PROTECTION TECHNIQUES IN OPERATIONS, MAINTENANCE AND PROTECTION OF ELECTRIC POWER SYSTEM, INJECTION SUBSTATIONS MANAGEMENT AND SAFETY PRECAUTIONS.

BY

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INTRODUCTION AND PHILOSOPHY OF PROTECTION AND RELAYING

INTRODUCTION:
The huge capital investment involved in a power system for the generation, transmission and distribution of electrical power is so great that proper precautions must be taken to ensure that;

i. The equipment operates as nearly as is possible at its peak efficiency.

ii. The equipment is protected from faults and damage to equipment is prevented or minimised.

iii. Accidents to life and property are avoided.

iv. The system provides with uninterrupted service of quality, is reliable and dependable.

PHILOSOPHY OF PROTECTION

2.1 Protection in general means that function in a power system designed primarily to prevent or minimise damage to equipment, life and property. Secondly it is also linked with maintaining reliable and uninterrupted service of quality. The type of protection depends upon the cost criteria.

2.2(a) The earliest form of protection was the fuse which still today is in use on distribution circuits because of its simplicity and cheapness. It however suffers from the disadvantage of not only requiring replacement before power supply could be restored but also lacked in speed of operation, selectivity, discrimination etc. As such these have been ultimately replaced by protective relays. Hence the usage of the common term “Protective Relaying”

2.2(b) A relay is an electrical device that responds to its input information in a prescribed way and by its contact operation, causes an abrupt change in associated control circuits.

2.3 The important requirements of protective relays are:

(i) Sensitivity - to detect faults

(ii) Reliability - to operate at all times when faults occur

(iii) Selectivity - to discriminate between faults and abnormal conditions.

(iv) Simplicity - easy to handle, maintain and repair
Speed of operation - Should clear the fault before damage to equipment, life and property can occur

Cost - Should be relatively cheap

**FAULTS**

2.4 It is now necessary to study the different types of faults and causes of faults. Every piece of electrical apparatus or equipment has insulation. The insulation medium may be solid, liquid or gaseous.

2.4.1 The faults that thus occur can be classified as:
   i. Faults to ground - single phase or double phase or three phase to ground.
   ii. Faults between phases - phase to phase or three phase
   iii. Abnormal conditions in a system are not essentially faults, but they can cause damage to equipment. These can be classified as:

2.4.2 **Overload**
   Over voltages in the system due to internal (switching) or external (atmospheric like lightning)
   Overheating, loss of cooling medium
   Fire hazards
   Unbalanced loading
   Loss of synchronism etc
   Protective Relaying is also applied to take care of such abnormal conditions. Relays not only prevent damage to equipment but reduce outages of equipments.

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3.0 **TYPES AND CLASSIFICATION OF RELAYS**
   Relays are classified as follows:
   1) Functional
   2) Input
3) Operating Principle
4) Structure
5) Performance characteristic

3.1(a) Protective Relays are which detect defective lines, apparatus or other dangerous or intolerable conditions. These relays can either initiate or permit switching or simply provide an alarm.

3.2(b) Monitoring Relays - which verify conditions on the power system or in the protection system. Examples are fault detectors, alarm units, synchronism verification, network phasing. These relays do not involve in switching operations.

3.3.(c) Programming Relays - which establish or detect electrical sequences. Examples are reclosing and synchronising.

3.4(d) Regulating Relays - which are activated when an operating parameter deviates from predetermined limits. They operate through supplementary equipment to restore the quantity to the prescribed limits.

3.5(e) Auxiliary Relays - which operate in response to the opening or closing of the operating circuit to supplement another relay or device. Examples are timers, contact multiplier relays, lockout relays, closing relays, trip relays, receiving relays etc.

4.1 **ZONES OF PROTECTION:**
The general philosophy of relay application is to divide the power system into protective zones that can be protected adequately with the minimum amount of the system disconnected.

