y	At node B
$I_R + I_{BR} = I_{RY}$	$I_Y + I_{RY} = I_{YB}$	$I_B + I_{YB} = I_{BR}$
$I_R = I_{RY} - I_{BR}$	$I_Y = I_{YB} - I_{RY}$	$I_B = I_{BR} - I_{YB}$

Taking V_{RY} as reference to draw the vector diagram. One can redraw the vector diagram from star connected system for line voltages only in vector diagram.
Rewriting vector diagram for I_R
Write - I_{BR} in opposite direction to I_{BR}
Drawing perpendicular lines from vectors I_{RY} & -I_{BR}. Their point of interaction gives I_R
In Delta connected system: **$V_L = V_{Ph}$ -------** (1)

Vector diagram Writing line voltages from star connected system

Assume load being Inductive. Current will lag for the applied voltage. Thus phase current will lag for the applied phase voltages.

From triangle AOB,

$$Cos\,30 = \frac{Base}{Hypotenuse} = \frac{OA}{OB} \quad where\ OA = \frac{I_R}{2} \text{ and } OB = I_{RY}$$

$$\frac{\sqrt{3}}{2} = \frac{I_R/2}{I_{RY}}$$

$$\sqrt{3} * I_{RY} = I_R$$

$$\sqrt{3}\, I_{Ph} = I_L$$

$$I_L = \sqrt{3}\, I_{Ph} \quad -----(2)$$

Vector Diagram for I_R

$$I_L = \quad I_{Ph} \quad -----(2)$$

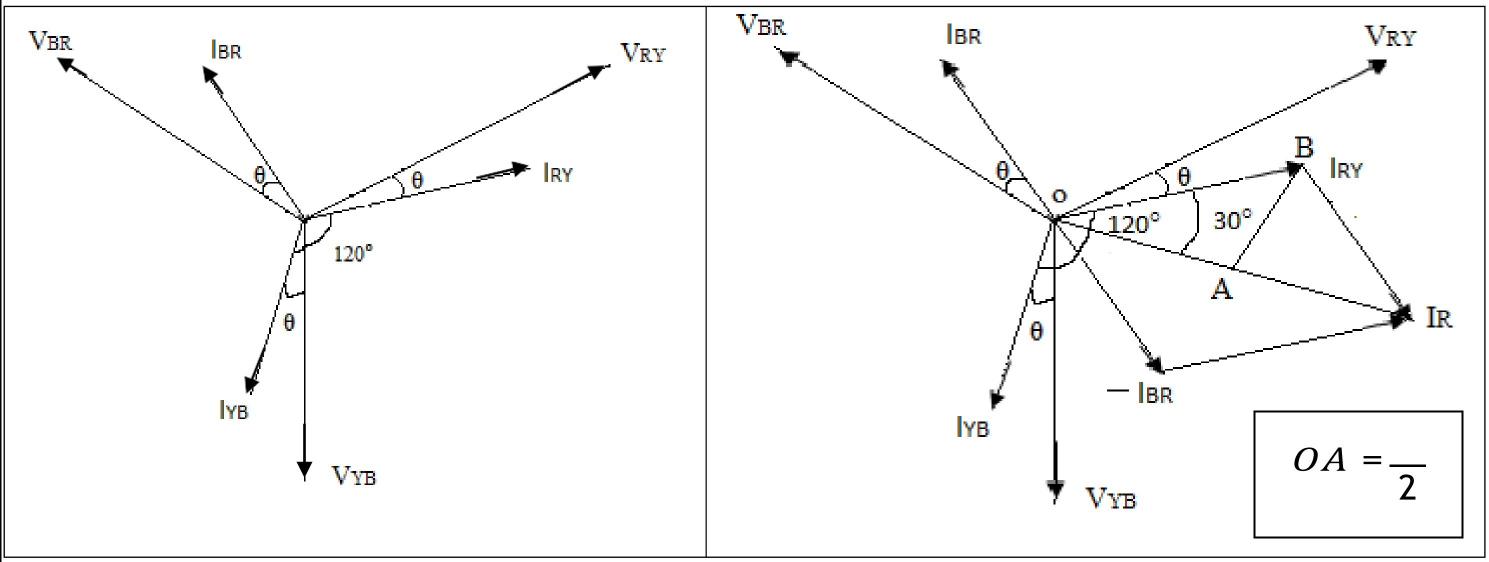
Current relation: $\mathbf{I_L = \surd \quad I_{Ph}}$ -----------C Voltage relation: $\mathbf{V_L = V_{Ph}}$ -------- D

