SUBJECT: TESTING AND COMMISSIONING OF POWER SYSTEM APPARATUS (15EE752)

Module 1 : TRANSFORMERS

Syllabus: Electrical Tools, accessories*: Tools, Accessories and Instruments required for Installation, Maintenance and Repair Work, India Electricity Rules, Safely Codes Causes and Prevention of Accidents, Artificial Respiration, and Workmen's Safety Devices.*

Transformers*: Installation, Location Site Selection, Foundation Details, Code of Practice for Terminal Plates, Polarity and Phase Sequence, Oil Tanks, Drying of Winding sand General Inspection. Commissioning Tests As Per National and International Standards - Volts Ratio Earth Resistance, Oil Strength, Insulation Tests, Impulse Tests Polarizing Index, Load Temperature Rise Tests. Specific Tests for Determination of Performance Curves like Efficiencies, Regulation Etc., Determination Mechanical Stress under Normal and Abnormal Conditions.*

Introduction:

- Standards are evolved to meet a generally recognized demand, taking into account the interest of manufacturers and users and fulfilling the needs of economy.
- The international standards published by **IEC (International Electro technical Commission)** are accepted universally.
- Indian Standards Institution (Bureau of Indian Standards) publishes IS standards.
- The manufacturers and users in India have to follow IS standards and IEC standards.
- The word specification or rating denotes **the assigned numerical value of capabilities**.
- The transformer is assigned with certain definite ratings. These assigned ratings are guaranteed by the manufacturer.

Need for standardization of specification:

- Transformer is a **job specific** (tailor made) product and **requires effort in its design** and drafting, even if a single parameter is changed.
- Standardization of the specification and design parameters of this vital equipment of energy transport will not only help in **ensuring optimal deployment of available resources** but also go a long way in economizing the capital costs.
- The Central Electricity Authority (CEA) report and the Central Board of Irrigation and power (CBIP) specifications are the outcome of a concerted effort over years.

Specifications of transformers

- The specifications of transformers should be supplied to the purchaser.
- The transformer is to be operated as per the specifications in order to avoid failure.
- The life expectancy of transformer is increased by proper handling

- **Indian standard IS 2026** *"Specification for Power Transformers"* is the governing standard on Power Transformers.

- This has been revised time to time and is now in five parts and is an exhaustive standard on power transformers.
- **Standard specifications of a Power Transformer**
  - ✓ Number of phases: single or polyphase
  - ✓ Frequency : 50Hz
  - ✓ KVA Rating : generally rated in MVA (like 200 MVA)
  - ✓ Rated voltages for each winding: 440KV/220KV, 220KV/66KV(greater than 33KV)
  - ✓ Connection symbol : star/delta
  - ✓ Requirements of on-load / off-load tap changers
  - ✓ Impedance voltage at rated current
  - ✓ Indoor or outdoor type
  - ✓ Type of cooling : ONAN,ONAF,OFAF,OFWF
  - ✓ Temperature rises and ambient temperature conditions including altitude and in case of water cooling, chemical analysis of water.
  - ✓ Number of cooling banks, spare capacity and cooling pumps & fans.
  - ✓ Highest system voltage for each winding
  - ✓ Method of system earthing for each winding
  - ✓ Insulation levels
  - ✓ Over fluxing conditions
  - ✓ Details of auxiliary supply voltage (for fans, pumps, OLTC, motor alarm, control).
  - ✓ Controls of tap changers
  - ✓ Short circuit levels of the system
  - ✓ Vacuum and pressure withstanding values of the transformer tank
  - ✓ Noise level requirement
  - ✓ Number of rails and rail gauge for movement along shorter and longer axes
  - ✓ Fittings required with their vivid description

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Standard specifications of a Distribution Transformer

- **Indian standard IS 2026** *"Specification for Distribution Transformers"* is the governing standard on Distribution Transformers.

The following information must be available with enquiry and order for the design and drafting of the transformer.

- ✓ Number of phases: single or polyphone
- ✓ Frequency : 50Hz
- ✓ KVA Rating : generally rated in MVA or KVA (less than 200 MVA)
- ✓ Rated voltages for each winding: 33KV/11KV, 11KV/440V(less than 33KV)
- ✓ Connection symbol : delta/star
- ✓ Requirements of on-load / off-load tap changers
- ✓ Impedance voltage at rated current
- ✓ Indoor or outdoor type
- ✓ Type of cooling : ONAN,ONAF
- ✓ Temperature rises and ambient temperature conditions including altitude and in case of water cooling, chemical analysis of water.
- ✓ Number of cooling banks, spare capacity and cooling pumps & fans.
- ✓ Highest system voltage for each winding
- ✓ Method of system earthing for each winding
- ✓ Insulation levels

- ✓ Over fluxing conditions
- ✓ Details of auxiliary supply voltage (for fans, pumps, OLTC, motor alarm, control).
- ✓ Controls of tap changers
- ✓ Short circuit levels of the system
- ✓ Vacuum and pressure withstanding values of the transformer tank
- ✓ Noise level requirement
- ✓ Number of rails and rail gauge for movement along shorter and longer axes Fittings required with their vivid description

Installation:

Location, site preparation and foundation details:

Location

- The location factor deserves careful attention simply because of its long term consequences. Any mistake in selection of a proper location could prove to be costly.

Transportation Facilities

- The raw materials and end products require to have uninterrupted receipt and dispatch facilities through good road connections, proper linking with ports and railheads. Possibility of an in-plant rail siding has to be looked into depending on the amount of raw materials and products to be handled.

Manpower Availability

- Local availability of skilled and semi skilled manpower will add to the efficient running

Environmental condition

- Now-a-days, there is a great deal of awareness towards maintenance of natural ecological balance. Regarding the effect of pollution from specific type of plants, social obligations are to be met. The nature of the site selected should preferably have some advantages to meet this requirement

Site preparation

- The location may be indoor or outdoor.
- For indoor installation, the following aspects should be considered:
  - (i) Ventilation Noise level
  - (ii) Space required for movement, maintenance etc
  - (iii) Trenches for cables
- Minimum clearances between the transformer and the walls should be as follows.
  - ✓ Clearance on all four sides of wall:1.25 m
  - ✓ Clearance on all three sides of wall: 1 m
  - ✓ Clearance on a wall on backside only: 0.5 m
- The clearance of 0.5 m (minimum) should be provided between the top most point of the conservator and the roof.
- Ventilation area: The ventilation area required is as follows.
  - ✓ Outlet: $2m^2$ per 1000 KVA
    Inlet: $1m^2$ per 1000 KVA minimum
- Indoor transformers having oil capacity of more than 2000 liters should be provided with soak pits.
- Power cables and control cables should never be run in the same conduit or cable tray or and windings during transit.
- To send small and medium transformers trucks and large transformers road trailers

or rail wagons are generally used.

Foundation:

- No special foundation is required for the installation of a transformer except **a level floor** strong enough to support the weight and prevent accumulation of water.
- Foundations with **oil drainage facilities** during fire and emergency are recommended for large transformers.
- Transformers should be positioned on the foundation so that **easy access is available all around to read or reach different fitments.**
- For outdoor installations, the **clearance between live parts and neighboring structures, equipments** etc., should be adhered to electricity rules.
- Simple, firm, horizontal and leveled foundation is necessary.
- The **level of concrete plinth with bearing plates of sufficient size and strength** can be adopted.
- The space between the plinth and base of the transformer should be prevented by use of **rust proof bituminous compound**.
- The **suitable rail tracks** should be provided where rollers are used.
- Once the wheels of the transformer are in final position and then should be **locked** to prevent accidental movement.
- Transformers having oil capacity **more than 9000 liters** should be provided with **drainage facility**.
- For medium voltages, **cable connector or bare conductor connection** is used

Inspection upon arrival at site:

- Immediately after arrival at site, it should be inspected for possible damages during transit.
- The nitrogen gas pressure should be checked.
- Positive pressure if not found, indicates that there is leakage, and there is a possibility of the moisture entering the tank during transit.
- This can be ascertained by dew point measurement which indicates the amount of surface moisture content in transformer insulation.
- Internal inspection should be carried out to the extent possible through inspection covers.
- Particular attention should be paid to the connections, bolt links, coil clamping bolts, tap changers.
- Current transformers and the general insulation.
- Break down strength of oil of transformer tank and drums containing transformer oil should be examined carefully.
- An inspection of the transformer on arrival at site is to be carried out preferably in the presence of the representative of the manufacturer.

Design of Transformer Tanks and Testing of transformer tanks:

- The transformer tank shall be of adequate **strength to withstand positive and negative pressures** built up inside the tank while the transformer is in operation.
- The transformer tank covers **shall be welded** with **tank rim** so as to **make a leak-proof joint.**
- The exterior of the transformer tank and other ferrous fittings shall be thoroughly **cleaned, scraped and given a primary coat and two finishing coats** of durable oil and a weather resisting paint or enamel.
- The tank sizes **reach the transportable limits** and call for a lot of ingenuity in the design, to meet **stringent conditions as minimum electrical clearances** from high voltage points of windings and **leads proper shaping to reduce oil quantity, transportable profile suitable for loading on rail wagons, transportable weight**, etc.
- From these design considerations, in general, and for large power ratings, transformer tanks are structurally quite complicated.
- For medium size, plain tanks are also used quite often for the sake of ease and economy of cost of fabrication.
- The structural design of transformer tanks comprises the computation of the combined behavior of plate and shells with stiffeners, which involves a realistic estimate of boundary conditions.
- For calculating the stresses and displacements at a few selected points the classical method is convenient, however for the stresses and displacements in global sense, one has to make use of rigorous methods such as finite element method.

❖ Transformer tanks may be classified as

✓ **Plain tanks**: Plain tanks are **rectangular box type** in shape and are commonly used for small and medium rating transformers.

✓ **Shaped tanks**: Here the profile of the tank body is **suitably shaped** to make it more economical. The shaping is decided by the **electrical layout, considerations of transformer windings and terminal gear/tap changers mounting arrangements.**

✓ **Bell shaped tanks**: Tanks which are made into **two separable parts** are known as bell type tanks. When the **top portion** is removed, the height of the lower portion is such that there is accessibility to the core and winding for inspection and maintenance

✓ **Corrugated tanks**: An alternative for providing **vertical ribs welded to the plates** is to form corrugation on the plates by suitably folding the plates. The merits are additional cooling area on the tank walls and reduction in tank weight.

✓ **Stub-end wagon type tanks**: These tanks are of special construction and designed to **withstand dynamic loading** during transit besides the static load. Such large size transformers are not supported on girders thereby reducing the height during transport. The design is such that **these tanks are supported from either end stub-end**

wagons and the transformer hangs in the vertical position, with minimum clearance between the bottom of the tank and railway track.

Testing of tanks:

- The oil pressure and vacuum testing are conducted to ensure against leakages and to check for strength.

Oil pressure test:

- The oil is filled up to tank cover and the required pressure is applied using pump.
- The pressure is maintained for few hours and all the wildings are checked for leakages.
- In case of leakage, rectification is done by draining out the oil. The tank deflection readings are measured before the starting of oil pressure, at full oil pressure and after releasing the oil pressure.

Vacuum test:

- The oil is completely drained.
- After ensuring all the fitting, the vacuum pump is started and the required vacuum is measured by a vacuum gauge.
- During vacuum testing the air leakage points are detected by air leakage detecting instrument.
- If the leakages are found in casketed rims, the bolts are tightened.
- The deflection reading at the starting and after maintaining full vacuum for one hour and releasing the vacuum are taken to find out the permanent deflection.
- This shall be within specified allowable limits of deflection, depending on the size of the tanks.

Measurement of stresses:

- At various locations stresses are required to be measured.
- The strain gauges are fixed to the tank structure with proper adhesive.
- A gauge consists of a fine wire suitably fixed to the body of the structure.
- Under load, strains are developed on the body.
- This results in displacements of the points to which the ends of the gauges are fixed.
- This changes the resistance of the gauge wire, which is measured electrically using a suitable electric / electronic bridge.
- One typical strain gauge is Rosette delta with six wires connected to the ends of wire gauges and brought to the bridge for measurement.
- The bridge is set to null balance prior to the commencement of the measurements.
- The readings are simultaneously recorded.
- The tank is subjected to full vacuum and readings are taken.
- The strain gauges are fixed inside and outside the tank wall to compare the top and bottom principal stresses on the surface.
- The strain gauge gives values of strains in the direction of Rosettes from which the two principal stresses and their directions are calculated.

Characteristics of oil and their importance:

The, characteristics of transformer oil as per IS: 335.

Properties of insulating oil:

Physical properties:

- ✓ **Density**: The maximum density of insulating oil at 29.50C must be 0.89 g/m2
- ✓ **Interfacial tension (1FT):** This is the measure of the molecular attractive force between oil and water molecules at their interface. A test is carried out for detecting the soluble polar contamination and products of deterioration that reduces molecular attractive force between oil and water.
- ✓ **Moisture content**: The moisture content is the amount of free and dissolved water present in the oil and is expressed in pap (parts per million by weight i.e. mg/kg). Presence of moisture is harmful as it has adverse effect on the elect cal characteristics of oil.
- ✓ **Flash point**: It is the temperature at which the oil gives vapor, that this vapor, when mixed with air, gives a momentary flash on application of test flame under specified conditions. A minimum flash point is specified to prevent the risk of fire that may result by accidental ignition.
- ✓ **Viscosity**: This is a measure of oil resistance to flow continuously without external forces. The oil must be mobile. The heat transfer in transformers takes place by convection currents. The viscosity increases with decrease in temperature, it is necessary that viscosity be as low as possible at low tem prelatures.
- ✓ **Pour point**: The temperature at which oil will just flow under specified conditions is known as pour point. If the oil becomes too viscous or solidifies, it will hinder the formation of convection currents and thus cooling of the equipment will be severely affected.

Electrical properties:

- ✓ **Electric strength** (Breakdown voltage): BDV is the voltage at which breakdown occurs between two electrodes when oil is subjected to an electric field under prescribed conditions. Electric strength is the prime parameter for insulation design of a transformer. It helps to know the presence of contaminating agents like moisture, fibrous materials, carbon particles, perceptible sludge and sediment.
- ✓ **Specific resistance (Resistivity):** This is the most sensitive property of oil requiring utmost care for its determination. Resistivity in Acme is numerically equivalent to the resistance between opposite faces of a centimeter cube of the liquid. Insulation resistance of windings of a transformer is also dependent upon the resistivity of oil. A low value indicates the presence of moisture and conductive contaminants.
- ✓ **Dielectric dissipation factor (DDF):** DDF is numerically equal to sine of the loss angle (approximately equal to tangent of loss angle for dielectrics) and is a good tool to indicate the quality of insulation. A high value of DDF means the presence of contaminants or deterioration products such as water, oxidation products, metal soaps, soluble varnishes and resins.

Chemical properties:

- ✓ **Neutralization value (total acidity)**: It is a measure of free organic and inorganic acids present in the oil and is expressed in terms of milligrams of KOH required to neutralize the total free acids in one gram of oil.

- ✓ **Oxidation stability:** This gives the presence of natural inhibitors which impart anti-oxidation characteristics to oil. This test is a measure of neutralization value and sludge after oil is aged by simulating the actual service conditions of a transformer.
- ✓ **Corrosive Sculpture**: Crude petroleum usually contains sculpture compounds, most of which are eliminated by refining. The traces of free corrosive sculpture may be present in oil. This will result in pitting and black deposit on the surface of the bare conductor used in transformer which adversely affects the dissipation of heat.

Characteristics of transformer oil

- ✓ The fresh dielectric oil has **pale yellow color**. Dark or cloud color indicates deterioration
- ✓ The oil should never contain s**uspended particles, water soluble acids and bases, and active sculpture of colloidal carbon**. These impurities accelerate deterioration rate
- ✓ It should be free from dust particles, carbon particles and sludge.
- ✓ It should have **high dielectric strength**.
- ✓ It should have **low viscosity.**
- ✓ It should have **high flash point**.
- ✓ It should posses good electrical characteristics
- ✓ Density: The **maximum density** of insulating oil at 29.50C must be 0.89 g/m^2.
- ✓ It should posses good chemical properties
- ✓ It should posses **less** Interfacial tension
- ✓ It should have **high** specific resistance

Testing of transformer oil:

Testing of dielectric strength:

BDV test:

- The test sample from the bottom of the drum or transformer tank is collected in the standard test cup size.
- Electrodes are polished brass spheres of 12.5 to 13 mm diameter mounted horizontally.
- The gap is 2.5 mm to 4 mm ± 0.2 mm depending upon the magnitude of voltage available for breakdown test.
- Allow the sample in the cup for 20 minutes for air bubbles to vanish, apply ac voltage gradually and steadily till the breakdown occurs between electrodes.
- Six breakdown tests are conducted at an interval of one or five minutes.
- After each breakdown test, the oil is gently stirred with clean, dry glass rod. Average of five subsequent tests is considered as the BDV (breakdown value) of oil sample.

Crackle test:

- This test is performed to determine free water.
- A sample is heated rapidly over silent flame.
- The presence of moisture above 50-60 pap of water will give typical crackling sound.
- The Karl Fisher Solution test is used for determining the moisture more accurately (up to 2 pap).
- During periodic maintenance crackle test, dielectric test, acidity test and moisture

measurement is carried out.

Drying of Transformers:

- The transformer oil and insulation are hygroscopic (absorbs moisture).
- When the transformer is dispatched without oil or is left idle for a long period, the oil and insulation absorb moisture and drying out is required before commissioning.
- When the power transformer is idle for more than a month, drying out is necessary prior to re commissioning.
- The main purpose of the drying out is to expel the moisture from the oil, the winding insulation and other internal parts.
- If the transformer is not dried out properly, it cannot withstand specified voltage for long duration leading to premature failure of insulation.
- In drying out process the transformer oil/winding is heated by one of the approved methods for a prolonged period (ten hours to four weeks).

Precautions to be taken while drying in a transformer:

1) Only spirit type thermometers are to be used for temperature measurement. Mercury thermometers shall not be used except in the pockets provided for this purpose.
2) The temperature of transformer oil in the top should not be more than 85°C. The maximum sustained temperature to which anything in contact with the oil should be raised, is 90°C.
3) Under no condition the transformer is left unattended during any part of the dry out period. The transformer should be under constant observation throughout the dry out process and all observations shall be carefully recorded.
4) It is recommended to keep firefighting equipment ready during dry-out period. Naked lights and flames should be kept away while the drying operation is in progress.
5) process and all observations shall be carefully recorded.
6) It is recommended to keep firefighting equipment ready during dry-out period. Naked lights and flames should be kept away while the drying operation is in progress.

Procedure / steps involved in drying out of power transformer

- ✓ Preliminary preparation of the machine, source of heat , Measurements etc
- ✓ Arrangement of the set up
- ✓ Heat is applied gradually by one of the methods to maintain the steady temperature of winding and oil at following values
- ✓ Top oil temperature not to exceed 85°C
- ✓ Winding temperature not to exceed 95°C
- ✓ During drying out period the following readings to be taken
- ✓ Clock time
- ✓ Temperature of different parts
- ✓ Insulation resistance values
- ✓ Winding resistance
- ✓ Oil temperature
- ✓ Gradually reduce the heat applied and stop.

Different methods of drying out of Transformer:

Drying with oil

I) Drying of core and coils with oil by oven

II) Drying of core and coils with oil by short circuit method

Drying without oil

III) Drying with oil removed by using external heat

IV) Drying with oil removed by using both external and internal heat.

Drying of core and coils with oil by using oven

- The core and coils can be effectively dried in a suitable oven, by raising the temperature to a value not exceeding 80°C.
- A large volume of air should pass through the oven to remove moisture and vapors.
- Insulation resistance check will indicate when the coils are dry.

