Unit-1

BALANCED THREE PHASE CIRCUITS

1.1 Introduction:

There are two types of systems available in electrical circuits, single phase and three phase. In single phase circuits, there will be only one phase, i.e the current will flow through only one wire and there will be one return path called neutral line to complete the circuit. So in single phase minimum amount of power can be transported. Here the generating station and load station will also be single phase. This is an old system using from previous time.

In 1882, new invention has been done polyphase system, that more than one phase can be used for generating, transmitting and for load system. Three phase circuit is the polyphase system where three phases are send together from generator to the load. Each phase are having a phase difference of 120^0, i.e 120^0 angle electrically. So from the total of 360^0, three phase are equally divided into 120^0 each. The power in three phase system is continuous as all the three phases are involved in generating the total power. The sinusoidal waves for 3 phase system is shown below .

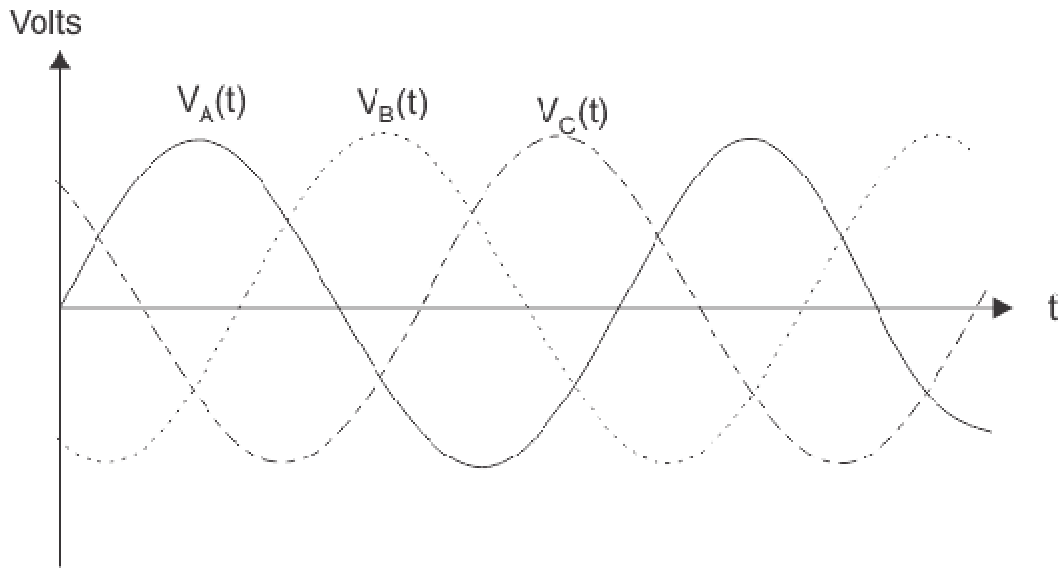

Fig.1.1

The three phase can be used as single phase each. So if the load is single phase, then one phase can be taken from the three phase circuit and the neutral can be used as ground to complete the circuit.

1.1.1 Why three phase is preferred over single phase?

There are various reasons for this question because there are numbers of advantages over single phase circuit. The three phase system can be used as three single phase line so it can act as three single phase system. The three phase generation and single phase generation is same in the generator except the arrangement of coil in the generator to get 120^0 phase difference. The conductor needed in three phase circuit is 75% that of conductor needed in single phase circuit.

And also the instantaneous power in single phase system falls down to zero as in single phase we can see from the sinusoidal curve but in three phase system the net power from all the phases gives a continuous power to the load.

Till now we can say that there are three voltage sources connected together to form a three phase circuit and actually it is inside generator. The generator is having three voltage sources which are acting together in 120^0 phase difference. If we can arrange three single phase circuit with 120^0 phase difference, then it will become a three phase circuit. So 120^0 phase difference is must otherwise the circuit will not work, the three phase load will not be able to get active and it may also cause damage to the system.