Total power in three phases = Power in Phase R + Power in phase Y + Power in Phase B

$$V_{ph} * I_{ph} \cos\theta \quad + \quad V_{ph} * I_{ph} \cos\theta \quad + V_{ph} * I_{ph} \cos\theta$$

$P = \mathbf{3\ V_{ph} * I_{ph} \cos\theta}$; substituting for V_{ph} & I_{ph} from eq C & D we get

$P = \surd\overline{\ }\mathbf{V_L\ I_L \cos\theta}$ in **KW** known as Active or Real power



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$Q = \sqrt{3}\, V_L\, I_L \sin\theta$ in **KVAR** known as Reactive or Imaginary Power

$S = \sqrt{3}\, V_L\, I_L$ in **KVA** known as Apparent or Total power

NOTE: One can notice that three phase active, reactive and apparent power in star and delta is same

Writing for other phase and line currents, the vector diagram can be drawn as below in Fig.10.

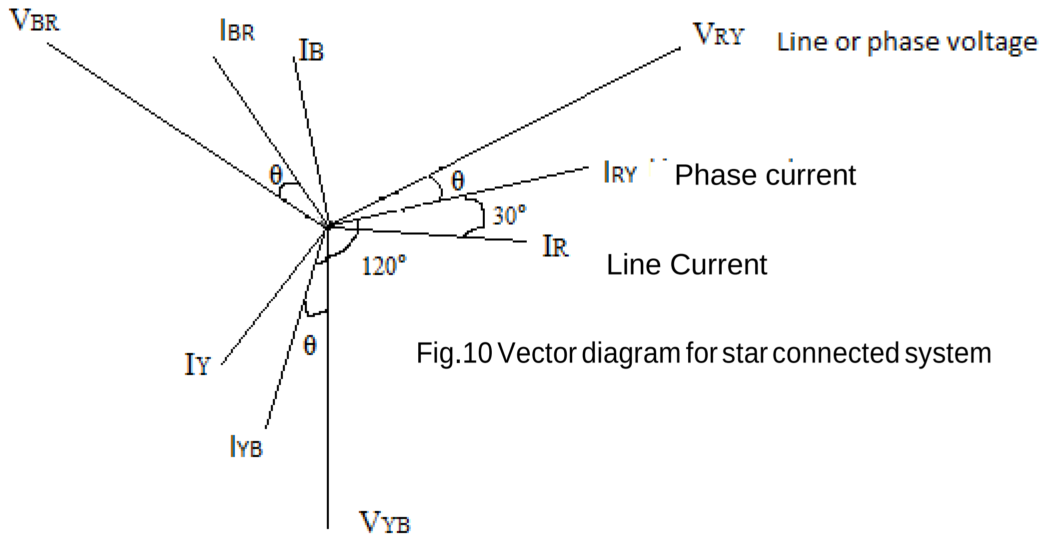


Fig.10 Vector diagram for star connected system

Measurement Of Three Phase Power

Various methods are used **measurement of three phase power** in three phase circuits on the basis of number of wattmeter used. We have three methods

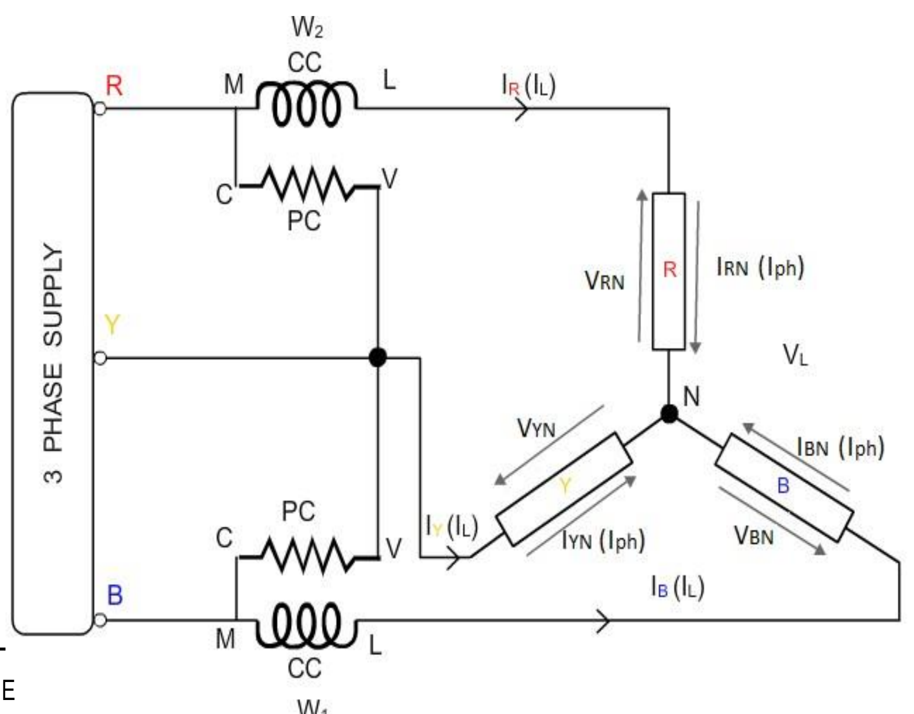
1. Three wattmeter's method
2. ***Two wattmeter's method*** (For **Star connected load in syllabus** and Delta connected Load)
3. Single wattmeter method.

