# INDEX

**Topics** **Page. No.**

# 1. SUMMARY

Three phase transformers are used throughout industry to change values of three-phase voltage and current. Since three-phase power is the most common way in which power is produced, transmitted, and used, an understanding of how three phase transformer connections are made is essential. In this section it will discuss different types of three phase transformers connections.

A three-phase transformer is constructed by winding three single-phase transformers on a single core. These transformers are put into an enclosure, which is then filled with dielectric oil. The dielectric oil performs several functions. Since it is a dielectric, a nonconductor of electricity, it provides electrical insulation between the windings and the case. It is also used to help provide cooling and to prevent the formation of moisture, which can deteriorate the winding insulation.

There are only 4 possible transformer combinations:

- Delta-to-Delta - use: industrial applications
- Delta to Wye – use: most common; commercial and industrial
- Wye to Delta – use: high voltage transmissions
- Wye-to-Wye – use: rare, don’t use causes harmonics and balancing problems.

There are three basic configurations of transformers used in the trade. Primary voltages are typically AC (alternating current), while the secondary voltage might be AC or DC (direct current).

a) Step down transformers
b) Step up transformers
c) Isolation transformers

A basic transformer consists of two sets of coils or windings. Each set of windings is simply an inductor. AC voltage is applied to one of the windings, called the primary winding. The other winding, called the secondary winding, is positioned in close proximity to the primary winding, but is electrically isolated from it.The alternating current that flows through the primary winding establishes a time-varying magnetic flux, some of which links to the secondary winding and induces a voltage across it.

The magnitude of this voltage is proportional to the ratio of the number of turns on the primary winding to the number of turns on the secondary winding. This is known as the “turns ratio.”

To maximize flux linkage with the secondary circuit, an iron core is often used to provide a low-reluctance path for the magnetic flux. The polarity of the windings describes the direction in which the coils were wound onto the core. Polarity determines whether the flux produced by one winding is additive or subtractive with respect to the flux produced by another winding.

This is a collective term which covers all the equipment used for detecting, locating and initiating the removal of a fault from the power system. Relays are extensively used for major protective functions, But the term also covers direct-acting A.C. trips and fuses.

In addition to relays the term includes all accessories such as current and voltage transformers, shunts, D.C. and A.C. wiring and any other devices relating to the protective relays.

In general, the main switchgear, although fundamentally protective in its function, is excluded from the term 'protective gear', as are also common services, such as the station battery and any other equipment required to secure operation of the circuit breaker.

In order to fulfil the requirements of discriminative protection with the optimum speed for the many different configurations, operating conditions and construction features of power systems, it has been necessary to develop many types of relay which respond to various functions of the power system quantities.

For example, observation simply of the magnitude of the fault current suffices in some cases but measurement of power or impedance may be necessary in others. Relays frequently measure complex functions of the system quantities, which are only readily expressible by mathematical or graphical means.

In many cases it is not feasible to protect against all hazards with any one relay. Use is then made of a combination of different types of relay which individually protect against different risks. Each individual protective arrangement is known as a 'protection system'; while the whole coordinated combination of relays is called a 'protection scheme'.

Transformer protection falls under two major categories:

1) Protection of the system against the effects of faults arising inside the transformer.
2) Protection of the transformer against the effect of faults occurring on any part of the system (external).

Faults occurring internal to the transformer are

1) Earth faults
2) Phase to Phase faults
3) Inter turn faults
4) Core faults
5) Tank faults

There are many tests which are used in industries for appropriate working of transformers which are mentioned as below:-

1. Power Transformer Field Testing
2. Magnetic/ Electric Circuit Test
3. No-load test
4. Load test (short circuit test, Impedance measurement).
5. Winding Resistance.
6. Dielectric System Test
7. Electric Tests to the Dielectric Circuit.
8. Partial Discharge test.
9. Physical chemical Tests
10. Dissolved Gas Analysis & Ratios.

We have described most of the usual "standardized" test in measurement protocols.With a short number of measuring elements we can have a clear idea of the complete transformer status. Anyway, it is of a great importance to go more deeply in the knowledge of this tests to insure their tracking both in the performance on our own or subcontracted.This test will be performed taking into account a series of precautions related both in their normatives and in the experience logic. In all dielectric system tests, is important to take note of transformer temperature and around conditions.

# 2. INTRODUCTION

In hydroelectric power plants the potential energy of water due to its high location is converted into electrical energy. The total power generation capacity of the hydroelectric power plants depends on the head of water and volume of water flowing towards the water turbine.

HYDRO POWER PLANT :-

The hydroelectric power plant, also called as dam or hydro power plant, is used for generation of electricity from water on large scale basis. The dam is built across the large river that has sufficient quantity of water throughout the river. In certain cases where the river is very large, more than one dam can built across the river at different locations.

Working Principle of hydroelectric power plant:-

The water flowing in the river possesses two type of energy: the kinetic energy due to flow of water and potential energy due to the height of water. In hydroelectric power and potential energy of water is utilized to generate electricity.

The formula for total power that can be generated from water in hydroelectric power plant due to its height is given

P=rhg ,where, p is the power produced in "watt" and "r" is the rate of flow of water which in cubic meter/second"h"= height of water which is measured in "meter"its also head of water .the difference between source of water (from where water is taken) and the water’s outflow (where the water is used to generate electricity, it is the place near the turbines).g- is the gravity constant 9.81 m/second square

The formula clearly shows that the total power that can be generated from the hydroelectric power plants depends on two major factors: the flow rate of water or volume of flow of water and height or head of water. More the volume of water and more the head of water more is the power produced in the hydroelectric power plant.To obtain the high head of water the reservoir of water should as high as possible and power generation unit should be as low as possible. The maximum height of reservoir of water is fixed by natural factors like the height of river bed, the amount of water and other environmental factors. The location of the power generation unit can be adjusted as per the total amount of power that is to be generated. Usually the power generation unit is constructed at levels lower than ground level so as to get the maximum head of water.The total flow rate of water can be adjusted through the pen stock as per the requirements. If more power is to be generated more water can be allowed to flow through it.

# 3.WORK

My work at Ram Nivas Hydro Power plant was to study the transformers and their testing installed there. I was involved in the following tests of transformers:-

1.Field testing
2.Magnetic/Electric circuit test
3.Online Tap Changer
4.Load Test
5.Dielectric System Test
6.Recovery Voltage measurement
7.Partial Discharge test
8.Physical-chemical test

# 4.INDUSTRY

Ranjit Sagar dam project is one of the largest multipurpose river valley projects on the river Ravi. About 24 km up stream of Madhopur heads works. It has four generating units of 150 MW each with total installed capacity of 600 MW. It has firm power 207 MW at 100% load factor. Annual generation from this project is 150.9crore units out of which 4.6% of energy generated is supplied free of cost to Himachal Pardesh and 20% of energy generated is supplied to Jammu& Kashmir. Ranjit Sagar Dam (Thein dam) is a gigantic Multipurpose The construction of Ranjit Sagar Dam is a part of the total plan for the utilization of the water of three eastern rivers namely Sutlej, Beas and Ravi for irrigation and Power generation. Ranjit Sagar Dam is located in a gorge section of river Ravi near village. Thein in J&K state, in seismically active zone of Himalayas constituting the Shivalik range. The Project is an embodiment of interstate relationship and co-operation amongst the States of Punjab, J&K and Himachal Pradesh. Ranjit Sagar Dam is an ambitious project of the Govt. Of Punjab. It had been heavily funded by Central Government and the construction of this dam had provided good employment opportunity to the people of this area who are otherwise solely dependent on agriculture to earn their daily bread. This has developed in to a favourite tourist attraction while on way to Dalhousie Hill Station. Just 5km down the line is a village Doongh which has an Ancient Place from the times of Mahabharat the famous Epic of Indian Mythology. Pandaves have spent a short span of time during their Agayat Vaas at this place on the bank of river ravi.

TECHNICAL DATA:

| | |
|---|---|
| Installed capacity of 4 generating units | 4*150= 600MW |
| Number of Power house | one |
| Cost of project | Rs 3601 crore(6/2000) |
| Cost per unit | Rs 8.04 per unit |
| Type of turbine | Francis Turbine |
| Rated Discharge | 168.1 cubic m/ sec |
| Design Net head | 100m |
| Maximum head | 121m |
| Minimum head | 76m |
| Rated speed of turbine | 166.67rpm |
| No. of Guide Vanes | 24 |
| Turbine shaft diameter | 1050mm |
| Number of poles | 36 |
| Rotation | clockwise(top) |
| Rated power factor | 0.9pf lag |
| Stator winding connection | star |
| Stator Resistance | 0.0091 ohm/phase |
| Field Resistance | 0.1813 ohm/phase |

**DAM**

| | |
|---|---|
| TYPE | EARTH CORE & GRAVEL DAM |
| Max. height above riverbed | 135m |
| Max. height | 160m |
| Width at top | 14m |
| Max. width at base | 692m |
| Level of top | 540m |

| | |
|---|---|
| Max. length at the top | 623m |

OUT LET WORKS:

No. of outlets of the tunnels -four

Max. velocity through the gate opening -35.5 m/s

Type of gates for regulating -Vertical lift slide Gates

PENSTOCKS:

No. of penstock tunnels -two

Unique Features of the Project:

The Ranjit Sagar Dam is the highest earth core-cum-gravel shell dam in India.

The Power Plant has the second biggest Hydro-Turbine in India.

The Project is the highest gravity dam in Asia.

The foundation gallery under the Rock fill Dam has been provided for the first time in India

**Selection of Site for Dam:**

**T**he following points should be taken into consideration while selecting a site for a dam.

For achieving economy the water storage should be largest for the minimum possible height and length. Naturally site should be located in a narrow valley.

For safe and cheap construction good foundation should be available at moderate depth.

Good and suitable basin should be available.

Material for construction should be available at a dam site or nearby. As huge quantities of construction materials are required for construction of the dam, the distance at which the material is available affects the total cost of the project.

For passing the surplus water, after the reservoir has been filled up to its maximum capacity a spillway is to be provided. There should be a good and suitable site available for spillway construction. It may be in dam itself or near the dam on the periphery of the basin.

The value of the property and the land likely to be submerged by the proposed dam should be sufficiently low in comparison with benefits expected from the project.

## HYDRO PLANT SETUP AND POWER GENERATION

### *2.1 Hydro plant setup*

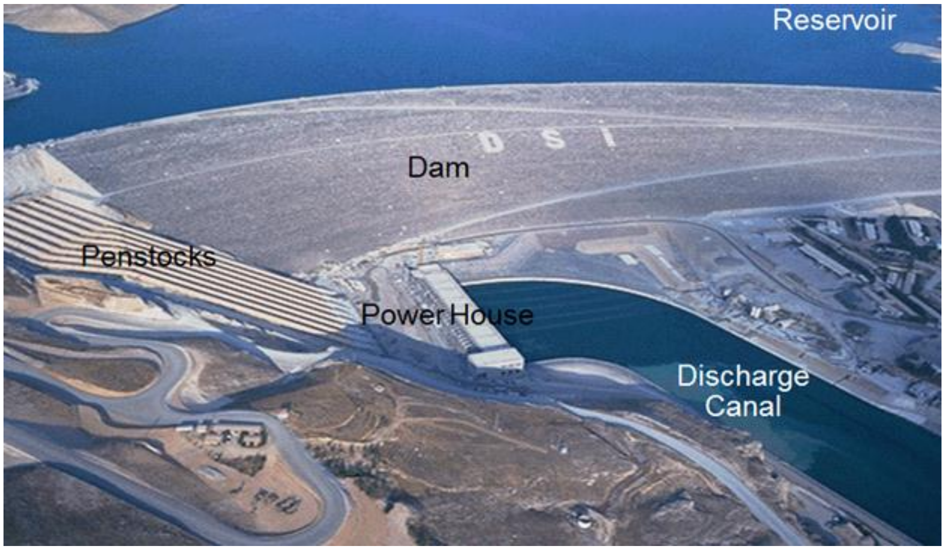



**FIG.2.1 HYDRO PLANT SETUP OVERVIEW**

The water from a river, reservoir or lake flows through the PENSTOCK, a large pipe that can be above or below ground, into the Powerhouse.

The Turbine, Generator, Step-up Transformer and all associated Mechanical & Electrical Auxiliaries are generally located in the POWERHOUSE.

The TURBINE Blades are pushed by flowing Water from the Penstock, causing them to rotate. The Rotor of the GENERATOR connected to the Turbine Shaft rotates as the Turbine move, producing Electricity.

The STEP-UP TRANSFORMER increases the voltage of the Electricity produced by the Generator.

The TRANSMISSION LINES carry Electricity from Power Plant Substation to Substations in our communities. The voltage is decreased and distributed to home & businesses.

The SPILLWAYS are used to release water not used for energy production over the Dam.

The Mechanical & Electrical BOP includes all necessary Auxiliaries Systems & Equipment for the complete operation of the Turbine & Generator. The Operators will operate & supervise all the Power Plant Equipment from the Centralized Control & Protection Systems.

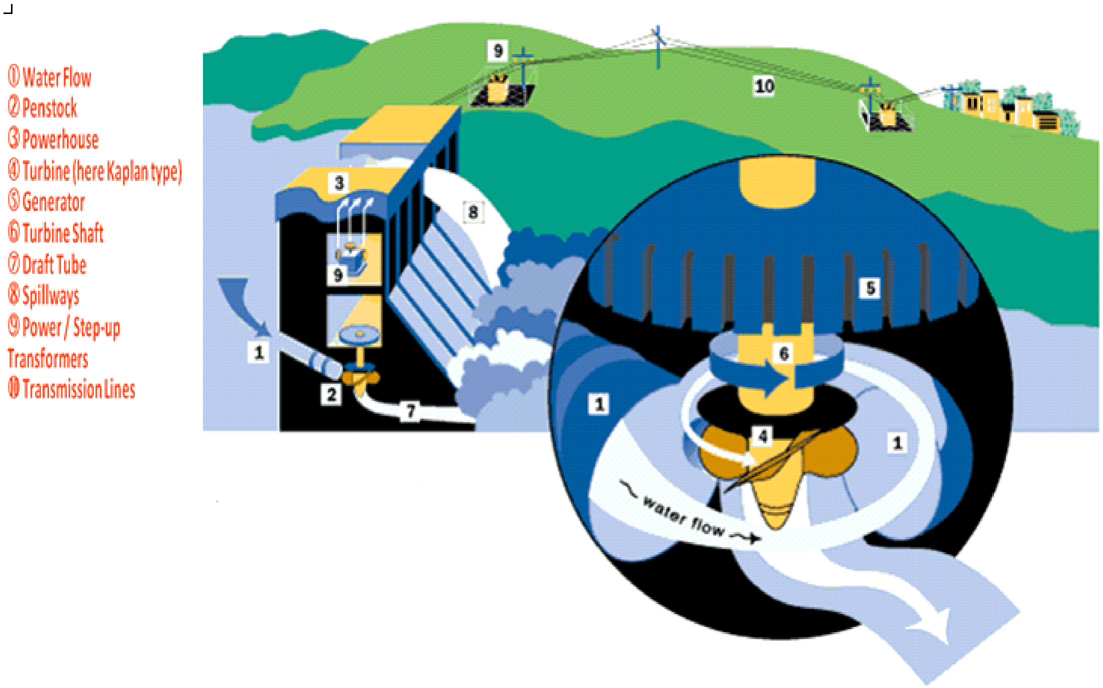



**FIG.2.2 3D POWER HOUSE SETUP**

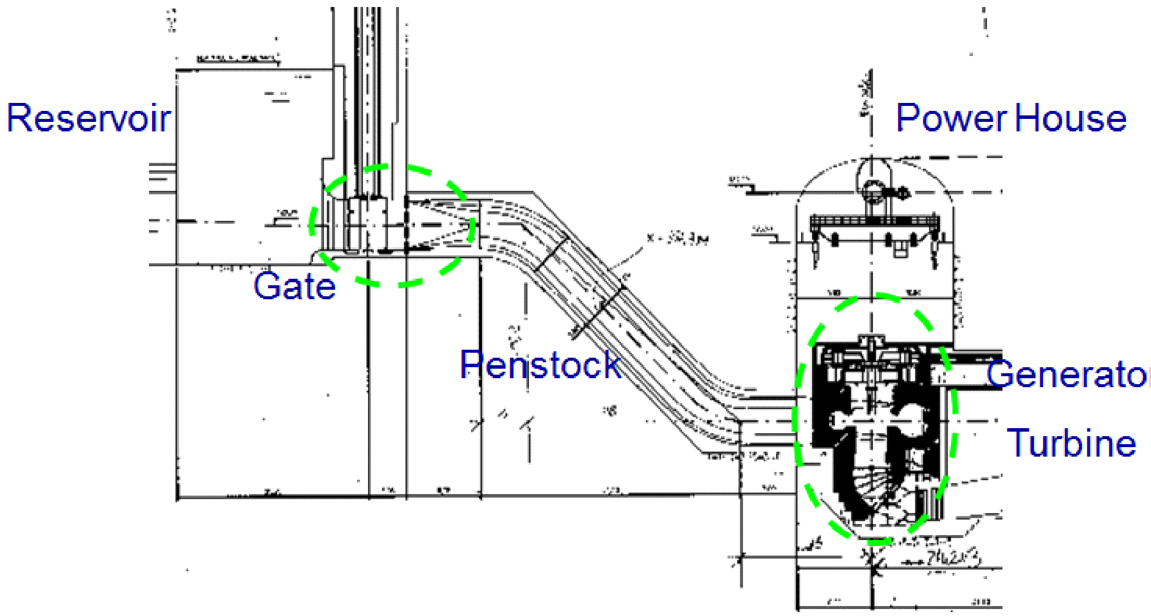



**FIG.2.3 3D VIEW OF HYDRO PLANT**

Main Equipment

Turbine

Generator

Transformer

Switchgear

Auxiliary Equipment

BFV or SV

UCB & LT Panel

Governor

OPU

Excitation Unit

Cooling water system

Dewatering & Drainage system

Auxiliary AC&DC System

Optional Auxiliary Equipment

SCADA System

Remote Control System

### *2.2 Advantages*

- No fuel required:
- One of the major advantages of the hydroelectric power plants is that they don't require any fuel for producing power. The hydroelectric power plants utilize renewable energy of water to generating electricity.

