G.H. RAISONI INSTITUTE OF ENGINEERING & TECHNOLOGY, NAGPUR

(An Autonomous Institute)

Department of Electrical Engineering

Subject:- BASIC ELECTRICAL MACHINE
Subject Code:- UEEL204
3rd Sem EE

Presented By,
Rashmi S. Phasate
EE Department

Unit 2: Three-Phase Transformer

- Principle of operation of three phase transformer
- O.C. & S.C. test on three phase transformer
- Determination of equivalent circuit parameters
- Regulation, Efficiency
- Magnetizing current and harmonics
- Winding identifications, various connections with vector group.
- Three phase to two phase conversion
- Parallel operation of three phase transformer
- Methods of cooling
- Back to back test
- Maintenance of transformer
- Insulation of transformer.

Need of Three Phase Transformer

- The electric power is generated in the form of three phase voltage. The distribution of the electric power is also three phase.
- The voltage generation takes place at very high voltage level typically at 13.2kV or 22 kV or even higher. The transmission of electricity takes place at voltage level such as 110kV, 132kV.
- So it is necessary to use the step up transformer to raise the voltage levels from 13.2kV to 132 kV etc. The three phase transformer are used for the same.
- Such high voltages can not be used by the domestic or industrial users. So the voltage should be stepped down. Three phase step down transformer are used as distribution transformer.

Construction of Three Phase Transformer

A three-phase transformer can be obtained in two different ways.

1] Three numbers of identical single-phase transformers can be suitably connected to make a three-phase transformer. Such three-phase transformers are called a *bank of three-phase transformer.*

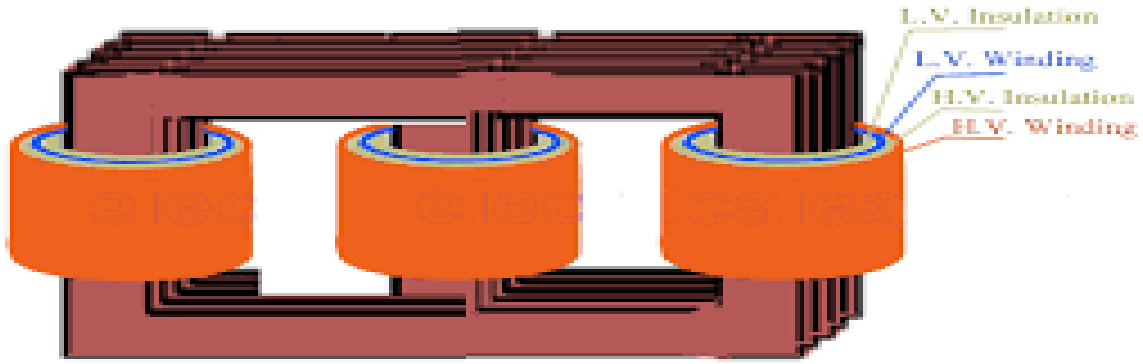
2]Alternatively, a three-phase transformer can be constructed as a single unit.

ADVANTAGES OF SINGLE UNIT THREE-PHASE TRANSFORMER

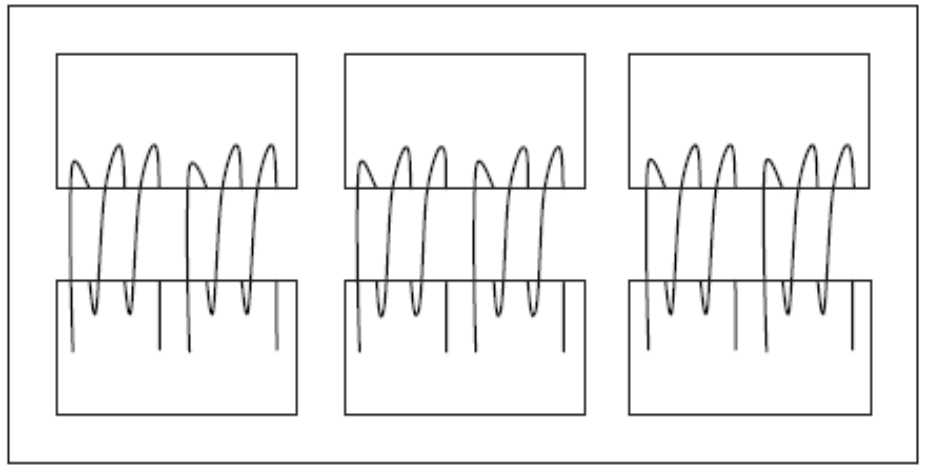
1. It occupies less space
2. Its weight is less
3. Its cost is comparatively less
4. It is much easier to transport
5. It is more efficient
6. Core size is comparatively small

DISADVANTAGES OF SINGLE UNIT THREE-PHASE TRANSFORMER

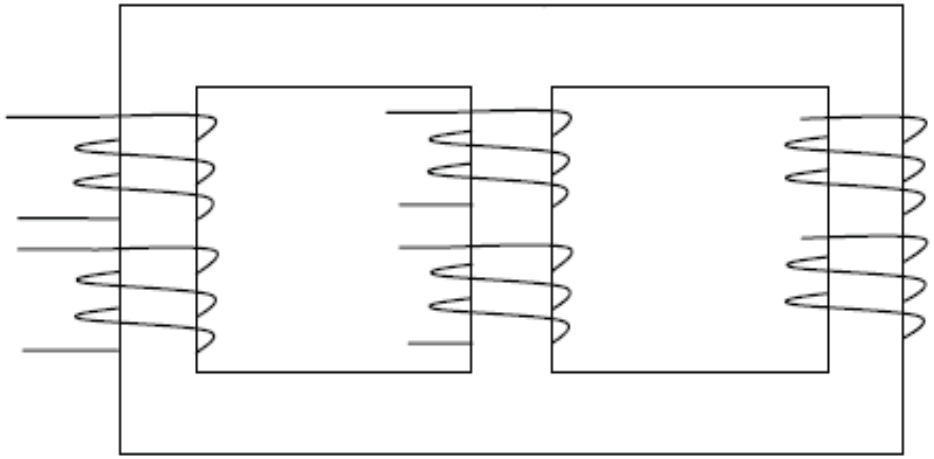
1. When one of the phases of a single-unit three-phase transformer becomes faulty, the entire unit of three-phase transformer needs to be removed from the supply for repair.
2. But in the case of a bank of three-phase transformer, only the faulty transformer is removed from the supply for repair while the other two transformers remain connected in the system without interrupting the supply completely.



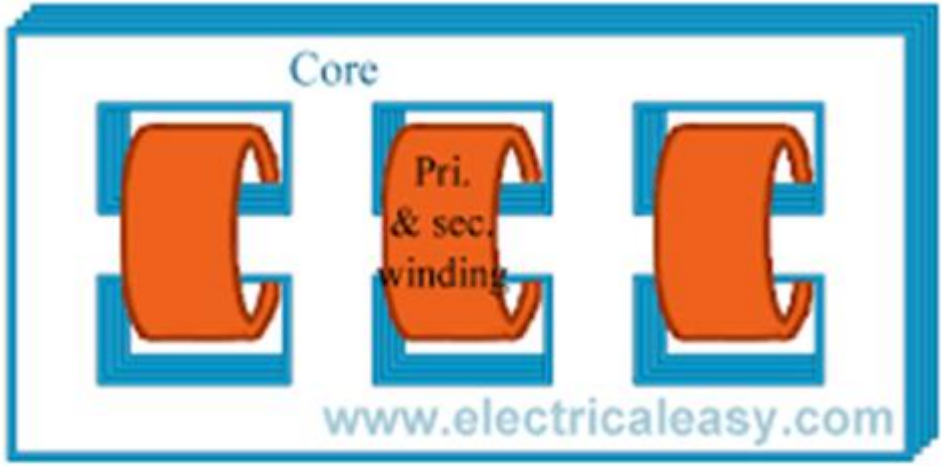
Core-type 3-phase Transformer



SHELL Type Transformer



CORE Type Transformer



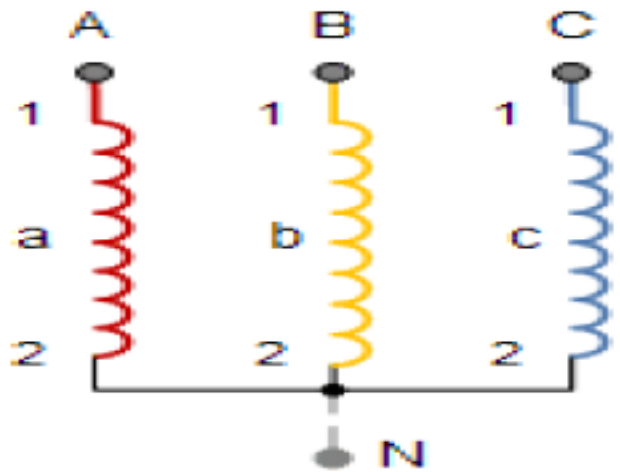
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- There are several methods of connecting primaries and secondary of three phase transformer. They are:

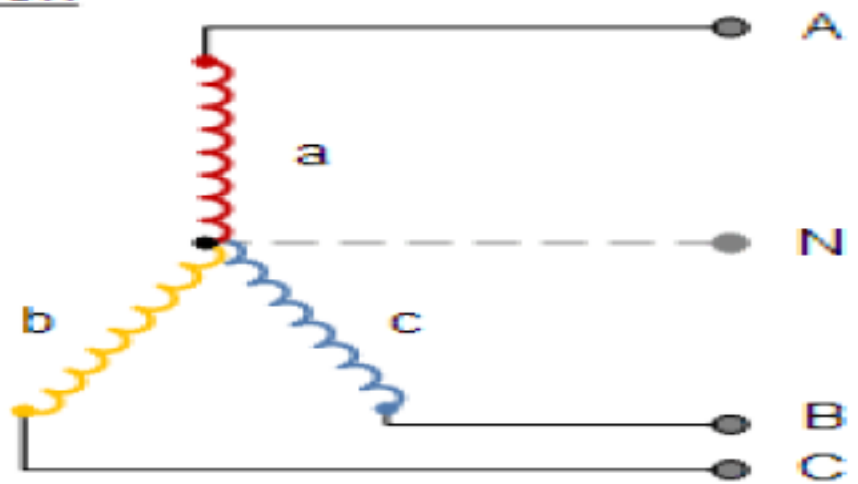
1. Star-Star (Y-Y) connection
2. Delta-Delta connection
3. Star-Delta connection
4. Delta-Star connection
5. V - V or open delta connection
6. T - T or Scott connection

- These connections may be step-up or step-down.
- Out of these transformer the delta-star type transformer is most commonly used for the distribution applications.

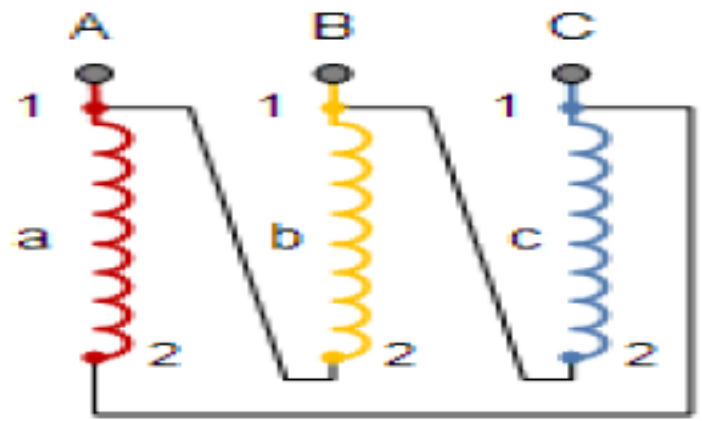
Star Connection



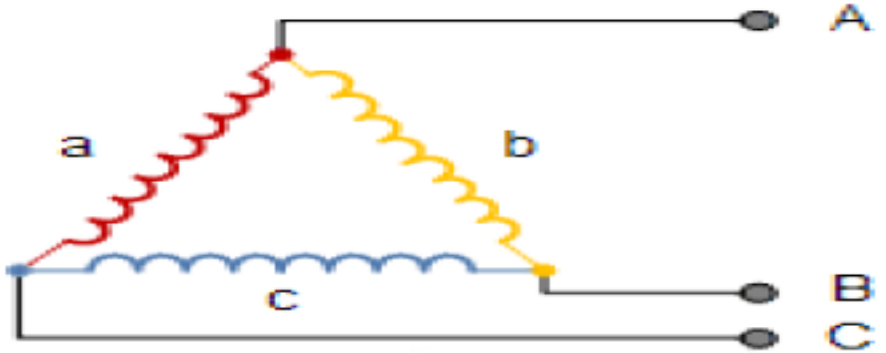
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Delta Connection



≡

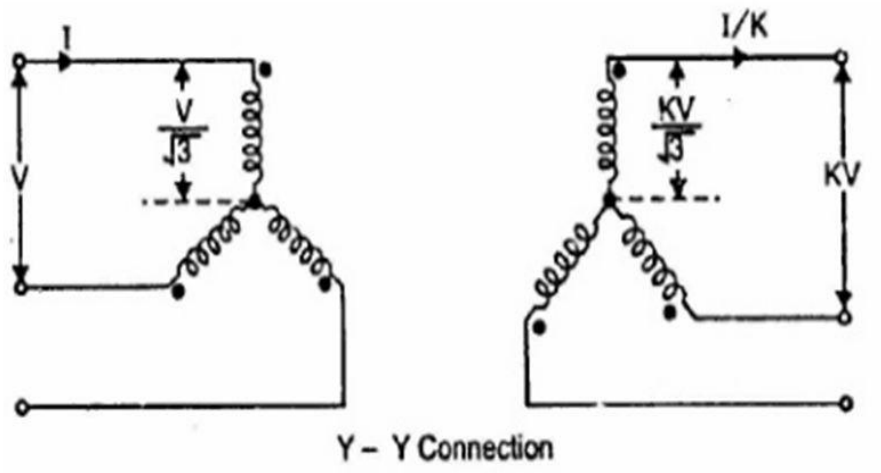


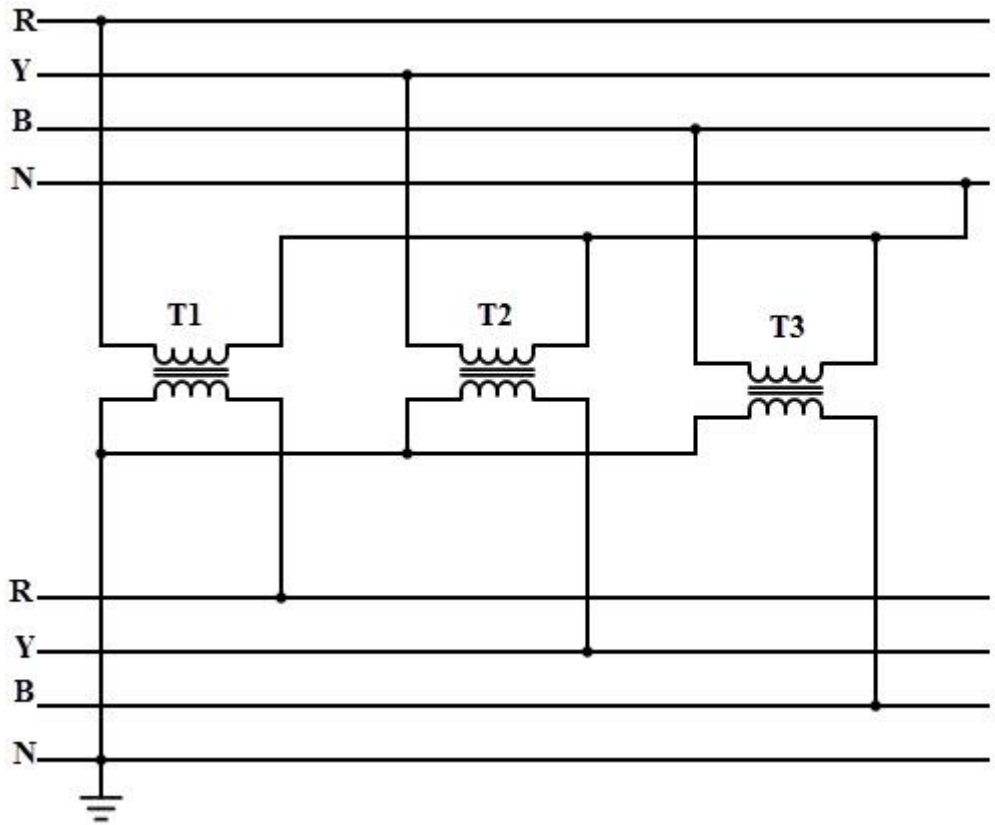
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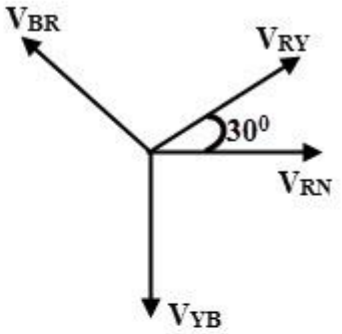
Star–Star (Y–Y) Connection of Three-phase Transformer

