3.14.All day efficiency of transformer

For a transformer, the efficiency is defined as the ratio of output power to input power. This is its efficiency. But power efficiency is not the true measure of the performance of some special types of transformers such as distribution transformers.

Distribution transformer serve residential and commercial loads. The load on such transformers vary considerably during the period of the day. For most period of the day these transformers are working at 30 to 40 % of full load only or even less than that. But the primary of such transformers is energised at its rated voltage for 24 hours, to provide continuous supply to the consumer. The core loss which depends on voltage, takes place continuously for all the loads. But copper loss depends on the load condition. For no load, copper loss is negligibly small while on full load it is at its rated value. Hence power efficiency can not give the measure of true efficiency of such transformers. in such transformers, the energy output is calculated in kilo watt hour (kWh). **Then ratio of total energy output to total energy input (output + losses) is calculated. Such ratio is called energy efficiency or All Day Efficiency of a transformer**. Based on this efficiency, the performance of various distribution transformers is compared. All day efficiency is defined as,

$$\% \text{ All day } \eta = \frac{\text{Output energy in kWh during a day}}{\text{Input energy in kWh during a day}} \times 100$$

$$= \frac{\text{Output energy in kWh during a day}}{\text{Output energy + Energy spent for total losses}} \times 100$$

While calculating energies, all energies can be expressed in **watt hour** (Wh) instead of kilo watt hour (kWh).

Such distribution transformers are designed to have very low core losses. This is achieved by limiting the core flux density to lower value by using a relative higher core cross-section i.e. larger iron to copper weight ratio. The maximum efficiency in such transformers occurs at about 60-70 % of the full load. So by proper designing, high energy efficiencies can be achieved for distribution transformers.

Q.1. A 400 KVA, distribution transformer has full load iron loss of 2.5 kW and copper loss of 3.5 kW. During a day, its load cycle for 24 hours is,

6 hours 300 kW at 0.8 p.f.

10 hours 200 kW at 0.7 p.f.

4 hours 100 kW at 0.9 p.f.

Determining its all day efficeincy.

Ans :

Given Data :

Transformer rating = 400 KVA

Full load iron loss = 2.5 KW

Full load copper loss = 3.5 KW

The iron loss for 24 hr is constant

$\therefore$ The total iron loss in watt hr

$= 2.5 \times 10^3 \times 24 = 60{,}000\ Wh = 60\ KWh$

Total energy output in a day from given load cycle is,

Energy output $= (300 \times 6\ hr + 200 \times 10 + 100 \times 4)$ KWh

$= (1800 + 2000 + 400)$ KWh

$= 4200$ KWh

TO calculate energy loss due to copper loss :-

SL NO	Load in KW	pf	KVA conversion = KW/pf	$\eta = \frac{\text{Load in KVA}}{\text{KVA rating}}$	P_{cu} load = $\eta^2 \times P_{cu}$ fl. = $\eta^2 \times 3.5$ KW	Time in hours	Total energy in kWh.
1.	300	0.8	$\frac{300}{0.8} = 375$	$\eta = \frac{375}{400} = 0.9375$	$(0.9375)^2 \times 3.5 = 3.076$	6	$3.076 \times 6 = 18.456$
2.	200	0.7	$\frac{200}{0.7} = 285.714$	$\eta = \frac{285.714}{400} = 0.7142$	$(0.7142)^2 \times 3.5 = 1.7852$	10	$1.7852 \times 10 = 17.852$
3.	100	0.9	$\frac{100}{0.9} = 111.111$	$\eta = \frac{111.111}{400} = 0.2777$	$(0.2777)^2 \times 3.5 = 0.2699$	4	$0.2699 \times 4 = 1.0796$

Total energy loss = 37.3876

Therefore; Total energy lost =

$60 + 37.3876 = 97.3876 \text{ kWh}$.

$$\%\eta_{\text{all day}} = \frac{\text{Total o/p in 24 hr}}{\text{Total o/p in 24 hr} + \text{Total energy lost}} \times 100$$

$$= \frac{4200}{4200 + 97.3876} \times 100$$

$$= 97.73\%$$

3.16.Parallel operation of Transformer

Why Parallel Operation of Transformers is required?
OR Necessity of Parallel Operation of Transformer?

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,

1. 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 fulfill the total demand. In this way we can run the system with maximum efficiency.
2. To maximize electrical power system availability:
   If numbers of transformers run in parallel, we can shutdown any one of

them for maintenance purpose. Other parallel transformers in system will serve the load without total interruption of power.

3. 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.
4. 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 full-fill 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**.