- Cost of electricity is constant:
- Since no fuel is required for the hydroelectric power plants, the cost of electricity produced by them is more or less constant. It does not depend on the cost of fuels like coal, oil and natural gas in the international market. The country doesn't even have to import the fuel for running the hydroelectric power plant thus saving lots of local currency.

- No air-pollution is created
- Since the hydroelectric power plants don't burn any fuel no pollution is caused by them. It does not emit harmful gases and particulate matter, thus keeps the surrounding atmosphere clean and healthy for living.

- Long life:
- The life of hydroelectric power plants is longer than the life of thermal power plants. There are some hydroelectric power plants that were built more than 50-100 years ago and are still running.

- Cost of generation of electricity:
- For the working of hydroelectric power plant very few people are required since most of the operations are automated, thus operating costs of hydroelectric power plants are low. Further, as the hydroelectric power plants become older, the cost of generation of electricity from it becomes cheaper since initial capital cost invested in the plant is recovered over the long period of operations.

- Can easily work during high peak daily loads:
- The daily demand of power is not constant throughout the day. The peak power occurs at night. It is very difficult to start and stop the thermal and nuclear power plants on daily basis. The hydroelectric power plants can be easily started and stopped without consuming much time. Water can be collected in the dam throughout the day and this can be used to generate electricity during peak periods.

- Irrigation of farms:
- Water from the dams can also be used for the irrigation of farm lands thus producing the agriculture outputs throughout the year even in the areas where there is scanty or no rainfall.

- Water sports and gardens:
- In vicinity of the dams the water from reservoir can be utilized to develop public recreational facilities like water parks for water sports and gardens.

- Prevents floods:
- The dams also help prevent floods in the areas adjoining the large rivers.

## *2.3 Disadvantages*

### 1. Ecosystem damage and loss of land

Large reservoirs required for the operation of hydroelectric power stations result in submersion of extensive areas upstream of the dams, destroying biologically rich and productive lowland and riverine valley forests, marshland and grasslands. The loss of land is often exacerbated by the fact that reservoirs cause habitat fragmentation of surrounding areas.

Since turbine gates are often opened intermittently, rapid or even daily fluctuations in river flow are observed. For example, in the Grand Canyon, the daily cyclic flow variation caused by Glen Canyon Dam was found to be contributing to erosion of sand bars.

### 2. Flow shortage

Changes in the amount of river flow will correlate with the amount of energy produced by a dam.

Lower river flows because of drought, climate change or upstream dams and diversions will reduce the amount of live storage in a reservoir therefore reducing the amount of water that can be used for hydroelectricity.

The result of diminished river flow can be power shortages in areas that depend heavily on hydroelectric power.

### 3. Methane emissions (from reservoirs)

Lower positive impacts are found in the tropical regions, as it has been noted that the reservoirs of power plants in tropical regions may produce substantial amounts of methane.

This is due to plant material in flooded areas decaying in an anaerobic environment, and forming methane, a very potent greenhouse gas.

According to the World Commission on Dams report, where the reservoir is large compared to the generating capacity (less than 100 watts per square meter of surface area) and no clearing of the forests in the area was undertaken prior to impoundment of the reservoir, greenhouse gas emissions from the reservoir may be higher than those of a conventional oil-fired thermal generation plant.

there is a greater amount of methane due to anaerobic decay, causing greater damage than would otherwise have occurred had the forest decayed naturally.

#### 4. Relocation

Another disadvantage of hydroelectric dams is the need to relocate the people living where the reservoirs are planned. In February 2008, it was estimated that 40-80 million people worldwide had been physically displaced as a direct result of dam construction.

In many cases, no amount of compensation can replace ancestral and cultural attachments to places that have spiritual value to the displaced population.

Additionally, historically and culturally important sites can be flooded and lost.

Such problems have arisen at the Aswan Dam in Egypt between 1960 and 1980, the Three Gorges Dam in China, the Clyde Dam in New Zealand, and the Ilisu Dam in Turkey.

#### 5. Failure hazard

Because large conventional dammed-hydro facilities hold back large volumes of water, a failure due to poor construction, terrorism, or other causes can be catastrophic to downriver settlements and infrastructure.

Dam failures have been some of the largest man-made disasters in history. Also, good design and construction are not an adequate guarantee of safety.

Dams are tempting industrial targets for wartime attack, sabotage and terrorism, such as Operation Chastise in World War II.

**Comparison with other methods of power generation**

Hydroelectricity eliminates the flue gas emissions from fossil fuel combustion, including pollutants such as sulfur dioxide, nitric oxide, carbon monoxide, dust, and mercury in the coal. Hydroelectricity also avoids the hazards of coal mining and the indirect health effects of coal emissions. Compared to nuclear power, hydroelectricity generates no nuclear waste, has none of the dangers associated with uranium mining, nor nuclear leaks. Unlike uranium, hydroelectricity is also a renewable energy source.

Compared to wind farms, hydroelectricity power plants have a more predictable load factor. If the project has a storage reservoir, it can be dispatched to generate power when needed. Hydroelectric plants can be easily regulated to follow variations in power demand.

Unlike fossil-fuelled combustion turbines, construction of a hydroelectric plant requires a long lead-time for site studies, hydrological studies, and environmental impact assessment. Hydrological data up to 50 years or more is usually required to determine the best sites and operating regimes for a large hydroelectric plant. Unlike plants operated by fuel, such as fossil or nuclear energy, the number of sites that can be economically developed for hydroelectric production is limited; in many areas the most cost effective sites have already been exploited. New hydro sites tend to be far from population centers and require extensive transmission lines. Hydroelectric generation depends on rainfall in the watershed, and may be significantly reduced in years of low rainfall or snowmelt. Long-term energy yield may be affected by climate change. Utilities that primarily use hydroelectric power may spend additional capital to build extra capacity to ensure sufficient power is available in low water years.

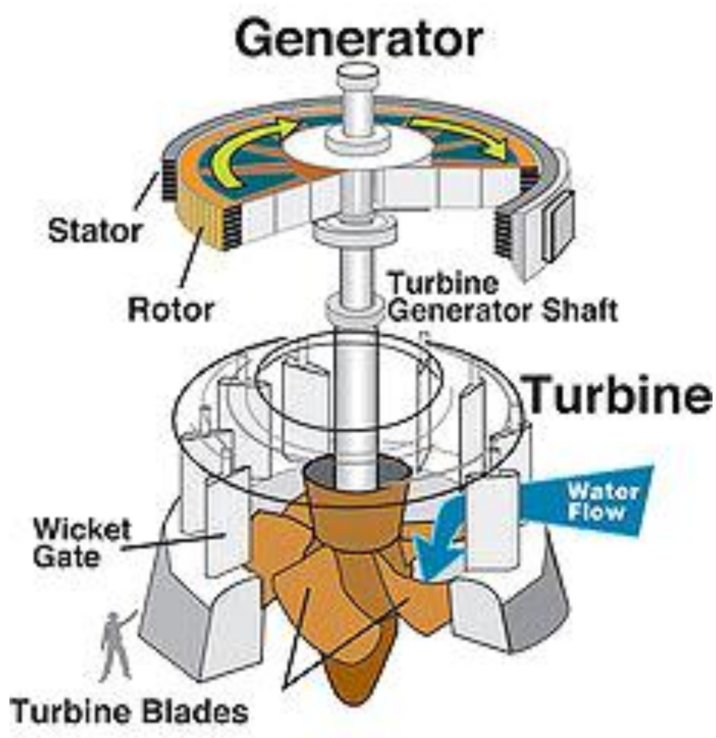



**FIG.2.4 TURBINE-GENERATOR SETUP**

*2.4 Turbines*

Hydraulic Turbines is classified on basis of:

Type of Action on the runner

(a) Impulse Turbine (b) Reaction Turbine

Direction of Flow through Runner

(a) Tangential flow (b) Radial flow (c) Axial flow

Head at inlet of Turbine

(a) High head (b) Medium head (c) Low head

According to specific speed

( a) High (b) Medium (c) Low

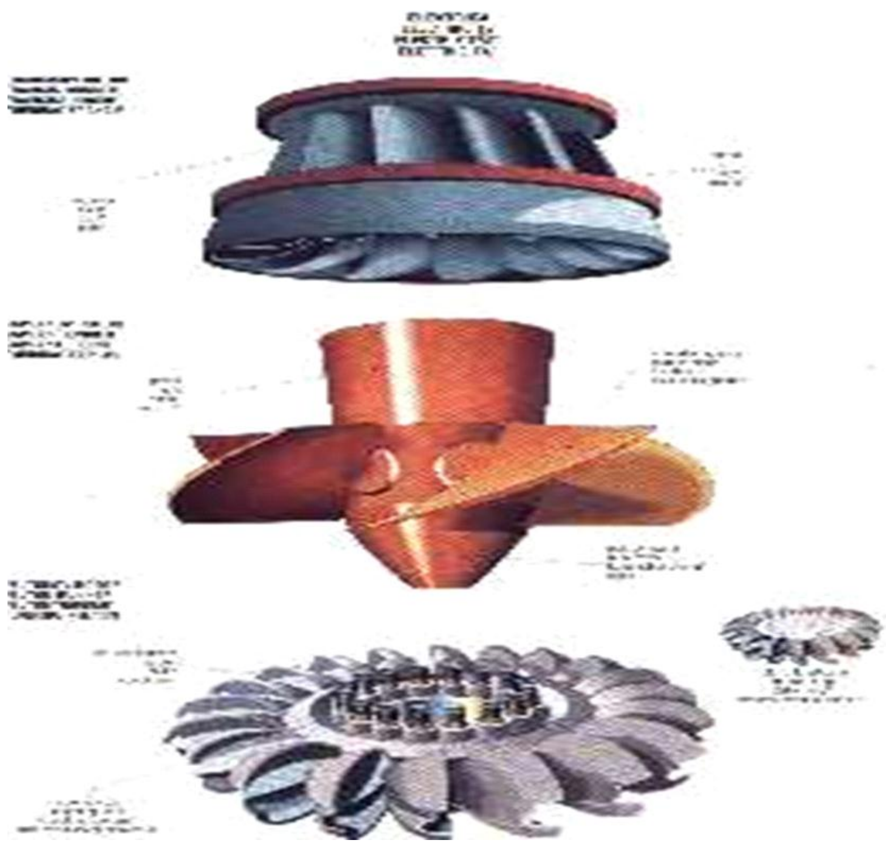
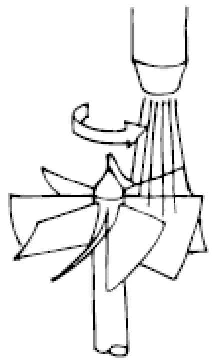


**FIG.2.5 a) FRANCIS b) KEPLAN c) PELTON**

### 2.4.1 Impulse Turbine (Pelton runner)

If the available energy at the inlet of the Turbine is only K.E., then the turbine is known as Impulse Turbine. As the water flows over the blades, the pressure is atmospheric from inlet to the outlet of the Turbine. Impulse turbines spin freely in the air. Water is directed toward the turbine by a spout or nozzle. As long as there is some flow, the nozzle can be adjusted to regulate the flow-especially in a cross-flow turbine. Impulse turbines are the most commonly used in micro hydro systems.



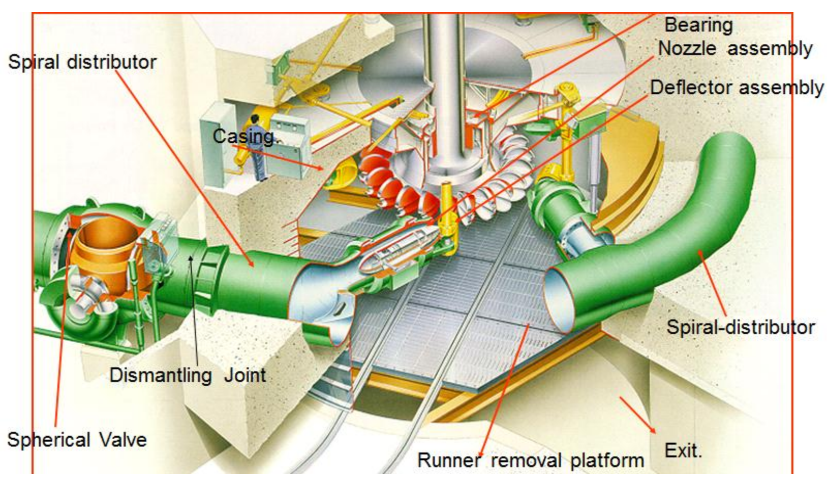
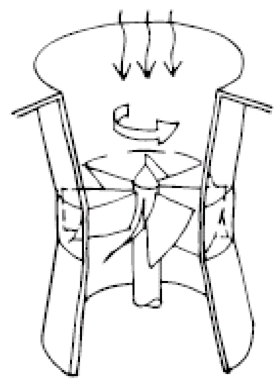



**FIG. 2.6 PELTON RUNNER**

### 2.4.2 Reaction Turbine (Francis runner and Kaplan runner)

If at the inlet of the turbine, the water possesses K.E. as well as P.E., then the turbine is known as Reaction Turbine. As the water flows through the runner, the water is under pressure and the pressure energy goes on changing into K.E. The Runner is completely enclosed in an air-tight casing and the Runner & Casing is completely full of water. A reaction turbine is fully immersed in water and is entirely enclosed in housing, so that the full pressure of the water turns the turbine. These are more likely to be used if water flow is relatively consistent throughout the year and the water pressure (or head) is low grade



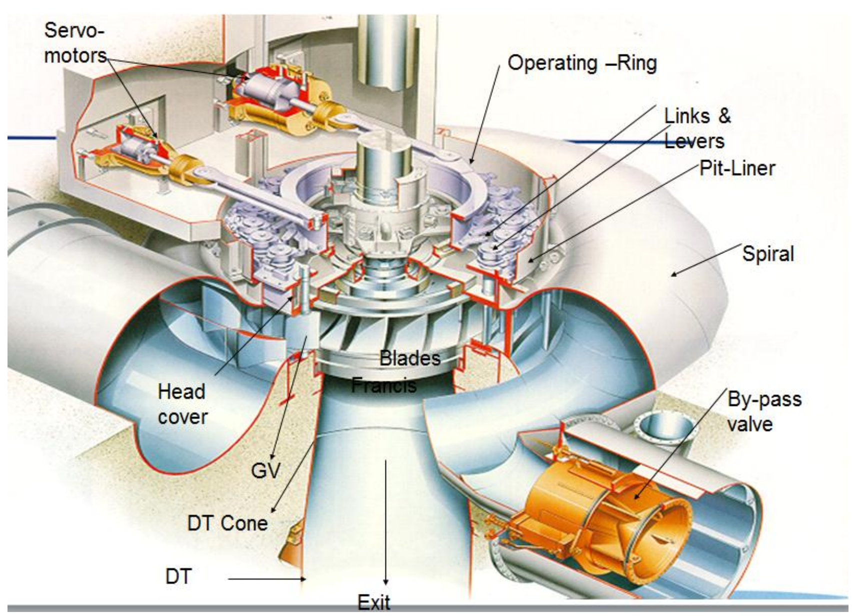


**FIG. 2.7 FRANCIS RUNNER**

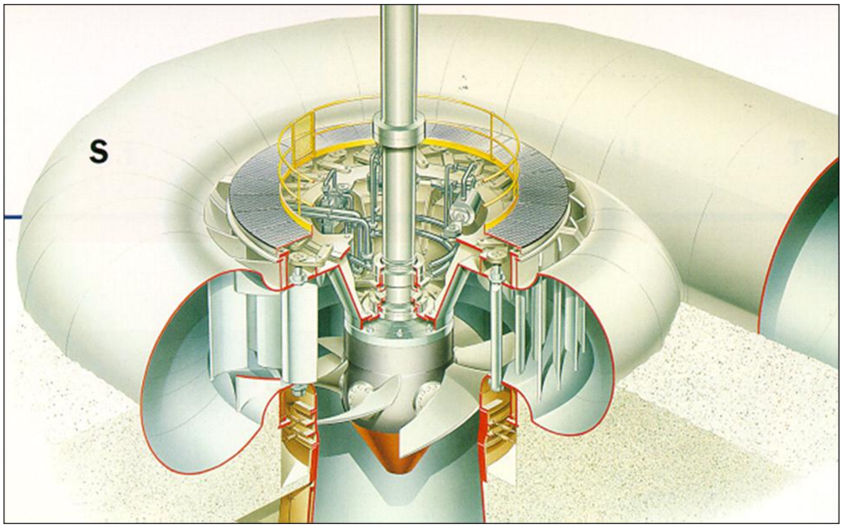



**FIG. 2.8 KEPLAN RUNNER**

TECHNICAL DATA

| | | | |
|---|---|---|---|
| FRANCIS RUNNER | Ns=80-430 rpm | H=50-400 m | Medium head |
| PELTON RUNNER | Ns=40-80 rpm | H=>300 m | High head |
| KAPLAN RUNNER | Ns=300-1000 rpm | H=Up to 50 m | Low head |

### *2.5 Hydro-generator*

Introduction

Hydro-generator or synchronous generator or alternator works by the same principle as DC generators, namely, when the magnetic field around a conductor changes, a current is induced in the conductor. Typically, a rotating magnet called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an induced EMF, as the mechanical input i.e prime mover causes the rotor to turn. The rotating magnetic field induces an AC voltage in the stator windings. Often there are three sets of stator windings, physically offset so that the rotating magnetic field produces three phase currents, displaced by one-third of a period with respect to each other. The rotor magnetic field is produced by a rotor winding energized with direct current through slip rings and brushes.

A Synchronous Generator runs at a constant speed and draws its excitation power source from an external power source or independent of the load or transmission network it is supplying. A synchronous Generator exciter enables the synchronous generator to produce its own reactive power and also to regulate its voltage. Synchronous Generator can operate in parallel with the utility or in ISLAND mode.

