SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
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Madagadipet, Puducherry - 605 107

Department of Electrical and Electronics Engineering

Subject Name: Electrical Machines - I **Subject Code: EE T33**

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UNIT V

POLYPHASE TRANSFORMERS AND SPECIAL TRANSFORMERS

Auto-transformer- construction and saving in copper – Three phase transformers – Principle - Construction - Poly phase connections – Star, Zig, Open-delta, Scott connection, three-phase to single phase conversion – On load tap changing – variable frequency transformer – Voltage and Current Transformers – Audio frequency transformer.

Two Marks

1. What is auto transformer and its uses?

Auto transformer is kind of electrical transformer where primary and secondary shares same common single winding.

The autotransformer is used

(i). To increase the voltage or current to get the exact rated voltage.
(ii). To give small boost to a distribution cable to correct for the voltage drop.
(iii). As induction motor starter.

2. How transformers are classified according to their construction?

(i). Core type
(ii). Shell type.

In core type, the winding (primary and secondary) surround the core and in shell type, the core surrounds the winding.

3. List the arrangement of stepped core arrangement in a transformer?

1. To reduce the space effectively
2. To obtain reduce length of mean turn of the winding
3. To reduce I^2R loss.

4. What determines the thickness of the lamination or stampings?

1. Frequency
2. Iron loss

5. What are the applications of step-up & step-down transformer?

Step-up transformers are used in generating stations. Normally the generated voltage will be either 11kV. This voltage (11kV) is stepped up to 110kV or 220kV or 400kV and transmitted through transmission lines (simply called as sending end voltage).

Step-down transformers are used in receiving stations. The voltage are stepped down to 11kV or 22kV are stepped down to 3phase 400V by means of a distribution transformer and made available at consumer premises. The transformers used at generating stations are called power transformers.

6. What are the different types of connections? April 2015

1. Star – Star Transformer
2. Delta – Delta Transformer
3. Delta – Star Transforme)
4. Star – Delta Transformer
5. Zig-zag Transformer
6. Scott (–T‖ Type) Transformer

7. What are the advantages of Y-Y Connection?

Use for Three phases Four Wires System
Handle Heavy Load
Required Less Insulation Level
Required Few Turns for winding
No Phase Displacement
Eliminate Distortion in Secondary Phase Voltage
Sinusoidal voltage on secondary side
Used as Auto Transformer
Better Protective Relaying

8. What are the disadvantages of Y-Y Connection?

The Third harmonic issue
Overvoltage at Lighting Load
Voltage drop at Unbalance Load
Overheated Transformer Tank
Over Excitation of Core in Fault Condition
Neutral Shifting
Distortion of Secondary voltage
Over Voltage at Light Load
Difficulty in coordination of Ground Protection
Increase Healthy Phase Voltage under Phase to ground Fault
Trip the T/C in Line-Ground Fault
Suitable for Core Type Transformer

9. What is the application of three phase transformer?

This Type of Transformer is rarely used due to problems with unbalanced loads.

It is economical for small high voltage transformers as the number of turns per phase and the amount of insulation required is less.

10. Does transformer draw any current when secondary is open? Why?

Yes, it(primary) will draw the current from the main supply in order to magnetize the core and to supply for iron and copper losses on no load. There will not be any current in the secondary since secondary is open.

11. Explain on the material used for core construction?

The core is constructed by sheet steel laminations assembled to provide a continuous magnetic path with minimum of air gap included. The steel used is of high silicon content sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities. The eddy current loss is minimized by laminating the core, the laminations being used from each other by light coat of core-plate vanish or by oxide layer on the surface. The thickness of lamination varies from 0.35mm for a frequency of 50Hz and 0.5mm for a frequency of 25Hz.

12. What is the angle by which no-load current will lag the ideal applied voltage?

In an ideal transformer, there are no copper & core loss i.e. loss free core. The no load current is only magnetizing current therefore the no load current lags behind by angle 900. However the winding possess resistance and leakage reactance and therefore the no load current lags the applied voltage slightly less than 900.

13. Can the voltage regulation go –ive? If so under what condition?

Yes, if the load has leading PF.

14. Distinguish power transformers & distribution transformers?

Power transformers have very high rating in the order of MVA. They are used in generating and receiving stations. Sophisticated controls are required. Voltage ranges will be very high. Distribution transformers are used in receiving side. Voltage levels will be medium. Power ranging will be small in order of kVA. Complicated controls are not needed.

15. Name the factors on which hysteresis loss depends?

1. Frequency 2. Volume of the core 3. Maximum flux density

16. Why the open circuit test on a transformer is conducted at rated voltage?

The open circuit on a transformer is conducted at a rated voltage because core loss depends upon the voltage. This open circuit test gives only core loss or iron loss of the transformer.

17. What is the purpose of providing Taps in transformer and where these are provided? Nov'2013

In order to attain the required voltage, taps are provided, normally at high voltage side (low current).

18. Distinguish power transformers & distribution transformers?

Power transformers have very high rating in the order of MVA. They are used in generating and receiving stations. Sophisticated controls are required. Voltage ranges will be very high. Distribution transformers are used in receiving side. Voltage levels will be medium. Power ranging will be small in order of kVA. Complicated controls are not needed.

19. Define variable frequency transformer? April 2015

A variable frequency transformer consists of a rotary transformer for continuously controllable phase shift, together with a drive system and control that adjust the angle and speed of the rotary transformer to regulate the power flow. It allows control of the power flow between two networks.

20. Define Audio frequency transformer? April 2015, Nov' 2014

Audio Frequency (AF) Transformers work at frequencies between about 20Hz to 20kHz and are used in audio amplifier circuits, they were essential in valve (tube) designs for matching the high impedance outputs of theses amplifiers to low impedance loudspeakers.

21. Distinguish between two winding transformer and auto transformer April 2015

Auto transformer

In practice it is possible to use only one winding for the auto transformer so that part of this winding is common to the primary and secondary. Such a special type of transformer having only one winding such that part of the winding is common to the primary and secondary is called autotransformer.

Two winding transformer

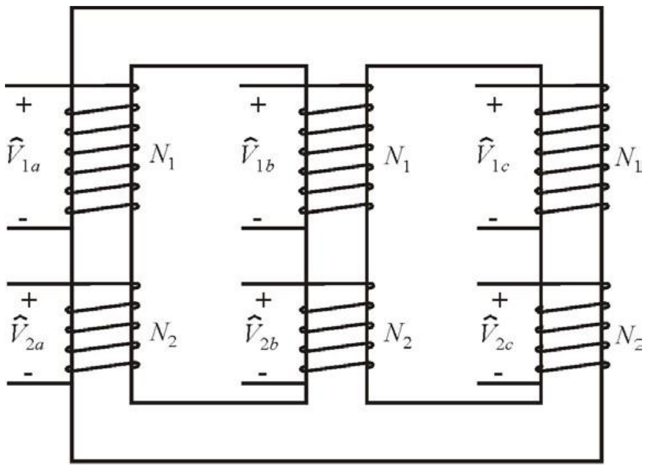
In ordinary transformer two windings are electrically connected and it works on the principle of conduction as well as induction. Such an autotransformer is very much economical where the voltage ratio is less than 2 and the electrical isolation of the two windings is not necessary. The power transfer in 2 winding transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

22. The Δ-Y connection is employed where it is necessary to step up the voltage April 2014

- The main use of this connection is to step up the voltage i.e. at the beginning of high tension transmission system. It can be noted that there is a phase shift of 30° between primary line voltage and secondary line voltage as leading.
- As secondary side is star connected, use of three phase, four wire system is possible.
- Thus single phase and three phase loads can be supplied with this type of connection.

23. Write the short notes on 3 phase auto transformer. April 2014

- Transformer power levels range from low-power applications, such as consumer electronics power supplies to very high power applications, such as power distribution systems. For higher-power applications, three-phase transforms are commonly used. The typical construction of a three-phase transformer is shown in Figure



- The detailed analysis of this circuit is not straightforward since there are numerous combinations of flux paths linking various windings. For this reason, the three-phase transformer will be modeled as three independent single-phase transformers.
- The common core three-phase transformer also requires much less external wiring than the bank of single phase transformers and can typically achieve a higher efficiency.

24. What is onload tap changing transformer ? Nov'2014

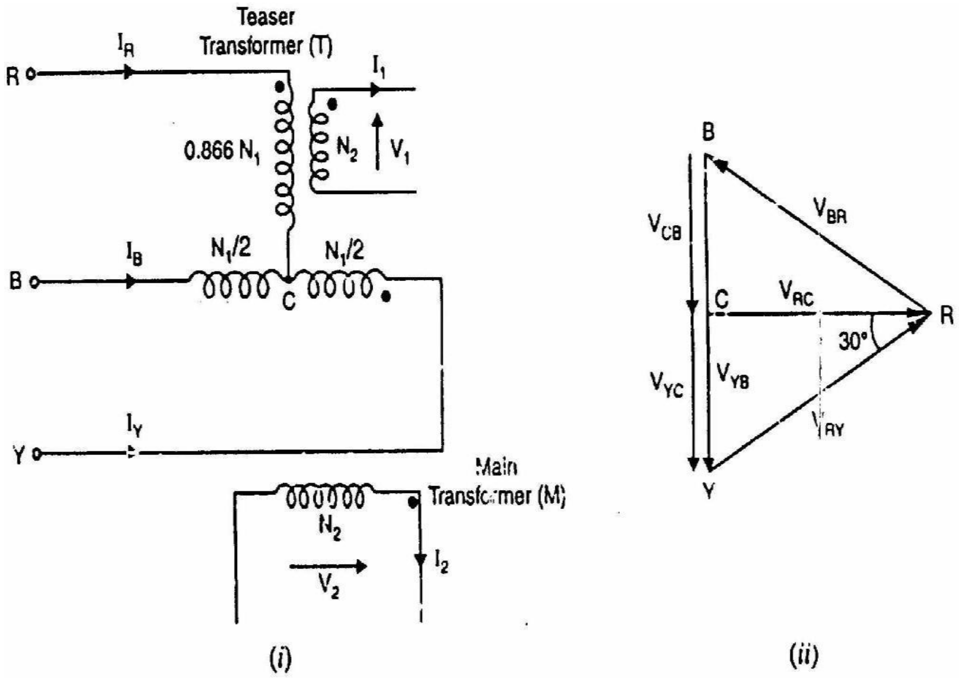
Under the load conditions, it is required to maintain the voltage on the secondary side of the transformer with the help of certain arrangement when transformer is connected to a system. If this arrangement works without making the load off from the transformer then it is called on load tap changing. Without interruption in the supply, the tap changing gear should change the turns ratio.

25. What are the phase conversions available in 3 phase transformer? Nov'2013

- Three-phase to two-phase conversion and vice-versa
- Scott connection or t – t connection
- Open-delta or v –v connection
- Zigzag connection
- Le blanc connection

26. Draw the scott type of connections in poly phase transformer. April 2013

Scott connection of two single-phase transformers enables us to convert 3-phase supply to 2-phase supply.



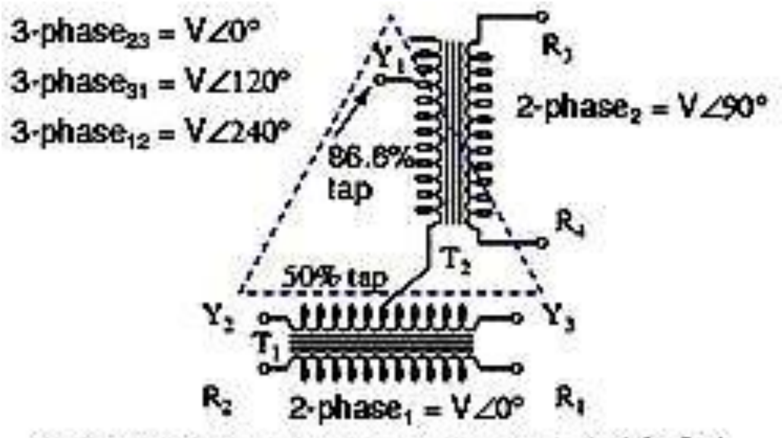
27. What are the conditions for parallel operations of 3 phase transformer? April 2013

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance. These are the conditions for **parallel operation of transformers**.

1. Same voltage ratio of transformer.
2. Same percentage impedance.
3. Same polarity.
4. Same phase sequence.

28. Define teaser transformer April 2012

Assuming the desired voltage is the same on the two and three phase sides, the Scott-T **transformer**connection (shown right) consists of a centre-tapped 1:1 ratio main **transformer**, T1, and an 86.6% (0.5√3) ratio**teaser transformer**, T2.



29. It is practicable to connect the instrument and meters directly to the lines in high voltage circuit (yes/no) April 2012.

No, with the help of current transformer and potential transformers instruments and meters are connected to the high voltage line in order to avoid the damage of meters.

30. What is the function of tertiary winding in a 3 phase transformer? Nov'2012

In some high rating transformer, one winding in addition to its primary and secondary winding is used. This additional winding, apart from primary and secondary windings, is known as Tertiary winding of transformer. Because of this third winding, the transformer is called three winding transformer or 3 winding transformer.

Tertiary winding is provided in electrical power transformer to meet one or more of the following requirements

1. It reduces the unbalancing in the primary due to unbalancing in three phase load.
2. It redistributes the flow of fault current.
3. Sometime it is required to supply an auxiliary load in different voltage level in addition to its main secondary load. This secondary load can be taken from tertiary winding of three winding transformer.
4. As the tertiary winding is connected in delta formation in 3 winding transformer, it assists in limitation of fault current in the event of a short circuit from line to neutral.

11 Marks

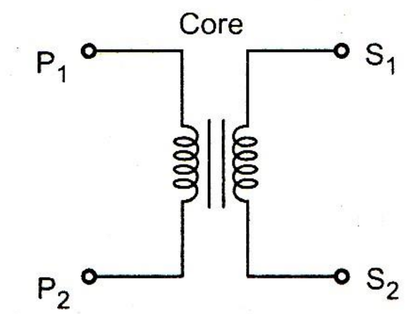
1. Explain the construction of an auto transformer. Nov' 2014

Uptill now the two winding transformers are discussed in which the windings are electrically isolated and the e.m.f. in secondary gets induced due to induction. In practice it is possible to use only one winding for the transformer so that part of this winding is common to the primary and secondary. Such a special type of transformer having only one winding such that part of the winding is common to the primary and secondary is called autotransformer. Obviously the two windings are electrically connected and it works on the principle of conduction as well as induction. Such an autotransformer is very much economical where the voltage ratio is less than 2 and the electrical isolation of the two windings is not necessary. The power transfer in 2 winding transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

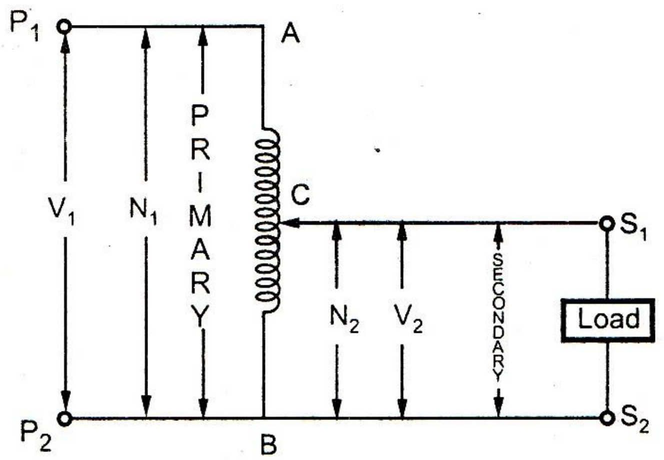
CONSTRUCTION

In an autotransformer only one winding is wound on a laminated magnetic core while in 2 winding transformer, two windings are wound. The single winding of the autotransformer is used as primary and secondary. The part of the winding is common to both primary and secondary. The voltage can be stepped down or stepped up using an autotransformer. Accordingly the autotransformers are classified as step-up autotransformer and step-down autotransformer.