5.0 **PROTECTION, OPERATION AND MAINTENANCE OF INJECTION SUBSTATIONS**

5.1 **INTRODUCTION**
Injection substations are substations that step down voltages from 33KV – 11KV. They control power by means of transformers, regulating devices, circuit breakers, isolator etc. Their location is based on the following criteria

For minimum losses and better voltage regulation, the substation should be close to the loads of its service area, so that the addition of load time’s respective distances from the substation is a minimum.
The location should provide proper access for incoming subtransmission lines and outgoing primary feeders and also allow for future growth/expansion.

5.2 **SUBSTATION SIZE**
The size of substation depends upon
- Load density e.g. MW/KM2
- Load growth
- Utilization of transformer capacity
- Maximum fault level
- Flexibility

5.3 Normally, in city areas with higher load densities, the size of substation will be higher than in Rural Areas. This is mainly because of the fact that the cost to distribute the power is lower when the load densities is high. But the presence of intermediate voltage level influences the substation size considerably.

Seen from the upper voltage level (for instance), the size will be because of the fact that the density of the substations of the voltage level will be decreased.

At the lower voltage level (for instance) the presence of the intermediate voltage level leads to a lower size, but to a higher density substations.

In city areas, the values of the sub transmission voltage levels can be selected, in order to make it profitable to redevelop with fewer intermediate voltage levels. In Rural Areas, because of much load densities, this is less likely option.

This means that the network structure, the sizes and densities of substations significantly different between Urban and Rural situations.
6.0 PROTECTION OF TRANSFORMERS

6.1 INTRODUCTION

The advancement of technology has resulted in the manufacture of very large capacity transformers. The increasing size and capacity of transformer units has enabled considerable reduction in the operation and maintenance costs. But the risk of interruption of power supplies is always if there is a breakdown in the transformer.

Although every precaution is taken in the design, manufacture, assembly, erection and installation of a transformer, yet there is still a need to provide an adequate scheme of protection to prevent a forced outage. To understand as to what scheme of protection is required, it is necessary to have a knowledge of the faults to which a transformer is subject to while in service.

6.2 NATURE OF TRANSFORMER FAULTS

A transformer is subjected to the following types of faults:
Through faults or External faults
Internal faults.
6.3 **THROUGH FAULTS OR EXTERNAL FAULTS**
These may be further classified into:

a) Over loads  
b) External short circuit  
c) Internal faults  
d) Over voltages and over fluxing  
A transformer must be isolated from these faults as these faults produce electro mechanical and thermal stresses in the windings which may ultimately lead to the failure of time.

6.4 **EXTERNAL SHORT CIRCUIT**
An external short circuit subjects the transformer to sudden electromagnetic stresses and overheating. Modern power transformers are designed to withstand short circuit currents of a certain KA value for 1 second. The external short circuit must be cleared within this period. An external short circuit is detected primarily by the main protection of the loads or feeders and subsequently by the backup protection of the transformer. As these faults are detected by time graded over current relays.

6.5 **OVERLOADS:**
A transformer is capable of withstanding a sustained overload for a long period. This period is determined by the permissible rise of the oil and windings, and the type of cooling. Normally a 10% overload is permissible for not more than an hour, 25% overload for not more than 15 to 30 minutes, a 50% overload for not more than 5 to 10 minutes.

Excessive overloading for long frequent and intermittent periods results in rapid deterioration of the insulation and subsequently results to failure. An overload condition with permissible overloads can be detected by a thermal relay or a temperature relay initially to give an alarm and finally to trip the transformer.

When an alarm is sounded the operator must ensure to relieve the transformer from overload by pulling out non essential loads. Normally winding and oil temperature indicators are provided with alarm and trip contacts on all power transformers.

6.6 **TERMINAL FAULTS:**
Terminal fault on the primary side of the transformer has no
adverse effect.
But a similar fault on the secondary side does have a serious effects. Such a fault falls within the protected zone of the transformer and is detected by protection schemes to be covered under internal faults and also by gas pressure relays.