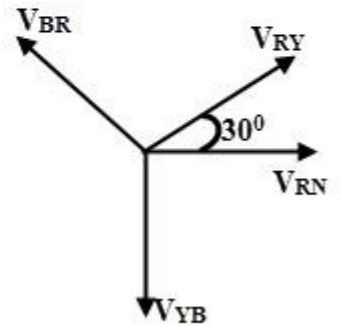
Star-star connection is generally used for small, high-voltage transformers. The ratio of line voltages on the primary side and the secondary side is equal to the transformation ratio of the transformers. Line voltages on both sides are in phase with each other.

Y-Y Connection









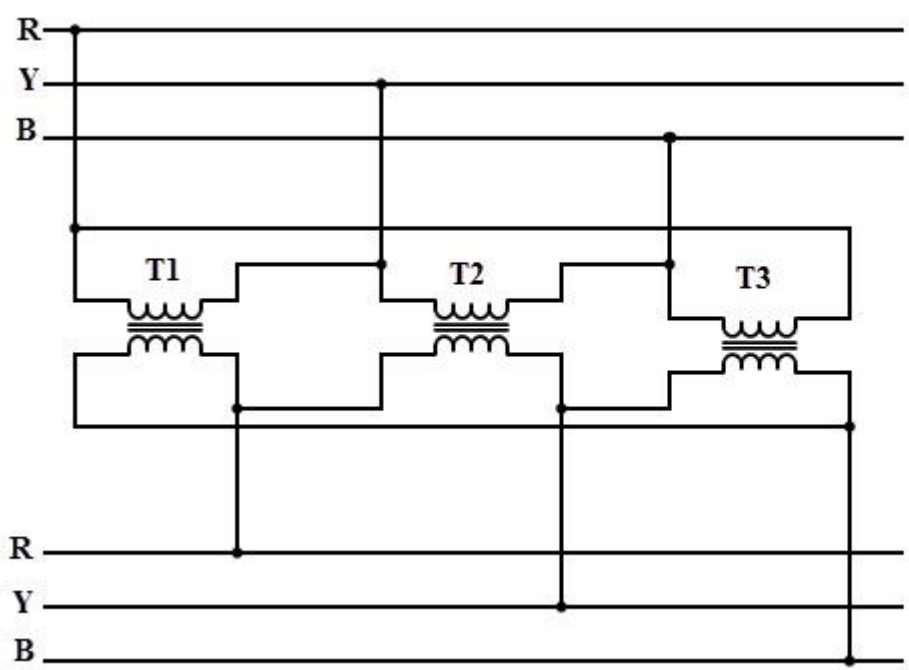
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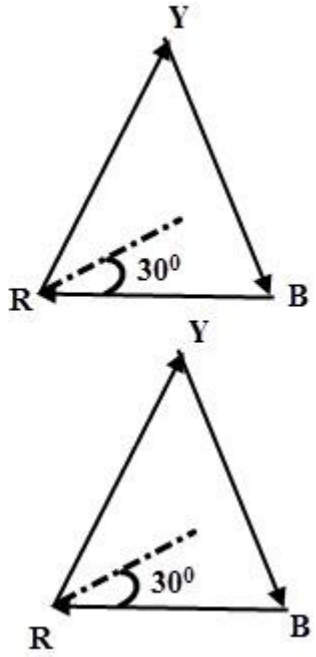
Star–Star (Y–Y) Connection of Three-phase Transformer

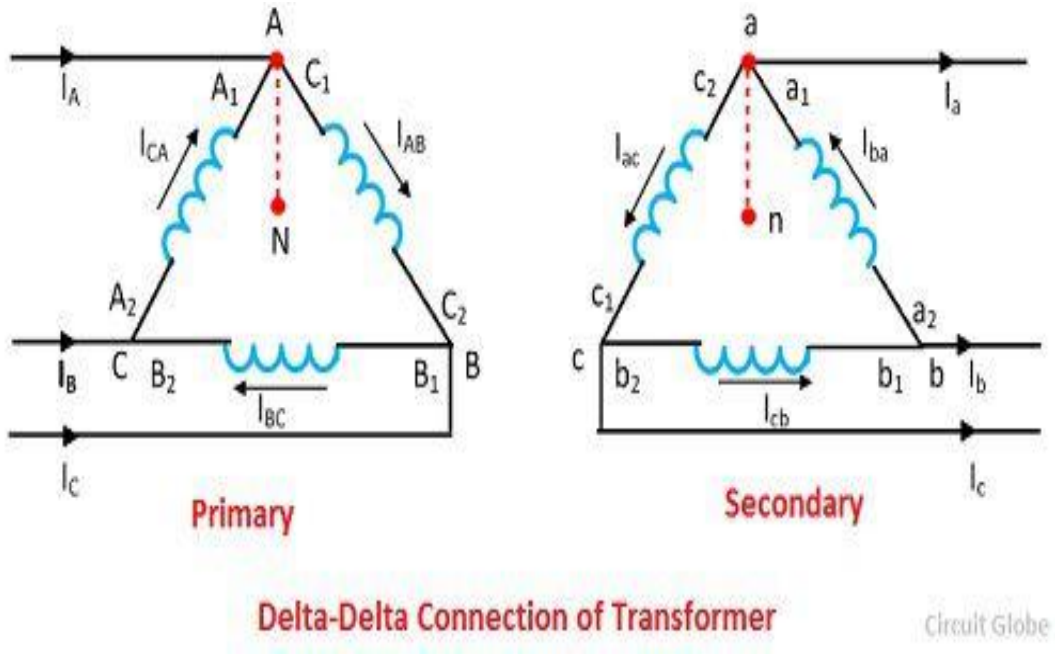
- In this, both primary and secondary windings are connected in star fashion and also there exist no phase difference between the primary and secondary voltages.
- In this, current flowing through both primary and secondary windings are equal to the currents of the lines to which they are connected (supply source and load). And voltages between line phases on either end equal to 1.732 times respective winding voltages.
- Due to neutral availability, it is well suited for three phase four wire system.
- This type connection satisfactorily works if the load is balanced. But if the load is unbalanced, the neutral point shift causes unequal phase voltages.
- Large third harmonic voltages would appear in both primary and secondary windings without the neutral tie. This may lead to the insulation failures.
- This connection considerably generates interference with communication lines and hence with this connection configuration, telephone lines cannot be run in parallel.
- Due to these disadvantages, the star-star connection is rarely used and not employed in practice.

Delta–Delta (Δ–Δ) Connection of Three-phase Transformer

Delta Delta connection is used on all high voltage transmission line transformers, say 11 KV/33 KV, 33 KV/ 132 KV etc., since in these cases neutral is not needed, and is more convenient. This connection is useful when neutral is not required.







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Delta–Delta (Δ–Δ) Connection of Three-phase Transformer

•This type of connection is used when the supply source is delta connected and the secondary load needs single voltage with high current. This is generally employed for three phase power loads (like three phase motor).

•In this, both primary and secondary windings are connected in delta fashion.

•The voltage across the load is equal to the secondary voltage and voltage across the primary winding is equal to source voltage. In this, the current flow through the load will be 1.732 times the secondary current and the feeder current will equal to the 1.732 times current through the primary winding. Due to these high supply and load currents, it is recommended to place transformer much closer to both source and load circuits.

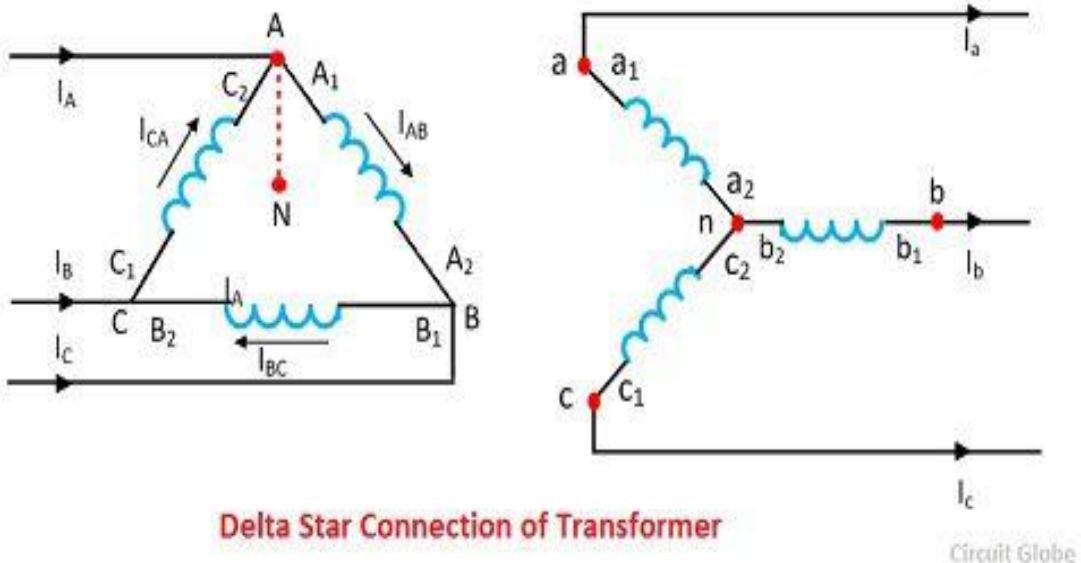
•In this, there exists no phase difference between the primary and secondary voltages.

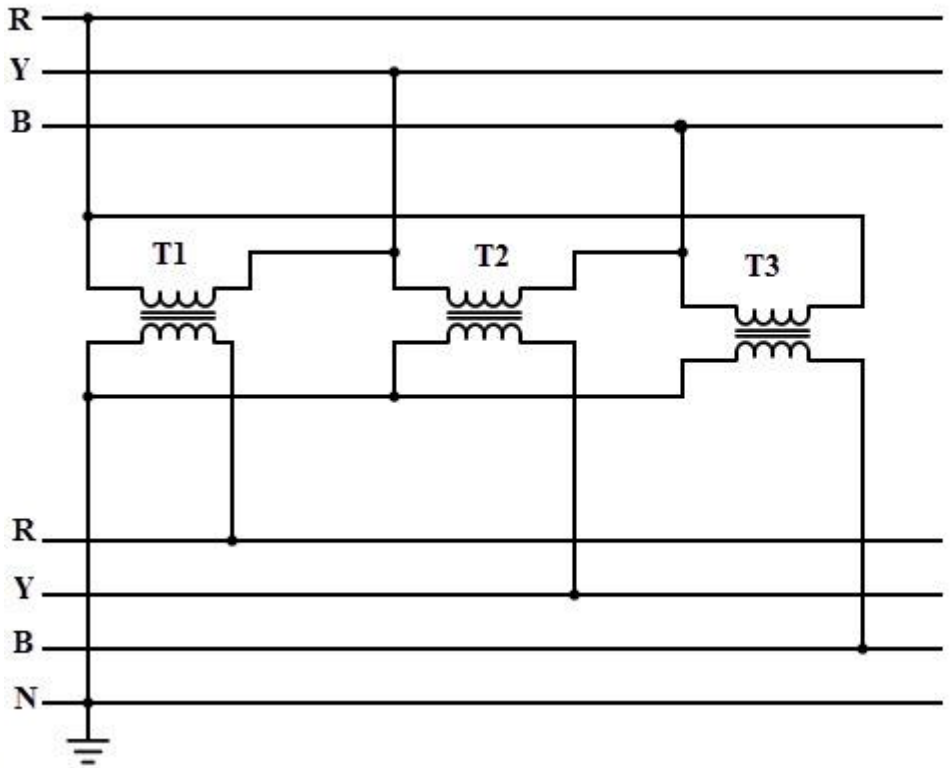
•The three phase voltages remains constant even with unbalanced load, thus allows unbalanced loading.

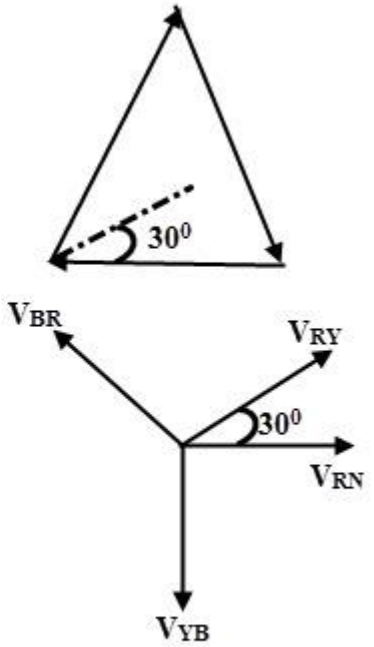
•The main advantage of this connection is if the one transformer is defective or removed for service (open delta connection), then remaining two transformers continue to deliver thee phase power at reduced load capacity.

Delta–Star (Δ –Y) Connection of Three-phase Transformer

Delta-star connected transformers are widely used in low power distribution with the primary windings providing a three-wire balanced load to the utility company while the secondary windings provide the required 4th-wire neutral or earth connection.