The size or metal quantity of three phase devices is not having much difference. Now of we consider the transformer, it will be almost same size fro both single phase and three phase because transformer will make only the linkage of flux. So the three phase system will have higher efficiency compared to single phase for the same or little difference in mass of transformer, three phase line will be out whereas in single phase will be only one. And losses will be minimum in three phase circuit. So overall in conclusion the three phase system will have better and higher efficiency compared to the single phase system.

A balanced polyphase system is one in which there are two or more equal voltages of the same frequency displaced equally in time phase, which supply power to loads connected to the lines. In general, in a *n*-phase balanced polyphase system, there are *n*-equal voltages displaced in time phase by $\frac{360^0}{n}$ or $\frac{2\pi}{n}$ (except in the case of a 2-phase system, in which there are two equal voltages differing in phase by 90^0). Systems of six or more phases are used in polyphase rectifiers to obtain rectified voltage with low ripple. But three phase system is most commonly used polyphase system for generation and transmission of power. Hence we study in detail the 3-phase voltage generation and analysis of 3-phase circuit in this unit.

A 3-phase system has the following advantages over single phase system. For a given frame size of a machine a 3-phase machine will have large capacity than a single phase machine. The torque produced in a 3-phase motor will be more uniform where as in a 1-phase motor it is pulsating. The amount of copper required in a certain amount of power over a particular distance, is less compared to a single phase system.

1.1.2 Phase sequence:

It is the order in which the phase voltages will attain their maximum values. From the fig it is seen that the voltage in A phase will attain maximum value first and followed by B and C phases. Hence three phase sequence is ABC. This is also evident from phasor diagram in which the phasors with its +ve direction of anti-clockwise rotation passes a fixed point is the order ABC, ABC and so on. The phase sequence depends on the direction of rotation of the coils in the magnetic field. If the coils rotate in the opposite direction then the phase voltages attains maximum value in the order ACB. The phase sequence gets reversed with direction of rotation. Then the voltage for this sequence can be represented as

$$e_a = E_m \sin \omega t$$
$$e_c = E_m \sin(\omega t - 120^0)$$
$$e_b = E_m \sin(\omega t - 240^0)$$

The RMS values of voltage can be expressed as

$$E_A = E\angle 0^0$$
$$E_C = E\angle -120^0$$
$$E_B = E\angle -240^0$$

1.1.3 Star and Delta connection

The three phase windings have six terminals i.e., A,B,C are starting end of the windings and A',B' and C' are finishing ends of windings. For 3 phase systems two types of common interconnections are employed.

1.1.3(a) Star connection: the finishing ends or starting ends of the three phase windings are connected to a common point as shown in. A', B', C' are connected to a common point called neutral point. The other ends A, B, C are called line terminals and the common terminal neutral are brought outside. Then it is called a 3 phase 4 wire star connected systems. If neutral point is not available, then it is called 3 phase, 3 wire star connection.

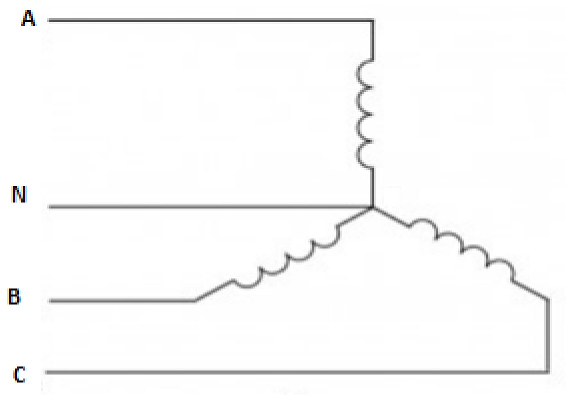

Fig.1.2

1.1.3(b) Delta connection: in this form of interconnection the dissimilar ends of the three coils i.e A and B', B and C', and C and A' are connected to form a closed Δ circuit (starting end of one phase is connected to finishing end of the next phase). The three junction are brought outside as line terminal A, B, C. the three phase windings are connected in series and form a closed path. The sum of the voltages in the closed path for balanced system of voltages at any instant will be zero fig.

