

STUDY OF FAULT PROTECTION SCHEME AND CASE STUDY OF 400 KV SUBSTATION KHANDWA ROAD, INDORE



Project No. – 6

**Submitted as a
Major Project for the
Degree of Bachelor of Engineering
Year 2005-2006**

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Major Project

*A Dissertation submitted to
Rajiv Gandhi Proudyogiki Vishwavidhyalaya, Bhopal
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in
Electrical Engineering
Year 2005-2006*

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CERTIFICATE

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SYNOPSIS

INTRODUCTION

Electrical energy management system ensures supply of energy to every consumer at all times at rated voltage, rated frequency and specified wave form, at lowest cost and with minimum environmental degradation. The capital investment involved in a power system for the generation, transmission & distribution of electrical power is so great that proper precautions must be taken to ensure that the equipment not only operates as nearly as possible to peak efficiencies, but also that it is protected from accidents & faults.

Every electrical needs a switching device & protective device. The switching & protective devices have been developed in various forms. Switchgear is a general term covering a wide range of equipment concerned with switching & protection .Switchgears are necessary at every switching point in AC power system. Between the generating station & final load point, there are several voltage levels & fault levels. Hence, in the various applications, the requirements of switchgear vary depending upon the location & ratings.

Faults and Abnormal conditions

A fault in electrical equipment is defined as a defect in its electrical circuit due to which the current is diverted from the intended path. Faults are generally caused by breaking of conductors or failure of insulation. The other causes of faults include mechanical failure, accidents, excessive internal and external stresses, etc. The fault impedance being low, the fault currents are relatively high. During the faults the voltages of the three phases become unbalanced. The fault currents being excessive, they can damage the faulty equipment and the supply insulation. During the faults,

the power flow is diverted towards the fault and the supply to the neighboring zone is affected.

As fault occurs in a power system, the current increases to several times the normal current because of the low fault impedance. The value of the fault currents depends on the voltage at the faulty point and the total impedance up to the fault.

During the fault, the current & voltage undergo a conditions change & the phenomena observed are called *transient phenomena*. Transient refers to temporary happening which lasts for short duration of time. The fault current varies with time.

The Fault Clearing Process

The protective relays are connected in the secondary circuits of current transformers and/or potential transformer. The relay senses the abnormal conditions and closes the trip circuit of the associated circuit-breaker. The circuit-breaker opens its contacts. An arc is drawn between the contacts as they separate. The arc is extinguished at a natural current zero of the AC wave by suitable medium and technique.

Protective Relaying

The protective relays are automatic devices which can sense the fault and send instructions to the associated circuit breaker to open. The circuit-breaker opens and clears the fault. Switchgear includes switches, fuses, circuit-breakers, isolators, relays, control panes, lightning arresters, current transformers and various associated equipments.

AC power system is covered by several protective zones. Each protective zone covers one or two components of the system. The neighboring protective zones overlap so that no part of the system is disconnected from the remaining system. The protective schemes for large electrical

equipment comprise several types of protective systems. For low voltage equipment of relatively small ratings, fuses and thermal relays are generally adequate.

Primary and Backup Protection

Primary (main) protection is the essential protection provided for protecting a machine/equivalent. As a precautionary measure an additional measure is generally provided & is called “Backup Protection”.

The Primary protection is the first to act & the Backup protection is next in line of defense, to remove the faulty part from the healthy system.

The extent, to which the Backup Protection is provided, depends upon economic & technical consideration. The cost of Backup Protection is justified on the basis of probability of failure of individual components in system, cost of protection equipment, importance of protection equipment, location of protection equipment, etc.

Fault Protection Schemes

A selected set of protective system which protects one or two components of the power system against abnormal conditions, e.g., generator protection scheme, transformer protection scheme, Bus-Bar Protective scheme etc.

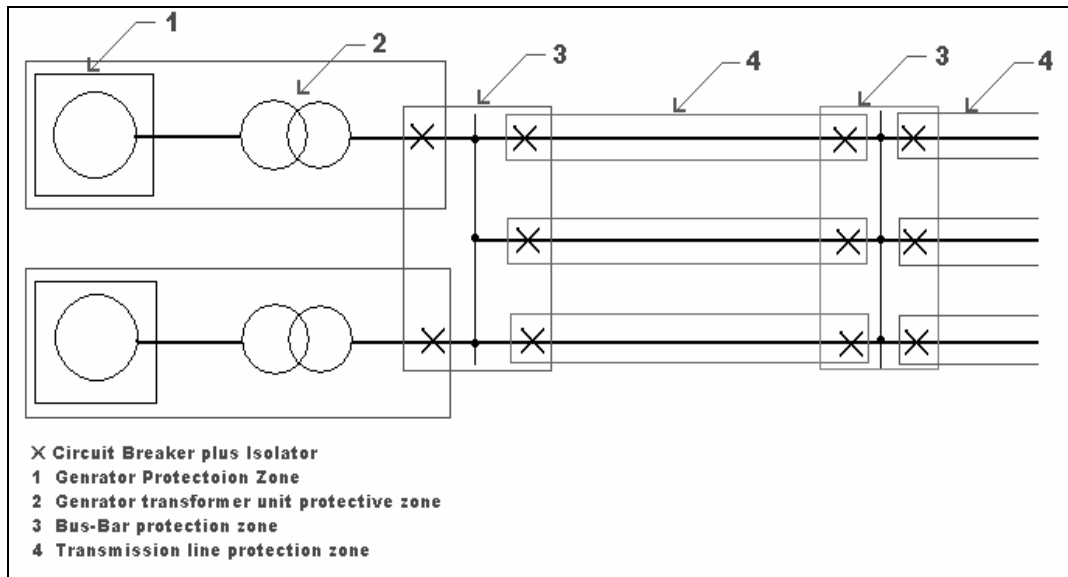
Protection schemes are planned along with the system design of a power system. The Circuit-Breakers are located at appropriate point such that any component of the power system can be disconnected for usual operation & maintenance requirements, & also during abnormal condition such as short circuit.

Depending on rating of machine, its location, relative importance, probability of faults & abnormal conditions each power system component (Generator, Transformer, Transmission line, Bus-Bar, Individual Loads,

etc.) is covered by a protective zone. The entire power system is covered by several protective zones & no part of system is left unprotected.

Types of Protective Zone:

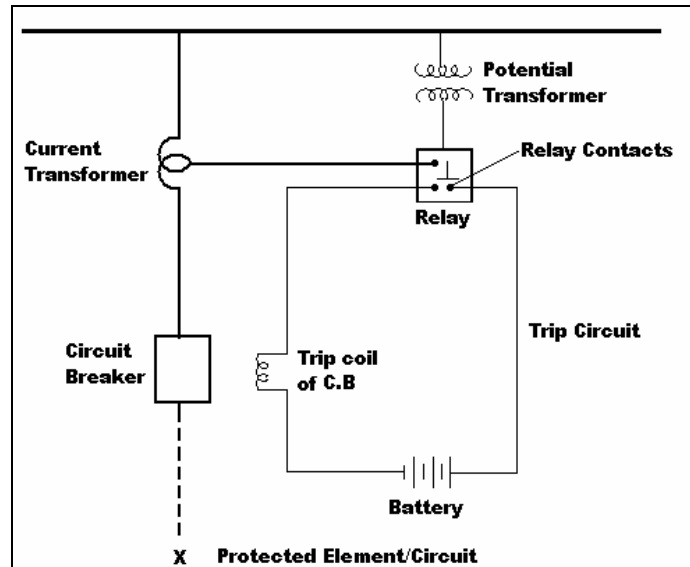
1. Generator Protection Zone.
2. Generator Transformer Unit Protection Zone.
3. Bus-Bar Protection Zone.
4. Transmission Line Protection Zone.



Protective Zones in a Power System

Protective Relaying

The relays are compact, self contained devices which respond to abnormal condition. Whenever an abnormal condition develops, relay closes its contacts. Thereby trip circuit of circuit breaker is closed. Current is supplied from battery supply flows in trip coil of circuit breaker and the circuit breaker opens & faulty part is disconnected from the supply.



Simplified Diagram of Circuit Breaker Control of Opening Operation

There are two groups of relaying for protecting any electrical equipment in the power system:

1. Primary relaying equipment.
2. Back-up relaying equipment.

Primary relaying is the first line of defiance for protecting the equipments whereas the back-up protection relaying works only when the primary relaying equipments fails which means back-up relaying is inherently slow in action.

Types of Relay:

1. Electromagnetic Relays.
2. Distance Protection Relay.
3. Earth Fault Relay.
4. Over-Current Relay.
5. Over-Voltage Relay.
6. Differential Relay.

Functions of protective relay:

- To sound an alarm.
- To trip the circuit.
- To disconnect the abnormal operating part.
- To localize the fault.
- To improve the stability.

Functional characteristics of relay:

- Reliability
- Selectivity
- Speed
- Sensitivity

CIRCUIT BREAKER

An electrical power system is very complex. It needs some form switchgear in order that it may be safely and efficiently controlled or regulated under normal and abnormal operating conditions. Circuit-Breaker in a power station serves to control the electrical equipments in many added and more complex feature.

The basic construction of any circuit-breaker requires the separation of contacts in any insulating fluid which servers two function here:

1. It extinguishes the arc drawn between the contacts when the circuit-breaker opens.
2. It provides adequate insulation between the contacts and from each contact to earth.

Many insulating fluids are used for any extinction and the fluid chosen depends upon the rating and type of circuit-breaker. The insulating fluids commonly used for circuit-breaker are:

1. Air at atmospheric pressure.
2. Compressed air.
3. Oil which produces hydrogen for arc extinction.
4. Ultra high vacuum.
5. Sulphur hexafluoride (SF_6).

Gases which have been considered for circuit-breaker are:

1. Simple gases- air, oxygen, hydrogen, nitrogen, carbon-dioxide.
2. Electronegative gases- sulphur hexafluoride (SF_6).

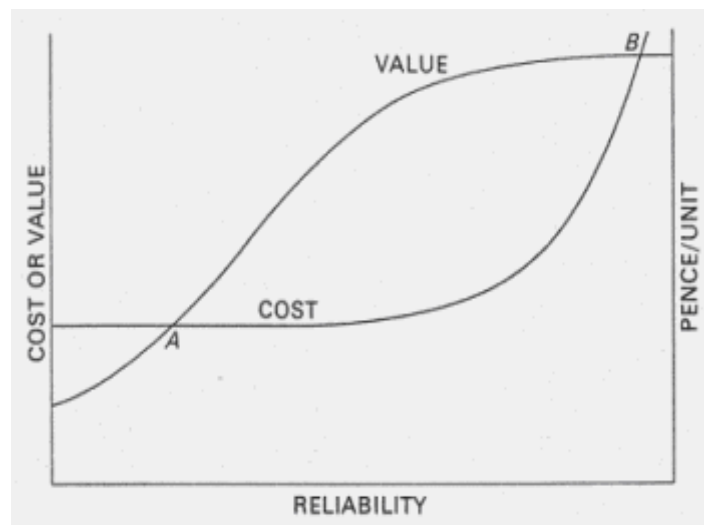
Properties required of a gas for circuit-breaker use are:

1. High dielectric strength.
2. Thermal and chemical stability.
3. Non-inflammability.
4. High thermal conductivity.
5. Arc extinguishing ability.
6. Commercial availability at moderate cost.

INTRODUCTION

Electrical energy management system ensures supply of energy to every consumer at all times at rated voltage, rated frequency and specified wave form, at lowest cost and with minimum environmental degradation. The purpose of an electrical power generation system is to distribute energy to a multiplicity of points for diverse applications. The system should be designed and managed to deliver this energy to the utilization points with both reliability and economy.

As these two requirements are largely opposed, it is instructive to look at the relationship between the reliability of a system and its cost and value to the consumer.



Relationship between reliability of supply

It is important to realize that the system is viable only between the cross-over points A and B. The diagram illustrates the significance of reliability in system design, and the necessity of achieving sufficient reliability. On

the other hand, high reliability should not be pursued as an end in itself, regardless of cost, but should rather be balanced against economy, taking all factors into account. Security of supply can be bettered by improving plant design, increasing the spare capacity margin and arranging alternative circuits to supply loads. Sub-division of the system into zones, each controlled by switchgear in association with protective gear, provides flexibility during normal operation and ensures a minimum of dislocation following a breakdown.

A fault in electrical equipment is defined as a defect in its electrical circuit due to which the current is diverted from the intended path. As fault occurs in a power system the current increase to several times the normal current because of the low fault impedance. The value of the fault currents depends on the voltage at the faulty point and the total impedance up to the fault. Faults are generally caused by breaking of conductors or failure of insulation. The other cause of faults includes mechanical failure, accidents, excessive internal and external stresses, etc. The fault impedance being low, the fault currents are relatively high. During the faults the voltages of the three phases become unbalanced. The fault currents being excessive, they can damage the faulty equipment and the supply insulation. During the faults, the power flow is diverted towards the fault and the supply to the neighboring zone is affected.

The greatest threat to a secure supply is the shunt fault or short circuit, which imposes a sudden and sometimes violent change on system operation. The large current which then flows, accompanied by the localized release of a considerable quantity of energy, can cause fire at the fault location, and mechanical damage throughout the system, particularly to machine and transformer windings. Rapid isolation of the fault by the

nearest switchgear will minimize the damage and disruption caused to the system.

There is saying “*A stitch in time saves nine*”, this also reflex in modern power system. A power system represents a very large capital investment. To maximize the return on this outlay, the system must be loaded as much as possible. For this reason it is necessary not only to provide a supply of energy which is attractive to prospective users by operating the system within the range AB, but also to keep the system in full operation as far as possible continuously, so that it may give the best service to the consumer, and earn the most revenue for the supply authority. Absolute freedom from failure of the plant and system network cannot be guaranteed. The risk of a fault occurring, however slight for each item, is multiplied by the number of such items which are closely associated in an extensive system, as any fault produces repercussions throughout the network. When the system is large, the chance of a fault occurring and the disturbance that a fault would bring are both so great that without equipment to remove faults the system will become, in practical terms inoperable.

CHAPTER 1

FAULTS

Chapter 1

FAULTS

A fault in electrical equipment is defined as a defect in its electrical circuit due to which the current is diverted from the intended path. The most and dangerous fault that occurs in power system is the short circuit or shunt fault. Such type of fault involves power conductor or conductor to ground or short circuit between conductors and causes a flow of heavy current, called the short circuit current, through the power system equipment. Thus as a result of short circuit fault in the power system there is considerable damage to the equipment and interruption of supply to the public. Faults on power systems are occurrences of abnormal conditions. Modern power systems are built with a high degree of flexibility so that some parts of the system may be out of service with a minimum interruption of supply of power to the customers. It is neither practical nor economical to build fault-proof power systems. However, it is necessary to know the conditions that will exist on the system during faults so that the equipment can be properly sized and adequate protection during each possible fault can be provided.

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1.1 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 fulfill 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'.

1.2 Nature and Causes of Faults

The nature of a fault simply implies any abnormal condition, which causes a reduction in the basic insulation strength between phase conductors, or between phase conductors and earth, or any earthed screens surrounding the conductors. Actually the reduction of the insulation is not considered as a fault until it produces some effect on the system that is until it results either in an excess current or in the reduction of the impedance between conductors or between conductors and earth to a value below that of the lowest load impedance normal to the circuit.

In a power system consisting of generators, switchgear, transformers, transmission and distribution circuits, it is inevitable that sooner or later in

such a large network some failure will occur somewhere in the system. The probability of the failure or occurrence of abnormal condition is more on the power lines, simply because of their greater length and exposure to the atmosphere as already mentioned.

Before proceeding to the examination of the several causes of failures, it would be well to classify them according to the causes of their incidence. These are mentioned below.

1. Breakdown may occur at normal voltage on account of
 - (i) The deterioration of insulation and
 - (ii) The damage due to unpredictable causes such as the perching of birds, accidental short circuiting by snakes, kite strings, tree branches, etc.
2. Breakdown may occur because of abnormal voltages, though the insulation is otherwise healthy to withstand normal voltage. This may happen because of either
 - (i) Switching surges or
 - (ii) Surges caused by lightning.

The present day practice is to provide a high insulation level of the order of 3 to 5 times the nominal value of the voltage. But still the pollution on an insulator string which is commonly caused by deposited soot or cement dust in industrial areas and by salt deposited by wind- borne sea-spray in coastal areas cause the insulation strength to decrease. This will initially lower the insulation resistance, and cause a small leakage current to be diverted, thus hastening the deterioration. Even if the installation is enclosed, such as sheathed and armored cables as well as metal-clad

switchgear, deterioration of the insulation occurs because of ageing. Void formation in the insulating compound of underground cables due to the unequal expansions and contractions caused by the rise and fall of temperatures is another cause of insulation failure.

The line and apparatus insulation may be subjected to transient over voltages because of the switching operations. The voltage, which rises at a rapid rate, may achieve a peak value, which approaches three times phase to neutral voltage. It is for this purpose that a higher insulation level is provided initially. If the insulation levels have been correctly chosen and the system will withstand these routine over-voltages. But if the insulation has developed some form of weakness, it is at the time of switching that failure may be expected.

Lightning produces a very high voltage surge in the power system of the order of millions of volts and thus it is not feasible to provide an insulation, which can withstand this abnormality. These surges travel with the velocity of light in the power circuits; the limiting factors are the surge impedance and the line resistance.

1.3 Consequence of Faults

The most serious result of a major uncleared fault is fire, which may not only destroy the equipment of its origin but may spread in the system and cause total failure. The most common type of fault, which is also the most dangerous one, is the short circuit, which may have any of the following consequences:

1. A great reduction of the line voltage over a major part of the power system. This will lead to the breakdown of the electrical supply to the consumer and may produce wastage in production.
2. Damage caused to the elements of the system by the electrical arc, which almost always accompanies a short circuit.
3. Damage to other apparatus in the system due to overheating and due to abnormal mechanical forces setup.
4. Disturbances to the stability of the electrical system and this may even lead to a complete shutdown of the power system.
5. A marked reduction in the voltage, which may sometimes be so great that relays having pressure coils tend to fail.
6. Considerable reduction in the voltage on healthy feeders connected to the system having fault. This may cause either an abnormally high current being drawn by the motors or the operation of no-voltage coils of the motors. In the latter case considerable loss of industrial production may result, as the motors will have to be restarted.