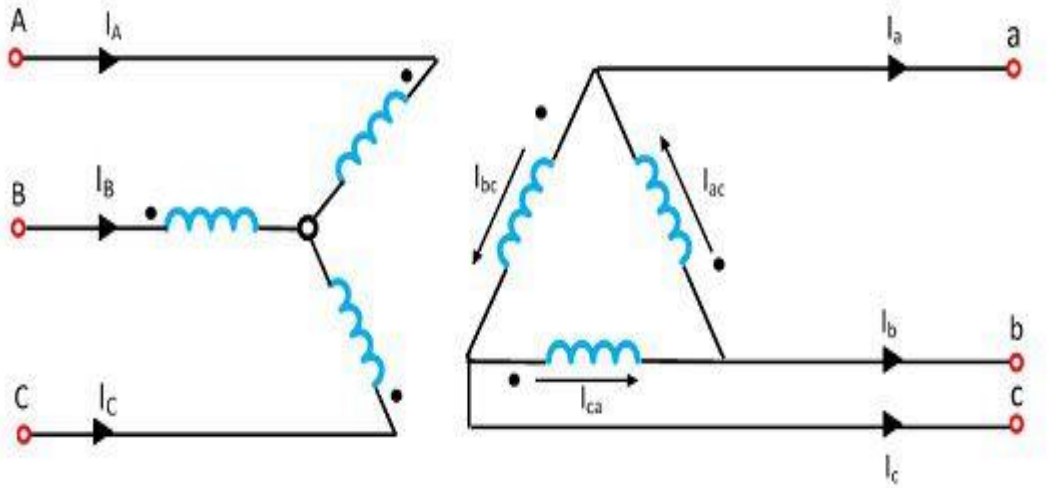




Delta–Star (Δ –Y) Connection of Three-phase Transformer

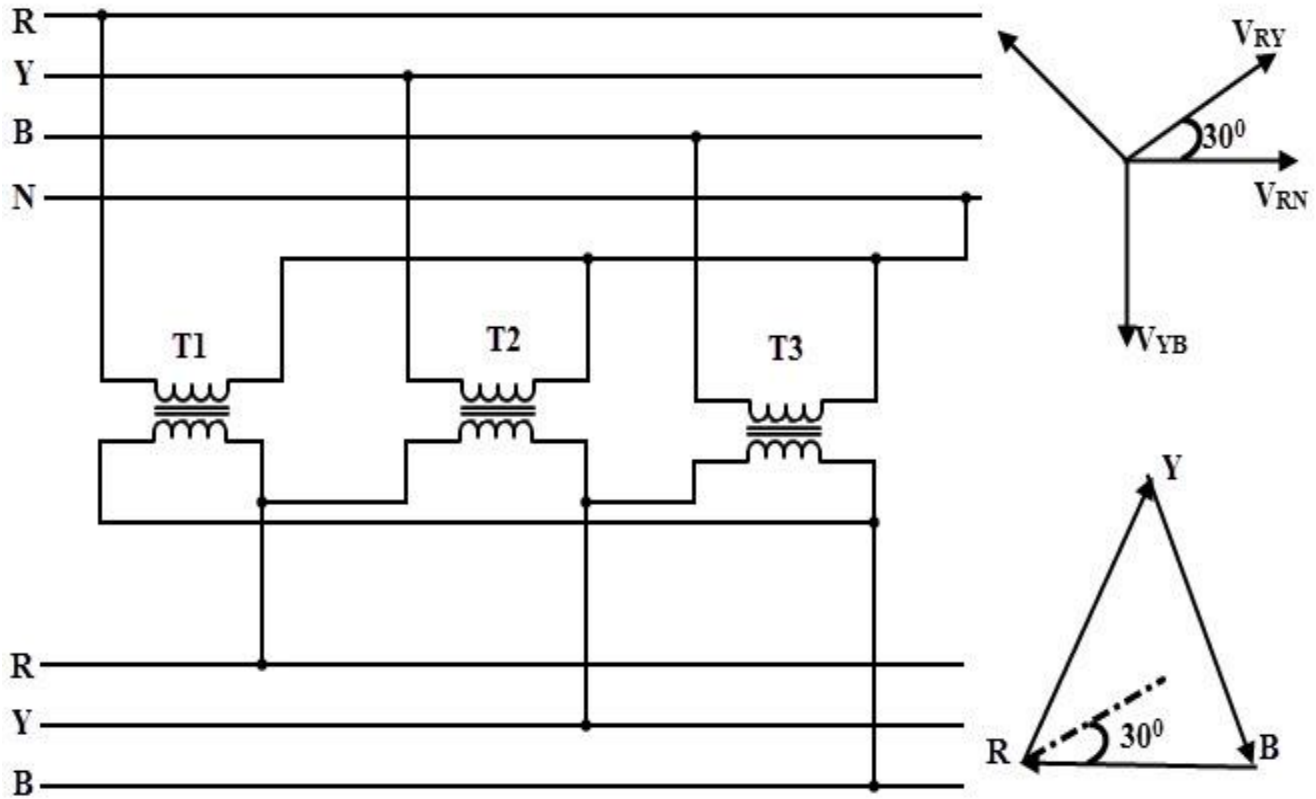
- This connection is used to step-up the voltage level and is commonly employed in sending end or starting of high tension transmission system.
- In this, the primary is connected in delta fashion and secondary in star fashion so that three phase 4 wire system at secondary is possible.
- The secondary voltage to the load is √3 times the delta connected primary voltage. Also the load and secondary currents will be the same due to the same series circuit.
- This connection provides three single phase circuits at both lower and higher voltages and one three phase circuit at higher voltage so that single and three phase loads can be supplied.
- Dual voltages are obtained delta-star connection. Low single phase voltages are obtained by wiring between any phase and ground. Higher single phase voltages are obtained by wiring between any two phases. And by connecting all three phases to the load, three phase voltage is obtained.
- The insulation requirement on high voltage side is lowered due to the star (less number of turns per phase) connected secondary.
- Similar to star-delta, this connection causes to create a 30 degrees phase difference between primary and secondary line voltages.

Star–Delta (Y–Δ) Connection of Three-phase Transformer



Star Delta Transformer

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Star–Delta (Y–Δ) Connection of Three-phase Transformer

This type of connection is commonly used to step-down the voltages to a lower value in transmission end substations. Utility companies use this connection to reduce the voltage levels for distribution systems.

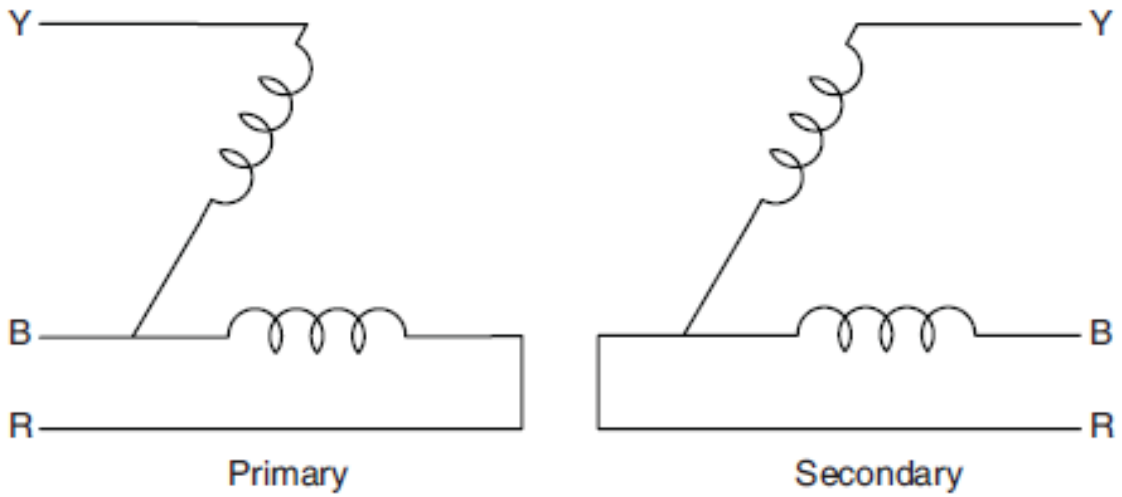
- In this, the primary winding of the transformer is connected in star and secondary in delta connection.
- The neutral point on the primary or high voltage side can be grounded which is desirable in most of the cases.
- The line voltage ratio between secondary and primary is $1/\sqrt{3}$ times the transformation ratio of each transformer.
- There exists 30 degrees phase difference between primary and secondary line voltages.
- Since the actual primary coil voltage is 58% of the primary line voltage, the insulation requirements for HV windings is reduced by using this winding.
- In this connection balanced three phase voltage are obtained at the secondary or LV side, even when the unbalanced currents are flowing the in the primary or HV side due to neutral wire. The neutral wire grounding also provides lightning surge protection.

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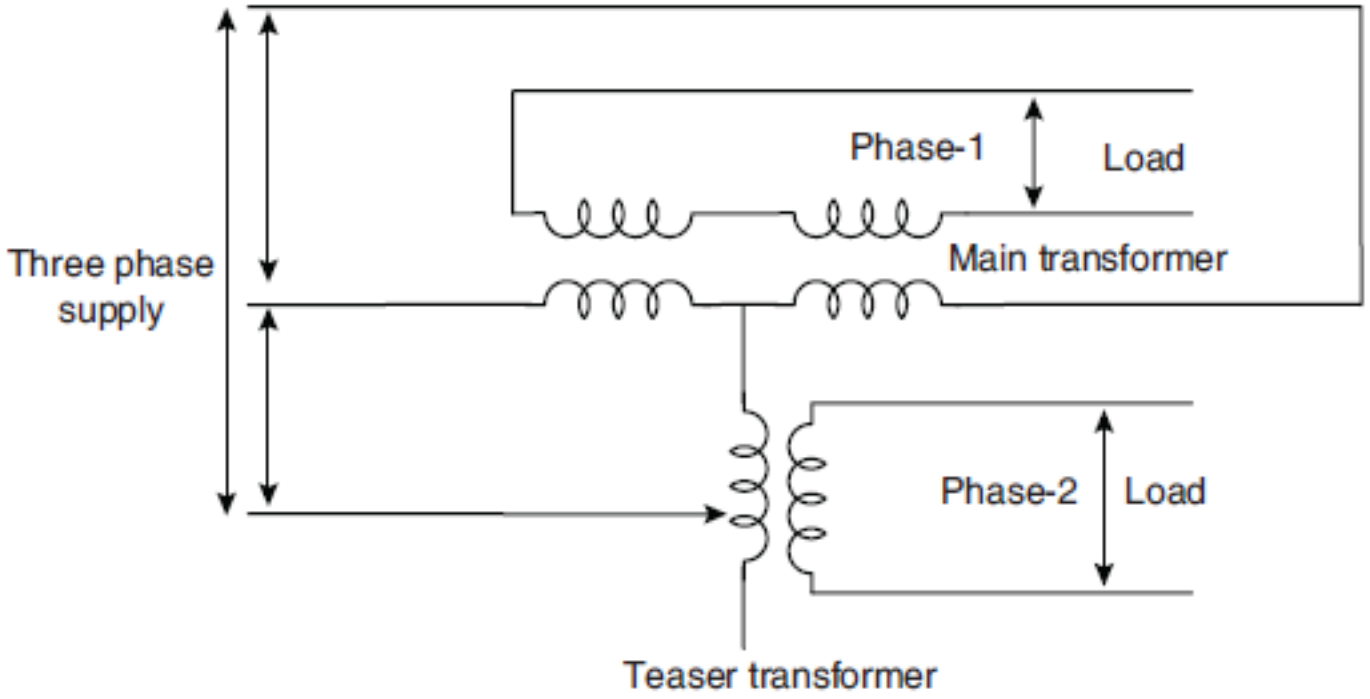
Open Delta (V–V) Connection of Three-phase Transformer



Some of the features of open delta connection are

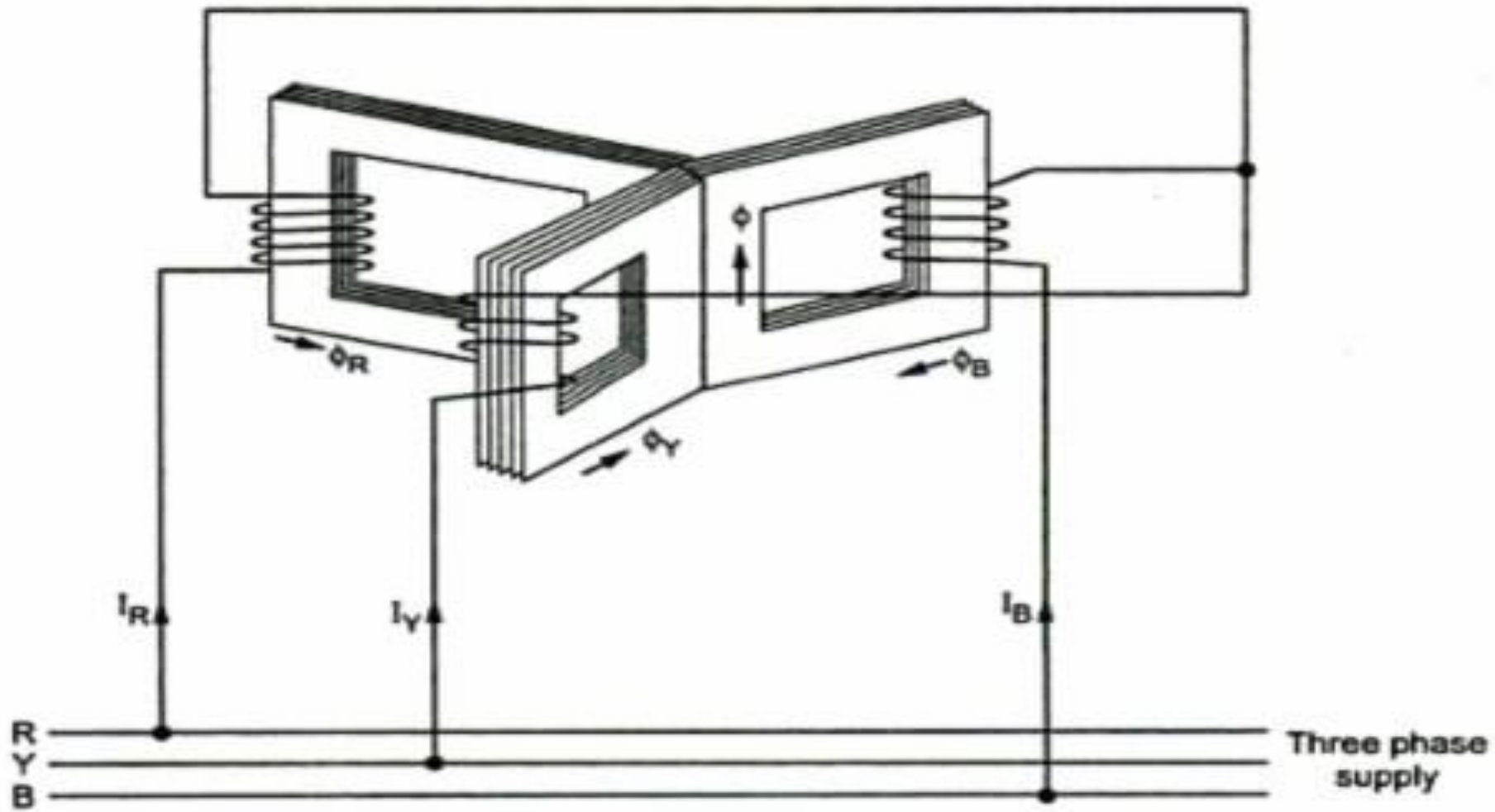
- The power handling capacity of open delta circuit is 0.577 times that of delta–delta circuit.
- The secondary terminal voltage becomes unbalanced with increase in load.
- The power factor is 86.6% of the balanced load factor.