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

(parallel operation of Transformer)

Same Voltage Ratio:

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 I^2R 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 emf 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.

parallel operation of transformer:

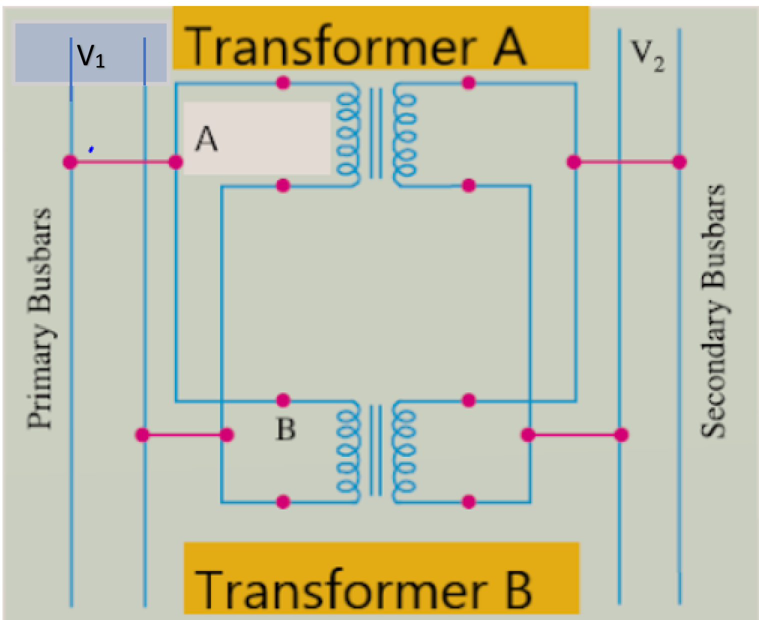


Fig- Parallel Operation connection diagram of transformer A & B

Transformer **Parallel Operation** is means a multiple transformers with same characteristics operates using same voltage from a unique voltage source to supply the same level of voltage for a common load. In short the transformers in **parallel operation** are connected as primary windings are in a common voltage supply, and the secondary windings are in a common load. The simple **parallel operation** connection diagram of two transformers is shown in the figure above.

For supplying a larger load of the rating of an existing transformer A, a second or additional transformer B may be connected in parallel with existing transformer that is shown in above figure.

You will find here that primary windings are connected to the supply bus bars and secondary windings are connected to the load bus-bars. In connecting two or multiple transformers in parallel, it is essential that their terminals of similar polarities are joined to the same bus-bars as in figure above.

Important issues for transformer **parallel operation** is if the above conditions are not fulfilled, the two e.m.f.s. induced in the secondaries which are paralleled with incorrect polarities, will act together in the local secondary circuit even when supplying no load and will hence produce the equivalent of a dead short-circuit.

4.Auto Transformer

Introdution:

An autotransformer is a type of electrical transformer in which a part of the winding is common to both primary and secondary circuit. Unlike a two winding transformer where power transfer is only inductive, the power transformer in an autotransformer is both inductive and conductive.

Constructional features of Auto transformer:

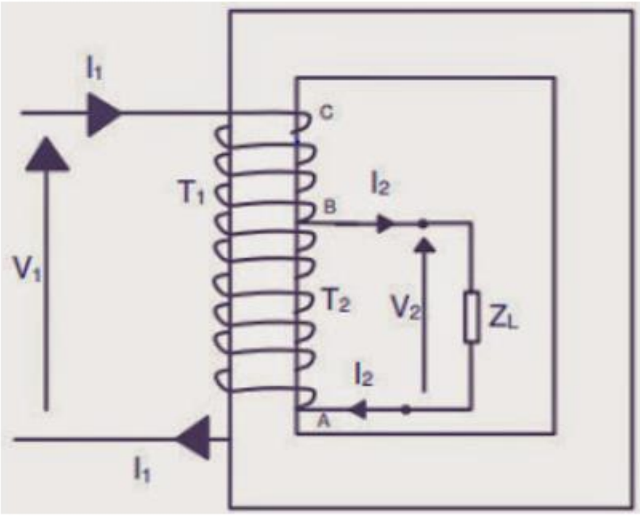
This ingenious thought led to the invention of an *autotransformer*. The figure shows the physical arrangement of an **auto transformer**. The total number of turns between A and C are T1.At point B a connection is taken. Section AB has T2 turns. As the volts per turn, which is proportional to the flux in the machine, is the same for the whole winding,

$$V_1 : V_2 = T_1 : T_2$$

For simplifying the analysis, the magnetizing current of the transformer is neglected. When the secondary winding delivers a load current of I2 ampere the demagnetizing ampere turns is I2T2.This will be countered by a current I1 flowing from the source through the T1 turns such that,

$I_1T_1 = I_2T_2$

.