6.7 **INTERNAL FAULTS**
Internal faults are classified into two main categories:
- a) Electrical Faults
- b) Incipient or Miscellaneous faults

6.8 **ELECTRICAL FAULTS:**
These cause serious damage to the transformer and are detected by unbalanced currents and voltage. These faults may be categorized as:
- a) Terminal faults on the secondary
- b) Phase to earth fault on the primary / secondary terminals inside the transformer or on the windings.
- c) Short circuits between turns of H.V and L.V windings
- d) Phase to phase faults between H. V. And or L. V. Windings or terminals inside the transformer.
- d) Interturn faults in H. V. And or L.V. windings. Faults between phases and to earth inside a transformer are generally rare. But it is claimed that most of the transformer failures are due to interturn faults. These faults being serious, have to be isolated instantaneously.

6.9 **MISCELLANEOUS OR INCipient FAULT**
These are actually faults of a minor nature, but if not taken care of may gradually, sooner or later develop into a major fault. Such faults are due to:
- a) Poor quality or inadequacy of the insulation of the laminations and core bolts
- b) Accidental damage to lamination and core-bolt during erection and or assembly
- c) Poor quality or inadequacy of the insulation between the windings
- d) Mechanical damage to the windings due to bad handling during erection/assembly.
- e) Badly formed joints or connection
- f) Deterioration of the oil due to overloading and or aging
- g) Deterioration of the oil due to ingress of moisture, oxidation of the oil due to over heating, sludge formation.
h) Coolant failure causing rise of temperature even when operating below full load conditions, choking of radiator tubes, fins due to sludge.
  i) Improper load sharing causing overheating due to circulating currents.

7.0 **PROTECTION AGAINST INTERNAL FAULTS:**

a) The protections applied to a transformer against these faults are:

b) Gas operated relays or sudden pressure relays

c) Over current and earth fault protection

d) Balance earth fault protection or restricted earth fault protection

e) Frame leakage protection

f) Differential protection

7.1 The failure of the insulation of the core windings causes local heating around the point of failure. This local heating causes the rise of the oil temperature surrounding it.

The oil when it reaches a temperature of 200 to 3500C depending upon the characteristic of the oil decomposes and evolves gasses. The gasses rise through the oil and accumulate on the top of the transformer.

The evolution of the gas and the quantity and rate at which it evolves is made use of to actuate these relays.

7.2 **BUCHOLZ RELAY**

This is the most common type of gas actuated relay used in almost all types of power transformers fitted with an oil conservator. The relay is connected in the piping between the oil conservator and the transformer tank.

The relay has two mercury operated float switches, one located at the top, the other at the bottom is in the direct line of oil flow from the conservator to tank. The angle of displacement of the mercury switch for making contact is between 5 to 15 degrees. Hence the piping in which it is located is at an angle, and the inclination must be at least 2 degrees to permit accumulation of gas.

When gas accumulates slowly, the upper float switch is displaced and makes contact to give an alarm. The analysis of the gas gives and indication as to the nature and type of fault, such as burning of paper, wood etc.
When there is a sudden surge of oil or when the gas rate of evolution is very rapid the bottom float switch operates and trips or isolates the transformer from the sources.

This sudden oil surge or rapid gas evolution takes place if there is arching, burning or local overheating inside the transformer indicating seriousness. There is an arrow indication on every Bucholz relay. This arrow indicates the direction of the gas flow to operate the relay. Hence while mounting the Bucholz relay, care is taken to mount it with the arrow pointed towards the conservator.

7.3 **SUDDEN PRESSURE RELAY (SPR)**

The SPR is again a gas operated relay which operates on a rate of rise of gas in the transformer. Some manufacturers also call it as a fault pressure relay. Theses relays are popular only in America where transformers are manufactured without a conservator but with a sealed air cushion or chamber above the oil level. The relay is mounted to the tank or manhole cover above the oil level.