Drying by short circuit method:

- The transformer can also be dried by heating the coils by short circuiting the low voltage winding and supplying a reduced voltage at the HV terminals.
- Current should not exceed 70% of the rated current and oil temperature should not exceed 75°C.
- The winding temperature under no condition should exceed 90°C.
- This method is more effective in drying the insulation at site.
- the temperature of the windings can be determined by the formula

$$T_2 = \frac{R2}{R1}(235 + T_1) - 235$$

where T_2 -Final average temperature of copper

T_1- Initial average temperature of copper

R_1- Final resistance of the windings

R_2- Initial resistance of the windings

By external heat:

- The transformer may be placed in its own tank without oil.
- Externally heated air is blown into the tank at the bottom through the main oil valve.
- A small blower or fan should be used to get the proper circulation.
- It is desired to-force as much of the heated air as possible through the ducts in the transformer windings.
- To accomplish this, baffles should be placed between the core and the case, closing off as much of the space as possible.
- The convenient way to get the heated air is by passing air through grid resistors.
- The resistors are in fire proof box.
- The temperature of the air should not exceed 115°C.
- The heat may also be obtained by direct combustion but care is to be taken to avoid the products of combustion entering into the transformer tank.
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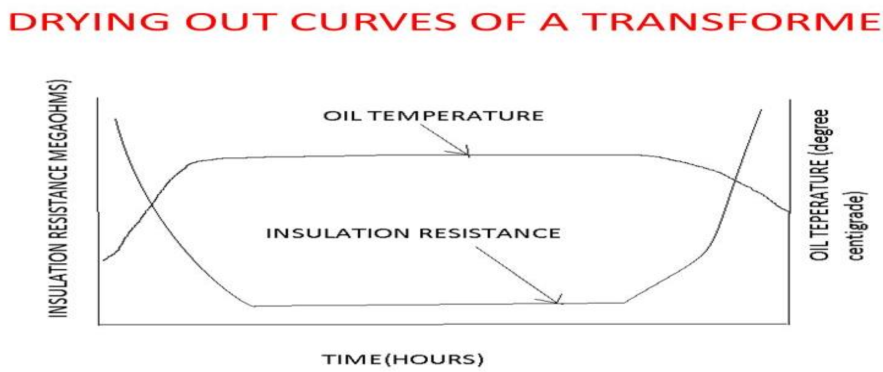
By both external and internal heat:

- This is a combination of the hot air circulation and short circuit method.
- The current circulated in the windings should, of course, be less than when drying out is done by the method of short circuit alone.

The drying out procedure has three distinct phases.

- In the beginning the insulation resistance decreases indicating that the moisture is getting released within the insulation.
- After few hours the insulation resistance reaches the steady state value indicating the moisture content is distributed within the winding.
- In the last stage the insulation resistance start increasing indicating the moisture is expelled out. The drying out procedure is stopped when the desired value of hot insulation resistance and polarization index are achieved for each winding .



Testing of Transformers

Following tests are carried out when the work is at different stages, prior to the insertion of core and coil assembly in the tank.

These tests help in locating any fault at an early stage.

1. Core insulation
2. Core Loss test
3. Check of ratio, polarity, vector relationship and winding resistance of transformer assembly.
4. Preliminary Load Loss and impedance voltage measurements

The completely assembled transformer is subjected to the following final tests in accordance with international standards.

These tests are

a)*Routine tests*: These tests are conducted on every transformer before it Leaves the factory, to ensure that it is in accordance with the specifications.

1. Voltage ratio
2. Polarity test
3. Winding resistance test
4. Impedance voltage, short circuit impedance and Load Loss Measurement.
5. Dielectric tests
6. No Load Losses and current Measurement.
7. On Load tap changers
8. Power frequency withstand test

b) *Type tests*: These tests are performed on a single transformer which is representative of batch of transformers, to demonstrate that they comply with specified requirements and are not covered by routine tests.

1. Temperature rise test
2. Lightning impulse test
3. Air pressure test
4. Permissible flux density and over fluxing Noise Level test.
5. Sudden short circuit withstand test

C) ***Special Tests***: The tests conducted other than routine or Type tests, based on the agreement between the manufacturer and purchaser as asked for in the tenders/orders placed;

1. Zero sequence impedance on three phase transformers .
2. Acoustic sound level
3. Harmonics on the no-load current
4. Power taken by fan and oil-pump motors
5. Partial discharge test
6. Vibration test
7. Tan delta test

Special tests and type tests are to be performed in the presence of the purchaser or his representative. Commissioning tests are conducted at site before commissioning.

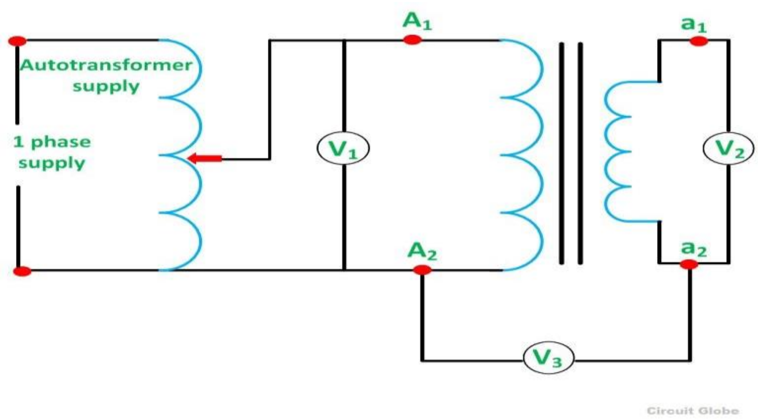
Routine Tests

1. *Polarity testing*

Polarity means the direction of the induced voltages in the primary and the secondary winding of the transformer. If the two transformers are connected in parallel, then the polarity should be known for the proper connection of the transformer. There are two types of polarity one is **Additive**, and another is **Subtractive.**

Each of the terminals of the primary as well as the secondary winding of a transformer is alternatively positive and negative with respect to each other as shown in the figure below. Let A_1 and A_2 be the positive and negative terminal respectively of the transformer primary and a_1, a_2 are the positive and negative terminal of the secondary side of the transformer. **If A_1 is connected to a_1 and A_2 is connected to a_2** that means similar terminals of the transformer are connected, then the polarity is said to be **additive**. **If A_1 is connected to a_2 and A_2 to a_1**, that means the opposite terminals are connected to each other, and thus the voltmeter will read the **subtractive polarity**.

Connect the circuit as shown in fig and apply the voltage gradually. Now note down the values of voltmeter V_1,V_2 andV_3. If V_3 reads $\mathbf{V_1 + V_2}$ shows the proper connections and the connections made permentanly. If V_3 reads $\mathbf{V_1 - V_2}$ shows the improper connection then connection has to be changed

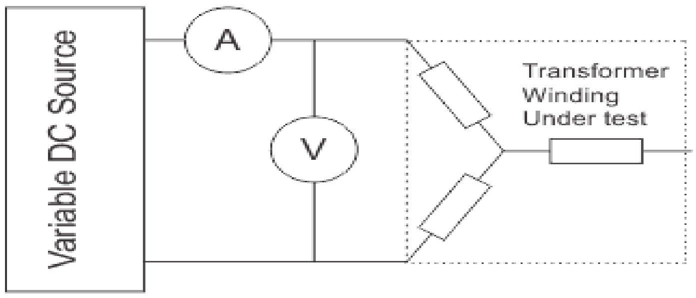


2. *Measurement of winding resistance*

To calculate the I^2R Loss, it is necessary to know the dc resistance of winding This can be done in two methods - **Current Voltage Method and Wheatstone/Kelvin bridge method.**

Current Voltage Method

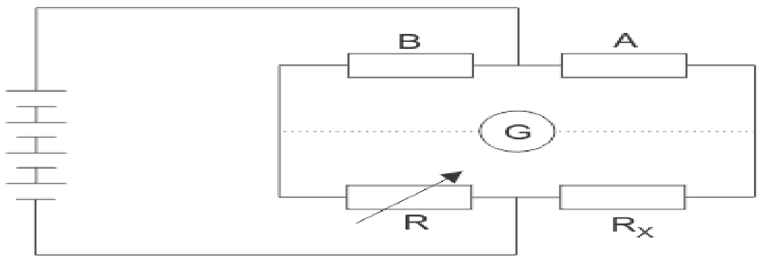
Before measurement the transformer should be kept in **OFF condition** without excitation at least for 3 to 4 hours. During this the winding temperature becomes **equa**l to oil temperature. Measurement is done once the DC current reaches steady state. The DC voltage applied gradually to windings. The readings of the current and voltage have been taken and resistance is calculated.



Current Voltage Method of Star
Winding Resistance Measurement

By wheat stone bridge/ Kelvin bridge

This test is conducted at stable temperature .The winding is connected across unknown resistanceQA1 terminal of the bridge The resistance is determined



Whetstone Bridge Method of
Resistance Measurement

The resistance per winding is calculated by

Resistance per winding = 1.5 × Measured value

Winding Resistance at standard temperature of 75ºC is calculated by

$$\frac{R_0}{R_1} = \frac{(234.5 + T_0)}{(234.5 + T_1)}$$

where R_0 = Winding resistance at temperature T_0.
T_0 = Ambient temperature
R_1 =Winding resistance at temperature T_1
T_1= Standard temperature say 75ºC

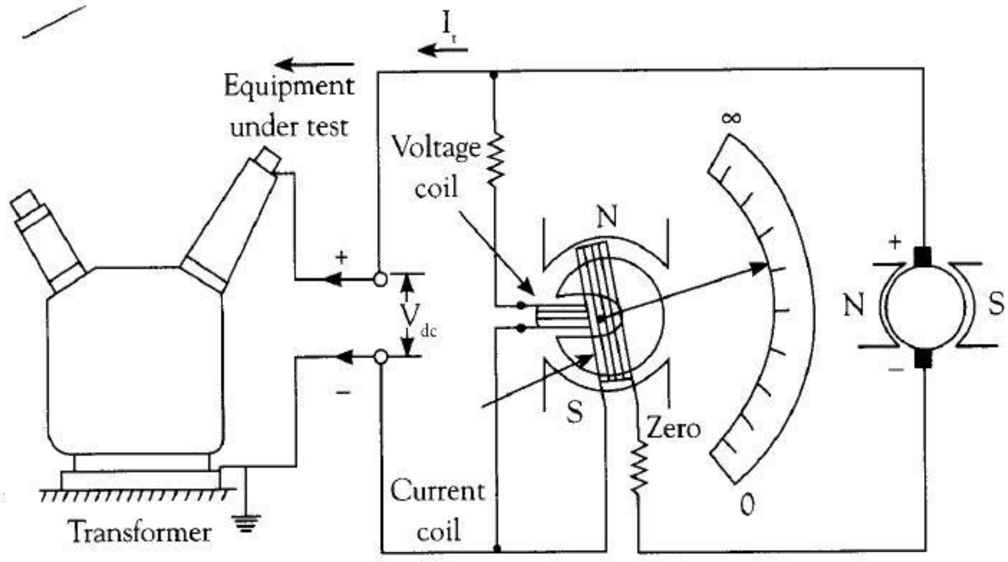
3. Ratio test

This test can be done using calibrated voltmeter .But it is preferable to do it by ratio-testing apparatus called **RATIOMETER.** This consists of portable transformer with fixed primary and secondary winding have large number of taps connected to a two selector switches, one course and the other is fine, so that any desired could be obtained for direct reading.

The HV side of the transformer under test is connected to a low voltage mains supply say 400 or 220 V and the induced voltage in the secondary is compared with the voltage output of Ratiometer, after ensuring the two voltages are in opposition. Accurate readings are obtained by an ammeter connected between the two windings.

4. Insulation resistance test

The insulation resistance is measured between two parts separated by insulation. Insulation resistance of electrical equipment refers to the resistance between conducting part and earth. It is expressed in mega ohms. Insulation resistance is measured by megger which consists of a hand driven generator. Meggers are available for dc voltages of 500V, 1000V and 2500V.One of the terminals of megger is connected to conducting part. Other terminal is connected to the earthed frame as shown in fig. The generator is hand driven and the reading is directly obtained on the scale graduated from zero to infinity in mega ohms.



when dc voltage is applied, initially the insulation draws capacitive charging current (Ic) in addition to leakage current (IL). Initial megger reading is given by

$$I_0R_0 = \frac{V_{dc}}{I_{dc}}$$

$$I_0R_0 = \frac{V_{dc}}{I_c + I_l}$$

where I_c --- is the charging current and I_l --- is the leakage current

After sometime the charging current reduces to zero and only leakage current is present.

$$I_0R_0 = \frac{V_{dc}}{I_l}$$

Polarization Index: Polarization index gives the true idea about the quality of insulation and also the extent of dryness. It depends upon the temperature at which insulation resistance is measured.

Polarization index is the ratio of megger value taken for 60 sec to the megger value taken for 15sec.

$$\frac{I_0 R_{60}}{I_o R_{15}} > 1$$

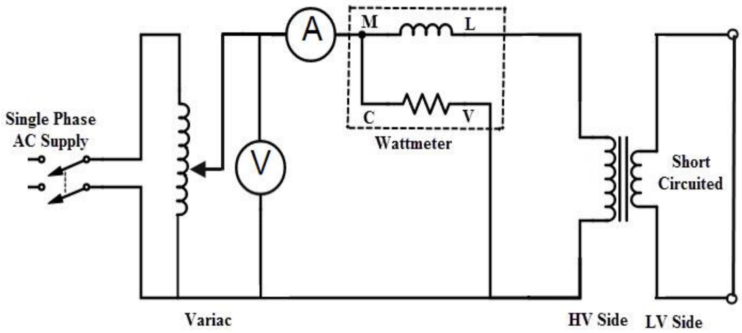
5. *MEASUREMENT OF IMPEDENCE VOLTAGE AND LOAD LOSS*:

(short circuit test)

The voltage to be applied to transformer to circulate rated current in short circuited secondary is called **Leakage impedance voltage or Impedance voltage** .The load loss is sum of IR^2 losses in winding and stray losses due to eddy currents in conductors clamps and tank. The stray losses vary with frequency. The load loss and impedance voltage are guaranteed at 75' C ,but are measured at ambient temperature

The test is carried out by short circuiting ,usually the LV winding and by supplying the impedance voltage to HV winding .The measured power will also include small core loss. Load loss and impedance voltage can be corrected for MVA as follows

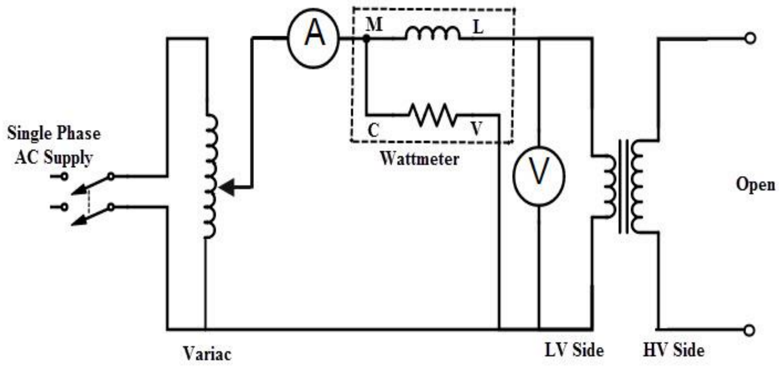
Computed loss at rated current = Measured loss at test current * Rated current Test current



For calculating the load loss and impedance at different tap positions ,recording should be very quick and also the interval between the measurements at different taps should be sufficient to avoid errors due to momentary temperature rise Three watt meters are instead of two watt meters to avoid large wattmeter multiplier constant. The power factor during load loss should be less than 0.1 and wattcmeters suitable for such low power should be used.

6. *NO LOAD CURRENT AND NO LAOD LOSSES*

No load current is current drawn by the transformer when there is no load . Usually no-load current is less than 4% of full load current. Hence I^2R losses are negligible .However only iron losses (hysteresis and eddy current losses) are present in no-load condition .No load test is performed at normal voltage and frequency with HV winding open circuited. The LV winding is supplied with normal voltage. the input power measured will give no-load loss. The no-load current and losses are useful in evaluating the efficiency of transformer



TYPE TESTS

1.Temperature Rise Test

The temperature rise test is one of the type tests which confirms the design for temperature rise. The is called as **Heat run test** . The test simulates the conditions of continuous rated load and occurrence of temperature rise

For standard tank, the dissipation constant is known. in such case it is necessary to measure only transformer losses and to calculate the temperature rise of the coil and winding on continuous loading .For non-standard tank, it is necessary to carry our temperature rise on the transformer and different methods to obtain the temperature rise are as follows

1. Short circuit test
2. Back to Back test
3. Delta/Delta test
4. Open circuit test

Short circuit test

In this method One winding is short circuited and the Voltage applied to the other equal to Full load losses of the transformer. The Measurement of temperature is done using Thermocouples placed in the transformer.

Delta/Delta test

In this method the Full rated voltage is applied to one winding Which accounts for full load iron losses. By external source full load current is circulated in another winding**,**Which accounts for full load copper losses. As current circulated in winding the temperature in the winding rises Record the temperature of the winding for every 15mins till it reaches steady value**.**Time take to reach the final temperature is **Thermal time constant.**

Significance of temperature rise test

- Gives temperature rise during the load
- Conditions for rated load
- It gives full load copper and iron losses
- Idea about cooling

2.IMPULSE VOLTAGE TEST

Lightning is probably the most common cause of flashover on overhead transmission lines. The terminal equipments of high voltage transmission lines experience the lightning pulse in service. Hence impulse voltage test is done for transformer to check the withstand capacity.

Test set up for impulse testing of power transformer

The impulse voltage is produced by discharge of a capacitor or number of capacitors into a wave generating network and so produced impulse voltage is applied across the object under test. For HV impulse test a multi stage impulse generator which is the modified marx's original circuit is used. This consists of number of capacitors initially charged in parallel and discharged in series by the sequential firing of interstage gaps. Fig shows simple single stage impulse generator and test setup

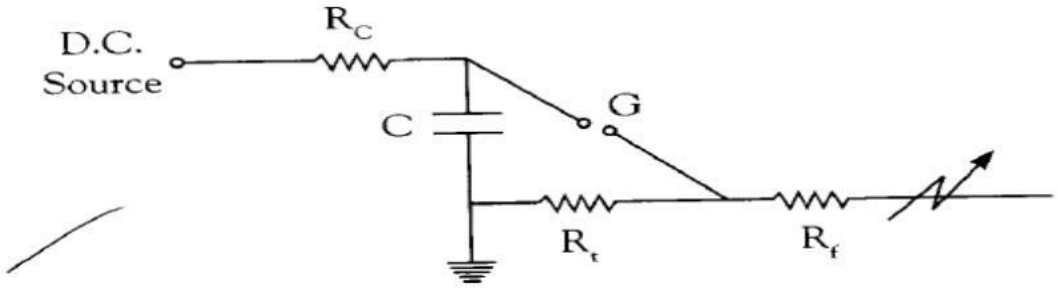


Figure 1.22: Single stage impulse generator

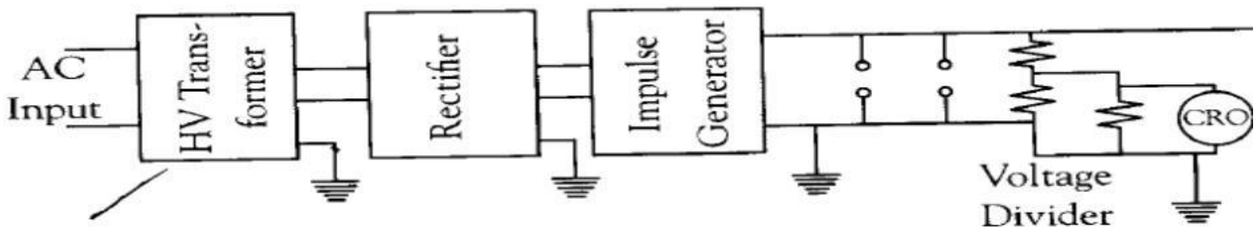
where,

R_c-Charging resistor

R_f-Series resistor controlling wavefront

R_t-Discharging resistor controlling wave tail

G-Gap



This test is necessary for all indoor and outdoor transformer. Standard impulse wave of specified amplitude is applied twice in succession. If there is no flash over and puncture of the insulator, then the transformer is considered to have passed the test , on other hand ,if there is puncture occurs ,is considered to have failed the test. During the test one wave should be applied with reversal of polarity. The peak value and wave shape of the test voltage is recorded by means of storage oscilloscope

3.Power frequency withstand test

It is a routine test conducted at specified test voltage .The test voltage is depending upon the type of transformer . The test Voltage is derived from AC generator driven by motor .The High voltage Transformers are cascaded to get High voltage. The test voltage is gradually raised and kept applied for 1 minute to check the withstand capacity. This test is performed to check the flash over or breakdown

4. Sudden short circuit withstand test

This is a type test conducted in short circuit testing station to check the withstand capacity for external short circuit. The power transformer must be designed to withstand the mechanical and thermal stress caused by external short circuit. When the short-circuit current flows through the winding, the winding is subjected to radial electromagnetic force. These forces produce stresses on outer windings as well as inner winding which may be tending to collapse the winding. Therefore the winding should not get deform when short circuit current is circulated .In order to check this the secondary of the Transformer is shorted and specified voltage is applied for 2 seconds to observe the deforming of windings.