**Hydro generators have an extremely wide range of rotational speed depending on individual site condition. Due to this range (usually 50 - 1200 rpm), the construction configuration of the shaft and bearings, diameter and structure of the rotor, have a several possibility. ALSTOM currently produces three basic types of hydro generators both for new plants and in service application:**

**Generators for river flow (low/medium speed);**

**Generators for high-head plants (medium/high speed);**

**Motor-generators for pumped storage systems.**

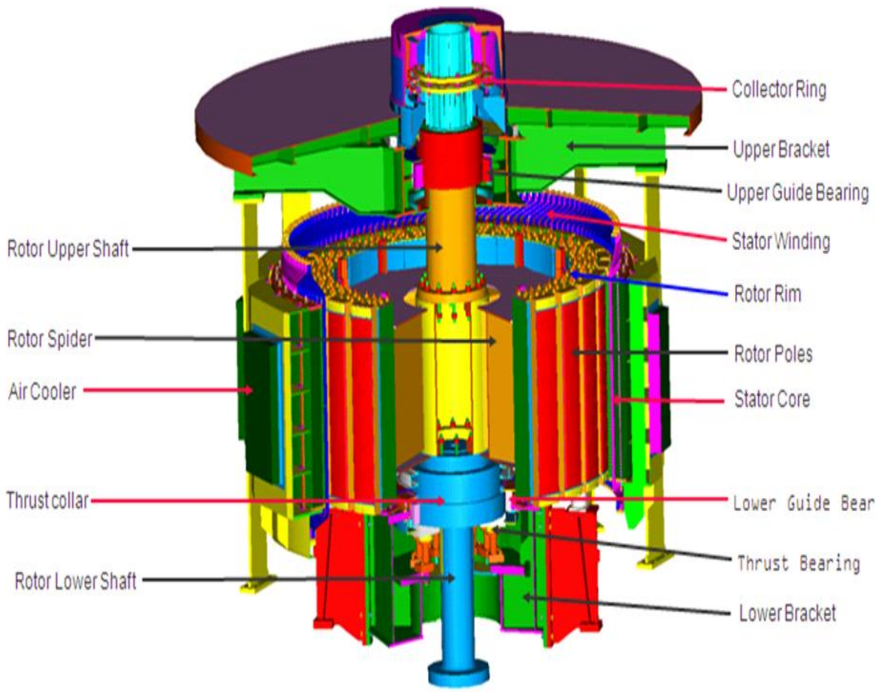



**FIG. 2.9 3D VIEW OF THE HYDRO GENERATOR**

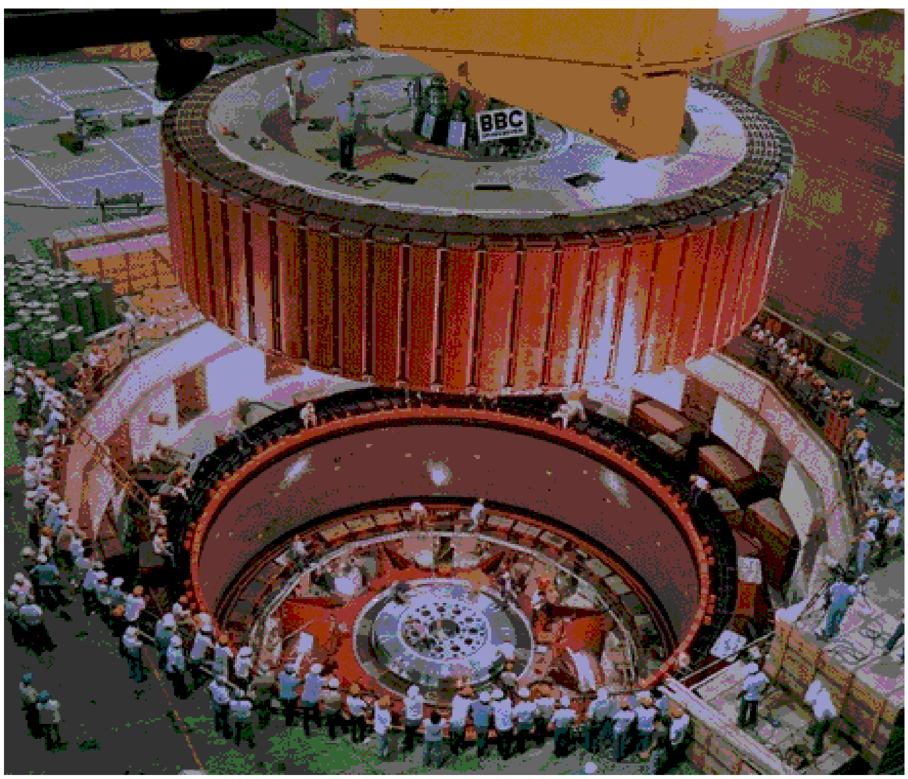



**FIG. 2.10 HYDRO GENERATOR ASSEMBLY AT SITE**

**Main components-**

Stator

Rotor

Bearings and brackets

**Auxiliaries for the generator operation-**

Static Excitation system

Air cooling system

**Specifications of SUBANSIRI generator**

| | | | |
|---|---|---|---|
| - | Active Power | = | 250 MW |
| - | Voltage | = | 11000 Volts |
| - | Current | = | 22727 Amps |
| - | P. F. | = | 0.8 lag |
| - | Speed | = | 250 RPM approx. |
| - | Frequency | = | 50Hz |
| - | Connection of Stator Winding | = | Y |

## Constructional features

**Stator:**

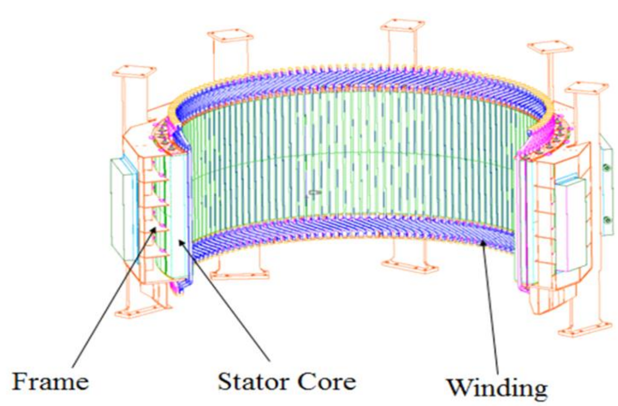



**FIG. 2.11 STATOR OVERVIEW**

### Stator Frame

It is of welded construction & supports the laminated core, winding & both air duct pipes. The stator frame hold and position the magnetic core punching properly, support the weight of the magnetic core, winding and upper bracket, allow stator handling ,take over the magnetic core clamping forces, transmit the vertical loads, the normal and accidental torques and also the radial forces to the foundations, guide the cooling air towards the heat exchangers and support the connections and terminals .

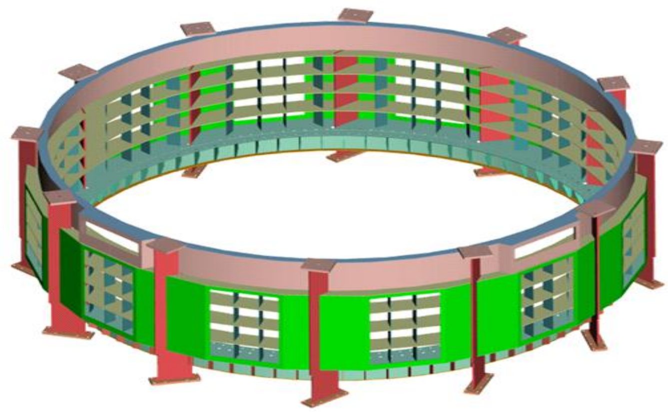


**FIG. 2.12 STATOR FRAME**

### Stator Core

It is made from insulated electrical sheet steel laminations having high silicon content. The stator frame is kept vertical while the core is stacked with lamination segments in individual layers. The stator core conducts magnetic flux lines to generate useful output power. The thickness of lamination is usually 0.35 or 0.5mm, coated on both sides by insulating varnish to reduce magnetic losses. The material used mostly is CRNGO (Cold Rolled Non-Grain Oriented Silicon Steel).


**FIG. 2.13 STATOR CORE**

**Stator Winding**

The stator winding is a half fractional pitch two-layer type, consisting of individual bars. The bars are located in slots of rectangular cross section, which are uniformly distributed on the circumference of the stator core. The main function of stator winding is to generate voltage when current flow from it. Basically it includes copper strips and insulation. In bar winding, lap and wave winding connection is possible. It is useful when current per circuit is more than 1500 Amp. Installation and repairing is easy. If required, additional water cooling system can be provided for individual bar.

Advantages of bar winding:

Electrical design flexibility is low

Useful when current per circuit is higher than 1500 A

High space factor compare to coil winding

Useful for deeper slots i.e. higher bar height

Overall costly compare to coil winding due to roebelling by hand, requirement of insulating caps etc.

Installation is easy

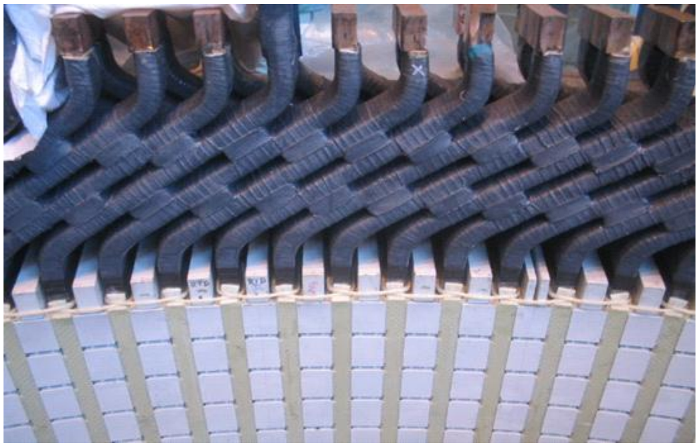


**FIG. 2.14 STATOR WINDINGS**

**Rotor:**

In low speed hydro generators the rotor comprises the poles, the laminated rotor rim, the welded spider and the shaft. The laminated rotor rim consists of segments assembled on site at the plant, thus overcoming any transport problems. Each segment is made of punched steel plate with well-defined surface finish, flatness and thickness characteristics and other mechanical properties. The spider, made of welded steel plates, consists of a central hub and radial arms welded to the central hub. Slots are axially obtained at the end of the arms suitable for wedge-shaped keys. They lock the spider to the rim in a tangential and radial direction. The most frequent configuration of rotor for high speed generators and generator-motors involves forged rings with cast hub and stub shafts. Forgings are comprehensively inspected by sampling and ultrasonic testing.

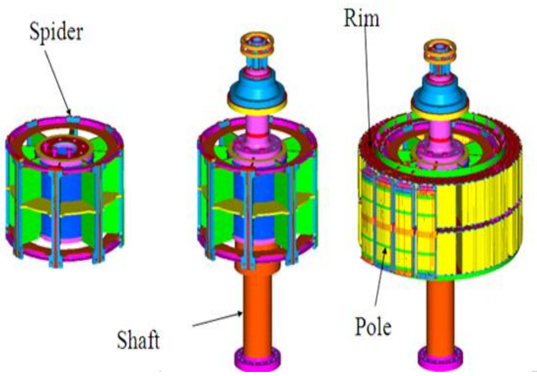



**FIG. 2.15 ROTOR OVERVIEW**

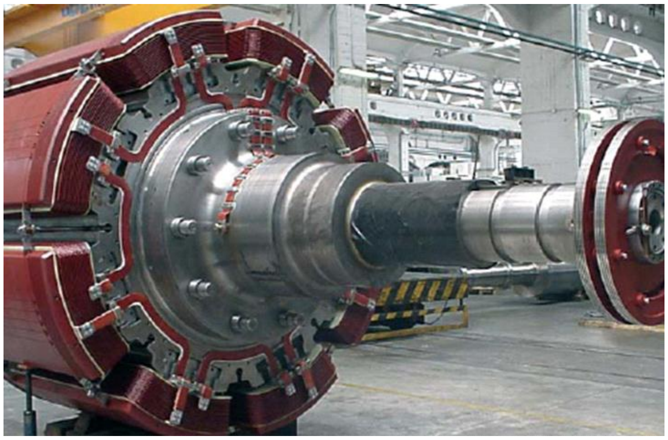


**FIG. 2.16 ROTOR ASSEMBLY AT SITE**

**Bearing and brackets**

There are two types of bearing:

• Thrust Bearing: To carry all vertical loads (Generator rotor wt. + Turbine weight) and axial hydraulic thrust from turbine

• Guide Bearing: To keep Shaft line (Generator + Turbine) system in center.

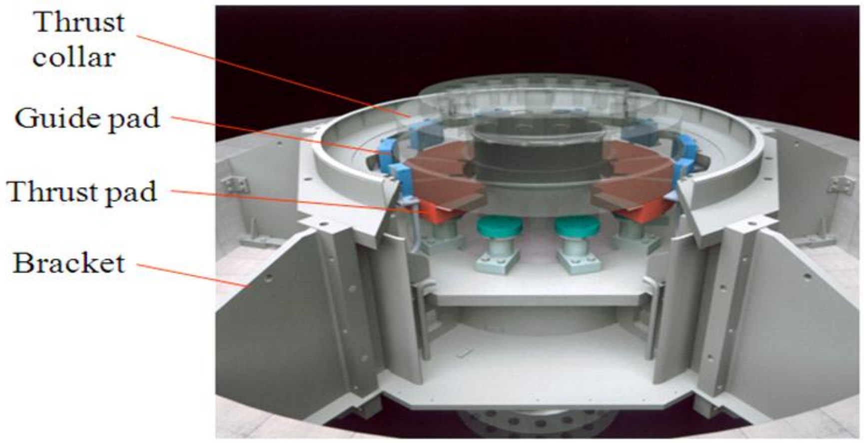



**FIG. 2.17 BEARING AND BRACKETS**

**Excitation system:**

The exciter is the "backbone" of the generator control system. It is the power source that supplies the dc magnetizing current to the field windings of a synchronous generator thereby ultimately inducing ac voltage and current in the generator armature

Two basic kinds of exciters:

• Rotating (Brush and brushless)

• Static exciters (Shunt and series)

The amount of excitation required to maintain the output voltage constant is a function of the generator load. As the generator load increases, the amount of excitation increases.

• Reactive lagging pf loads require more excitation than unity pf loads

• Leading pf loads require less excitation than unity pf loads

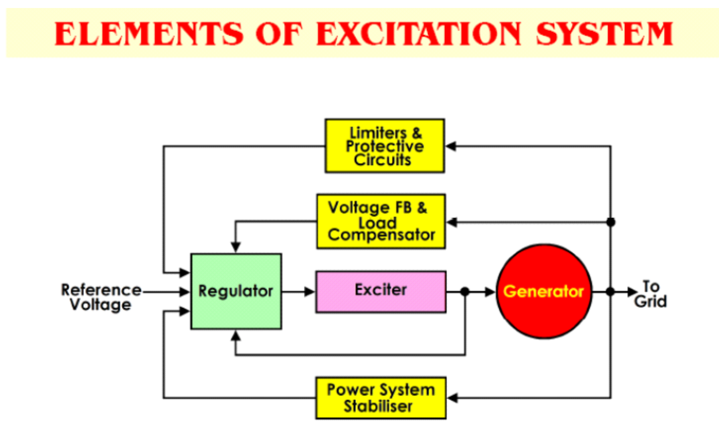



**FIG. 2.18 EXCITATION SYSTEM**

## Rotating exciters:

**Brushless:** do not require slip-rings, commutators, brushes and are practically maintenance free.

**Brush Type:** require slip-rings, commutators and brushes and require periodic maintenance

## Static exciters:

Static excitation means no moving parts. It provides faster transient response than rotary exciters

**Shunt Type:** operating field power from generator output voltage

**Series Type:** operating field power from generator output voltage & current

## Automatic voltage control:

Voltage transformers provide signals proportional to line voltage to the avr where it is compared to a stable reference voltage. The difference (error) signal is used to control the output of the exciter field. For example, if load on the generator increases, the reduction in output voltage produces an error signal which increases the exciter field current resulting in a corresponding increase in rotor current and thus generator output voltage. Due to the high inductance of the generator field windings, it is difficult to make rapid changes in field current. This introduces a considerable "lag" in the control system which makes it necessary to include a stabilizing control to prevent instability and optimize the generator voltage response to load changes. Without stabilizing control, the regulator would keep increasing and reducing excitation and the line voltage would continually fluctuate above and below the required value.

Modern voltage regulators are designed to maintain the generator line voltage within better than +/- 1% of nominal for wide variations of machine load.

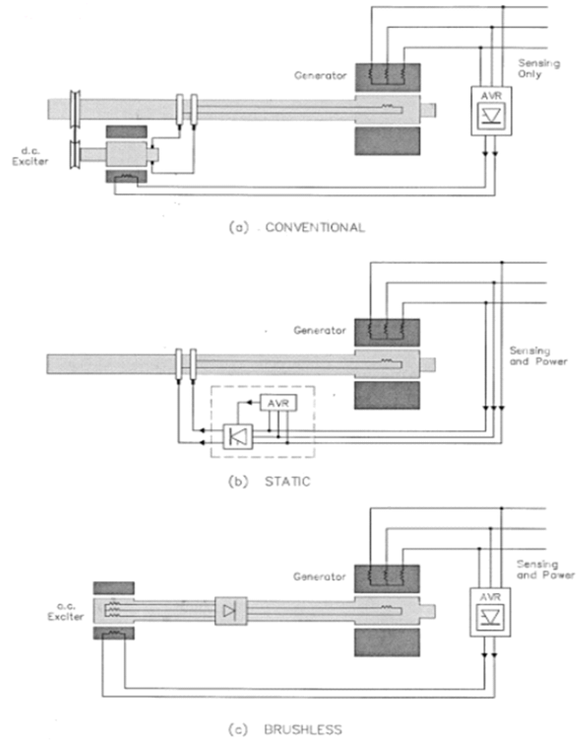



**FIG. 2.19 EXCITATION METHODS**

**Synchronization of generators:**

Synchronization is the process of running two OR more than two systems in parallel & share load in proportion to their ratings. The system which is to be synchronized is called in coming system and the system with which it is to be synchronized is called running system.

Before synchronization following condition are to be satisfied

1. The machine should have same terminal voltage.
2. The machine should have same frequency.
3. Phase sequence should be same.

In our system synchronization with GEB is done on generation Bus 1 & 2 through start up transformer –1 and can be done through start up transformer –2 with Generation Bus 1 & 2 bus coupler closed.

Once the generator attains the full speed, Generator Field Breaker is switched on and excitation is increased so as to achieve the rated voltage of the incoming Generator.