Auto transformer

Working principle of single phase Auto Transformer:

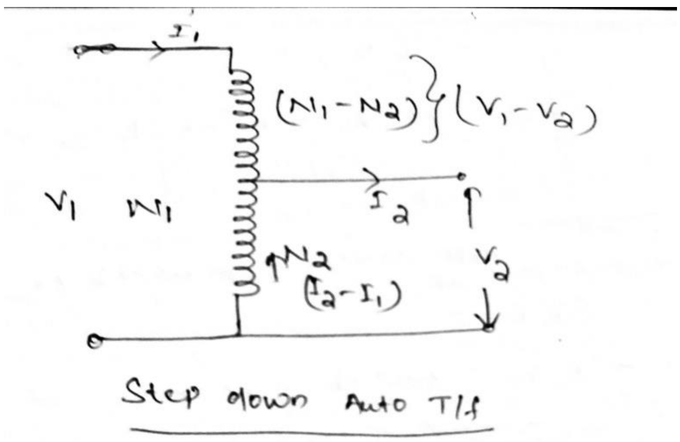
A current of I1 ampere flows through the winding between B and C. The current in the winding between A and B is (I2 - I1) ampere. The cross section of the wire to be selected for AB is proportional to this current assuming a constant current density for the whole winding. Thus some amount of material saving can be achieved compared to a **two winding transformer**. The magnetic circuit is assumed to be identical and hence there is no saving in the same. To quantify the saving the total quantity of copper used in an **auto transformer** is expressed as a fraction of that used in a **two winding transformer** as,

This means that an **auto transformer** requires the use of a lesser quantity of copper given by the ratio of turns. This ratio, therefore, denotes the savings in copper. As the space for the second winding need not be there, the window space can be less for an *auto transformer*, giving some saving in the lamination weight also. The larger the ratio of the voltages, smaller is the savings. As T2 approaches T1 the savings become significant. Thus *auto transformers* become an ideal choice for close ratio transformations. The savings in material is obtained, however, at a price. The electrical isolation between primary and secondary has to be sacrificed.

Auto transformer is a transformer in which a part of the winding is common to both primary and secondary circuits. The total power transfer consists of inductive transfer and conductive transfer.

In a two winding transformer, there is only inductive power transfer. In auto-transformer, there is additional power transfer on account of physical connection between source and the load through a series winding. This conductive power transfer is the main factor responsible for massive saving and increased kva output in an auto-transformer as compared to a two winding transformer of same capacity and voltage rating.

Let us consider an step down auto transformer as shown in the figure bellow.



Let in the above auto trans former $\frac{N_2}{N_1}$=K(Transformation ratio)

Again in the transformer MMF is constant so that

$$(N_1 - N_2)I_1 = (I_2 - I_1)N_2$$

$$N_1 I_1 - N_2 I_1 = I_2 N_2 - I_1 N_2$$

$$N_1 I_1 = I_2 N_2$$

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

Again in a n auto transformer Input power is equal to out put power i.e

$$V_1 I_1 = I_2 V_2$$

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

The power transfer in an auto transformer by transformer action i.e the power transfer inductively=$(V_1 - V_2) \cdot I_1$

The input power to auto transformer=$V_1 I_1$

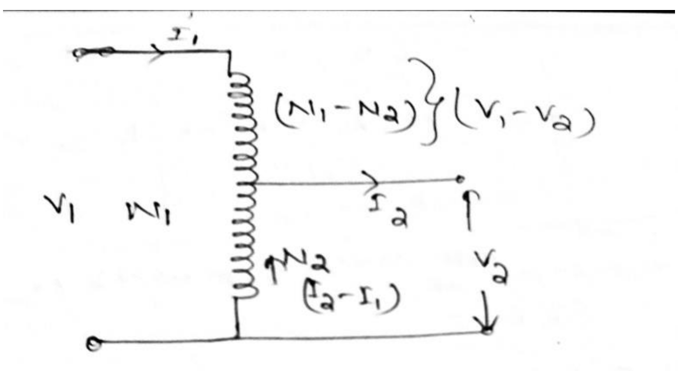
Therefore the power transfer conductively= $V_1 I_1$-$(V_1 - V_2) \cdot I_1$

=$V_2 I_1$=K$V_1 I_1$=KX(Input power to transformer)

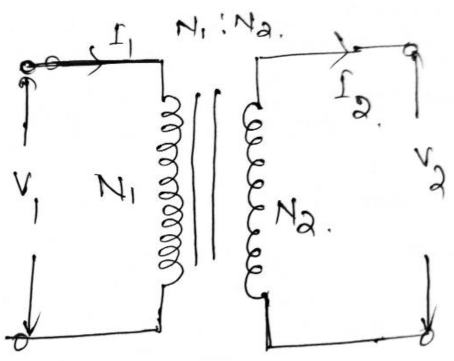
Then power transfer inductively= Total input-power transfer inductively=(1-K)X(Input power to transformer)

Comparison of Auto transformer with an two winding transformer (saving of Copper):

Consider an auto-transformer having same rating as two winding transformer and having same voltage ratio. We are here comparing the weight of copper needed in auto transformer as in 2 winding transformer.



Step down Auto T/f



2 winding Transformer.