Transformer Accessories, Fitments and Safety devices

Transformer accessories plays an important role in ensuring proper functioning of the main equipment. Some accessories provide safety during fault condition

1. Cooling

The oil act as an insulating medium and cooling medium. Heat generated is removed by the oil and transferred to atmospheric air or water

The effective cooling ensures **longer life** due less **thermal degradation**

Methods of cooling of Transformer

Transformers can be divided in two types as (i) dry type transformers and (ii) oil immersed transformers. Different cooling methods of transformers are -

For dry type transformers

- Air Natural (AN)
- Air Blast

For oil immersed transformers

- Oil Natural Air Natural (ONAN)
- Oil Natural Air Forced (ONAF)
- Oil Forced Air Forced (OFAF)
- Oil Forced Water Forced (OFWF)

Air Natural or Self Air Cooled Transformer

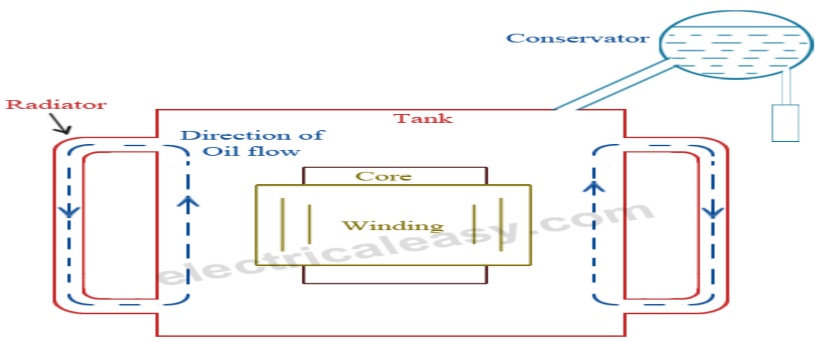
This method of transformer cooling is generally used in small transformers (upto 3 MVA). In this method the transformer is allowed to cool by natural air flow surrounding it.

Air Blast

For transformers rated more than 3 MVA, cooling by natural air method is inadequate. In this method, air is forced on the core and windings with the help of fans or blowers. The air supply must be filtered to prevent the accumulation of dust particles in ventilation ducts. This method can be used for transformers upto 15 MVA.

Oil Natural Air Natural (ONAN)

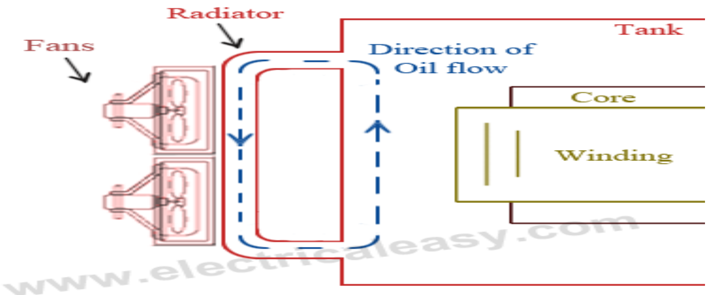
This method is used for oil immersed transformers. In this method, the heat generated in the core and winding is transferred to the oil. According to the principle of convection, the heated oil flows in the upward direction and then in the radiator. The vacant place is filled up by cooled oil from the radiator. The heat from the oil will dissipate in the atmosphere due to the natural air flow around the transformer. In this way, the oil in transformer keeps circulating due to natural convection and dissipating heat in atmosphere due to natural conduction. This method can be used for transformers upto about 30 MVA



Oil Natural Air Natural (ONAN) - Cooling of Transformer

Oil Natural Air Forced (ONAF)

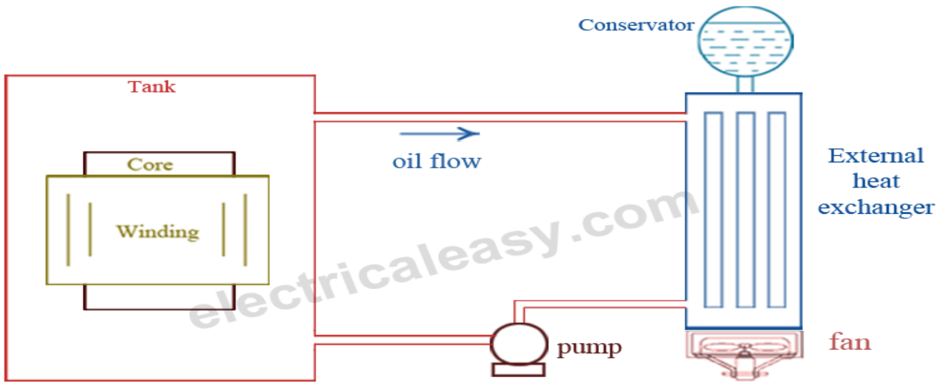
The heat dissipation can be improved further by applying forced air on the dissipating surface. Forced air provides faster heat dissipation than natural air flow. In this method, fans are mounted near the radiator and may be provided with an automatic starting arrangement, which turns on when temperature increases beyond certain value. This transformer cooling method is generally used for large transformers upto about 60 MVA.



Oil Natural Air Forced (ONAF)
Cooling of Transformer

Oil Forced Air Forced (OFAF)

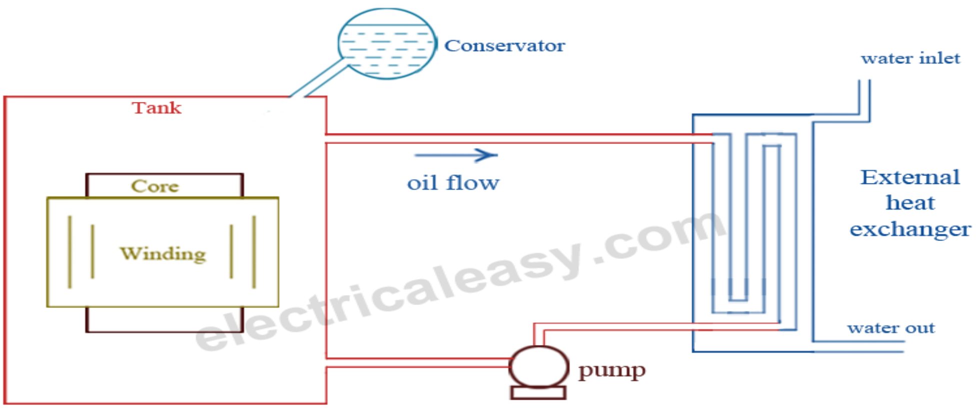
In this method, oil is circulated with the help of a pump. The oil circulation is forced through the heat exchangers. Then compressed air is forced to flow on the heat exchanger with the help of fans. The heat exchangers may be mounted separately from the transformer tank and connected through pipes at top and bottom as shown in the figure. This type of cooling is provided for higher rating transformers at substations or power stations.



Oil Forced Air Forced (OFAF) - Cooling of Transformer

Oil Forced Water Forced (OFWF)

This method is similar to OFAF method, but here forced water flow is used to dissipate hear from the heat exchangers. The oil is forced to flow through the heat exchanger with the help of a pump, where the heat is dissipated in the water which is also forced to flow. The heated water is taken away to cool in separate coolers. This type of cooling is used in very large transformers having rating of several hundred MVA.



Oil Forced Water Forced (OFWF) - Cooling of Transformer

2.Buchholz Relay

Buchholz relay is used for the protection of oil filled transformer from incipient faults below oil level. This relay is installed between the transformer tank and conservator. Whenever the fault occurs due to low oil level the relay gives the alarm. The arc due to the fault causes the decomposition of oil. The product of decomposition contains more than 70% of hydrogen gas, which being light, rises upwards and tries go in the conservator. The buchholz relay is fitted in the leading to conservator . The gas get collected in the upper portion of relay, there by the oil level in the relay drop down .The float, floating in the oil levelin the relay tilts down with the lowering oil level. While doing so the mercury switch , attached to the float is closed and mercury switch closes the alarm circuit. Thereby the operators know about there is some fault in transformer and is disconnected as soon as possible. The gas sample is tested and testing gives idea regarding the type of fault. The schematic diagram is as shown in the fig

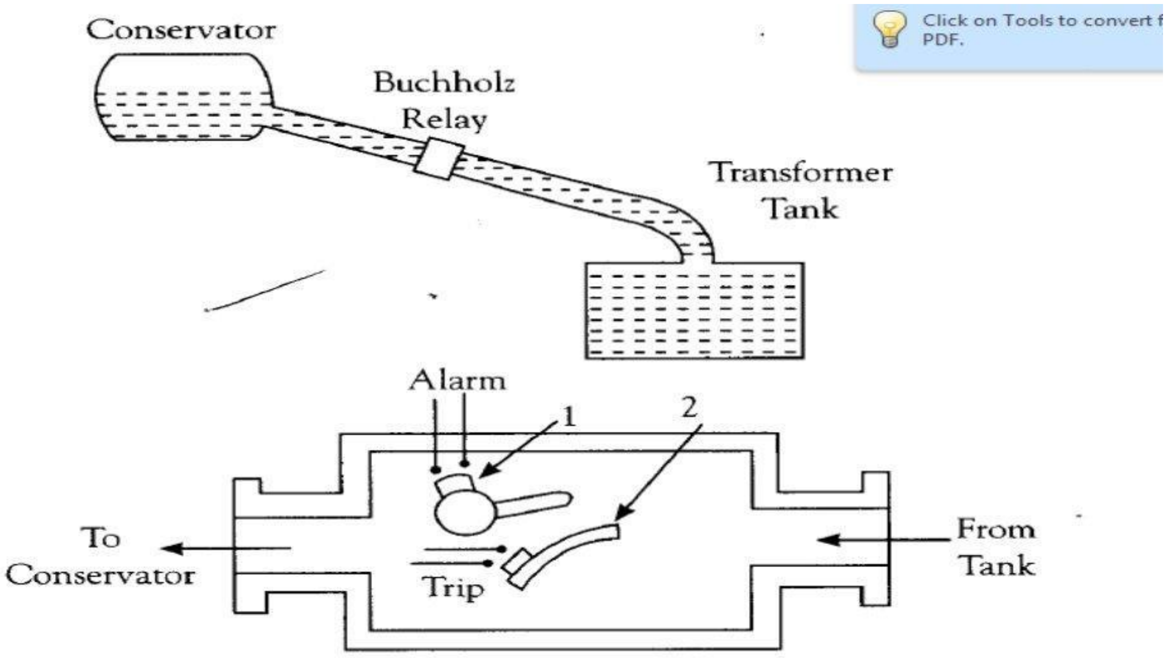


Figure 1.27: Buchholz relay

3.TAP CHANGERS

The voltage variation is a normal phenomenon ,because of rapid growth of electrical load and distribution network. It is necessary to maintain system voltage within the specified limit for the better health of electrical equipment .The system voltage maybe adjusted by changing the tapping on the power transformer. The variation in voltage may be brought in either by step or step less control .But the practice proved that voltage variation is handled effectively in steps without creating objectionable disturbance on the system. This variation is generally achieved by means of tappings on the power transformer because of the smaller currents to be dealt with , are normally located on the higher voltage winding

- **Off circuit tap changer:** The economic method of changing the turns ratio of a transformer is the use of off-circuit tap changer. As the name suggest ,it is necessary to de-energize the transformer before changing the tap. A mechanical lock is provided to prevent unauthorized operatin and inadvertent operation. The transformer are normally provided with off-circuit taps with +2.5 percent and +5 percent on hv side. The station transformers are preferably provided with OLTC with +10% in steps of 1.25 percent on hv side

- **On Load Tap Changer(OLTC);** OLTC are employed to change turns ratio of transformer to regulate to regulate system voltage while the transformer is delivering norml load. With the inception of OLTC , the operating efficiency has considerably improved. All forms of OLTC circuit posses an impedance, which is introduced to avoid short circuiting of tapping section during tap changer operation. The OLTC can in general, be classified as resistor or rector type. As the motor drive unit is initiated by a push button or voltage control relay, tap selector changes tap. the diverter switch diverts the current .The tap changers function without interruption in load current.

4. Flow or oil level indicator: it is fitted in oil circulation system which indicates the Flow rate. it is used for control purpose in combination with float switches for starting and stopping of oil pumps

5.Pressure relief valve: It is fitted on the tank to act as an exit for gasses formed of oil. A up of gaseous pressure .If this pressure is not relieves within few milliseconds ,the transformer tank gets ruptured ,spilling oil over wide area..

6.Sudden pressure relay: (Rate of rise of pressure relay): The rate of rise of pressure relay responds to sudden rise of pressure due to internal arcing. The relay is fitted on the tank

7. Conservator: It is a large cylinder connected by pipe to the transformer. The oil is filled upto certain level in the conservator

8.Breather: one end of breather is connected to air cushion in conservation and the other end is towards the external air

9.Oil temperature indicators: the thermocouple is placed in the pocker provided with the tank near hot oil

10. Winding temperature indicator (Hot spot indicator)with alarm and tripping contacts: Thermocouples are placed in the tank near hot oil. The indicator is provided with alarm and tripping contacts

MAINTENANCE OF POWER TRANSFORMER

It is essential to have periodic preventive maintenance of power transformer by trained person with maintenance facilities. The transformer needs regular maintenance for satisfactory service. The transformer maintenance includes

1. Routine daily inspections
   a. Check tank and radiators for unusual noise, oil and water leaks
   b. Check oil level in conservator
   c. Check oil level in main tank bushings
   d. Check whether cooling water in flowing, whether oil circulation pump is operating whenever necessary, fans start when necessary
   e. Check relay panel temperature indicators and confirm normal condition
   f. Check position of tap changer
   g. See that oil control/alarm / power/ Supply circuit switches are closed and fuses in the circuit are well placed
2. Routine monthly inspections
   a. Check oil level in main tank , oil filled bushing, etc. if the oil level has fallen down below specified level for a given temperature the cause of leakage should be determined
   b. Check and record oil temperature
   c. Check bushing surface for signs of chipping dirt, oil, etc.
   d. Check terminal connections, earthing connections for tightness
   e. Other checks mentioned in the daily checks
3. Routine annual inspections
   a. Check water flow indicators and relays for proper operations
   b. Check foundation for cracking and settling
   c. Clean dirt and oil from radiating surfaces
   d. Check external supply and drain piping for leaks
   e. Clean and test water tubes similar to cooling coil, check for oil and water leaks
   f. Tighten all buss and ground connection
   g. Inspect contacts and clean if reachable on internal inspection
   h. Drain oil from contact compartment, clean and refinish contact surfaces
   i. Check insulation resistance between each winding and between winding and ground
   j. Check the dielectric strength of the insulating oil

Module-2 Synchronous Machines

a. ***Specifications:*** *As per BIS standards.*

b. ***Installation:*** *Physical inspection, foundation details, alignments, excitation systems, cooling and control Gear, drying out.*

c. ***Commissioning Tests:*** *Insulation, Resistance measurement of armature & field windings, waveform & Telephone interference tests, line charging capacitance*

d. ***Performance tests:*** *Various tests to estimate the performance of generator operations slip test, Maximum lagging current, maximum reluctance power tests, sudden short circuit tests, transient & sub Transient parameters, measurements of sequence impedances, capacitive reactance, and separation of losses, Temperature rise test, and retardation tests*

Introduction:

- Synchronous generators and Synchronous Motors are called Synchronous Machine
- Synchronous generator is the major component of power system.
- Based on the source of power generation they are classified a) Turbo Alternator b) Gas turbo -generators c) Industrial Synchronous generators

Standard specifications of a Rotating Machines

The important step in selection of Synchronous Machines for specific application is deciding the ratings considering all affecting parameters.

- ✓ **Voltage Rating**: 11KV, 3.3KV,1.1KVetc
- ✓ **Excitation Voltage**: 110V-1000V DC
- ✓ **Excitation Current**: 10 to 100A
- ✓ **Power Rating**: specified in KW
- ✓ **Type of Mounting**: The mounting is to be specified like vertical mounting, Horizontal mounting etc.
- ✓ **Rated Current and rated frequency with variation**
- ✓ **Class of insulation**: The class of insulation used for winding is to be given i. e class A, E, B, F and H
- ✓ Ambient temperature
- ✓ Type of construction and bearing arrangements
- ✓ Cooling system
- ✓ Method of starting and drive details
- ✓ Performance requirements with respect to efficiency and related parameter

INSTALLATION OF SYNCHRONOUS MACHINES

Various steps in installation of an alternator

- Installation of bed plate and the leveling of bed plate
- Installation of the bearing pedestals and leveling of the bearing pedestals
- Checks on stator and rotor
- Assembly of the rotor onto the shaft
- Installation of the stator
- Installing the rotor in the stator
- Checking of the air gap between stator and rotor
- Preparation of shaft couplings
- Mounting of shaft couplings on shaft
- Preparation of shafts and alignment of shafts.
- Installation of cooling systems
- Drying out
- Testing
- Commissioning

Each of the above activities should be carried out by technically skilled staff. The instruction manual supplied by the manufacturer should be referred in practice. Shaft alignment should be, perfect to get trouble free mechanical performance of the

generator with the driven equipment. The rating plate is of definite dimensions as per IS Code. The ratings are etched or engraved and is fixed to the machine in a clearly visible position.

1. Physical Inspection: The synchronous generator received at site must be stored in a safe place. before storing ,the machine should pass an acceptance procedure intended to check it for missing or damaged parts. Take the necessary measures for excluding the violation of installation terms. Checking should be done in presence of representative of the supplier. Large capacity synchronous generators are delivered in a disassembled condition.

2. Foundation : Large alternators require strong foundation depending on the type of mounting i.e. Horizontal or Vertical . Alternators in generating stations are usually vertically mounted. Foundations should be separated from columns and supporting structures of the building so as to prevent the transfer of vibrations of machine to the building. Basic dimensions of the foundations are specified by the manufacture in the drawing. The foundation must be provided with holes to receive anchor bolts shall be fixed in the concrete. The alternator is installed in a strong structure constructed for this purpose only

Excitation system

The rotor of a synchronous machine needs dc current for excitation. The field current is supplied and controlled by the excitation system. An excitation system includes all the equipment required for supply of field current and voltage regulator system. Excitation response is the rate of change of exciter voltage and is expressed in terms of volts per second.

The maximum voltage that may be attained by an exciter under specified condition of load is termed as excitation ceiling voltage. The function of the excitation system is to supply and regulate field current.

Brushless (static) excitation system:

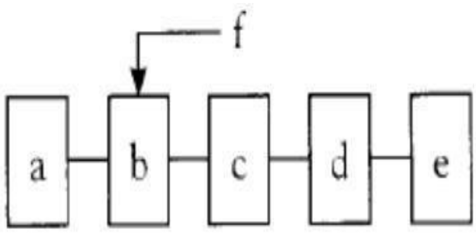


Figure 3.1: Block diagram of brushless excitation system

a- Permanent magnet alternator (Rotating field, stationary armature)
b - Magnetic amplifier
c - AC exciter (Rotating armature, stationary field) d - Silicon diode rectifier (Revolving with rotor)
d—silicon diode rectifier.
e - Main generator field or rotor
f - Feed back of generator voltage for control and regulation

The silicon diode rectifier is mounted on the same shaft to excite the field of the main generator directly. An ac exciter is used to feed power to the revolving rectifier. The field of the ac exciter is fed by a magnetic amplifier that controls and regulates the output voltage of the main generator. The excitation power for the magnetic amplifier is obtained from a small permanent magnet alternator which is also driven from the main shaft. The voltage and frequency of ac exciter are selected so as to optimize the performance and design of the overall system

Automatic Voltage Regulators and Excitation System

Performance of a synchronous generator has interface with the complete generator- turbine unit, bus bar connected other units and the grid.