Scott (T–T) Connection of Transformer



It is a type of circuit used to derive two-phase electric power from a three-phase source, or vice-versa. The Scott connection evenly distributes a balanced load between the phases of the source.

Principle of Operation



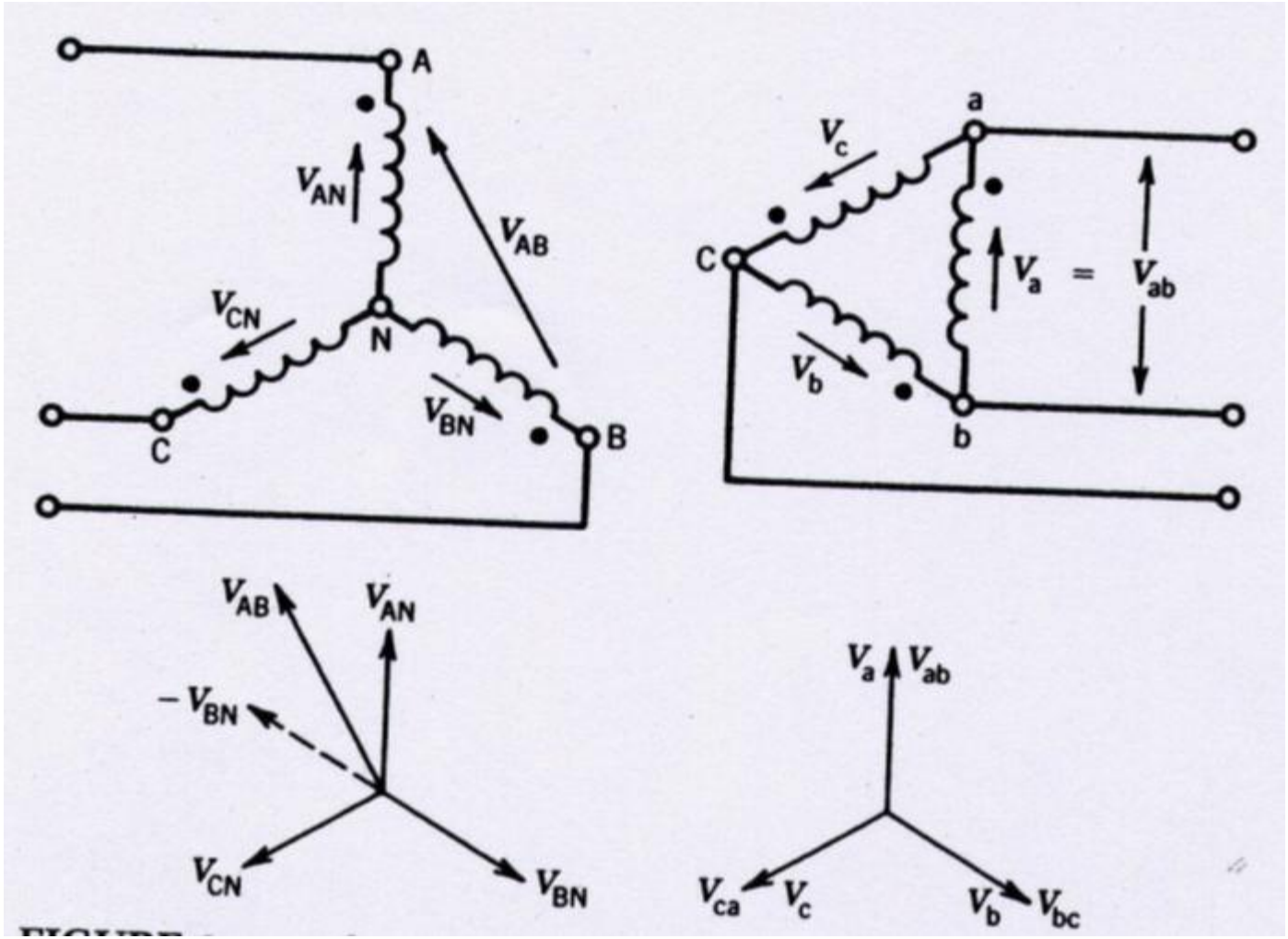
Principle of Operation

- The figure shows the three-phase transformer, wherein three cores are placed at 120° from each other.
- This figure is simplified to show only primary windings and their connection to the three-phase power supply.
- As soon as the three-phase supply is excited, the currents IR, IY, and IB are carried by the primary windings and thus inducing the fluxes ϕR, ϕY, and ϕB individually in each core. The center leg will carry the sum of all the fluxes, and the center leg combined all the legs of a core.
- For instance, if the sum of the currents IR+IY+IB is zero in a three-phase system, then the sum of all the three fluxes also becomes zero, resulting in the center leg carrying no flux. Therefore, removing the center leg makes no difference for other transformer conditions.

- Likewise, in three phase system where any two conductors acts as return for the current in third conductor, any two legs acts as a return path of the flux for the third leg if the center leg is removed in case of three phase transformer. Therefore, while designing the three phase transformer, this principle is used.

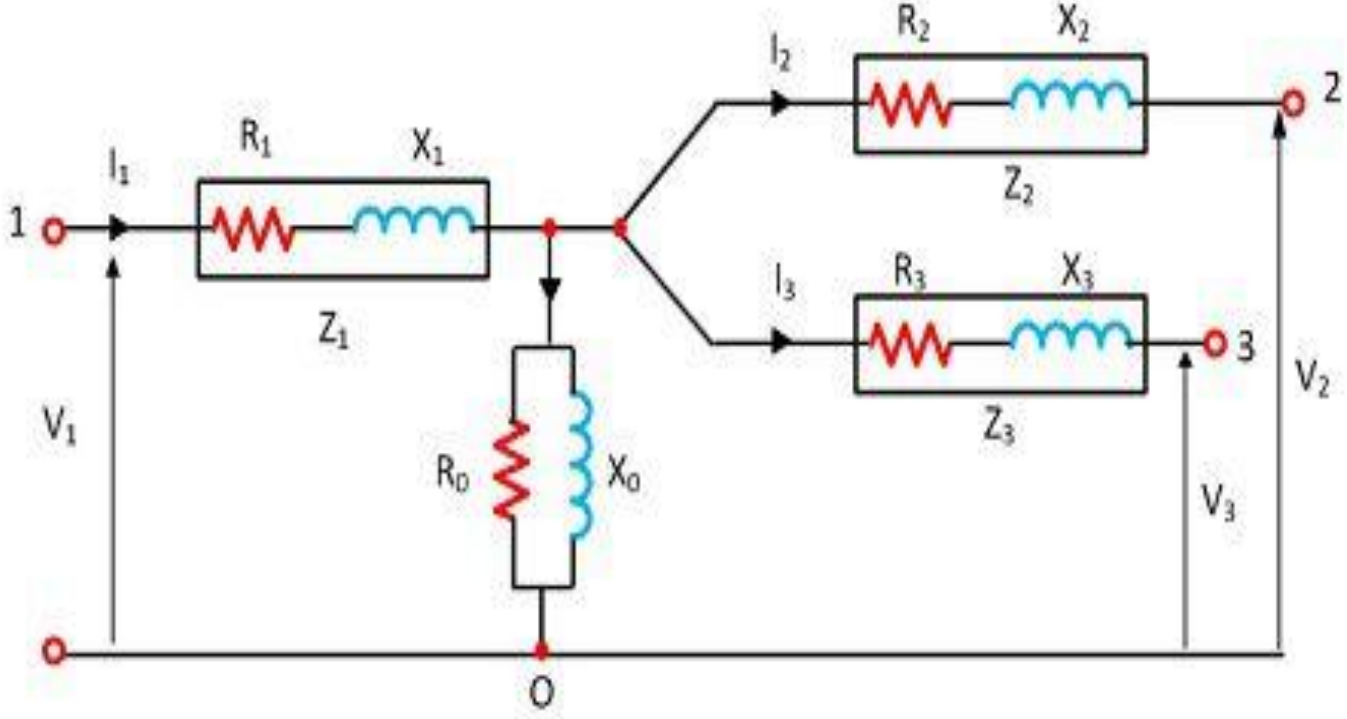
- These fluxes induce the secondary EMFs in respective phase such that they maintain their phase angle between them. These EMFs drives the currents in the secondary and hence to the load. Depends on the type of connection used and number of turns on each phase, the voltage induced will be varied for obtaining step-up or step-down of voltages.

Phase-shift between line-line voltages in transformers



Equivalent Circuit of a Three Phase Transformer

- The equivalent circuit diagram of the three-phase transformer is shown in the figure. Consider the R_1, R_2 and R_3 are the resistance and the X_1, X_2 and X_3 are the impedance of their windings.
- The V_1, V_2, V_3 are the voltages and the I_1, I_2, I_3 are current flows through their windings.



Equivalent Diagram of a 3-Winding Transformer

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Short Circuit Test

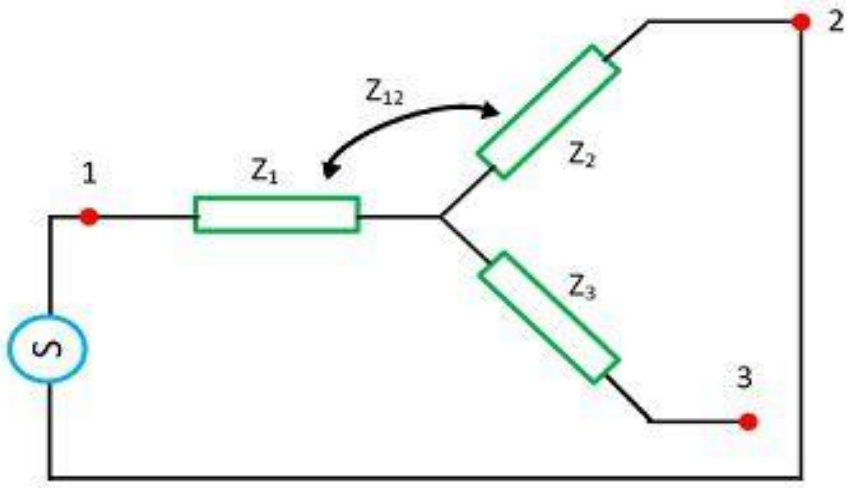
Consider the Z_1, Z_2 and Z_3 are the impedances of the three winding transformers. These impedances are considered as the base for performing the short circuit test. For the short-circuit test, the two winding is short circuit and the third winding is kept open.

In the first step, consider the winding 1 and 2 are short-circuited. The low voltage winding is applied to the winding 1 due to which the full load current flows through the winding 2. The Z_{12} indicates the impedance of winding 1 and 2 and it measured as

$$Z_{12} = \frac{V_1}{I_1}$$

Equivalent resistance, $$R_{12} = \frac{P_1}{I_1^2}$$

Equivalent leakage reactance, $$X_{12} = \sqrt{Z_{12}^2 - R_{12}^2}$$



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The Z_{12} is the series combination of Z_1 and Z_2 respectively,

$$Z_{12} = R_{12} + jX_{12} = Z_1 + Z_2$$

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In the second step, the third winding is short-circuited with the second winding and the first winding is kept open. The low voltage source is applied across the third winding so that the full load current flows through the second winding. The Z_{23} represents the impedance of the winding 2 and 3 and the below equation expresses it.

$$Z_{23} = Z_2 + Z_3$$

In the third step, the second winding is opened and first and third winding are short-circuited. The low voltage is supplied to the third winding, and full load current flows through the first windings. The Z_{13} is the impedance of the first and third winding.

Solving equation (1), (2) and (3) we get the leakage impedance Z_1, Z_2 and Z_3 all referred to as primary,

$$Z_1 = \frac{1}{2}(Z_{12} + Z_{13} - Z_{23})$$

$$Z_1 = \frac{1}{2}(Z_{23} + Z_{12} - Z_{13})$$

$$Z_1 = \frac{1}{2}(Z_{13} + Z_{23} - Z_{12})$$

Open-Circuit Test

- The open circuit test is carried out to determine the core loss, magnetizing impedance and turn ratios. In open circuit test the voltmeter, ammeter and wattmeter are connected in low voltage winding. The secondary side is kept open, and the voltmeter is connected.
- Since the high voltage side is opened the current drawn by the primary is no load current and I_0 measured by the ammeter. The magnetizing impedance may be found by exciting current winding 1 with both winding 2 and 3 be open circuit. Then we have,

$$a_{12} = \frac{V_1}{V_3}, a_{13} = \frac{V_1}{V_3}$$

$$a_{23} = \frac{V_2}{V_3} = \frac{a_{23}}{a_{12}}$$

Voltage Regulation

Regulation Down:

Regulation down is the change in terminal voltage when a load current at any power factor is applied, expressed as a fraction of the no-load terminal voltage.

$$\text{Regulation Down} = \frac{Vnl - Vl}{Vnl}$$

Where,

V_{nl} = no-load terminal voltage

V_l = load terminal voltage

Regulation Up:

Regulation up is the ratio of the change in the terminal voltage when a load at a given power factor is removed, and the load voltage.

$$\text{Regulation Up} = \frac{Vnl - Vl}{Vl}$$

Efficiency

$$\eta = \frac{\text{Output power in KW}}{\text{Output power in Kw} + \text{Losses}}$$

$$= \frac{\text{Output power in KW}}{\text{Output power in Kw} + \text{Core loss} + \text{Copper loss}}$$

Magnetizing current and harmonics

Even when no load is connected to the secondary coil of the transformer, a current will flow in the primary coil. This current consists of:

The magnetization current i_m needed to produce the flux in the core; The core-loss current

i_{h+e} hysteresis and eddy current losses.