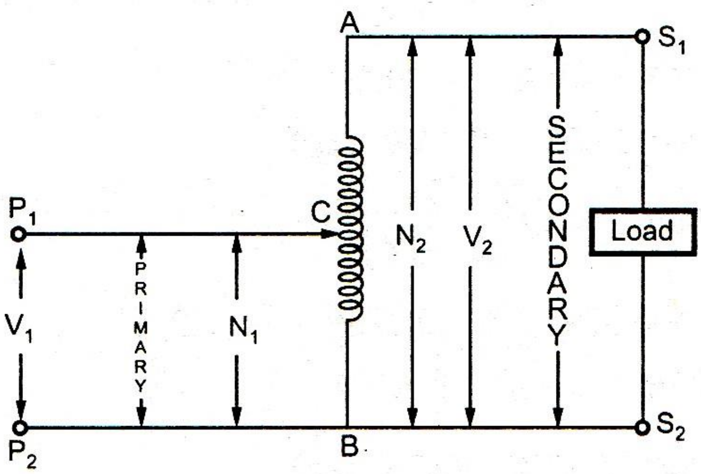
The Fig. 5.1 (a) shows the conventional two winding transformer while the Fig. 5.1 (b) and (c) show the step down and step up autotransformers respectively.



(a) 2 winding transformer



(b) step-down autotransformer

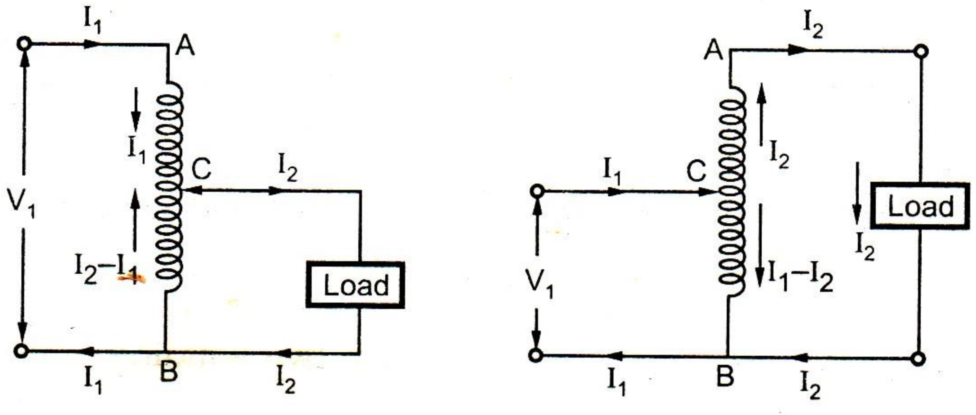


(c) Step up autotransformer

Fig. 5.1 Autotransformer

In step down autotransformer shown in the Fig. 5.1 (b), the entire winding acts as a primary while the part of the Winding is used common to both primary and secondary. Thus AB forms the primary having N1 turns while BC forms the secondary with N2 turns. As $N_2 < N_1$, the output voltage $V_2 < V_1$ and it acts as a step-down auto transformer. In step-up autotransformer shown in the Fig. 5.1 (c), the entire winding acts as secondary while the part of the winding is used common to both primary and secondary. Thus AB forms the secondary having N_2 turns while BC forms the primary with N_1 turns. As $N_2 > N_l$, the output voltage $V_2 > V_1$ and it acts as a step-up autotransformer.

The current distribution in the step down and step up autotransformers is shown in the Fig. 5.2 (a) and (b) respectively.



(a) step-down autotransformer (b) step up autotransformer

Fig. 5.2 Current distribution in autotransformer

TRANSFORMATION RATIO OF AN AUTOTRANSFORMER

Neglecting the losses, the leakage reactance and the magnetising current, the transformation ratio of an autotransformer can be obtained as,

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

K is greater than unity for step-up autotransformer while K is less than unity for step down autotransformer. `

Due to the use of single winding, compared to the normal two winding transformer, for the same capacity and voltage ratio, there is substantial saving in copper in case of autotransformers.

Let us obtain the expression for the copper saving in the autotransformers.

2. Derive an expression to find out the weight of copper saving in an auto transformer. **April 2015**

COPPER SAVING IN AUTOTRANSFORMER

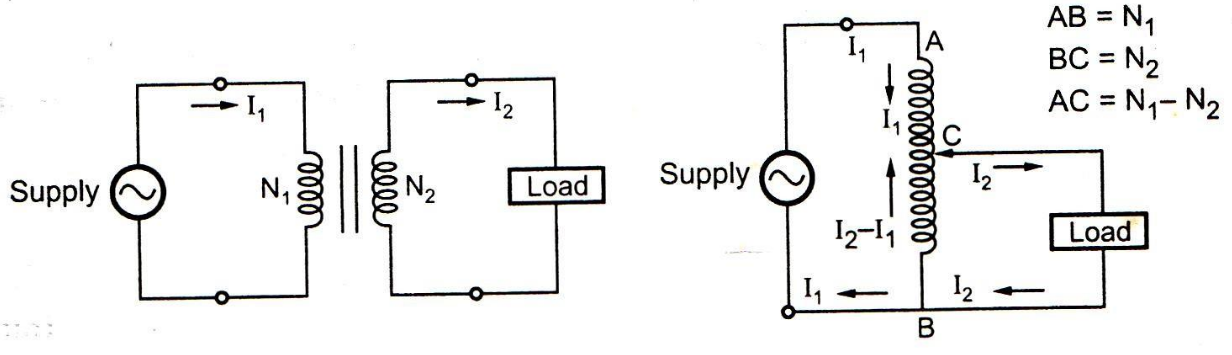
For any winding, the cross-section of winding is proportional to the current I. While the total length of the winding is proportional to the number of turns N. Hence the weight of copper is proportional to the product of N and I.

∴ Weight of copper α NI

Where I = current in the winding

and N = number of turns of the winding

Consider a two winding transformer and step-down autotransformer as shown in Fig. 5.3 (a) and (b).



(a) Two winding transformer (b) Step down transformer

Fig.5.3

Let W_{TW} = total weight of copper in two winding transformer

W_{AT} = weight of copper in autotransformer

In two winding transformer,

Weight of copper of primary $\alpha\ N_1 I_1$

Weight of copper of secondary $\alpha\ N_2 I_2$

$W_{TW}\ \alpha\ N_1I_1 + N_2 I_2$ ….. total weight of Cu

In case of step-down autotransformer.

Weight of copper of section AC $\alpha\ (N_1 - N_2) I_1$

Weight of copper of section BC $\alpha\ N_2 (I_2 - I_1)$

$W_{AT}\ \alpha\ (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ …..total weight of Cu

Taking ratio of the two Weights,

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + N_2 I_2}{(N_1 - N_2)I_1 + N_2(I_2 - I_1)}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 + N_2 I_2 - 2N_2 I_1}$$

But $K = \frac{N_2}{N_1} = \frac{I_1}{I_2}$

$$\therefore \quad \frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + KN_1(\frac{I_1}{K})}{N_1 I_1 + KN_1(\frac{I_1}{K}) - 2KN_1 I_1}$$

$$= \frac{2N_1 I_1}{2N_1 I_1 - 2kN_1 I_1} = \frac{1}{1-K}$$

$\therefore$ $W_{AT} = (1-K)\ W_{TW}$

$\therefore$ Saving of copper $= W_{TW} - W_{AT} = W_{TW} - (1-K)\ W_{TW}$

Saving of copper $= K\ W_{TW}$ ….. For step down autotransformer

Thus saving of copper is K times the total weight of copper in two winding transformer.

And Saving of copper $= \frac{1}{K} W_{TW}$ ….. For step up autotransformer

3. **Explain the construction and principle of operation of transformer on load with vector diagram. Nov'2014.**

THREE-PHASE TRANSFORMER

The generation of an electrical power is usually three phase and at higher voltages like 13.2 kV, 22 kV or somewhat higher. Similarly transmission of an electrical power is also at very high voltages like 110 kV, 132 kV or 400 kV. To step-up the generated voltages for transmission purposes it is necessary to have three phase transformers. At the time of distribution it is necessary to reduce the voltage level upto 6600 V, 440 V, 230 V etc. For which step-down three phase transformers are essential. Thus three phase transformers proves to be economical in transmission and utilization of electrical energy.

Previously it was a common practice to employ suitably interconnected three single phase transformers than to have a single three phase transformer which is popular now a days and used widely. In a single three phase transformer there is improvement in design and manufacture.

Advantages of 3 phase transformer

Some of the advantages of a single three phase transformer are as follows :

1. A three phase transformer occupies less space for same rating, compared to a bank of three single phase transformers.
2. It weighs less.
3. Its cost is less.
4. Only one unit is required to be handled which makes it easy for the operator.
5. It can be transported easily.
6. The core will be of smaller size and the material required for the core is less.
7. Single three phase unit is more efficient.
8. In case of three single phase units, six terminals are required to be brought out while in case of one three phase unit, only three terminals are required to be brought out.
9. The overall busbar structure, switchgear and installation of single three phase unit is simpler.

6.2 Construction of Three Phase Transformers

The three phase transformers can be core type or shell type. The three core type single phase transformers can be combined to get three phase core type transformers. Similarly three single phase shell type transformers can be combined together to form a three phase shell type transformer.

6.2.1 Core Type Construction

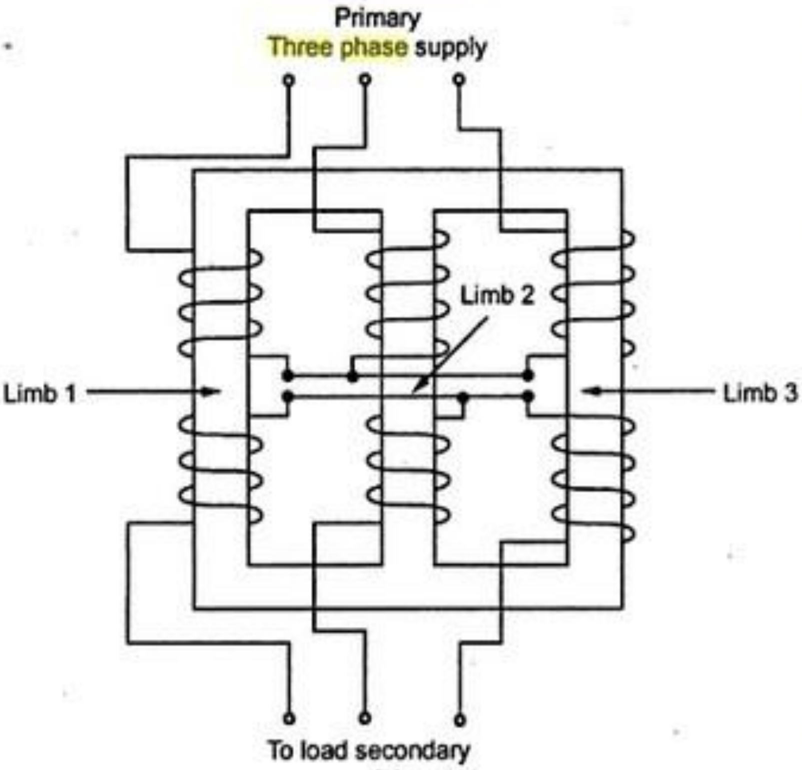


Fig. 6.1

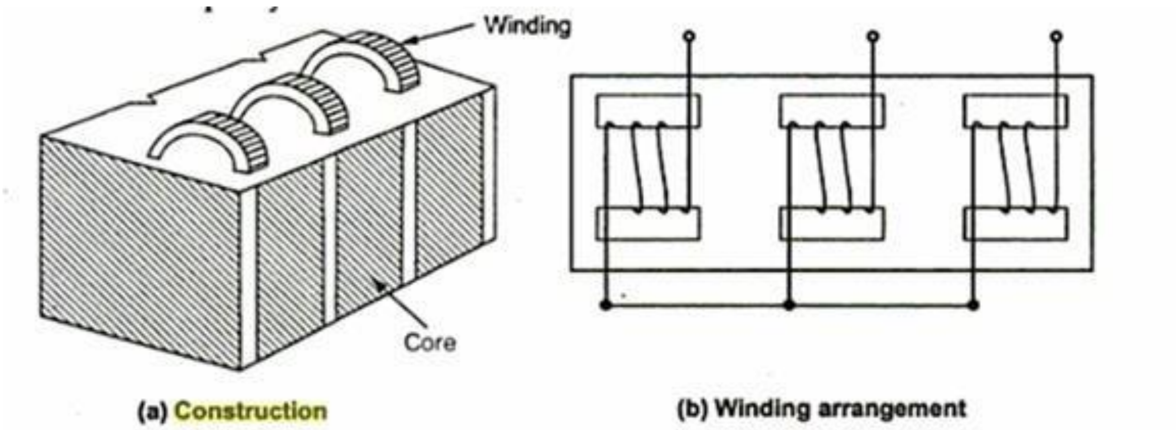
Core type three phase transformer has three limb construction as shown in the Fig. 6.1.

The core consists of three legs with the magnetic circuit completed through two yokes, one at the top and the other at the bottom. Each limb has primary and secondary winding arranged concentrically. The core type transformers usually wound with circular cylindrical coils.

A primary and a secondary winding of one phase are wound on one leg. Flux flows up each leg in turn and down the other two legs in general so that the magnetic circuits of different phases are in series and therefore independent. The transformer is having only two windows each of which is containing two primary and two secondary windings.

6.2.2 Shell Type Construction

In shell type transformer the three phases are more independent than they are in the core type of three phase transformer. This is because each phase has an individual magnetic circuit which is independent of the other. The construction of shell type three phase transformer is shown in the Fig. 6.2 (a), while the arrangement of the windings is shown in the Fig. 6.2 (b). While showing the winding arrangement only one winding is shown for the simplicity.