A synchronous generator has a 3-phase distributed AC Armature winding on stator and DC excitation main field winding on the rotor. The rotor is driven at synchronous speed by prime mover. The main excitation field winding on rotor of the alternator is supplied DC Voltage by the excitation system. The main alternator excitation field current is increased or decreased by changing the exciter voltage by **Automatic voltage regulator(AVR)** and its feedback control system. Rotating magnetic field of Dc excitation field of rotor induces 3 phase Ac EMF in stator armature winding. Flow of stator armature current Ia produces induced

revolving magnetic field in the air-gap, revolving At synchronous speed and locked with the rotor magnetic field. The angle between the stator field and rotor field is the load angle **δ** which increases with load and undergoes oscillation during disturbances.
The main exciter provides DC field Voltage and current to the rotor field winding of the generator. The exciter terminal voltage decides the excitation current. The AVR controls exciter terminal voltage and alternator excitation rotor field current to regulate generator terminal voltage. The pilot exciter feeds power to the field winding of main exciter.

The AVR in the excitation system plays a very vital role Voltage control, controlling reactive power supply, emf, Voltage and power factor of generator, and also maintaining power system dynamic stability, and in protection of alternators by imposing several limits on generators variables.

The Functions of an AVR

1. Regulation of terminal voltage automatically: To regulate the terminal voltage within specified limits of the generator automatically under steady state operating condition of varying load/pf. This is done by controlling field current by means of a feedback system involving voltage transformer and AVR.

2. To facilitate reactive power load sharing with other generators operating in parallel

3. To regulate the voltage and load angle δ under abnormal conditions and transient disturbing such as faults, power swings, sudden switching in of large loads, etc

4. To damp swing and electromagnetic oscillations in load angle under abnormal conditions and transient/dynamic disturbing conditions rotor oscillations of synchronous generators and ensure stable operation.

5. To ensure protection of generators and excitation system by giving tripping command under appropriate abnormal conditions of variables.

6. Limiting Features: To inhibit the tripping of the generators unit by protection system under permissible swings in active power and reactive power. AVR operates in close liaison with the generator protection system and raises the operating limits for ensuring generator service during disturbances.

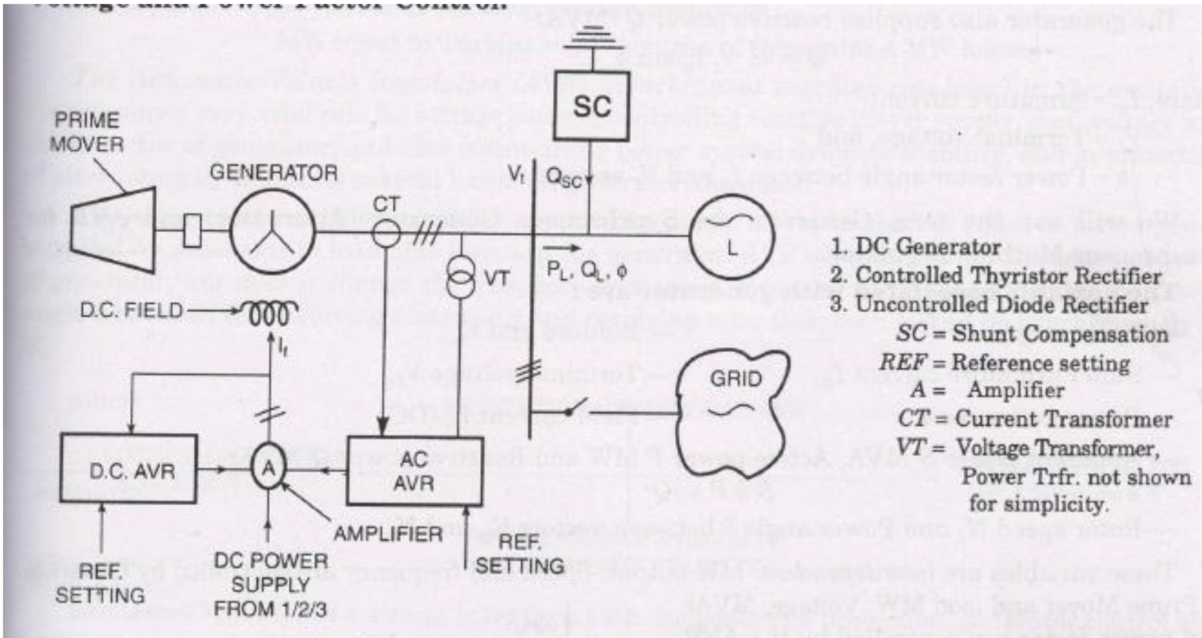


Fig. Q. 1068 (a). Schematic of a Generator unit, load and AVR.

Cooling Methods

The methods employed for cooling of synchronous machine are

- **Open circuit cooling**: A method of cooling in Which the coolant is drawn from the medium surrounding the machine, passes through the machine and then returns to the surrounding medium.
  The methods used in open circuit cooling
  - Enclosed ventilated
  - Weather protected
  - Output water/heat exchanger
- **Closed circuit cooling**: The primary coolant is circulated in a closed circuit through the machine and if necessary, through heat exchanges. Heat is transferred to the secondary coolant.
  The methods used in closed circuit cooling
  - Totally enclosed
  - Totally enclosed fan cooled
  - Totally enclosed fan/tube cooled
  - Totally enclosed separate air cooled
  - Closed air circuit air-cooled integral fan
  - Closed air circuit air-cooled separately driven-fan
- Further the cooling system may be
  - Standby or emergency cooling system
  - Dependent circulating circuit components &Independent circulating circuit components & Integral circulating circuit components
  - Machine mounted circulating circuit components v' Separately mounted
  - circulating components
  - Hydrogen cooling
  - Water cooling

Hydrogen cooling of turbo - generators:

The thermal conductivity of hydrogen is about 7 times that of air. The density of hydrogen is 0.07 times that of air. The specific heat of hydrogen is 14 times that of air. Hence hydrogen gas is preferred to air as a coolant in Large turbo generators of capacity 60 MW and above. It reduces noise and improves heat transfer. The hydrogen cooling is direct cooling i.e. the cooling medium is in direct contact with conductors. The hydrogen gas is passed through the rectangular tubular cross section rotor conductors. The stator conductors are hollow and hydrogen gas from a separate circuit is circulated through the stator conductors. The pressure of the gas is of the order of 1.5 Kgjm2 and flow rate is about 15 m3 jess. Hydrogen blowers are required to circulate hydrogen gas through direct cooled machine.

TYPES OF ENCLOSURES

1.**Open Pedestal:** In this the stator and rotor ends are open to the outside ambient temperature, the rotor being supported on pedestal bearings mounted on the bedplate.

2.**Open End Bracket** : In this the bearings forms part of the end shields which are fixed to the stator housing . The air is in comparatively free contact with stator and rotor.

3.**Protected or End-Cover type with guarded Openings:** The protector may be Screen or fine mesh covers.

4.**Drip.Splash or hose proof:** This is complete protected Machine with openings in the end shield for Cooling.

5.**Pipe or Duct Cooled:** With the end covers Closed except for flanged openings for connection to cooling pipes.

6.**Totally Enclosed:** In this type , the air will not be in contact with the ambient air, The machine is totally air tight. Total enclosure may be associated with an internal rotor fan, an external fan.

7.**Flame proof or Explosion proof:** This Motor is used in hazardous location such as mines, chemical Industries.

Duty

The duty requirements shall explicitly be given by the purchasers as accurate as possible. The Duty requirement may be declared numerically or with the aid of time sequence graphs. The duty declaration for an electric motor is very important as the electric motors have the time rate of temperature rise.

Classes of Duty:

- S1 - continuous Duty: The motor is running long enough
- S2 - short time Duty: Time of operation is very low
- S3 - Intermittent periodic Duty: The motor operates for some time and then there is rest period
- S4 - intermittent periodic Duty with starting
- S5 - continuous duty with intermittent periodic loading
- S6 - continuous duty with starting & electric braking
- S7 - continuous duty with periodic speed change

Drying of Windings

The Insulation of Rotating machine is **Hygroscopic(absorbs moisture)** in nature. The Moisture reduces the insulation resistance. It is essential to remove the moisture before commissioning of the machine. The high resistance of Insulation gives the degree of dryness of the insulation. The moisture is evaporated from winding due to thermal diffusion. The moisture gradient depends on temperature gradient within wet insulation. The Desired temperature is obtained by heating the winding. The insulation is measured by means of DC Mega ohm meter(Megger). The Phase to Phase and Phase to earth insulation resistance I_0R_{60}(Mega ohms). At the Working temperature of the machine should not be lower than the Value found from the Equation.

$$\mathbf{I_0R_{60}} = \frac{V_{rated}}{1000+0.01P}$$

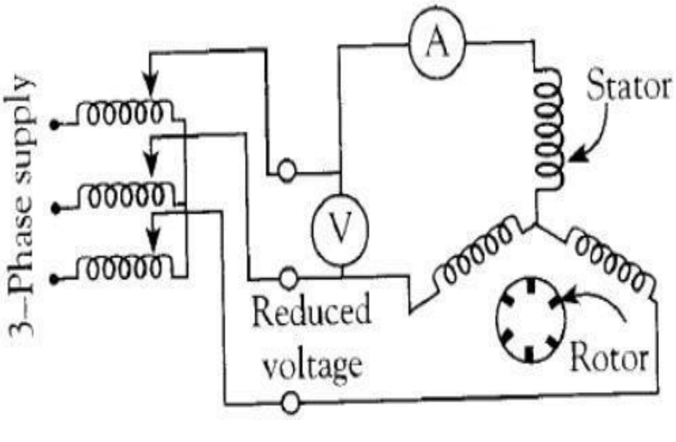
Where V_{rated} -- Rated voltage across the machine in Volts
P -- Rated output of the machine in KW.

Polarization Index: Is the ratio of insulation resistance of 60sec megger readings to the insulation resistance of 15sec megger readings.

$$PI = \frac{IoR60}{IoR15}$$

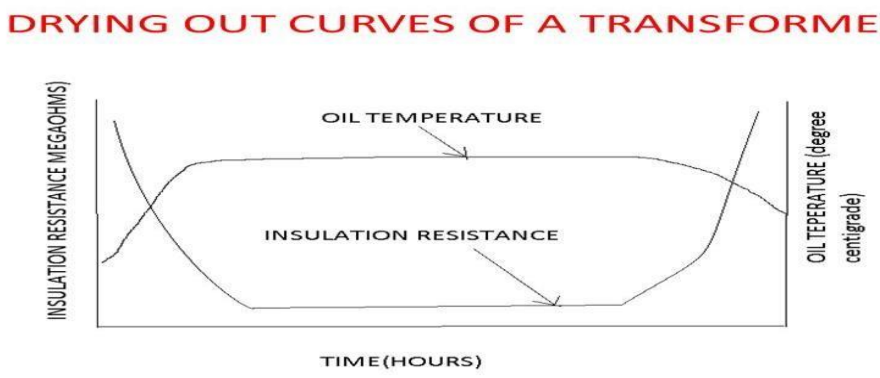
Procedure for Drying out of Synchronous Machine

The machine is connected to low voltage source. The input voltage, current, power, the temperature of winding, temperature of body, temperature of hot air is periodically recorded. The end covers of the machine are removed. The machine body is covered with tarpaulin. The increase and decrease of the temperature should be gradual. The rotor is blocked. The current through the stator winding not to exceed 50% of the rated current



The drying out procedure has three distinct phases.

- In the beginning the insulation resistance decreases indicating that the moisture is getting released within the insulation.
- After few hours the insulation resistance reaches the steady state value indicating the moisture content is distributed within the winding.
- In the last stage the insulation resistance start increasing indicating the moisture is expelled out. The drying out procedure is stopped when the desired value of hot insulation resistance and polarization index are achieved for each winding .



Testing of Synchronous Machines

1. Tests on synchronous generators:

- Insulation resistance test on stator winding
- Measurement of dc resistance of armature and field windings
- Dielectric test on stator windings by AC voltage for 1 min.
- Dielectric test with DC voltage
- Measurement of dc resistance of field discharge resistor
- Testing of insulation of the field discharge resistor with respect to frame.
- Testing of insulation resistance and dielectric withstand of field insulation.
- Measurement of vibrations.
- Noise measurement
- Measurement of air gaps between stator and rotor
- Open circuit characteristic the measuring terminal voltage for various field currents at no load and rated speed
- Short circuit characteristics by changing field current and measuring short circuit armature current
- Sudden 3 phase circuit test to record the oscillograms of short circuit current at three phase
- Testing on voltage regulator excitation systems

2. Tests on synchronous motors:

- Measurement of dc resistance of armature & field windings
- Dielectric tests on armature and field windings
- Mechanical balancing test
- Current balance on no load
- Direction of rotation
- Phase sequence test
- over speed test
- Harmonic analysis
- Telephone interference ./ Short circuit test
- Reactance and time constants ./ Speed torque characteristics Efficiency calculations
- Bearing insulation test

1. INSULATION RESISTANCE TEST

The insulation resistance of stator winding to earthed frame, rotor winding to earthed frame, phase to phase winding pedestal and bearing insulation resistance is measured using megger. The megger readings for 15 seconds and 60 seconds are taken to find the polarization index.(for diagram and explanation refer Transformer 1&2 unit notes)

2. MEASUREMENT OF DC RESISTANCE OF WINDINGS

The dc resistance of armature windings, field windings and field discharge resistance are measured using the following methods.

a) Voltmeter ammeter method: In which voltage applied across the winding and current through the winding are noted at the specified temperature. Then the resistance is calculated. This is suitable for field resistance measurement. Built in bridges via Wheatstone bridge and Kelvin's double bridge are used to measure field resistance & armature resistance respectively. As resistance is sensitive to temperature, temperature is also recorded and three to five readings are taken.

b) Reference Field Resistance: The resistance is normally measured at standstill condition by allowing rotor being exposed to sufficient time. This is for entire rotor to reach the ambient temperature. This reference resistance helps in determining the field temperature during running by the method of variation of resistance. When reference resistance is measured, the current circulation through the field coil shall be low , so as not to cause change in temperature. Both the resistance and temperature can be determined more accurately by conducting the test when the generator isrunning near normal speed.

3. OPEN CIRCUIT TEST (NO LOAD SATURATION TEST)

The open circuit characteristics of a synchronous machine is the curve showing the relationship between armature terminal voltage and field excitation. The prime mover is run at rated speed. The excitation is varied in steps and corresponding no load voltage is recorded. The characteristic curve may be plotted in per unit where unit voltage and unit excitation corresponding to rated voltage and excitation current on the air gap Line. The open circuit characteristics represent the relation between the space fundamental component of the air gap flux and the miff on the magnetic circuit when the field winding constitutes the only source. During no Load test the no Load Losses of the machine can be obtained. The test circuit for No load test and NO load characteristics are shown.

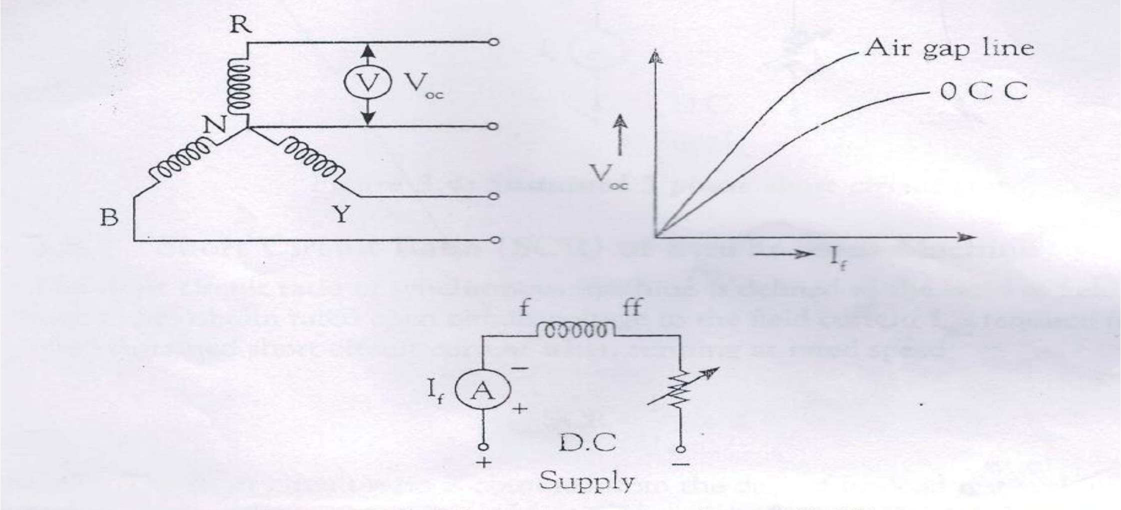


Figure 3.3: No load test circuit and OCC

4. SUSTAINED THREE PHASE SHORT CIRCUIT TEST

In this test, the synchronous generator terminals are shorted through ammeters as shown in fig. and the field current is gradually increased till the ammeter current reaches a maximum safe value (about 1.5 times rated current). The relation between field current and short circuit current is drawn and is known as short circuit characteristics. In sustained Short circuit test, the values of field current and armature current refer to the steady state values and measured using indicating meters.

The sustained three phase short circuit test is also conducted by a retardation test on the machine. The machine under test is driven by an electric motor at rated speed and is excited to get the short circuit current in the armature. The machine under test is retarded by putting off the supply to driving machine. The armature current in each phase and the corresponding field current are noted. If the machine has retardation above 4 percent of its rated speed per second, excitation from separate source is used to get stable excitation during the test

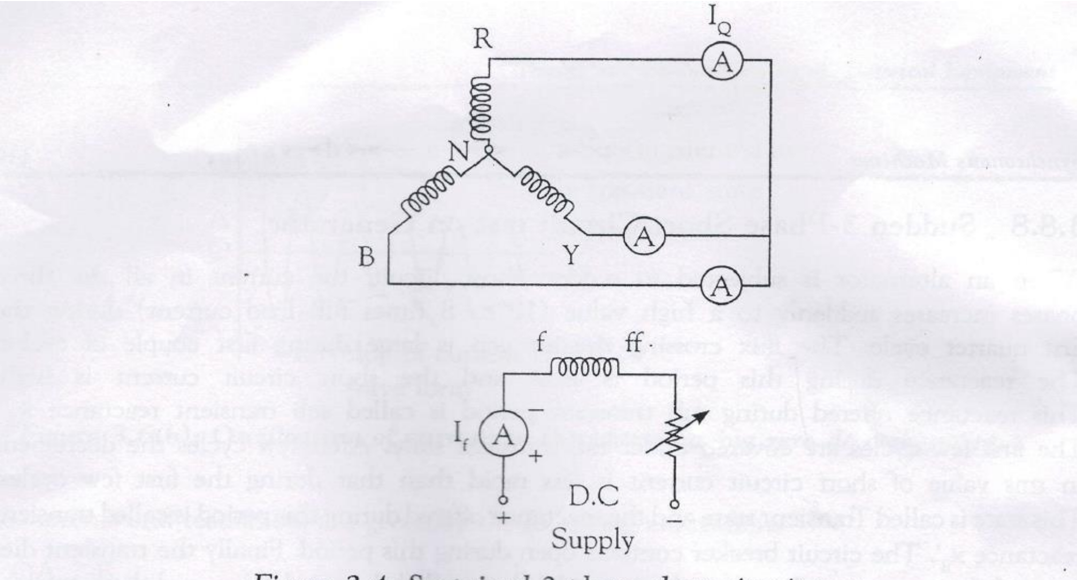


Figure 3.4: Sustained 3 phase short circuit test

5. SHORT CIRCUIT RATION (SCR) OF SYNCHRONOUS MACHINE

The Short circuit ration of synchronous machine is defined as the ratio of **field current** $\mathbf{I_{foc}}$ required to obtain rated open circuit voltage to the field current $\mathbf{I_{fsc}}$ required for obtaining rated sustained short circuit current when running at rated speed .

$$SCR = \frac{Ifo}{Ifsc} = K$$

The SCR is obtained from the data of the No load test and sustained short circuit test conducted on a machine as shown in fig. The impedance in the steady state condition is is known as the synchronous impedance and defined as the ratio of field current at rated armature current on sustained symmetrical short circuit to the field current at normal open circuit voltage on the air gap line.