Ignoring flux leakage and assuming time-harmonic primary voltage, the average flux is:

$$\bar{\emptyset} = \frac{1}{N_p}\int V_p(t)dt = \frac{1}{N_p}\int V_m \cos\omega t dt = \frac{V_m}{\omega N_p}\sin\omega t\,[Wb]$$

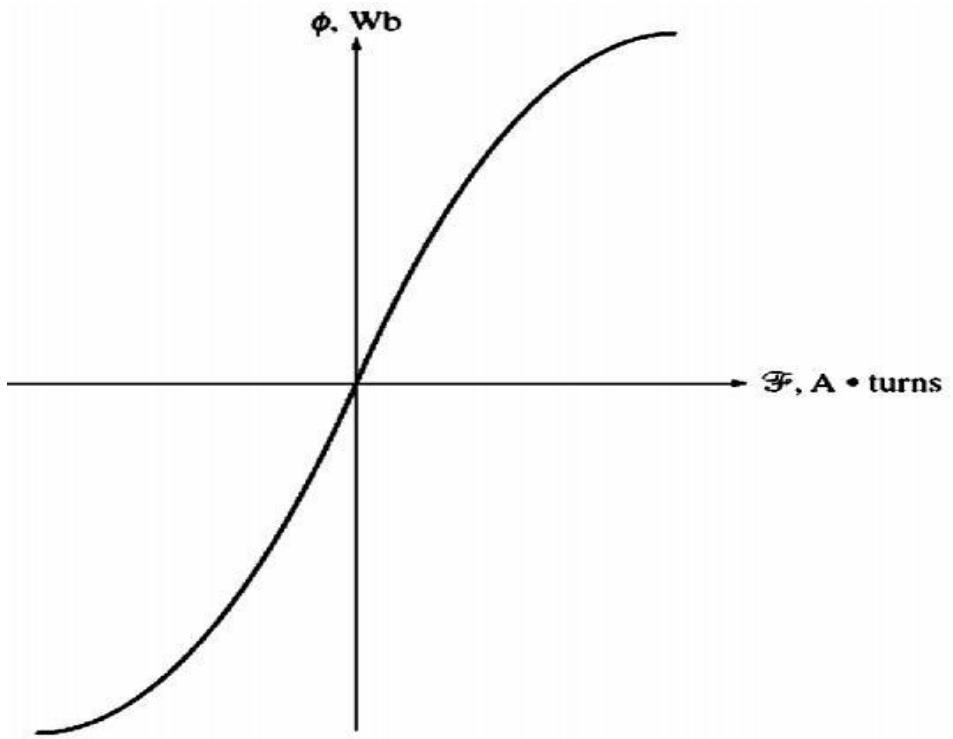
If the values of current are comparable to the flux they produce in the core, it is possible to sketch a magnetization current. We observe:

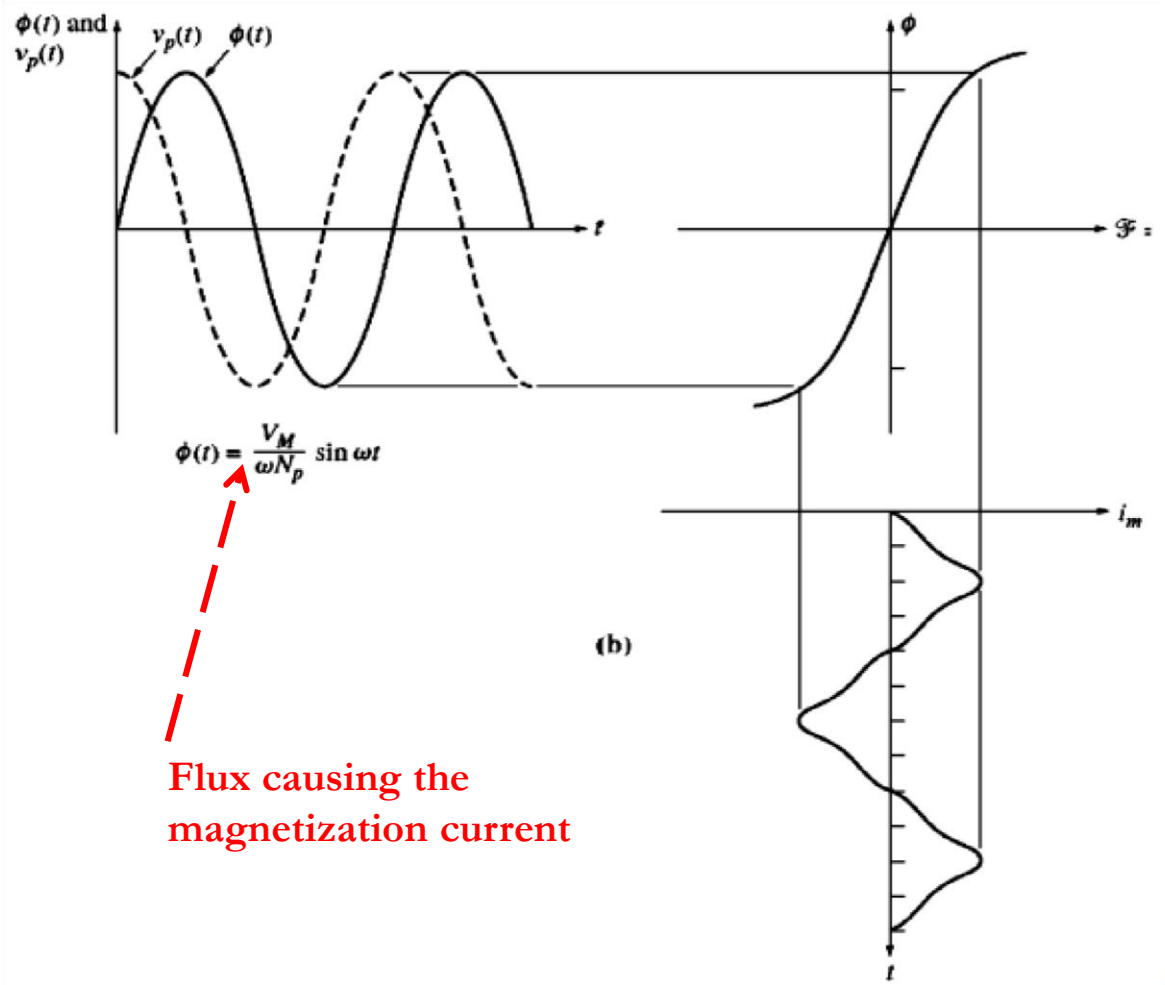
The magnetization current in the transformer is not sinusoidal. The higher frequency components in the magnetization current are due to magnetic saturation in the transformer core.

Once the peak flux reaches the saturation point in the core, a small increase in peak flux requires a very large increase in the peak magnetization current

The fundamental component of the magnetization current lags the voltage applied to the core by 90°.

The higher-frequency components in the magnetization current can be quite large compared to the fundamental component. In general, the further a transformer core is driven into saturation, the larger the harmonic components will become.



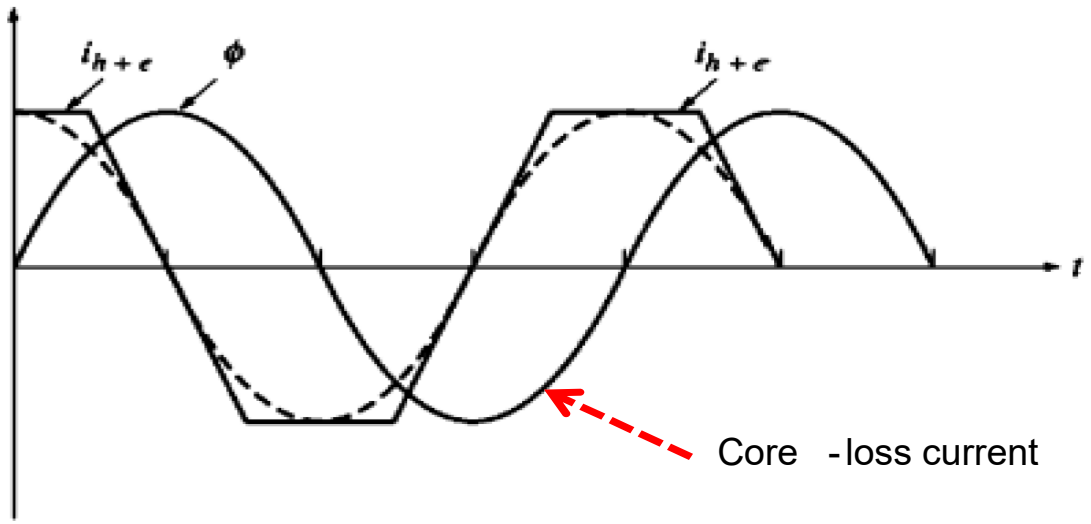


Flux causing the magnetization current

Typical magnetization curve

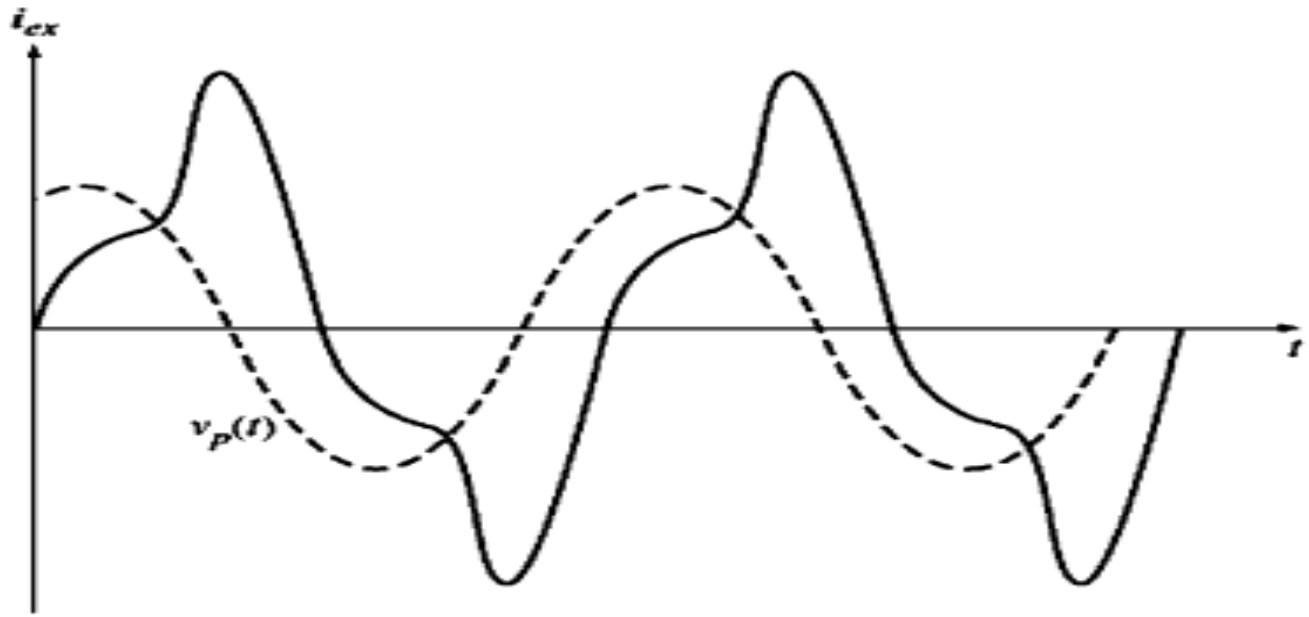
- The other component of the no load current in the transformer is the current required to supply power to make up the hysteresis and eddy current losses in the core is the core loss current.
- Core-loss current is:

- The core- loss current is nonlinear because of the nonlinear effects of hysteresis.
- The fundamental component of the core- loss current is in phase with the voltage applied to the core. Non linear due to nonlinear effects of hysteresis;



The total no-load current in the core is called the excitation current of the transformer: It is just the sum of the magnetization current and the core- loss current in the core:

$$iex = im + ih + e$$

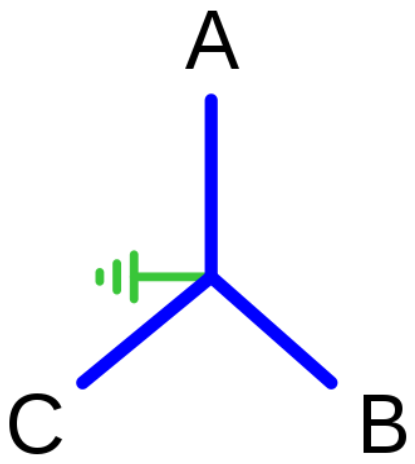


Winding Identification or Vector group of Transformer

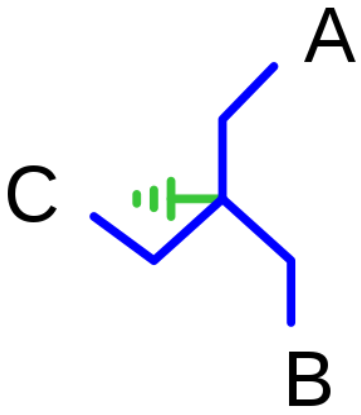
- It is the International Electro-technical Commission (IEC) method of categorizing the high voltage (HV) winding and low voltage (LV) winding configuration of three phase transformer.
- The vector group designation indicates the winding configuration and the difference in phase angle between them. For eg. A Wye HV wdg and Delta LV wdg with a 30 ° lead is denoted as Yd11
- In delta, polarity end of one wdg ia connected to non-polarity end of next wdg.
- In star, all three non polarity ends are connected together.
- The secondary wdg are connected similarly. Means 3ph transformer can have its primary and secondary wdg connected the same (Y-Y or Δ-Δ) or differently (Y- Δ or Δ-Y)
- But when wdg are connected differently, the secondary voltage waveform will differ from corresponding primary voltage waveform by 30°. This is called 30° phase shift.
- When two transformer are connected in parallel, their phase shift must be identical, otherwise short circuit will occure.

Zigzag Transformer

- A **zigzag transformer** is a special-purpose transformer with a zigzag or "interconnected star" winding connection, such that each output is the vector sum of two (2) phases offset by 120°. It is used as a grounding transformer
- Each of the three "limbs" are split into two sections. The two halves of each limb have an equal number of turns and are wound in opposite directions.