(a) Construction (b) Winding arrangement

Fig. 6.2

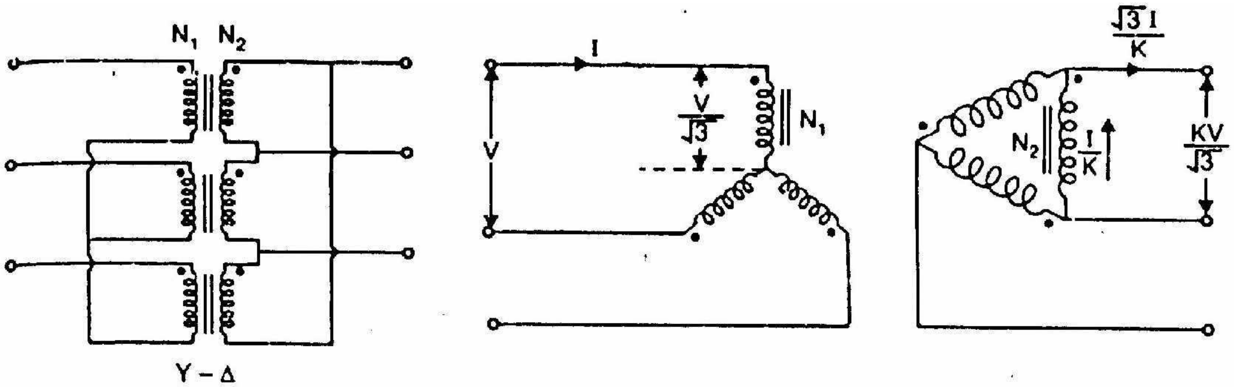
PRINCIPLE OF OPERATION

Three phase voltages are raised or lowered by means of three-phase transformers. A three-phase transformer can be built in two ways viz., (i) by suitably connecting a bank of three single-phase transformers or (ii) by constructing a three-phase transformer on a common magnetic structure. In either case, the windings may be connected in Y □□Y, □□□□□, Y □□□□or □□□□Y.

(I) BANK OF THREE SINGLE-PHASE TRANSFORMERS

Three similar single-phase transformers can be connected to form a three-phase transformer. The primary and secondary windings may be connected in star (Y) or delta (□) arrangement. Fig. (5.4 (i)) shows a Y - □□connection of a three phase transformer. The primary windings are connected in star and the secondary windings are connected in delta. A more convenient way of showing this connection is illustrated in Fig. (5.4 (ii)). The ratio of secondary phase voltage to primary phase voltage is the phase transformation ratio K.

Phase transformation ratio, $K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{N_2}{N_1} = \frac{I_{P1}}{I_{P2}}$



(i) **(ii)**

Fig. 5.4

Referring to Fig. (5.4 (ii)), primary line-to-line voltage is V and the primary line current is I. The phase transformation ratio is K (= N2/N1). The secondary line voltage and line current are also shown.

(II) THREE-PHASE TRANSFORMER

A three-phase transformer can be constructed by having three primary and three secondary windings on a common magnetic circuit. The basic principle of a 3-phase transformer is illustrated in Fig. (5.5 (i)). The three single-phase core type transformers, each with windings (primary and secondary) on only one leg have their unwound legs combined to provide a path for the returning flux.

The primaries as well as secondaries may be connected in star or delta. If the primary is energized from a 3-phase supply, the central limb (i.e., unwound limb) carries the fluxes produced by the 3-phase primary windings. Since the phasor sum of three primary currents at any instant is zero, the sum of three fluxes passing through the central limb must be zero. Hence no flux exists in the central limb and it may, therefore, be eliminated.

This modification gives a three leg core type 3-phase transformer. In this case, any two legs will act as a return path for the flux in the third leg. For example, if flux is □□in one leg at some instant, then flux is □/2 in the opposite direction through the other two legs at the same instant. All the connections of a 3-phase transformer are made inside the case and for delta-connected winding three leads are brought out while for star connected winding four leads are brought out.

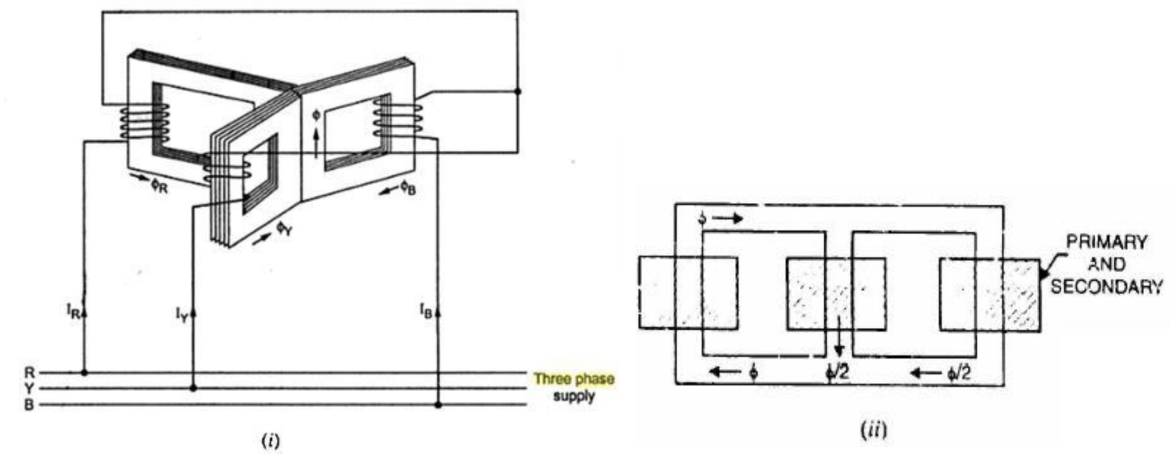


Fig. 5.5

For the same capacity, a 3-phase transformer weighs less, occupies less space and costs about 20% less than a bank of three single-phase transformers.

Because of these advantages, 3-phase transformers are in common use, especially for large power transformations.

A disadvantage of the three-phase transformer lies in the fact that when one phase becomes defective, the entire three-phase unit must be removed from service. When one transformer in a bank of three single-phase transformers becomes defective, it may be removed from service and the other two transformers may be reconnected to supply service on an emergency basis until repairs can be made.

4. **List the four possible ways of connecting a bank of 3 phase service. Explain them in detail with connection and vector diagram, and current and voltage relationship.April 2015**
5. **Explain with the help of connection and phasor diagrams, the Star – star and delta – delta connection of 3 phase transformer and also bring out their advantages. Nov'2012**
6. **Explain the construction details and working of various types of 3 phase transformers Nov'2014**

THREE-PHASE TRANSFORMER CONNECTIONS

A three-phase transformer can be built by suitably connecting a bank of three single-phase transformers or by one three-phase transformer. The primary or secondary windings may be connected in either star (Y) or delta (□) arrangement. The four most common connections are (i) Y ~~Y (ii) □ -□□(iii) Y -□□and (iv) □~~ Y.

$$K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{V_{Ph2}}{V_{Ph1}} = \frac{N_2}{N_1}$$

1. Y-Y CONNECTION.

In the Y-Y connection 57.7% (or 1/ $\sqrt{3}$) of the line voltage is impressed upon each winding but full line current flows in each winding. There will be a phase shift of 30º between the phase voltage and line voltage on both primary and secondary side. The line voltages on both the sides are in phase with each other.

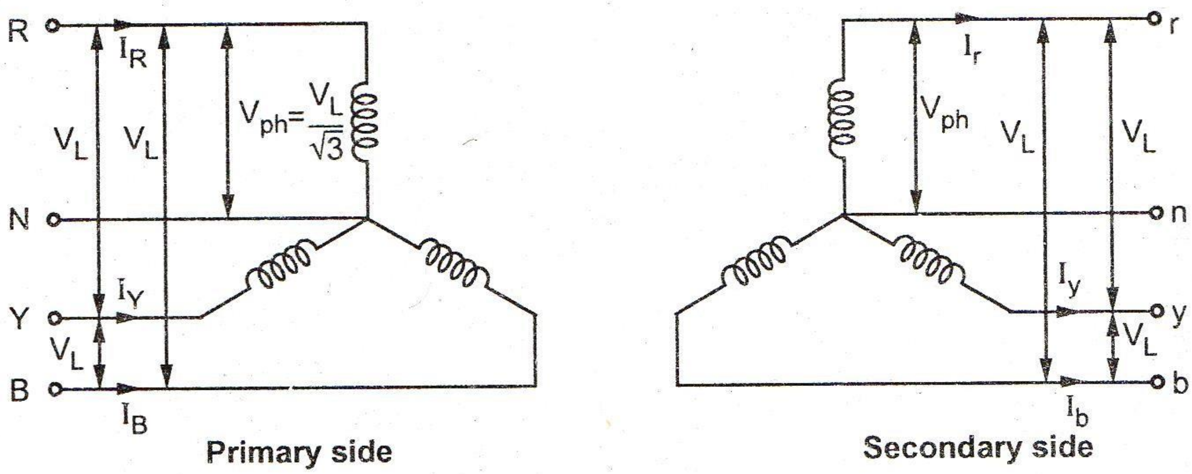


Fig. 5.6 Star-Star connection

The voltages on primary and secondary sides can be represented on the phasor diagram as shown below.

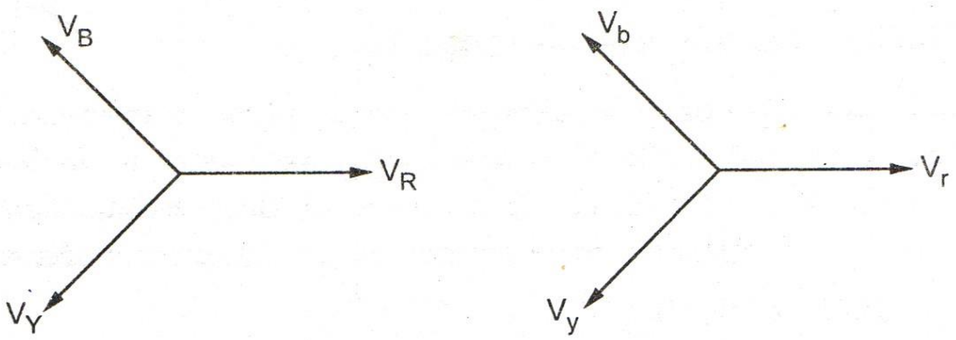


Fig. 5.7 Y-Y Connection

If V_{L1} is the line voltage on the primary side then phase voltage on primary side is given as,

$$V_{ph1} = \frac{V_{L1}}{\sqrt{3}}$$

If K is the turns ratio or transformation ratio then phase voltage on secondary side is given as, Secondary phase voltage,= $V_{ph2} = K(\frac{V_{L1}}{\sqrt{3}})$ as $\frac{V_{Ph2}}{V_{Ph1}} = K$

Note : Suffix 1 indicates primary side whereas suffix 2 indicates secondary side The line voltage V_{L2} on secondary side is given as,

$V_{L2} = \sqrt{3} V_{Ph2} = \sqrt{3}\, K\, (\frac{V_{L1}}{\sqrt{3}}) = K\, V_{L1}$

Key Point: The line voltage on secondary side is K times line voltage on primary side.

Advantages

1. 1. Due to star connection, phase voltage is $\frac{1}{\sqrt{3}}$ times line voltage. Hence less number of turns are required. Also the stress on insulation is less. This main connection economical for small high voltage purposes.
2. Due to star connection, phase current is same as line current. Hence windings have to carry high currents. This makes cross section of the windings high. Thus the windings are mechanically strong and windings can bear heavy loads and short circuit.
3. There is no phase shift between the primary and secondary voltages.
4. As neutral is available, it is suitable for three phase, four wire system.

Disadvantages

1. If the load on the secondary side is unbalanced then the performance of this connection is not satisfactory then the shifting of neutral point is possible. To prevent this, star point of the primary is required to be connected to the star of the generator.
2. Eventhough the star or neutral point of the primary is earthed, the third harmonic present in the alternator voltage may appear on the secondary side. This causes distortion in the secondary phase voltages.
3.

Key Point: Due to the disadvantages, this connection is rare in practice and used only for small high voltage transformers.

2. DELTA-DELTA CONNECTION

In this type of connection, both the three phase primary and secondary windings connected in delta.

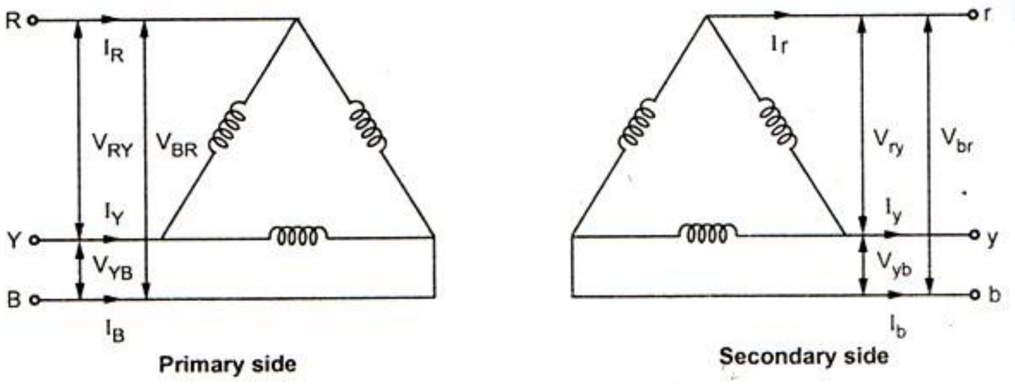


Fig. 5.8 Delta-Delta connection

The voltages on primary and secondary sides can be shown on the phasor diagram shown below.

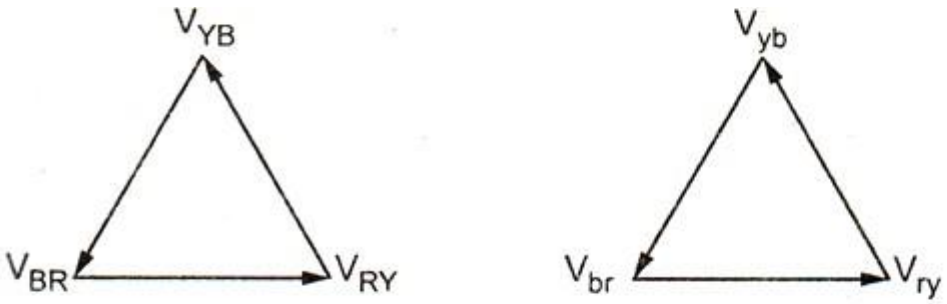


Fig. 5.9

This connection proves to be economical for large low voltage transformers as it increases number of turns per phase.

Key Point: It can be seen that there is no phase shift between primary and secondary voltages.

Let

V_{L1}= Line voltage on primary side

V_{L2}= Line voltage on secondary side

V_{ph1}= Phase voltage on primary side

V_{ph2}= phase voltage on secondary side

K = Transformation ratio

For delta connection, $V_{L1} = V_{ph1}$

Now since $\frac{V_{Ph2}}{V_{Ph1}} = K$

$\therefore V_{Ph2} = KV_{Ph1}$

But again since secondary is connected in delta

$V_{L2} = V_{ph2} = KV_{L1}$

Advantages

1. In order to get secondary voltage as sinusoidal, the magnetizing current of transformer must contain a third harmonic component. The delta connection provides a closed path for circulation of third harmonic component of current. The flux remains sinusoidal which results in sinusoidal voltages.
2. Even if the load is unbalanced the three phase voltages remain constant. Thus it allows unbalanced loading also.
3. The important advantage with this type of connection is that if there is bank of single phase transformers connected in delta-delta fashion and if one of the transformers is disabled then the supply can be continued with remaining two transformers of course with reduced efficiency.
4. There is no distortion in the secondary voltages.
5. Due to delta connection, phase voltage is same as line voltage hence windings

have more number of turns. But phase current is $\frac{1}{\sqrt{3}}$ times the line current. Hence the cross section of the windings is very less. This makes the connection economical for low voltage transformers.