Frequency of incoming Generator is adjusted such that it is slightly higher than that of the running system. Voltage of incoming Generator is adjusted to match it with that of the running system

Synchronization is done with the help of synchronoscope. When the incoming machines is plugged in to the synchronoscope by the putting the key in CHECK position, the pointer on the instrument indicates whether the incoming machine is running too fast or two slow & accordingly its speed is adjusted by adjusting be steam input to the turbine. When the pointer become stationery in the vertical position, the circuit breaker is closed & the machine start operating in parallel. The lamp is also mounted on the synchronoscope Panel as an additional aid. This lamp also glows when 12 ‘O’ clock positions is attained. The machine is loaded after synchronization.

When the system is connected to the infinite bus bar (grid), in such cases the Bus bar voltage remains constant or is determined by the condition of the grid system. This voltage is not affected by individual alternator operating in parallel with the grid.

# 5.Details of Work:

**Testing and Protection of Transformer**

Three phase transformers are used throughout industry to change values of three-phase voltage and current. Since three-phase power is the most common way in which power is produced, transmitted, and used, an understanding of how three phase transformer connections are made is essential. In this section it will discuss different types of three phase transformers connections.

A three-phase transformer is constructed by winding three single-phase transformers on a single core. These transformers are put into an enclosure, which is then filled with dielectric oil. The dielectric oil performs several functions. Since it is a dielectric, a nonconductor of electricity, it provides electrical insulation between the windings and the case. It is also used to help provide cooling and to prevent the formation of moisture, which can deteriorate the winding insulation.

**B. Three-Phase Transformer Connections**

There are only 4 possible transformer combinations:

● Delta-to-Delta - use: industrial applications

● Delta to Wye – use: most common; commercial and industrial

● Wye to Delta – use: high voltage transmissions

● Wye-to-Wye – use: rare, don't use causes harmonics and balancing problems.

a) **Y/Y Connection**

A Y/Y connection for the primary and secondary windings of a three-phase transformer is shown in the figure below. The line-to-line voltage on each side of the three-phase transformer is $\sqrt{3}$ times the nominal voltage of the single-phase transformer. The main advantage of Y/Y connection is that we have access to the neutral terminal on each side and it can be grounded if desired. Without grounding the neutral terminals, the Y/Y operation satisfactory only when the three-phase load is balanced. The electrical insulation is stressed only to about 58% of the line voltage in a Y-connected transformer.(4:225)

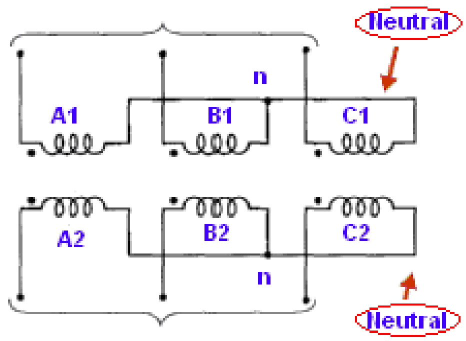



Figure (1) Y/Y connected three-phase transformer

**b) Y/Δ Connection**

This connection as shown in figure below is very suitable for step-down applications. The secondary winding current is about 58% of the load current. On the primary side the voltages are from line to neutral, whereas the voltages are from line to line on the secondary side. Therefore, the voltage and the current in the primary are out of ohase with the voltage and the current in the secondary. In a Y/Δ connection the distortion in the waveform of the induced voltages is not as drastic as it is in a Y/Y-connected transformer when the neutral is not connected to the ground the reason is that the distorted currents in the primary give rise to a circulating current in the Δ-connected secondary.(4:256)

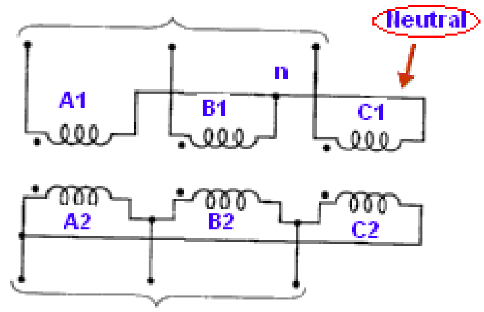



Figure (2) Y/ Δ connected three-phase transformer

**c) Δ/Y Connection**

This connection as shown in figure below is proper for a step-up application. However, this connection is now being exploited to satisfy the requirements of both three-phase and the single-phase loads. In this case, we use a four-wire secondary. The single-phase loads are taken care of by the three line-to-neutral circuits. An attempt is invariably made to distribute the single-phase loads almost equally among three-phases.(4:256)

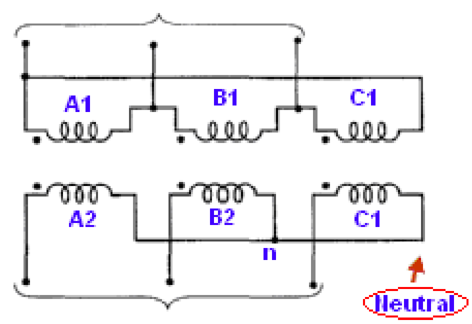



Figure (3) Δ/Y connected three-phase transformer

**d) Δ/Δ Connection**

as shown below the three transformers with the primary and secondary windings connected as Δ/Δ. The line-to-line voltage on either side is equal to the corresponding phase voltage. Therefore, this arrangement is useful when the voltages are not very high. The advantage of this connection is that even under unbalanced loads the three-phase load voltages remain substantially equal. This disadvantage of Δ/Δ connection is the absence of a neutral terminal on either side. Another drawback is that the electrical insulation is stressed to the line voltage. Therefore, a Δ-connection winding requires more expensive insulation than a Y-connected winding for the same power rating.(4:255)

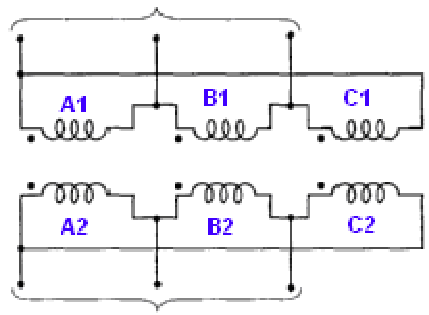



Figure (4) Δ/Δ connected three-phase transformer

## C. Analysis of three-phase Transformer

Under steady-state conditions, a single three-phase transformer operates exactly the same way as three single-phase transformers connected together. Therefore, in our discussion that follows we assume that we have three identical single-phase transformers connected to form a three-phase transformer.(4:257)

D. Electrical Characteristics

Transformers in the trade are either autotransformers (non isolating) or isolation transformers. The main difference between the two is that isolating transformers protect the load from any problems associated with the supply voltage. These are ideally suited for loads that are finicky to voltage spikes and dips, or there is a concern for damage to expensive electronic components.

Speaking of protection, the majority of transformers have inherent protection for the secondary through a fuse or thermal link. The fuse may or may not be easily replaceable. When installing transformers, if there is any doubt, at the least install secondary fusing to protect the transformer and/or load on the transformer. It is also recommended to install primary line side fusing for maximum protection.

There are three basic configurations of transformers used in the trade. Primary voltages are typically AC (alternating current), while the secondary voltage might be AC or DC (direct current).

a) Step down transformers

This is used where a lower voltage is required to supply a load or control voltage. Example: A unit has a 230-volt supply, and the control circuit requires 24 volts. A unit has 600-volt supply and a damper motor requires 120 volts.

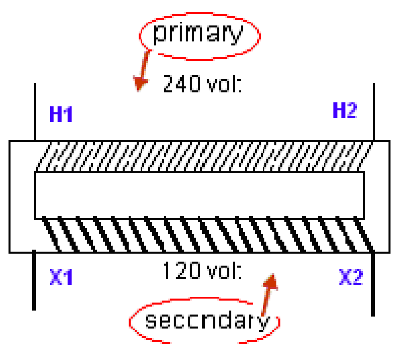



Figure (5) step down transformer

b) Step up transformers

Rarely seen in the trade but is sometimes used, it is used where a higher voltage is required. Example: Unit supply voltage is 120 volts and a crankcase heater requires a 230-volt supply.

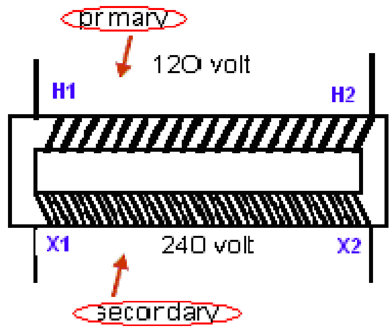



Figure (6) step up transformer

c) Isolation transformers

Another transformer that is sometimes used is Isolation transformer, which has the same primary and secondary voltages. They are used to protect the secondary load from supply voltage irregularities. Note that isolation transformers are also available in step up and step down configurations.

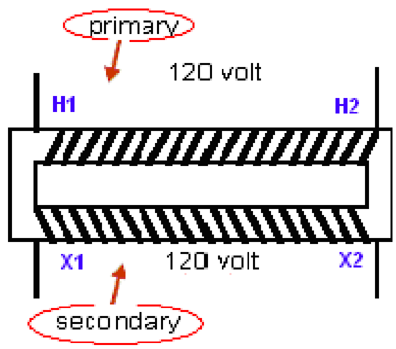



Figure (7) isolation transformer

## E. How transformers work

A basic transformer consists of two sets of coils or windings. Each set of windings is simply an inductor. AC voltage is applied to one of the windings, called the primary winding. The other winding, called the secondary winding, is positioned in close proximity to the primary winding, but is electrically isolated from it.

The alternating current that flows through the primary winding establishes a time-varying magnetic flux, some of which links to the secondary winding and induces a voltage across it. The magnitude of this voltage is proportional to the ratio of the number of turns on the primary winding to the number of turns on the secondary winding. This is known as the “turns ratio.”

To maximize flux linkage with the secondary circuit, an iron core is often used to provide a low-reluctance path for the magnetic flux. The polarity of the windings describes the direction in which the coils were wound onto the core. Polarity determines whether the flux produced by one winding is additive or subtractive with respect to the flux produced by another winding. A basic two-winding transformer is shown in the Figure below.

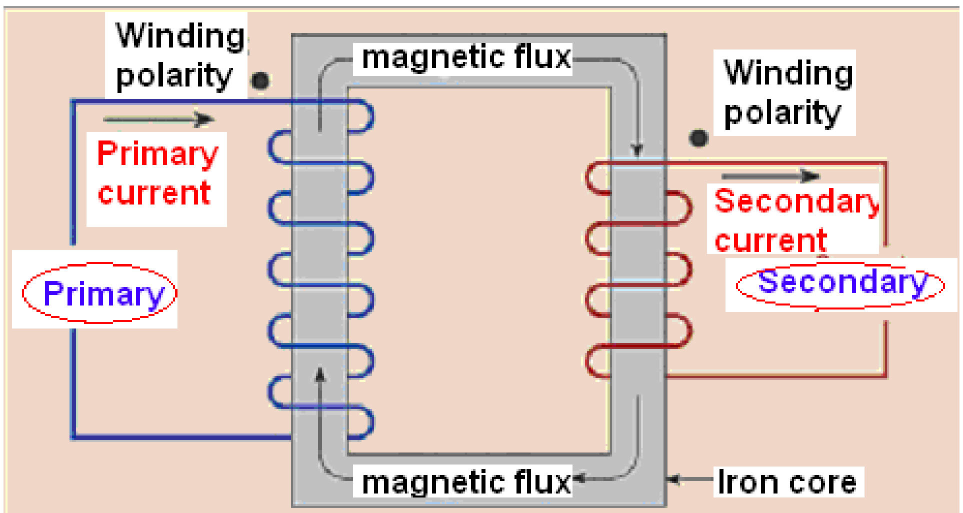



Figure (8) how transformer work

***F. Transformer Construction***

The simple elements of a transformer consist of two coils having mutual inductance and a laminated steel core. The two coils are insulated from each other and the steel core. Other necessary parts are some suitable container for assembled core and windings; a suitable medium for insulating the core and its windings from its container; suitable bushings (either of porcelain, oil filled or capacitor type) for insulating and bringing out the terminals of windings from the tank.

In all type of transformers, the core is constructed of transformer sheet steel laminations assembled to provide a continuous magnetic path with a minimum of air gap included. The steel used is of high silicon content, some times heat treated to produce a high permeability and low hysteresis loss at the usual operating flux densities. Laminating the core minimizes the eddy current loss, the laminations being insulated from each other by a light coat of core-plate varnish or by an oxide layer on the surface. The thickness of lamination varies from 0.35mm for a frequency of 50 Hz to 0.5 mm for a frequency of 25 Hz. The core laminations (in the form of strips) are joined.

The joints in the alternate layers are staggered in order to avoid the presence of narrow gaps right through the cross-section of the core. Such staggered joints are said to be 'Imprecated'. Constructional distinguished from each other merely by the manner in which the primary and secondary coils are placed around the laminated core. The two types are known as:

***1)*** **Core Type;**

***2)*** **Shell Type;**

In the so-called core type transformers, the windings surround a considerable part of the core. Where as shell type transformer, the core surrounds a considerable part of the windings.

In the simplified diagram for the core type transformers, the primary and secondary windings are shown located on the opposite legs of the core, but in actual construction, these are always interleaved to reduce leakage flux. As shown in the figure, half the primary and half the secondary windings have been placed side by side or concentrically on each limb, not primary on one limp and the secondary on the other. In both core and shell type transformers, the individual laminations are cut in the form of long strips of L's, E's and I's. In order to avoid high reluctance at the joints where the laminations are butted against each other, the alternate layers are stacked differently to eliminate these joints.

**Core-type transformer**

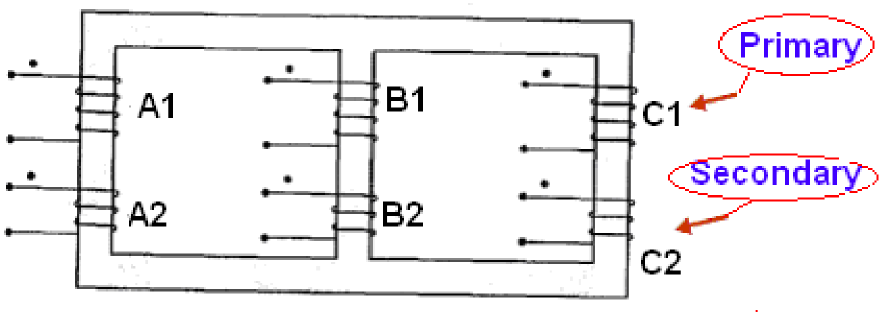



Figure (9) core type transformer

The coils are form-wound and are of cylindrical type. The general form of these coils may be circular or oval or rectangular. In small size core-type transformers, a simple rectangular core is used with cylindrical coils, which are either circular or rectangular in form. But for large size core-type transformers, round or circular coils are used which are so wound as to fit over a cruciform core section. The circular coils are used in most of the core-type transformers because of their mechanical strength. Such coils are wound in helical layers with different layers insulated from each other by paper, cloth, or cooling ducts. Since the low voltage (LV) winding is easiest to insulate, it is placed nearest to the core.

Because of lamination and insulation, the net or effective core area is reduced, due allowance for which has to be made. It is found that in general, the reduction in core cross-sectional area due to the presence of paper, etc. is of the order of 10% approx.

Rectangular cores with rectangular cylindrical coils can be used for small size core-type transformers. For large size transformers, circular cylindrical coils are preferred. Obviously, a considerable amount of useful space is wasted. A common improvement on square-core is to employ cruciform core which demands at least two sizes of core strips. For very large transformers, further core stepping is done which not only gives high space factor but also results in reduced length of the mean turn and consequent $I^2R$ loss.

**Shell-type transformers**

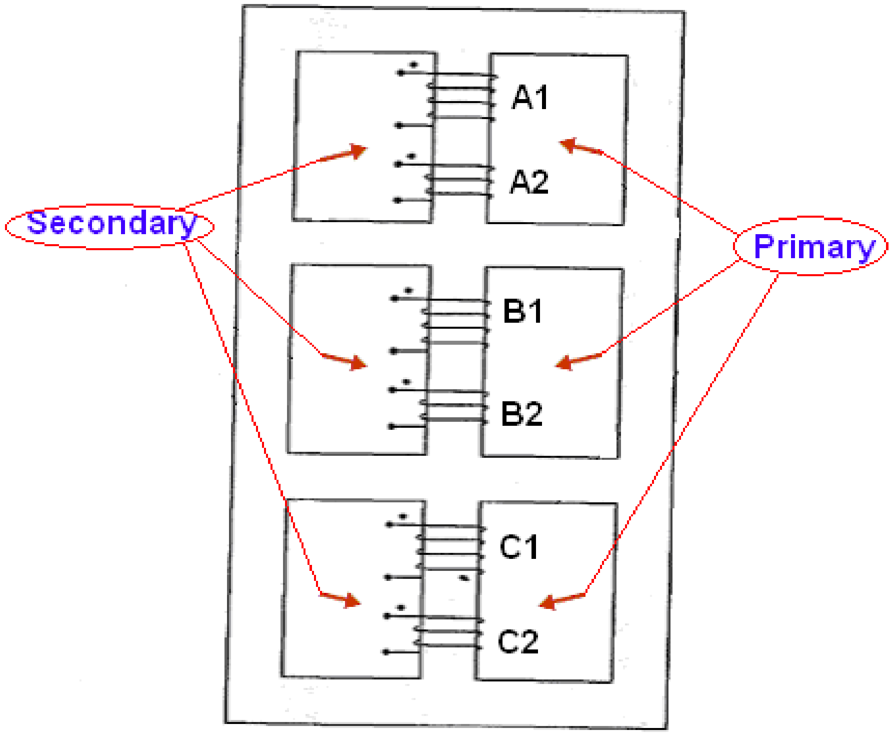



Figure (10) shell type transformer

The coils are form wound but are multilayer disc type usually wound in the form of pancakes. The different layers of such multilayer discs are insulated from each other by paper. The complete winding consists of stacked discs with insulation space between the coils, the spaces forming horizontal and cooling ducts.

It may be pointed out that cores and coils of transformers must be provided with rigid mechanical bracing in order to prevent movement and possible insulation damage. Good bracing reduces vibration and the objectionable noise _ a humming sound _ during operation.