Measurement of three phase power by ***Two wattmeter method***

Let us assume that two wattmeter W_1 & W_2 are connected to phase R and B as shown in fig.11 & 12 for *Star and Delta* connected Load respectively.

Assuming the ***phase sequence to be RYB***, the phase voltages are V_{RN}, V_{YN} and V_{BN}. Let the phase angle between the phase voltage and phase current be θ degree.

The ***load*** is assumed to be ***inductive*** in nature then current in each-phase lags the phase voltage by θ degrees. The phase currents in all three phases (I_R, I_Y, I_B) lags by an angle θ with respect to phase voltages (V_{RN}, V_{YN} & V_{BN}) as shown in vector diagram below.



For Wattmeter W_1:

Current I_B flows in current coils; voltage across potential coil is V_{BY}

i.e.

$W_1 = V_{BY} * I_B * \cos \angle(V_{BY}, I_B)$

From the vector diagram we know the angle between Line and Phase quantity is 30°.

angle between V_{BN} & V_{BY} is 30°

angle between V_{BN} & I_B is θ

∘ angle between V_{BY} & I_B 30° - θ

∘ $W_1 = V_{BY} * I_B * \cos(30° - \theta)$

For Wattmeter W_2:

Current I_R flows in current coils; voltage across potential coil is V_{RY}

i.e.

$W_2 = V_{RY} * I_R * \text{Cos} \angle V_{RY}\, I_R$

From the vector diagram we know the angle between Line and Phase quantity is 30°.

angle between V_{RN} & V_{RY} is 30°

angle between V_{RN} & I_R is θ

- angle between V_{RY} & I_R $30° + \theta$
- $W_2 = V_{RY} * I_R * \text{Cos}(30° + \theta)$

Total Power = $W_1 + W_2$

$V_{BY} * I_B * \text{Cos}(30° - \theta) + V_{RY} * I_R * \text{Cos}(30° + \theta)$

But

$V_{BY} = V_{RY} = V_L$ and $I_B = I_R = I_L$

$= V_L I_L \cos(30° - \theta) + V_L I_L \cos(30° + \theta)$

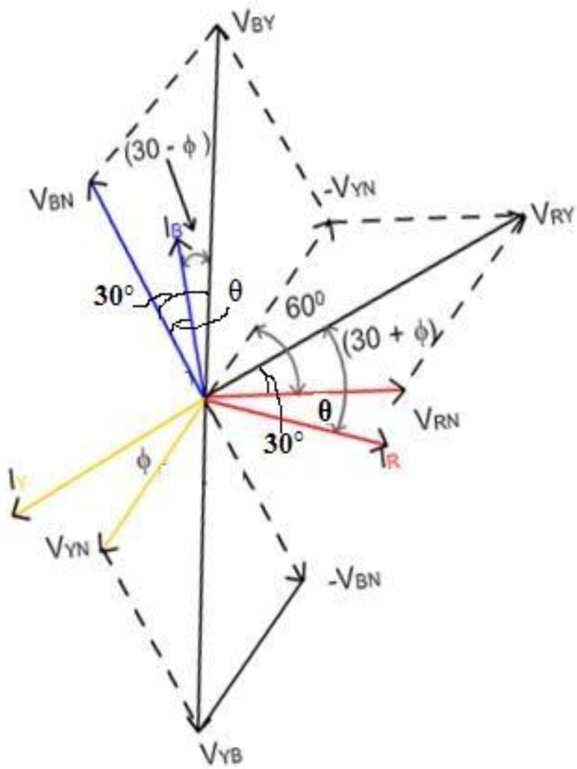
$= V_L I_L [\cos(30° - \theta) + \cos(30° + \theta)]$

$= V_L I_L [\cos 30° * \cos\theta + \sin 30° * \sin\theta + \cos 30° * \cos\theta - \sin 30° * \sin\theta]$