Disadvantage

Due to absence of neutral point it is not suitable for three phase four wire system.

Key Point : The connection is commonly used for large low voltage transformers.

3. STAR-DELTA CONNECTION

In this type of connection, the primary is connected in star fashion while the secondary is connected in delta fashion as shown below.

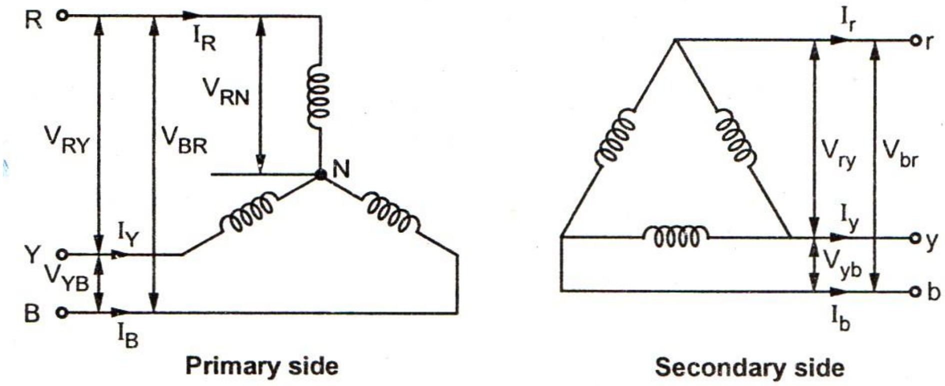


Fig. 5.10

The voltages on primary and secondary sides can be represented on the phasor diagram as shown below.

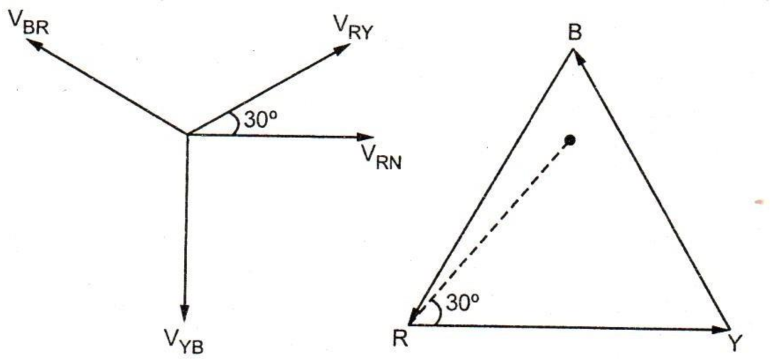


Fig. 5.11

This type of connection is commonly employed at the substation end of the transmission line. The main use with this connection is to step down the voltage. The neutral available on the primary side is grounded. It can be seen that there is phase difference of 30° between primary and secondary line voltages.

Key Point: The delta connection on secondary side allows third harmonic current to flow which provides a sinusoidal flux.

Let

V_{L1}= Line voltage on primary side

$V_{L\ 2}$= Line voltage on secondary side

V_{phl} = Phase voltage on primary side

V_{ph2} = Phase voltage on secondary side

K = Transformation ratio

$$V_{Ph1} = \frac{V_{L1}}{\sqrt{3}}$$

Now $\frac{V_{Ph2}}{V_{Ph1}} = K$

$\therefore$ $V_{Ph2} = K\,V_{Ph1} = K\,\frac{V_{L1}}{\sqrt{3}}$

Since secondary is connected in delta

$V_{ph2} = V_{L2}$

$\therefore V_{L2} = K\,\frac{V_{L1}}{\sqrt{3}} = (\frac{K}{\sqrt{3}})V_{L1}$

The connection suffers no problems due to unbalanced load as secondaries are connected in delta. This type of transformers are commonly employed at receiving end.

Advantages

1. The primary side is star connected. Hence fewer number of turns are required. This makes the connection economical for large high voltage step down power transformers.
2. The neutral available on the primary can be earthed to avoid distortion.
3. Large unbalanced loads can be handled satisfactorily.

Disadvantage

In this type of connection, the secondary.voltage is not in phase with the primary. Hence it is not possible to operate this connection in parallel with star-star or delta connected transformer.

4. DELTA-STAR CONNECTION

In this type of connection, the primary is connected in delta fashion while the secondary is connected in star fashion as shown below.

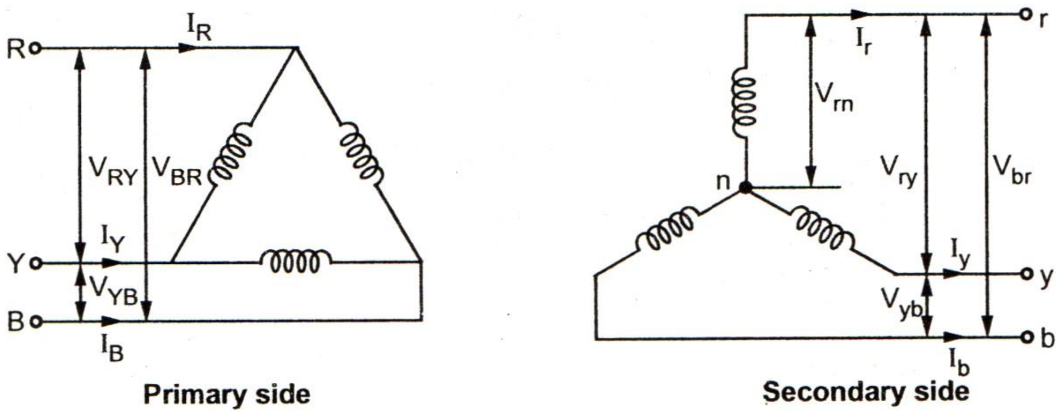


Fig. 5.12

The voltages on primary and secondary side can be represented on the phasor diagram as shown in the Fig below.

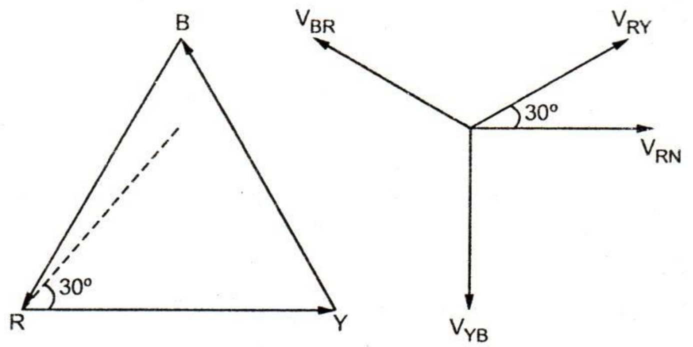


FIG. 5.13

The main use of this connection is to step up the voltage i.e. at the begining of high tension transmission system. It can be noted that there is a phase shift of 30° between primary line voltage and secondary line voltage as leading.

Key Point: As secondary side is star connected, use of three phase, four wire system is possible.

Thus single phase and three phase loads can be supplied with this type of connection.

Let

V_{L1} = Line voltage on primary side

V_{L2} = Line voltage on secondary side

V_{Ph1}= Phase voltage on primary side

V_{ph2} = Phase voltage on secondary side

K = Transformation ratio.

As primary is delta connected,

$$V_{L1} = V_{Ph1}$$

Now $$\frac{V_{Ph2}}{V_{Ph1}} = K$$

$\therefore$ $$V_{Ph2} = KV_{Ph1}$$

Here secondary is connected in star

$$V_{L2} = \sqrt{3}\, V_{ph2}$$

$$\therefore\ V_{L2} = (\sqrt{3}K)\, V_{Ph1}$$

$$\therefore\ V_{L2} = (\sqrt{3}K)\, V_{L1}$$

Advantages

1. On primary side due to delta connection winding cross-section required is less.
2. On secondary side, neutral is available, due to which it can be used for 3 phase, 4 wire supply system.
3. There is no distortion due to third harmonic components.
4. The windings connected in star makes it economical due to saving in cost of insulation.
5. Large unbalanced loads can be handled without any difficulty.

Disadvantage

Due to phase shift between primary and secondary voltages, the limitation of Star-Delta connection continues for this type of connection as well.

Voltage and Current Relationships for Different Types Of Connections

Type of connection	Primary side			Secondary side			
	Line voltage	Phase voltage	Phase current	Phase voltage	Phase current	Line voltage	Line current
Star-Star	V_L	$\frac{V_L}{\sqrt{3}}$	I_L	$\frac{KV_L}{\sqrt{3}}$	$\frac{I_L}{K}$	KV_L	$\frac{I_L}{K}$
Delta-Delta	V_L	V_L	$\frac{I_L}{\sqrt{3}}$	KV_L	$\frac{I_L}{\sqrt{3}K}$	KV_L	$\frac{I_L}{\sqrt{3}}$
Star- Delta	V_L	$\frac{V_L}{\sqrt{3}}$	I_L	$\frac{KV_L}{\sqrt{3}}$	$\frac{I_L}{K}$	$\frac{KV_L}{\sqrt{3}}$	$\frac{I_L}{\sqrt{3}}$
Delta- Star	V_L	V_L	$\frac{I_L}{\sqrt{3}}$	KV_L	$\frac{I_L}{\sqrt{3}K}$	$\sqrt{3}KV_L$	$\frac{I_L}{\sqrt{3}K}$

Choice Of Transformer Connections

Connection	Choice	Remarks
Star-Star	For small H.V transformer	Rarely used.
Delta-Delta	For large L.V transformers	Large load unbalance can be tolerated.
Star- Delta	For power system as a step down transformer	The phase shift of 30° must be taken care of.
Delta- Star	For power system as a step up transformer	

7. Explain the open delta configuration of 3 phase transformer

OPEN DELTA OR V-V CONNECTION

As seen previously in Δ - Δ connection of three single phase transformers that if one of the transformers is unable to operate then the supply to the load can be continued with the remaining two transformers at the cost of reduced efficiency. The connection thus obtained is called V-V connection or open delta connection.

Consider the Fig. 5.14 in which 3 phase supply is connected to the primaries. At the secondary side three equal three phase voltages will be available on no load.

The voltages are shown on phasor diagram. The connection is used when the three phase load is very very small to warrant the installation of full three phase transformer.

If one of the transformers fails in Δ - Δ bank and if it is required to continue the supply eventhough at reduced Capacity until the transformer which is removed from the bank is repaired or a new one is installed then this type of connection is most suitable.

When it is anticipated that in future the load will increase, then it requires closing of open delta. In such cases open delta connection is preferred.

Key Point: It can be noted here that the removal of one of the transformers will not give the total load carried by V - V bank as two third of the capacity of Δ - Δ bank.

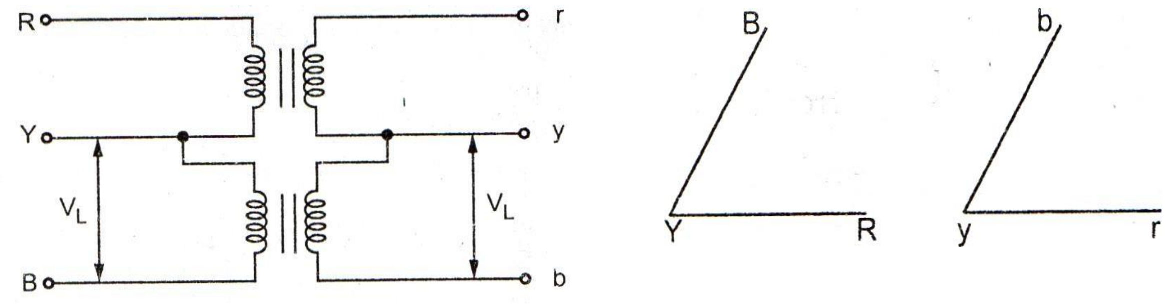


Fig. 5.14

The load that can be carried by V - V bank is only 57.7 % of it. It can be proved as follows.

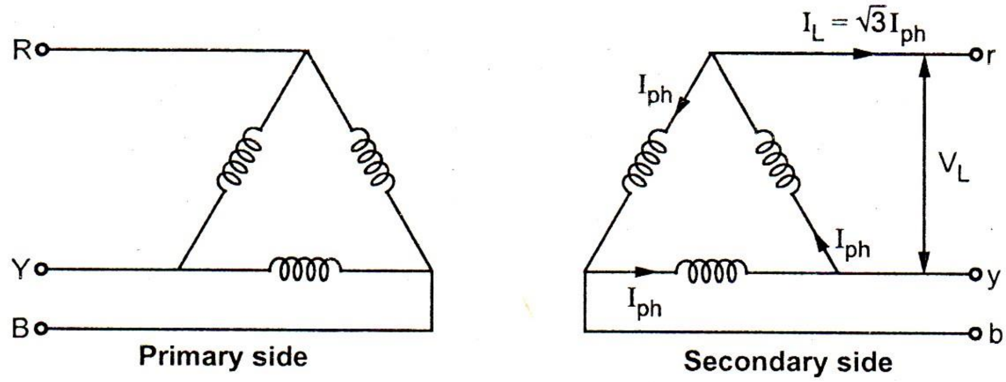


Fig. 5.15 (a) Δ – Δ connection

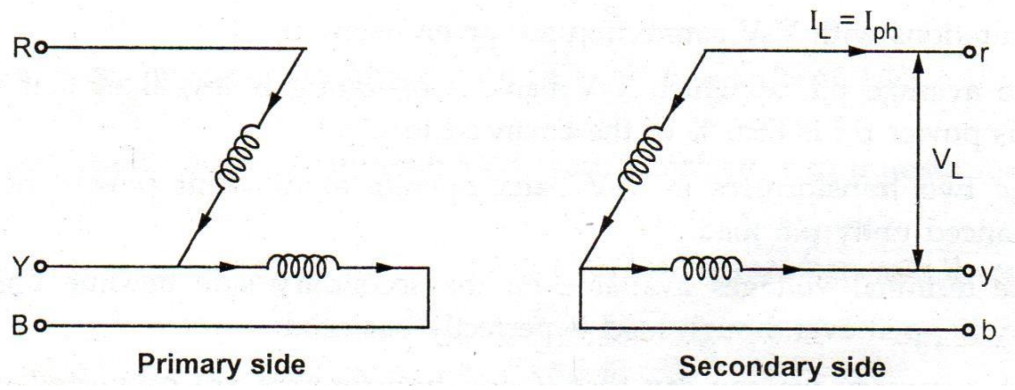


Fig. 5.15 (b) V - V connection

It can be seen from the Fig. 5.15 (a)

$$\Delta - \Delta \text{ capacity} = \sqrt{3}\, V_L\, I_L = \sqrt{3} V_L\, (\sqrt{3} I_{ph})$$

$$\Delta - \Delta \text{ capacity} = 3 V_L\, I_{ph} \qquad \ldots \text{(i)}$$

It can also be noted from the Fig. 5.15 (b) that the secondary line current I_L is equal to the phase current I_{ph}.