1.4 Fault Statistics

It is useful to have some idea of the frequency of the incidence of faults on the different items of equipment in a power system. This information is of help in considering the problems of design and application of protection. Table gives an idea of how faults are distributed in the various sections of a power system.

Frequency of fault occurrence in different links of a power System

Equipment	% of total
O.H lines	50
Cables	10
Switchgear	15
Transformers	12
CTs and PTs	2
Control Equipment	3
Miscellaneous	8

It is of interest to note that faults on overhead lines account for nearly half of the total number of faults. It would be worthwhile therefore, to analyze the nature of faults on the overhead lines. On a three phase system the breakdown of insulation between one of the phases and earth is known as line to ground fault or a single phase earth fault, the break down of insulation between either of the two phases is known as line to line fault, the breakdown of insulation between two phases and earth is known as double line to ground fault, and the breakdown of insulation between the three phases is known as three phase fault.

It is evident, therefore, that the line to ground fault occurs most commonly in overhead line practice. Fortunately a large number of these faults are transitory in nature and may vanish within a few cycles—as would be the case when a twig falls across a line and a cross-arm and burns itself out or just falls down.

In our country where the neutral is not kept isolated, these earth faults do produce fairly large magnitudes of fault current. So in designing a system of protection greater attention should be paid to the reliable operation of relays under line-to-ground fault conditions.

1.5 Classification of Faults

Broadly speaking fault can be classified as:

1. Shunt faults (short circuits)
2. Series faults (open conductor)

Shunt type of fault involve power conductor or conductor to ground or short circuit between conductors. When circuits are controlled by fuses or any device which does not open all the three phases, 1 or 2 phases of the circuit may be open while the other phases or phase is closed. These are called series type of faults. These faults may also occur with 1 or 2 broken conductor. Shunt fault are characterized by increase in current and fall in voltage and frequency, where as series faults are characterized by increase in voltage and frequency and fall in current in faulted phases.

Shunt type of fault are classified as:

1. Line to Ground fault
2. Line to Line fault
3. Double Line to Ground fault
4. 3-Phase fault

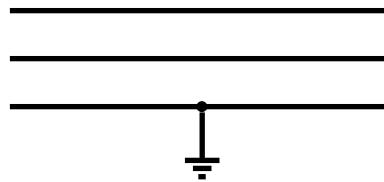
Of these the first three are unsymmetrical faults as the symmetry is disturbed in one all two phases. The method of symmetrical components will be utilized to analyze the unbalancing in the system. The three-phase fault is a balanced fault, which could also be analyzed using symmetrical components.

Voltages and currents produced during faults depend on the type of fault, and on the impedance of the circuit. There are four types of faults that can occur:

- **Phase-to-earth fault**

The conditions for a solid fault from line a to earth are represented by the equations $I_b=0$, $I_c=0$ and $V_a=0$,

Single-phase fault connected to earth

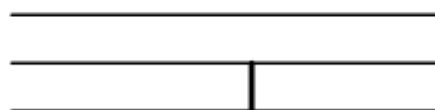


As in the previous equations, it can easily be deduced that $I_{a1} = I_{a2} = I_{a0} = E_a / (Z_1 + Z_2 + Z_0)$. Therefore, the sequence networks will be connected in series, as indicated in Figure. The current and voltage conditions are the same when considering an open-circuit fault in phases b and c, and thus the treatment and connection of the sequence networks will be similar.

- **Phase-to-Phase fault**

The conditions for a solid fault between lines b and c are represented by the equations

Phase to phase fault



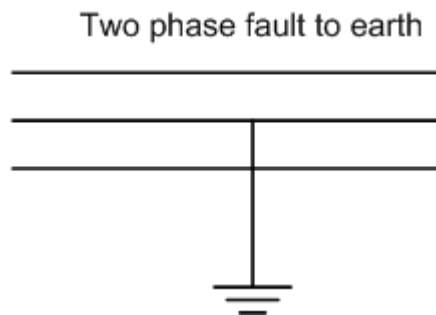
$$I_a = 0, I_b = -I_c \text{ and } V_b = V_c.$$

Equally, it can be shown that

$$I_{a0} = 0 \text{ and } I_{a1} = E_a / (Z_1 + Z_2) = I_{a2}.$$

For this case, with no zero-sequence current, the zero-sequence network is not involved and the overall sequence network is composed of the positive- and negative-sequence networks in parallel as indicated in Figure 2.10b.

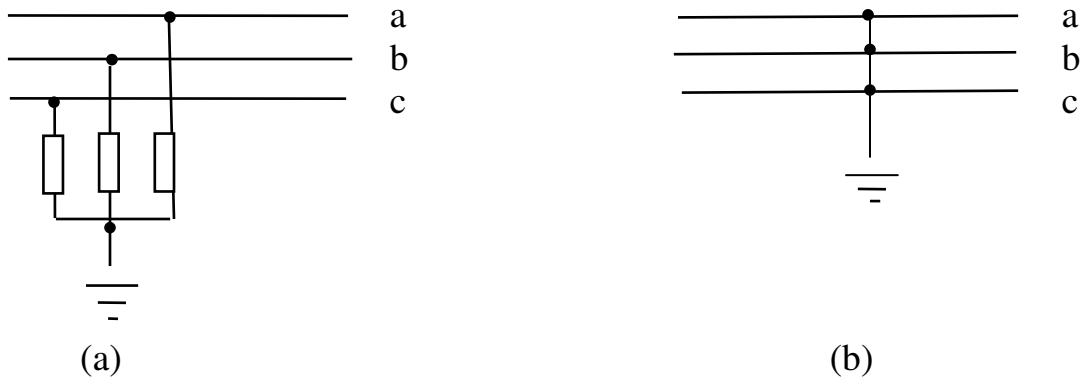
• **Phase-to-Phase-to-earth fault**



The conditions for a fault between lines b and c and earth are represented by the equations $I_a = 0$ and $V_b = V_c = 0$. From these equations it can be proved that:

$$I_{a1} = \frac{E_a}{Z_1 + \frac{Z_o Z_2}{Z_o + Z_2}}$$

• **Three Phase Fault**



Three Phase Fault (a) with fault impedance Z
(b) With zero fault impedance

The *series faults* are classified as:

1. One open conductor
2. Two open conductor

These faults also disturb the symmetry in one or two phases and are therefore unbalanced faults. The method of symmetrical components can be used for analyzing such situations in the system.

1.6 Basic Principle of operation of Protective System

Each relay in a protection scheme performs a certain function and responds in a given manner to a certain type of change in circuit quantities. For example one type of relay may operate when current increases above a certain magnitude, while another may compare current and voltage and operate when the ratio V/I is less than a given value. The first relay is known as an overcurrent relay while the latter impedance relay. Similarly various combinations of these quantities could be worked out according to the requirements particular situation, because for every type and location of failure the distinctive difference in these quantities, and there are

various protective relaying equipments available, each of which is designed to recognize a particular difference and to operate in response to it.

1.7 Primary and back-up protection

The system is divided into protective zones as explained earlier, each having its protective relays for determining the existence of a fault in that zone and having circuit breakers for disconnecting that zone from the system.

The relays operate usually from currents and voltages derived from current and potential transformers or potential devices, a station battery usually provides the circuit breaker trip current. Successful clearing depends on the condition of the battery, the continuity of the wiring and trip coil, and the proper mechanical and electrical operation of the circuit breaker as well as the closing of the relay trip contacts. In the event of failure of one of these elements, so that the fault in a given zone is not cleared by the main or the primary protection scheme, some form of backup protection is ordinarily provided to do the next best thing. This means first of all to clear the fault automatically if at all possible, even though this requires disconnection of a considerable portion of the system. The measures taken to provide backup protection vary widely depending on the value and importance of the installation and the consequence of failure. 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. Backup 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 in feeds 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 in feeds. 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 EHV 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.

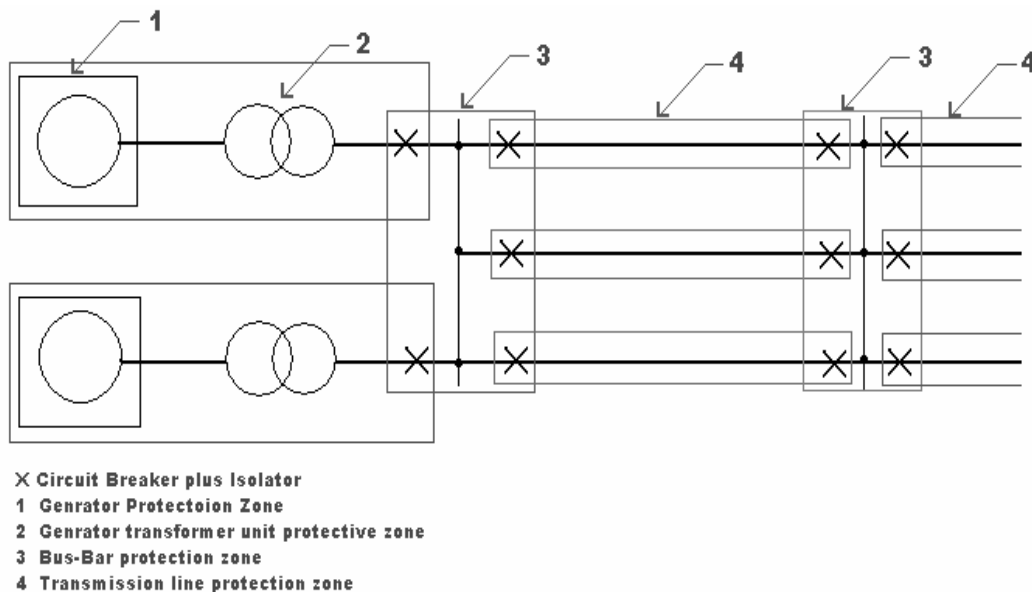
CHAPTER 2

PROTECTION SCHEMES

CHAPTER 2

PROTECTION SCHEMES

A selected set of protective system which protects one or two components of the power system against abnormal conditions, e.g., generator protection scheme, transformer protection scheme, Bus-Bar Protective scheme etc. Protection schemes are planned along with the system design of a power system. The Circuit-Breakers are located at appropriate point such that any component of the power system can be disconnected for usual operation & maintenance requirements, & also during abnormal condition such as short circuit depending on rating of machine, its location, relative importance, probability of faults & abnormal conditions each power system component (Generator, Transformer, Transmission line, Bus-Bar, Individual Loads, etc.) is covered by a protective zone. The entire power system is covered by several protective zones & no part of system is left unprotected.



Protective Zones in a Power System

2.1 Over-current Protection

As the fault impedance is less than load impedance, the fault current is more than load current. If a short circuit occurs the circuit impedance is reduced to a low value and therefore a fault is accompanied by large current. Over-current protection is that protection in which the relay picks up when the magnitude of current exceeds the pickup level. The basic element in Over-current protection is an Over-current relay. The Over-current relays are connected to the system, normally by means of CT's. Over-current relaying has following types:

1. High speed Over-current protection.
2. Definite time Over-current protection.
3. Inverse minimum time Over-current protection.
4. Directional Over-current protection (of above types).

Over-current protection includes the protection from overloads. This is most widely used protection. Overloading of a machine or equipment (generally) means the machine is taking more current than its rated current. Hence with overloading, there is an associated temperature rise. The permissible temperature rise has a limit based on insulation class and material problems. Over-current protection of overloads is generally provided by thermal relays. Over-current protection includes short-circuit protection. Short circuits can be phase faults, earth faults or winding faults. Short-circuit currents are generally several times (5 to 20) full load current. Hence fast fault clearance is always desirable on short-circuits. When a machine is protected by differential protection, the over-current is provided in addition as a back up and in some cases to protect the machine from sustained through fault.

Several protective devices are used for over-current protection these include:

1. Fuses
2. Circuit breakers fitted with overloaded coils or tripped by over-current relays.
3. Series connected trip coils operating switching devices.
4. Over-current relays in conjunction with current transformers.

The primary requirements of over-current protection are:

The protection should not operate for starting currents, permissible over-current, and current surges. To achieve this, the time delay is provided (in case of inverse relays). If time delay cannot be permitted, high-set instantaneous relaying is used. The protection should be coordinated with neighboring over-current protections so as to discriminate.

Applications of Over-current Protection

Over-current protection has a wide range of applications. It can be applied where there is an abrupt difference between fault current within the protected section and that outside the protected section and these magnitudes are almost constant.

The over-current protection is provided for the following:

Motor Protection: Over-current protection is the basic type of protection used against overloads and short-circuits in stator windings of motors. Inverse time and instantaneous phase and ground over-current relays can be employed for motors above 1200 H.P. For small/medium size motors where cost of CT's and protective relays is not economically justified,

thermal relays and HRC fuses are employed, thermal relays used for overload protection and HRC fuses for short-circuit protection.

Transformer Protection: Transformers are provided with over-current protection against faults, only, when the cost of differential relaying cannot be justified. However, over-current relays are provided in addition to differential relays to take care of through faults. Temperature indicators and alarms are always provided for large transformers. Small transformers below 500 KVA installed in distribution system are generally protected by dropout fuses, as the cost of relays plus circuit breakers is not generally justified Line Protection. The lines (feeders) can be protected by

- (1) Instantaneous over-current relays.
- (2) Inverse time over-current relays.
- (3) Directional over-current relay.

Lines can be protected by impedance or carrier current protection also.

Protection of Utility Equipment

The furnaces, industrial installations commercial, industrial and domestic equipment are all provided with over-current protection.

Relays used in Over-current Protection

The choice of relay for over-current protection depends upon the Time / current characteristic and other features desired. The following relays are used.

1. For instantaneous over-current protection. Attracted armature type, moving iron type, permanent magnet moving coil type and static.

2. For inverse time characteristic. Electromagnetic induction type permanent magnet moving coil type and static.
3. Directional over-current protection. Double actuating quantity induction relay with directional feature.
4. Static over-current relays.
5. HRC fuses, drop out fuses, etc. are used in low voltage medium voltage and high voltage distribution systems, generally up to 11 kV.
6. Thermal relays are used widely for over-current protection.

Note: Now Digital Numerical Relay you can use for all types

Characteristics of relay units for over current protection

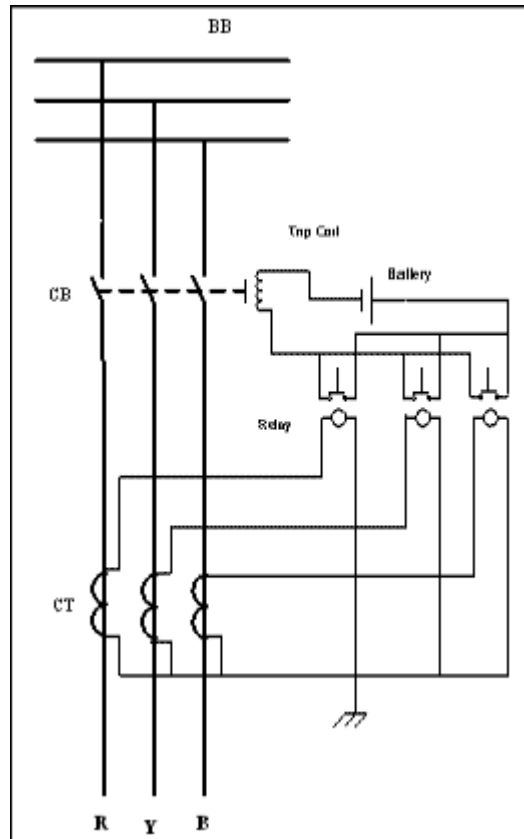
There are a wide variety of relay-units. These are classified according to their type and characteristics. The major characteristic includes:

1. Definite characteristic
2. Inverse characteristic
3. Extremely Inverse
4. Very inverse in definite characteristic, the time of operation is almost definite i.e.

Principle of Trip Circuit

The three current transformers and relay coils connected in star and the star point is earthed. When short circuit occurs in the protected zone the secondary current of CT's increases. These current flows through relay coils and the relay picks-up, the relay contacts close, thereby the trip circuit is closed and the circuit breaker-operates. The over-current protection scheme with three over-current relays responds to phase faults and earth

faults including single-phase to earth fault. Therefore such schemes are used with solidly earthed systems where phase-to-phase and phase to earth faults are likely to occur. For proper functioning of over-current and earth fault protection, the choice of CT's and polarity connections should be correct.



Over Current protection with three phase OC relays

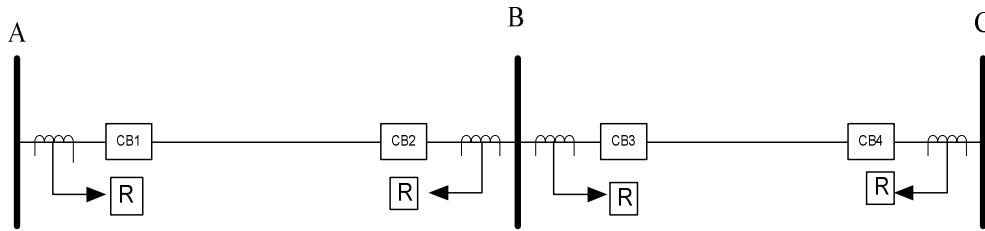
2.2 Earth-Fault Protection

When the fault current flows through earth return path, the fault is called Earth Fault. Other faults, which do not involve earth, are called phase faults. Since earth faults are relatively frequent, earth fault protection is necessary in most cases. When separate earth fault protection is not economical, the phase relays sense the earth fault currents. However such

protection lacks sensitivity. Hence separate earth fault protection is generally provided. Earth fault protection senses earth fault current. It is convenient to incorporate phase-fault relays and earth-fault relay in a combined phase-fault and earth-fault protection. The increase in current of phase causes corresponding increase in respective secondary currents. The secondary current flows through respective relay-units. Very often only two-phase relays are provided instead of three, because in case of phase faults current in any at least two phases must increase. Hence two relay-units are enough.