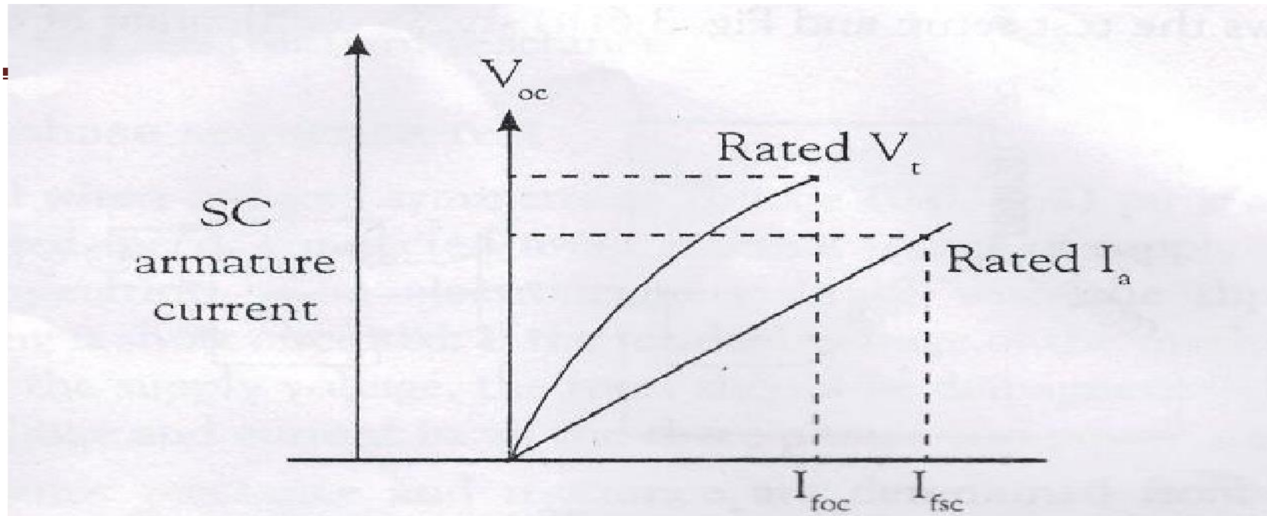


Figure 3.5: S.C. Ratio from occ and scc

<u>SUDDEN 3-ϕ SHORT CIRCUIT TEST</u>

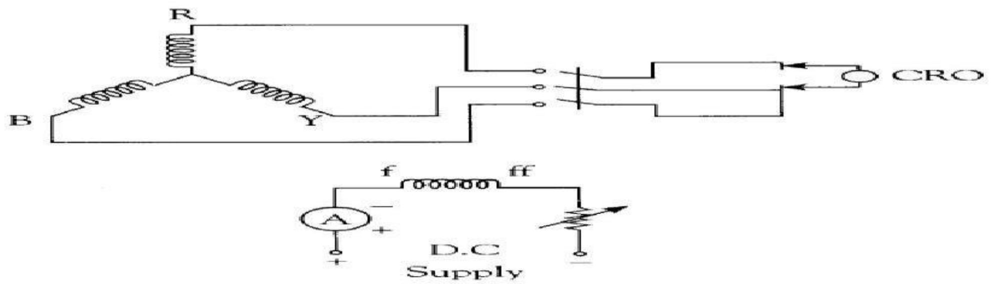
When an alternator is subjected to sudden short circuit, the current in all the three Phases increases suddenly to a high value (10 to 8 times full Load current) during the First quarter cycle. The flux crossing the air gap is Large during first couple of cycles. The reactance during this period is Least and the short circuit current is high. This Reactance offered during sub transient period is called as sub transient reactance X_d''. The First few cycles are covered under sub transient state. After few cycles the decrement in rms value of short circuit current is Less rapid than that during the first few cycles. This State is called as Transient state and the reactance offered during this period is called as transient reactance X_d'. The circuit breaker contacts open during this period. Finally the transient dies out and the current reaches a steady sinusoidal state called the steady state and the reactance offered during this state is called as steady state reactance X_d. Since the short circuit current lag the voltage by 90°, the reactance involved is direct axis reactance.

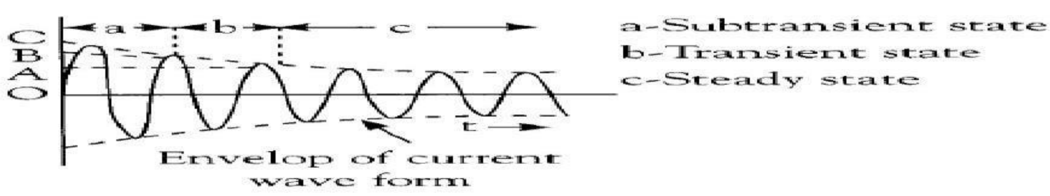
The sudden 3-phase short circuit test is conducted at rated speed and at desired no load voltage.

- The 3 phases are shorted suddenly.
- To measure short circuit current storage oscilloscope with proper probe multiplier is used.
- The terminal voltages of machine and excitation current and winding temperature are measured just before the short circuit.
- To obtain quantities corresponding to the unsaturated state of the machine, the test is performed at several armature voltages of 0.1 and 0.3PU of rated value.

  To get quantities corresponding to the saturated state of the machine, the test is performed with rated at the terminals of the machine before applying the short circuit to the armature winding.
- To determine the machine quantities, oscillogram of the armature current in the excitation is taken.
- The short circuit is initiated by closing the circuit breaker

Fig A shows the test set up and fig B shows the oscillogram current





The currents and reactance are given by the following expressions

$I = \frac{OA}{\sqrt{2}} = \frac{Ea}{Xd}$; X_d -- Steady state reactance = $\frac{Ea}{I}$

$I' = \frac{OB}{\sqrt{2}} = \frac{E}{Xd'}$; X'_d -- Transient state reactance = $\frac{Ea}{I'}$

$I'' = \frac{OC}{\sqrt{2}} = \frac{Ea}{Xd''}$; X''_d -- Sub transientstate reactance = $\frac{Ea}{I''}$

Where OA,OB,OC are intercepts of X-axis as shown in fig
E_a - rms value of positive sequence emf, per phase , induced by the generator
I - Steady state short circuit current, rms value
I' - Transient short circuit current, rms value
I'' - Sub transient short circuit current , rms value

6. NEGATIVE PHASE SEQUENCE TEST

The test is conducted when reduced symmetrical voltage (0.02-0.2) up is applied to the machine driven at rated speed, connected to an external source of supply with negative phase sequence i.e. operating as an electromagnetic brake with the slip equal to 2. The excitation winding is short circuited. If the residual voltage of the machine under test exceeds 0.30 times of the supply voltage, the rotor should be demagnetized before testing the machine. The voltage and current in all the three phases and power are noted.

7. SLIP TEST AND CALCULATION OF Xq & Xd

During the slip test, subnormal symmetrical three phase voltage of magnitude 10 to 20% of the rated voltage is applied to the armature terminals of the machine. The field of the alternator is either open circuited or short circuited. The prime mover is run at slightly less than synchronous speed to get a slip of 0.01. Armature current and voltages are measured using indicating instruments or recorded by using oscilloscope. The ammeter & volt meter readings will indicate two values which are to be taken as minimum and maximum quantities respectively. To find out Xq and Xd

$$Xq = \frac{Vmin}{\sqrt{3}\,Imax} \text{ ohm}$$

$$Xd = \frac{Vma}{\sqrt{3}\,Imin} \text{ ohm}$$

If Imax do not coincide with Vmin, use in calculations Imax as a base and its corresponding voltage.
If during the test, the residual voltage of the machine is in the limits of 0.1-0.3 of the supply test voltage

8. POWER FREQUENCY VOLTAGE WITHSTAND TEST

This test is conducted on 3 phase ac windings of an ac generator with the specified values of power frequency test voltage. The test voltage of (2V+l) KV is applied for specified time (1 minute) between windings and earthed frame. The machine parts should not exhibit flash over, to consider it to have passed the test.

9. VIBRATION TEST

The vibration test is carried out on the complete machine after assembly and balancing of the machine. A set of three orthogonal accelerometers are fixed on each bearing. The vibrations are measured in two directions normal to the shaft. For vibration test the machine is run at no load without coupling to any machine.

Noise in Motors

The noise of a rotating machine is generated by a cooling air from its fan as it passed through or over the machine. Some noise reduction is possible by substituting unidirectional trailing bladed fans by the normal radial blades Further reduction is achieved by inlet and outlet silencers or the adoption of closed ventilation circuit of cooling air.
The noise is also caused by magnetic effects and dependent on the stator and rotor slots. It c a large vibration of air-gap flux density. This may produce a penetrating note at approximately slot frequency (e.g. 0.5 – 1.5kHz). The amplitude of stator permeance variation may be the cause, but the amplitude also depends on higher order rotor m.m.f. space harmonics. The frequency of the noise is twice the product of the supply frequency with that integer nearest to the number of slot per pole.

Noise Reduction : Noise is caused by 1. Magnetostriction, 2. Aerodynamics, 3. Bearing noise of rotating shaft

Speed and Power effect:

- Totally enclosed machine give least sound. Open ventilated machine give maximum sound.
- Ventilation noise predominates in 2-pole machines
- Magnetic noise is predominating in machines with more number of poles
- When bearing, noise become audible, the other two become less significant

Methods to reduce the noise for DC Machine

- Reduced magnetic loading.
- Increase number of armature slots – Skewing of slots.
- Continuously graded main pole gap (more at pole end and least at pole centre)
- Increase in air gap – Brace commutating poles against main poles
- 12 pulse thyristor for speed control and not 6-pluse
- Semi- enclosed slots or closed slots for compensating windings

an occur in machine with fractional number of open slots per pole, producing a relatively

10. LOW SLIP TEST

During the low slip test, sub normal symmetrical 3phase voltage is applied to the armature terminals of the machine under test. The voltage should be such that the machine does not pull in. The excitation winding should be open circuited and rotor should be driven by a prime mover at a slip less than 0.01pu. There by the current induced by the damper winding during synchronous operation will have negligible influence on the measurements. During switching on and off of the supply, the excitation winding should be closed to avoid possible damage. The armature current and voltage and slip ring voltage and Slip are measured by indicating instruments or recorded by Oscillograph If the residual voltage measured before the test is larger than 0.3 of the supply test voltage, the rotor should be demagnetized.

To determined Xq from the low slip test, armature current and voltage are measured to maximum excitation winding voltage (U) and Xq is calculated using the formula

$$Xq = \frac{Vmin}{\sqrt{3}\, Imax} \text{ohm}$$

$$Xd = \frac{Vmax}{\sqrt{3}\, Imin} \text{ohm}$$

11. Temperature rise test:

The aim of this test is to find out the temperature rise on different parts of the motor while running at rated conditions. During temperature rise test, the motor should be shielded from currents of air entering from adjacent pulleys and other machines. A small current of air may cause great discrepancy in results obtained. The duration of temperature rise test depends on the type of rating of the motor. For motors of continuous rating, the test should be continued till the thermal equilibrium is reached. For motors of short time rating the duration of test corresponds to the declared short time rating, the test should be continued till the thermal equilibrium is reached. Methods of measuring temp The following methods are approved for determining the temperature of windings and other parts of motor.

1) Embedded temperature detector method:

Embedded temperature detectors are resistance thermo-meters or thermocouples built in the machine at points which are inaccessible when the m chine is assembled. This method is generally employed for the slot portion of stator windings. At least six detectors to be built in a machine suitably distributed around the circumference.

2) Resistance Method:

This method is generally used for stator whirling’s. Here temperature is determined by the increase in the resistance of the windings.

3) Thermometer method:

In this method, the temperature is determined by thermometers placed at the accessible surface of the rotor.

ABNORMAL CONDITIONS AND EFFECTS ON SYNCHRONOUS GENERATOR

1. **External faults beyond generator protection:**
   During external faults with large short circuit current s, severe mechanical stress will be imposed on the stator windings. If any mechanical defects already exeunt in winding, these may be further aggravated. The temperature rise is however, relatively slow and a dangerous temperature level may be obtained after about 10seconds. With asymmetrical faults, severe vibration and overheating of rotor may occur
2. **Thermal overloading**
   Continued loading may increase the winding temperature to such an extent that the insulation will be damaged and its useful life reduced.
   Temperature rise can also be caused by failure of cooling system.
3. **Unbalanced loading**
   Continued unbalanced load cause dangerous heating of the cylindrical rotator in turbo generator
   Unbalanced loading on generator can be due to unsymmetrical false in the system or due to the mal operation of circuit breaker near generation station
4. **Stator winding faults**
   a. Phase to earth faults: These faults normally occur in the armature slots. The damage at the point of fault is directly related to the selected neutral earthing register. Severe damaged may be caused owing to the large time constant of the field circuit and relatively long time required to completely surplus the field flux
   Phase to phase faults: A phase to earth fault may cause the phase to phase faults within the slots. It is most likely to be located at the end connection of the armature winding. This fault causes a severe arcing with high temperatures, melting of copper and risk of fire
5. **Field winding faults**
   The unbalanced loading of generator gives rise to negative sequence currents which causes negative sequence component of magnetic field. The negative sequence field rotates in opposite direction of the main field and induced emf in the rotor winding, thus causes rotor heatin
6. **Over voltages Surge due to lightening and switching**
   Surge voltages are caused by direct lightening strokes to the aerial lines in the HV systems. The amplitude and the duration of the surged on the generator side dependence on the type of surge arresters used on HV side. This causes the insulation failure
7. **Loss of excitation:** Results in loss of synchronism and slightly increased speed. The machine continues to run at an inductance generator, drawing excitation current from bus bars the damper winding acts like a squirrel cage. This causes over heating winding and rotor winding
8. **Motoring of generator:** When the input to the prime mover stops the generator draws a power from bars and runs as synchronous motors in the same direction. Effect depends upon the type of prime mover and the power drawn from buss bar during motoring
9. **Over fluxing of transforms in the generating stations :** Causes heating of core bolts and failure in core bolt insulations

Module 3: Induction Motors

Syllabus: a. ***Specifications:*** *Power and distribution transformers as per BIS standards.*
b. Installation*: Location, site, selection, foundation details (like bolts size, their number, etc), code of practice for terminal plates, polarity & phase sequence, oil tanks, drying of windings and general inspection.*
c. Commissioning tests: *Following tests as per national & International Standards, volt ratio test, earth resistance, oil strength, Bucholz& other relays, tap changing gear, fans & pumps, insulation test, impulse test, polarizing index, load & temperature rise test.*
d. Specific Tests: *Determination of performance curves like efficiency, regulation etc, and determination of mechanical stress under normal &abnormal conditions.*

Introduction:

- Induction motors are widely used as industrial drives because of its simplicity, reliability and low cost.
- With the application of thyristor control, induction motor can be used for variable speed drive.
- Induction motor works with better efficiency appreciable over-load capacity and maintenance required is minimum.
- Three phase induction motor are available with various rating from fractional HP to several thousand HP.

Standard specifications of a Induction Motor

The important step in selection of induction motor for specific application is deciding the ratings considering all affecting parameters.

- ✓ **Output Rating**: The preferred output rating for induction motors upto and including 110KW are 0.06, 0.09, 0.12, 0.18, 0.25, …….100KW
- ✓ **Type of Mounting**:The mounting is to be specified like foot mounting, bed mounting etc.
- ✓ **Rated voltage and rated frequency with variation**
- ✓ **Class of insulation**: The class of insulation used for winding is to be given i. e class A, E, B, F and H
- ✓ Ambient temperature
- ✓ Type of construction and bearing arrangements
- ✓ Type of enclose and cooling system
- ✓ Method of starting and drive details
- ✓ Performance requirements with respect to efficiency and related parameters

Procurement of Induction Motor

When enquiring, and placing an order of induction motor the following particular should be supplied

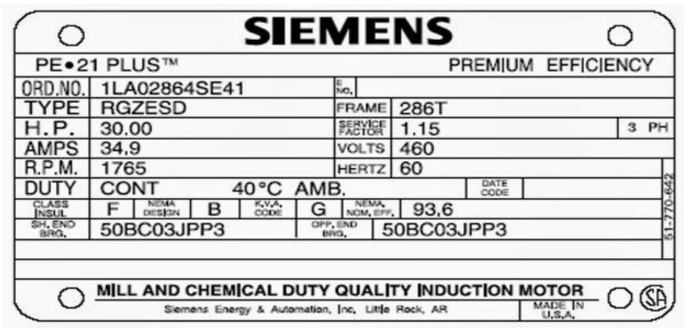
- ✓ Site & operating conditions
- ✓ Types of enclosure
- ✓ Reference to this standard i.e IS code number
- ✓ Types of duty
- ✓ Method of cooling
- ✓ Types of construction
- ✓ Frequency in HZ
- ✓ No of phase
- ✓ Mechanical output in KW
- ✓ Rated voltage & permitted variation
- ✓ Class of Insulation
- ✓ Speed in rpm ,at rated voltage
- ✓ Direction of rotation, looking from driving end
- ✓ Uni &bidirectional of rotation required
- ✓ The maximum temperature of air & water used for cooling
- ✓ Maximum permissible temperature rise

Name Plate details of Induction Motor

Rating plate giving the following details should be supplied with each motor

- ✓ Reference to standard ex ref IS:325
- ✓ Induction motor
- ✓ Name of the manufacture
- ✓ Manufacture's number &frame reference
- ✓ Types of duty
- ✓ Class of insulation
- ✓ No of phases
- ✓ Speed in rpm
- ✓ Rated o/p in KW
- ✓ Rated voltage & winding connections
- ✓ Current in amp rated o/p
- ✓ Rotor voltage & current
- ✓ Ambient temperature when above 40*c

Sample Name Plate



Types of Enclosures

- Open ventilated motor
- Ventilated motor
- Drip proof motor
- Water protected motor
- Totally enclosed motor
- Totally enclosed fan cooled motor
- Environment proof motor
- Weather proof motor
- Hose proof motor

Duty

The duty requirements shall explicitly be given by the purchasers as accurate as possible. The Duty requirement may be declared numerically or with the aid of time sequence graphs. The duty declaration for an electric motor is very important as the electric motors have the time rate of temperature rise.

Classes of Duty:

- S1 - continuous Duty: The motor is running long enough
- S2 - short time Duty: Time of operation is very low
- S3 - Intermittent periodic Duty: The motor operates for some time and then there is rest period
- S4 - intermittent periodic Duty with starting
- S5 - continuous duty with intermittent periodic loading
- S6 - continuous duty with starting & electric braking
- S7 - continuous duty with periodic speed change
-

Explosion Proof/Flame Proof

Flame-proof Enclosures are specially designed and built for installation in hazardous locations. The hazardous locations include those which have

- Highly inflammable gases/vapours or liquids.
- Combustible dust
- Combustible fibres floating in air
- Highly inflammable liquids like petrol, napthal, benzene, ether, acetone, etc. This explosive mixture of air and inflammable gas can explode in presence of electric arc or electric spark. The primary consideration in the design of flame-proof enclosures is to prevent such explosion. The flame-proof switchgear should be built such that
- The construction should be strong enough to with stand the high pressure from within, caused by explosion of gas which enters the enclosure.
- The design should be such that the flame or spark within the enclosure should be carried out of the enclosure
- The enclosure should be gas tight.

- The flame- proof motors and switchgear should be installed, as for as possible away from hazardous location. The motor and switch gear should be ‘flame-proof, or ‘ explosion -proof’ and should satisfy the codes and standards specified for such switchgear.

The Type **'n'** Motor is an improved version of a normal Induction motor with the following additional requirements.