V-V capacity = $\sqrt{3}$ V_L I_L =$\sqrt{3}V_L$ I_{ph} ...(ii)

Dividing equation (ii) by equation (i)

$\frac{V-V\ capacity}{\Delta-\Delta\ capacity} = \frac{\sqrt{3}V_L\ I_{ph}}{3V_L\ I_{ph}} = \frac{1}{\sqrt{3}}$ = 0.557 = 58 % …(iii)

Thus the three phase load that can be carried without exceeding the ratings of the transformers is 57.7 percent of the original load. Hence it is not 66.7 % which was expected otherwise.

The reduction in the rating can be calculated as $\frac{66.67-57.735}{57.735}$X1OO = 15.476

Suppose that we consider three transformers connected in Δ – Δ fashion and Supplying their rated load. Now one transformer is removed then each of the remaining two transformers will be overloaded. The overload on each transformer will be given as,

$\frac{Total\ load\ in\ V-V}{VA\ /\ transformer} = \frac{\sqrt{3}V_L\ I_{ph}}{V_L\ I_{ph}} = \sqrt{3}$ = 1.732

Key Point: This overload can be carried temporarily if provision is made to reduce the load otherwise overheating and breakdown of the remaining two transformers would take place.

Limitations

The limitations with V-V connection are given below :

1. The average p.f. at which V-V bank is operating is less than that with the load. This p.f is 86.6 % of the balanced load p.f.
2. The two transformers in V-V bank operate at different power factor except for balanced unity p.f. load.
3. The terminal voltages available on the secondary side become unbalanced. This may happen eventhough load is perfectly balanced.

Thus in summary we can say that if two transformers are connected in V-V fashion and are loaded to rated capacity and one transformer is added to increase the total capacity by $\sqrt{3}$ or 173.2 %. Thus the increase in capacity is 73.2 % when converting from a V - V system to a Δ – Δ system.

With a bank of two single phase transformers connected in V-V fashion supplying a balanced 3 phase load with cos Φ as p.f., one of the transformer operates at a p.f. of cos (30 - Φ) and other at cos (30 + Φ). The powers of two transformers are given by,

$$P1 = kVA\cos(30-\Phi)$$
$$P2 = kVA\cos(30+\Phi)$$

8. Give connection diagram and explain the working of Scott connection. Mention its applications. Nov'2014

SCOTT CONNECTION OR T-T CONNECTION

Although there are now no 2-phase transmission and distribution systems, a 2-

phase supply is sometimes required (eg. Furnaces). We can convert 3-phase supply into 2-phase supply through scott or T-T connection of two single-phase transformers. One is called the main transformer M which has a centre-tapped primary; the centre-tap being C.

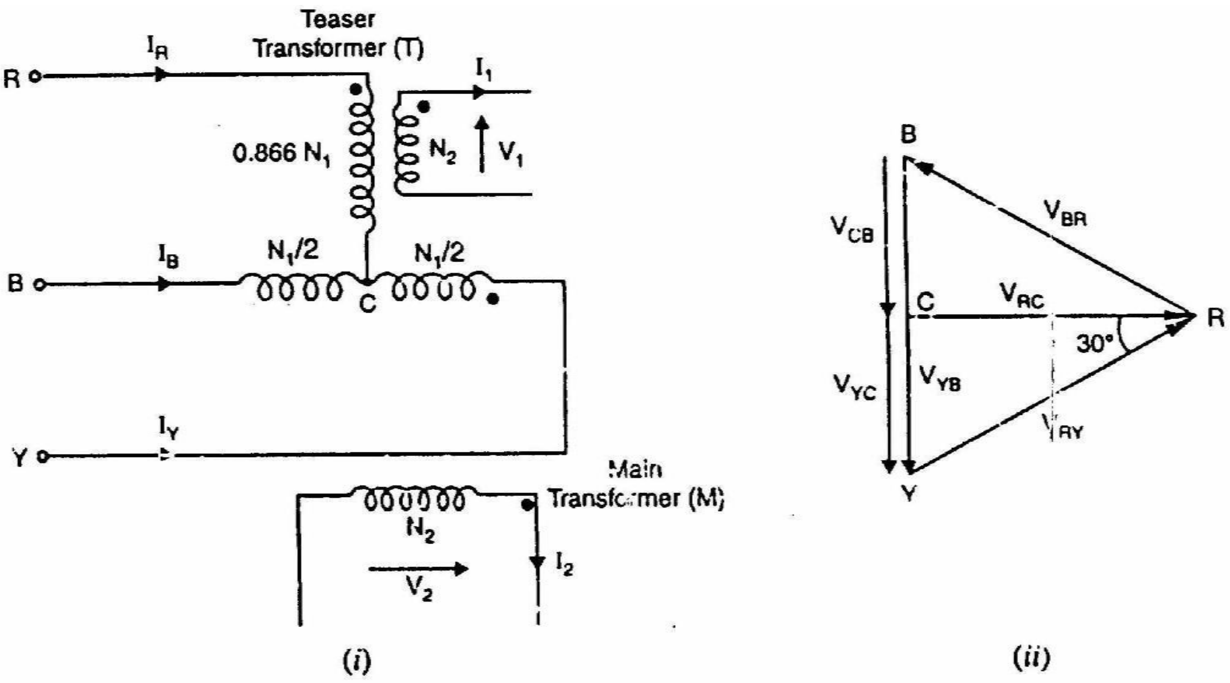


Fig. 5.15

The primary of this transformer has N1 turns and is connected between the terminals B and Y of the 3-phase supply. The other transformer is called teaser transformer T and its primary has 0.866 N1 turns. One end of this primary is connected to centre-tap C and the other end to the terminal R of the 3-phase supply. The number of turns (N2) of the secondary windings of the two transformers are equal. As we shall see, the voltages across the secondaries are equal in magnitude having a phase difference of 90°. Thus scott connection of two single-phase transformers enables us to convert 3-phase supply to 2-phase supply.

Theory

Referring to Fig. 5.15 (i), the centre-tapped primary of the main transformer has line voltage VYB applied to its terminals. The secondary terminal voltage V2 of the main transformer is

$$V_2 = \frac{N_2}{N_1} = V_{BY} = \frac{N_2}{N_1} V_L \qquad (V_L = \text{Line voltage})$$

Fig. 5.15 (i) shows the relevant phasor diagram. The line voltages of the 3-phase system V_{RY}, V_{YB} and V_{BR} are balanced and are shown on the phasor diagram as a closed equilateral triangle. The voltages across the two halves of the centre tapped primary of the main transformer, V_{CB} and V_{YC} are equal and in phase with

V_{YB}. Clearly, V_{RC} leads V_{YB} by 90°. This voltage (i.e., V_{RC}) is applied to the primary of the teaser transformer.Therefore, the secondary voltage V_1 of the teaser transformer will lead the secondary voltage V_2 by 90° as shown in Fig. 5.16. We now show that magnitudes of V_2 and V_1 are equal,

$$V_{RC} = V_{RY} \cos 30° = \frac{\sqrt{3}}{2} V_L = 0.866\, V_L$$

$$V_1 = \frac{N_2}{0.866\, N_1} V_{RC} = \frac{N_2}{0.866\, N_1} \times 0.866\, V_L = \frac{N_2}{N_1} V_L = V_2$$

Thus voltages V_1 and V_2 constitute balanced 2-phase system consisting of two voltages of equal magnitude having a phase difference of 90°.

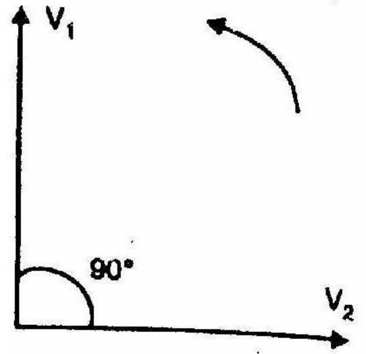


Fig. 5.16

9. **With the help of a neat diagram, explain the working of an on load tap charging mechanism in a transformer for regulated voltage.** April 2015
10. **Write short notes on: (a) On load tap charging** April 2015
11. **Explain the working of an on load tap charging mechanism in a transformer for regulated voltage** Nov'2012

ON LOAD TAP CHANGING

Under the load conditions, it is required to maintain the voltage on the secondary side of the transformer with the help of certain arrangement when transformer is connected to a system. If this arrangement works without making the load off from the transformer then it is called on load tap changing. Without interruption in the supply, the tap changing gear should change the turns ratio.

Normally in case of on load tap changing the tappings are connected at the neutral end of high voltage winding. The tap changer is normally in the form of selector switch. There are various ways by which tap changer is operated viz. motor operated mechanism, remote control or with the help of handle for manual operation in case of emergency.

The most vital factor in case of on load tap changing is continuity of circuit throughout the operation of tap changing. If the circuit is disconnected, the continuity of supply to load will be lost. As the selector switch should not break current, additional separate oil filled compartment is used to mount diverter switch which breaks the load current by interrupted arc which can form carbon. It should not be mixed with the oil in the main tank to decrease its dielectric strength.

The main consideration is that when one tapping is opened, the contact must be established to other tapping. Hence make before break switch is used and in the transition period connection is made to adjacent taps which may result into short circuit of turns between adjacent tappings. This short circuit current can be limited by using resistors or reactors. The reactors which were used in old days are replaced by resistors now.

The on load tap change in shown in the Fig. 5.17 .The selector switch 1 and 2 are provided on taps 1 and 2 respectively. The diverter switch is connecting tap 1 to the neutral terminal of the transformer Winding.

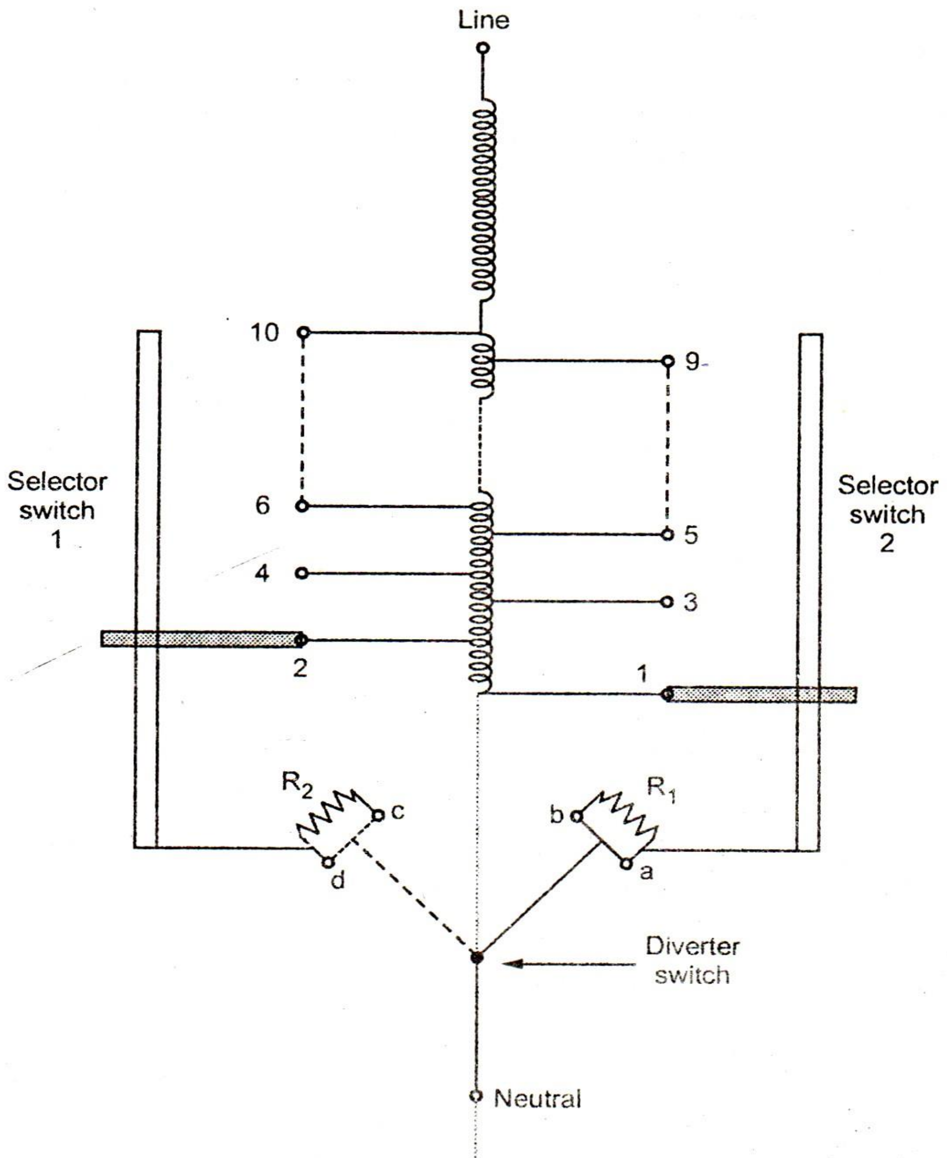


Fig. 5.17 On load tap changer

If we want to change the tap from position 1 to 2 then following is the sequence of operation : _

i. The resistance R1 is short circuited as contacts a and b are closed. The load current flows through contact a from tap. This is nothing but the running position at the tap 1.
ii. With the help of external operating mechanism, the diverter switch' is moved to open the contact a. The load current now flows through resistance R1 and contact b.
iii) The contact c closes to open the resistance R1 when the moving contact of diverter switch continues its movement to the left. The resistances R1 and R2 are now connected across taps 1 and 2 so that the load current flows through these resistances to mid point of junction of b and c.

iv) With further movement of diverter switch to the left makes contact b to open. Now the load current flows from tap 2 through resistance R2 and contact c

v) At last the diverter switch moves to the extreme left position which closes the contact d. This short circuits resistance R_2. The load current flows from tap 2 through Contact d which is the running position of tap 2.

It can be seen that the change of tap from position 1 to 2 does not involve the movement of selector switches 1 and 2. But if it is desired to have further tap change from tap 2 to tap 3 then the selector switch S2 is moved to tap 3 before the movement of diverter switch. Then the same sequence as described above but in reverse order is to be followed and the diverter switch is moved.

As the resistances are included in the circuit there will be some loss of energy which can be reduced by keeping these resistances in circuit for minimum time as possible. For economical considerations, as the resistors are designed for short time rating, they should be kept in the circuit for minimum time. This needs some form of energy storage in driving mechanism which ensures the completion of tap change once initiated under the failure of control supply. Modern on load tap changers use springs as energy storage elements which reduce the time of resistor in a circuit to minimum. This type of tap changer is compact in size while due to high speed breaking, contact wear reduces.