2.3 Directional Over-current Protection

The over-current protection can be given directional feature by adding directional element in the protection system. Directional over-current protection responds to over-currents for a particular direction flow. If power flow is in the opposite direction, the directional over-current protection remains un-operative. Directional over-current protection comprises over-current relay and power directional relay- in a single relay casing. The power directional relay does not measure the power but is arranged to respond to the direction of power flow. Directional operation of relay is used where the selectivity can be achieved by directional relaying. The directional relay recognizes the direction in which fault occurs, relative to the location of the relay. It is set such that it actuates for faults occurring in one direction only. It does not act for faults occurring in the other direction. Consider a feeder AC passing through sub-section B. The circuit breaker CB3 is provided with a directional



Principle of directional protection

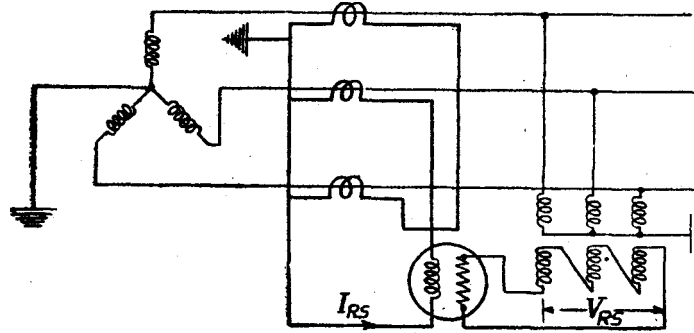
Relay 'R' which will trip the breaker CB3 if fault power flow in direction C alone. Therefore for faults in feeder AB, the circuit breaker CB3 does not trip unnecessarily.

2.4 Directional Earth-Fault Protection

In the directional over-current protection the current coil of relay is actuated from secondary current of line CT. whereas the current coil of directional earth fault relay is actuated by residual current. In directional over-current relay, the voltage coil is actuated by secondary of line VT. In directional earth fault relay, the voltage coil is actuated by the residual voltage. Directional earth fault relays sense the direction in which earth fault occurs with respect to the relay location and it operates for fault in a particular direction. The directional earth fault relay (single phase unit) has two coils. The polarizing quantity is obtained either from residual current $IRS = (I_a + I_b + I_c)$ or residual voltage

$$VR_s = V_a + V_b + V_c$$

Where V_a , V_b and V_c are phase voltages.



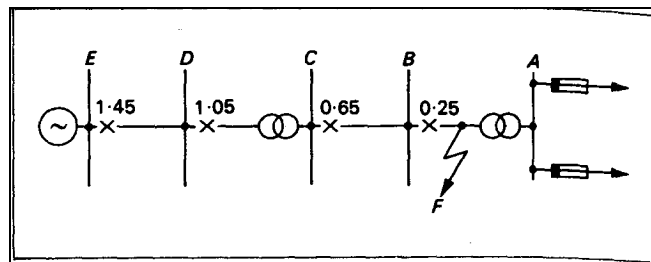
Connections of a directional earth-fault relay.

2.5 Principal of Time/Current Grading

Among the various possible methods used to achieve correct relay co-ordination are those using either time or over current or a combination of both time and over-current. The common aim of all three methods is to give correct discrimination. That is to say, each one must select and isolate only the faulty section of the power system network, leaving the rest of the system undisturbed.

1. Discrimination by time:

In this method an appropriate time interval is given by each of the relays controlling the circuit breakers in a power system to ensure that the breaker nearest to the fault opens first. A simple radial distribution system is shown in (Fig.) to illustrate the principle.



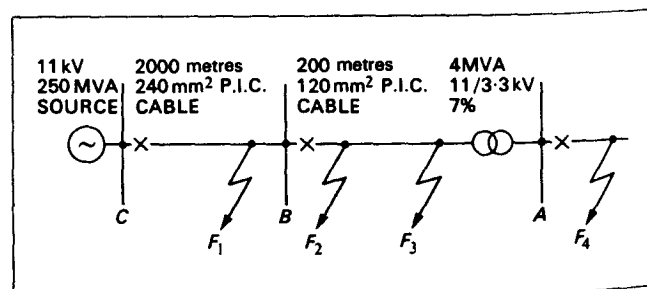
Radial systems with time discrimination

Circuit breaker protection is provided at B, C, D and E, that is, at the infeed end of each section of the power system. Each protection unit comprises a definite time delay over current relay in which the operation of the current sensitive element simply initiates the time delay element. Provided the setting of the current element is below the fault current value this element plays no part in the achievement of discrimination.

The main disadvantage of this method of discrimination is that the longest fault clearance time occurs for faults in the section closest to the power source, where the fault level (MVA) is highest.

2. Discrimination by current:

Discrimination by current relies on the fact that the fault current varies with the position of the fault, because of the difference in impedance values between the source and the fault. Hence, typically, the relays controlling the various circuit breakers are set to operate at suitably tapered values such that only the relay nearest to the fault trips its breaker. Fig. illustrates the method.



Radial system with current discrimination

2.6 VARIOUS PROTECTION SCHEMES

2.6.1 TRANSFORMER PROTECTION

The two major items of equipment in a power system are the generators and transformers. Chances of fault occurrence on them are very rare as compared to on lines, but the damage caused by the faults usually takes much more time and money to repair than are required to repair the damage caused by the faults on the lines. Rapid reclosing of circuit breakers is feasible on lines and it helps in saving the amount of damage while a fault in a generator! Transformer always requires some attention of the supervisory staff. Fast clearing of faults, however, assists in reducing the damage to the equipment and also reduces the interruption in power service caused by drop in voltage and from instability. Power transformers are static devices, totally enclosed and usually oil immersed, and therefore, chances of fault occurrence on them are very rare. But the consequences of even a rare fault may be very serious unless the transformer is quickly disconnected from the system. Hence automatic protection of transformers against possible faults is essential and of utmost importance. The faults occurring in power transformers are open-circuit faults (an open-circuit in one phase of a 3-phase transformer), earth faults, phase-to-phase faults, inter-turn faults and overheating from overloading or from some internal cause such as core-heating. Frequent on leads of three phase transformers, while the interphase short-circuits within the windings are less frequent. Earth faults and inter-turn faults have the highest probability on the power transformers. Winding short-circuits, also called the internal faults, generally result from failure of insulation due to temperature rise or

deterioration of transformers oil. An open-circuit in one phase of a 3-phase transformer may cause undesirable heating but this condition is relatively harmless and so no relay protection is required against open-circuits, on the occurrence of such a fault, the transformer can be disconnected manually from the system. As already mentioned above, the most common types of internal winding faults are earth faults and inter-turn faults. Since the inter-turn faults develop rapidly into earth faults, only earth fault protection is essentially provided. The choice of a protective gear for a transformer depends upon several factors such as:

- (i) Type of transformer i.e., distribution transformer or power transformer
- (ii) Size of the transformer
- (iii) Type of cooling
- (iv) System where used i.e., its electrical location in the network and
- (v) The importance of service for which it is required.

For distribution transformers employed in rural area, the normal practice is to use the fuses for its protection against external faults but for urban distribution networks, where discrimination is absolutely necessary; fuses will not serve the purpose. For power transformers, the protection is to be provided usually against dangerous Overloads and excessive temperature rise. Dangerous overloads may be due to external faults or the internal ones. External faults, however, are cleared by the relay system outside the Transformer within the shortest possible time in order to avoid any danger to the transformer Due to these faults. Hence the protection for internal faults is to be provided in such transformers. Differential protection is the most important type of protection used for protection against internal phase-to-phase and phase-to-earth faults. The other protection systems

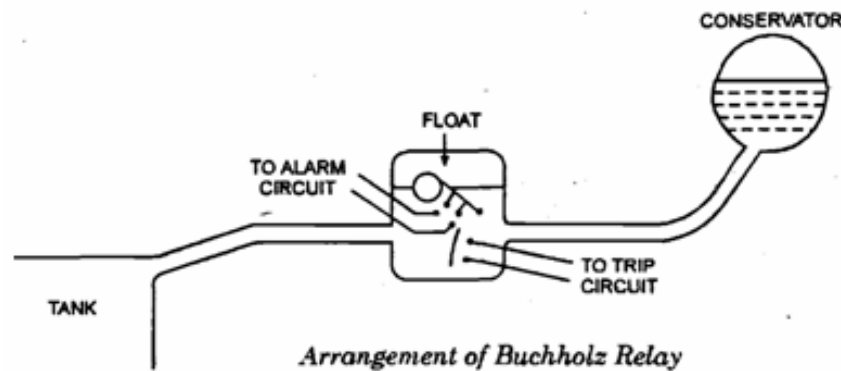
employed for protection of transformers against internal faults are Buchholz protection, core balance leakage protection, combined leakage and overload protection, restricted earth—fault protection. Different protection systems commonly used for protection of transformers will be discussed here.

- ***Buchholz Protection***

On the occurrence of internal fault in an oil-immersed power transformer gas is usually Generated, slowly for an incipient fault (such as sparking, small arcing, loose connections in conducting path etc.,) and violently for heavy faults. Most short-circuits caused either by impulse breakdown between adjacent turns at the end turns of the winding or as a poor initial point contact which will immediately heat to arcing temperature. The heat generated by the large local currents causes the transformer oil to decompose and generate gases, which can be used in detection of winding faults. The relays based on this principle are pressure relays and pressure relief devices which act on the measurement of the total accumulated pressure,

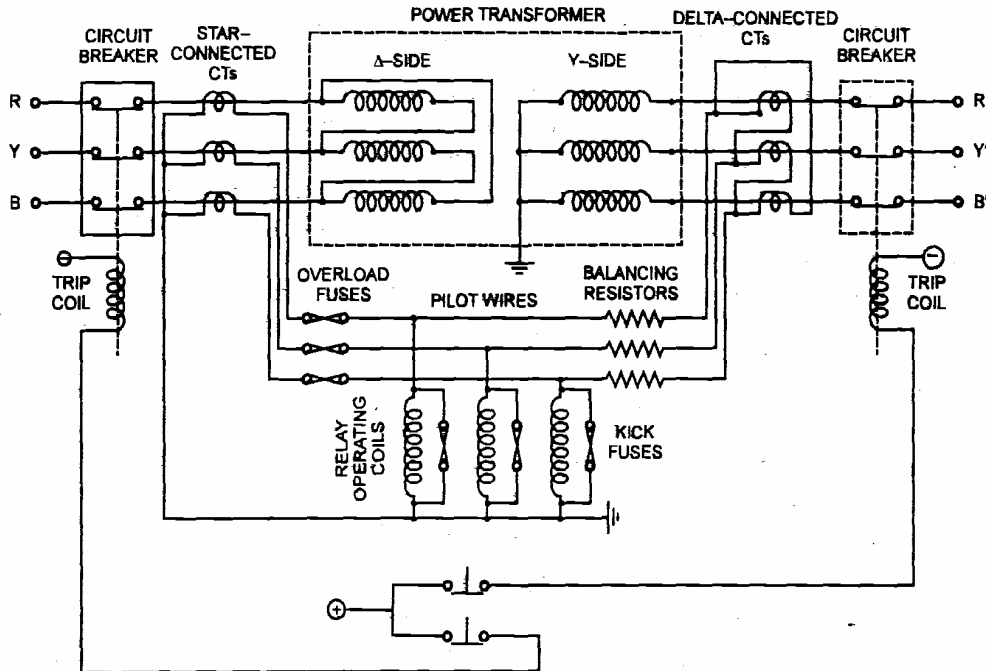
- (i) rate of pressure rise relay, which acts on the measurement of the rate of formation of the gas and
- (ii) gas accumulator relay, most commonly known as Buchholz Relay, actuated by the gas formed.

Buchholz protection employing Buchholz relay is the simplest form of protection and is most commonly used on all oil-immersed transformers provided with conservator.



• ***Differential Protection for Power Transformers***

The differential protection used for power transformers is based on Merz-Price circulating current principle. Such protection provides protection against internal phase-to-phase and phase-to-earth faults and is generally used for transformers of rating exceeding 2 MVA. This protection system as applied to power transformers is fundamentally the same as that for generators but with certain complicating features not encountered in the generator application. Fig. shows the Merz-Price protection system as applied to a star/delta power transformer. The overload protection is provided by the use of overload fuses in the pilot wires between the three pairs of CTs. When the overload blows a fuse one of the pair of OTs is disconnected from the relay which receives the current from the remaining Cm. The balance is thus disturbed and the relay operates. Thus a back-up protection is provided.



*Schematic Diagram of Differential Protection
as Applied to a Star/Delta Power Transformer*

On energisation of transformer the transient inrush of magnetizing current flowing into the transformer may be as large as 10 times full-load current and it decays relatively slowly. Since the large magnetizing current flows only in primary windings, it causes difference in CTs output and makes the differential protection of transformer to operate falsely. In order to prevent operation of differential protection due to inrush of magnetizing current, the “kick fuses” are provided across the relay coils, as shown in fig 9.3. These fuses are of the time- limit” type with an inverse characteristic and do not operate in short-time duration of the switching-in-surge. Under sustained fault conditions, however, the fuses operate (blow off and the full current flows through the relay coils and operate the protection system. This scheme affects the relay setting and to avoid this, arrangements are sometimes made to have the “kick fuses” in circuit only during the period of switching-in. This problem can also be overcome by using a relay with

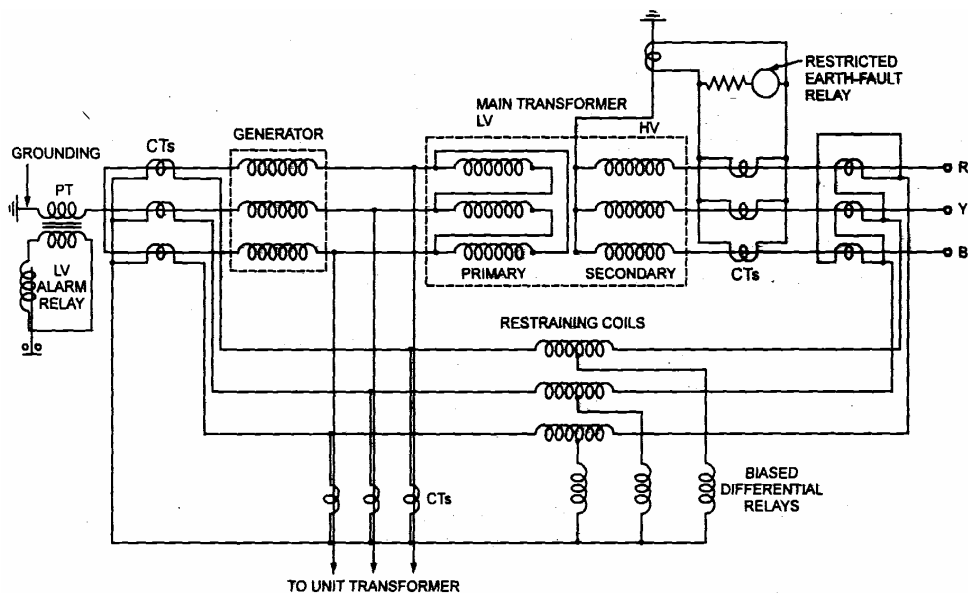
an inverse and definite minimum time characteristic instead of an instantaneous type.

2.6.2 GENERATOR-TRANSFORMER UNIT PROTECTION

In hv transmission the bus-bars are operated at higher voltages than that of generation; it is common practice to connect the generators directly to step-up transformers. In this protection scheme no circuit breaker is interposed in between the generator and transformer. The main advantage of such protection is that it simplifies the protection; mainly the differential protection for both generator and transformer can be combined together by employing CTs on the neutral side of the generator and on the hv side of the power transformer, as illustrated in fig. Because of the occurrence of magnetizing inrush current transients the relay settings in this protection scheme must be considerably higher than those for protecting a generator only. The zone of differential protection includes the stator windings of the generator, the step-up transformer and the intervening connections.

It is necessary to take care of the phase shift within the power transformer and the connections of CTs. If a unit transformer is tapped off at the generator terminals, this also has to be taken care of by suitable connections of the CTs for protection. CTs located on the neutral side of the generator are star-connected while the CTs on the secondary by side of the main transformer are delta- connected so as to cancel the 300 displacement between line currents introduced by delta- connected primary of the main transformer. The unbalance caused between CT pairs due to load of unit transformer is avoided by providing another set of star-

connected CTs in the primary leads of the latter. In healthy condition, the sum of secondary currents of these CTs and the secondary currents of the generator star-point CTs is equal to the currents in the pilot wires from the secondaries of the delta-connected CTs on the secondary side of the main transformer. On occurrence of fault differential relays are energized. The hv winding of the main transformer is protected against earth faults by the restricted earth fault protection scheme. From the schematic diagram of generator-transformer unit protection shown in fig, it is obvious that the stator winding of the generator and the lv or primary windings of the main transformer and unit transformer comprise a separate circuit having no electrical connection with the hv circuits. So an earth fault at any point of this separate circuit will cause a flow of current through the earth connection and through a PT connected in series with it. An alarm relay connected across the secondary winding of PT will get energized and give the necessary signal.