The weight of copper used in transformer= Volume of copper=(Area of cross section of copper) X (length of copper wire)

Area of cross section of wire is directly proportional to current carrying capability i.e. I

Length of copper wire is directly proportional to Number of turns i.e. N

Therefore, the weight of copper in a transformer is directly proportional to NI.

First consider two winding transformer:

The weight of copper in primary side α N_1I_1

The weight of copper in secondary side α N_2I_2

Total weight of copper in two winding transformer α $(N_1I_1 + N_2I_2)=2 N_1I_1$

Then consider Auto-Transformer

The weight of copper in upper part α $(N_1-N_2)I_1$

The weight of copper in upper part α $(I_2-I_1)N_2$

Total weight of copper in auto transformer α $(N_1-N_2)I_1+ (I_2-I_1)N_2$

$$= N_1I_1- N_2I_1+ N_2I_2- N_2I_1$$

$$= N_1I_1+ N_2I_2- 2N_2I_1$$

$$= 2N_1I_1- 2N_2I_1 \quad \text{(in auto tf. } N_1I_1= N_2I_2 \text{)}$$

Therefore $$\frac{Weight\ of\ copper\ in\ auto\ transformer}{Weight\ of\ copper\ in\ two\ winding\ transformer} = \frac{2N1I1- 2N2I1}{(N1I1\ + N2I2)}$$

$$\frac{Weight\ of\ copper\ in\ auto\ transformer}{Weight\ of\ copper\ in\ two\ winding\ transformer} = \frac{2N1I1- 2N2I1}{2\ N1I1}$$

$$\frac{Weight\ of\ copper\ in\ auto\ transformer}{Weight\ of\ copper\ in\ two\ winding\ transformer} = \frac{N1- N2}{N1}$$

$$\frac{Weight\ of\ copper\ in\ auto\ transformer}{Weight\ of\ copper\ in\ two\ winding\ transformer} =(1 - K)$$

Therefore, Weight of copper in auto transformer=(1-K)x(weight of copper in two winding transformer)

Therefore saving of copper in auto transformer= (weight of copper in two winding transformer)- (1-K)x(weight of copper in two winding transformer)

=K X(weight of copper in two winding transformer)

Uses of Auto transformer:

There is large variety of application of auto transformer. Some of them are given bellow

1. In power applications – Autotransformers are used in power applications to interconnect systems operating at different voltage classes like 132 kV to 66 kV for

transmission. In long rural power distribution lines, special autotransformers with automatic tap-changing equipment are inserted as voltage regulators to receive the same average voltage at the end of the line.

2. In audio systems – Tapped autotransformers are used in audio applications to adapt speakers to constant-voltage audio distribution systems, and for impedance matching.

3. In railway applications – Autotransformers are used in railways to link the contact wire to the rail and to the second supply conductor to increase usable transmission distance, and reduce induced interference into external equipment.

4. To test an electronic device after repairs – After repairing, an electronic device needs to power up to ensure that the replaced parts do not burn. If high voltage is supplied without testing, the parts burn out. But, using an autotransformer to slowly power up the repaired device prevents such damage. You can also power up an old amplifier or radio with the help of an autotransformer. The electrolytic capacitors need to be reconditioned by applying reduced voltage through such a transformer.

5. To adjust AC supply voltage – An autotransformer can easily adjust AC power supply's output voltage. By changing the AC voltage that is being applied to AC motors, speed can be controlled. This is where autotransformers can help by changing the AC voltage and controlling the speed of motors that drive fans. An autotransformer can also alter the AC voltage within a resistance-type heater, thus adjusting its temperature. An autotransformer can also control the hot wire's temperature and adjust it to meet the desired requirements.

6. To compensate for line voltage drop – Long power line suffer from voltage drop in applications that draw high current. Autotransformers can be used to compensate for this loss of voltage.

7. To construct unregulated DC power supply of high current – An unregulated DC power supply of high current can be constructed with the help of an autotransformer. However, this should be done only if you are aware of the safety concerns associated with an autotransformer. Autotransformers are connected with AC power, making AC voltage directly accessible, thus increasing the risk of electric shock.

Tap Changer:

A **tap changer** is a mechanism in transformers which allows for variable turn ratios to be selected in distinct steps. This is done by connecting to a number of access points known as taps along either the primary or secondary winding.

Tap changers exist in two primary types,

1. No load tap changers (NLTC), which must be de-energized before the turn ratio is adjusted,
2. On load tap changers (OLTC), which may adjust their turn ratio during operation.

(A typical tap changer inside the transformer)

The tap selection on any tap changer may be made via an automatic system, as is often the case for OLTC, or a manual tap changer, which is more common for NLTC. Automatic tap changers can be placed on a lower or higher voltage winding, but for high-power generation and transmission applications, automatic tap changers are often placed on the higher voltage (lower current) transformer winding for easy access and to minimize the current load during operation.