VOLTAGE AND CURRENT TRANSFORMERS

These transformers are designed to meet the specific need of measurement and instrumentation systems, which accepts voltages in the range of 0-120 V and currents upto 5 A. Power system voltages can be as high as 750kv and currents up to several tens of KA. Their measurement requires accurate ratio voltage and current transformations, which is accomplished by potential and current transformers.

(a) Voltage transformer

It is a device that is used to measure high alternating voltage. It is essentially a step-down transformer having small number of secondary turns as shown in Fig.5.17 The high alternating voltage to be measured is connected directly across the primary. The low voltage winding (secondary winding) is connected to the voltmeter.

It must transform the input voltage accurately to output both in magnitude and phase. The impedance presented by the instrument on measurement system to the transformer output terminals is called burden. It is mainly resistive in nature and has large value.

The errors are to be kept within the limit defined, in order to achieve this a PT is designed and constructed to have low leakage reactance, low loss and high magnetizing reactance (low magnetizing current).

Low reactance is achieved by interlacing primary and secondary both on core limb. High magnetizing reactance requires minimum iron path and high permeability steel. Low loss requires low-loss steel and very thin laminations.

Most important thing for low errors is to make the burden (Z_b) as high as possible.

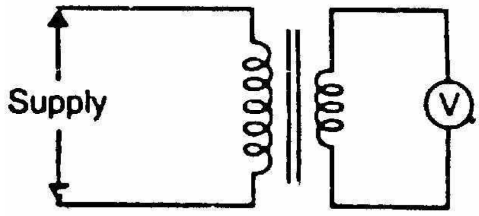


Fig. 5.17 Potential transformer

$$\frac{V_p}{V_s} = \frac{N_1}{N_2}$$

$$V_p = \frac{N_1}{N_2} V_s$$

(b) Current transformer

A current transformer is a device that is used to measure high alternating current in a conductor and provide a step down current to current measuring instruments like an ammeter. Such instruments presents a short-circuit to the CT secondary. It means that burden Z_b=0. Fig. (5.18) illustrates the principle of a current transformer. The conductor carrying large current passes through a circular laminated iron core. The conductor constitutes a single-turn primary winding. The secondary winding consists of a large number of turns of much fine wire wrapped around the core as shown. The secondary is rated 1-5 A.

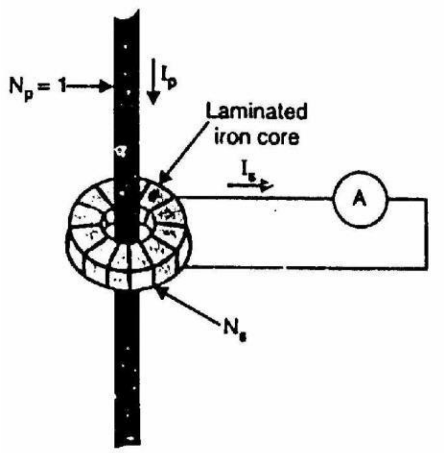


Fig. 5.18 Current transformer

Due to transformer action, the secondary current is transformed to a low value which can be measured by ordinary meters.

Secondary current, $I_s = I_p \times \frac{N_p}{N_s}$

The remedy for errors are same as for a PT discussed earlier in this section.

The burden impedance (which in fact is practically resistive) cannot be allowed to exceed beyond a limit. Most important precaution in use of a CT is that in no case should it be open circuited (even accidentally). As the primary current is independent of the secondary current, all of it acts as a magnetizing current when the secondary is opened. This results in deep saturation of the core which cannot be returned to the normal state and so the CT is no longer usable.

12. Explain the construction and principle of operations of variable frequency transformer. Nov’2014

VARIABLE FREQUENCY TRANSFORMER (VFT)

VFT is a fully bidirectional device that provides a means for controlling power flow between two grids. The two grids need not be synchronous. While primarily designed to move power across an asynchronous interconnection, the VFT also has shown itself to have remarkable stabilizing benefits.

The VFT is composed of rotary transformer, a torque motor and an associated drive and control system.

Construction

The rotary transformer is composed of stator that is very much like a stator of hydro generator. There are laminations of steel stacked inside a stator frame. Winding bars are configured into three phase four pole arrangement. When viewed from outside the lower level of VFT appears to look very much like a hydro generator. Instead of an armature carrying a field, as would be found in a generator. The rotor is constructed in a same manner as the stator. The rotor also contains three phase four pole windings.

One grid is connected to the stator windings, while the other is to the rotor. The net effect is that a circular transformer has been produced, with the windings separated by an air gap. In order to make connection to the rotor and still allow the rotor to turn freely, a slip ring arrangement is necessary.

The VFT contains a device known as the collector. The collector consists of three phases of brushes and large copper rings. The number and size of the elements of a collector are such that the full rating of the machine current can be transferred continuously through the full range of speeds in either direction including zero speed.

Also on the shaft of VFT is a torque motor. This motor is used to align the rotor with respect to the stator and maintain the rotation necessary to bridge the differences in the frequency of the two grids.

Because of the VFT’s unique construction, simply turning of one of the transformer windings with respect to the other can introduce a difference in phase angles, thereby effecting power flow. The angle introduced in the rotor with respect to stator by the torque motor is proportional to the amount of torque applied to the shaft.

$$P \propto T$$

Operation

Consider an example of VFT connecting two asynchronous grids. For this example, they shall be called as grid A and grid B. When both the grids are operating at exactly the same frequency say

50 Hz. The VFT rotor will be stopped. If grid A's frequency increases slightly to 50.1 Hz while grid B's frequency remains constant, the rotor of VFT will turn to allow for this difference. Consider now the condition where grid A's frequency slows down to 49.9 Hz and grid B is still at 50 Hz. The rotor will now be turning in the opposite direction.

13. Write short notes on: High frequency transformer. April 2015

AUDIO-FREQUENCY TRANSFORMER

It is used at the output stage of audio frequency electronic amplifier for matching the load to the output impedance of the power amplifier stage. Here the load is fixed but the frequency is variable over a band (audio, 20 Hz to 20 kHz), the response being the ratio V_2 / V_1. A flat frequency response over the frequency band of interest is most desirable. The corresponding phase angle (angle of V_2 W.r.t. V_1) is called phase response. A small angle is acceptable.

The transformer is used in electronic circuits (control, communication, measurement etc.) for stepping up the voltage or impedance matching. They are normally small in size and have iron cores. It is essential that distortion should be as low as possible.

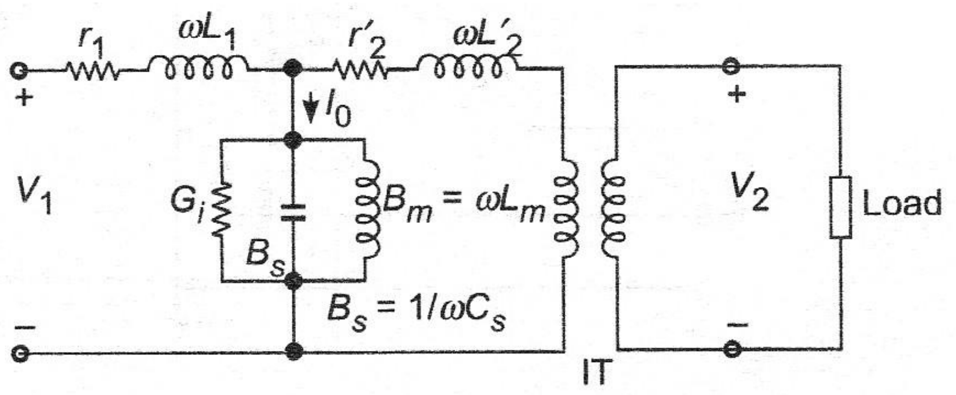


Fig. 5.19

Figure 5.19 shows the exact circuit model of a transformer with frequency variable over a wide range. Here the magnetizing shunt branch is drawn between primary and secondary impedances (resistance and leakage reactance). Also represented is the shunting effect of transformer windings stray capacitance Cs. In the intermediate frequency (IF) range the shunt
branch acts like an open circuit and series impedance drop is also negligibly small such that V_2/V_1, remains fixed (flat response) as in Fig. 5.20.

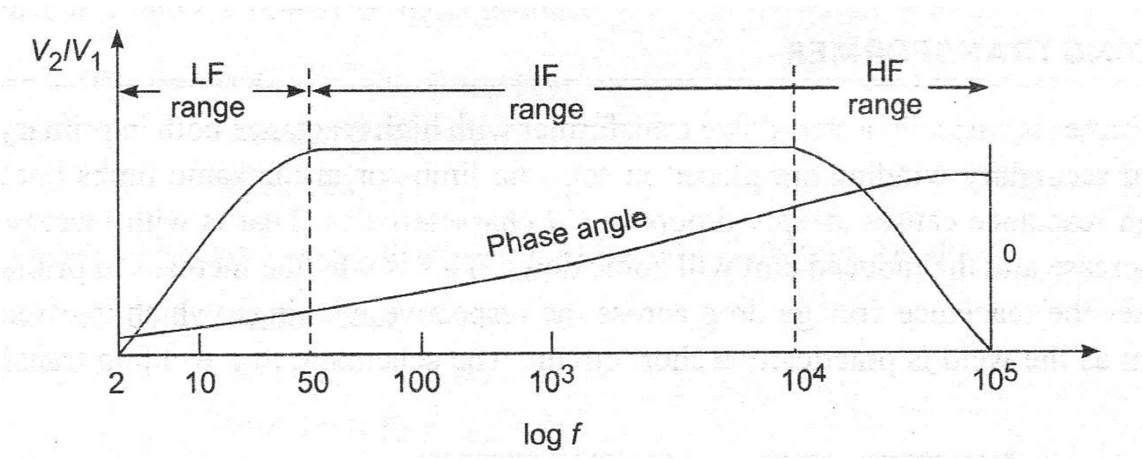


Fig. 5.20

In the LF (low frequency) region the magnetizing susceptance is low and draws a large current with a consequent large voltage drop in (r_l +jωL_1). As a result V_2/V_1 drops sharply to zero as Bm = 0 (Fig. 5.20). In the HF (high frequency) region $B_s = 1/\omega C_s$, (stray capacitance susceptance) has a strong shunting effect and V_2/V_1 drops off as in Fig. 5.20, which shows the complete frequency response of a transformer on logarithmic frequency scale.

14. Explain the construction and principle of operation of star, zig-zag and open delta poly phase connection. April 2013

Open-Delta or V −V connection

If one of the transformers of a Δ − Δ is removed and 3-phase supply is connected to the primaries as shown in Fig. 33.11, then three equal 3-phase voltages will be available at the secondary terminals on no load. This method of transforming 3-phase power by means of only two transformers is called the open − Δ or V – V connection.

It is employed:

1. When the three-phase load is too small to warrant the installation of full three-phase transformer bank.
2. When one of the transformers in a Δ − Δ bank is disabled, so that service is continued although at reduced capacity, till the faulty transformer is repaired or a new one is substituted.
3. When it is anticipated that in future the load will increase necessitating the closing of open delta.

One important point to note is that the total load that can be carried by a V− V bank is not two-third of the capacity of a Δ − Δ bank but it is only 57.7% of it. That is a reduction of 15% (strictly, 15.5%) from its normal rating. Suppose there is Δ − Δ bank of three 10-kVA transformers. When one transformer is removed, then it runs in V − V. The total rating of the two transformers is 20 kVA. But the capacity of the V – V bank is not the sum of the transformer kVA ratings but only 0.866 of it i.e.20 ×0.866 = 17.32 (or 30 ×0.57 = 17.3 kVA). The fact that the ratio of V-capacity to Δ-capacity is as follows

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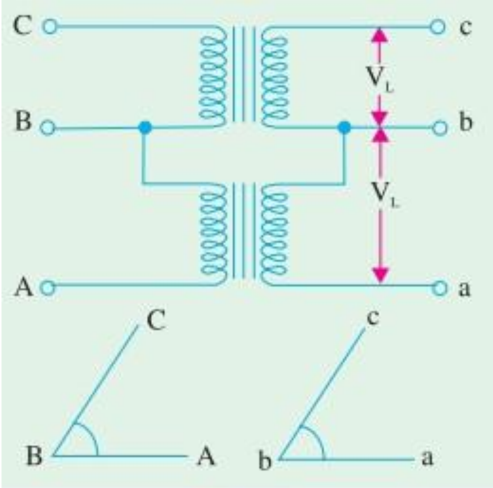


Fig. 33.11

As seen from Fig. 33.12 (*a*)

$\Delta - \Delta$ capacity $= \sqrt{3} \cdot V_L \cdot I_L = \sqrt{3} \cdot V_L (\sqrt{3} \cdot I_S) = 3 V_L I_S$

In Fig. 33.12 (*b*), it is obvious that when $\Delta - \Delta$ bank becomes $V - V$ bank, the secondary line current I_L becomes equal to the secondary phase current I_S.

$\therefore \quad V - V \text{ capacity} = \sqrt{3} \cdot V_L I_L = \sqrt{3}\, V_L \cdot I_S$

$$\therefore \quad \frac{V - V \text{ capacity}}{\Delta - \Delta \text{ capacity}} = \frac{\sqrt{3} \cdot V_L I_S}{3 V_L I_S} = \frac{1}{\sqrt{3}} = 0.577 \text{ or } 58 \text{ per cent}$$

It means that the 3-phase load which can be carried ***without exceeding the ratings*** of the transformers is 57.7 per cent of the original load rather than the expected 66.7%.

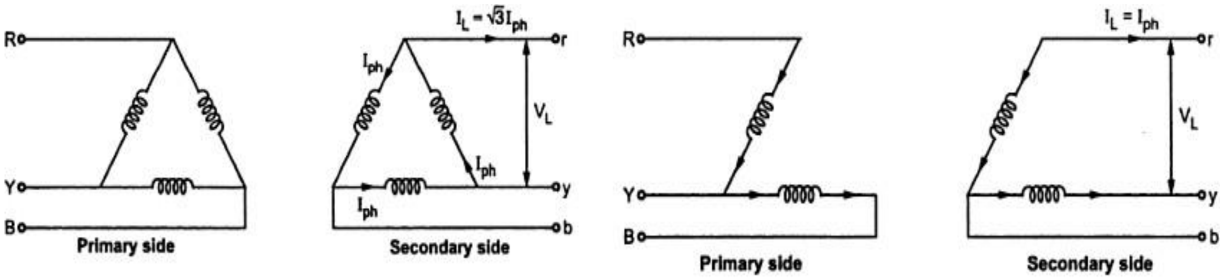


Fig. 33.12 (a) Δ - Δ connection **Fig. 33.12 (b) V - V connection**

It is obvious from above that when one transformer is removed from a Δ − Δ bank.

1. The bank capacity is reduced from 30 kVA to 30 × 0.577 = 17.3 kVA and not to 20 kVA as might be thought off-hand.
2. Only 86.6% of the rated capacity of the two remaining transformers is available (i.e.20 × 0.866 = 17.3 kVA). In other words, ratio of operating capacity to available capacity of an open-Δ is 0.866. This factor of 0.866 is sometimes called the utility factor.
3. Each transformer will supply 57.7% of load and not 50% when operating in V − V.