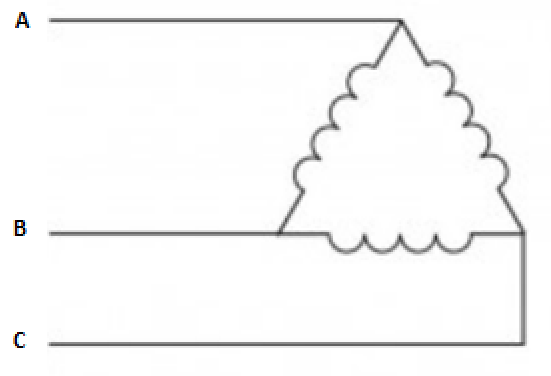

Fig.1.3

The main advantage of star connection is that we can have two different 3-phase voltages. The voltage that was the line terminals between A & B, B&C, and C & A are called line voltages and form a balanced three phase voltage. Another voltage is between the terminals A & N, B& N, and C &N are called phase voltage and form another balanced three phase voltage (line to neutral voltage or wye voltage).

1.2 Relation between line and phase voltage and currents in balanced systems:

In this section we will derive the relation between line and phase values of voltages and currents of 3-phase star connected and delta connected systems.

1.2.1 Star connection:

We will employ double subscript notation to represent voltages and currents. The terminal corresponding to first subscript is assumed to be at a higher potential with respect to the terminal corresponding to second subscript.

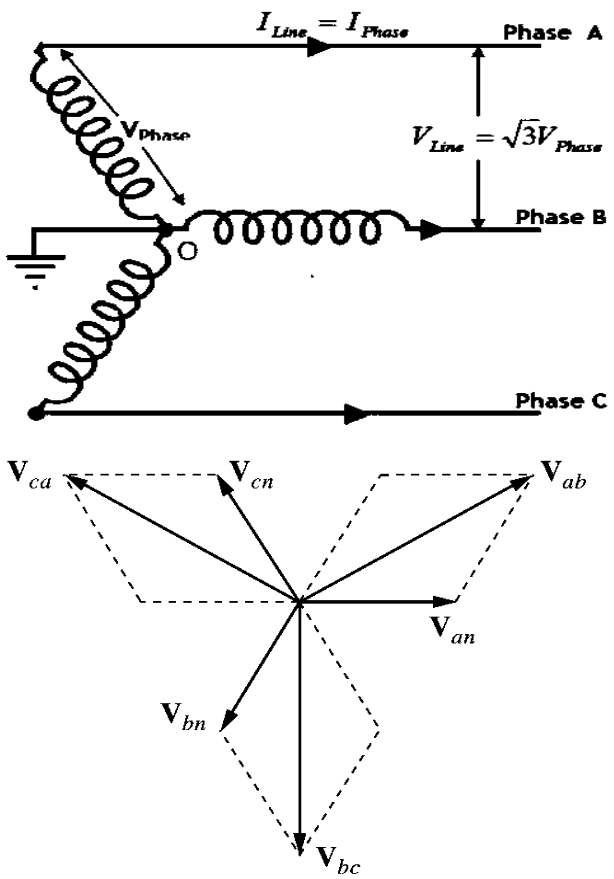

Fig.1.4

The voltage across each coil, i.e., the voltage between A & A',B& B', and C & C' are called phase voltages(acting from finishing end to starting end).

V_{AA}, V_{BB}, V_{CC}, or V_{AN}, V_{BN}, V_{CN} represent phase voltages.