1.No load tap changers (NLTC) or Off-Load tap changer:

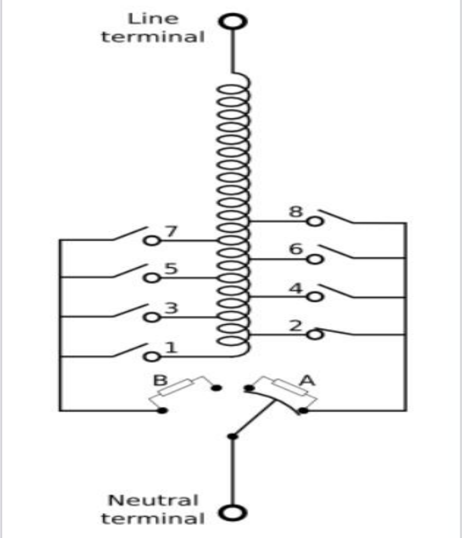
1. **No-load tap changer (NLTC)**, also known as **Off-circuit tap changer (OCTC)** or **De-energized tap changer (DETC)**, is a tap changer utilized in situations in which a transformer's turn ratio does not require frequent changing and it is permissible to de-energize the transformer system.
2. This type of transformer is frequently employed in low power, low voltage transformers in which the tap point often may take the form of a transformer connection terminal, requiring the input line to be disconnected by hand and connected to the new terminal. Alternatively, in some systems, the process of tap changing may be assisted by means of a rotary or slider switch.
3. No load tap changers are also employed in high voltage distribution-type transformers in which the system includes a no load tap changer on the primary winding to accommodate transmission system variations within a narrow band around the nominal rating.
4. In such systems, the tap changer will often be set just once, at the time of installation, although it may be changed later to accommodate a long-term change in the system voltage profile.

For more detail you can see on you-tube: https://youtu.be/_FLMta5QcUQ

On-load tap changer:

1. **On-load tap changer (OLTC)**, also known as **On-circuit tap changer (OCTC)**, is a tap changer in applications where a supply interruption during a tap change is unacceptable, the transformer is often fitted with a more expensive and complex on load tap changing mechanism.
2. On load tap changers may be generally classified as either **mechanical, electronically assisted, or fully electronic.**
3. These systems usually possess 33 taps (one at centre "Rated" tap and sixteen to increase and decrease the turn ratio) and allow for ±10% variation (each step providing 0.625% variation) from the nominal transformer rating which, in turn, allows for stepped voltage regulation of the output.
4. Tap changers typically use numerous **tap selector** switches which may not be switched under load, broken into even and odd banks, and switch between the banks with a heavy-duty **diverter switch** which can switch between them under load.

Consider One possible design (flag type) of on load mechanical tap changer is shown bellow. It commences operation at tap position 2, with load supplied directly via the righthand connection. Diverter resistor A is short-circuited; diverter B is unused. In moving to tap 3, the following sequence occurs:



A mechanical **On load tap changer (OLTC)**, also known as **under-load tap changer (ULTC)** design, changing back and forth between tap positions 2 and 3

1. Switch 3 closes, an off-load operation.
2. Rotary switch turns, breaking one connection and supplying load current through diverter resistor A.
3. Rotary switch continues to turn, connecting between contacts A and B. Load now supplied via diverter resistors A and B, winding turns bridged via A and B.

4. Rotary switch continues to turn, breaking contact with diverter A. Load now supplied via diverter B alone, winding turns no longer bridged.
5. Rotary switch continues to turn, shorting diverter B. Load now supplied directly via left hand connection. Diverter A is unused.
6. Switch 2 opens, an off-load operation.

The sequence is then carried out in reverse to return to tap position 2.

For more detail you can see on you-tube https://youtu.be/f3uQQBDI1o4

Reference- wikipedia- https://en.wikipedia.org/wiki/Tap_changer#No-load_tap_changer

5.INSTRUMENT TRANSFORMERS

Introduction:

Instrument Transformers are used in AC system for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. **Instrument transformers** are also used with protective relays for protection of power system.

Basic function of **Instrument transformers** is to step down the AC System voltage and current. The voltage and current level of power system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high-level voltage and current. Generally measuring instruments are designed for 5 A and 110 V. The measurement of such very large electrical quantities, can be made possible by using the Instrument transformers with these small rating measuring instruments.