- Non –sparking terminals
- Adequate clearances
- Welded end rings to prevent sparking while starting
- Adequate clearances between
  - Stator and rotor
  - Shaft and bearing
- Increased safety for terminal box
- Special enclosures
- Suitable axial and radial clearance between the fan and finned portions of the motor.

INSTALLATION OF INDUCTION MOTOR

The various stages in the installation of induction motor are as follows:

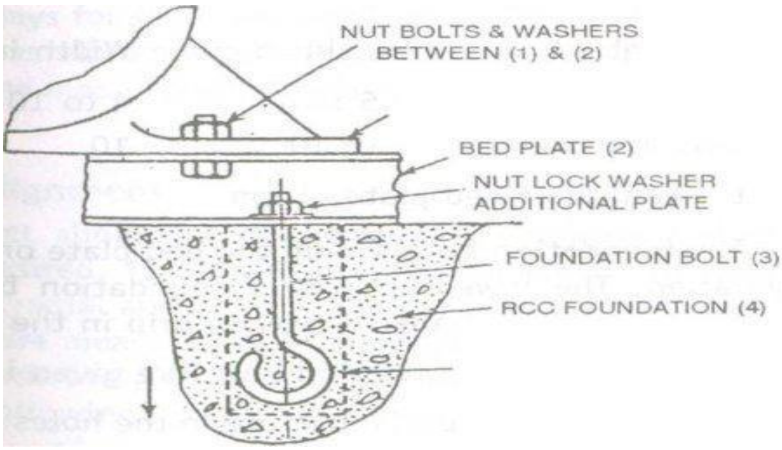
- Acceptance and proper storage at site
- Foundation and civil work
- Drawing of supply and control cables
- Preparing motor for installation
- Preparing driven machine and shaft alignment ready
- Installation of cooling systems for large machines
- Checking the insulation, starter, supply and control cable
- Drying out
- Checks and tests on the machine and related accessories.
- Trial run on load under observation
- Settings of protective relays
- Final commissioning and handing over to operating staff

Acceptance and proper storage at site

- The electrical machine received at site must be placed in permanent storage within 4 days of their arrival.
- The location in the store depends upon sequence of their handing over for installation.
- Before keeping in store the machine should pass on acceptance procedure intended to check it for missing or damaged parts so as to take a necessary measure for avoiding the violation of installation terms.
- The electrical machines must be stored in dry, clean and well ventilated store room protected against dam gases, coal dust etc.
- The exposed metal surface of machine shall be coated with anti-corrosive grease and wrapped in a moisture resistance material.

Civil work and Foundation

- All civil construction and foundation of the machine room should be fully completed before the installation of the machine.
- The machine room must have a enough space for the installation and dismounting of machines
- The cable conduit trenches should be cleaned and dried out
- The machine room should be equipped with overhead travelling cranes of sufficient load carrying capacity for handling assembled machines
- Depending upon the size of the motor appropriate foundation is to be designed
- The function of the foundation is to transmit the static and dynamic load of the running motor to the ground.
- The foundation should be strong to prevent displacement and vibration of a running machine.
- Three basic requirements of machine foundation are:
  1. Horizontal level 2. Rigidity 3. Freedom from vibrations
- It comprises the following essential features :
  1) Foundation made on cement-concrete 2)Bed-plate 3) Foundation bolts
- The machine is bolted to the Bed-plate. The Bed-plate is fixed on leveled foundation
- The foundation bolts are used to securing the bed plate to the concrete foundation.
- Rolled I-sections are placed in concrete on which the bed plate rest



1. Concrete Foundation

The machine with or without bed-plate should be securely bolted to solid, firm, level foundation. The design of foundation depends on the size and speed of the machine .The qualities of a good foundation are rigidity and freedom from vibration. The depth of concrete foundation should be enough. For this excavation should be enough depth.The depth should be depends on bearing capacity of soil.

Place the wooden farmers around the edges of the excavation at the floor level.Also Place the I-shaped rolled sections in horizontal formation to provide reinforcement to the concrete. The wooden farmers give the shape to the concrete plinth the cable ducts should be provided with suitable patterns.

2. Bed-plate

The bed plates are secured to the concrete by means of foundation bolts. The machine are bolted to the bed plate .the bed plates for large machines are fabricated thick sheet steel or rolled I-section, large beams. The bed plate has sufficient stiffeners and ribs provided in its structure. The holes drilled on the top and bottom faces of the bed plate according to the design The fabricated bed plate is generally of rectangular shape.

3) Foundation bolts

The foundation bolts fix –up the bed –plate onto the concrete foundation. The lower portion of the foundation bolts has an eye –shape or saw-tooth shape to provide grip in the foundation. The foundation bolt is inserted in the holes of the bed plate with the spring washer and plain packing washer between the nut and the plate flange. The foundation bolts should be located with the bed plate hole before lowering bed plate .Fill the space around the bolts with cement paste up to the surface level of foundation. Fill up the cavities by using suitable rod for ramming the grouting and then it allowed to set hard. After this the foundation nuts are tightened lightly, set carefully, aligned.

Vibrations

The excessive vibration in the rotating machine can be caused by one or many of the following

- Misalignment between motor and driven equipment
- Loose of foundation bolts.
- Badly worn bearings
- Mechanically unbalanced rotor
- Bent or cracked shaft
- Highly pulsating load
- Magnetic effects of high frequency

Periodic measurement of vibration provide useful preventive maintenance data about its mechanical condition. A sudden increase in the amplitude of vibration indicate severe unhealthy condition. A gradual increase in vibration may not be noticed until damage occurs

Measurement of vibration: Displacement indicators are useful for vibration measurements during preventive maintenance. The dial type vibration indicator consist of a dial mounted in a heavy case that rests on a coil spring. A plunger from the dial extends through the springs to make contact with the vibrating part. The vibrometer is used for vibration measurement. It has a stem and a dial, the stem is touched to the motor shaft in the direction of vibration.

Excessive vibration of is minimized by:

1. Checking the bolts, coupling, foundation and bearing
2. Run the motor for a vibration test without a driven machine. If the motor vibrates, it may be out of balance.

3. If the motor does not vibrate when running alone, the vibration may be in the driven equipment or caused by the shaft alinement
4. The shaft has to be aligned by using various method

Shimming work during Installation

Shims are the thin strips of steel sheet of size 0.2mm to 2mm.These are used to insert under the foot of the motor to raise or Align the shaft with the driven equipment. The exact *Alignment* of driven and driving axes is achieved by adding or removing the shims.

Shaft Alignment

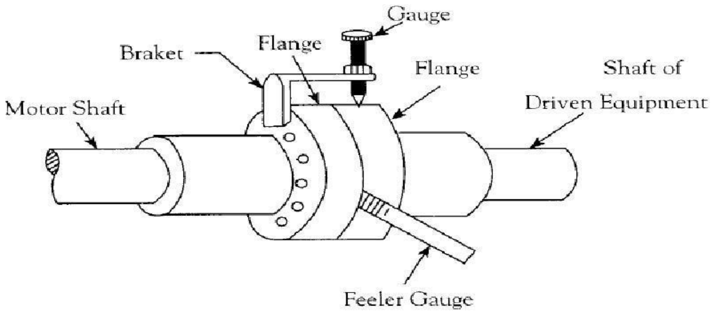
The perfect alignment of shaft of driving and driven machine is desired. The misalignment will affects the machine operation. The radial and axial clearance between the couplings of two shafts are measured after alignment. When the rotor is turned through approximately 0° C,90°C, 180°C, 270°C and 360°C shall not differ by the following values

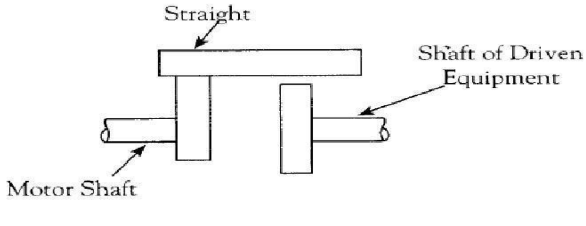
- 0.03mm for 300 mm diameter coupling
- 0.5mm for 500 mm diameter coupling

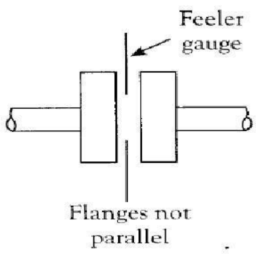
The shaft of driven and driving machine is aligned by different methods. There are 3 steps in the alignments

1. Axial positioning of the shafts
2. Paralleling the shaft axis
3. Centering of the shaft axis

The shaft of driving and driven machines is aligned on the bed plates in their final position by using Shims under the feet of the machine. The feeler gauge is used to know the difference by turning the rotor. The single point turn run over gauge is used to know the difference in heights of vertical surfaces of couplings. Figure a & b shows the shaft alignment procedure





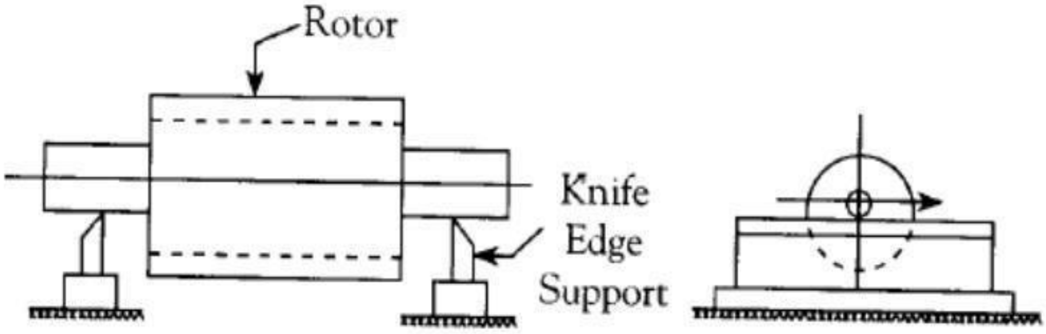


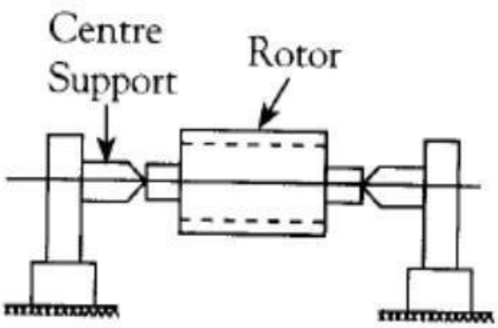
Balancing of Rotor

It is essential that the rotor is to be mechanically balanced for smooth running without developing vibrations. The balancing is obtained by adding or shifting weights fixed on the rotor for counter balancing or the material from the rotor is etched /drilled out from heavy side. The balancing can be achieved in two ways

a. Static balancing for low speed machines
b. Dynamic balancing for high speed machines

Static balancing: The rotor to be balanced is fixed on two knife edges of the balancing. The centers or the knife edges must be in perfect horizontal plane. The well balanced rotor will remain in standing in any position when turned about the axis in any direction, in any position and will not oscillate. When the rotor is unbalanced, the heavier side is always try to come down and the rotor cannot stay in any position. The balancing is achieved by addition of weight or removing material from heavier portion of the rotor.





Dynamic balancing: This is carried out by using special balancing machines. The rotor of themachine to be balanced is mounted on the axis of the balancing machine and driven at high speed. If the rotor is unbalanced, it will vibrate at higher speeds. Dynamic balancing machine has bearings supported by springs. To locate an unbalanced portion, one of the bearing is locked and the other is left free to vibrate. An indicating needle is gently touched to the rotor and leaves a mark at uneven portion. The same is repeated by rotating the rotor in reverse direction. The heavy portion lies between the two marks which is removed or counter weight is placed.

Selection of bearings in an Induction motor

Factors to be considered in selection of bearings are

1. Speed
2. Temperature limits
3. Load capacity
4. Space and weight limitation
5. Noise and vibration
6. Corrosive resistance
7. Infiltration of duct, dust, etc
8. Cost

Drying of Windings

The Insulation of Rotating machine is **Hygroscopic (absorbs moisture)** in nature. The Moisture reduces the insulation resistance. It is essential to remove the moisture before commissioning of the machine. The high resistance of Insulation gives the degree of dryness of the insulation.

The different methods of Drying out are:

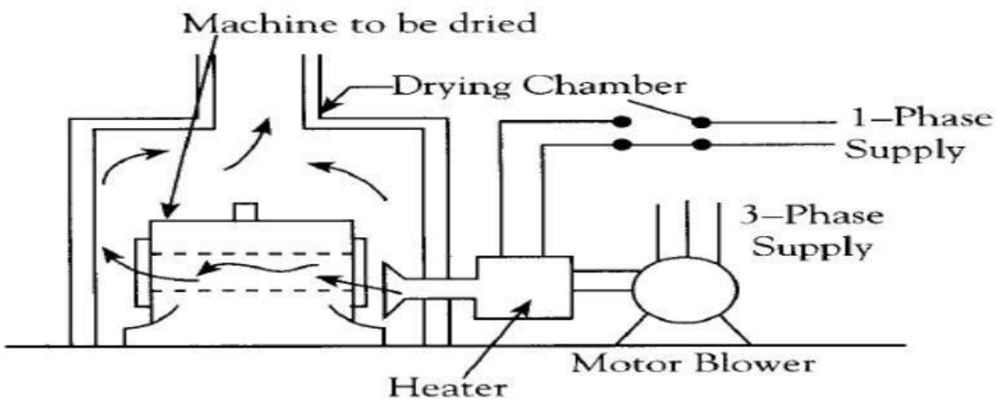
1. Drying out of induction motor by drying chamber and resistor heater

2.Drying out by radiating lamps

3. Drying out by circulating short circuit current

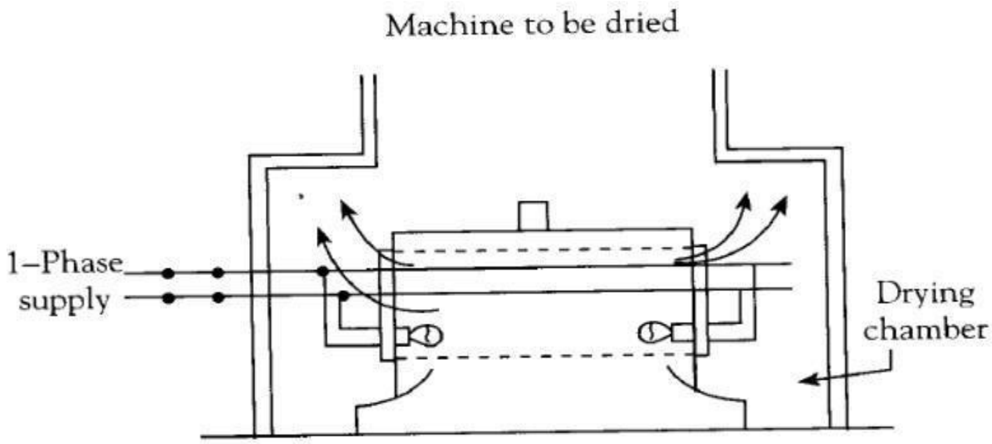
1. Drying out of induction motor by drying chamber and resistor heater

Dry the induction motor using drying chamber. The machine to be dried is housed in a drying chamber. The volume of drying chamber should be nearly four times the volume of the induction motor. The heated air by using resistor heaters is circulated by means of fans and air circulation system. The air temperature is measured using thermometers. The moisture 15 expelled from the machine is let out of the drying chamber through air outlet. For large machines heater blowers of 25 KW are suitable. The chamber should be thermally insulated to avoid heat loss. The machine body is covered with canvas to prevent heat loss. Temperature of the air shall be controlled by turning off the heater from time to time. The temperature is gradually raised i.e. not faster than lode per hour. Higher rate of heating may result in damage due to differential expansion of metals and insulation. It is required to preferably maintain steady temperature throughout the heating. the fig is as shown



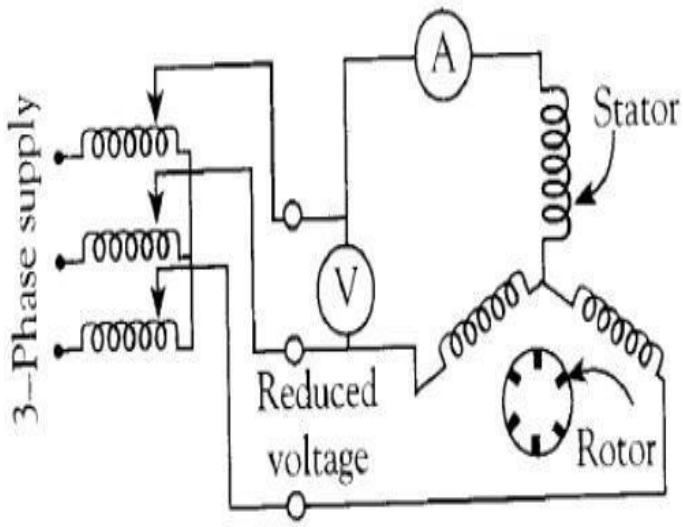
2.Drying out by radiating lamps

This is the convenient and simple method used for medium and small motors. The infrared lamps are located in the chamber facing the motor windings with rotor removed. This method is applicable to dismantled motor for drying the stator winding and rotor Winding separately. The fig is as shown



3. Drying out by circulating short circuit current

This is convenient method for drying out slip-ring induction motors. The machine is connected to low voltage source. The input voltage, current, power, the temperature of winding, temperature of body, temperature of hot air is periodically recorded. The end covers of the machine are removed. The machine body is covered with tarpaulin. The increase and decrease of the temperature should be gradual. The rotor is blocked. The current through the stator winding not to exceed 50% of the rated current



Tests on Induction Motor

- **Type Test**:These tests are conducted on the machine to confirm the design
- **Routine Test**: These tests are conducted on each motor to confirm proper manufacture and to ensure trouble free performance at a site
- **Commissioning Test**: These tests are conducted after installation before final commissioning to ensure the machine is free from defects
- **Special Test**: These tests are conducted to analyze the performance or for special investigation
- **Development Test**: These tests are conducted to analyze the effect of various design parameters and stresses
- **Reliability Test**: These tests are conducted to access the reliability of motor

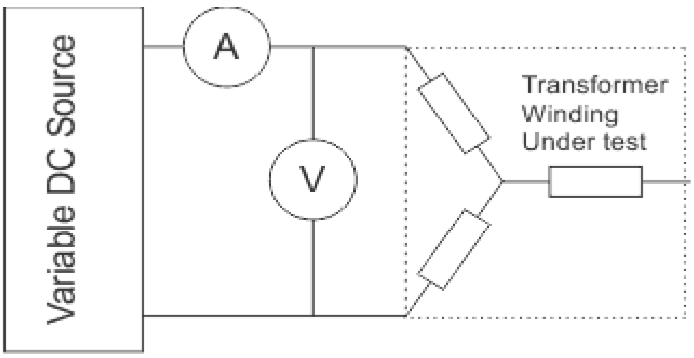
1.Insulation resistance test

The insulation resistance is done by using megger like transformer. (refer unit one and two notes page 15-16) . **If megger is not available we will go for volt-ammeter method.**

2.Measurement of winding resistance

The following are the methods to measure the winding resistance of the motor

1.**The Drop of Potential or Voltmeter- Ammeter Method:** In this simple method DC voltage and current are measured by using volt meter connect in parallel and by ammeter connected in series with the winding, when the values became steady.



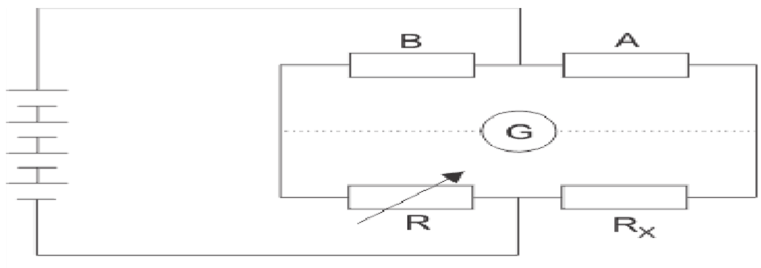
Current Voltage Method of Star Winding Resistance Measurement

Since the resistance between two terminals is usually of 2 phases are in series, the resistance perphase

Rdc = V/2I

The ac resistance is 1.5 times dc resistance because of proximity effect skin effect of ac current.
Rac = 1.5Rdc = 1.5V/2I = 1.5Rdc

2.**Kelivin- Thompson double bridge Method:**Resistance less than 1 ohm shall be measured by Kelvin double bridge. The winding is connected at unknow resistance terminal of the bridge. And the resistance is determined by varying the variable resister until the galvanometer shows zero deflection. The variation of resistance between phases to the extended of 5 % may be permitted.