The spiral _core transformer employs the newest development in core construction. The core is assembled of a continuous strip or ribbon of transformer steel wound in the form of a circular or elliptical cylinder. Such construction allows the core flux to follow the grain of the iron. Cold _ rolled steel of high silicon content enables the designer to use considerably higher operating flux densities with lower loss per kg. The use of higher flux density reduces the weight per KVA. Hence, the advantages of such construction are

A relatively more rigid core

Lesser weight and size per kVA rating

Lower iron losses at higher operating flux densities

Lower cost of manufacture.

**G. Mathematical Working of a Transformer**

An alternating voltage applied to primary circuit P circulates an alternating current through P and this current produces an alternating flux in the steel core. If the whole of the flux produced by P passes through secondary circuit S, the emf induced in each turn is the same for P and S. Hence, if $N_1$ and $N_2$ be the number-of turns on P and S respectively,

$$\frac{\text{Total em. induced in S}}{\text{Total emf. induced in P}} = \frac{N_2 \text{ x emf. per turn}}{N_1 \text{ x emf. per turn}} = \frac{N_2}{N_1}$$

When the secondary is on open circuit, its terminal voltage is the same as the induced emf. The primary current is then very small, so that the applied voltage $V_1$ is practically equal and opposite to the emf. induced in P. Hence:

$$\frac{V2}{V1} = \frac{N_2}{N_1}$$

Since the full-load efficiency of a transformer is nearly 100 percent,

$I_1V_1$ x primary power factor = $I_2$ $V_2$ x secondary power factor.

But the primary and secondary power factors at full load are nearly equal,

$$I_1 / I_2 = V_2 / V_1$$

An alternative and more illuminating method of deriving the relationship between the primary and secondary currents is based upon a comparison of the primary and secondary ampere-turns. When the secondary is on open circuit, the primary current is such that the primary ampere-turns are just sufficient to produce the flux necessary to induce an emf. that is practically equal and opposite to the applied voltage. This magnetizing current is usually about 3- 5 per cent of the full-load primary current.

When a load is connected across the secondary terminals, the secondary current by Lenz's Law produces a demagnetizing effect. Consequently the flux and the emf induced in the primary are reduced slightly. But this small change can increase the difference between the applied voltage and the emf. induced in the primary from, say, 0.05 pet cent to, say, 1 per cent, in which case the new primary current would be 20 times the no-load current.

The demagnetizing ampere-turns of the secondary are thus *nearly* neutralized by the increase in the primary ampere-turns; and since the primary ampere-turns on no load are very small compared with the full-load ampere-turns,

Full-load primary ampere-turns = full-load secondary ampere-turns,

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

It will be seen that the magnetic flux forms the connecting link between the primary and secondary circuits and that any variation of the secondary current is accompanied by a small variation of the flux and therefore of the emf. induced in the primary, thereby enabling the primary current to vary approximately proportionally to the secondary current. This balance of primary and secondary ampere-turns is an important relationship wherever transformer action occurs.

***Fundamentals of protection practice***

This is a collective term which covers all the equipment used for detecting, locating and initiating the removal of a fault from the power system. Relays are extensively used for major protective functions, But the term also covers direct-acting A.C. trips and fuses. In addition to relays the term includes all accessories such as current and voltage transformers, shunts, D.C. and A.C. wiring and any other devices relating to the protective relays.

In general, the main switchgear, although fundamentally protective in its function, is excluded from the term 'protective gear', as are also common services, such as the station battery and any other equipment required to secure operation of the circuit breaker.

In order to fulfil the requirements of discriminative protection with the optimum speed for the many different configurations, operating conditions and construction features of power systems, it has been necessary to develop many types of relay which respond to various functions of the power system quantities.

For example, observation simply of the magnitude of the fault current suffices in some cases but measurement of power or impedance may be necessary in others. Relays frequently measure complex functions of the system quantities, which are only readily expressible by mathematical or graphical means.

In many cases it is not feasible to protect against all hazards with any one relay. Use is then made of a combination of different types of relay which individually protect against different risks. Each individual protective arrangement is known as a 'protection system'; while the whole coordinated combination of relays is called a 'protection scheme'.

***Reliability***

The need for a high degree of reliability is discussed in Section 1. Incorrect operation can be attributed to one of the following classifications:

a. Incorrect design.

b. Incorrect installation.

c. Deterioration.

d. Protection performance

***1. Design***

This is of the highest importance. The nature of the power system condition which is being guarded against must be thoroughly understood in order to make an adequate design. Comprehensive testing is just as important, and this testing should cover all aspects of the protection, as well as reproducing operational and environmental conditions as closely as possible. For many protective systems, it is necessary to test the complete assembly of relays, current transformers and other ancillary items, and the tests must simulate fault conditions realistically.

***2. Installation.***

The need for correct installation of protective equipment is obvious, but the complexity of the interconnections of many systems and their relation-ship to the remainder of the station may make.

Difficult the checking of such correctness. Testing is therefore necessary; since it will be difficult to reproduce all fault conditions correctly, these tests must be directed to proving the installation. This is the function of site testing, which should be limited to such simple and direct tests as will prove the correctness of the connections and freedom from damage of the equipment.

No attempt should be made to 'type test' the equipment or to establish complex aspects of its technical performance;

***3. Deterioration in service.***

After a piece of equipment has been installed in perfect condition, deterioration may take place which, in time, could interfere with correct functioning. For example, contacts may become rough or burnt owing to frequent operation, or tarnished owing to atmospheric contamination; coils and other circuits may be open-circuited, auxiliary components may fail, and mechanical parts may become clogged with dirt or corroded to an extent that may interfere with movement.

One of the particular difficulties of protective relays is that the time between operations may be measured in years, during which period defects may have developed unnoticed until revealed by the failure of the protection to respond to a power system fault. For this reason, relays should be given simple basic tests at suitable intervals in order to check that their ability to operate has not deteriorated.

Testing should be carried out without disturbing permanent connections. This can be achieved by the provision of test blocks or switches.

Draw-out relays inherently provide this facility; a test plug can be inserted between the relay and case contacts giving access to all relay input circuits for injection. When temporary disconnection of panel wiring is necessary, mistakes in correct restoration of connections can be avoided by using identity tags on leads and terminals, clip-on leads for injection supplies, and easily visible double-ended clip-on leads where 'jumper connections' are required.

The quality of testing personnel is an essential feature when assessing reliability and considering means for improvement. Staff must be technically competent and adequately trained, as well as self-disciplined to proceed in a deliberate manner, in which each step taken and quantity measured is checked before final acceptance.

Important circuits which are especially vulnerable can be provided with continuous electrical super-vision; such arrangements are commonly applied to circuit breaker trip circuits and to pilot circuits.

***4. Protection performance***

The performance of the protection applied to large power systems is frequently assessed numerically. For this purpose each system fault is classed as an incident and those which are cleared by the tripping of the correct circuit breakers and only those are classed as 'correct'.

The percentage of correct clearances can then be determined.

This principle of assessment gives an accurate evaluation of the protection of the system as a whole, but it is severe in its judgment of relay performance, in that many relays are called into operation for each system fault, and all must behave correctly for a correct clearance to be recorded.

On this basis, a performance of 94 % is obtainable by standard techniques.

Complete reliability is unlikely ever to be achieved by further improvements in construction. A very big step, however, can be taken by providing duplication of equipment or 'redundancy'. Two complete sets of equipment are provided, and arranged so that either by itself can carry out the required function. If the risk of an equipment failing is **x**/unit, the resultant risk, allowing for redundancy, is $\mathbf{x^2}$. Where x is small the resultant risk ($\mathbf{x^2}$) may be negligible.

It has long been the practice to apply duplicate protective systems to bus-bars, both being required to operate to complete a tripping operation, that is, a 'two-out-of-two' arrangement. In other cases, important circuits have been provided with duplicate main protection schemes, either being able to trip independently, that is, a 'one-out-of-two' arrangement. The former arrangement guards against unwanted operation, the latter against failure to operate.

These two features can be obtained together by adopting a 'two-out-of-three' arrangement in which three basic systems are used and are interconnected so that the operation of any two will complete the tripping function.

Such schemes have already been used to a limited extent and application of the principle will undoubtedly increase. Probability theory suggests that if a power network were protected throughout on this basis, a protection performance of 99.98 % should be attainable.

This performance figure requires that the separate protection systems be completely independent; any common factors, such as, for instance, common current transformers or tripping batteries, will reduce the overall performance to a certain extent.

- ***Selectivity.***

Protection is arranged in zones, which should cover the power system completely, leaving no part unprotected. When a fault occurs the protection is required to select and trip only the nearest circuit breakers. This property of selective tripping is also called 'discrimination' and is achieved by two general methods:

1. Time graded systems.

Protective systems in successive zones are arranged to operate in times which are graded through the sequence of equipments so that upon the occurrence of a fault, although a number of protective equipments respond, only those relevant to the faulty zone complete the tripping function. The others make incomplete operations and then reset.

**2. Unit systems.**

It is possible to design protective systems which respond only to fault conditions lying within a clearly defined zone. This 'unit protection' or 'restricted Protection' can be applied throughout a power system and, since it does not involve time grading, can be relatively fast in operation.

Unit protection is usually achieved by means of a comparison of quantities at the boundaries of the zone. Certain protective systems derive their 'restricted' property from the configuration of the power system and may also be classed as unit protection.

Whichever method is used, it must be kept in mind that selectivity is not merely a matter of relay design.

It is a function of the correct co-ordination of current transformers and relays with a suitable choice of relay settings, taking into account the possible range of such variables as fault currents, maximum load current, system impedances and so on, where appropriate.

- **Zones of protection**

Ideally, the zones of protection should overlap across the circuit breaker as shown in Figure 2, the circuit breaker being included in both zones.

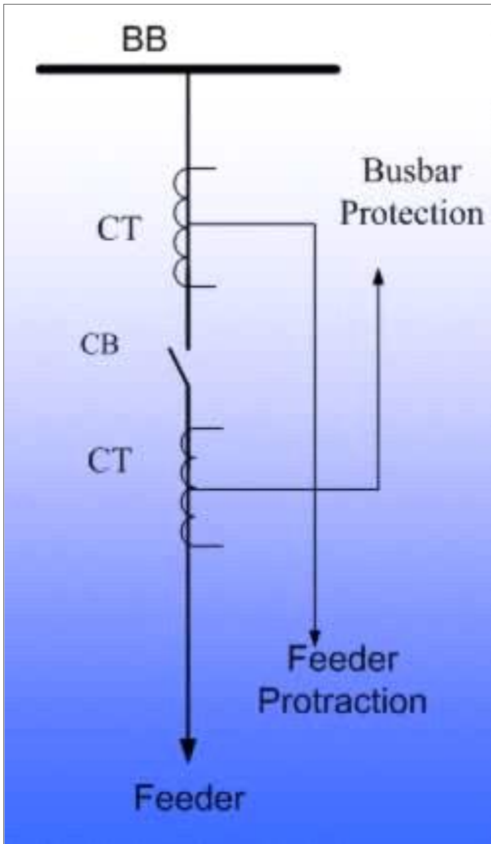



Figure **2.** Location of current transformers on both sides of the circuit breaker.

For practical physical reasons, this ideal is not always achieved, accommodation for current trans-formers being in some cases available only on one side of the circuit breakers, as in Figure 3. This leaves a section between the current transformers and the circuit breaker A within which a fault is not cleared by the operation of the protection that responds. In Figure 3 a fault at F would cause the bus-bar protection to operate and open the circuit breaker but the fault would continue to be fed through the feeder.

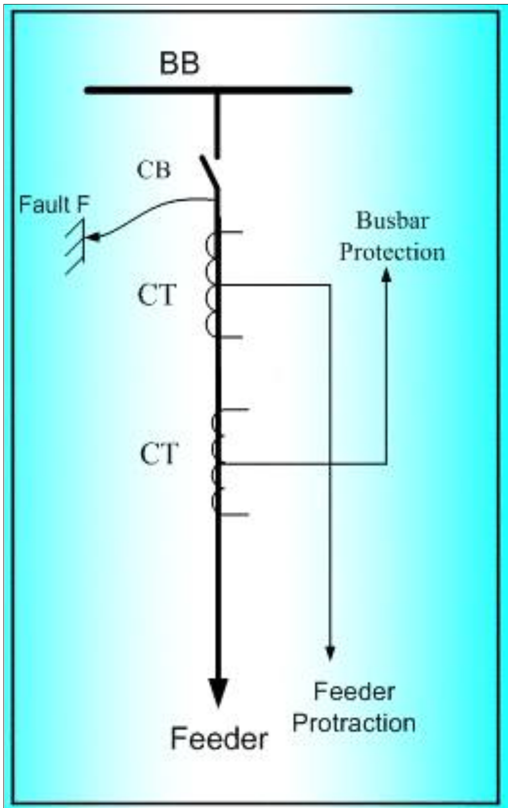



Figure **3** Location of current transformers on circuit side of the circuit breaker.

The feeder protection, if of the unit type, would not operate, since the fault is outside its zone. This problem is dealt. With by some form of zone extension, to operate when opening the circuit breaker does not fully interrupt the flow of fault current. A time delay is incurred in fault clearance, although by restricting this operation to occasions when the bus-bar protection is operated the time delay can be reduced.

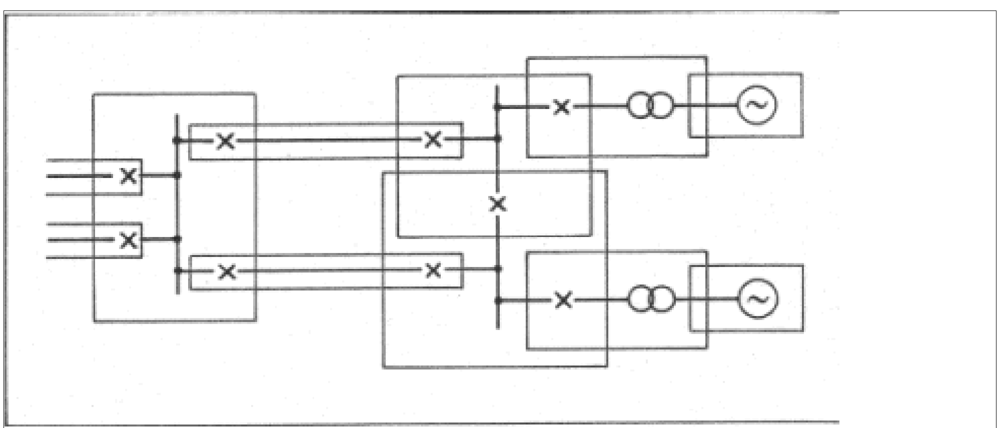


Figure **4** Overlapping zones of protection systems.

The point of connection of the protection with the power system usually defines the zone and corresponds to the location of the current transformers. The protection may be of the unit type, in which case the boundary will be a clearly defined and closed loop. Figure 4 illustrates a typical arrangement of overlapping zones.

Alternatively, the zone may be unrestricted; the start will be defined but the extent will depend on measurement of the system quantities and will therefore be subject to variation, owing to changes in system conditions and measurement errors.

**Stability.**

This term, applied to protection as distinct from power networks, refers to the ability of the system to remain inert to all load conditions and faults external to the relevant zone. It is essentially a term which is applicable to unit systems; the term 'discrimination' is the equivalent expression applicable to non-unit systems.

**Speed.**

The function of automatic protection is to isolate faults from the power system in a very much shorter time than could be achieved manually, even with a great deal of personal supervision. The object is to safeguard continuity of supply by removing each disturbance before it leads to widespread loss of synchronism, which would necessitate the shutting down of plant.

Loading the system produces phase displacements between the voltages at different points and therefore increases the probability that synchronism will be lost when the system is disturbed by a fault. The shorter the time a fault is allowed to remain in the system, the greater can be the loading of the system. Figure 1.5 shows typical relations between system loading and fault clearance times for various types of fault.

It will be noted that phase faults have a more marked effect on the stability of the system than does a simple earth fault and therefore require faster clearance.

It is not enough to maintain stability; unnecessary consequential damage must also be avoided. The destructive power of a fault arc carrying a high current is very great; it can burn through copper conductors or weld together core laminations in a transformer or machine in a very short time. Even away from the fault arc itself, heavy fault currents can cause damage to plant if they continue for more than a few seconds

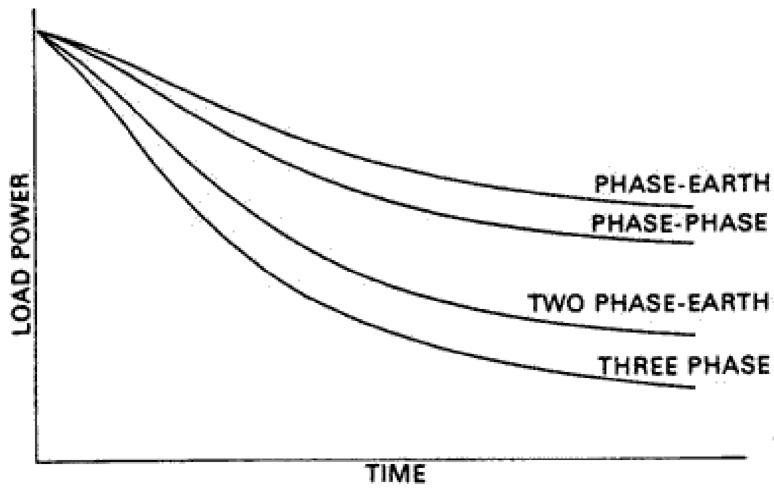



Figure **5** Typical values of power that can be transmitted as a function of fault clearance time.

It will be seen that protective gear must operate as quickly as possible; speed, however, must be weighed against economy.

For this reason, distribution circuits for which the requirements for fast operation are not very severe are usually protected by time-graded systems, but generating plant and EH**V** systems require protective gear of the highest attainable speed; the only limiting factor will be the necessity for correct operation.

**Sensitivity**

Sensitivity is a term frequently used when referring to the minimum operating current of a complete protective system. A protective system is said to be sensitive if the primary operating current is low.

When the term is applied to an individual relay, it does not refer to a current or voltage setting but to the volt-ampere consumption at the minimum operating current.

A given type of relay element can usually be wound for a wide range of setting currents; the coil will have an impedance which is inversely proportional to the square of the setting current value, so that the volt-ampere product at any setting is constant.

This is the true measure of the input requirements of the relay, and so also of the sensitivity. Relay power factor has some significance in the matter of transient performance.