(A typical CT used in power grid)

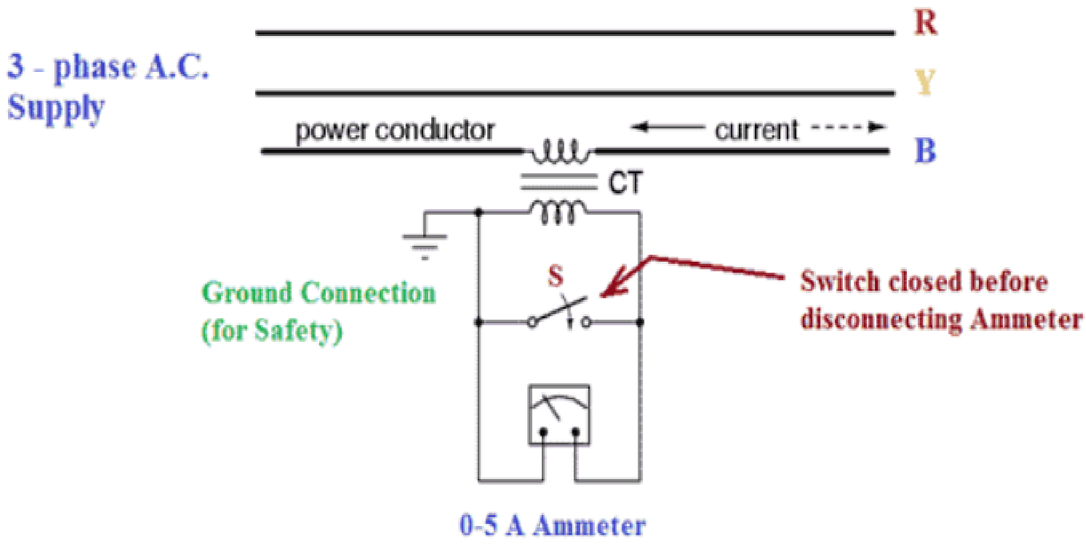
Types of Instrument Transformers

Instrument transformers are of two types –

1. Current Transformer (C.T.)
2. Potential Transformer (P.T.)

Current Transformer (C.T.)

Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.



Current Transformer (C.T.)

1. Primary of C.T. is having very few turns. Sometimes bar primary is also used. Primary is connected in series with the power circuit. Therefore, sometimes it also called **series transformer**.
2. The secondary is having large no. of turns. Secondary is connected directly to an ammeter. As the ammeter is having very small resistance. Hence, the secondary of current transformer operates almost in short circuited condition.
3. One terminal of secondary is earthed to avoid the large voltage on secondary with respect to earth. Which in turns reduce the chances of insulation breakdown and also protect the operator against high voltage.
4. More ever before disconnecting the ammeter, secondary is short circuited through a switch 'S' as shown in figure above to avoid the high voltage build up across the secondary.

Current Transformer error:

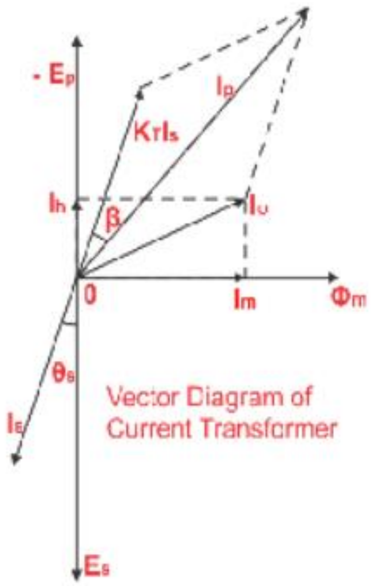
But in an actual Current Transformer (CT), errors with which we are connected can best be considered through a study of phasor diagram for a CT,

I_s – Secondary current.

E_s – Secondary induced emf.

I_p – Primary current.

E_p – Primary induced emf.
K_T – Turns ratio = Numbers of secondary turns/number of primary turns.



I_0 – Excitation current.
I_m – Magnetizing component of I_0.
I_w – Core loss component of I_0.
Φ_m – Main flux.

Let us take flux as reference. EMF E_s and E_p lags behind the flux by 90°. The magnitude of the passers E_s and E_p are proportional to secondary and primary turns. The excitation current I_o which is made up of two components I_m and I_w.

The secondary current I_0 lags behind the secondary induced emf E_s by an angle Φ_s. The secondary current is now transferred to the primary side by reversing I_s and multiplied by the turns ratio K_T. The total current flows through the primary I_p is then vector sum of K_T I_s and I_0.

The Current Error or Ratio Error in Current Transformer or CT

From above phasor diagram it is clear that primary current I_p is not exactly equal to the secondary current multiplied by turns ratio, i.e. K_TI_s. This difference is due to the primary current is contributed by the core excitation current. The **error in**

current transformer introduced due to this difference is called current error of CT or some- times **ratio error in current transformer**.

$$\text{Hence, the percentage current error} = \frac{|I_p| - |K_T.I_s|}{I_p} \times 100\ \%$$

Phase Error or Phase Angle Error in Current Transformer:

For a ideal CT the angle between the primary and reversed secondary current vector is zero. But for an actual CT there is always a difference in phase between two due to the fact that primary current has to supply the component of the exiting current. The angle between the above two phases in termed as **phase angle error in current transformer** or CT.

Here in the phasor, diagram it is β; the phase angle error is usually expressed in minutes.