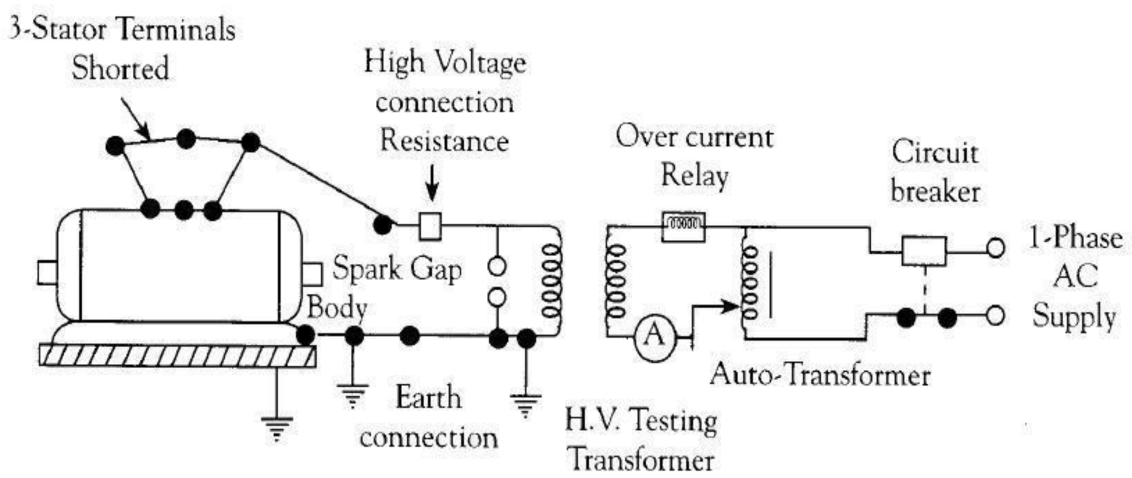
Whetstone Bridge Method of Resistance Measurement

3.High Voltage Test

The test is conducted to check the capability of insulation of windings. The test voltageis of power frequency and sine wave. The value of maximum test voltage at site test is given by the expression:

Vac(site)= 75%[2*rated voltage+1000] volts
Vac= 1.5 rated line to line voltage

The test set up is shown in fig

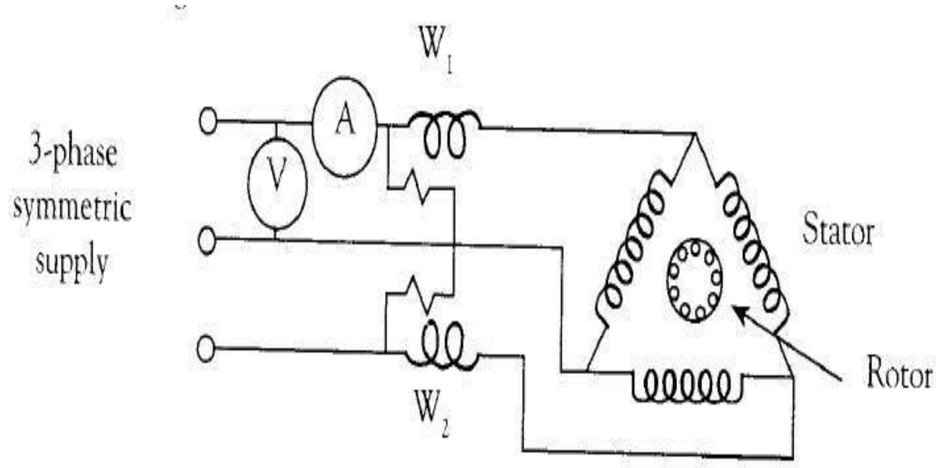


The three terminals of the motor are connected together and to the high voltage terminal of test supply. The body is earthed and is connected to the earth terminal of test supply. In this test, the test voltage is raised quickly to the maximum test voltage and applied for one minute and reduced slowly to zero.

If the breakdown occurs, the test supply is automatically tripped. The test is conducted on go/not go basis. While conducting the test, reference to the relevant standards and manufactures instruction is to be made.

4. No load Test

This test is conducted to determine the no-load current, core loss and friction and wind age losses. The motor is run on no-load at rated voltage and frequency until the input power is constant. The readings of voltage, frequency, current and power are noted. This test shall be preferably conducted immediately after the temperature rise test. The input power is the sum of friction and wind age losses, core loss and no-load primary I^2R loss. The friction and wind age losses and core losses may be separated if required. The test setup is as shown.



5. Locked rotor test

This test is a carried out by holding the rotor stationary by clamps. The stator is supplied with low voltage of normal frequency. The applied voltage is gradually increased till the rated current is circulated in the stator windings. The readings of voltage, current and power are noted. The leakage impedance reduces with higher current as a result of saturation. Locked rotor test gives copper loss for particular stator current. Iron losses are ignored.

6. Load Test

The test with the load are conducted for the determination of performance such as efficiency, power factor, speed and temperature raise. For all the test with load, the machine shall be properly aligned and secured fastened.

The motor may be loaded by AC or DC coupled generator either directly or by belt. The output of generator is measured and its effeminacy at various loads must be known to calculate the output of the motor under test. The input to the motor is measured by using Watt meters. When belt drive is used, the power loss in the belt should be considered. When a pony break is used, for large machines, then break gets extremely hot, so the observation must be taken very quickly. This method is suitable for small machines testing in the laboratory.

7. Temperature rise test:

The aim of this test is to find out the temperature rise on different parts of the motor while running at rated conditions. During temperature rise test, the motor should be shielded from currents of air entering from adjacent pulleys and other machines. A small current of air may cause great discrepancy in results obtained. The duration of temperature rise test depends on the type of rating of the motor. For motors of continuous rating, the test should be continued till the thermal equilibrium is reached. For motors of short time rating the duration of test corresponds to the declared short time rating, the test should be continued till the thermal equilibrium is reached. Methods of measuring temp The following methods are approved for determining the temperature of windings and other parts of motor.

1) Embedded temperature detector method:

Embedded temperature detectors are resistance thermo-meters or thermocouples built in the machine at points which are inaccessible when the m chine is assembled. This method is generally employed for the slot portion of stator windings. At least six detectors to be built in a machine suitably distributed around the circumference.

2) Resistance Method:

This method is generally used for stator windings. Here temperature is determined by the increase in the resistance of the windings.
The temperature is determined by the formula

T2 – Ta = ~~x(235~~+T1)+T1-Ta

Where Ta – Temperature of cooling air at the end of the test
T2 - Temperature of winding at the end of the test
T1 - Temperature of winding at the time of initial resistance measurement
R2 – Resistance of the winding at the end of the test
R1 – Initial resistance of the winding

3) Thermometer method:

This method is used when temperature measurement by embedded detector and resistance method is not possible In this method, the temperature is determined by thermometers placed at the accessible surface of the rotor.

8. Determination of Slip of Induction Motor

a) Speed measurement method:
In this method the speed of the motor is measured by tachometer. The slip is calculated by knowing the synchronous speed taking exact value of frequency of the applied voltage

$$\% \text{ of slip} = \frac{Ns - N}{Ns} \times 100$$

b) Stroboscopic Method:
In this method, the disc is painted with alternate black and white strips and it is attached to motor shaft.The disc is illuminated by neon lamp from stroboscope.The complete apparent revolution of disc correspondence to slip per pair of poles. Slip is calculated using

$$\text{Slip} = \frac{Apprant\ rpm}{60} \text{ x pairs of pole}$$

c) Slip Coil Method:
In this method, the insulated wire is passed axially over the motor and it's 2 ends are connected to centre of galvanometer. When the motor is running the galvanometer pointer will oscillate. The number of oscillations shall be counted in one direction for a time 'T' seconds. Slip is calculated by

$$S = \frac{n\ X\ 100}{T\ X\ f}$$

where n is number of oscillation

d) Magnetic Needle Method:
The Magnetic needle is placed on the body of the motor horizontally. When the motor is running the needle will oscillate. The number of oscillations shall be counted in one direction for a time 'T' seconds. Slip is calculated by

$$S = \frac{n\ X\ 100}{T\ X\ f}$$

where n is number of oscillation

e) Rotor Frequency oscillation measurement:
The moving coil ammeter with centre zero is inserted in the rotor circuit to know the rotor frequency. The frequency can be found by counting the oscillation of the pointer
Slip is calculated by

$$\%\text{ of slip} = \frac{Rotor\ frequency}{Stator\ frequency} \text{ x } 100$$

9. Noise in Motors

The noise of a rotating machine is generated by a cooling air from its fan as it passed through or over the machine. Some noise reduction is possible by substituting unidirectional trailing bladed fans by the normal radial blades Further reduction is achieved by inlet and outlet silencers or the adoption of closed ventilation circuit of cooling air.
The noise is also caused by magnetic effects and dependent on the stator and rotor slots. It can occur in machine with fractional number of open slots per pole, producing a relatively

a large vibration of air-gap flux density. This may produce a penetrating note at approximately slot frequency (e.g. 0.5 – 1.5kHz). The amplitude of stator permeance variation may be the cause, but the amplitude also depends on higher order rotor m.m.f. space harmonics. The frequency of the noise is twice the product of the supply frequency with that integer nearest to the number of slot per pole.

Noise Reduction: Noise is caused by 1. Magnetostriction, 2. Aerodynamics, 3. Bearing noise of rotating shaft

Speed and Power effect:

- Totally enclosed machine give least sound. Open ventilated machine give maximum sound.
- Ventilation noise predominates in 2-pole machines
- Magnetic noise is predominating in machines with more number of poles
- When bearing, noise become audible, the other two become less significant

Methods to reduce the noise for DC Machine

- Reduced magnetic loading.
- Increase number of armature slots – Skewing of slots.
- Continuously graded main pole gap (more at pole end and least at pole centre)
- Increase in air gap – Brace commutating poles against main poles
- 12 pulse thyristor for speed control and not 6-pluse
- Semi- enclosed slots or closed slots for compensating windings

INSTALLATION OF LARGE ROTATION MACHINE RECEVIED IN DISMANTLED CONDITION

Various steps in installation of a large rotation machine received in dismantled condition are:

- Installation of bed plate and the leveling of bed plate
- Installation of the bearing pedestals and leveling of the bearing pedestals
- Checks on stator and rotor
- Assembly of the rotor onto the shaft
- Installation of the stator
- Installing the rotor in the stator
- Checking of the air gap between stator and rotor
- Installation of the the driven and drive machine in the similar fashion.
- Preparation of shaft couplings
- Mounting of shaft couplings on shaft
- Preparation of shafts and alignment of shafts.
- Installation of cooling systems
- Drying out
- Testing
- Commissioning

Each of the above activities should be carried out by technically skilled staff. The instruction manual supplied by the manufacturer should be referred in practice. Shaft alignment should be, perfect to get trouble free mechanical performance of the generator with the driven equipment. The rating plate is of definite dimensions as per IS Code. The ratings are etched or engraved and is fixed to the machine in a clearly visible position

Various Abnormal conditions & the Protections provided

The abnormal conditions in induction motor can be classified into:

1. Prolonged overloading: It caused due to the mechanical loading, short time cyclic overloading. this results in temperature rise of the winding and deterioration of the of insulation resulting in winding fault.

Protection: The motor should be provided with the overload protection, thermal overload relays and overload release.

2. Single phasing: one of the supply lines gets disconnected due to the rupturing of the fuse or open circuit in one of three supply connections. In such case motor continues to run with the single supply. If the motor is loaded to its full rate load, it draws excessive current on single phasing. The windings get overheated and damage the insulation of the winding.

The single phasing also causes the unbalanced load resulting in excessive heating of the rotor due to negative sequence component.

Protection: the motor should be protected with the negative phase sequence relay, thermal overload relays and static single phasing relays.

3. Internal faults in the motor: It is mainly due to the overloading, abnormal supply conditions which results in failure of insulation resistance and temperature rise

Protection: the motor should be protected with the differential protection, over current relay the motor should be protected with the s,HRC fuses

4. Stalling: If the motor dos not start due to the excessive load, it draws heavy current . It should be immediately disconnected from the supply.

Protection: the motor should be protected with the thermal relays and instantaneous O.C relays.

5. Excessive harmonics in supply voltage:

Protection: the motor should be protected with the AC harmonic filters connectecd near motor terminals

6. Switching surges:

Protection: the motor should be protected with the RC surge modifiers, Zno arresters near motor terminals

Factors to be considered in selecting motors for Industrial drives

Important factors to be considered in selecting motors for industrial drives are:

1. **Relationship between size, weight,power,torque and speed of electric motor**
   The torque and speed determine the size of an electric motor. Machine of equal power may deliver different torque at different speeds and thus be too different sizes. High speed motors are smaller than lower speed machines of the power.
2. **Standardization and Type of motor, specifications.**
   Electric machines have different operating characteristics. Machine is designed to get particular characteristics and design feature. For the sake of greater uniformity, the size, power, speed voltages, power factors etc of electrical machines are standardized.
3. **Type of frame**
   Different frame types of rotary electrical machines are categorized in DIN42950. The various frame types are denoted by letter/number codes. Three criteria used to differentiated types are 1) The bearing type 2) The form of stator 3) The position of shaft.
4. **Types of Degree of protection**
   The electrical plants are exposed to different operating condition. The degree of protection against these external influences is indicated by the type of protection
5. **Operating Duty and ratings**
6. **Cooling**
   The operating temperature of a machine depends on cooling as well as the load. If large quantity of heat is removed by cooling, the machine can be loaded more. Cooling systems according to their type and functions.
7. **Insulation Class**
   The machine must be insulated in accordance with its voltage rating, power rating and duty cycle. The type of insulation used depends on the operating temperature.
8. **Transmission of shaft power and interface with drive**
   The power output of an electric motor must be transmitted to the machinery it is driving. The two machines can be directly coupled. In this case their shafts speed will be identical torque and power are transmitted directly
9. **Speed torque characteristics**
10. **Braking requirements**
11. **Maintenance requirements**.

Preventive maintenance schedule of Induction motor

The objective of the maintenance is to reduce the number of failures. During normal working, some parts wear out and calls for replacement and minor defects are to be rectified to avoid failure. The breakdown of motor results in loss / damage /outage /inconvenience. The down time of the machine must be kept as minimum as possible. Hence preventive maintenance is justified

The preventive maintenance needs

- Proper records
- Skilled labor and staff
- Facilities for repairs

- Storage of spares

The repeated inspection leads to wastage of time and money. The neglected/hardly Inspection leads to failure.
The frequency of inspection must depend on

- Importance of the machine
- Duty cycle
- Age
- Overloads, service conditions
- The maintenance schedule is always recommended by the manufacture

EVERY WEEK

1. Examine commutator and brushes, ac and dc.
2. Check oil level in bearings.
3. See that oil rings turn with shaft.
4. See that exposed shaft is freeof oil and grease from bearings.
5. Examine the starter switch, fuses, and other controls; tighten loose connections.
6. See that the motor is brought up to speed in normal time.

EVERY SIX MONTHS

1. Clean motor thoroughly, blowing out dirt from windings, and wipe commutator and brushes.
2. Inspect commutator clamping ring.
3. Check brushes and replace any that are more than half worn.
4. Examine brush holders, and clean them if dirty. Make certain that brushes ride free in the holders.
5. Check brush pressure.
6. Check brush position.
7. Drain, wash out, and replace oil in sleeve bearings.
8. Check grease in ball or roller bearings.
9. Check operating speed or speeds.
10. See that end play of shaft is normal.
11. Inspect and tighten connections on motor and control.
12. Check current input and compare it with normal.
13. Examine drive, critically, for smooth running, absence of vibration, and worn gears, chains, or belts.
14. Check motor foot bolts, end-shield bolts, pulley, coupling, gear and journal set screws, and keys.
15. See that all covers, and belt and gear guards are in place, in good order, and securely fastened.

ONCE A YEAR

1. Clean out and renew grease in ball or roller bearing housings.
2. Test insulation by megohmmeter.
3. Check air gap.
4. Clean out magnetic dirt that may be clinging to poles.
5. Check clearance between shaft and journal boxes of sleeve bearing motors to pre vent operation with worn bearings.
6. Clean out undercut slots in commutator. Check the commutator for smoothness.
7. Examine connections of commutator and armature coils.
8. Inspect armature bands

Module-4 laying of Underground cables

Syllabus:

Laying of Underground Cables: *Inspection, Storage, Transportation and Handling of Cables, Cable Handing Equipment, Cable Laying Depths and Clearances from other Services such as Water Sewerage, Gas, Heating and other Mains, Series of Power and Telecommunication Cables and Coordination with these Services, Excavation of Trenches, Cable Jointing and Terminations Testing and Commissioning. Location of Faults using Megger, Effect of Open or Loose Neutral Connections, Provision of Proper Fuses on Service Lines and Their Effect on System, Causes and Dim, and Flickering Lights.*

Introduction:

- *An* underground cable *essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.*
- Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements.
- In general, a cable must fulfill the following necessary requirements:

  (i) The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. Stranding is done so that conductor may become flexible and carry more current.

  (ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

  (iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

  (iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

  (v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

- The reliability of underground cable network depends to a considerable extent upon the proper laying and attachment of fittings i.e., cable end boxes, joints, branch connectors etc.
- There are three main methods of laying underground cables viz.,
  1. direct laying,
  2. draw-in system
  3. Solid system.

1. Direct laying:

- This method of laying underground cables is simple and cheap and is much favored in modern practice.
- In this method, a trench of about 1•5 meters deep and 45 cm wide is dug.
- The trench is covered with a layer of fine sand (of about 10 cm thickness) and the cable is laid over this sand bed.

- The sand prevents the entry of moisture from the ground and thus protects the cable from decay.
- After the cable has been laid in the trench, it is covered with another layer of sand of about 10 cm thickness..

Advantages

1. It is a simple and less costly method.
2. It gives the best conditions for dissipating the heat generated in the cables.
3. It is a clean and safe method as the cable is invisible and free from external disturbances.

Disadvantages

1. The extension of load is possible only by a completely new excavation which may cost as much as the original work.
2. The alterations in the cable network cannot be made easily.
3. The maintenance cost is very high.
4. Localization of fault is difficult.
5. It cannot be used in congested areas where excavation is expensive and inconvenient.

This method of laying cables is used in open areas where excavation can be done conveniently and at low cost.

2. Draw-in system:

- In this method, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route.
- Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires.
- Care must be taken that where the duct line changes direction; depths, dips and offsets be made with a very long radius or it will be difficult to pull a large cable between the manholes. The distance between the manholes should not be too long so as to simplify the pulling in of the cables.
- The cables to be laid in this way need not be armored but must be provided with serving of hessian and jute in order to protect them when being pulled into the ducts.

Advantages

(i) Repairs, alterations or additions to the cable network can be made without opening the ground.

(ii) As the cables are not armored, therefore, joints become simpler and maintenance cost is reduced considerably.

(iii) There are very less chances of fault occurrence due to strong mechanical protection pro-vided by the system.

Disadvantages

(i) The initial cost is very high.
(ii) The current carrying capacity of the cables is reduced due to the close grouping of cables and unfavorable conditions for dissipation of heat.

3. Solid system:

- In this method of laying, the cable is laid in open pipes or troughs dug out in earth along the cable route.
- The toughing is of cast iron, stoneware, asphalt or treated wood.
- After the cable is laid in position, the troughing is filled with a bituminous or asphaltic compound and covered over.
- Cables laid in this manner are usually plain lead covered because troughing affords good mechanical protection.

Disadvantages

(i) It is more expensive than direct laid system.
(ii) It requires skilled labor and favorable weather conditions.
(iii) Due to poor heat dissipation facilities, the current carrying capacity of the cable is reduced.