The voltages across line terminals A & B, B & C, C & D are called line voltages. The connection diagram and the corresponding phasor diagram of voltages is shown in fig. From the star connected 3 phase system, it is clearly observed that whatever currents flow through the lines A, B, C also flow through the respective phase windings. Hence in star connected system, the phase currents and line currents are identical.

$$\text{Phase current } (I_{ph}) = \text{Line currents } (I_L)$$

$$I_{ph} = I_{Line}$$

The voltage V_{AB} between lines A and B is obtained by adding V_{AN} and V_{NB} respectively.

$$V_{AB} = V_{AN} + V_{NB} = V_{AN} - V_{BN}$$

Similarly

$$V_{BC} = V_{BN} + V_{NC} = V_{BN} - V_{CN}$$

$$V_{CA} = V_{CN} + V_{NA} = V_{CN} - V_{AN}$$

The line voltage V_{AB} is obtained by adding V_{AN} with reversed vector of V_{BN}.V_{AB} bisects the angle between V_{AN} and $-V_{BN}$

$$V_{AB}^2 = V_L^2 = V_{ph}^2 + V_{ph}^2 + 2\,V_{ph}V_{ph}\cos 60^0$$

$$= 3V_{ph}^2$$

$$V_{AB} = \sqrt{3}\,V_{ph}$$

$$\text{Line voltage} = \sqrt{3}\text{ phase voltage}$$

The line voltages V_{AB}, V_{BC}, V_{CA} are equal in magnitude and differ in phase by 120^0. Hence they form a balanced 3-phase voltage of magnitude $\sqrt{3}\,V_{ph}$. The two voltages differ in phase by 30^0. When the system is balanced, the three phase currents I_A, I_B, I_C are balanced. The magnitude and phase angle of current is determined by circuit parameters.

I_A, I_B, I_C are line or phase currents. The current in the neutral wire is I_N and is by applying kirchoff's current law at star point, we get

$$I_N = -(I_A + I_B + I_C)$$

If the currents are balanced, then the neutral current is zero.

1.2.2 Delta connection or MESH connection:

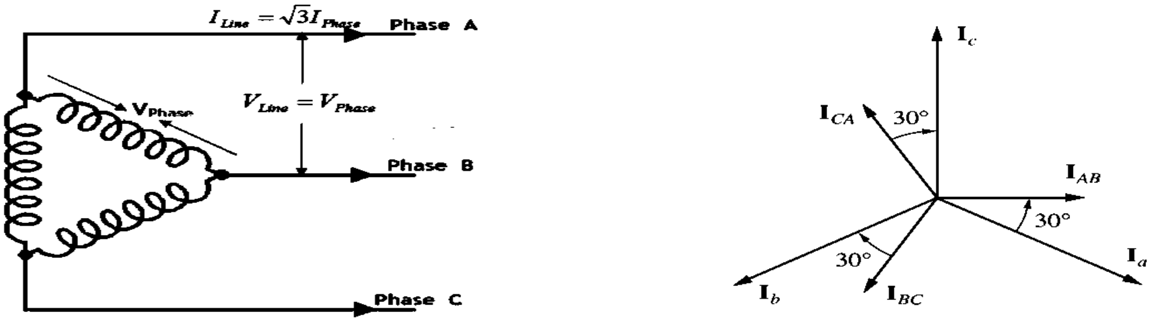

Fig.1.5.

The currents flowing through the phase windings I_{AA}’, I_{BB}’, and I_{CC}’ or I_{AB}, I_{BC}, and I_{CA} are called phase currents and are balanced as shown in phase diagram Fig.1.5.

By applying KCL at node A

$$I_A + I_{CA} = I_{AB} \text{ , } I_A = I_{AB} - I_{CA}$$

Similarly by applying KCL at nodes B and C

$$I_B = I_{BC} - I_{AB} I_C = I_{CA} - I_{BC}$$

The line current I_A is obtained by adding I_{AB} and $–I_{CA}$ vectorially. I_A bisects the angle between I_{AB} and $-I_{CA}$

$$I_A^2 = I_{Line}^2 = I_{ph}^2 + I_{ph}^2 + 2 I_{ph} I_{ph} \cos 60^0$$

$$= 3I_{ph}^2$$

$$I_L = \sqrt{3} I_{ph}$$

Line current(I_L) = √3 phase voltage(I_{ph})

The line current I_A, I_B, I_C and also equal and differ in phase by 120^0. They form a balanced system of currents. The line and phase currents differ in phase by 30^0.