Protection of Generator-Transformer Unit
Fig. 9.15

PROTECTION OF TRANSFORMER

Abnormal Conditions	Types of protection	Remarks
Faults related to oil level	Buchholz relay (gas actuated relay)	It is used for transformers of rating 500 KVA & above.
Saturation of magnetic circuit	1. Over fluxing protection 2. Over voltage protection	It is used for generator transformers & feeder transformers.
Earth faults	1. Differential protection 2. Earth fault relay	It is used for transformers of & above 5 MVA.
Overloads	1. Thermal overload relays. 2. Temperature relay sound alarm	Generally temp. indicators are provided on transformers. Temp. increase is indicated on control panel also. Fans start at certain temp.

2.6.3 PROTECTION OF FEEDERS AND TRANSMISSION LINES

The probability of faults occurrence on the overhead lines is much more due to their greater lengths and exposure to atmospheric conditions. The protective schemes employed for alternators and transformers, with slight modifications, may also be employed for protection of feeders and transmission lines. The modifications are required because of length of lines, capacitance currents and other reasons. Moreover, the necessity of discrimination in supply networks has called forward many protective schemes which have no application to the comparatively simple cases of transformers and generators. The main requirements of line protection are:

- (i) In the event of a short-circuit, the circuit breaker nearest to the fault should open, all other circuit breakers remaining in a closed position.
- (ii) If the breaker nearest to the fault fails to open, backup protection should be provided by the adjacent circuit breakers.
- (iii) The relay operating time should be the smallest possible in order to preserve system stability but without unnecessary tripping of circuits.

The protection of lines presents a problem quite different from the protection of apparatus such as generators, transformers and busbars. While differential protection is an ideal protection for lines, but it is much more expensive to use. The two ends of a line may be many kilometers apart and for comparison of two currents, a costly pilot-wire circuit is required. This expense may be justified but generally less costly protective schemes may be used. There are several protective schemes for

transmission lines and may be grouped into two groups viz, non-unit type and unit type. The non-unit type of protection includes time-graded overcurrent protection, current-graded overcurrent protection, and distance protection, while the unit type protection includes pilot- wire differential protection, carrier-current protection based on phase comparison method etc. Separate protection systems are necessary for ground faults because ground faults are more frequent on overhead transmission lines than phase fault, and ground fault current is different from phase fault current in magnitude. The selection of a particular scheme of protection depends upon the following factors:

1. Economic justifiability of the scheme to ensure 100 % continuity of supply.
2. Types of feeders-radial or ring mains.
3. Availability of pilot wires.
4. Number of switching stations in series between supply end and the far end of the system.
5. System earthing—whether the neutral or insulated.

Time-graded overcurrent protection is normally employed for backup protection in large transmission systems or where a time-lag can be permitted and instantaneous operation is not necessary i.e., where time-lag in fault clearance does not cause instability or damage to the lines. In distribution feeders, it plays a more important role and may be coordinated with fuses. Overcurrent protection is also employed for ground faults. Fuses are employed in distribution systems, where relays and circuit breakers are not necessary and fuses are preferred due to their low cost, current-limiting features etc.

Distance protection is a high speed form of protection and is used when time-lag cannot be permitted from considerations of stability. Today trend is toward the use of static distance protection for all types of line faults (phase-to-phase faults as well as phase-to-ground faults), main and backup for short medium and long transmission lines. Distance protection is preferred to overcurrent protection because it is not nearly so much affected by changes in short-circuit current magnitude as overcurrent protection is, and therefore, is much less affected by changes in generation capacity and in system configuration. In distance protection there are three main types of measuring units viz, impedance, reactance and mho type distance relays. Each type has certain advantages and disadvantages and own field of applications. For very short lines reactance type is preferred, for medium length lines impedance relay suits and mho relays are suitable for phase faults of longer lines.

The pilot-wire protection is a unit type of protection which would operate only for faults occurring within the protected zone providing no backup protection. It is used whenever high. speed protection is required for all types of short-circuits and for any fault Pilot-wire protection based on differential circulating current principle (Merz-Price) is employed for short lines where cost of pilot wires is not prohibitive. Carrier-current protection is employed for long lines and inter-connected lines.

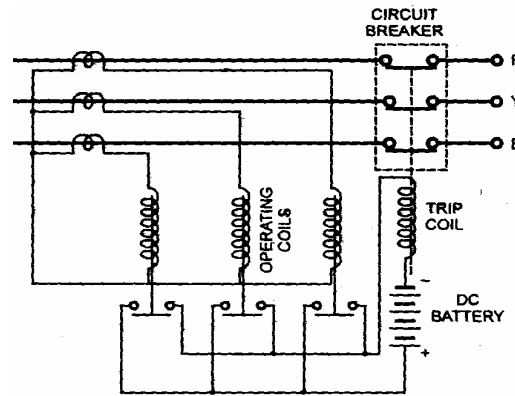
Main transmission lines operating on 220 kV and above are provided with the fastest and the most reliable protection. Carrier-pilot or high-speed distance protections are necessarily employed on main transmission circuits. 33 kV transmission lines are provided with directional time-lag overcurrent relays or high-speed distance relays. Radial feeders operating on 11 kV and below are usually provided with time-lag overcurrent relays

supplemented by instantaneous relays. Sometimes only HRC fuses are used on these lines.

Autoreclosure schemes are incorporated in the protection of distribution and transmission lines. Autoreclosure of distribution lines is mainly for improving service continuity while autoreclosure of transmission lines is mainly for improving system stability.

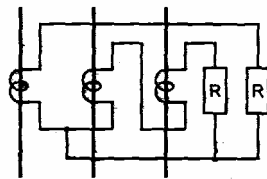
- ***Overload Protection***

This is the simplest way of protecting a line and is, therefore, widely used. Overload or overcurrent protection owes its application to the fact that the fault current in the event of a short-circuit will rise to a value several times that of the maximum load current. The ratio of minimum fault current to maximum load current is chosen as criterion in order to prevent the possibility of mal operation under normal operating conditions. This form of protection can be applied only in simple systems. The over-current protection is provided at the supply end of the line. Fig illustrates the scheme against overloading of feeders. Three are mounted, one on each phase of the feeder and are connected across the three relay coils. In case of overloading the solenoid plunger system of the relays operate to close the trip coil circuit, which in turn opens the circuit breaker, thereby disconnecting the protected feeder. The relays need readjustment or even replacement whenever a change in the system is made. 'Operation times are generally large'.



Overload Protection
Fig. 11.1

The alternative method for overload or over-current protection is the well known Z-connection which requires only two relays for the protection of a 3-phase circuit. This scheme is shown in fig.



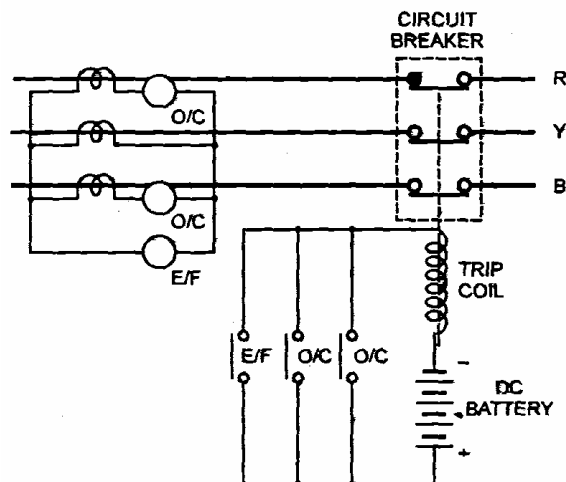
Z-Connection For Overload Protection
Fig. 11.2

• **Overcurrent and Earth-Fault Protection**

The general practice is to employ a set of two or three over-current relays for protection against phase- to-phase faults and a separate overcurrent relay for single line-to-ground faults. Separate earth fault relays are generally preferred because they can be adjusted to provide faster and more sensitive protection for single line-to-ground faults than that can be provided by the phase relays. Earth fault current depends on the type of neutral earth whether solidly earthed, insulated or earthed through some resistance or reactance. Where no neutral point is available, grounding transformer is employed. Whatever the type of neutral earthing be

employed, the earth-fault current will be small as compared to phase-fault currents in magnitude. The relay thus connected for earth fault protection is different from the ones provided for phase-to-phase faults. In case of resistance earthed or solidly earthed systems, the overcurrent element connected residual circuit of CTs is preferred. The setting of earth-fault relays may be made less than rated full-load current of the line.

In the above protection scheme two IDMT type overcurrent relays are connected in two phases through CT's and one earth-fault relay, as illustrated in fig. in case of phase-to- phase faults or overload the IDMT relays trip the circuit breaker. Under healthy conditions, the sum of all the three currents of CTs is zero and the earth-fault relay remains inoperative. As soon as phase-to-ground fault occurs unbalancing in currents causes the earth-fault relay to operate, which in turn trips the circuit breaker.



*Overcurrent and Earth-Fault
Protection Scheme
Fig. 11.3*

PROTECTION OF TRANSMISSION LINE

Types of protection	Remarks
Distance protection	Applied as main protection for main lines.
Over current protection	Applied as main protection for distribution line & backup for main lines.
Earth-fault protection	Separate earth-fault protection is necessary In addition to phase fault protection.

2.6.4 BUSBAR PROTECTION

The busbar in electric power stations and substations are the one of the most vital elements. Although with the advent of modern design methods the probability of occurrence of faults has been reduced to negligible, but if a fault occurs on a bus bar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided for isolation of the faulty bus-bar. The busbar area or zone, for the purpose of protection, includes not only the bus-bars themselves but also the isolating switches, circuit breakers, instrument transformers and bus-sectionalizing reactors etc.

Busbar protection needs special attention because of the following reasons.

1. Fault level at busbars is very high.
2. The fault on the busbar would result in widespread supply interruption.
3. 'The system stability is adversely affected by fault in bus zone.

In the event of fault on any section of the busbar, all the circuit equipments connected to that section must be tripped out to give complete isolation in shortest possible time e.g., (60 ms), so that damage is avoided to the installation due to heating of conductors. Internal bus faults are less frequent than line faults. A bus fault tends to be appreciably more severe, both with respect to the safety to personnel system stability and the damage. A major system shutdown may be caused in the absence of adequate bus protection. It is of utmost importance therefore the bus zone protection should be quick acting, stable and most reliable. The desirable features of bus protection are given below:

1. High speed operation (less than 3 cycles).
2. Discrimination between fault in its protected section and fault elsewhere.

3. Stability for external faults.
4. Freedom from unwanted operation.
5. No operation due to CT saturation or power swings.
6. Separate control of trip circuit of each circuit breaker.
7. 'Main' and 'check' protection to ensure the isolation only when desirable.
8. Non-autoreclosure, no single pole tripping of circuit breakers for bus-fault.
9. Interlock overcurrent protection for tripping generator unit in the event of operation of bus-zone protection.

BUS-BAR ARRANGEMENTS

Bus-bar term is used for a main bar or conductor carrying an electric current to which many connections may be made. The term bus is derived from the word omnibus, meaning collector of things. Thus electrical bus-bar is the collector of electrical energy at one location. Bus-bars are merely convenient means of connecting switches and other equipment into various arrangements. The usual arrangement of connections in most of the substations permits working on almost any piece of equipment without interruption to incoming or outgoing feeders. The bus-bars used in substations are usually bare rectangular x-section bars but they can be of other shapes also, as round tubes, round solid bars, or square tubes. The bus-bars are usually of aluminium (less frequently of copper). The use of aluminium as an electric conductor is made due to its numerous advantages over copper such as higher conductivity on weight basis, lower cost for equal current carrying capacity, excellent corrosion resistance and ease of formability. For proper reliable electrical connections aluminium buses are

coated with silver. The most common sizes of bus-bars are 40 x 4 mm (160 mm²), 40 x 5 mm (200 mm²), 50 x 5 mm (250 mm²), 50 x 6 mm (300 mm²), 60 x 8 mm (480 mm²), 80 x 8 (640 mm²), and 100 x 10 mm (1,000 mm²) according to the maximum current to be carried. The bus-bars are of 5 or 6 meters in length. There are several types of bus-bar arrangements. The choice of a particular arrangement depends upon different factors such as system voltage, position of substation in the system, reliability of supply, flexibility and cost.

- **BUS ZONE FAULTS**

According to statistical information, the majority of the faults are single phase in nature and are, in part, temporary in character. The causes of the bus zone faults are:

- a. Failure of support insulator, due to material deterioration, resulting in earth fault.
- b. Flashover across support insulator, caused by prolonged and excessive overvoltages.
- c. Faulty operations performed by the attending personnel.
- d. Heavily polluted insulator causing flashover.
- e. Foreign objects accidentally falling across bus-bars.
- f. Failure of circuit breakers to interrupt fault current or failure to clear under through fault conditions.

The clearing of a bus fault requires the opening of all the circuits branching from the faulty bus or bus section (leaving circuits having no back feed).

The most commonly used schemes for bus-zone protection are:

1. Backup protection. 2. Circulating current protection and 3. Frame leakage protection.

All the protection schemes must also be provided with a check system to ensure that the protection responds only to earth faults occurring within the bus zone and not to extraneous earth faults.

PROTECTION OF BUS-BAR

Types of protection	Remarks
Instantaneous over current relays & earth fault relays.	Used in distribution system.
Differential protection.	Used in major stations.
Earth fault relay connected to secondary of CT.	Metal frames of switchgear are earthed through Ct.
Back-up Protection. ▪ Over current protection ▪ Distance protection	Used for precaution purpose.
Over voltage protection.	Connected to bus – VT

2.7 REACTOR

Reactor is a coil which has high inductive reactance as compared to its resistance and is used to limit the short circuit current during fault conditions. To perform this function it is essential that magnetic saturation at high current does not reduce the coil reactance. If an iron cored inductor is expected to maintain constant reactance for currents two to three times its normal value it will turn out to be very costly and heavy. Therefore air cored coils having constant inductance are generally used for current limiting reactors.

Air cored reactors are normally of two types:

- (i) Oil immersed type, and
- (ii) Dry type.

Oil immersed reactors can be cooled by any of the means used for cooling the power transformer whereas the dry type are usually cooled by natural ventilation and are sometimes designed with forced-air and heat exchanger auxiliaries. Reactors are usually built as single phase units. With the increase in interconnection of power system the fault levels are increasing. It is, therefore, necessary to increase the reactance by introducing reactors at strategic points in the system. The following are the various possibilities:

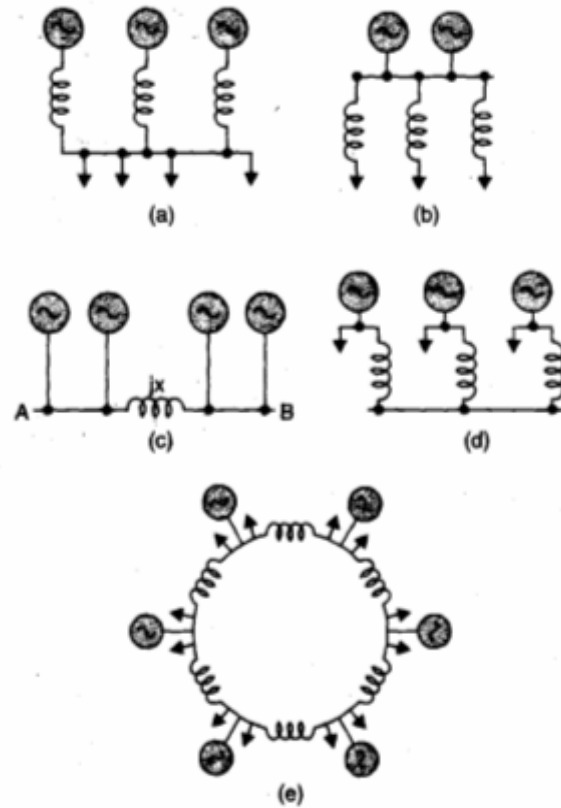
(i) Generator reactors: The reactance of modern alternators may be as high as 2.0 p.u. which means even a dead short-circuit at the terminals of the alternator will result in a current less than full load current and, therefore, no external reactor is required for limiting the short circuit current of such a machine. However, if some old machines are being used

along with the modern alternator, these old machines need the reactors for limiting the short circuit “current.

(ii) Feeder reactor: The per unit value of reactance of a feeder based on its ratings may be small but when compared with the rating of the whole system, its value is quite large and hence a small reactor will be effective in limiting the short circuit current should a fault occur close to the generating station. In case this feeder reactor is not there, a fault in such a location would bring the bus bar voltage almost down to zero value and there is a possibility of various generators falling out of step. We know that to improve the transient stability of a system the critical clearing angle should be as small as possible, i.e., the breakers should be as fast as possible. In order to obtain this situation and at the same time to reduce the current to be interrupted the feeder must be associated with a reactor .

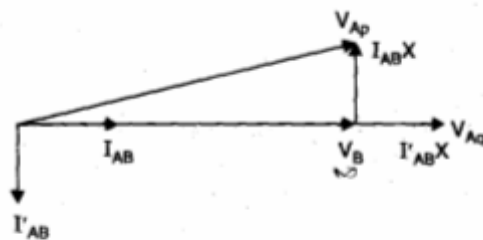
(iii) Busbar reactor: There are three methods of interconnecting the bus bar through the reactor .The simple method is suit able for plants of moderate output whereas for large- sized plants either the star or ring system of connection is used. It is to be noted that any transfer of power from say section A to section B of the generators, a difference in potential between the bus sections is developed. If the power to be transferred is wattles the difference in voltage between the buses sections will be much more as compared to when active power of same magnitude will be transferred.

Two conditions when resistance of the system is neglected is shown in the fig



Types of Reactors (a) Generator

(b) Feeder (c-e) Busbar



Phasor diagram

CHAPTER 3

CIRCUIT BREAKER

Chapter-3

CIRCUIT BREAKER

A circuit breaker is a device that interrupts the abnormal or fault currents and in addition performs the function of a switch. Circuit breakers and fuses both possess a time element of operation, whereby they operate practically instantaneously on short-circuits but with definite time lag on overloads. Circuit breakers can be reset in less time and with less trouble that are required to replace blown fuses and spare parts are seldom required. For low voltage circuits fuses may be used to isolate the faulty circuits; but for higher voltages, say from 3.3 kV upwards, isolation is achieved by circuit breaker. Circuit breakers may also be preferred where continuity of service is an important consideration or where frequent fuse replacement may be expected.