For D.C. relays the VA input also represents power consumption, and the burden is therefore frequently quoted in watts.

Primary and back-up protection

The reliability of a power system has been discussed in earlier sections. Many factors may cause protection failure and there is always some possibility of a circuit breaker failure. For this reason, it is usual to supplement primary protection with other systems to 'back-up' the operation of the main system and ensure that nothing can prevent the clearance of a fault from the system.

Back-up protection may be obtained automatically as an inherent feature of the main protection scheme, or separately by means of additional equipment.

Time graded schemes such as over current or distance protection schemes are examples of those providing inherent back-up protection; the faulty section is normally isolated discriminatively by the time grading, but if the appropriate relay fails or the circuit breaker fails to trip, the next relay in the grading sequence will complete its operation and trip the associated circuit breaker, thereby interrupting the fault circuit one section further back. In this way complete back-up cover is obtained; one more section is isolated than is desirable but this is inevitable in the event of the failure of a circuit breaker.

Where the system interconnection is more complex, the above operation will be repeated so that all parallel infeeds are tripped.

If the power system is protected mainly by unit schemes, automatic back-up protection is not obtained, and it is then normal to supplement the main protection with time graded over current protection, which will provide local back-up cover if the main protective relays have failed, and will trip further back in the event of circuit breaker failure.

Such back-up protection is inherently slower than the main protection and, depending on the power system configuration, may be less discriminative. For the most important circuits the performance may not be good enough, even as a back-up protection, or, in some cases, not even possible, owing to the effect of multiple infeeds. In these cases duplicate high speed protective systems may be installed. These provide excellent mutual back-up cover against failure of the protective equipment, but either no remote back-up protection against circuit breaker failure or, at best, time delayed cover.

Breaker fail protection can be obtained by checking that fault current ceases within a brief time interval from the operation of the main protection. If this does not occur, all other connections to the bus bar section are interrupted, the condition being necessarily treated as a bus bar fault. This provides the required back-up protection with the minimum of time delay, and confines the tripping operation to the one station, as compared with the alternative of tripping the remote ends of all the relevant circuits.
The extent and type of back-up protection which is applied will naturally be related to the failure risks and relative economic importance of the system. For distribution systems where fault clearance

Times are not critical, time delayed remote back-up protection is adequate but for EH**V** systems, where system stability is at risk unless a fault is cleared quickly, local back-up, as described above, should be chosen.

Ideal back-up protection would be completely independent of the main protection. Current trans-formers, voltage transformers, auxiliary tripping relays, trip coils and D.C. supplies would be duplicated. This ideal is rarely attained in practice. The following compromises are typical:

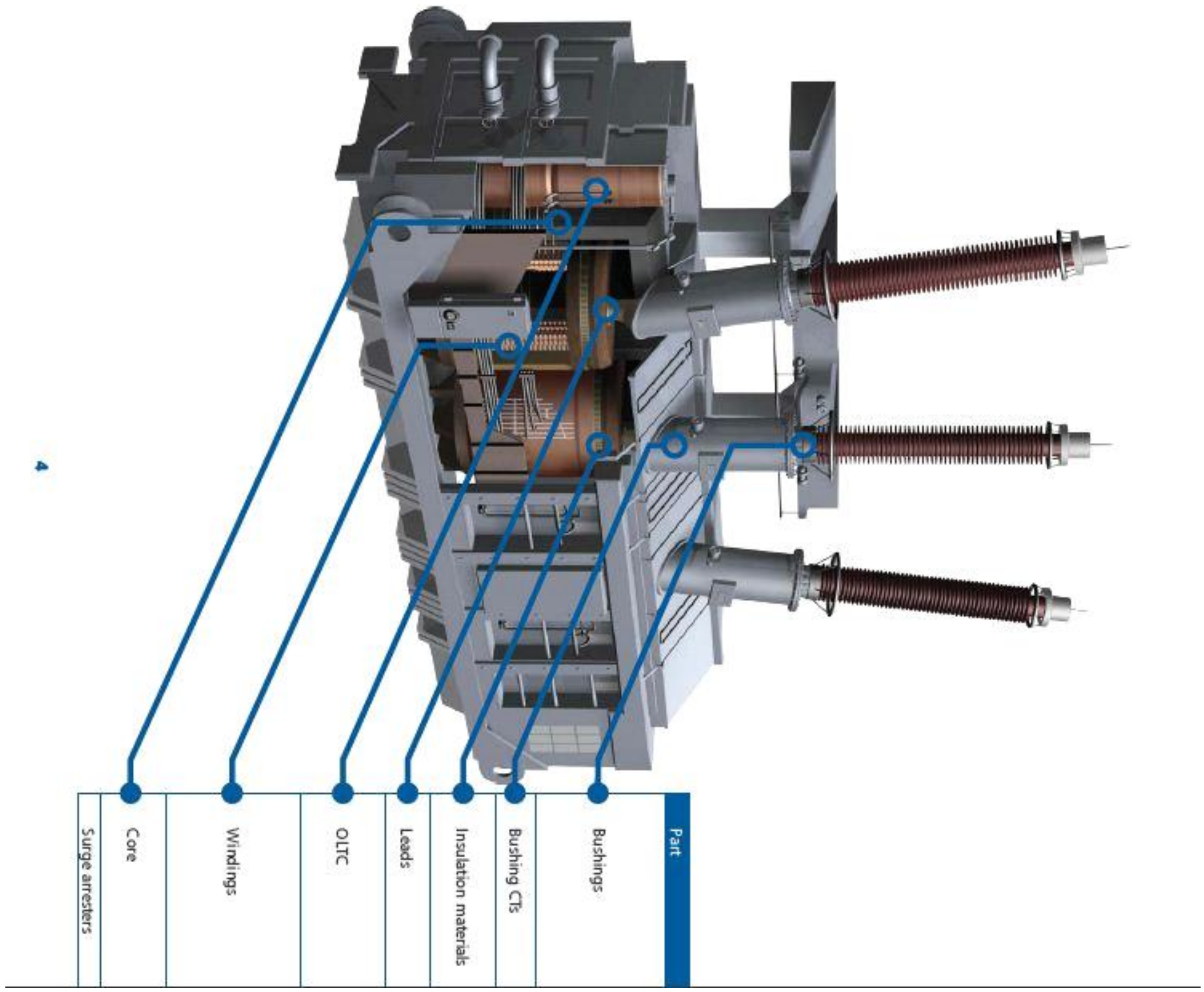
a. Separate current transformers (cores and secondary windings only) are used for each protective system, as this involves little extra cost or accommodation compared with the use of common current transformers which would have to be larger because of the combined burden.

b. Common voltage transformers are used because duplication would involve a considerable increase in cost, because of the voltage transformers them-selves, and also because of the increased accommodation which would have to be provided. Since security of the VT output is vital, it is desirable that the supply to each protection should be separately fused and also continuously supervised by a relay which will give an alarm on failure of the supply and, where appropriate, prevent an unwanted operation of the protection.

c. Trip supplies to the two protections should be separately fused. Duplication of tripping batteries and of tripping coils on circuit breakers is sometimes provided. Trip circuits should be continuously supervised.

d. It is desirable that the main and back-up protections (or duplicate main protections) should operate on different principles, so that unusual events that may cause failure of the one will be less likely to affect the other.

The Power Transformer is one of the most important links in a power transmission and distribution system. A Transformer fault will cause a large interruption in power supplies the impact is more serious than a transmission line outage and also cause damage to power system stability.




Transformer protection falls under two major categories:

Protection of the system against the effects of faults arising inside the transformer.

Protection of the transformer against the effect of faults occurring on any part of the system (external).

## FAULTS INTERNAL TO THE TRANSFORMER

Earth faults

Phase to Phase faults

Inter turn faults

Core faults

Tank faults

EARTH FAULTS:

In this case, the fault current is controlled mainly by the leakage reactance of the winding and generally the currents are of high magnitude.

PHASE – TO – PHASE FAULTS:

Faults between phases within a transformer are relatively rare, if such a fault does occur it will give rise to a substantial current compared to the earth fault current.

INTER – TURN FAULTS:

A high voltage transformer connected to an overhead transmission system is very likely to be subjected to step fronted impulse voltages. Hence the risk of partial winding flash over is high. It is opined that 70% to 80% of all transformer failures arise from faults between turns or inter turn faults.

A short circuit of a few turns of the winding will give raise to heavy faults current in the short-circuited loop, but the impact on terminal currents will be very small because of the high ratio of transformation between the whole windings and the short circuited turns.

CORE FAULTS:

If any portion of the core insulation becomes defective, it will cause sufficient eddy currents to flow, causing serious overheating, which may reach a magnitude sufficient to damage the winding.

The additional core-loss, although causing severe local heating, will not produce a noticeable change in input current and could not be detected by normal electrical protections. However, it is very much essential to detect this condition before a major fault has been created.

Fortunately, in an oil immersed transformer, the local heating will cause breakdown of some of the oil with an accompanying evolution of gas, which will escape towards the conservator. These are detected by a bucholz relay. Even much earlier detection is possible using DGA.

TANK FAULTS:

Loss of oil through tank leak, failure of welded joints etc. may lead to a dangerous condition.

EXTERNAL SYSTEM CONDITIONS:

Over-load

System faults (phase to phase/ phase to earth)

Over voltage

Reduced system frequency.

OVERLOAD

Over load causes increased copper loss and a consequent temperature rise.

Overloads can be allowed for limited period depending on the initial temperature and the cooling conditions.

System short circuits produce a relatively intense rate of heating of the feeding transformers, the copper loss increasing in proportion to the square of the per unit fault current.

Large fault currents produce severe mechanical stresses in transformers; the maximum stress occurs during the first cycle of asymmetric faults current and so cannot be arrested by automatic tripping of the circuit.

Hence the control of such stresses is to be taken care of at the time of design itself.

Transformer needs to be protected from feeding external phase to phase and phase to ground faults on connected 400kV or 220kV system.

These faults include unclear faults in 220kV system and 400kV system. Backup directional OC protection is used.

The protection to be coordinated properly to operate with a time delay to avoid unwanted tripping of ICT for external faults.

OVER VOLTAGE

Over Voltage conditions are of two types:

1.Transient Surge Voltage: Transient over voltages arise from switching and lightning disturbances and are liable to cause inter- turn faults

2. Power Frequency Over-voltage: Power frequency over voltage causes both an increase in stress on the insulation and a proportionate increase in the working flux.

MAGNETISING INRUSH:

The phenomenon of magnetizing inrush is a transient condition, which occurs primarily when a transformer is energized.

It is not a fault condition and therefore does not necessitate the operation of protection, which on the contrary must remain stable during the inrush transient, which is a major factor that is to be taken care of in the design of transformer protection.

Magnetizing inrush wave has the following harmonics

1. 2nd harmonic – 63 %
2. 3rd harmonic – 27 %
3. 4th harmonic – 5%
4. 5th harmonic – 4%

<u>OVER HEATING PROTECTION</u>

The rating of a transformer is based on the temperature rise above assumed maximum ambient temperature.

At a lower ambient temperature some degree of overload can be safely applied.

Short period overloads are also permissible to an extent dependent on the previous loading conditions.

NORMAL PROTECTIONS FOR TRANSFORMER

Differential Protection : DTH31,RADSB,RADHA

Ground Fault Protection : CAG14, RADHD

Over Current Protection : CDD,RXIG

Over Load Protection : VTU,RXEG

Over Fluxing Protection : GTT,RATUB

Buchholz Relay (OLTC & Main Tank)

Pressure Relief Device

Oil and Winding temp alarms and trips

Oil Level Monitoring (MOLG)

**Transformer differential protection**

CT secondary connections must be compensated for phase shift due to vector group.

CT ratio must be chosen to suit the tap changing variations .

The effect of Magnetizing Inrush current during energization to be taken care.

Out of balance current due to above is much higher than the normal setting.

BIAS is introduced to ensure the stability of relay under the above conditions.

Stable for through fault current.

Auxiliary CT is introduced to match the CT ratios

H. The second harmonic content is filtered and relay is made non operative when the 2nd harmonic is >20%.

I. The differential element has a fixed setting of 15% of the rated current - ie. for 1A relay the pick-up value is 150 mA.

J. The bias setting is adjustable to 15%, 30% or 45% by varying the plug settings.

K. The instantaneous high set unit pick up setting is 10 times the rated current - ie. for a 1A relay, the setting is 10A.

**Restricted earth fault current**

Adequate earth fault sensitivity is difficult in differential protection.

An operating current sensitivity of atleast 10% of nominal current.

Tuned to the system frequency

High or low impedance principle.

Suitable non-linear resistor to limit the peak voltage during in-zone faults in case of high impedance principle.

Delta connected transformers are protected with REF by using Earthing transformer.

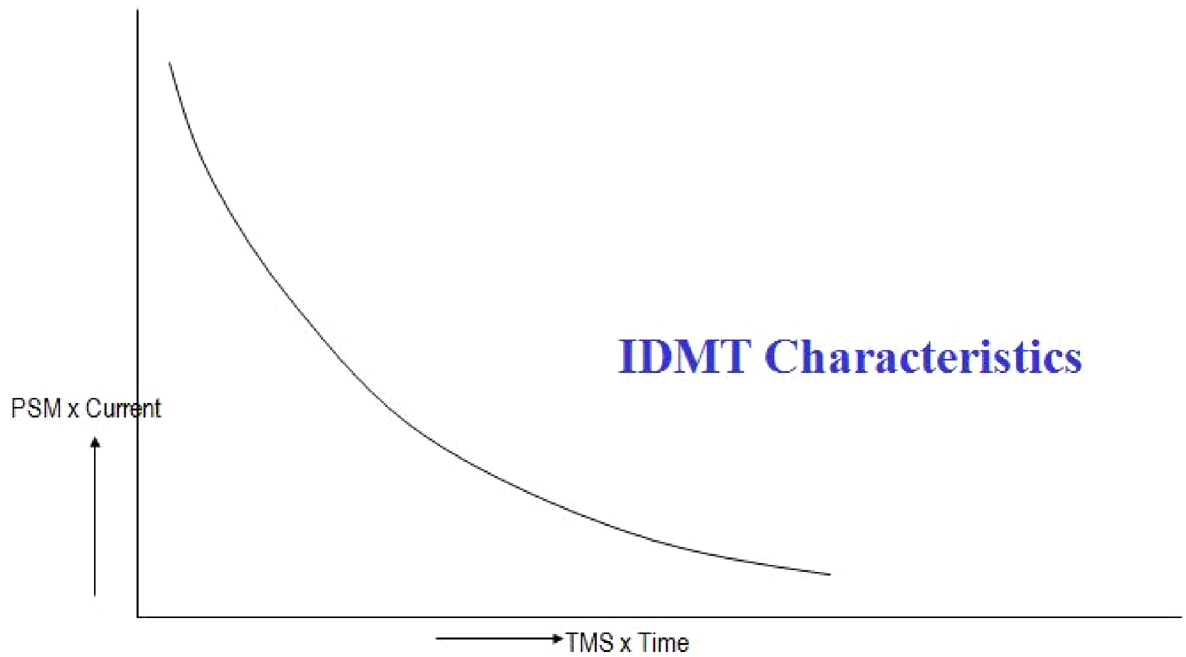
**Back up over current and earth fault protection**

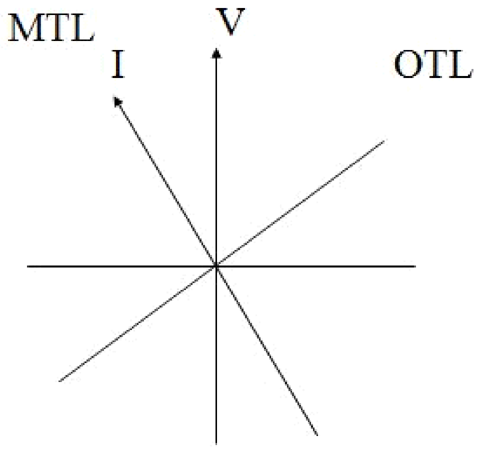
Inverse Definite Min Time (IDMT) relays with directional element as well as O/C instantaneous element are used.

Three Directional O/C Relays + One Directional E/F relay on each side of Transformer are provided (Total 8 relays)

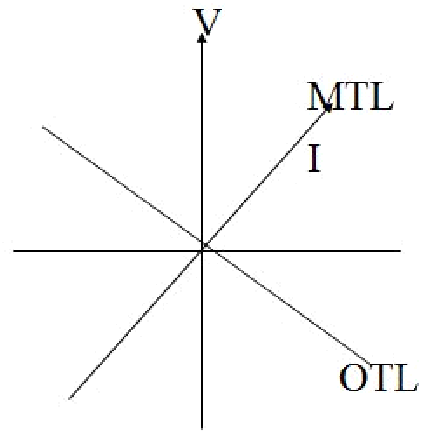
PT voltage required for O/C relays is taken from connected bus through a PT voltage selection relay, which is a latch relay being operated by isolator contact.

All the relays are made to look towards transformer





O/C Relays



E/F Relays

**Transformer maintenance**

The politic change in some companies had a great influence in maintenance and operation works in their electric machines. Those, have seen many times a decrease in maintenance works allowing a cost decrease in a short term but generating a greater risk of use of them in a mean and long term. The operating conditions also have changed in the sense of taking the maximum advantage of each machine making it work at the maximum possible ratings and some times above nominal values. This situation trends to premature age the machine fleet and if those are not part of a minimum maintenance program detecting risk situations or load limitation, the resultant situation will lead in a mean time to an irregular manoeuvre field (breakdowns, forced outages, supply interruptions…) that today are so usual and negative to the end customer.