Star (wye) winding

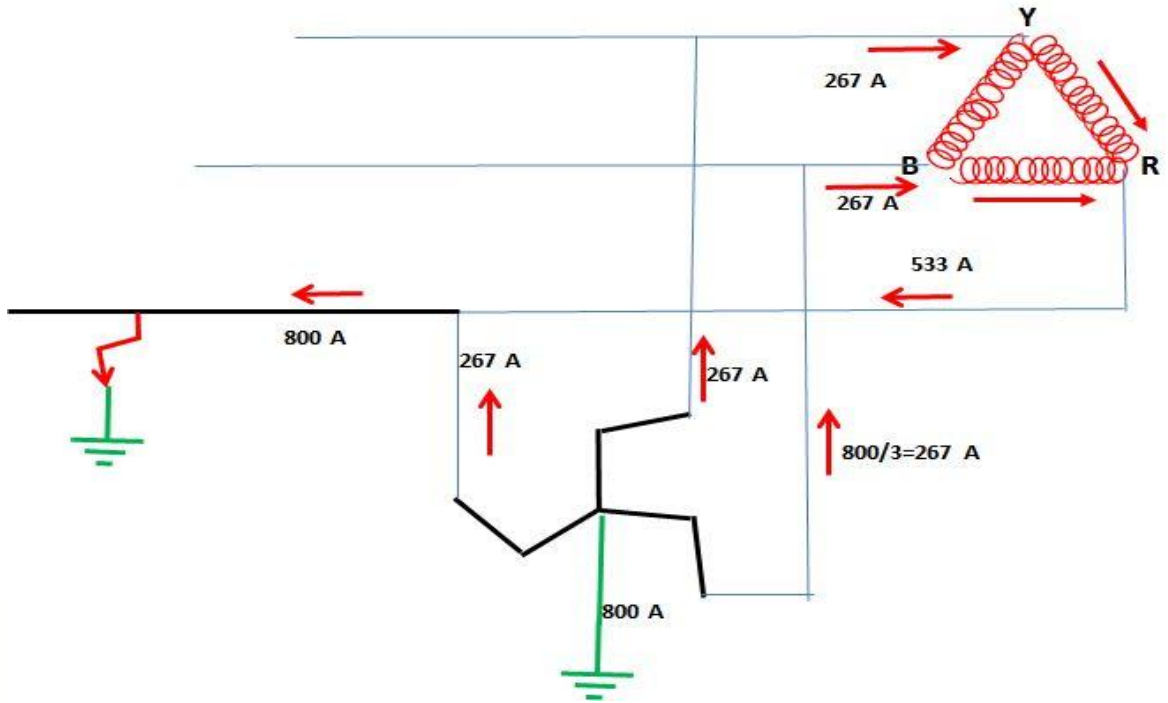


Zigzag winding

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Zigzag Transformer

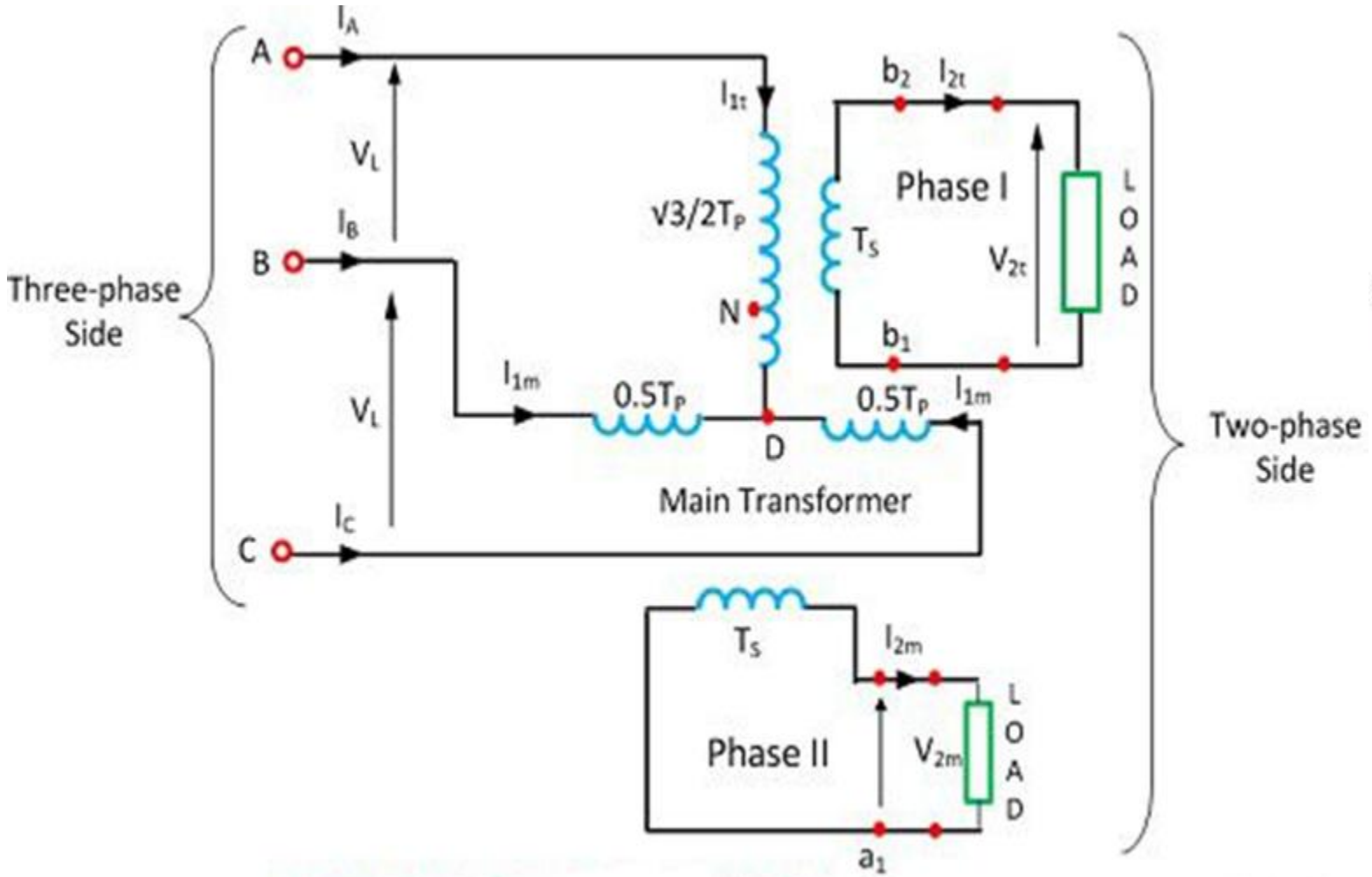
- A combination of star, delta, and zigzag windings may be used to achieve a vector phse shift. For example, a transmission network of 110 kV/33 kV star/star transformers, with 33 kV/11 kV delta/star for the high voltage distribution network. If a transformation is required directly between the 110 kV/11 kV network an option is to use a 110 kV/11 kV star/delta transformer. The problem is that the 11 kV delta no longer has an earth reference point. Installing a zigzag transformer near the secondary side of the 110 kV/11 kV transformer provides the required earth reference point.

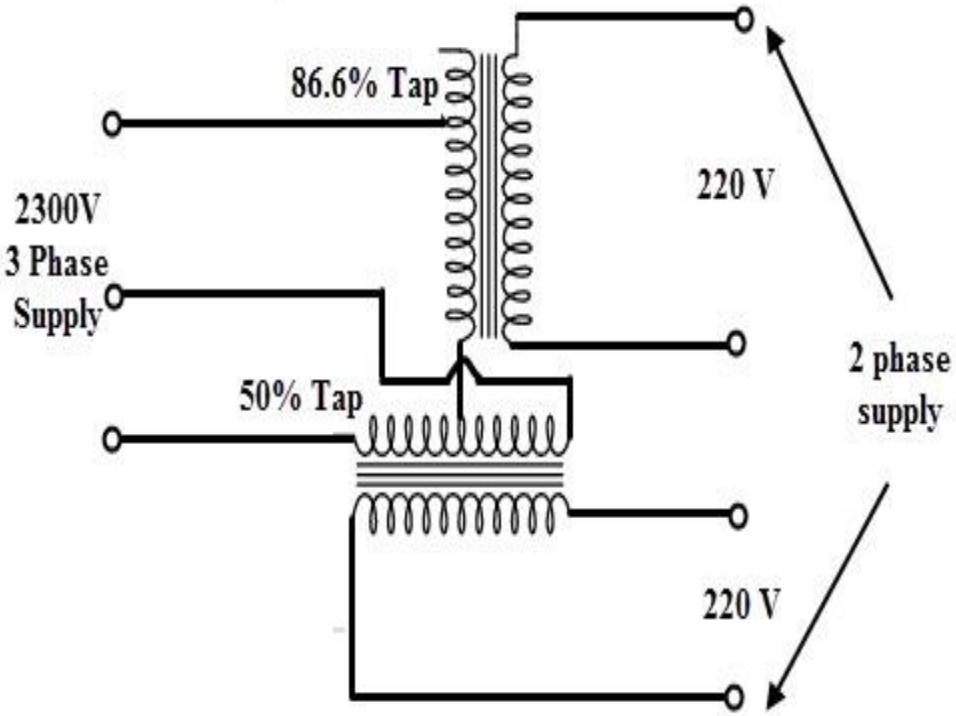


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Three phase to Two phase Conversion or Scott Connection

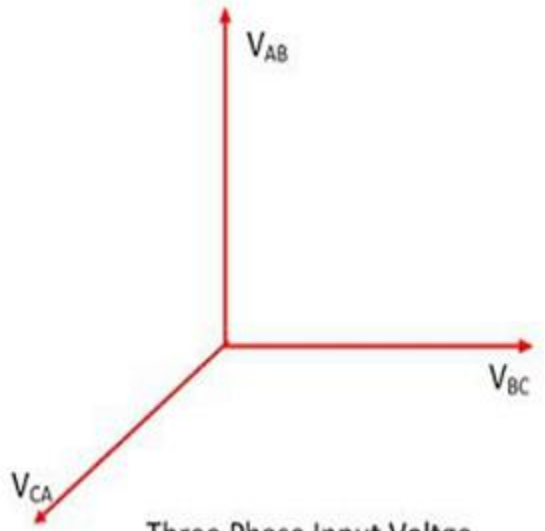
- The Scott-T Connection is the method of connecting two single phase transformer to perform the 3-phase to 2-phase conversion and vice-versa.
- The two transformers are connected electrically but not magnetically. One of the transformer is called the Main transformer and the other is called Auxiliary or Teaser transformer
- The figure shows the Scott-T transformer connection. The main transformer is Centre tapped at D and is connected to the line B and C of the 3-phase side. It has primary BC and secondary a_1a_2. The teaser transformer is connected to the line terminal A and the Centre tapping D. It has primary AD and the secondary b_1b_2
- The identical, interchangeable transformers are used for Scott-T connection in which each transformer has a primary winding of T_p turns and is provided with tapping at $0.289T_p$, $0.5T_p$and $0.866\ T_p$.


A
B
C
I_A
I_B
I_C
V_L
V_L
V_L
Three-phase Side
I_{1t}
$\sqrt{3}/2T_P$
N
I_{1m}
$0.5T_P$
D
$0.5T_P$
I_{1m}
Main Transformer
b_2
I_{2t}
Phase I
T_S
V_{2t}
b_1
LOAD
T_S
I_{2m}
Phase II
V_{2m}
LOAD
a_1
Two-phase Side

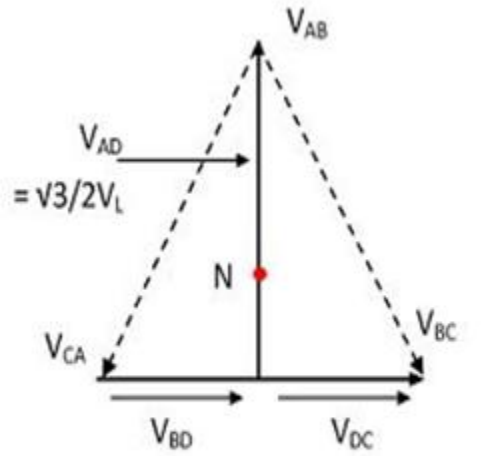

86.6% Tap
2300V
3 Phase
Supply
50% Tap
220 V
2 phase
supply
220 V

Phasor Diagram of Scott Connection of Transformer

The line voltages of the 3-phase system V_{AB}, V_{BC}, and V_{CA} which are balanced are shown in the figure below. The same voltage is shown as a closed equilateral triangle. The figure below shows the primary windings of the main and the teaser transformer.



Three Phase Input Voltge



Voltage on transformer Primary Winding

$$|V_{AB}| = |V_{BC}| = |V_{CA}| = |V_L|$$

The D divides the primary BC of the main transformers into two halves and hence the number of turns in portion BD = the number of turns in portion DC = $T_p/2$.The voltage V_{BD} and V_{DC} are equal, and they are in phase with V_{BC}.

$$V_{BD} = V_{DC} = \frac{1}{2}V_{BC} = \frac{1}{2}V_L < 0°$$

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The voltage between A and D is

$$V_{BD} = V_{DC} = \frac{1}{2}V_{BC} = \frac{1}{2}V_L < 0°$$

$$V_{AD} = V_{AB} + V_{BD}$$

$$V_{AD} = V_L\left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right) + \frac{1}{2}V_L$$

$$V_{AD} = V_L\left(j\frac{\sqrt{3}}{2}\right) = 0.866V_L < 90°$$

The teaser transformer has the primary voltage rating that is √3/2 or 0.866 of the voltage ratings of the main transformer. Voltage V_{AD} is applied to the primary of the teaser transformer and therefore the secondary of the voltage V_{2t} of the teaser transformer will lead the secondary terminal voltage V_{2m} of the main transformer by 90º as shown in the figure below.



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$$\frac{V_{S_1}}{V_{AD}} = \frac{T_S}{T_{AD}}$$

$$V_{2t} = \frac{T_S}{T_{AD}} V_{AD} = \frac{T_S}{\frac{\sqrt{3}}{2} T_P} \times \frac{\sqrt{3} V_t}{2}$$

$$\frac{T_S}{T_P} V_L = v_{2m}$$

- For keeping the voltage per turn same in the primary of the main transformer and the primary of the teaser transformer, the number of turns in the primary of the teaser transformer should be equal to $\sqrt{3}/2T_p$.
- Thus, the secondaries of both transformers should have equal voltage ratings. The V_{2t} and V_{2m} are equal in magnitude and 90º apart in time; they result in the balanced 2-phase system.

Position of Neutral point N

The primary of the two transformers may have a four wire connection to a 3-phase supply if the tapping N is provided on the primary of the teaser transformer such that

The voltage across AN = V_{AN} = phase voltage = $V_L/\sqrt{3}$.