Circuit breakers are mechanical devices designed to close or open contact members, thus closing or opening of an electrical circuit under normal or abnormal conditions. Automatic circuit breakers, which are usually employed for the protection of electrical circuits, are equipped with a trip coil connected to a relay or other means, designed to open the breaker automatically under abnormal conditions, such as over current. The automatic circuit breakers perform the following duties:

- (i) It carries the full—load current continuously without overheating or damage,
- (ii) It opens and closes the circuit on no load,
- (iii) It makes and breaks the normal operating current.

3.1 Operating Principle

A circuit breaker is a switching and current interrupting device. It consists, essentially, of fixed and moving contacts, which are touching each other and carry the current under normal conditions i.e., when circuit breaker is closed. When the circuit breaker is closed, the current carrying contacts, called the electrodes, engage each other under the pressure of a spring. During the normal operating condition the circuit breaker can be opened or closed by a station operator for the purpose of s and maintenance. To open the circuit breaker, only a small pressure is required to be applied on a trigger. Whenever a fault occurs on any part of the power system, the trip coils of the breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit. The separation of current carrying contacts produces an arc. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process-but it also generates enormous heat which may cause damage to the system or to the breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

3.2 Arc Extinction

When current carrying contacts of a circuit breaker are parted, an arc is formed, which persists during the brief period after separation of contacts. The arc provides a gradual transition from the current—carrying to the voltage isolating states of the contacts, but it is dangerous on account of the energy generated in it in the form of heat which may result in explosive force. The circuit breaker should be capable of extinguishing the arc without causing any damage to the equipment or danger to personnel. The arc plays a vital role in the behavior of the circuit breaker. The interruption

of dc arcs is relatively more difficult than ac arcs. In ac arcs, as the current becomes zero during the regular wave, the arc vanishes and it is prevented from restriking.

3.3 METHODS OF ARC EXTINCTION

There are two methods of arc extinction in circuit breakers.

1. High Resistance Method. In this case the arc is controlled in such a way that its effective resistance increases with the time so that the current is reduced to such a value that heat produced by it is not sufficient to maintain the arc and thus the current is interrupted or the arc is extinguished. The rate at which the resistance is increased or the current is reduced is not abnormal so as to cause harmful induced voltages in the system. Because of the resistive nature of the arc discharge, most of the energy in the system will be dissipated within the circuit breaker. Therefore, while designing the circuit breaker, provision of mechanical strength to withstand such sudden release of large quantities of energy must be made. This is the main drawback of this method of arc extinction and so its use is restricted to dc circuit breakers and air break type ac circuit breakers of relatively low capacities of the order of a few hundred MVA.

The resistance of the arc can be increased by

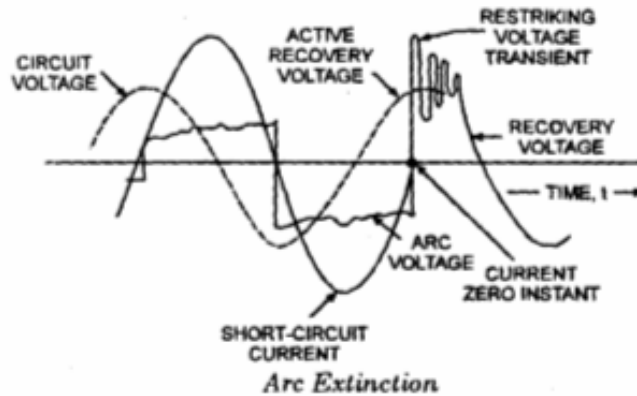
- Cooling of arc.
- Increasing the length of arc.
- Reducing the cross—section of arc
- Splitting of arc.

2. Low Resistance or Current Zero Interruption. This method is applicable only in ac circuit interruption because there is natural zero of current 100 times in a second for 50Hz 3 phase supply system. This property of ac circuit is exploited for interruption purpose and the current is not allowed to rise again after a zero occurs. Also it is neither necessary nor desirable to cut off the current at any other point on the ac wave because this will induced high voltage in the system. In this method the arc resistance is kept low until the current is zero where the arc extinguishes naturally and is prevented from restriking after it has gone out at a current zero. This method of arc extinction is employed in all modern high power ac circuit breakers

3.4 IMPORTANT TERM ASSOCIATED WITH CIRCUIT BREAKING

Restriking Voltage and Recovery Voltage. In ac circuit breakers, the current interruption takes place invariably at the natural zero of current wave. At current zero, a high frequency transient voltage appears across the breaker contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the power system. This transient voltage is known as restriking voltage. This voltage appearing across the breaker contacts at the moment of final current zero has a profound influence on the arc extinction process. Under the influence of this voltage the arc tries to restriking and hence it is named as the rest restriking voltage. After current zero, the arc gets extinguished if the rate of rise of restriking voltage between the contacts is less than the rate at which dielectric strength of the medium between at contacts gains.

Thus restriking voltage may be defined as the resultant transient voltage which appears across the breaker contacts at the instant of arc extinction.

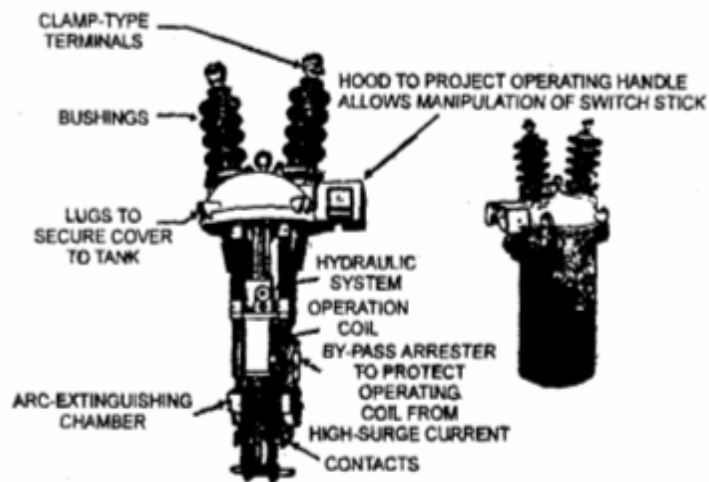


Arc Extinction

3.5 AUTO-RECLOSURE

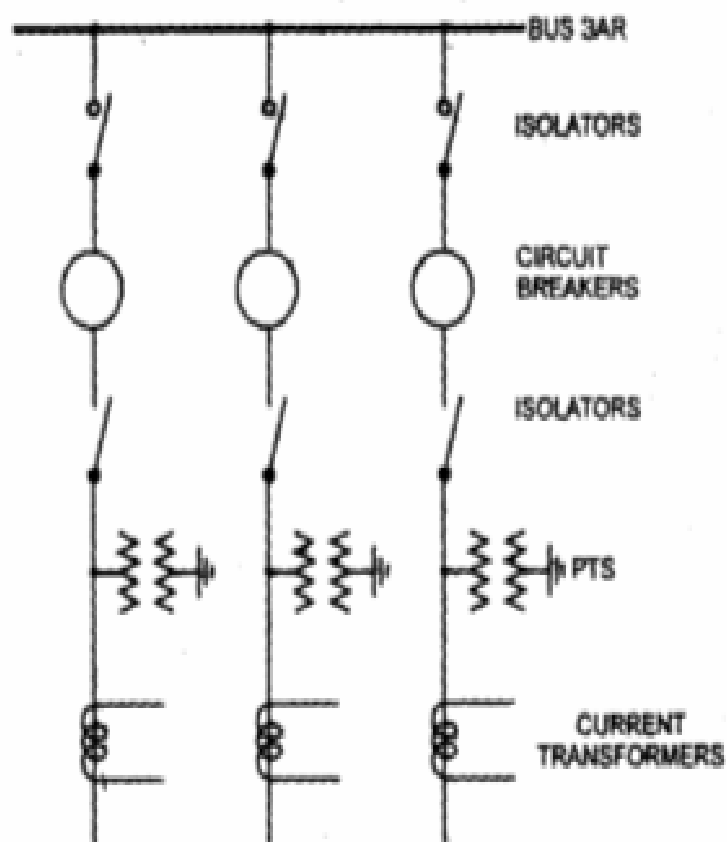
It has been found that most of the line faults on overhead transmission system are transient in nature. Statistical evidence shows that about 90 % of the faults are caused by lightning, birds, vines; tree branches etc. These conditions result in such arcing faults that if the fault energy in feed is interrupted for a short period, the arc extinguishes and the line can be re-energized. This fact is employed as a basis for auto reclosures schemes. In such schemes, after the relays at both ends of the line have picked up, the circuit, breakers are tripped as far as possible at the same time and reclosed after time has been allowed for deionization. The fault disappears if it is transient, and line is fully restored to service after the reclosure. If the fault is not cleared after the first reclosure, a double or triple attempt of isolation

and reclosure can be made. If the fault still persists, the breaker may permanently open till it is reset manually.



Oil-Circuit Reclosure (Single Phase)

Online diagram of Switch Yard



One Line Diagram of Substation

3.6 CLASSIFICATION OF CIRCUIT BREAKER

On the basis of type of current circuit breaker may be classified as ac circuit breaker and dc circuit breaker.

AC circuit breaker may be classified on the basis of rated voltage. Circuit breaker below rated voltage of 1000 volt is known as the low voltage circuit breaker and above 1000 volt is called as high voltage circuit breaker. However the most general way of classification of circuit breaker is on the basis of medium of arc extinction such as miniature circuit breaker oil circuit breaker, air blast circuit breaker, SF6 circuit breaker, vacuum circuit breaker. All the high voltage circuit breaker may be classified as oil circuit breaker and oil less circuit breaker.

1. Oil circuit breaker

- Bulk oil circuit breaker
- Minimum oil circuit breaker

2. Oil less circuit breaker

- Water circuit breaker
- Air blast circuit breaker
- Sulphur hexafluoride circuit breaker(SF6)
- Vacuum circuit breaker

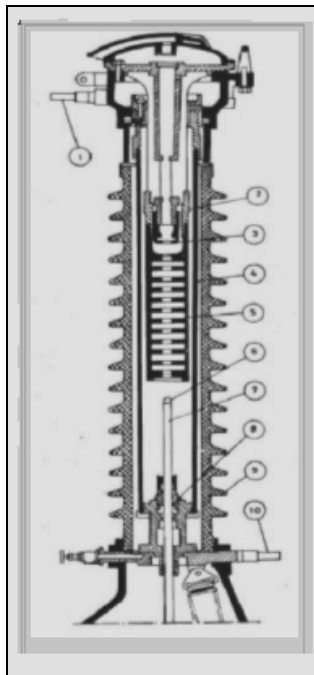
3.6.1 Small Oil Volume Breaker

As the system voltages and fault levels increased the Bulk Oil Breakers required huge quantities of insulating oil and became unwieldy in size and weight. This added enormously to the cost of a power system. Simultaneously improvements were made in the technique of ceramics. The function of oil as insulating medium in the Bulk Oil Breakers was

transferred to the porcelain containers. Only a small quantity of oil was used to perform its functions as arc quenching medium. This led to the development of small oil volume or low oil content breakers in the continent of Europe. To prevent the arc restricting after a natural Passage Through zero. The electric arc itself has, therefore, supplied the necessary energy for its own extinction. This takes the form of an insulating cylinder containing oil, in the axis of which moves the contact rod and within which breaking occurs. The arcing chamber is supported at its base by a casing enclosing a mechanism whose function is to move the contact rod.

In addition there are certain other advantages which may be summed up as under:

- (i). Light and reduced size rendering transport.
- (ii) Simple construction making erection easy.
- (iii).Quick and simple maintenance.



Minimum oil circuit breaker

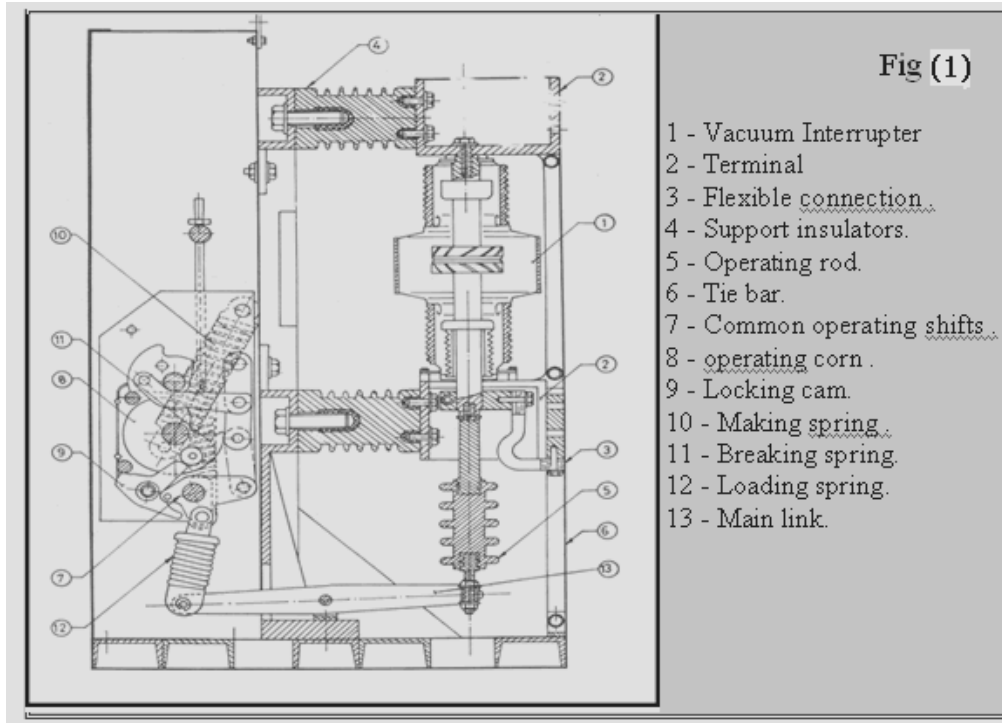
3.6.2 Vacuum Circuit Breaker

Sectional view of a Vacuum Circuit Breaker is shown in Fig. (1) the most important part is the vacuum interrupter, blown up view of which is given in Fig. (2) When the contacts separate, the current to be interrupted initiates a metal vapor arc discharge and flows through this plasma until the next current zero.

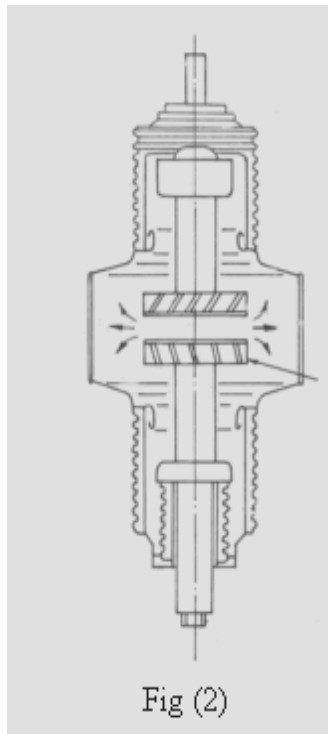
The arc is then extinguished and the conductive metal vapor condenses on the metal surfaces within a matter of microseconds. As a result, the dielectric strength in the break builds up very rapidly. The self generated field causes the arc root to travel, thereby preventing local overheating when large currents are being interrupted. Certain minimum current is necessary to maintain the metal vapor arc discharge.

Further the arc voltage developed in vacuum interrupter is low (say between 20 to 200 V) due to high conductivity of metal vapor plasma. For these reasons the arc energy developed in the break is very small. High Switching life is claimed on this account. Performance is claimed to be immune to pollution because of interrupters being hermetically sealed.

Vacuum Circuit Breakers are specially suited in industrial applications, where the Switching frequency is high combined with high degree of pollution.



Sectional view of a Vacuum Circuit Breaker Fig. (1)



Blown up view of Vacuum Circuit Breaker Fig. (2)

3.6.3 Sulphur Hexafluoride (SF₆ Circuit Breaker)

In circuit breakers discussed so far (oil circuit breakers, air break circuit breakers and air blast circuit breakers) the extinguishing force builds up relatively slowly after the moment of contact separation, and hence the arc is usually extinguished after a few half cycles of current have passed zero. The prevention arc re-ignition needs a high dielectric strength of the arc path and its fast recovery after current zero. In case of hv circuit breakers, these properties are particularly required to have quick arc extinction and have less time for quick recovery voltage build up. Vacuum circuit breakers and SF₆ circuit breakers have better properties in this regard compared to conventional bulk oil, minimum oil as well as air—blast circuit breakers. Hence modern trend is to employ vacuum circuit breakers and SF₆ circuit breakers in hv systems.

Construction.

Such a circuit breaker essentially consists of two parts, namely (i) the interrupter unit and (ii) the gas system.