It will not operate on static pressure or pressure changes resulting from normal operation of the transformer.

It is extremely sensitive and will operate at pressure changes as low as 33 1bs/in2.

The operating time from ½ cycle to 30 cycles depending upon the severity and magnitude of the fault. The location of the SPR.

The relay has a diaphragm which is deflected by differential oil pressures and it is bye passed by an equalizer hole which normally equalizes the pressure on responsive to the rate of pressure.

The gas accumulating unit is at the top in the dome.

7.4 **OVER CURRENT AND UNRESTRICTED EARTH FAULT PROTECTION**

This protection is applied against external short circuit and excessive overloads. It also acts as a backup protection, to the feeder loads connected to the transformer and to the transformer itself if there are other forms of protection. The relays used are time over current relays of the inverse type or of the IDMT type or the definite time.

The protection is applied separately to both the primary and secondary windings as shown:
The over current relays fail to distinguish between conditions of external short circuits, overloads or internal faults within the transformer. The operation is governed purely by the current and time setting.

Hence in order to make use of the permissible overload capacity of the transformer and also to coordinate with similar other relays in the system, it is necessary to set the relay at about 120 to 150% of the full load current of the transformer but well below the short circuit current. Thus they seldom serve as a reliable form of protection and is only in the form of a back up protection. If this type of protection is provided on both the windings, then each protection trips its own breaker and no inter-tripping of breakers is provided. For example if the L.V. side relays etc. They trip only the L.V. side breaker, but not the H.V. side breaker.

The earth fault relay at times tends to mal operate on external earth faults if the earth relays are not properly coorordinated with the other relays in the system to avoid indiscriminate tripping.

![Over Current and Earth Fault Protection Scheme](image-url)
8.1 **BALANCED EARTH FAULT OR RESTRICTED EARTH FAULT PROTECTION (REFR)**

This form of protection is provided to prevent the EFR acting on spurious external faults and acts only when there is an internal earth fault within the transformer.

Thus its operation is limited to detection of earth faults within the transformer. Hence the name Restricted Earth Fault Protection. The protection is applied separately to each winding of the transformer.

8.2 **USE OF STABILIZING RESISTORS:**

In such balanced type of protective schemes, spill currents or operating currents in the relay circuit can cause indiscriminate operation. To avoid unwanted operation from this cause a stabilizing resistors (SR) is connected in series with the current relay.

The value of the stabilizing resistor is so chosen that under maximum steady state through fault conditions there is insufficient voltage developed across the C.T. leads to causes a spill current equal to the relay operating current. In calculating the value of the SR the following assumptions are made:

a) One set of Ct’s is completely saturated  
b) The whole of the primary fault current is perfectly transformed by the remaining CT’s

The maximum loop lead burden between the relay and the CT’s is used. With one set of C.T’s saturated, the maximum voltage appearing across the relay circuit mainly across the relay coil and the SR is

\[
\frac{1f}{N}(Rs + Rb) \text{ Volts}
\]

Where 1f is the maximum fault current N is the C.T. ratio Rs the secondary internal resistance of the C.T. Rb the maximum lead burden.

For stability, the current through the relay coil at this voltage must be insufficient to cause relay operation. ASR is chosen which will just allow setting current to flow through the relay coil.
8.3 **FRAME LEAKAGE PROTECTION**

This protection is also called as Tank Earth Leakage protection. It is a comparatively inexpensive and simpler alternative to Restricted Earth Fault protection. This scheme is very popular in France and also elsewhere it has not gained much popular.

In this scheme the transformer is lightly insulated from the earth by mounting it on a concrete plinth so that the insulation resistance is not less that 10 ohms. The earthing of the tank is done as shown with a C.T in the secondary F.