However, it is worth noting that if three transformers in a $\Delta - \Delta$ bank are delivering their rated load and one transformer is removed, the overload on each of the two remaining transformers is 73.2% because,

$$\frac{\text{total load in } V - V}{VA/\text{transformer}} = \frac{\sqrt{3}\,.\,V_L I_S}{V_L I_S} = \sqrt{3} = 1.732$$

This over-load may be carried temporarily but some provision must be made to reduce the load if overheating and consequent breakdown of the remaining two transformers is to be avoided.

The disadvantages of this connection are:

1. The average power factor at which the V-bank operates is less than that of the load. This power factor is actually 86.6% of the balanced load power factor. Another significant point to note is that, except for a balanced unity power factor load, the two transformers in the V – V bank operate at different power factors.
2. Secondary terminal voltages tend to become unbalanced to a great extent when the load is increased, this happens even when the load is perfectly balanced.

Scott Connection or T – T Connection

This is a connection by which 3-phase to 3-phase transformation is accomplished with the help of two transformers as shown in Fig. 33.13. Since it was first proposed by Charles F. Scott, it is frequently referred to as Scott connection.

One of the transformers has centre taps both on the primary and secondary windings (Fig. 33.13) and is known as the main transformer. It forms the horizontal member of the connection (Fig. 33.14).

The other transformer has a 0.866 tap and is known as teaser transformer. One end of both the primary and secondary of the teaser transformer is joined to the centre taps on both primary and secondary of the main transformer respectively as shown in Fig. 33.14 (a). The other end A of the teaser primary and the two ends B and C of the main transformer primary are connected to the 3-phase supply.

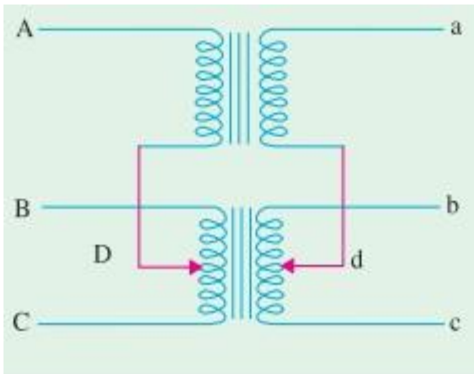


Fig. 33.13

The voltage diagram is shown in Fig. 33.14 (a) where the 3-phase supply line voltage is assumed to be 100 V and a transformation ratio of unity.

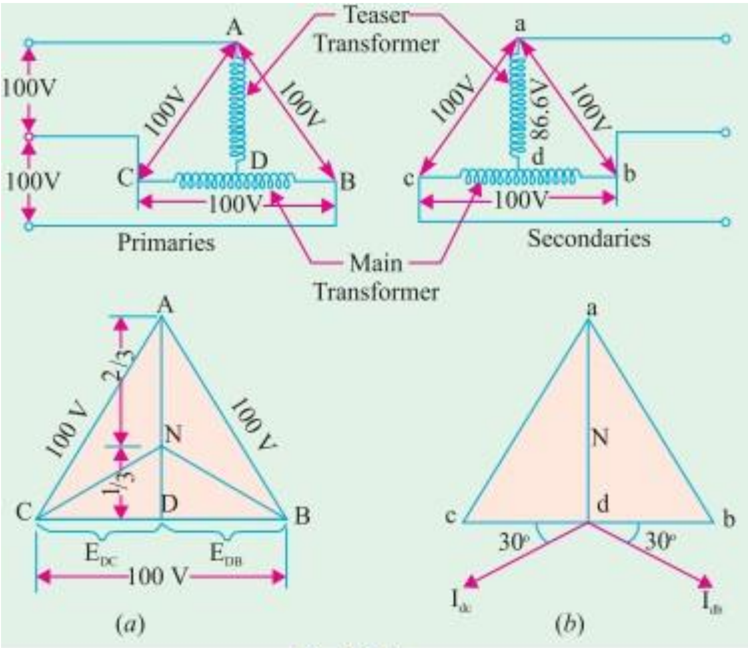


Fig. 33.14

In the primary voltage T of Fig. 33.14 (a), E_{DC} and E_{DB} are each 50 V and differ in phase by 180°, because both coils DB and DC are on the same magnetic circuit and are connected in opposition. Each side of the equilateral triangle represents 100 V. The voltage E_{DA} being the altitude of the equilateral triangle is equal to $(\sqrt{3}/2) \times 100 = 86.6$ V and lags behind the voltage across the main by 90°. The same relation holds good in the secondary winding so that abc is a symmetrical 3-phase system.

With reference to the secondary voltage triangle of Fig. 33.14 (b), it should be noted that for a load of unity power factor, current I_{db} lags behind voltage E_{db} by 30° and I_{dc} leads E_{dc} by 30°. In other words, the teaser transformer and each half of the main transformer, all operate at different power factors.

Obviously, the full rating of the transformers is not being utilized. The teaser transformer operates at only 0.866 of its rated voltage and the main transformer coils operate at cos30° = 0.866 power factor, which is equivalent to the main transformer's coils working at 86.6 per cent of their kVA rating. Hence the capacity to rating ratio in a T–T. connection is 86.6% — the same as in V −V connection if two identical units are used, although heating in the two cases is not the same.

If, however, both the teaser primary and secondary windings are designed for 86.6 volts only, then they will be operating at full rating, hence the combined rating of the arrangement would become (86.6 + 86.6)/(100 + 86.6) = 0.928 of its total rating. In other words, ratio of kVA utilized to that available would be 0.928 which makes this connection more economical than open-Δ with its ratio of 0.866.

As seen, the neutral point nis one third way up from point d. If secondary voltage and current vector diagram is drawn for load power factor of unity, it will be found that

1. Current in teaser transformer is in phase with the voltage.
2. In the main transformer, current leads the voltage by 30° across one half but lags the voltage by 30° across the other half as shown in Fig. 33.14 (b).

Three/One-phase Conversion

A single-phase power pulsates at twice the frequency, while the total power drawn by a balanced 3-phase load is constant. Thus a l-phase load can never be transferred to a 3-phase system as a balanced load without employing some energy-storing device (capacitor, inductor or rotating machine). Suitable transformer connections can be used in distributing a l-phase load on all the three phases though not in a balanced fashion. For large 1-phase loads, this is better than allowing it to load one of the phases of a 3-phase system. A variety of transformer connections are possible. Figure 5.21 shows how Scott-connected transformers could be used for this purpose.

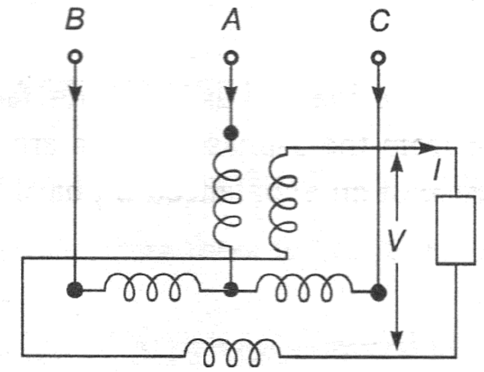


Fig. 5.21

Zigzag Connection

The zigzag connection is also called the interconnected star connection. This connection has some of the features of the Y and the Δ connections, combining the advantages of both.

The zigzag transformer contains six coils on three cores. The first coil on each core is connected contrariwise to the second coil on the next core. The second coils are then all tied together to form the neutral and the phases are connected to the primary coils.Each phase, therefore, couples with each other phase and the voltages cancel out. As such, there would be negligible current through the neutral pole and it can be connected to ground

One coil is the outer coil and the other is the inner coil. Each coil has the same number of windings turns (Turns ratio=1:1) but they are wound in opposite directions.

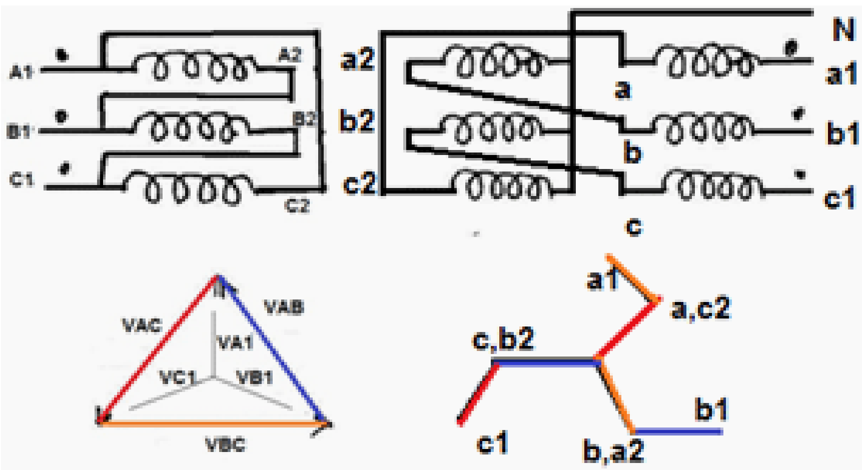


Fig. 5.22 ZigZag transformer coil connections

The transformer coils are connected as follows:

- The outer coil of phase **a1-a** is connected to the inner coil of phase **c2-N**
- The outer coil of phase **b1-b** is connected to the inner coil of phase **a2-N**
- The outer coil of phase **c1-c** is connected to the inner coil of phase **b2-N**
- The inner coils are connected together to form the **neutral** and our **tied to ground**
- The outer coils are connected to phases **a1**,**b1**,**c1** of the existing delta system.

If three currents, equal in magnitude and phase, are applied to the three terminals, the ampere-turns of the **a2-N** winding cancel the ampere-turns of the **b1-b** winding, the ampere-turns of the **b2-N** winding cancel the ampere turns of the **c1-c** winding, and the ampere-turns of the **c2-N** winding cancel the ampere turns of the **a1-a** winding. Therefore, the transformer allows the three in-phase currents to easily flow to neutral.

If three currents, equal in magnitude but 120° out of phase with each other, are applied to the three terminals, the ampere-turns in the windings cannot cancel and the transformer restricts the current flow to the negligible level of magnetizing current. Therefore, the zigzag winding provides an easy path for in-phase currents but does not allow the flow of currents that are 120°out of phase with each other.

Under normal system operation the outer and inner coil winding's magnetic flux will cancel each other and only negligible current will flow in the in the neutral of the zigzag transformer.The purpose of a zigzag transformer is to provide a return path for earth faults on delta connected systems. With negligible current in the neutral under normal conditions, engineers typically elect to under size the transformer; a short time rating is applied. Ensure the impedance is not too low for the desired fault limiting.

The neutral formed by the zigzag connection is very stable. Therefore, this type of transformer, or in some cases an auto transformer, lends itself very well for establishing a neutral for an ungrounded 3 phase system.

Many times this type of transformer or auto transformer will carry a fairly large rating, yet physically be relatively small. This particularly applies in connection with grounding applications. The reason for this small size in relation to the nameplate KVA rating is due to the fact that many types of grounding auto transformers are rated for 2 seconds. Zigzag transformers used to be employed to enable size reductions in drive motor systems due to the stable wave form they present.

Advantages of Zig-Zag Transformer

The Δ -zigzag connection provides the same advantages as the Δ-Y connection.

1. It is typically the least costly than Y-D and Scott Transformer.
2. Third harmonic suppression
3. Ground current isolation
4. No phase displacement

15. Discuss the condition Scott connection and mark the terminals April 2015

16. Give connection diagram and explain the working of Scott connection. Mention its applications. Nov'2014

Scott Connection or T – T Connection

This is a connection by which 3-phase to 3-phase transformation is accomplished with the help of two transformers as shown in Fig. 33.13. Since it was first proposed by Charles F. Scott, it is frequently referred to as Scott connection.

One of the transformers has centre taps both on the primary and secondary windings (Fig. 33.13) and is known as the main transformer. It forms the horizontal member of the connection (Fig. 33.14).

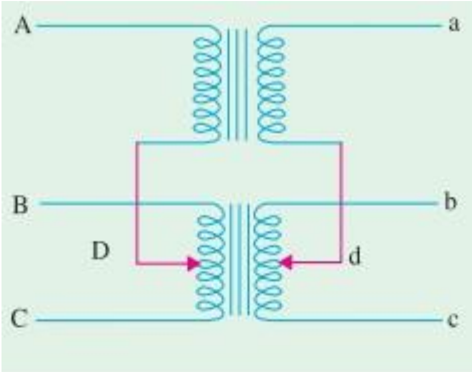


Fig. 33.13

The other transformer has a 0.866 tap and is known as teaser transformer. One end of both the primary and secondary of the teaser transformer is joined to the centre taps on both primary and secondary of the main transformer respectively as shown in Fig. 33.14 (a). The other end A of the teaser primary and the two ends B and C of the main transformer primary are connected to the 3-phase supply.

The voltage diagram is shown in Fig. 33.14 (a) where the 3-phase supply line voltage is assumed to be 100 V and a transformation ratio of unity.

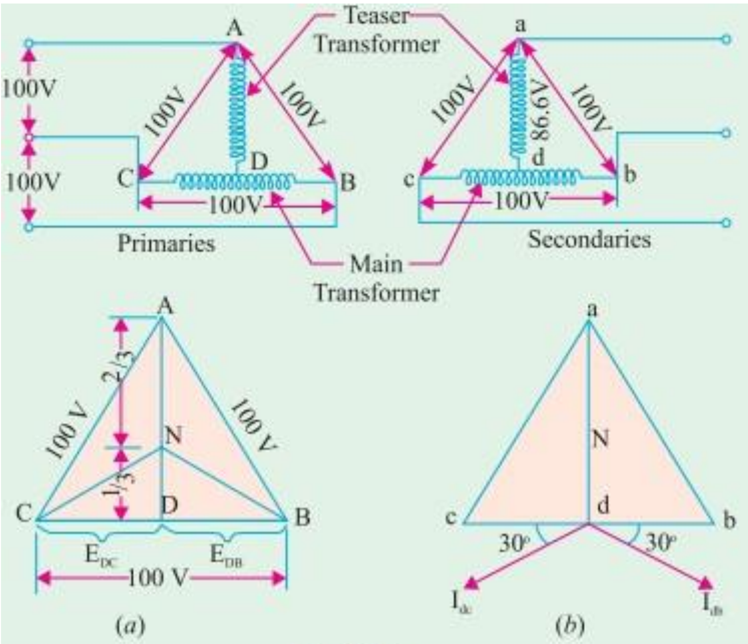


Fig. 33.14

In the primary voltage T of Fig. 33.14 (a), E_{DC} and E_{DB} are each 50 V and differ in phase by 180°, because both coils DB and DC are on the same magnetic circuit and are connected in opposition. Each side of the equilateral triangle represents 100 V. The voltage E_{DA} being the altitude of the equilateral triangle is equal to $(\sqrt{3}/2) \times 100 = 86.6\ V$ and lags behind the voltage across the main by 90°. The same relation holds good in the secondary winding so that abc is a symmetrical 3-phase system.