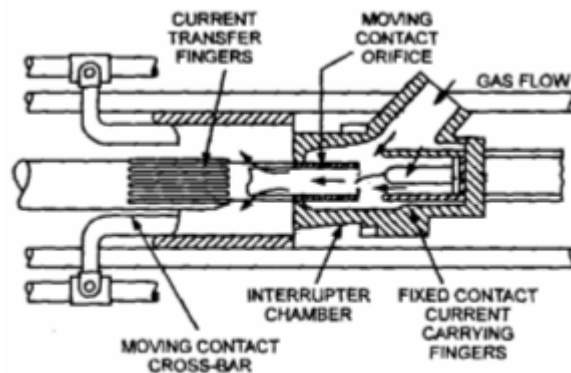
The Interrupter Unit

This unit consists of moving contact and fixed contacts comprising a set of current carrying fingers and an arcing probe. In the close position of the breaker, the fingers make contact round the circumference of the moving contact having the arcing probe enclosed within its hollow end. The contacts are surrounded by interrupting nozzles and blast shield to control the arc displacement and the movement of the hot gas. The moving contact is in the form of hollow nozzle sliding in a second set of spring loaded fingers. Side vents in the moving contact permits the high pressure gas into the main tank. When the moving contact is withdrawn from the fixed finger contacts an arc is struck between the moving nozzle and the arcing

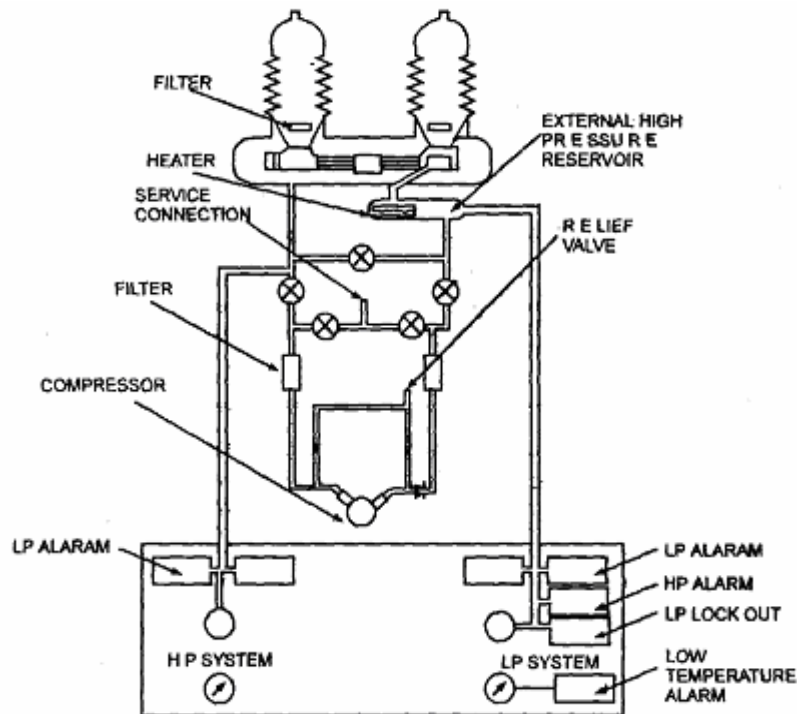
probe. With the increasing separation between the contacts the arc is extended and attenuated and it is finally extinguished by the flow of gas from the high pressure to low pressure systems.

The Gas System

The closed circuit gas system is employed in SF₆ circuit breakers. Since the gas is costly, it is reconditioned and reclaimed after each operation of the breaker. Necessary auxiliary system is provided for such purpose. The low and high pressure systems are provided with low pressure alarms and a set of lock out switches which give a warning the moment the gas pressure drops below a certain value, failing which dielectric strength will be reduced and arc quenching ability of the circuit breaker will be endangered. On reaching danger limit the safety devices immobilize the breaker. The gas is stored in the high pressure chamber at 16 atmospheres while the gas pressure on the low pressure side is 3 atmospheres. Lot of care is required to prevent gas leakages at joints by providing perfect sealing. The temperature is kept 200 C. A heater backed with a thermostat at 16°C is provided in the high pressure chamber to prevent liquefaction of the gas in the high pressure chamber at low temperature.



Interrupter head



The gas system

3.6.4 Air blast Circuit Breaker

Airblast circuit breaker employs compressed air at a pressure of 20 kg/cm² for arc extinction and finding there best application in system operating at 132 KV and up to 400 KV With breaking capacity up to 7500 MVA during short circuit fault. Such breakers have been design to cover the voltage range of 6600 V to 132000 V.

Advantages:

1. There is no risk of explosion and fire hazard.
2. Due to less ark energy in it as compared to that in O.C.B burning of contact is less.

3. It provides facility of high speed reclosure.
4. It requires less maintenance.

Disadvantages:

1. Compressor plant for compressed air is required.
2. Air leaks at the fitting of the pipe line.
3. IT is very sensitive to restriking voltage.

3.7 COMPARISON OF DIFFERENT TYPE OF CIRCUIT BREAKER

Type of Circuit Breaker	Arc-Quenching Medium	Voltage-Breaking Capacity	Design Features	Applications	Remarks
1. Air-break Circuit Breaker Miniature Circuit Breaker	Air at atmospheric pressure —do—	430-600 V, 5-15-35 MVA 3.6-12 kV, 500 MVA 430-600 V	Arc runners, arc splitters, magnetic coils. Small size, current limiting feature.	For medium low voltages ac/dc. Industrial circuit breakers For low and medium voltages	Have current limiting features —
2. Oil Circuit Breakers (i) Bulk-oil (ii) Minimum oil	Dielectric oil (Transformer oil) —do—	12 kV, 3.6 kV, 500 MVA 3.6 kV to 145 kV preferably	One tank upto 36 kV, three tanks above 36 kV, fitted with arc control devices. Small size, arc control device used.	Used upto 12 kV, 500 MVA For metal enclosed switchgear upto 36 kV, outdoor type between 36 and 245 kV	Getting obsolete now. Now superseded by SF ₆ circuit breakers.
3. Air-blast Circuit Breakers	Compressed air (20-30 kg/cm ²)	245 kV, 35,000 MVA upto 1,100 kV, 50,000 MVA	Unit type construction, several units per pole.	Suitable for all EHV applications, Also for arc furnace duty.	High speed operation. Requirement of auxiliary compressed air system. Now superseded by SF ₆ circuit breakers for 145 kV and above.
4. SF ₆ Circuit Breakers (Single pressure puffer type)	SF ₆ gas (5 kg/cm ²)	12 kV, 1000 MVA 36 kV, 2,000 MVA 145 kV, 7,500 MVA 245 kV, 10,000 MVA 420 kV, 40 kA	One interrupter pole upto 245 kV	Most popular over wide range of voltages from 3.6 kV to 750 kV	Maintenance free.
5. Vacuum Circuit Breakers	Vacuum	Upto 36 kV, 750 MVA	Variety of designs	Suitable for variety of applications from 3.6 kV to 36 kV. Preferred for indoor switchgear upto 36 kV, 750 MVA	Long life, modest maintenance.
6. HVDC Circuit Breaker	Oil or Air-blast	33 kV, 2 kA	Artificial current zero by switching in capacitors.	For HV direct current interruption.	—

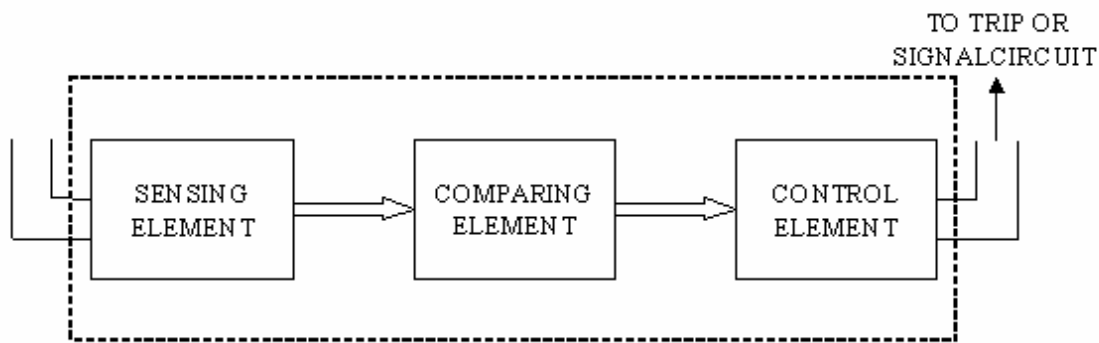
CHAPTER 4

RELAYS

In modern power system to have the normal operation of the system without electrical failure and damage to the equipment protection schemes are required. Protection schemes required for the protection of power system component against abnormal conditions such as faults etc. essentially consist of protective relaying and circuit breaker. Protective relay function s sensing device, it sense the fault, then determines its location and finally, it sends tripping command to the circuit breaker. The circuit breaker after getting the command from the protective relay, disconnects the faulted element

The protective relay may be defined as an electrical device interposed between the main circuit and the circuit breaker in such a manner that any abnormality in the circuits acts on the relay ,which in turn ,if the abnormality is of a dangerous character , causes the breaker to open and so to isolate the faulty element . The relay ensures the safety of the circuit equipment from any damage which might be other wise caused by the fault.

Protective relaying is necessary with almost every electrical plant, & no part of the power system is left unprotected. The choice of protection depends upon several aspects such as type and rating of the protected equipment, its importance, location, probable abnormal conditions, cost, etc. Between generators and the final load points thee are several electrical equipment and machines of various rating. Each needs certain adequate protection.



Basic Elements of a Relay

1. **Sensing Element:** It is also known as measuring element. It responds to the change in the actuating quantity, the current in a protected scheme in case of over-current relay.
2. **Comparing Element:** It compares the action of the actuating quantity on the relay with a pre-selected relay setting.
3. **Control Element:** On the pick up of the relay, accomplishes a sudden change in the control quantity such as closing of the operative current circuit.

4.1 Operating Principle of the Relay

All the relays employed for the protection against short-circuits operated by the virtue of the current or voltage supplied to them by CTs or PTs. Failure in the system are indicated by the individual or the relative changes in the currents or voltages supplied to the protective relaying equipment. For every type and location failure ,there is some distinctive difference in these quantities and there are various types of protective relays available, each o which is designed to recognize a particular difference and to operate in response to it. the difference may be in terms of the magnitude,

frequency, phase angle, ratio change, harmonics of wave shape ,duration of the conditions etc.

A typical relay circuit is shown in the fig. The connections are divided into three mains circuits consisting of (a) primary winding of the CT connected in series with the main circuit to be protected (b) secondary winding of the CT and the relay operating winding and (c) the tripping circuit.

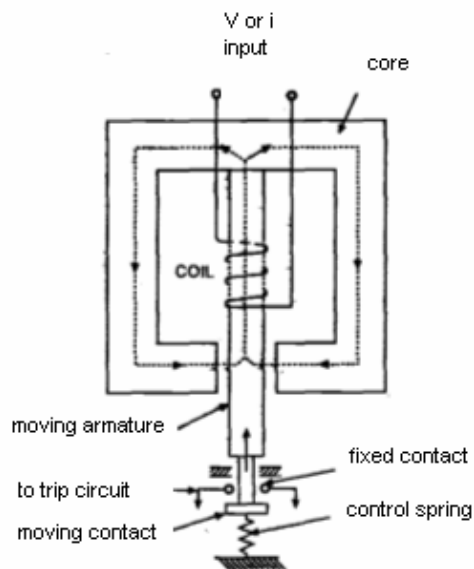
The protective relaying senses the abnormal conditions in a part of the power system and gives an alarm or isolates that part from the healthy system. Whenever an abnormal condition develops the relays close its contacts .Thereby the trip circuit of circuit breaker is closed .Current from the battery supply flows in the trip coil of the circuit breaker and the circuit breaker opens and the faulty part is disconnected from the supply. The entire process occurrence of fault operation of relay-opening of circuit breaker-removal o faulty part from the system', is automatic and fast.

The main principle employed in the operation of the relay is either electro-magnetic attraction or electro-magnetic induction. In the case of electro-magnetic attraction relay, a plunger is drawn into a solenoid or an armature is attracted to the poles of an electro-magnetic. Such relays can be operated either by dc or ac. In case of electro-magnetic induction relays, the principle of induction motor is used and the torque is developed by electro-magnetic Induction. Such relays are operated by ac quantities only.

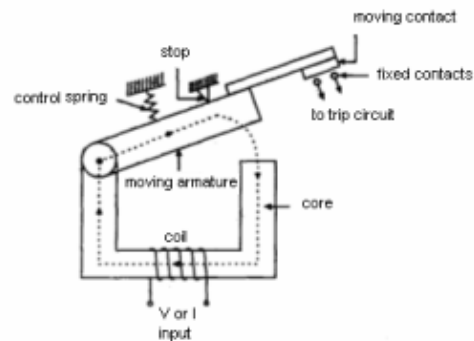
4.1.1 Electro-Magnetic Attraction Relay

These are the simplest type of relays and include plunger (or solenoid), hinged armature, rotating armature (or balanced beam) and moving iron polarized relays All of these relays operate on the same principle i.e., in such relays the operation is obtained by virtue of an armature being

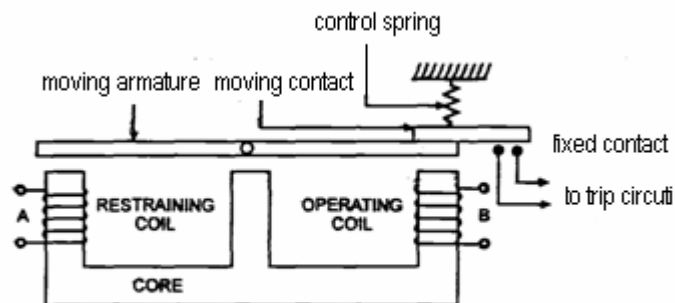
attracted to the poles of an electro-magnet or a plunger being drawn into a solenoid. The electro-magnetic force exerted on the moving element is proportional to the square of flux in the air gap or the square of the current flowing through the coil. It is basically a single actuating quantity relay. Such relays respond to both ac and dc because operating torque is proportional to the square of current flowing through the coil. With dc the torque developed is constant and if it exceeds the restraining torque or force caused by the controlling spring, the relay operates reliably.



(a) Plunger Type



(b) Hinged Armature Type



(c) Balanced Beam Type

In case of ac quantity the electro-magnetic force developed is given as.

$$F_e = KI^2 = K (I_{\max} \sin \omega t)^2$$
$$= 1/2K (I_{\max}^2 - I_{\max}^2 \cos 2\omega t)$$

It shows that the electro-magnetic force consists of two components, one constant independent of time ($1/2K I_{\max}^2$) and another dependent upon time and pulsating at double the supply frequency ($1/2K I_{\max}^2 \cos 2\omega t$). The total electro-magnetic force, therefore, pulsates at double the supply frequency. Since the restraining force produced by the spring is constant and the electro-magnetic force developed is pulsating, the relay armature vibrates at double the power supply frequency. This causes the relay to hum and produce noise and also is a source of damage to the relay contacts.. This leads to sparking and unreliable operation of the relay operative circuit contacts due to make and break of the circuit.

To overcome this difficulty in ac electro magnetic attraction relays, the flux developing the electro-magnetic force is splitted into two fluxes acting simultaneously but differing in time phase, so that the resultant deflecting force is always positive and constant. This can be easily achieved either by providing two windings on the electro magnet having a phase shifting network, or by putting shading rings on the poles of the electro-magnet. The latter method is simpler and is widely used. Hinged armature relays are mainly employed as auxiliary relays, e.g., tripping relays, ac and dc voltage and current relays.

In the case of a balanced beam type relay two quantities I_A^2 and I_B^2 are compared because electro-magnetic forces developed vary as the square of the ampere- turns. Ratio of reset/operating current for such relays

is low. If set for fast operation, it will have a tendency to over reach on transient conditions.

The sensitivity of the hinged armature relays can be increased for dc operation by the addition of a permanent magnet. This is known as a polarized moving iron relay. It is more robust in construction; most of these employ leaf-spring supported armatures.

Modern attraction armature relays are compact, robust, reliable and fast. VA burden depends on construction, setting etc. For a typical relay it is of the order of 0.2 to 0.6 VA for current range of 0.1 to 0.4 A. Such relays are usually instantaneous type but can be made a definite time lag or inverse-time lag by using an oil dash pot, an air-escapement chamber, a clock-work mechanism or by placing a fuse in parallel with the relay. These relays do not have directional feature unless they are provided with additional polarized coil.

The attraction armature relays have fast operation and fast reset because of small length of travel and light moving parts. As these relays are fast and operate on dc as well as on ac they are affected by transients. The transients contain dc component in addition to ac wave. Therefore, though the steady-state value may be less than relays pick-up value, the relay may pick-up during transient state.

Attraction armature relays have many applications in protection of ac and dc equipment. They are, however, sensitive to starting currents, load fluctuations and current surges. Attraction armature relays can be designed to respond to over and under current, over/ under voltage, for both dc and ac operations. They are employed as measuring or auxiliary relays.

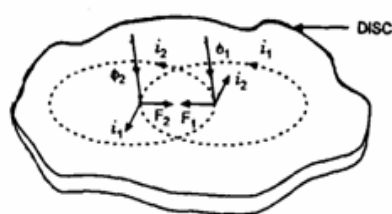
Balanced beam relay is difficult to be designed over a wide range current because the force is proportional to square of current. Such relays are fast

and instantaneous but can be made a definite time lag or inverse—time lag by using an oil dash pot, an air-escapement chamber, a clock-work mechanism or by placing a fuse in parallel with the relay. Such relays can have operating time of the order of 0.02 second. High ratio of resetting quantity can be had. VA burden depends on application. In current balance type the VA burden is of the order of 0.2, 0.4, 0.6 VA for 0.1 to 0.6 A current range. This relay is being largely superseded by permanent magnet moving oil relay having better accuracy and lower VA burden.

4.1.2 Electro-Magnetic Induction Relay

Electro-magnetic induction relays are the most widely used relays for protective relaying purposes involving only ac quantities. These relays operate on the simple principle of split-phase induction motor. Actuating force is developed on a moving element, that may be disc or other form of rotor of non-magnetic current-conducting material (such as aluminum), by the interaction of electro-magnetic fluxes with eddy currents that are induced in the rotor by these fluxes.

Various quantities are shown at an instant when both fluxes are directed downward and are increasing in magnitude. Each flux induce voltage around itself in the rotor, and currents flow in the rotor under the influence of the two voltages. The current produced by one flux reacts with the other flux, and vice-versa, to produce forces that act on the rotor.