How to Reduce Error in Current Transformer:

It is desirable to reduce these errors, for better performance. For achieving minimum error in current transformer, one can follow the following,

1. Using a core of high permeability and low hysteresis loss magnetic materials.
2. Keeping the rated burden to the nearer value of the actual burden.
3. Ensuring minimum length of flux path and increasing cross-sectional area of the core, minimizing joint of the core.
4. Lowering the secondary internal impedance.

Burden on CT:

Burden of CT can be specified as Volt-Ampere absorbed at certain Power Factor i.e the VA that can be consumed by the load. The burden can also be expressed as total Impedance in terms of ohms connected on secondary of CT i.e. pilot conductor and instrument burden (I2 x R=VA).

To simplify the above point, let us take an example: for a 100/5A CT with a Burden of 0.4ohm impedance, the burden can be expressed as 2VA at 5A secondary current " I2 x R = 5 x .4 = 2VA ". In industries, VA is more commonly used unit for CT burden.

Uses of CT:

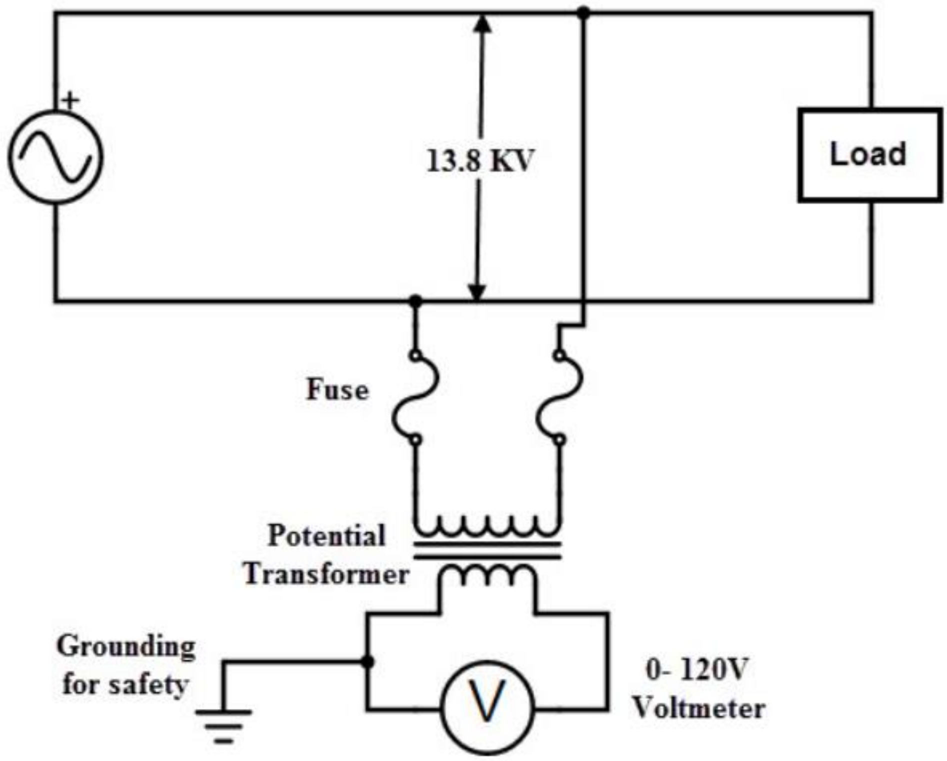
The current transformers are used in a wide variety of applications ranging from power system control to the precise current measurement in industrial, medical, automotive and telecommunication systems. Some of the applications include

- Extending the range of measuring instruments such as ammeter, energy meter, KVA meters, wattmeter, etc.
- Differential circulating current protection systems.
- Distance protection in power transmission systems.
- Over current fault protection.

Potential Transformer:

Potential transformer is a voltage step-down transformer which reduces the voltage of a high voltage circuit to a lower level for the purpose of measurement. These are connected across or parallel to the line which is to be monitored.

The basic principle of operation and construction of this transformer is similar to the standard power transformer. In common, the potential transformers are abbreviated as PT.



The primary winding consists of a large number of turns which is connected across the high voltage side or the line in which measurements have to be taken or to be protected. The secondary winding has lesser number of turns which is connected to the voltmeters, or potential coils of wattmeter and energy meters, relays and other control devices. These can be single phase or three phase potential transformers. Irrespective of the primary voltage rating, these are designed to have the secondary output voltage of 110 V.

Since the voltmeters and potential coils of other meters have high impedance, a small current flows through the secondary of PT. Therefore, PT behaves as an ordinary two winding transformer operating on no load. Due to this low load (or burden) on the PT, the VA ratings of PTs are low and in the range of 50 to 200 VA. On the secondary side, one end is connected to the ground for safety reasons as shown in figure.

Similar to the normal transformer, the transformation ratio is specified as

$$V1/V2 = N1/N2$$

From the above equation, if the voltmeter reading and transformation ratio are known, then high voltage side voltage can be determined.