Since the voltage across the portion AD.

$$V_{AD} = \frac{\sqrt{3}}{2} V_L$$

the voltage across the portion ND

$$V_{ND} = V_{AD} - V_{AN} = \frac{\sqrt{3}}{2} V_L - \frac{V_L}{\sqrt{3}} = \frac{V_L}{2\sqrt{3}}$$

The same voltage turn in portion AN,
ND and AD are shown by the equations,

$$T_{AN} = \frac{T_P}{\sqrt{3}} = 0.577T_P$$

$$T_{ND} = \frac{T_P}{2\sqrt{3}} = 0.288T_P$$

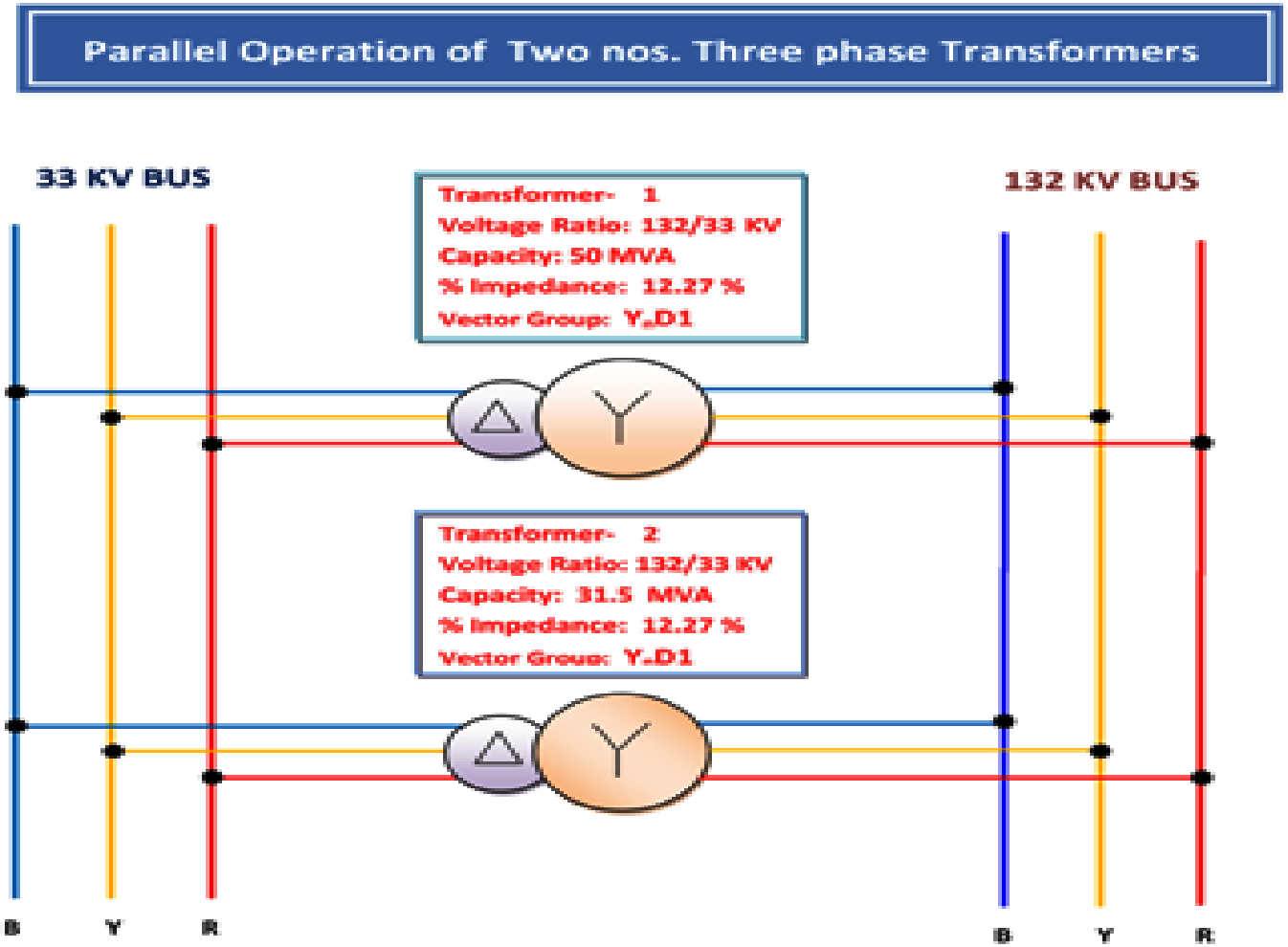
$$T_{AD} = \frac{\sqrt{3}T_P}{2} = 0.866T_P$$

$$\frac{T_{AN}}{T_{ND}} = \frac{T_P}{\sqrt{3}} + \left(\frac{T_P}{2\sqrt{3}}\right) = 2$$

The equation above shows that the neutral point N divides the primary of the teaser transformer in ratio.

AN : ND = 2 : 1

Parallel Operation of Transformer



The following conditions are to be fulfilled before paralleling two three phase Transformers:-

1.The voltage transformation ratio of the both transformer must be same.

2.The polarity must be same.

3.The percentage impedance should be same.

4.The vector diagram and the phase displacement must be same.

5.The phase sequence must be same.

Effects of percentage impedance on load sharing in parallel operation of Transformer :-

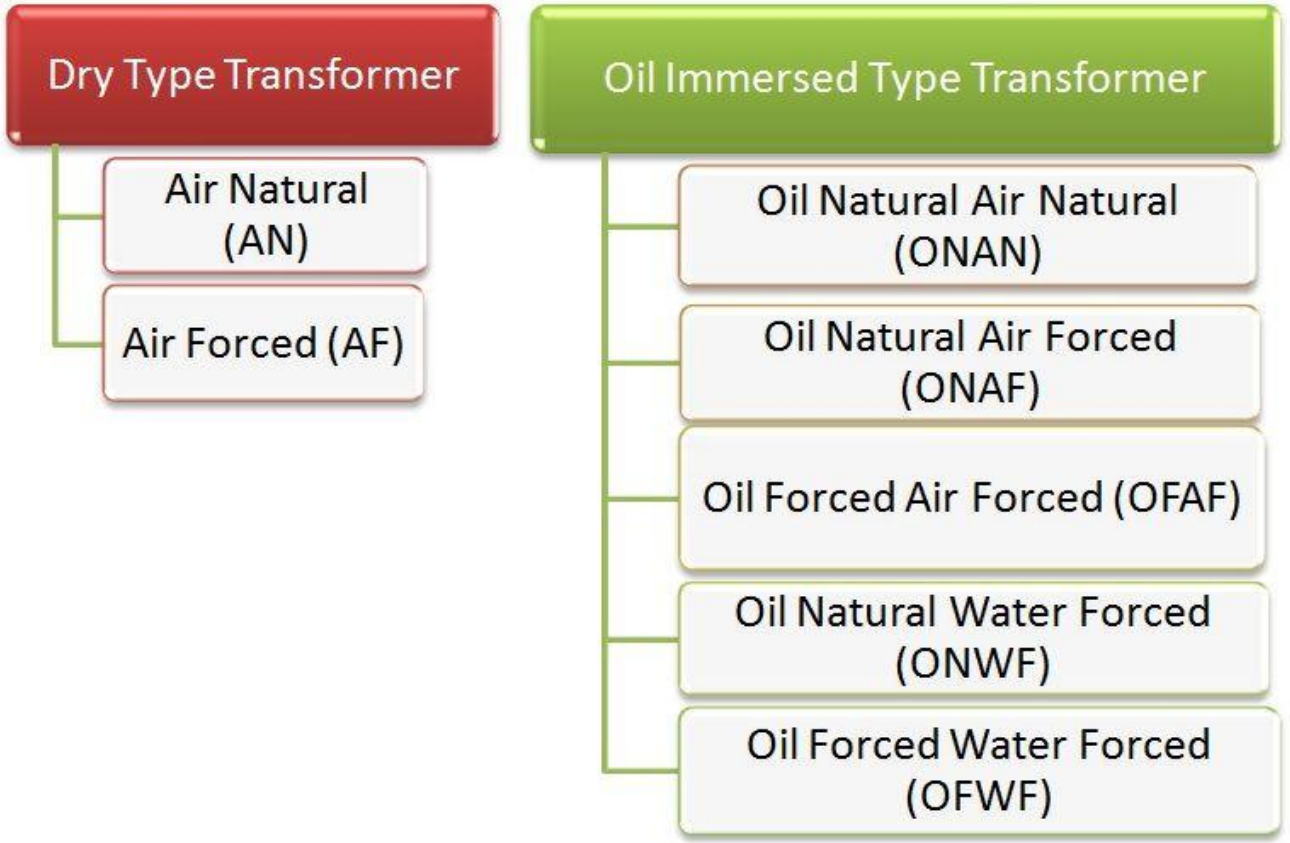
Voltage drop between no load to full load of transformer is determined the percentage impedance of the transformer. Now, we describe the effect of percentage impedance on load sharing in parallel operation. Let, Percentage impedance of Transformer 1 = Z1 % And Percentage impedance of Transformer 2 = Z2 %

1.If the percentage impedances of the transformers are equal (i.e Z 1 % = Z 2 %) running in parallel , both the transformers will share the load in proportion to their capacities i.e Ratting of transformer (MVA/KVA rating).

2.If percentage impedance of Transformer-1 is greater than the percentage impedance of Transformer-2 (I.e Z 1 % > Z 2 %) and both are running in parallel operation. That time, lower percentage transformer, i.e Transformer-2 will have less voltage drop and therefore it will take greater share of the load. Transformer -1 (i.e higher percentage impedance) will have higher voltage drop and therefore it will take lower share of the load.

Cooling Methods of Transformer

Basically, there are **two types of transformer** one is the **dry type,** and another one is oil-immersed **type**. For the cooling of transformers, the following cooling methods listed below are used.



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Air Natural (AN):

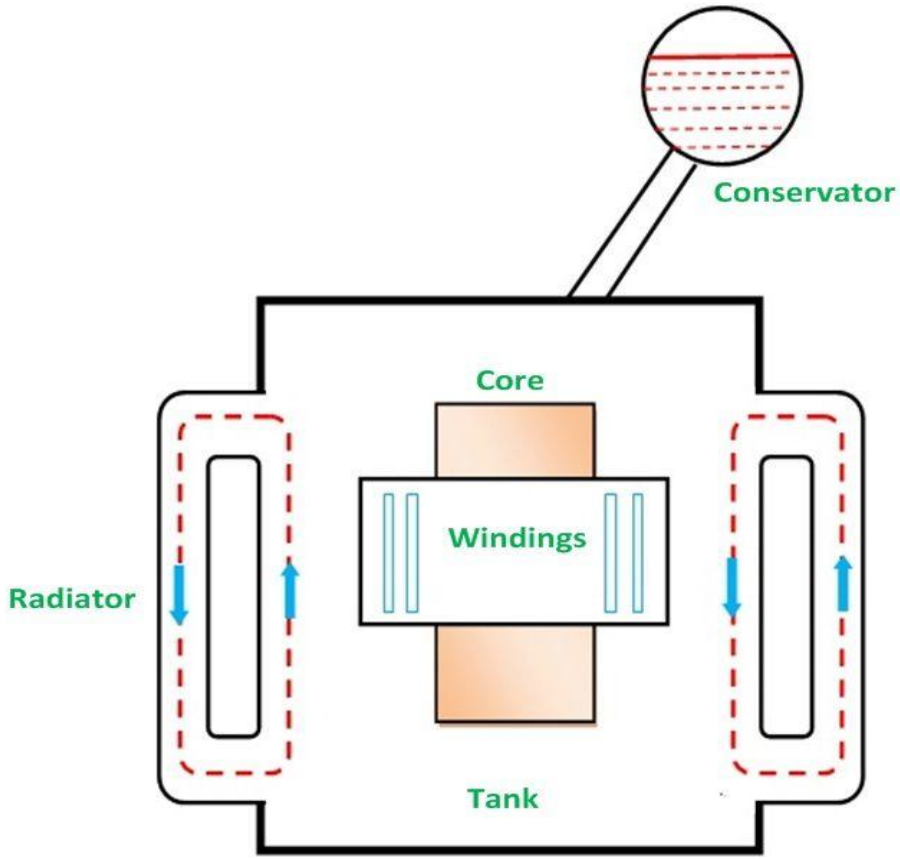
By Air Natural method the generated heat in the transformer is cooled by the circulation of natural air. When the temperature of the transformer becomes higher as compared to the temperature of the surrounding air, thus by the process of natural convection, heated air is replaced by the cool air. This method is also known as a **self-cooled method**. This method is used for cooling the smaller output transformer rating that is up to **1.5 MVA**.

Air Forced (AF) or Air Blast:

In this method, the heat generated is cooled by the **forced air circulation** method. With the help of fans and blowers, high velocity of air is forced on the core and the windings of the transformer. As the temperature inside the transformer goes beyond the standard safe level, an alarm is activated, and the fans and blowers are switched ON automatically. This method is used for transformer rating up to **15MVA**.

Oil Natural Air Natural (ONAN)

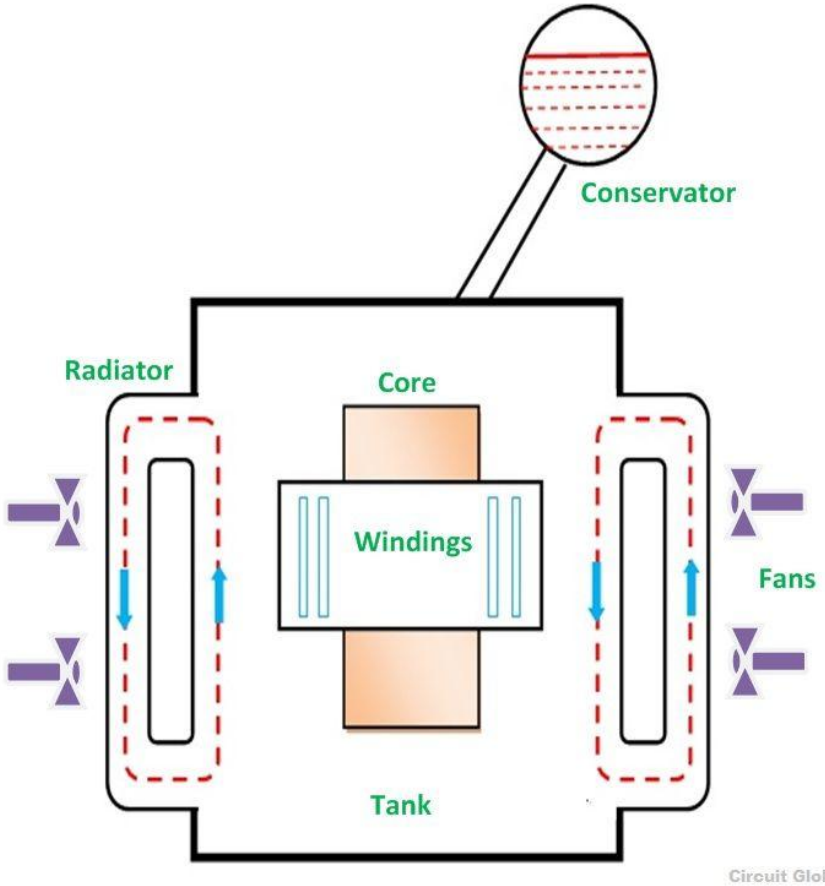
Natural convection process is used for this type of cooling. The assembly of the core and windings are placed in the oil-immersed tank. As the core and the windings heat up the temperature of the oil in the transformer rises. As a result, the oil moves upward and flows from the upper portion of the transformer tank. This hot oil dissipates heat in the air by natural convection and conduction process, the oil gets cooled by the circulation of natural air and passes through the radiator again for the use of the transformer. This type of cooling is used for the transformer rating up to **30 MVA**.



Oil Natural Air Forced (ONAF)

ONAF method is used for the cooling of the transformer of rating up to **60 Mega volts ampere**. As discussed above that in ONAN method, the dissipation of heat is taking place by the convection process in which air is naturally circulated to cool down, but in this type, the forced air is used for the purpose of cooling the transformer.