Production of Torque in an Induction Relay

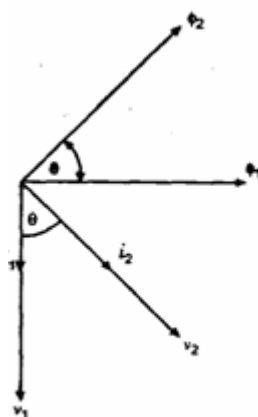
The quantities shown in fig may be expressed as

$$\phi_1 = \phi_{1\max} \sin \omega t$$

$$\phi_2 = \phi_{2\max} (\sin \omega t + \theta)$$

Where ϕ is the angle by which ϕ_2 leads ϕ_1

It may be assumed with negligible error that the paths in which the rotor currents flow have negligible self inductance, and therefore rotor currents are in phase with their respective induced voltages. The phasor diagram is shown



Phasor Diagram

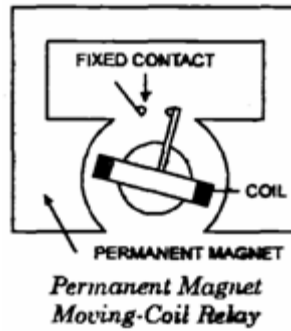
The different types of structures that have been used for obtaining the phase difference in the fluxes and hence the operating torque in induction relays are (i) shaded pole structure (disc type) (ii) watt-hour meter or double winding structure (disc type) and (iii) induction cup structure.

High, low and adjustable speeds are possible in induction type relays. The ratio of reset to pick-up is inherently high in case of induction relays as compared to attraction armature relays as their operation does not involve any change in the air gap of the magnetic circuit as it is in the case of latter. The ratio lies between 95% and 100%. This is not perfectly 100% because of the friction and imperfect compensation of the control spring torque.

The accuracy of an induction type relay recommends it for protective relaying purposes. Such relays are comparable in accuracy to meters employed for registration of electrical energy consumption. This accuracy is not a consequence of the induction principle, but because such relays invariably employ jewel bearings and precision parts that minimize friction. Induction type relays are employed extensively for protection against overloads, short-circuits, and earth faults on transmission/distribution lines and in industrial plants.

4.2 Permanent Magnet Moving Coil Relay

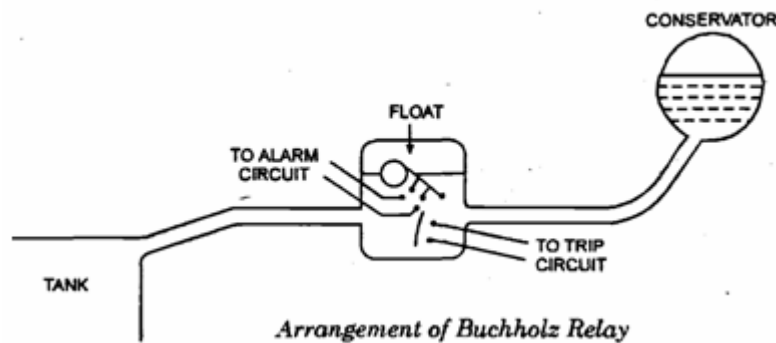
The arrangement is shown in fig. In this relay, the coil is free to rotate in the magnetic field of a permanent magnet. The torque is developed by the interaction between the field of the permanent magnet and the coil field developed due to flow of actuating current in the coil. The time current characteristic of such relays is an inverse-time characteristic. The relay responds to dc only but it can be used with ac in conjunction with a rectifier. The characteristic can be varied by adjusting the control spring. The time setting is obtained by adjusting the position of the contact.



The operating torque is proportional to the actuating current. Such a relay has uniform torque for different positions of the coil and therefore, can be accurately set. Theoretically the reset value is equal to the operating value.

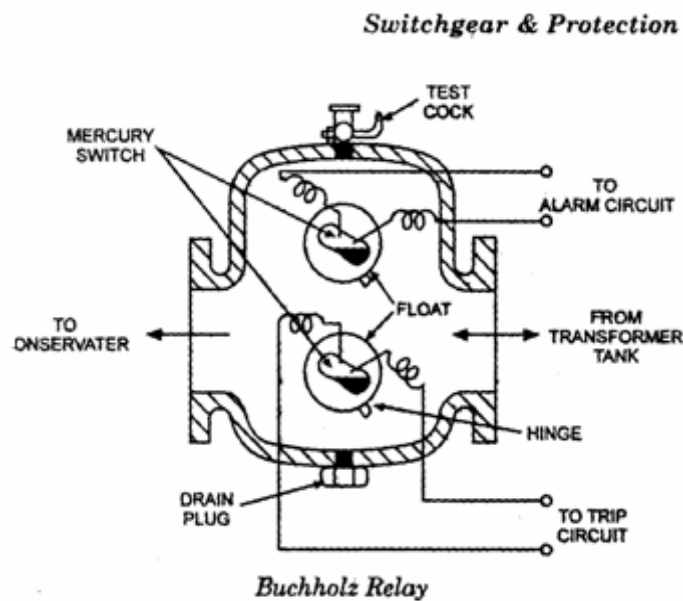
4.3 Buchholz Relay

Buchholz relay is a gas actuated relay. It is practically universally used on all oil immersed transformers having rating more than 500 KVA. Such relay can only be fitted to the transformers equipped with conservator tanks as it is installed in between the conservator tank and the main tank i.e., in the pipe connecting the two. It is employed in conjunction with some form of electrically operated protective gear because it provides protection only against transformer internal faults and does not respond to external bushing or cable connection faults.



Working Principle

Whenever a fault occurs inside the transformer, the oil of the tank gets over-heated and gases are generated. The generation of the gases may be slow or violent depending upon whether the fault is a minor or incipient one or heavy short-circuit. Most short-circuits are developed either by impulse breakdown between adjacent turns at the end turns of the winding or as a very poor initial contact which will immediately heat to arcing temperature. The heat generated by the high local current causes the transformer oil to decompose and produce gas which can be used to detect the winding faults.



Construction

The construction of a Buchholz relay is shown in fig. It consists of two hinged floats in a metallic chamber located in the pipe connection between the conservator and the transformer tank. One of the floats is near the top of the chamber and actuates the mercury switch connected to the external alarm circuit. The other float is opposite the orifice of the pipe to the

transformer and actuates the mercury switch connected to the tripping circuit.

Operation

When a minor fault occurs heat is produced due to current leakage, some of the oil in Buchholz Relay the transformer tank evaporates and some vapours collect in the top of the chamber while passing to the conservator tank. When a predetermined amount of vapours accumulate in the top of the chamber, the oil level falls, the mercury type switch attached to the float is tilted. And so closes the alarm circuit and rings the bell. Thereby the operator knows that there is some incipient fault in the transformer. The transformer is disconnected at the earliest possible and the gas sample is tested. The testing of gas provides clue regarding the type of insulation failure. Buchholz relay gives an alarm so that the transformer can be disconnected before the incipient fault grows into a severe one. A release cock is provided at the top of the chamber so that after operation the pressure in the chamber can be released and the gas emitted to allow the chamber to refill with oil.

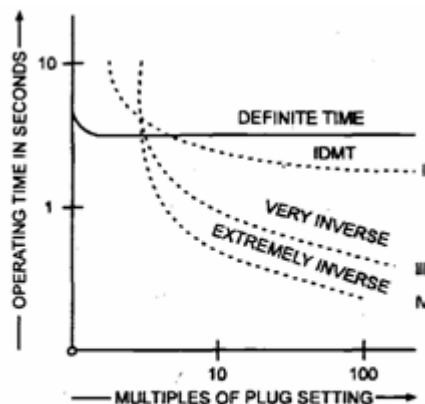
When a severe fault occurs large volume of gas is evolved so that the lower float containing a mercury switch mounted on a hinged type flat is tilted and the trip coil is energized. There after the transformer is removed from the service. The main advantage of Buchholz relays is that they indicate incipient faults, for example, between turns faults or core heating and so may enable a transformer to be taken out of service before serious damage occurs. However, Buchholz relays have some limitations- also, as given below. Only faults below oil levels are detected. For faults above the oil level, this relay is ignorant. These relays do not protect the connecting cables which must therefore have a separate protection. Setting of the

mercury switch cannot be very sensitive; otherwise there can be a false operation by vibrations, earthquakes, mechanical shocks to the pipe, sitting of birds etc. The relay is slow, minimum operating time is about 0.1 second, average time 0.2 second. This is not desirable.

4.4 Over Current Relays

Depending upon the time of operation over-current relays may be categorized as

- (i) Instantaneous over-current relays
- (ii) Inverse-time over-current relay
- (iii) Define time over-current relay
- (iv) Inverse definite minimum time (IDMT) over-current relay
- (v) Very inverse over-current relay and
- (vi) Extremely inverse over-current relay.



Characteristics of Various Over-Current Relays

(i) Instantaneous Over-Current Relay

An instantaneous over-current relay is one in which no intentional time delay is provided for operation. In such a relay, the relay contacts close immediately after the current in the relay coil exceeds that for which it is set. Although there will be a short time interval between the instant of

pick-up and the closing of the relay contacts, no intentional time delay is provided. This characteristic can be achieved with the help of hinged armature relays. Such relay has a unique advantage of reducing the time of operation to a minimum for faults very close to the source where the fault current is the greatest. The instantaneous relay is effective only where the impedance between the relay and source is small compared with the impedance of the section to be protected. One of the most important considerations in over-current and over-voltage protection is the speed of operation. With hinged armature relays, the time of operation of 0.01 second at three times the setting can be obtained. Such relays are employed for restricted earth-fault and other types of circulating current protection. With so fast an operation it is likely that the relay may operate on transients beyond the normal range of setting.

(ii) Inverse-time Over-Current Relay.

An inverse time relay is one in which the operating time is approximately inversely proportional to the magnitude of the actuating quantity. At values of current less than pick-up value, the relay never operates. At higher values, the operating time of the relay decreases steadily with the increase of current. The more pronounced the effect is the more inverse the characteristic is said to be. In fact, all time-current curves are inverse to a greater or lesser degree. They are normally more inverse near the pick-up value of the actuating quantity and become less inverse as it is increased.

The operating time of all over-current relays tends to become asymptotic to a definite minimum value with increase in the value of actuating quantity. This is inherent in electro-magnetic relays due to saturation of the magnetic circuit. So by varying the point of saturation different

characteristics are obtained. These are (i) definite time (ii) inverse definite minimum time (in) very inverse and (iv) extremely inverse

(iii) Definite-time Relays

If the core is made to saturate at a very early stage, the time of operation remains same over the working range. Such a relay operates after a specified time irrespective of the magnitude of the fault current. The definite-time relays are used in (i) radial or loop circuits having a few sections (ii) as back-up protection for other types of protection and (iii) on systems with wide variations of fault current due to source impedance.

(iv) Inverse Definite Minimum Time (IDMT) Relays

Such a relay is one in which operating time is approximately inversely proportional to fault current near pick-up value and becomes substantially constant slightly above the pick-up value of the relay, as illustrated by curve II in fig 6.17. This is achieved by using a core of the electro-magnet which gets saturated for currents slightly greater than the pick-up current.

(v) Very Inverse Relay

In such a relay the saturation of the core occurs at a still later stage,. The time-current characteristic is inverse over a greater range and after saturation tends to definite time. Relays with very inverse time-current characteristics are employed on feeders and long sub-transmission lines.

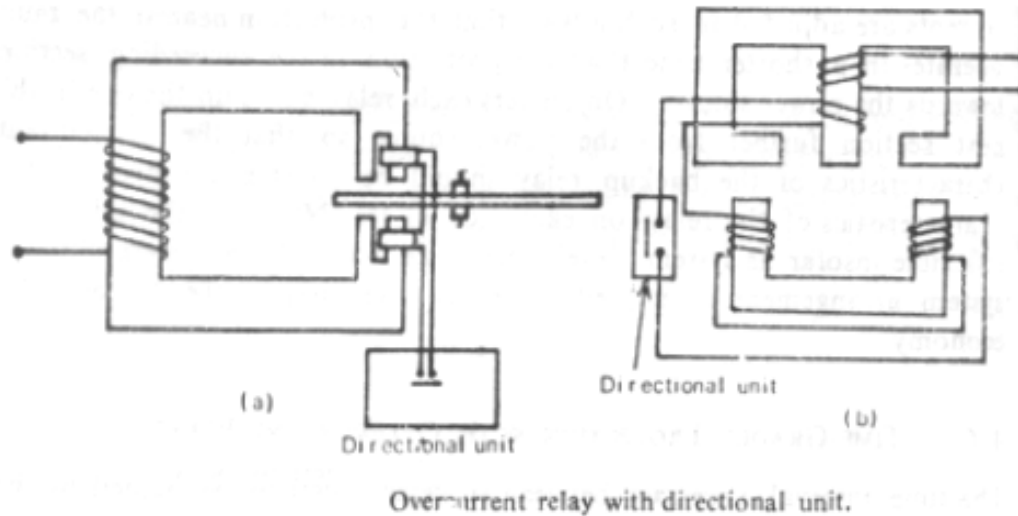
(vi) Extremely Inverse Relay

The curve W in fig 6.17 illustrate extremely inverse characteristic i.e., core saturation occurs at a very late stage. The equation describing the curve IV in the figure is approximately of the form $t = \frac{K}{I^2}$ where I is the operating current and t is the operating time. Such relays are quite suitable for the protection of transformers, cables etc, as it is possible to achieve accurate discrimination with fuses and auto-reclosure in their case, which can

seldom be made selective with standard IDMT relays. This is because of their ability to ride through starting currents and surges, providing at the same time fast operation under fault conditions. They are, thus more suitable for installations with large in-rush currents after an outage. Relays with inverse time-current characteristics are widely employed in distribution networks and industrial plant systems.

4.5 Directional Relay

Selective protection cannot be achieved with time graded over current protection systems in ring or loop systems as well as in radial circuits with two end power supplies. A directional feature is incorporated in the relay as shown in Fig .Fig shows how an induction disc type over current relay with split-pole magnet, having in addition a directional unit consisting of capacitance or a resistance capacitance circuit works. Figure shows the watt metric type of induction disc relay. Here the directional unit controls the angle between the two fluxes by varying the RX parameters of the lower electromagnet. Another method of control in the watt metric element is to supply the lower winding from a separate voltage source is equal and opposite to the output of the upper magnet secondary winding there is no current in the lower coil, and therefore no torque is produced. If it opposes and is less than the secondary output, or if it assists the secondary output, there is an operating torque. Conversely, if this source voltage opposes and exceeds the secondary output the current in the lower coil is reversed, giving a reverse torque. This latter method of control is the basis of the balanced voltage unit protection which will be described in a subsequent chapter.



Directional relays must have the following features:

- (i) High speed of operation;
- (ii) High sensitivity;
- (iii) Ability to operate with low values of voltage;
- (iv) Adequate short-time thermal rating;
- (v) Burden must not be excessive; and
- (vi) There should be no voltage creep and current creep.

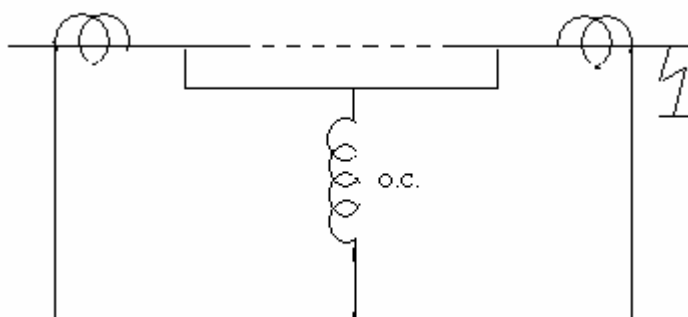
That is, if either the voltage coil alone or the current coil alone is energized with the other one unenergized there should be no movement.

4.6 Differential Relay

The differential relay is one that operates when the vector difference of two or more similar electrical quantities exceeds a predetermined value. This means for a differential relay, it should have: (1) two or more similar electrical quantities, and (2) these quantities should have phase displacement (normally approx. 180°), for the operation of the relay. The name is not due to a particular construction of the relay but is due to the

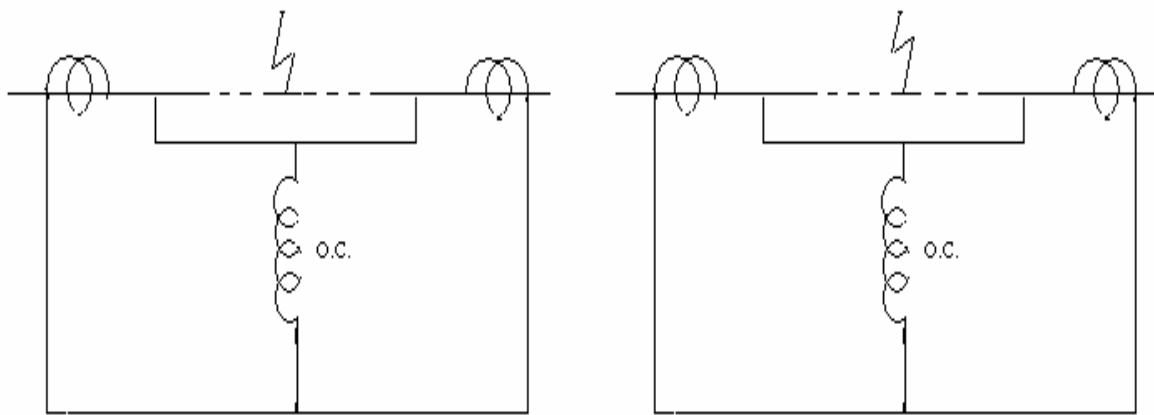
way in which the relay is connected in the circuit.

Consider Fig. for the operating principle of a differential relay. It is expected of the scheme that in case of a fault in the circuit between the two C.T.s the relay must operate, and in case the fault is outside this zone the relay should not operate. Such protection is known as unit protection. When the fault is outside the zone of protection, it is known as external fault or through fault.