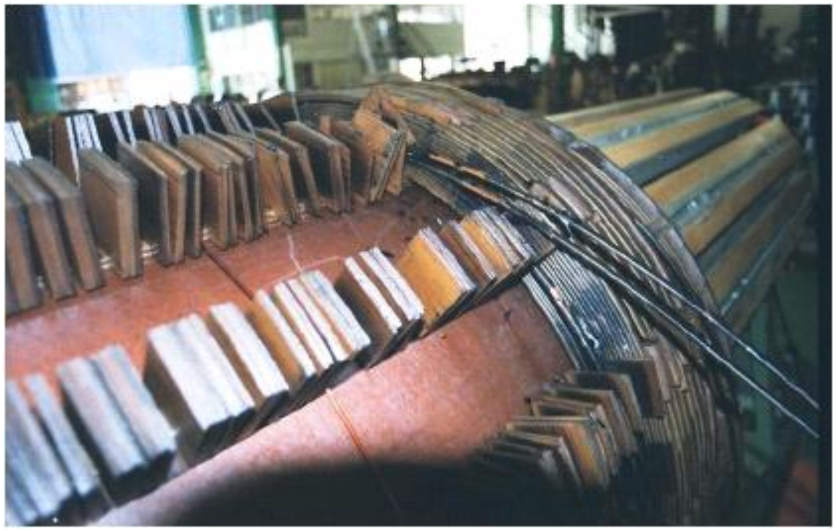


FIG 1. Breakdown of the dielectric system in a power transformer column. Courtesy from Electric Works Molina, Córdoba.

Power transformer is an electric machine with a useful life cycle of some 30 years. This doesn't mean to say that cannot be used above this time, in fact, a great part of the electric and industrial fleet is being operated with reliable machines above this time.
The really important fact is to know the status and evolution of the transformer to be in conditions to operate it with the maximum security and know if it is appropriate to continue it's use, know overload capacity, limit load, refurbish it or either take it out from active service.
There is a group of maintenance techniques that from an electric point of view and through some field tests are going to allow us to trace the transformer status as indicated and in the case of breakdown diligently detect the real problem and perform the required actions.


FIG 2. Field testing of a power transformer before putting into service (50MVA).

**POWER TRANSFORMERS FIELD TESTING.**

As a result of the owner company, the importance of the machine and the outage possibilities, it is necessary to perform on each transformer a fitted maintenance program with a test protocol previously accorded. Next will be indicated a series of test that can set up this program and that are something like a continuation of validation tests performed when manufacturing the transformer but adapted to field testing.

We have to take under account that in the field, in transformer installations, is not usually possible to have bulky equipments, what states certain limitations to field test with respect to manufacturing ones.

Described tests are chosen from the commercially available ones, standardized and usual into test programs.

## MAGNETIC / ELECTRIC CIRCUIT TESTS.

Those will be performed wit portable instrumentation (easily transported in vehicle/test van) of a series of measurements that allow obtaining base parameters from the transformer. It will be studied the punctual status to perform a diagnose and parameter trending values to perform scheduled works. All this tests are off-line.

Electric/Magnetic field testing:

· No-load test. Turns Ratio (TTR). Polarity, connection group y excitation current.

· Load test (short circuit test, impedance measurement).

· Winding resistance.

· Frequency response analysis (FRA).

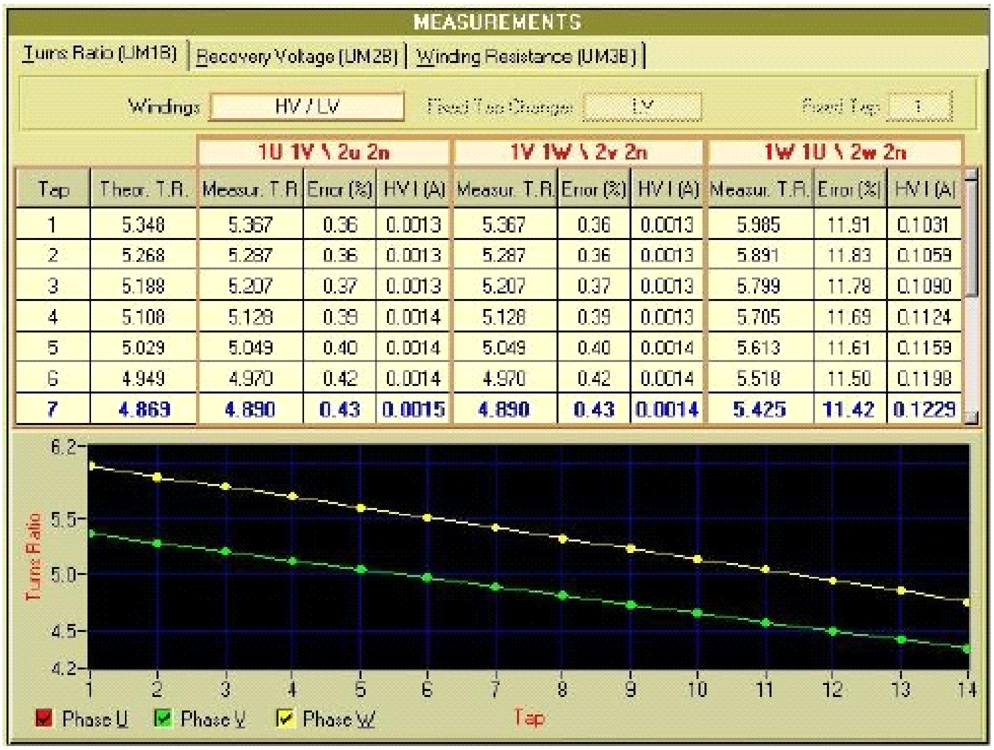
**- No-load test. Turns Ration. Polarity, connection group and excitation current.**

This test usually known as "no load" test and involves inserting an alternating voltage in the high voltage winding of the transformer in each of it's phases with low voltage side open. With the result values can be obtained basic parameters from the transformer:

Transformer Turns Ratio (TTR): quotient between high voltage / low voltage. Must match with protocol /nameplate values.

FIG 3. Monophase transformer turns ratio unit, from Megger Company, model TTR100.

In the power transformer with tap changer you will take advantage to make the register of each position from it giving extra information on its status and that of the On Line Tap Changer (OLTC). This measurement will directly inform of the existence of shorts between turns.



MEASUREMENTS

Turns Ratio (UM1B) | Recovery Voltage (UM2B) | Winding Resistance (UM3B)

Windings: HV / LV

| Tap | Theor. T.R. | 1U 1V \ 2u 2n Measur. T.R. | Error (%) | HV I (A) | 1V 1W \ 2v 2n Measur. T.R. | Error (%) | HV I (A) | 1W 1U \ 2w 2n Measur. T.R. | Error (%) | HV I (A) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.348 | 5.367 | 0.36 | 0.0013 | 5.367 | 0.36 | 0.0013 | 5.985 | 11.91 | 0.1031 |
| 2 | 5.268 | 5.287 | 0.36 | 0.0013 | 5.287 | 0.36 | 0.0013 | 5.891 | 11.83 | 0.1059 |
| 3 | 5.188 | 5.207 | 0.37 | 0.0013 | 5.207 | 0.37 | 0.0013 | 5.799 | 11.78 | 0.1090 |
| 4 | 5.108 | 5.128 | 0.39 | 0.0014 | 5.128 | 0.39 | 0.0013 | 5.705 | 11.69 | 0.1124 |
| 5 | 5.029 | 5.049 | 0.40 | 0.0014 | 5.049 | 0.40 | 0.0014 | 5.613 | 11.61 | 0.1159 |
| 6 | 4.949 | 4.970 | 0.42 | 0.0014 | 4.970 | 0.42 | 0.0014 | 5.518 | 11.50 | 0.1198 |
| **7** | **4.869** | **4.890** | **0.43** | **0.0015** | **4.890** | **0.43** | **0.0014** | **5.425** | **11.42** | **0.1229** |



FIG 4.

Results of a turns ratio test determining a short circuit between turns at low voltage side. Diagnose software from ETP system (TRR unit UM1B from UNITRONICS). Red and green phases over imposed, yellow separated.

Polarity / connection group. Connection group can also be checked with the previous results and aided with voltage diphase between high / low voltage.

FIG 5. 3-phase Transformer Turns Ratio Meter Unit from UNITRONICS Company, model UM1B.

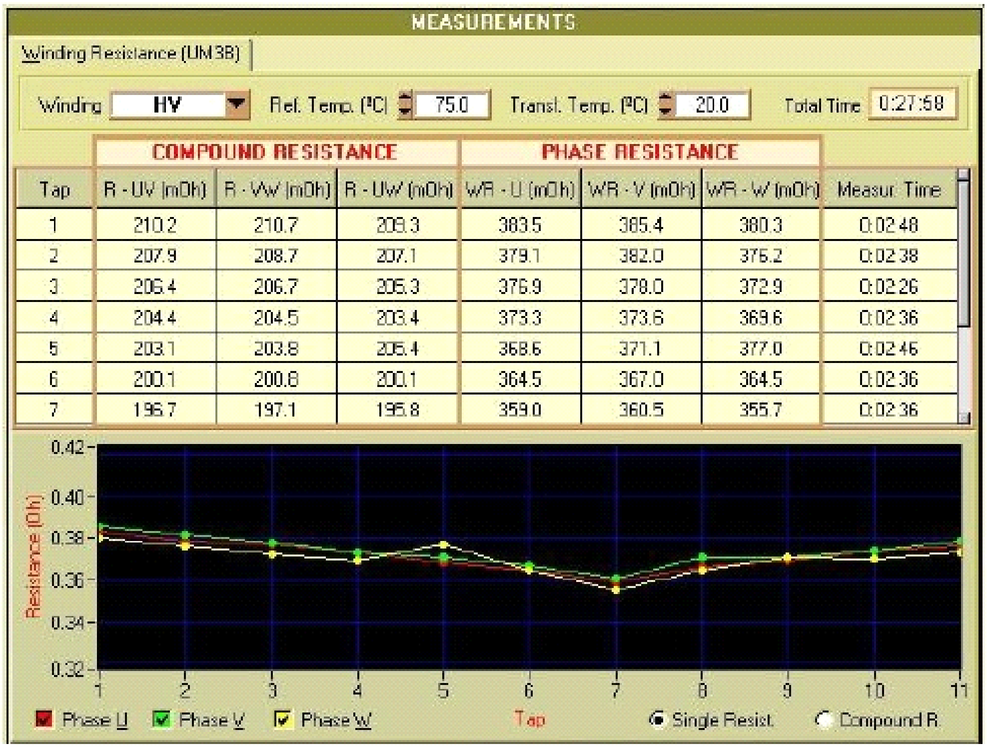
Excitation current. It's the current flowing into the high voltage winding with the low voltage side open. This current should be proportional to the No-load acceptance test but with the difference resultant from the use of test voltages different from nominal values.


FIG 6. Transformer Turns Ratio Meter Unit from Megger Company, model TTR

It shouldn’t exist excessive deflection from values measured between phases and its normal a slight difference (geometric) between extreme and central windings. It will exist great changes when appear heat points, degradation in the magnetic package, loose core or detached magnetic shunt.

**- Load test (short circuit test, Impedance measurement).**

This test usually known as “short circuit test” is based in the insertion of a voltage in one winding (high voltage one) with the other winding short-circuited. This test simulated the factory one but its not at all comparable in results because of not flowing nominal values. It is usual to register nominal and extreme positions if the transformer had an OLTC.




| Tap | R - UV (mOh) | R - VW (mOh) | R - UW (mOh) | WR - U (mOh) | WR - V (mOh) | WR - W (mOh) | Measur. Time |
|---|---|---|---|---|---|---|---|
| 1 | 210.2 | 210.7 | 208.3 | 383.5 | 385.4 | 380.3 | 0:02:48 |
| 2 | 207.9 | 208.7 | 207.1 | 379.1 | 382.0 | 376.2 | 0:02:38 |
| 3 | 206.4 | 206.7 | 205.3 | 376.9 | 378.0 | 372.9 | 0:02:26 |
| 4 | 204.4 | 204.5 | 203.4 | 373.3 | 373.6 | 369.6 | 0:02:36 |
| 5 | 203.1 | 203.8 | 205.4 | 368.6 | 371.1 | 377.0 | 0:02:46 |
| 6 | 200.1 | 200.8 | 200.1 | 364.5 | 367.0 | 364.5 | 0:02:36 |
| 7 | 196.7 | 197.1 | 195.8 | 359.0 | 360.5 | 355.7 | 0:02:36 |

FIG 7. 3phase short circuit impedance unit from UNITRONICS company, model UM5B.

Short circuit voltage. This parameter usually expressed in % and identified in the nameplate of the transformer is the extrapolated result from the test voltage to

nominal voltage and should be near the protocol /nameplate value from the transformer. It's change will indicate irregularities in the magnetic core, winding displacement, short-circuits, mechanical deformations…

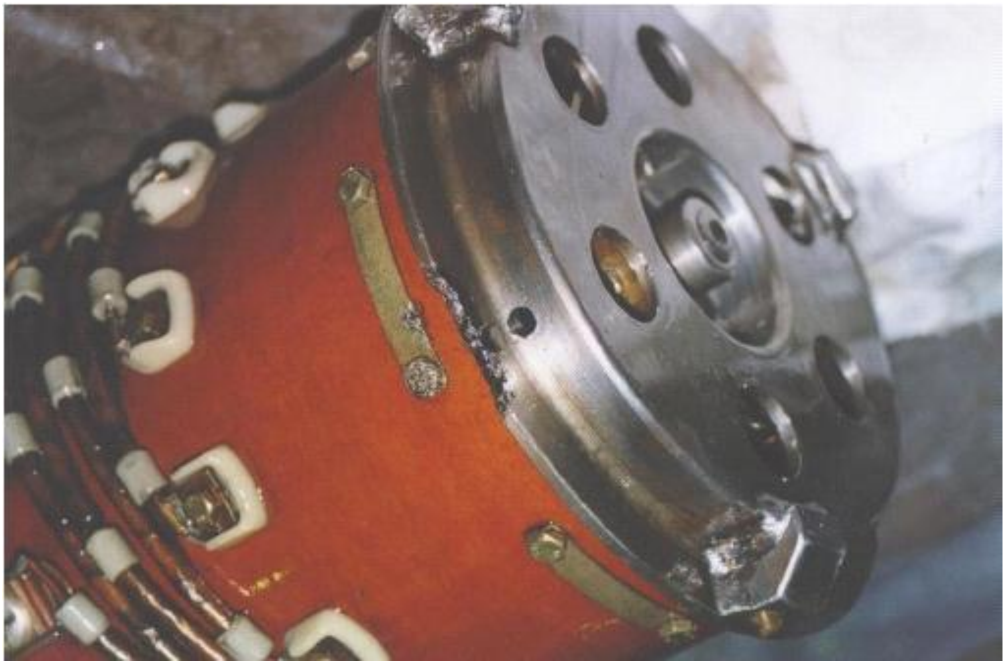


FIG 8. Results screen from a short circuit test (unit UM5B, UNITRONICS company) indicating changes in the geometric circuit.

**- Winding Resistance.**

With this test we search determinate the pure ohmic resistance from each phase windings both in high and low voltage and it exist a tap changer in each position. What in a first approach can be easy to measure, its not so, because it is necessary to make flow relatively high currents to register the usual low resistance values µW/mW/W with the required precision. This currents must also flow through the equivalent inductances of the transformer.

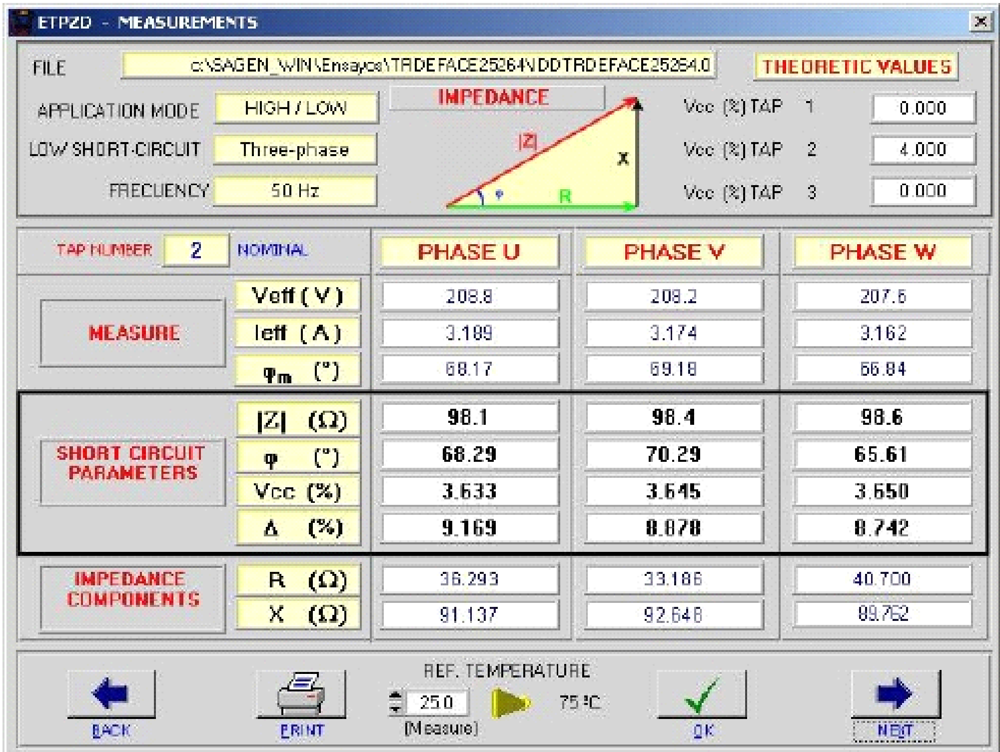



FIG 9. Results from a Winding resistance test showing a problem in the high voltage winding (system UM3B, UNITRONICS Company).

The high inductive character of power transformers (Equivalent L and magnetic core) implicates magnetization time and measurement stabilization should be taken under account while determination the measurement end and give the results.


FIG 10. 3-phase winding resistance meter from UNITRONICS Company, model UM3B.

This has more relevance in high power transformers or from special designs olta configurations

**DIELECTRIC SYSTEM TESTS.**

One of the operating key elements in the power transformer and the one determining its remaining useful life is the dielectric. Dielectric could be split in: liquid dielectric (usually mineral oil) in which we'll have certain manipulation degree trough possible treatments and solid dielectric (paper) in which our work is limited only to the external indirect check of it's status. As a function of the maintenance policy of the owner company, the importance of the machine and the tolerable failure risk, its suitable to perform on it tests with a previously accorded program and protocol. Maintenance programs will give as a result a bigger knowledge of the status and availability of transformers. In a long term, this will translate in a very important concept: "Extension of the life of Power Transformers".

In this section we will insist in the electric detection methods although we will also comment that there are another focused to laboratory and related to oil sampling.