Construction of PT:

Compared to the conventional transformer, potential transformers or PTs use larger conductor sizes and core. PTs designed for ensuring the greater accuracy and hence, at the time of designing economy of the material is not considered as main aspect.

PTs are made with special high quality core operating at lower flux densities in order to have small magnetising current so that no load losses are minimised. Both core and shell type constructions are preferred for PTs. For high voltages, core type PTs are used while shell type is preferred for low voltages.

To reduce the leakage reactance, co-axial windings are used for both primary and secondary. For reducing the insulation cost, low voltage secondary winding is placed next to the core. And for high voltage PTs, high voltage primary is divided into sections of coils to reduce the insulation between coil layers. For these windings, vanished cambric and cotton tape are used as laminations. In between the coils, hard fibre separators are used.

These are carefully designed to have minimum phase shift between the input and output voltages and also to maintain a minimum voltage ratio with variation in load. Oil filled PTs are used for high voltage levels (above the range of 7KV). In such PTs, oil filled bushings are provided to connect the main lines.

Errors in Voltage Transformer:

For an ideal voltage transformer, the voltage produced in the secondary winding is an exact proportion to the primary voltage and are exactly in phase opposition. But in actual PTs this is not so because of the presence of voltage drops in primary and secondary resistance and also due the power factor of the burden on secondary. This causes to occurrence of ratio and phase angle errors in voltage transformers. Let us know in detail.

Consider the phasor diagram of potential transformer shown above,

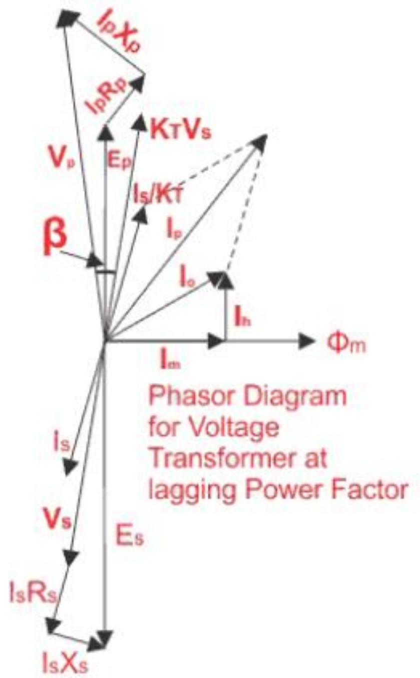
where

Io = No load current

Im = magnetizing component of no load current

Iu = Watt-full component of no load current

Es and Ep = Induced voltages in secondary and primary windings respectively



Errors in Voltage Transformer

Es and Ep = Induced voltages in secondary and primary windings respectively

Np and Ns = Number of turns in primary and secondary windings respectively

Ip and Is = Primary current and secondary current

Rp and Rs = Resistances of primary and secondary windings respectively

Xp and Xs = Reactance of primary and secondary windings respectively

β = Phase angle error

The primary induced voltage or EMF Ep is derived by subtracting the primary resistive (IpRp) and reactive drop (IpXp) from the primary voltage Vp. And also, secondary terminal voltage Vs is derived by subtracting secondary winding resistance drop (IsRs) and reactance drop (IsXs) vectorially from secondary induced EMF Es. Due to these drops nominal ratio of the potential transformer is not equal to the actual ratio of the PT, hence introduces a ratio error.

Ratio Error

The ratio error of the potential transformer is defined as the variation in actual ratio of transformation from nominal ratio.

$$\text{Percentage Ratio Error} = (K_n - R) / R \times 100$$

Where
Kn is the nominal or rated transformation ratio =
Kn = Rated primary voltage / Rated secondary voltage

Phase Angle Error:

In ideal PT, there should not exist any phase angle between the primary voltage and reversed secondary voltage. But in practice, there exist a phase difference between Vp and Vs reversed (as we can observe in above figure), thereby, introduces phase angle error. It is defined as the phase difference between the primary voltage and reversed secondary voltage.

In order to reduce these errors such that the accuracy is improved by designing the transformers in such a way that they windings have appropriate magnitudes of internal resistance and reactance. In addition to this, the core should require minimum magnetizing and core loss components of exciting current.

Applications of Voltage Transformers

- Electrical Metering systems
- Electrical protection systems
- Distance protection of feeders
- Synchronizing generators with grid
- Impedance protection of generators

The class of potential transformers used for metering is called as measurement voltage or potential transformers. On other hand PTs used for protection called as protection voltage transformers. In some cases PTs are used for both metering and protection purposes, in such cases, one secondary winding is connected to metering and other secondary winding is used for protection.

Refer to : 1. https://www.electrical4u.com/instrument-transformers/

2. https://www.electronicshub.org/current-transformer/

3. https://www.electronicshub.org/potential-transformers/