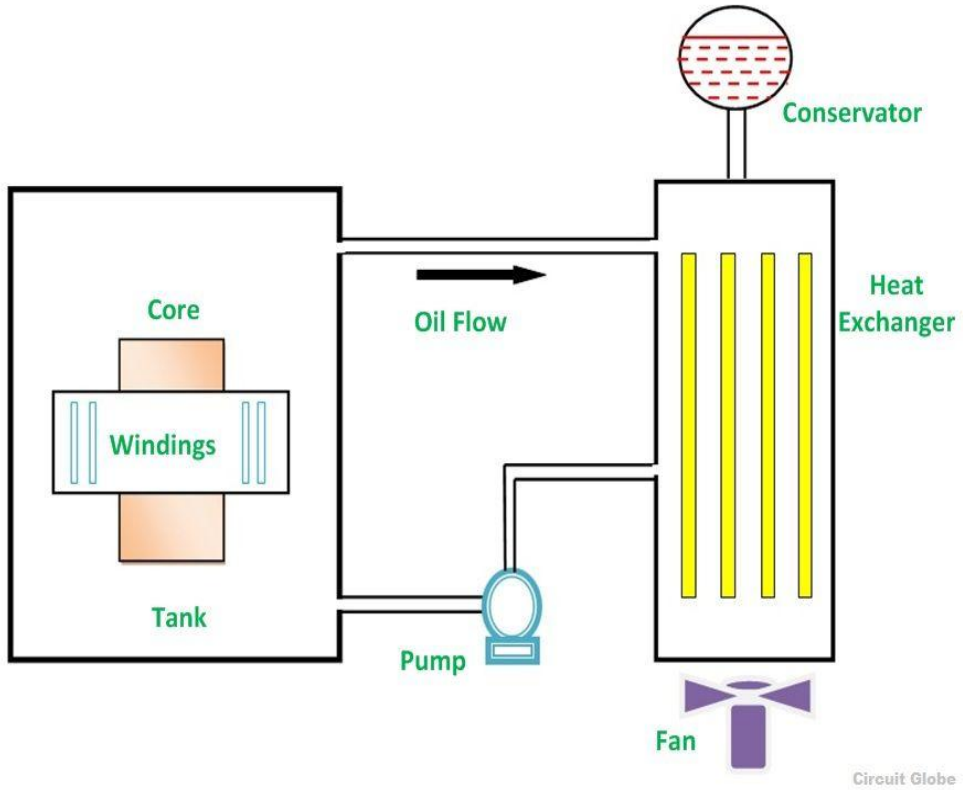
The cooling of oil will be faster if the area of the tank of the transformer is increased finally, which result in the increase in heat dissipation level. As the fans and blowers are installed, a high velocity of air is forcefully applied to the radiator and cooling towers which will help in cooling oil more quickly and efficiently.



Oil Forced Air Forced (OFAF)

As the name itself says that both the oil and the air are applied by force for cooling of a transformer. The Heat Exchanger is installed through which hot oil is circulated with the help of a pump. Air is forced to pass on the heat exchanger with the help of high-speed fans.

This method is similar to ONAN, as when there is low load on the transformer the cooling is done by a simple ONAN method. However, as soon as the load is increased, the generated heat will also be more and therefore the sensor gives an alarm that the dissipation of heat has exceeded the safe value and as a result, the fans and pumps are switched on automatically.



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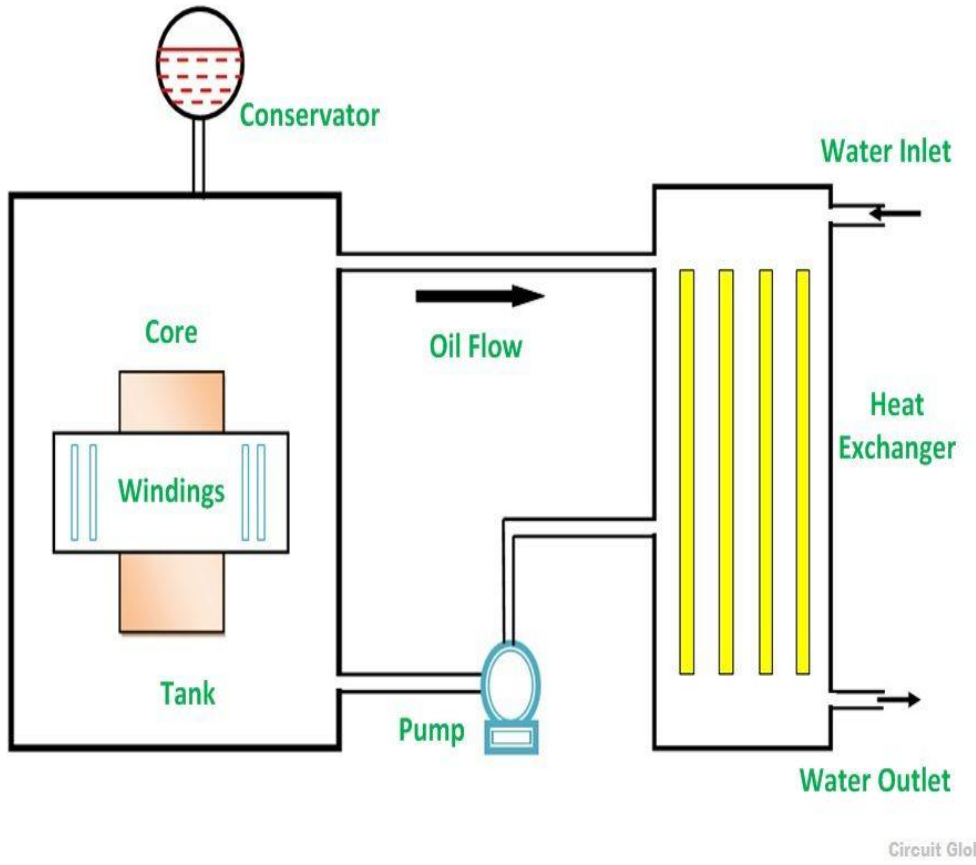
Oil Natural Water Forced (ONWF)

In Oil Natural Water Force cooling method, the transformer core and the windings are immersed in the oil tank. A radiator is installed outside the tank, as the temperature rises and the oil heats up and moves upward, the heat is dissipated by the natural process of convection and oil is passed through the radiator, but the water is pumped and passed through the heat exchanger for cooling of the oil.

Oil Forced Water Forced (OFWF)

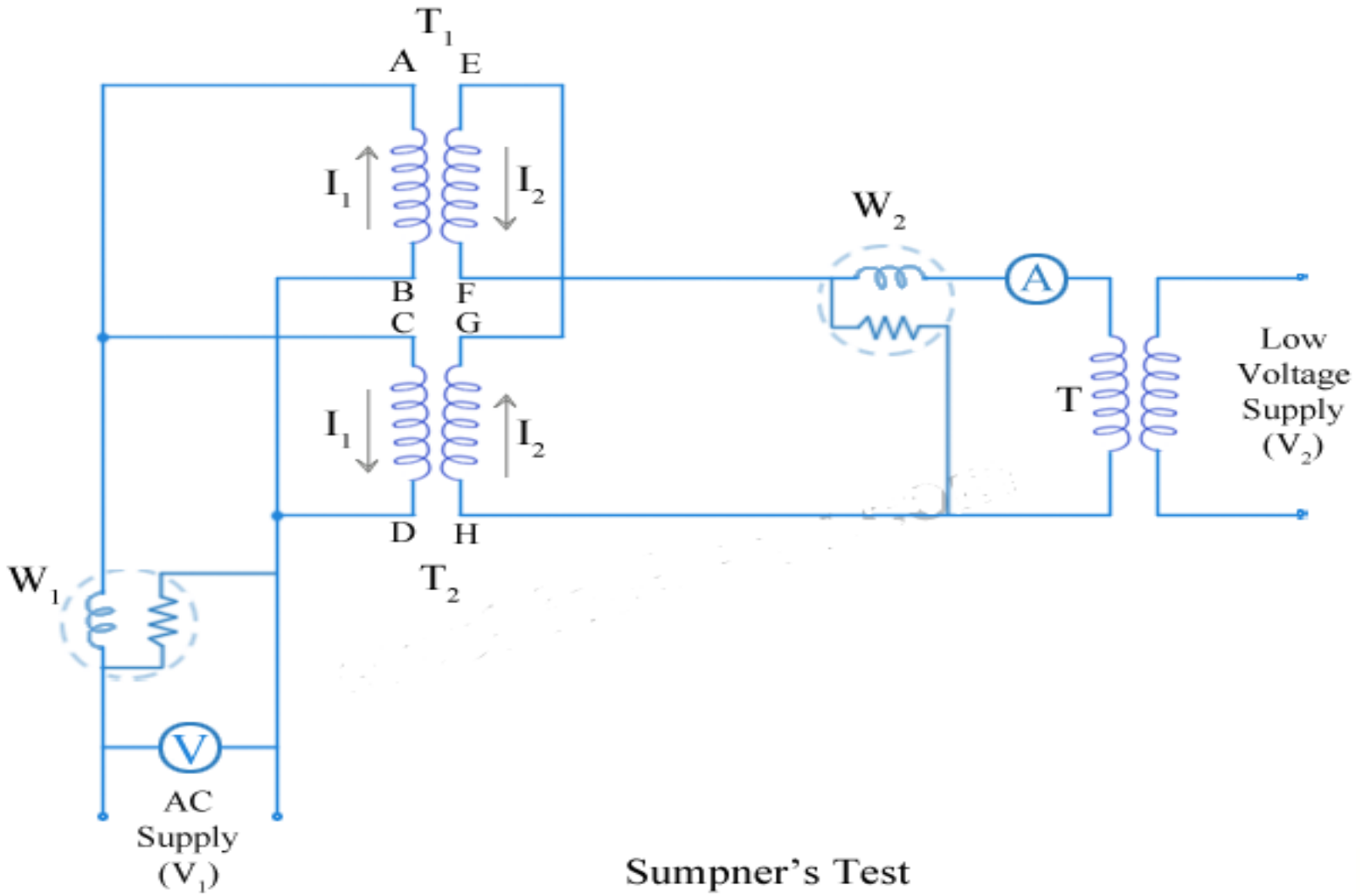
A heat exchanger is installed through which both oil and water are passed with the help of a pump. The level and pressure of the oil are always kept higher than that of water so that if any leakage occurs in the system the oil mixes with the water, but water does not get mixed up with the oil.

This type of method is suitable for large capacity of the transformer having rating as several hundred MVA or where banks of transformers are installed. Mainly this type of cooling is done for the transformer installed at the hydropower plant.



Back to Back (Sumpner's)Test

- Sumpner's test or back to back test on transformer is another method for determining transformer efficiency, voltage regulation and heating under loaded conditions.
- Short circuit and open circuit test on transformer can give us parameters of equivalent circuit of transformer, but they can not help us in finding the heating information.
- Unlike O.C. and S.C. tests, actual loading is simulated in Sumpner's test. Thus the Sumpner's test give more accurate results of regulation and efficiency than O.C. and S.C. tests.
- Sumpner's test or back to back test can be employed only when two identical transformers are available. Both transformers are connected to supply such that one transformer is loaded on another.
- Primaries of the two identical transformers are connected in parallel across a supply.
- Secondaries are connected in series such that emf's of them are opposite to each other.
- Another low voltage supply is connected in series with secondaries to get the readings.



Sumpner's Test

- In above diagram, T_1 and T_2 are identical transformers. Secondaries of them are connected in voltage opposition, i.e. E_{EF} and E_{GH}. Both the emf's cancel each other, as transformers are identical.
- In this case, as per superposition theorem, no current flows through secondary. And thus the no load test is simulated. The current drawn from V_1 is $2I_0$, where I_0 is equal to no load current of each transformer. Thus input power measured by wattmeter W_1 is equal to iron losses of both transformers.
  i.e. iron loss per transformer $P_i = W_1/2$.
- Now, a small voltage V_2 is injected into secondary with the help of a low voltage transformer. The voltage V_2 is adjusted so that, the rated current I_2 flows through the secondary. In this case, both primaries and secondaries carry rated current. Thus short circuit test is simulated and wattmeter W_2 shows total full load copper losses of both transformers.
  i.e. copper loss per transformer $P_{Cu} = W_2/2$.

From above test results, the full load efficiency of each transformer can be given as -

$$\%\ \text{full load efficiency of each transformer} = \frac{\text{output}}{\text{output} + \frac{W_1}{2} + \frac{W_2}{2}} \times 100$$

Determination of Temperature Rise:

The temperature rise of the transformer is determined by measuring the temperature of their oil after every particular interval of time. The transformer is operating back to back for the long time which increases their oil temperature. By measuring the temperature of their oil the withstand capacity of the transformer under high temperature is determined.

Maintenance of Transformer

For getting smooth performance from a transformer we have to perform some maintenance actions on a regular basis. The regular checking and maintenance of transformer is also known as **condition maintenance**.

Monthly Basis Maintenance of Transformer:

- The oil level in oil cap under silica gel breather must be checked in a one-month interval. If it is found the transformer oil inside the cup comes below the specified level, oil to be top up as per specified level.
- Breathing holes in silica gel breather should also be checked monthly and properly cleaned if required, for proper breathing action.
- If the transformer has oil filled bushing the oil level of transformer oil inside the bushing must be visually checked in the oil gage attached to those bushing. This action also to be done monthly basis.

Daily Basis Maintenance and Checking

1.Reading of MOG (Magnetic Oil Gauge) of main tank and Conservator tank
2.Color of silica gel in breather.
3.Leakage of oil from any point of a transformer.

Yearly Basis Transformer Maintenance Schedule

1.The auto, remote, manual function of cooling system that means, oil pumps, air fans, and other items engaged in cooling system of transformer, along with their control circuit to be checked in the interval of one year. In the case of trouble, investigate control circuit and physical condition of pumps and fans.
2.All the bushings of the transformer to be cleaned by soft cotton cloths yearly. During cleaning the bushing should be checked for cracking.
3.Oil condition of OLTC to be examined in every year. For that, oil sample to be taken from drain valve of divertor tank, and this collected oil sample to be tested for dielectric strength (BDV) and moisture content (PPM). If BDV is low and PPM for moisture is found high compared to recommended values, the oil inside the OLTC to be replaced or filtered.

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1.Mechanical inspection of Buchholz Relay to be carried out on yearly basis.
2.All marshalling boxes to be cleaned from inside at least once in a year. All illumination, space heaters, to be checked whether they are functioning properly or not. If not, required maintenance action to be taken. All the terminal connections of control and relay wiring to be checked an tighten at least once in a year.
3.All the relays, alarms and control switches along with their circuit, in R&C panel (Relay and Control Panel) and RTCC (Remote Tap Changer Control Panel) to be cleaned by appropriate cleaning agent.
4.The pockets for OTI, WTI (Oil Temperature Indicator & Winding Temperature Indicator) on the transformer top cover to be checked and if required oil to be replenished.
5.The proper function of Pressure Release Device and Buchholz relay must be checked annually. For that, trip contacts and alarm contacts of the said devices are shorted by a small piece of wire, and observe whether the concerned relays in remote panel are properly working or not.
6.Insulation resistance and polarization index of transformer must be checked with battery operated megger of 5 KV range.

Insulation of Transformer

1.Major Insulation:

- Insulating cylinder between LV & core
- Also between HV & LV Insulating barriers between limbs, coils & core yoke
- Oil impregnated paper used as it has high dielectric strength

2. Minor Insulation:

- Insulation between individual turns & between layers
- Conductor Insulation: paper & cotton
- Air insulated Transformer insulation used is glass tap

Thank you !