Transport and Handling of Cables:

- It is possible to store cable drums outdoors.
- When storage has occurred in heated rooms, a minimum 24-hour acclimatization period must be observed before installation
- For outdoor storage the ground must be even and clean.
- Stones or bumps in the ground should be removed or smoothed out.
- Damage to the wound goods/cable should be avoided at all costs.
- Cables should be secured against accidental rolling away.
- Under no circumstances should the drum flange of neighboring cables touch any wound goods.
- Cable drums should always be stored and transported standing on both flanges.
- They should not be pushed along the ground standing on the flanges.
- It is possible that the strength of the cable drum would then no longer be guaranteed.
- Observe the rolling direction.
- The arrow printed on the drum flange indicates the rolling direction so that the wound goods do not become loose.
- Always uncoil the cable at a tangent, never over the flange, since the torsion thus resulting would damage the cable and laying would not be possible.

Underground Cable Testing

- The cables are tested for the following faults:
  1. Short Circuiting
  2. Discontinuity

3. Earth fault

- Murray Loop Test For finding out the exact position of fault, cables are to be repaired without digging the whole cable route trench.
- For this purpose, the Murray loop test which is based upon the principle of wheat-stone bridge, and bridge Megger is used.
- The Murray loop test is used for the location of faults on lines of low resistance, such as power cables and telephone cables.

Cable fault location:

- Cable fault location is required anywhere where the fault cannot be seen.
- This is a multi-step process that must be performed as safely and as quickly as possible to prevent customers going without power.

Step 1 –

- Cable isolation and safety procedures: A cable fault is nearly always a permanent fault.
- This means that the cable in question will be in a condition where the protection devices at one or both ends of the cable will have tripped, leaving the cable isolated but NOT earthed (grounded).
- The first task is for the authorized person on the site to make the cable safe by isolating and then earthing (grounding) one or both ends.
- Only after the appropriate procedures have been carried out can any testing personnel be allowed to approach the cable and prepare for testing.

Step 2 –

- Cable identification: Where multiple cables exist, cable identification testing will identify the correct cable to work on.
- Clear identification before a cable is cut is intrinsic to safe maintenance work.
- Any mistakes here can be fatal and may cause much longer outages for the connected customers.

Step 3 –

- Cable tracing: When an underground cable is first laid, it rarely runs in a straight line, but rather meanders in depth and direction.
- Cable tracing is done to determine that the route of the cable is following the expected path.

Step 4 –

- Fault identification: The first major procedure is to determine the phase on which the fault has occurred and if it is of low or high resistance.
- This test determines the correct technique, and therefore equipment, needed to diagnose the fault.

- Typically, if the fault is found to be below 100 Ohms, a low voltage pulse (eg: 40 V) from a TDR (time domain reflect meter) can be used.
- If the fault is a higher resistance (> 100 Ohm), a low voltage pulse will likely not see it. For these types of faults, an impulse generator (shock discharge) or bridge, will be necessary.

Step 5 –

- Fault prelocation: A reliable and precise pre-location method is necessary to locate a cable fault quickly and efficiently.
- Good pre-location can determine the fault position to within a few percent of the cable length and will reduce pinpointing time to a few minutes.

Remember:

a) If it is a low resistance fault, pre-location is likely to be the only means necessary for location.

b) For high resistance faults, ARM (arc reflection) or ICE (impulse current) techniques on an SWG (surge wave generator) should be used. Alternatively, the decay method with an HV DC tester (bridge) can be used for pre-location.

Step 6 –

- Pinpointing: The aforementioned test methods will get the operator within 5% distance of the fault.
- Acoustic pinpointing techniques must be employed at this stage in order to narrow the margin of error to 0.1%.
- In most cases, shock discharge generators are used for pinpointing in conjunction with acoustic methods.
- The discharge creates a loud noise, which is pinpointed precisely using an acoustic pinpointing device.
- This device evaluates the time difference between the acoustic signal (speed of sound) and the electromagnetic (nearly the speed of light) impulse of the shock discharge.
- When the shortest time difference is indicated, the exact fault location is revealed.

Step 7 –

- Re-energization of the cable: Once all testing and repairs are completed, the Safety/Testing documentation is cancelled and the cable is handed back to the appropriate operators so they can reinstate it and re-energies the loads on the newly repaired cable.

Module 5

SWITCHGEAR AND PROTECTIVE DEVICES

Syllabus:

Switchgear and Protective Devices: Standards, Types, Specification, Installation, Commissioning Tests, Maintenance Schedule, Type and Routine Tests.
Domestic Installation: Introduction, Testing of Electrical Installation of a Building, Testing of Insulation Resistance to Earth, Testing of Insulation and Resistance between Conductors Continuity or Open Circuit Test, Short Circuit Test, Testing of Earthing Continuity, Location of Faults, IE Rules for Domestic Installation

Introduction:

- The term switchgear includes wide range of equipment used for switching, interruption, measurement, control, indication etc.
- The necessary units are arranged in a sequence.
- The components are enclosed in sheet metal enclosure or cast iron enclosures.
- Hence the name metal clad switchgear or metal enclosed switchgear.
- The components of indoor switchgear include
  (1) switching and interruption components viz. switches, switch fuse combinations, circuit breakers, HRC fuses, isolators and earthling switches
  (2) measuring components viz. CT, PT, meters etc.
- Faults occur on power system due to several reasons and no part of the power system is left unprotected.
- The unhealthy part is isolated immediately upon the occurrence of the fault by protective devices like relays and circuit breakers.
- The functions of different devices used in protection are mentioned below.

1. Relay: It is used to sense the change in the operating quantity when it exceeds certain preset value.

2. Fuse: It is a simple protective device which breaks the circuit when the current exceeds the rated value. After the clearance of the abnormality, the fuse element is to be replaced to resume normal operation.

3. Circuit breaker: It is used to break or make the circuit upon receiving the signal from the associated relay under abnormal and normal conditions respectively. Based on the location the making may be manual, semi-auto enclosure or auto closure.

4.Isolators: Isolators are used to isolate during off-load to ensure that the circuit breaker is de energized for scheduled or unscheduled maintenance activity and is provided with interlocking provision.

5. Load break switch: This is used to disconnect the load and overload currents and not short circuit current.

Circuit breaker

- A circuit breaker is capable of breaking & making the circuits under abnormal and normal conditions respectively.
- The parts of circuit breaker include
  a) Poles with interrupter, porcelain, arc quenching medium
  b) Operating mechanism
  c) Support structure
  d) Control cabinet
- Upon the occurrence of the fault, the current in the secondary side of CT is more than the current under normal condition and relay connected to the CT actuates and thereby closes its contacts.
- Battery supplies the" current to energize the trip coil of the circuit breaker to open the contacts.
- After resuming the normal condition, the battery circuit is open & circuit breaker contacts are closed.

Types of circuit breaker

- According to the method of control of the closing operation, circuit breakers are classified as (IS 1011 (Part-II)-1982).

  1. Dependent manual closing
  2. Independent manual closing
  3. Dependent power closing
  4. Stored energy closing

- According to the interrupting medium, circuit breakers are divided into
  1. Oil circuit breakers
  2. Bulk oil circuit breaker - up to 33 KV (now obsolete).
  3. Minimum oil circuit breaker - up to 36 KV, 1500 MVA, 132 KV, 3500 MVA
  4. Air circuit breaker - LV circuit breaker up to 1000 V
  5. Air blast circuit breaker - 132 KV, 220 KV, 400 KV, 760 KV
  6. Sulfur hexafluoride circuit breaker - 132 KV, 220 KV, 400 KV, 760 KV
  7. Vacuum circuit breaker - 11 KV, 33 KV
- The type of equipment is also further characterized by
  - Number of poles
  - Kind of current
  - Method of closing
  - Method of opening

Specifications of high voltage circuit breaker

Rated voltages: A circuit breaker is defined by the following rated voltages

Rated operational voltage , Rated insulation voltage

Rated current: The circuit breaker is defined by the following currents rated thermal current **rated uninterrupted current**

Rated frequency: The rated frequency of the equipment is so chosen as to suit the service frequency Rated short circuit breaking and making capacities:

- The rated short circuit breaking current is the highest value of short circuit current which the circuit breaker is capable of breaking under specified conditions of recovery voltage and power frequency recovery voltage.
- The rated making current must be at least 2.5 times the rms value of ac component of rated breaking current.

Rated short time withstand current: It is the rams value of the current that the circuit breaker can carry in a fully closed position during specified time.

- **Short circuit performance category:** The rated short circuit performance category of the equipment states the rated operating sequence and the condition of the circuit breaker after performing this sequence at the rated short circuit making and breaking capacities.
- For the same circuit breaker the value of the rated short circuit breaking and corresponding making capacities may be different for different short circuit performance categories.
- The following characteristics should also be considered while selecting the circuit breakers.

  a) **For control circuits:** Rated control supply voltage and type (ac or dc) of current.

  b) **For air supply system:** Rated pressure and its limits and volumes of air at atmospheric pressure required for each closing and opening operation.

  C) **For shunt release and under voltage release:** Rated voltage & kind of current.

  d) **For over current release:** Rated thermal current, kind of current and range of settings.

  e) **For auxiliary switches:** Rated voltage & current The circuit breakers intended for circuit operating below 1000 volts ac or 1200 volts dc are covered under the group low voltage circuit breaker.

Tests on circuit breakers

Type tests: These tests are conducted on the first circuit breaker manufactured to prove the capabilities and to confirm the specified characteristics of the circuit breaker of that design in a specially built testing laboratory.

Routine test: Routine tests are performed on each and every circuit breaker as per the recommendation of the standards to verify the performance.

Commissioning tests: These tests are conducted on the circuit breaker after installation at site to verify the readiness and proper functioning.

Development tests: These tests are carried on components, sub-assemblies and complete circuit breakers during and after the development of the circuit breaker. The designers and research scientists verify the effect of various parameters.

Types of test:

1. No Load mechanical operation test: This test is to verify speed of travel, operating time and closing time and is carried out at 85% and 110% rated voltage of shunt trip release.

2. Mechanical performance tests (endurance): It is to check the mechanical ability of opening and closing of the contacts by carrying out 1000 close and open operations or more.

3. Temperature rise test: Steady temperature of conducting part and insulating parts measured for rated continuous alternating current.

4. Dielectric tests:

- 1.2/50 IPSec Lightning impulse withstand
- One minute power frequency voltage withstand
- 250/2500 Ills switching impulse withstand

5. Short time current test: Rated short circuit current is passed through closed breaker for less or 3 secs.

6. Short circuit breaking and making tests: This test is conducted at 10%, 30%, 60% and 100% rated short circuit braking current with specified operating sequence and specified TRV (transient recovery voltage).

7. Line charging current breaking test: This test is conducted for circuit breakers 72.5 KV and above.

8. Cable charging current breaking test: This test is applicable to circuit breakers intended for long cable network.

9. Single capacitor bank breaking test: This test is applicable for circuit breakers used for capacitor switching.

10. Small inductive current breaking test: This test is to be conducted on circuit breakers with reactors, transformers, motors etc.

Commissioning tests:

- After the installation, the circuit breakers and protective gear are subjected to certain tests at site to ensure proper assembly and readiness of the circuit breaker.
- The commissioning tests include:
- **Mechanical operation tests**
- Measurement of travel, simultaneous closure of contacts Measurement of insulation resistance between terminals of pole Pre commissioning checks
- Checking close and open operation by energizing the manual operating signal
- Checking close and open operation by energizing relays etc
- The insulation resistance is measured using Megger. It consists of a built in hand driven dc generator.
- The two terminals of Megger are connected across the insulation i.e. one to the conductor and other to the earthed body.

- Then the dc generator is driven & corresponding resistance indicated by the Megger is recorded.
- For the switchgear 1000V or 2500V mugger is preferred.
- Insulation resistance of the control circuit, trip circuit, relay circuit etc. is measured using 500V mugger.

High voltage test at site

- High voltage test as per the relevant IS code is conducted after the erection of the circuit breaker.
- By conducting this test the defect in the insulation can be checked.
- The test voltage is generally applied for duration of one minute.
- The circuit breaker is isolated suitably during the test.
- The test voltage is applied between the to be 'tested part' and earthed parts as follows.

1) With breaker closed:

a) Tested part: R – phase earthed part: Y - phase, B - phase, frame of the circuit breaker

b) Similarly for the phase Y and B

2) With breaker open: This test is conducted on breaker contacts by shorting R, Y, B phases on bus bar side~ Voltage is applied from other side consecutively to each phase.

The purpose of high voltage test on circuit breaker is as follows:

- To define the insulation characteristics
- To standardize the insulation levels
- To specify the markings on the rating plates indicating insulation levels
- To confirm that, there are no cracks in porcelain, no dust and moisture is present in the circuit breaker

High voltage tests on circuit breaker include the following.

- Impulse voltage dry withstand test
- One minute power frequency voltage dry withstand test.
- One minute power frequency voltage wet withstand test Power frequency voltage withstand tests are conducted by applying specified high voltage alternating quantity for one minute.
- High voltage testing transformer is an important component of the high voltage testing of circuit breakers.
- Sphere gaps are used for the measurement of high voltage.
- The sphere gap gives the peak voltage from the known spacing and standard table, the peak Voltage at the instant of disruptive discharge can be obtained.

Temperature rise test

- This test is to be conducted on a circuit breaker that is the representative of a batch of circuit breakers manufactured
- Alternating current of rated value at rated frequency is passed through the circuit breaker by keeping the contacts in the closed position, continuously till the steady temperature is reached.

- Readings of various conducting, insulating and structural parts are taken at an interval of one or half an hour.
- When steady temperature is reached, the maximum temperature rise of each part should be less than the permitted values.

Mechanical test (Endurance test)

- The breaker should consistently open and close its contacts. In mechanical endurance test the circuit breaker is opened and closed many times (nearly 1000 times).
- Few opening & closing operations (nearly 50 times) is done by energizing the relay and the remaining are by closing the trip circuit by other means.
- Mechanical tests on high voltage ac circuit breakers are conducted without charging the main circuit.
- During mechanical tests adjustment or replacement of any part of the circuit breaker is not allowed.
- However lubrication is to be applied as per the instructions of the manufacturer. After repeated closing and opening operation, the contacts and other parts of circuit breaker must be in good position and there should not be any permanent deformation of any parts.
- The dimensions should be within original limits.
- During repeated operations, the breaker parts in the assembly may fail.
- The circuit breaker is then considered to have failed in the mechanical test.
- The tests are to be conducted after the improvement in the design and manufacture.

Test for contact resistance of circuit breaker pole

- This is measured by one of the following two methods.

1) **Micro ohmmeter**: A **micro ohmmeter** is connected **across** terminals of the pole to measure the **resistance** directly.

2) **Mill volt drop method**: The voltage drop across the circuit breaker pole is measured for different values of **dc current**. The voltage drop gives a measure of current carrying part and contacts. The dc current should be sufficiently high but must be less than the rated current. The resistance measurement of circuit breaker pole should be done at ambient temperature. The resistance must be of the order of few tens of micro ohms. This test is a routine test to be carried out to ascertain the performance when the circuit breaker is put in actual operation.

Impulse voltage test

- This test is carried· out on indoor and outdoor circuit breakers. Standard impulse wave of specified amplitude is applied five times in succession.
- During the test impulse wave with reversed polarity is also applied.
- The impulse wave is obtained from an impulse voltage generator.
- One terminal of the impulse generator is connected to the terminal of the circuit breaker pole and the other terminal is connected to the earth and frame of the circuit breaker.
- The peak value of the impulse wave and its shape is recorded using RO with calibrated voltage divider.
- The different impulse voltages will have different front Wave and tail wave.
- During the test if there is failure of the insulation or puncture, will be considered as the circuit breaker has failed.

Selection of circuit breakers:

- Circuit breakers are used at various voltage levels.
- The following factors are to be given consideration while selecting the circuit breakers.
  1) Ratings
  2) Break time
  3) Ambient conditions
  4) Type; indoor or outdoor
  5) Control desired
  6) Type of operating mechanism
  7) Type of breaker based on arc extinction medium
  8) To be operated alone or in group
  9) Frequency of operation
  10) Other protective equipment's with which to be co-ordinate

Installation procedure for circuit breakers:

- In the process of installation of circuit breakers, the preliminary preparations such as study of drawings, acceptance, report checking certificates, test reports of the equipment, completion of civil engineering work, arranging the tools, organizing the labor, preparation of schedule of installation, preparation of sequence cards for erection etc. are to be done.
- The different steps of installation include:
  1) Sequence card for erection of switchgear equipment
  2) Location of switchgear
  3) Unpacking
  4) Foundation
  5) Erection
  6) Bus bar earthling connections
  7) Connection of main cables
  8) Earthing

Ratings of LV circuit breakers

The important ratings of low voltage circuit breakers are as follows

- Rated voltage and frequency
- Rated currents
- Rated duty
- Rated short circuit making and breaking capacity
- Rated short time withstand categories
- Rated voltages: Rated operational voltage, rated Insulation voltage
- Rated currents: Rated thermal current, rated uninterrupted current
- Rated duty: short time, uninterrupted duty
- Rated short circuit making capacity
- Rated short circuit breaking capacity

Tests on low voltage ac circuit breakers

- The different tests to be carried out on live circuit breakers are as follows.

Type tests: To be conducted to confirm the design, on the first piece manufactured.

- Temperature rise limits test
- Dielectric tests
- Short circuit making and breaking tests
- Short time withstand current test
- Mechanical endurance test
- Overload performance

Routine tests: To be conducted to predict the performance behavior on each circuit breaker.

- Mechanical operation tests
- Calibration of releases
- Dielectric tests
- Insulation resistance test

For low voltage load control, the switchgear used may be one of the following

- Low voltage air breaks circuit breaker
- Low voltage contactor
- Switch fuse combination
- Miniature circuit breaker
- Molded case breaker

Maintenance of circuit breakers

- The circuit breaker is intended for repeated operations as the occurrence of the faults in the system is unpredictable.

- Hence to ensure the protection of system components, more emphasis is to be given to the maintenance of circuit breakers.

- The maintenance procedure differs from breaker to breaker based upon the quenching medium used.

- The maintenance to be carried out includes the following.

1) Period of maintenance under normal condition on clearing faults
2) Checking of contacts
3) Checking of arc control devices
4) Checking of insulators
5) Checking of relays

Precautions to be taken during maintenance:

- The maintenance work should be carried out with authentic permission by the concerned authority.

The following steps are to be followed.

1) Isolate the live part
2) Danger notices should be displayed
3) The neighboring switch should be locked to avoid accidental switch nag
4) The equipment and conductors should be earthed
5) Power tools and safety devices to be provided to the electricians
6) Well trained people must be allowed for the work
7) First aid should be available
8) There should not be any chance of negligence

HVDC circuit breaker

- In HVDC system, dc current is controlled by blocking the valves.
- The arc extinction in ac circuit breakers takes place at natural current zero of the wave.
- Thus, the energy in system inductance at current zero is nil and current interruption is relatively easy.
- In dc system a LC resonant circuit is introduced in parallel, just after contact separation of main circuit breaker, thereby oscillations are produced artificially
- The circuit breaker uses one of the current zeros so as to extinguish the arc.
- Such breakers are used for transferred nag current from earth return path to metallic return

Fuses

- Fuse is the weakest link in electrical circuit.
- It is the simplest current **interrupting device** used to **protect** from **excessive currents**.
- It is used for low voltage applications.
- However modern High Rupturing Capacity cartridge fuses (HRC) provide reliable discrimination and accurate characteristics.
- In some respects HRC fuses are superior to circuit breakers.
- The main difference between the two is that, fuse can break the circuit under abnormal conditions but cannot make the circuit on its own after the system returns to normal condition.

Types of fuse:

1. Semi enclosed or re wearable fuse
2. Totally enclosed or cartridge type
3. D-type
4. Bolted type
5. Expulsion fuse
6. High Rupturing capacity fuse (HRC)

- The following details pertaining to fuse are considered while selecting the fuse for particular application.
  - Rated current
  - Minimum fusing current
  - Perspective current
  - Pre-arcing time
  - Arcing time
  - Total operating time
  - Fusing factor