$= V_L I_L\, 2 \cos 30° \cos\theta$

$= V_L I_L\, 2 (\sqrt{3} / 2) \cos\theta$

$\mathbf{W = \sqrt{3}\, V_L I_L \cos\theta}$ **watts**



Delta connected Load with two wattmeter's, W1 & W2 to R & B phase respectively

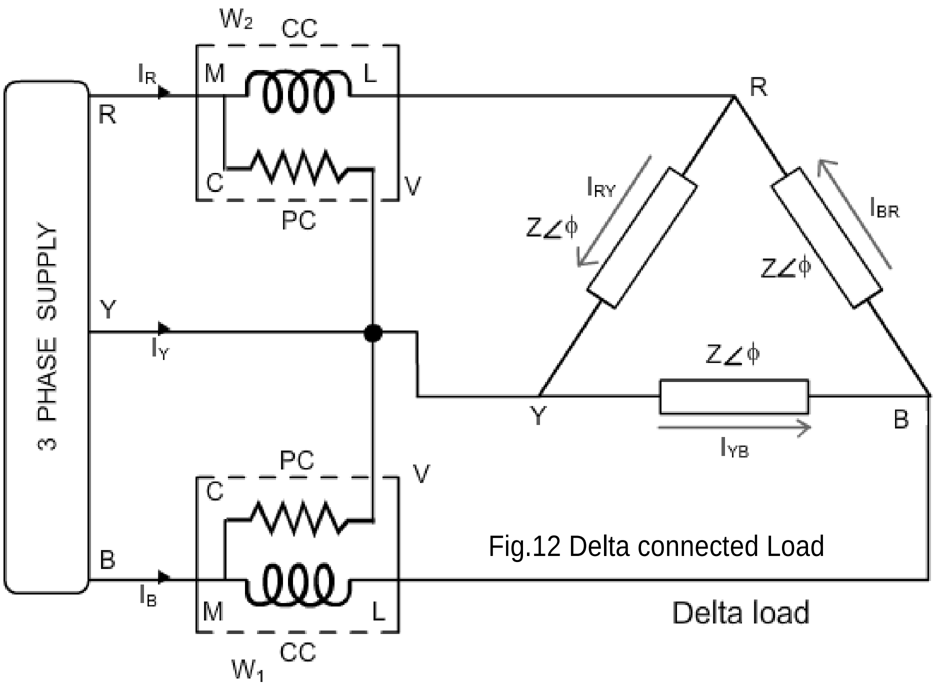


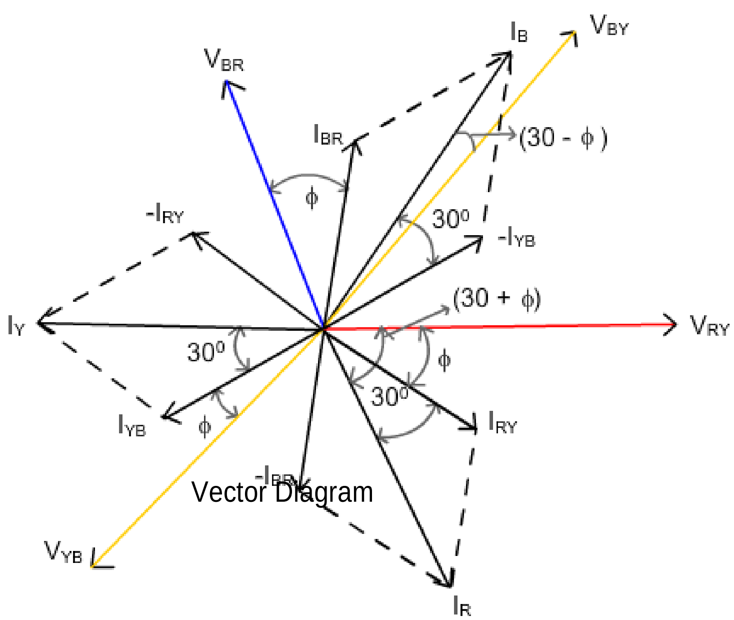
Fig.12 Delta connected Load

For Delta connected system
Assume the phase sequence to be RYB. Assuming inductive load, the phase angle between phase voltage and phase current is θ

In delta connected system, $V_L = V_{ph}$
For RYB phase sequence, three possible line voltages are V_{RY}, V_{YB} and V_{BR}.
$I_R = I_Y = I_B$ = line currents
$I_{RY} = I_{YB} = I_{BR}$ = Phase Currents

For Wattmeter W_1:
Current I_B flows in current coils; voltage across potential coil is V_{BY}
i.e.