Differential protection during a through fault

Consider the scheme in Fig. (a) for a through fault. The current flowing through the primaries of the two C.T.s is same whether the system is fed from one end or both the ends). If the two C.T.s behave identically for all fault currents, the secondary currents are of the same magnitude and phase. The difference current, therefore, being zero through the operating coil, the relay does not operate. This is a desirable feature. For an internal fault, consider Fig. (b) when the circuit is fed from one end and Fig. (c) When the circuit is fed from both the ends. It can be seen that in both the cases, a current will flow through the operating coil of the relay and it will operate. This form of protection is known as Merz- Price protection.



Differential protection for an internal fault (a) feed from one End and (b) fed from both the ends.

4.7 Distance Relay

Distance protection is the name given to the protection, whose action depends upon the distance of the feeding point to the fault. The time of operation of such a protection is a function of the ratio of voltage and current i.e., impedance. This impedance between the relay and the fault depends upon the electrical distance between them.

Distance-relay group is perhaps the most interesting and versatile family of relays. Principal types, of distance relays are (i) impedance relays (ii) reactance relays (iii) admittance or mho relays.

Distance relays differ in principle from other forms of protection in that their performance is not governed by the magnitude of the current or the voltage in the protected circuit but rather on the ratio of these two quantities. Distance relays are actually double actuating quantity relays with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage

element produces a negative or reset torque. The relay operates only when the VII ratio falls below a predetermined value (or set value). During a fault on a transmission line the fault current increases and the voltage at the fault point decreases. The VII ratio is measured at the location of CTs and PTs. The voltage at PT location depends on the distance between PT and the fault. If the fault is nearer, measured voltage is lesser and if the fault is farther, measured voltage is more. Hence assuming constant fault impedance each value of VII measured from relay location corresponds to distance between relaying point and the fault along the line. Hence such protection is called the *distance protection* or *impedance protection*.

Distance protection is non-unit type protection, the protection zone is not exact. The distance protection is high speed protection and is simply to apply. It can be employed as a primary as well as backup protection. It can be employed in carrier aided distance schemes and in auto-reclosing schemes. Distance protection is very commonly used in protection of *transmission* lines. .

Distance relays are used where over-current relaying is too slow and is not so selective. Distance relays are used for both phase fault and ground fault protection and they provide higher speeds for clearing faults than over current relays. Distance relays are also independent of changes in magnitude of the short-circuit, currents and hence they are not much affected by changes in the generation capacity and the system configuration. Thus they eliminate long clearing times for faults near the power sources required by over-current relays if used for the purpose.

CHAPTER 5

CASE STUDY

CHAPTER 5

CASE STUDY

400 KV Substation Khandwa Indore

This substation is situated about 10 Km from Indore on Khandwa road, Indore. It is spread in area of 5 acres. This substation was constructed in year 1982 & is operational since 1985. It is importing power from various generating stations like Indira Sagar Project (ISP), Punasa M.P. It is also importing power from Vindhyachal & from Itarsi by a double circuit. All the power is imported at 400 KV. This substation is exporting power both at 400 as well as 220 KV. Power is exported at 400 KV to Asoj by a double circuit & Nagda. Power is exported at 220 KV to Indore, Ujjain, Badwaah, Pithampur, Badnagar, Dewas.

Substation is divided in two sections i.e. 400KV & 220 KV side. Substation has a well-equipped control room in which various panel & relays are strategically placed. It also has a battery room for DC supply in case of fault & for supplying to PLCC equipments. Whole substation is earthed by an underground mesh, which covers all the areas of substation.

Total capacity of substation is 945 MVA. There is a set of six single-phase transformers of 105 MVA capacities each. There is spare single-phase unit also, which can be used when one of the transformers is out of order or on maintenance. There is one three-phase transformer of 315 MVA, making total of 945 MVA. All the power transformers are of autotransformer type & made by BHEL. Forced cooling is used for transformers. Each

transformer has lightening arrestors on both primary as well as secondary side. Transformers are separated with firebricks to prevent spread of fire.

This substation incorporates three-bus system i.e. two main & one auxiliary bus. This auxiliary bus can be used for division of power efficiently. There is one bay one breaker system used, which means that each bay has its own breaker. Series reactors of capacity 25 MVR & 50 MVR are used to limit the value of short circuit current in case of any fault.

PROTECTION USED

400 KV SIDE

On the 400 KV side duplicate protection is used. As the voltage level is high & cost of equipments is directly proportional to the voltage level, importance of protection increases. To increase the reliability of protection duplicate protection is essential. Duplicate means that both are exactly same in nature & preference. In this system there is no primary or backup protection. Both the protection act at the same time. In case any one of the protections fails then other will remove the faulty part from the circuit & safeguard the healthy part.

In this ever expanding power system protection techniques should improve in pace with growth of the system. Here numeric relays are used to sense any fault. These relays can be configured with a help of hand held device or a computer. They have high level of accuracy & chances of errors are minimized. They have another advantage that they can store the

observations in their memory & printout of the oscillogram at the time of fault can be taken if needed.

- ***Line Protection***

Distance protection relay & over voltage relay are the main relays used on the 400 KV side. D-60 *SIEMENS* is the relay type name of distance relay used. It is a microprocessor based numeric protection.

- ***Bus Bar Protection***

Bus Bar is an integral part of a substation. In case of a fault on bus there is a threat of failure of the whole interconnected system. Thus protection of bus bar is very essential. Bus differential protection is used for protecting the bus from any faults. It is based on the Kirchoff's Current Law (KCL) according to which on any node sum of all the currents is equal to zero. This law is applied here to protect bus bar. As bus is considered as a node the sum of all the currents should be equal to zero. But in case of fault this balance is disturbed as fault current flows. This unbalance is sensed by relays and circuit breakers are tripped. Here bus differential protection is used of make English Electric.

220KV Side

As compared to 400 KV cost of equipment is reduced in 220 KV side & thus protection used may be less expensive. Here Primary, Backup & Auxiliary protection scheme is used.

- ***Line Protection***

Distance protection acts as the main protection on 220 KV side. Overcurrent protection acts as backup protection and pole discrepancy as

auxiliary protection. Distance protection used is of make ABB, RAZFEE & ASEA. Over current relay are of make Easun Reyrolle.

- ***Bus Bar Protection***

In 220 KV side bus bar is protected with the help of Bus Differential protection of make English Electric.

Transformer Protection

Transformer is considered as heart of any substation. Transformers must be protected against faults like overload or rise in winding temperature, Here T – 60 SIEMENS Microprocessor based Numeric Protection is used for the transformers. Other protection used for transformers here at 400 KV substation are:

1. Differential winding protection.
2. Restricted earth fault.
3. Pressure release valve.
4. Buchholz relay

HARDWARE DETAILS

❖ Substation Capacity:

$(6 * 105) \text{ MVA} + (1 * 315) \text{ MVA} = 945 \text{ MVA}$		
<i>Single Phase Units 6</i>	<i>Three Phase Unit 1</i>	<i>Total.7</i>

❖ Transformers:

<i>Make:</i> BHEL

<i>Rating:</i> <u>(400/220/33) KV</u>
Y Y Δ

❖ Incoming and Outgoing on 400 KV Side:

➤ Incoming Feeders:

1. Vindhyachal.
 2. Itarsi1 & Itarsi 2.
 3. ISP 1 & ISP 2.
- TOTAL = 5

➤ Outgoing Feeders:

1. Asoj 1 & Asoj 2.
 2. Naagda
- TOTAL = 3

❖ Incoming and Outgoing on 220 KV Side:

➤ Outgoing Feeders:

1. South Zone 1& South Zone 2.
2. Ujjain.
3. Badwaah.
4. Pithampur.
5. Badnagar.
6. Dewas. (TOTAL = 7)

Buses: 3 Bus System- 2 Main 1 Auxiliary Bus.

Breaker: Air Blast circuit breaker & SF6 circuit breaker.

Reactor: 25 MVR & 50 MVR

1 Bay 1 Breaker System.

🔧 **PROTECTION SCHEMES USED IN 400 KV SUBSTATION:**

➤ LINE PROTECTION SCHEME ON 400 KV SIDE :

1. Distance Protection Relay.
(D – 60 SIEMENS Microprocessor based Numeric Protection)
2. Over Voltage Relay.

Duplicate Protection scheme is employed.

➤ BUS BAR PROTECTION SCHEME ON 400 KV SIDE:

1. Bus Differential Protection. (*English Electric*)

PROTECTION SCHEMES USED IN 220 KV SUBSTATION:

➤ LINE PROTECTION SCHEM ON 220 KV SIDE:

1. *Primary*: Distance protection relay.
(ABB, RAZFEE & ASEA)
2. *Backup*: Over Current relay.
(Easun Reyrolle)
3. *Auxiliary*: Pole Discrepancy

Primary & Backup Protection scheme is employed.

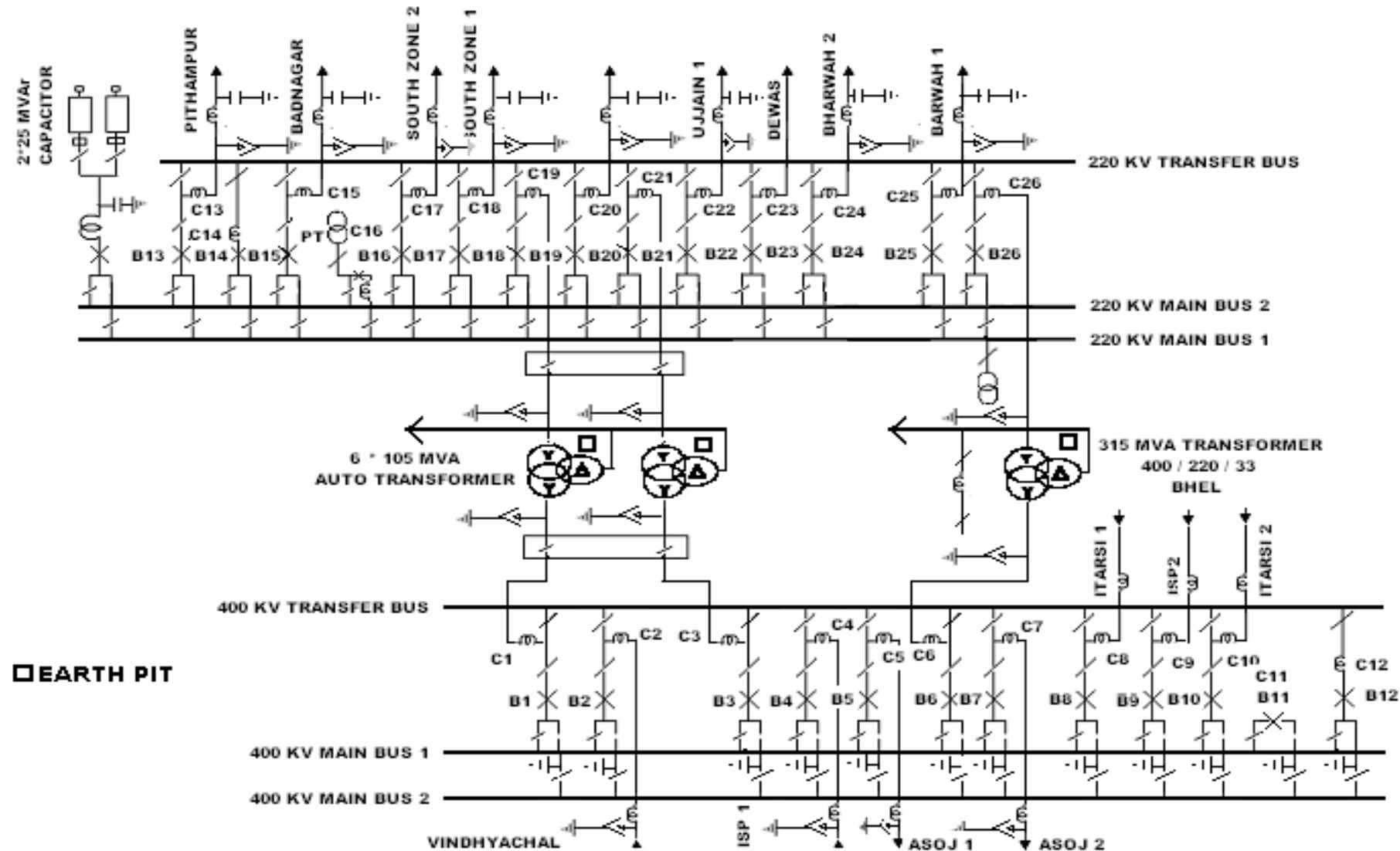
➤ BUS BAR PROTECTION SCHEME ON 220 KV SIDE:

1. Bus Differential Protection. (*English Electric*)

❖ TRANSFORMER PROTECTION SCHEME

(T – 60 SIEMENS Microprocessor based Numeric Protection)

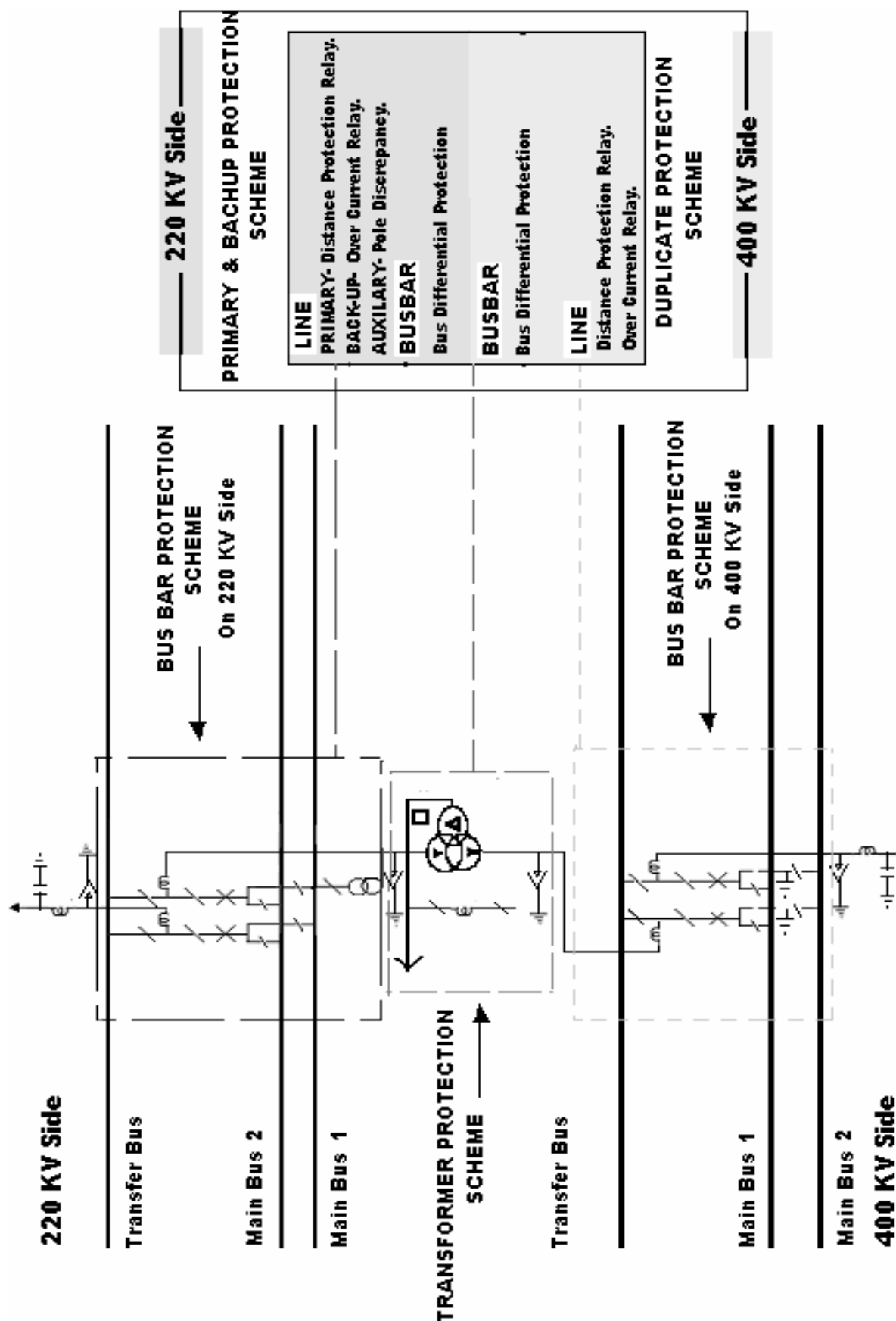
1. Differential winding protection.
2. Restricted earth fault.
3. Pressure release valve.
4. Buchholz relay (mercury contacts).



CONTROL ROOM

Protective Relays
For 400 KV &
220 KV side

LAYOUT OF 400 KV KHANDWA ROAD SUBSTATION



CONCLUSION

Electrical energy which is considered the back bone of any developing or developed nation, need to be protected from all the possible faults during its generation, transmission and distribution. If any fault in the system occurs, then it not only disturbs the consumer whether domestic or commercial or industrial but also produces loss to the generating company which is usually a public sector company. The basic idea behind the power system network is to deliver the energy to its fullest i.e with maximum efficiency possible, economical to the consumers.

During our study of fault protection schemes in substations we understand the basic idea behind the requirement, arrangement and principals regarding switchgear devices and the considerations which are taken into account during the design of any protection scheme. Out of various considerations; economic consideration is the priority and around which every thing is planned and designed.

We gained and learned a lot during our visit to 400 KV substation Khandwa, Indore. Substations are the intermediate links between the generating system and the distribution system, which contains all the basic and complex devices needed by the system to obtain the maximum efficiency and output. We gone through many hardware details, modern technology used for practicing such complex but efficient schemes of protection. The basic idea behind the schemes is : not to leave any block in power system without protection because of its importance in every aspect, for this power system network is divided into number of zones which overlap each other for practicing the idea.

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