**ELECTRIC TESTS TO TvHE DIELECTRIC CIRCUIT.**

It is a group of test that with measuring electronic instrumentation that can give a punctual status evaluation of the dielectric in the power transformer. We will describe the most usual test. Again, all they will be off-line (transformer out of service) apart from the indicated exceptions.

7. Insulation Resistance and Polarization Index (IR, PI).
8. Recovery voltage Measurement (RVM) and time constant.
9. Capacitance, Dissipation (power) factor (tan δ) and insulation losses in dielectric/ bushing.
10. Partial Discharge (PD).
11. Oil sampling.
12. Dielectric Strength.
13. Moisture content.
14. Dissolved Gases.
15. Furnan Analysis.

**- Insulation Resistance.**

This test has been the most usual historically, being called to "megger" the transformer (the term comes from the firm of the first Megger systems).

This test is performed on a measuring tester able to generate high continuous voltages usually of 5000V that applied between both dielectric terminals of the power transformer (one terminal to all the bushings joined in high voltage, the other to low voltage and ground) allow evaluating the punctual dielectric status inside. The tester has a high voltage tester operating from batteries or from the main. Measuring principle is based in measuring current / voltage in a continuous way that evolves as an answer to a voltage step.

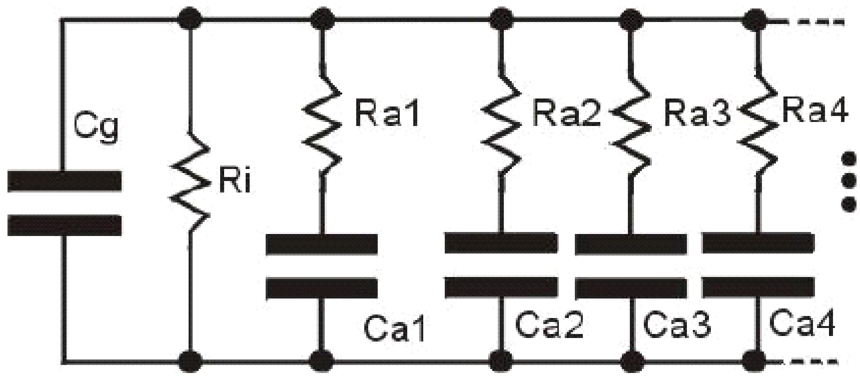
Insulation Resistance will be the quotient between voltage and current at the end of minute 1 of the test (~Ri in figure 18). This parameter should be above a minimum normalized value. It contains direct information from the dielectric system status in the transformer, but is very influenced by temperature (and should be temperature normalized / corrected). So, its usual another parameter named Polarization Index (PI). To measure it, the test is extended from minute 1 to minute 10, being PI, the quotient of currents in both time instants. This value is now independent from temperature and should be comparable in consecutive tests.

### Recovery Voltage Measurement (RVM).

Other approach to get a generic knowledge of the dielectric status inside the transformer (paper-oil) is with recovery voltage testing. With this test is obtained the polarization spectrum of the dielectric mixing information both of dissolved humidity and components degeneration.

Any dielectric can be simulated with an equivalent diagram as from figure

Recovery voltage testing pursues determining “temporal spectrum” of the different circuits Ra/Ca who include information of moisture/degradation in the dielectric.Test is performed with the circuit from figure 19. It has several charge / discharge steps of the dielectric from a continuous voltage source V whose result composes a plot spectrum named polarization spectrum. Each point comes from a charge process while a time T (S1 closed and S2 open) of the sample and discharges in a time T/2 (S1 open and S2 closed). Finally an electrometer (E= very high impedance voltmeter)registers the point as the maximum of the recovery voltage curve given by the Ra/Ca.




13

The final plot follows the equivalent spectra of all the Ra/Ca related to the circuit in figure . The appearance of the plot and the position of the maximum areindicative of the final quality of the dielectric paper / oil. Greater moisture = bigger deflection of the maximum to the left in the time axis.

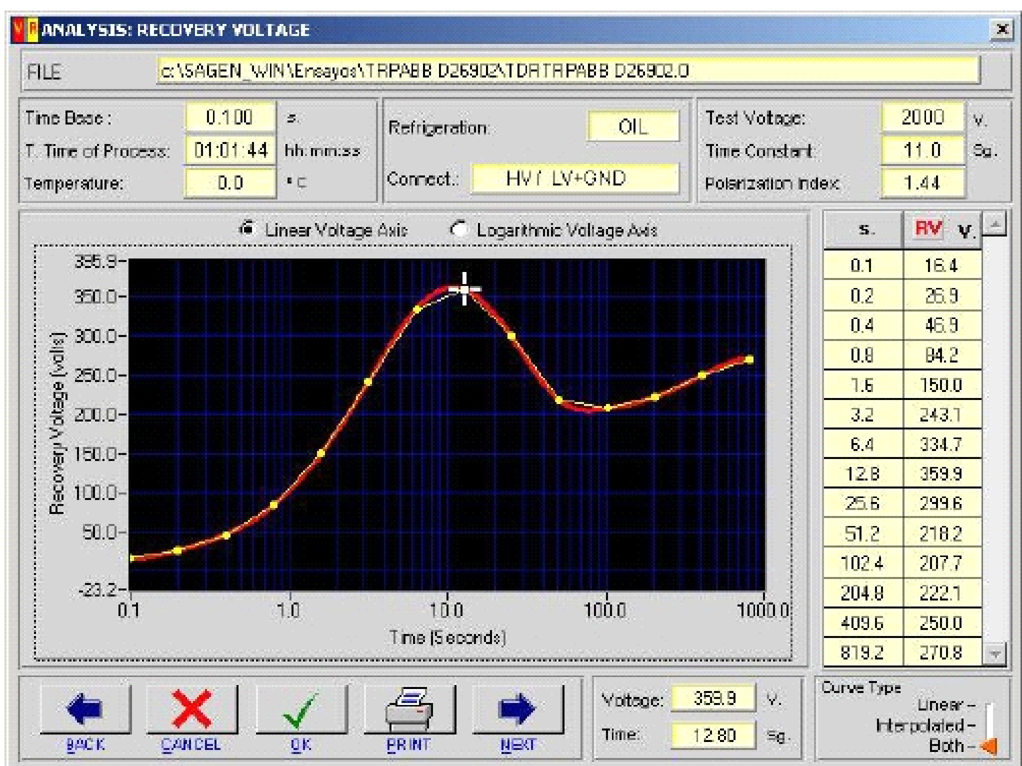


FIG .

Test screen from Unitronics RVM UM2B.

Test voltage has standardized in 2kV to be comparable and applicable to all power / power / distribution oil submerged transformers. In figure 20 screen you can see inhorizontal axis cycle and in vertical axis maximum per cycle of recovery voltage. In figure . system, apart from RVM test, includes in a time cycle greater than 10 minutes insulation resistance, polarization index and resistance evolution plot.

### Capacitance / Tan delta ( Dissipation Factor) & dielectric losses /bushings).

Another usual approach when performing dielectric evaluation is tan delta. This test uses AC and pursues to know loss angle of the tested element. This test system is usually more bulky because in order to generate current enough in AC voltage its necessary a greater power source. This measurement technique is again off-line although there are systems that allow an on-line approach. This measurement includes information of the moisture and contamination degree and emulates (greater voltage) the behaviour and voltage aggressions similar to service ones. It is important to take note of transformer temperature and environmental moisture (surface leakage).

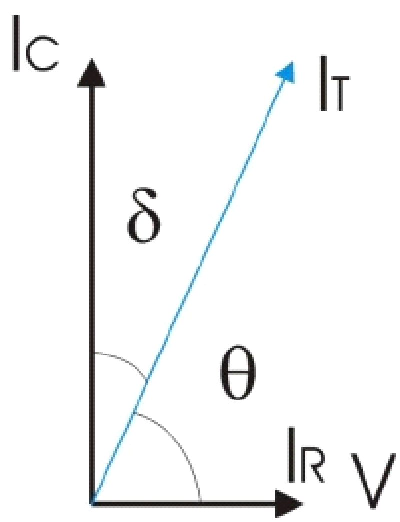



FIG . Diagram of currents flowing through dielectric, IR resistive is in phase to voltage and capacitive IC out of phase 90º. Total

IT, defines δ angle and tangent.

**- Partial Discharge test.**

It is possible to make partial discharge testing on power transformers, most of all on the most powerful or critical units. Partial discharge are small discharges that appear inside of the dielectric as a sign of its degeneration. They appear as a result of the increase of the electric field in small gaseous voids inside the oil and also inside the paper, epoxy or as a result of the presence of metallic contamination, etc.This discharge accelerate the thermal degradation effects and though for the oil are auto-regenerable, lead sometimes exponentially to the power transformer destruction.There are two usual detection systems, acoustic and electric. Acoustic system seeks sound mechanic manifestation (in ultrasonic range) of discharges even enabling eco-location. Electric systems should allow determinate discharges and correlate them with another parameters. This test can be made online or offline if a source apart is used to energize the machine (difficult chance in field). In this test is important again to take note of the temperature of the machine and environment conditions.

**PHYSICAL – CHEMICAL TESTS.**

Another important test group are those in which in the field you only extract properly (see normative) an oil sample on/off line from which certain operating characteristics of the transformer can be deduced.

**- Breakdown voltage.**

Oil degradation can be easily appreciated with this parameter tested. The test is based in the insertion of electrodes immersed in oil of an increasing voltage up to when discharge happens. Test is repeated six times to get a repeatable measurement. The only disadvantage is that it is necessary to extract from the transformer a significant sample (test cell will have 350...600ml). The report will include sample temperature.


FIG . Inside of the test vessel for breakdown voltage in oil of a Megger, model OTS60SX system. It can be seen discharge terminals and agitation propeller.

**- Moisture (Water content).**

Until recently, dissolved moisture in oil was a relatively complex laboratory process.Today, Megger company has got out to the marked a portable unit that close to easy to locate reactives and minimal test care, can perform the test in field / plant /repair shop in an easy and handy way. Implemented system is Karl-Fischer, the usual and laboratory regulated but in a portable manner. It has good repeatability and accuracy.It does only need a small oil sample (1ml) and the system executes the complete control of the chemical process eliminating dissolved moisture and indicating quantity in ppm, %...

FIG 25. System for moisture determination in oil, from Megger, Model KF875.

Another oil parameters.

Other usual laboratory test reporting complementary information of the oil / transformer status are:

Power factor in liquids, interfacial tension, acid number, Oxidation Inhibitor, colour, appearance, fire point, viscosity, PCB…

**- Dissolved Gas Analysis & Ratios.**

Oil dissolved gases testing started around 1956 in investigation from Buchholz relay trigger in transformers. Some investigation of the gases generated there have created specific normative that allow the interpretation of the possible problems inside the transformer. Base parameters are both quantities of some generated gases as relative proportions between gases and apparition / variation speed in taken samples. It can be taken so indirect evidence of Partial Discharge, hot points, arcing, combustion, aging and overheating, detecting incipient failures that could end the transformer life.

**- Furan Analysis.**

This laboratory test seeks determine the amount of some component (furaldehids) in an insulating oil sample. Theory says that this kind of furanic derivates is never present in oil in a natural way and will only exist as a sub product of paper degeneration inside the transformer.

As a complement, we will indicate that exist treatments to decrease moisture and purify the oil eliminating degradation products and taking away metallic particles, etc.Anyway paper access is limited to the interface with oil, so transformer life is paper life.

# 16. RESULTS

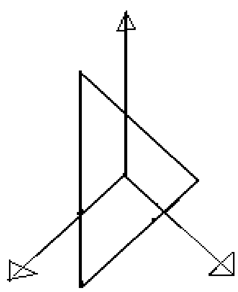
**Data Plate Of Step Up Transformer**

| | |
|---|---|
| Make | NGEF in Collaboration with Siemens AG |
| Type | OPEU 66660/220E |
| Standard | IS 2026 |
| Type of cooling | ODWF(oil dipped water forcing) |
| Rated KVA | 62500 |
| Rated Voltage at no load | HV<br>LV |
| Rated Current | HV<br>LV |
| Phases HV/LV | 1/1 |
| Serial No. | 680000 0152 |
| Impedance Voltage at principal tap | 4% |
| Max. Ambient Temp. | 50 C |
| Symmetrical Short circuit Current(HV) | 3.94KA |
| Max. Short Circuit duration | 2Sec |
| Frequency | 50Hz |
| Total Mass | 92.50 ton |
| Untanking Mass | 5 ton |
| Insulating Oil Mass | 16.60ton |
| Insulating Mass | 18865L |
| Winding Temp. Rise | 55 C |

The losses occur in the transformer is rated as below:-

| Losses(KW) | Granted (Max.) | Measured |
|---|---|---|
| No load | 40 | 39 |
| Load | 112 | 109.94 |
| Auxiliary | 6 | |

Vector Diagram



Year of Manufacture – 1968

*Rated Values*

| Off Voltage Tap Changer | | HV | |
|---|---|---|---|
| Switch Position | Connects | Volts | Ampere At 62.5MVA |
| 1. | 5-6,5′-6′ | 236500 | 458 |
| 2. | 6-4,6′-4′ | 231000 | 469 |
| 3. | 4-7,4′-7′ | 225500 | 480 |
| 4. | 7-3,7′-3′ | 220000 | 492 |
| 5. | 3-8,3′-8′ | 214500 | 505 |

**VOLTAGE RATIO TEST**

*Tested Values*

| Off Voltage Tap Changer | | HV | |
|---|---|---|---|
| Switch Position | Connects | Volts | Ampere At 62.5MVA |
| 1. | 5-6,5′-6′ | 236486 | 457.5 |
| 2. | 6-4,6′-4′ | 230976 | 468.3 |
| 3. | 4-7,4′-7′ | 225466 | 481 |
| 4. | 7-3,7′-3′ | 219956 | 492.3 |
| 5. | 3-8,3′-8′ | 214481 | 504.73 |

*Magnetic Balance*

| Tap position | HT Winding resistance in MΩ | | | LT Winding resistance in MΩ | | |
|---|---|---|---|---|---|---|
| | **RY** | **YB** | **BR** | **Rn** | **Yn** | **Bn** |
| 1 | 1161 | 1172 | 1185 | 10.6 | 10.4 | 11.3 |
| 3 | 1131 | 1118 | 1123 | | | |
| 5 | 1092 | 1082 | 1090 | | | |
| 7 | 1052 | 1052 | 1054 | | | |
| 9 | 1023 | 1018 | 1025 | | | |
| 11 | 990 | 981 | 989 | | | |
| 13 | 951 | 952 | 951 | | | |
| 15 | 917 | 916 | 926 | | | |
| 17 | 890 | 882 | 892 | | | |

*Insulation Resistance Test*

| **Contacts** | **Resistance** |
|---|---|
| HV- Earth | 3 GΩ |
| LV- Earth | 3 GΩ |
| HV-LV | 2 GΩ |

*Two Phase Supply (440V)*

| Tap Position | Voltage applied ( Volts) | | | Magnetizing current( mA ) |
|---|---|---|---|---|
| Normal Tap | **RY** | **YB** | **BR** | |
| | 438 | 366 | 118.9 | 2.6 |
| | 236 | 437 | 242.5 | 2.75 |
| (HV) | 125.5 | 361 | 436 | 2.73 |
| | **Rn** | **Yn** | **Bn** | |
| (LV) | 435 | 725 | 119.1 | 123.4 |
| | 225.9 | 433 | 249.6 | 82.1 |
| | 110.1 | 370 | 432 | 109.3 |

*Single phase supply (230V)*

| Tap Position | Voltage applied (Volts) | | | Magnetizing current( mA ) |
|---|---|---|---|---|
| Normal Tap | **RY** | **YB** | **BR** | |
| | 225.3 | 201.4 | 25.24 | 0.6 |
| | 95.3 | 225.3 | 129.8 | 0.24 |
| (HV) | 49.4 | 177 | 226 | 0.30 |
| | **Rn** | **Yn** | **Bn** | |
| (LV) | 226.1 | 182.7 | 45.4 | 82 |
| | 103.7 | 223.2 | 121.4 | 54.4 |
| | 41.4 | 190 | 227.1 | 74.5 |

Tan Delta Test

| **Switch Position** | **Tan (%)** | **Capacitance ( F )** | **Remarks** |
|---|---|---|---|
| HV/ LV+Gr | 1.27 | 0.011744 | Satisfactory |
| LV/ HV+Gr | .810 | 0.003246 | Satisfactory |
| HV/LV (UST) | 1.41 | 0.008516 | Satisfactory |

*OLTC Test*

The OLTC test gives satisfactory result when Position is changed from Normal condition the OLTC automatic changes the position back to Normal Tap i.e. $5^{th}$ position.

*Stability Test*

The test is to check the stability of transformer in this the current is injected to the primary the secondary current is checked if the difference of two is in appropriate range (.5%) then the transformer is considered to be stable this is equivalent to test if differential relay is operating or not. If differential transformer gives trip command then it implies transformer is unstable.

| | Primary current | Secondary current |
|---|---|---|
| 1 | 100 | 6.243 |

Thus,

=100 – (6.243*15.942) = 0.474%

As per this test the transformer is stable.

# 6. CONCLUSION

From the short downtime available nowadays it is necessary to use test systems that allow a maximum automation of tests to perform and conform a database with all the test performed to can optimize diagnosis and trending.

It is also necessary to perform zero test either in installations or on new machines: first to be certain the machine is in proper condition of use and fulfill contractual requirements and second to have data available with which perform a later predictive monitoring of faults.Again we need the maintenance people to have a deep knowledge of this tests and the way to perform them in order to get from them the maximum reliability either if made by the own utility as from subcontracted to avoid weak. This tests though easy and automatic, take with them some measurement details to take in account in order the measurements to be reliable all this apart from the security details of the user.

FIG26. Theoretical – practical formation in field testing on electric machines in UNITRONICS.

We have described most of the usual “standardized” test in measurement protocols.With a short number of measuring elements we can have a clear idea of the complete transformer status. Anyway, it is of a great importance to go more deeply in the knowledge of this tests to insure their tracking both in the performance on our own or subcontracted.This test will be performed taking into account a series of precautions related both in their normatives and in the experience logic. In all dielectric system tests, is important to take note of transformer temperature and around conditions.

Its crucial that workers who make the test have an optimal formation in this kind of testing, both making the tests as in diagnosis and trending.