With reference to the secondary voltage triangle of Fig. 33.14 (b), it should be noted that for a load of unity power factor, current I_{db} lags behind voltage E_{db} by 30° and I_{dc} leads E_{dc} by 30°. In other words, the teaser transformer and each half of the main transformer, all operate at different power factors.

Obviously, the full rating of the transformers is not being utilized. The teaser transformer operates at only 0.866 of its rated voltage and the main transformer coils operate at cos30° = 0.866 power factor, which is equivalent to the main transformer's coils working at 86.6 per cent of their kVA rating. Hence the capacity to rating ratio in a T–T. connection is 86.6% — the same as in V −V connection if two identical units are used, although heating in the two cases is not the same.

If, however, both the teaser primary and secondary windings are designed for 86.6 volts only, then they will be operating at full rating, hence the combined rating of the arrangement would become (86.6 + 86.6)/(100 + 86.6) = 0.928 of its total rating. In other words, ratio of kVA utilized to that available would be 0.928 which makes this connection more economical than open-Δ with its ratio of 0.866.

As seen, the neutral point nis one third way up from point d. If secondary voltage and current vector diagram is drawn for load power factor of unity, it will be found that

3. Current in teaser transformer is in phase with the voltage.
4. In the main transformer, current leads the voltage by 30° across one half but lags the voltage by 30° across the other half as shown in Fig. 33.14 (b).

17. Discuss the conditions to be fulfilled for operating two single phase transformer in parallel for 3 phase to 2 phase conversion. April 2015

Three-phase to Two-phase Conversion and vice-versa

This conversion is required to supply two-phase furnaces, to link two-phase circuit with 3-phase system and also to supply a 3-phase apparatus from a 2-phase supply source. For this purpose, Scott connection as shown in Fig. 33.17 is employed. This connection requires two transformers of different ratings although for interchangeability and provision of spares, both transformers may be identical but having suitable tappings.

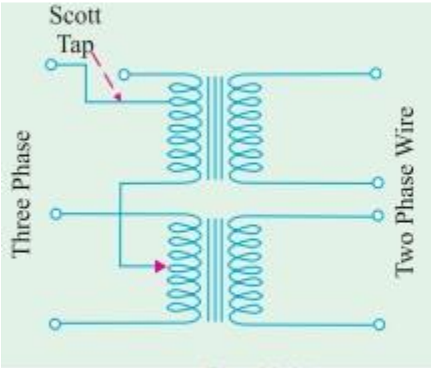


Fig. 33.17

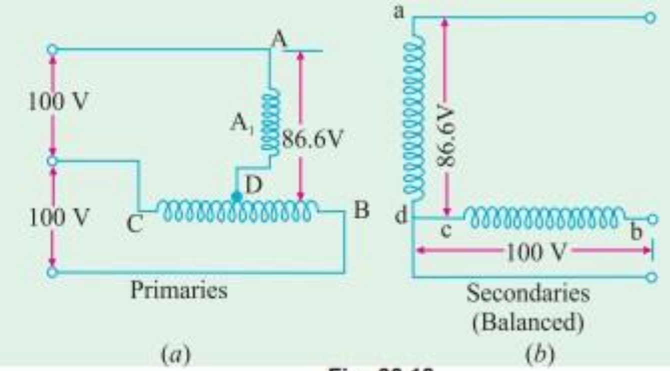


Fig. 33.18

If, in the secondaries of Fig. 33.14 (b), points c and d are connected as shown in Fig. 33.18 (b), then a 2-phase, 3-wire system is obtained. The voltage E_{dc} is 86.6 V but E_{cb} = 100 V, hence the Fig. 33.19 resulting 2-phase voltages will be unequal. However, as shown in Fig. 33.19 (a) if the 3-phase line is connected to point A_1, such that DA_1 represents 86.6% of the teaser primary turns (which are the same as that of main primary), then this will increase the volts/turn in the ratio of 100 : 86.6, because now 86.6 volts are applied across 86.6 per cent of turns and not 100% turns. In other words, this will make volts/ turn the same both in primary of the teaser and that of the main transformer. If the secondaries of both the transformers have the same number of turns, then secondary voltage will be equal in magnitude as shown, thus resulting in a symmetrical 2-phase, 3-wire system.

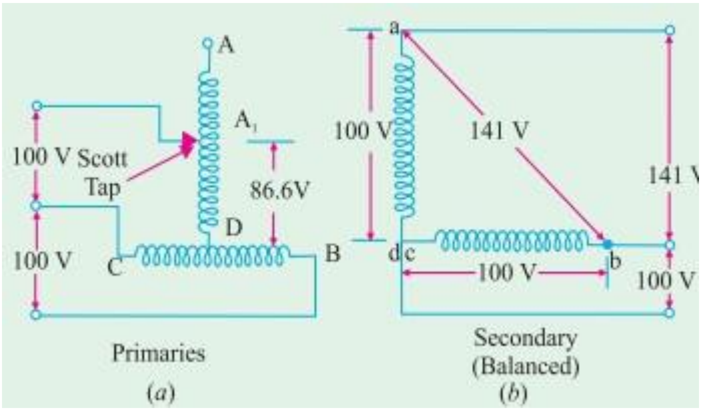
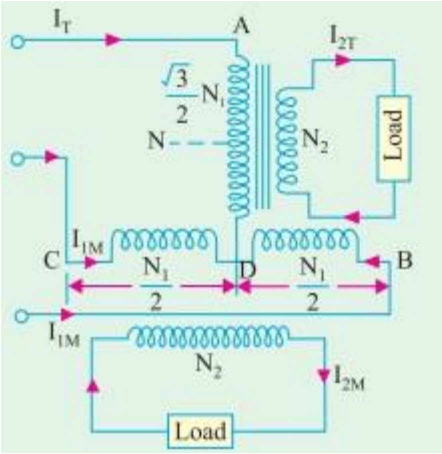


Fig. 33.19

Consider the same connection drawn slightly differently as in Fig. 33.20. The primary of the main transformer having N_1 turns is connected between terminals *CB* of a 3-phase supply. If supply line voltage is *V*, then obviously $V_{AB} = V_{BC} = V_{CA} = V$ but voltage between *A* and *D* is $V \times \sqrt{3}/2$. As said above, the number of turns between *A* and *D* should be also $(\sqrt{3}/2)\ N_1$ for making volt/turn the same in both primaries. If so, then for secondaries having equal turns, the secondary terminal voltages will be equal in magnitude although in phase quadrature.



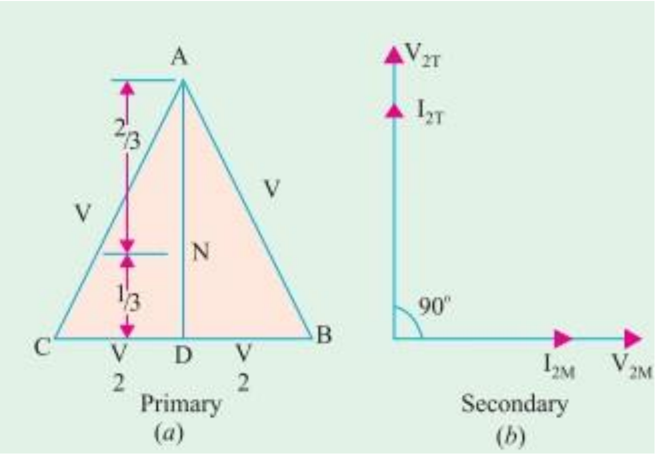


Fig. 33.20 Fig. 33.21

It is to be noted that point D is not the neutral point of the primary supply because its voltage with respect to any line is not $V/\sqrt{3}$. Let N be the neutral point. Its position can be determined as follows. Voltage of N with respect to A must be $V/\sqrt{3}$ and since D to A voltage is $V\times\sqrt{3}/2$, hence N will be $(\sqrt{3}V/2 - V/\sqrt{3})$ $= 0.288$ V or 0.29 V from D. Hence, N is above D by a number of turns equal to 29% of N_1. Since 0.288 is one-third of 0.866, hence N divides the teaser winding AD in the ratio 2 : 1.

Let the teaser secondary supply a current I_{2T} at unity power factor. If we neglect the magnetizing current I_0, then teaser primary current is $I_{1T} = I_{2T} \times$ transformation ratio.

$\therefore \quad I_{1T} = I_{2T} \times N_2/(\sqrt{3}N_1/2) = (2/\sqrt{3}) \times (N_2/N_1) \times I_{2T} = 1.15\ (N_2/N_1)\ I_{2T} = 1.15\ KI_{2T}$ where $K = N_2/N_1$ = transformation ratio of ***main*** transformer. The current is in phase with star voltage of the primary supply (Fig. 33.21).

The total current I_{1M} in each half of the primary of the ***main*** transformer consists of two parts :

(*i*) One part is that which is necessary to balance the main secondary current I_{2M}. Its value is

$$= I_{2M} \times \frac{N_2}{N_1} = KI_{2M}$$

(*ii*) The second part is equal to one-half of the teaser primary current *i.e.* $\frac{1}{2}I_{1T}$. This is so because the main transformer primary forms a return path for the teaser primary current which divides itself into two halves at mid-point D in either direction. The value of each half is $= I_{1T}/2 = 1.15\ KI_{2T}/2 = 0.58\ KI_{2T}$.

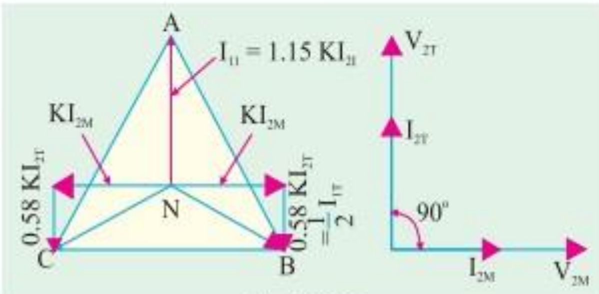


Fig. 33.22

Hence, the currents in the lines B and C are obtained vectorially as shown in Fig. 33.22. It should be noted that as the two halves of the teaser primary current flow in opposite directions from point D, they have no magnetic effect on the core and play no part at all in balancing the secondary ampere-turns of the main transformer.

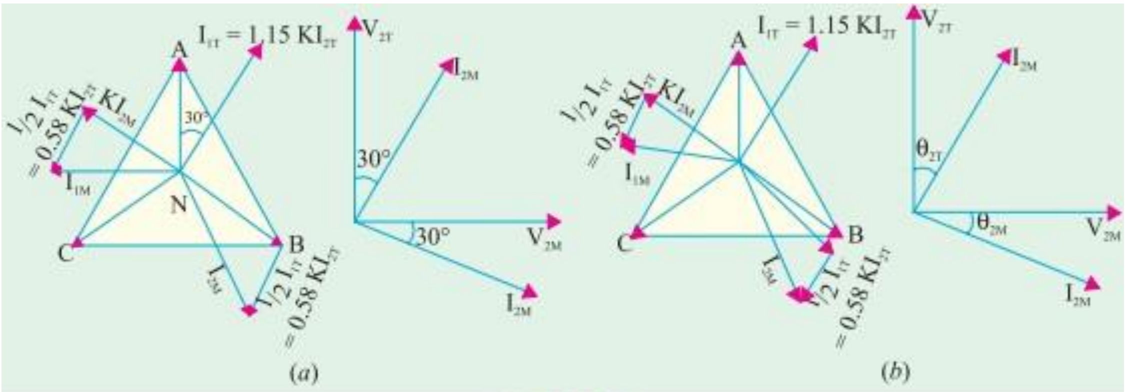


Fig. 33.23

The line currents thus have rectangular components of KI_{2M} and 0.58, KI_{2T} and, as shown in Fig. 33.22, are in phase with the primary star voltages V_{NB} and V_{NC} and are equal to the teaser primary current. Hence, the three-phase side is balanced when the two-phase load of unity power factor is balanced.

Fig. 33.23 (*a*) illustrates the condition corresponding to a balanced two-phase load at a lagging power factor of 0.866. The construction is the same as in Fig. 33.22. It will be seen that the 3-phase side is again balanced. But under these conditions, the main transformer rating is 15% greater than that of the teaser, because its voltage is 15% greater although its current is the same.

Hence, we conclude that if the load is balanced on one side, it would always be balanced on the other side. The conditions corresponding to an unbalanced two-phase load having different currents and power factors are shown in Fig. 33.23 (b). The geometrical construction is similar to those explained in Fig. 33.22 and 33.23 (a).

9. (a) Explain the conditions for the parallel operation of three phase transformers. **Nov'2012**

Parallel Operation of Transformers

It is economical to install numbers of smaller rated transformers in parallel than installing a bigger rated electrical power transformers. This has mainly the following advantages,

To maximize electrical power system efficiency: Generally electrical power transformer gives the maximum efficiency at full load. If we run numbers of transformers in parallel, we can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time. When load increases, we can switch none by one other transformer connected in parallel to fulfil the total demand. In this way we can run the system with maximum efficiency.

To maximize electrical power system availability: If numbers of transformers run in parallel, we can shut down any one of them for maintenance purpose. Other parallel transformers in system will serve the load without total interruption of power.

To maximize power system reliability: if any one of the transformers run in parallel, is tripped due to fault of other parallel transformers is the system will share the load, hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.

To maximize electrical power system flexibility: There is always a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfil the extra demand because, it is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money. Again if future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

Conditions for Parallel Operation of Transformers

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance. These are the conditions for parallel operation of transformers.

- ***Same voltage ratio of transformer.***
- ***Same percentage impedance.***
- ***Same polarity.***
- ***Same phase sequence.***
- ***Same Voltage Ratio***

Same voltage ratio of transformer.

If two transformers of different voltage ratio are connected in parallel with same primary supply voltage, there will be a difference in secondary voltages. Now say the secondary of these transformers are connected to same bus, there will be a circulating current between secondaries and therefore between primaries also. As the internal impedance of transformer is small, a small voltage difference may cause sufficiently high circulating current causing unnecessary extra I2R loss.

Same Percentage Impedance

The current shared by two transformers running in parallel should be proportional to their MVA ratings. Again, current carried by these transformers are inversely proportional to their internal impedance. From these two statements it can be said that, impedance of transformers running in parallel are inversely proportional to their MVA ratings. In other words, percentage impedance or per unit values of impedance should be identical for all the transformers that run in parallel.

Same Polarity

Polarity of all transformers that run in parallel, should be the same otherwise huge circulating current that flows in the transformer but no load will be fed from these transformers. Polarity of transformer means the instantaneous direction of induced emf in secondary. If the instantaneous directions of induced secondary emf in two transformers are opposite to each other when same input power is fed to both of the transformers, the transformers are said to be in opposite polarity. If the instantaneous directions of induced secondary e.m.f in two transformers are same when same input power is fed to the both of the transformers, the transformers are said to be in same polarity.

Same Phase Sequence

The phase sequence or the order in which the phases reach their maximum positive voltage, must be identical for two parallel transformers. Otherwise, during the cycle, each pair of phases will be short circuited.

The above said conditions must be strictly followed for parallel operation of transformers but totally identical percentage impedance of two different transformers is difficult to achieve practically, that is why the transformers run in parallel may not have exactly same percentage impedance but the values would be as nearer as possible.