1.3 Analysis of balanced three phase circuits

A set of three impedances interconnected in the form of a star or delta form a 3-phase star or delta connected load. If the three impedances are identical and equal then it is a balanced 3-phase load, otherwise it is an unbalanced 3-phase load.

The analysis of balanced 3-phase circuits is illustrated as follows

1.3.1 Balanced delta connected load:

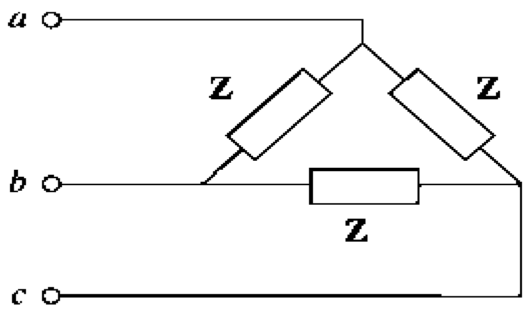

Fig.1.6

Let us consider a balanced 3-phase delta connected load

Determination of phase voltages:

$$V_{AB} = V\angle 0^0,\ V_{BC} = V\angle{-120^0},\ V_{CA} = V\angle -240^0 = V\angle 120^0$$

Determination of phase currents:

Phase current = Phase voltage/ Load impedance

$$I_{AB}=\frac{V_{AB}}{Z}\ ;\ I_{BC}=\frac{V_{BC}}{Z}\ ;\ I_{CA}=\frac{V_{CA}}{Z}$$

Determination of line currents:

Line currents are calculated by applying KCL at nodes A,B,C

$$I_A = I_{AB} - I_{CA}\ ;\ I_B = I_{BC} - I_{AB}\ ;\ I_C = I_{CA} - I_{BC}$$

Note: Line currents are also balanced and equal to $\sqrt{3}$phase current.

1.3.2 Balanced star connected load:

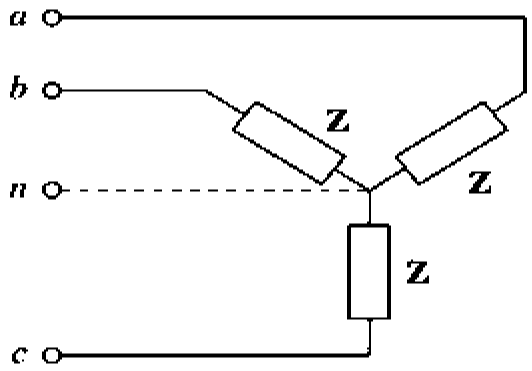

Fig.1.7

Let us consider a balanced 3-phase star connected load.

For star connection, phase voltage= Line voltage/(√3)

For ABC sequence, the phase voltage is polar form are taken as

$$V_{AN} = V_{ph}\angle -90^0 \; ; V_{CN} = V_{ph}\angle 150^0 \; ; V_{BN} = V_{ph}\angle 30^0$$

For star connection line currents and phase currents are equal

$$I_A = \frac{V_{AN}}{Z} \; ; I_B = \frac{V_{BN}}{Z} \; ; I_C = \frac{V_{CN}}{Z} \; ;$$

To determine the current in the neutral wire apply KVL at star point

$$I_N + I_A + I_B + I_C = 0$$

$$I_N = -(I_A + I_B + I_C) \quad \text{(since they are balanced)}$$

In a balanced system the neutral current is zero. Hence if the load is balanced, the current and voltage will be same whether neutral wire is connected or not. Hence for a balanced 3-phase star connected load, whether the supply is 3-phase 3 wire or 3-phase 4 wire, it is immaterial. In case of unbalanced load, there will be neutral current.