$$W_1 = V_{BY} * I_B * \cos \angle^{V_{BY}}_{I_B}$$



From the vector diagram we know the angle between Phase and Line quantity is 30°.
angle between I_{BY} & I_B is 30°
angle between V_{BY} & I_{BY} is θ
- angle between V_{BY} & I_B 30° - θ
- $W_1 = V_{BY} * I_B * \cos (30° - θ)$

For Wattmeter W_2:
Current I_B flows in current coils; voltage across potential coil is V_{BY}
i.e.

$$W_2 = V_{RY} * I_R * \cos \angle^{V_{RY}}_{I_R}$$

From the vector diagram we know the angle between
Phase and Line quantity is 30°.
angle between I_{RY} & I_R is 30°
angle between V_{RY} & I_{RY} is θ
- angle between V_{RY} & I_R 30° + θ
- $W_2 = V_{RY} * I_R * \cos (30° + θ)$

Total Power $= W_1 + W_2$
$= V_{BY} * I_B * \cos (30° - θ) + V_{RY} * I_R * \cos (30° + θ)$
$= V_L I_L \cos (30° - θ) + V_L I_L \cos (30° + θ)$
$= V_L I_L [\cos (30° - θ) + \cos (30° + θ)]$
$= V_L I_L [\cos 30° * \cos θ + \sin 30° * \sin θ + \cos 30° * \cos θ - \sin 30° * \sin θ]$
$= V_L I_L \, 2 \cos 30° \cos θ$
$= V_L I_L \, 2 (\sqrt{3} / 2) \cos θ$

$W = \sqrt{3} V_L I_L \cos θ$ watts

But
$V_{BY} = V_{RY} = V_L$
and
$I_B = I_R = I_L$

Power Factor By Two Wattmeter Method

We know W_1 & W_2 either for Star or Delta connected load is $W_1 = V_L I_L \cos(30° - \theta)$

$W_2 = V_L I_L \cos(30° + \theta)$

We know $W_1 + W_2$ either in Star or Delta connected load is $\sqrt{3} V_L I_L \cos\theta$ **-- (1)**

$W_1 - W_2 = V_L I_L \cos(30° - \theta) - V_L I_L \cos(30° + \theta)$

$= V_L I_L [\cos(30° - \theta) - \cos(30° + \theta)]$

$= V_L I_L [\cos 30° * \cos\theta + \sin 30° * \sin\theta - \cos 30° * \cos\theta + \sin 30° * \sin\theta]$

$= V_L I_L [2 \sin 30° * \sin\theta]$

$= V_L I_L [2 (½) \sin\theta]$

$W_1 - W_2 = V_L I_L \sin\theta$ ----------(2)

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\theta}{\sqrt{3} V_L I_L \cos\theta}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\sin\theta}{\sqrt{3}\cos\theta}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{1}{\sqrt{3}}\tan\theta$$

$$\sqrt{3}\,\frac{W_1 - W_2}{W_1 + W_2} = \tan\theta$$

$$\tan^{-1}\left[\sqrt{3}\left|\frac{W_1 - W_2}{W_1 + W_2}\right|\right] = \theta$$

$$\theta = \tan^{-1}\left[\sqrt{3}\left|\frac{W_1 - W_2}{W_1 + W_2}\right|\right]$$

$$Power\ Factor = \cos\theta ; \cos\left(\tan^{-1}\left[\sqrt{3}\left|\frac{W_1 - W_2}{W_1 + W_2}\right|\right]\right)$$

Advantages of poly-phase systems over single phase systems

1. The output of 3 phase machine is always greater than single phase machine of same size. The output will be approximately 1.5 times than single phase machine.
2. For given size and voltage 3 phase alternator or electrical machines occupy less space and less cost compared to single phase machine having same rating.
3. For transmission of electrical power three phase supply requires less copper or less conducting material than that of single phase system for given volt-amperes and voltage ratings. Hence 3 phase system is more economical compared to single phase system.
4. Single phase Induction machines are not self starting machines. On the other hand three phase Induction machines are self starting due to rotating magnetic field. Therefore in order to start a single phase machine an auxiliary device is required which not in the case of 3 phase machine.

5. Power factor of single phase machines is poor compared to three phase machines.
6. For converting systems like rectifiers, the dc voltage waveform becomes more smoother with the increase in the number of phases of the system. Hence three phase system is advantageous compared to single phase system.
7. 3 phase motors will have uniform torque whereas single phase motors will have pulsating torque.
8. Parallel operation of three phase generators will be simple compared to single phase generators because of pulsating reaction in single phase generator.