This CT is connected to an instantaneous EFR, of the attracted armature type. Earth fault current due to insulation breakdown in any winding finds its way to the earth through this path, thus energizing the CT and the relay. This scheme is extremely sensitive in detecting earth faults within the transformer zone. The scheme though it appears to be simple and cheap has many disadvantages. These are:

- Incapacity to respond to faults in the jumper connections between transformer terminals and the bus bar.
- The setting must be kept sufficiently high to prevent mal-operation due to capacitance currents resulting from external faults.
- It is difficult under humid and dusty humid and atmospheric conditions to keep the insulation resistance below 10 ohms.
- There is a possibility of the fault current of one transformer finding its way into the tank circuit of another adjacent transformer thereby causing a healthy transformer to be isolated.
- It is practical to adopt this system in forced oil cooled transformers

9.0 **DIFFERENTIAL PROTECTION**

This is the principal form of protection for all power transformers rated at 5MVA and above. It is a form of protection where a relay operates when the vector difference of two or more similar electrical quantities exceeds a predetermined amount.

Almost any type of relay when connected in a certain way can be made to operate as a Differential relay. In other words it is not so much as the construction of the relay, but the manner in which the relay is connected in a circuit that makes it a differential relay.
10.0 MAINTENANCE

INTRODUCTION
- Basically is the process of keeping a facility in manufactured operational condition.
- Categorised broadly into planned and unplanned maintenance.
- Planned maintenance arises from a culture of foreseeing changing conditions of equipment during use and detailing steps to counter them, with a view to maximising the use of same equipment before obsolescence of expiration.
- Unplanned arises accidentally such that equipment would have deteriorated to the point of breakdown, necessitating urgent action.
- Planned maintenance includes:
  - Preventive, Routine, Predictive, Running (‘on-line’) Part-Replacement, and shut-down (Turn-around) maintenance.
- Unplanned maintenance includes:
  - breakdown/incidental/Emergency, Total-Replacement and opportunity maintenance.

10.1 MAINTENANCE SCHEDULE SHOULD SPECIFY
- Location of equipment
- Indicate scope of work
- Quantify the time required for maintenance work
- Itemize the material contents of the job
- Come up with the cost implications.
10.2 ASSESS THE HUMAN RESOURCE NEEDS
- Keep records of maintenance schedules executed.
- Plan schedule for weekly, monthly, yearly, etc operations
- Estimate time required.

10.3 OPERATIONS AND MAINTENANCE IN POWER SYSTEM
- Working with or use of equipment in power systems is regarded as OPERATIONS.
- While MAINTENANCE is described as the collection of activities geared towards keeping the components in a proper working condition.

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MAINTENANCE RELATIONSHIP CHART

- Predictive Maintenance
- Corrective Maintenance
- Emergency Maintenance
- Planned Maintenance
- Unplanned Maintenance
- Inspections, Adjustments, and Lubrication
- Minor component rejuvenation, Shovel box repair, and inspection
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ANNUAL INJECTION SUBSTATIONS MAINTENANCE SCHEDULE

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1. Clearing of Panel Contacts
2. Checking of the Arc-quenching Medium
3. Check the Breaker Contacts
4. Check the Earthing
5. General Testing

11.1 MAINTENANCE JOB FOR AN INJECTION SUBSTATION
- Measuring of the earth resistances of the substations.
- Checks on the functionality of the Transformer/feeder protective devices
- Carrying out tests on the transformer/breaker oil.
- Tightening of the protective wirings at the transformer and breaker marshalling kiosk.
- Greasing and toping of the battery bank

12.0 SAFETY PRECAUTIONS
- Good Workmanship and work Procedure include the following.
- Have a clear view of scope of work.
- Understand the targeted work properly and operations of the equipment.
- Ensure the availability of the resources required for the job.
- Take record of the team mates and tools

12.1 Obtain outage in line with the laid down guideline.
- Ground the equipment temporarily before and after where you are working.
- Any remote and isolated point tagged ‘DO NOT OPERATE, MEN AT WORK’
- Execute the job properly and use correct tools.
12.2 Remove all temporary grounding devices, intimate your team mate about the intention to re-energized the equipment you worked on.
- Restore the power on completion of work.

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