ATME COLLEGE OF ENGINEERING

13th KM Stone, Bannur Road, Mysore - 570 028

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

NOTES

Course Title: High Voltage and Power System Protection

Course CODE: 21EE71

SEMESTER: VII

Academic Year - 2024-25

INSTITUTIONAL VISION AND MISSION

VISION:

- Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION:

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

Department Vision and Mission

Vision:

To create Electrical & Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

Mission:

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research & industry interaction.

Program Educational Objectives (PEOs)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make Graduates continuously acquire and enhance their technical and socio-economic skills.

PEO3: To aspire Graduates on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design / Development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12: Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

The students will develop an ability to produce the following engineering traits:

PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics

PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning

High Voltage and Power System Protection

Course Code	Course Title	Core/Elective	Prerequisite	Contact Hours				Total Hrs/ Sessions
				L	T	P	S	
21EE71	**High Voltage and Power System Protection**	**PCC**	Basic Electrical, Engineering Physics, Measuring Instruments	**2**	**0**	**2**	**0**	40 hours Theory + 10 Lab slots
Objectives	1. To discuss conduction and breakdown in gases, liquid dielectrics. 2. To discuss breakdown in solid dielectrics. 3. To discuss generation of high voltages and currents and their measurement. 4. To discuss overvoltage phenomenon and insulation coordination in electric power systems.							

Topics Covered as per Syllabus

Module-1

Introduction to High Voltage Engineering: Advantages, Limitations and applications.
Conduction and Breakdown in Gases: Introduction, Ionization Processes, Townsend's Current Growth Equation and it's Criterion for Breakdown, Streamer Theory of Breakdown in Gases, Paschen's Law, Breakdown in Nonuniform Fields and Corona Discharges.
Conduction and Breakdown in Liquid Dielectrics: Introduction, Conduction and Breakdown in Liquid Dielectrics
Breakdown in Solid Dielectrics: Introduction, Different types of breakdown studies in Solid Dielectrics

Module-2

Generation of High Voltages and Currents: Generation of High Direct Current Voltages, High Alternating Voltages, Impulse Voltages and Impulse Currents.
Measurement of High Voltages and Currents: Measurement of High Direct Current Voltages, High AC and Impulse Voltages, High Currents of Direct, Alternating and Impulse.
Non-Destructive Testing of Materials and Electrical Apparatus: Introduction, Measurement of Dielectric Constant and Loss Factor, Partial Discharge Measurements.

Module-3

Introduction to Power System Protection: Need for protective schemes, Types of Fault and it's Effects, Essential Qualities of Protection, Primary and Backup Protection. Relay Construction and Operating Principles: Introduction, Electromechanical Relays, Static Relays – Merits and Demerits of Static Relays, Numerical Relays, Comparison between Electromechanical Relays and Numerical Relays.
Overcurrent Protection: Introduction, Time–current Characteristics, Current Setting, Time Setting, Directional Relay, Protection of Parallel Feeders and Ring Mains, Earth Fault, Phase Fault Protection and Combined Earth and Phase Fault Protective Scheme, Static Overcurrent Relays, Numerical Overcurrent Relays.

Module-4:

Distance Protection: Introduction, Impedance Relay, Reactance Relay, Mho Relay, Effect of Power Surges, Line Length and Source Impedance on Performance of Distance Relays.
Pilot Relaying Schemes: Introduction, Wire Pilot Protection, Carrier Current Protection**.**
Differential Protection: Introduction, Differential Relays, Percentage Differential Relay, Balanced Voltage Differential Protection.
Protection of Generators, Transformer and Bus zone Protection: Introduction, Protection of Generators. Transformer Protection, Bus zone Protection.

Module- 5:

Circuit Breakers: Introduction, Arc Voltage, Arc Interruption, Restriking Voltage and Recovery Voltage, Current Chopping. Air Circuit Breakers, SF6 Circuit Breakers, Vacuum Circuit Breakers, Rating of Circuit Breakers,
Testing of Circuit Breakers.
Protection against Overvoltage: Causes of Overvoltage, Lightning phenomena, Klydonograph and Magnetic Link, Protection of power stations and Substations, Insulation Coordination.

List of Text Books

TEXT BOOKS:.

1. High Voltage Engineering, M.S.Naidu and Kamaraju- 5th Edition, THM, 2013
2. Power System Protection and Switchgear Badri Ram, D.N. Vishwakarma McGraw Hill 2nd Edition.

List of Reference Books

1. High Voltage Engineering Fundamentals, E. Kuffel, W.S. Zaengl, J. Kuffel, Newnes, 2 nd Edition, 2000
2. High Voltage Engineering, Wadhwa C.L., New Age International, 3 rd Edition, 2012.
3. Protection and Switchgear, Bhavesh et al, Oxford, 1st Edition, 2011.
4. Power System Switchgear and Protection, N. Veerappan, S.R. Krishnamurthy, S. Chand, 1st Edition, 2009

Module -3

Introduction for Power System Protection, Relay Construction and Operating Principles

Module -3 Introduction for Power System Protection

Course objectives: To discuss performance of protective relays, components of protection scheme and relay terminology & to explain relay construction and operating principles

1.0 NEED FOR PROTECTIVE SYSTEMS

An electrical power system consists of generators, transformers, transmission and distribution lines, etc. Short circuits and other abnormal conditions often occur on a power system. The heavy current associated with short circuits is likely to cause damage to equipment if suitable protective relays and circuit breakers are not provided for the protection of each section of the power system. Short circuits are usually called faults by power engineers. Strictly speaking, the term 'fault' simply means a ‘defect’. Some defects, other than short circuits, are also termed as faults. For example, the failure of conducting path due to a break in a conductor is a type of fault.

If a fault occurs in an element of a power system, an automatic protective device is needed to isolate the faulty element as quickly as possible to keep the healthy section of the system in normal operation. The fault must be cleared within a fraction of a second. If a short circuit persists on a system for a longer, it may cause damage to some important sections of the system. A heavy short circuit current may cause a fire. It may spread in the system and damage a part of it. The system voltage may reduce to a low level and individual generators in a power station or groups of generators in different power stations may lose synchronism. Thus, an uncleared heavy short circuit may cause the total failure of the system.

A protective system includes circuit breakers, transducers (CTs and VTs), and protective relays to isolate the faulty section of the power system from the healthy sections. A circuit breaker can disconnect the faulty element of the system when it is called upon to do so by the protective relay. Transducers (CTs and VTs) are used to reduce currents and voltages to lower values and to isolate protective relays from the high voltages of the power system. The function of a protective relay is to detect and locate a fault and issue a command to the circuit breaker to disconnect the faulty element. It is a device which senses abnormal conditions on a power system by constantly monitoring electrical quantities of the systems, which differ under normal and abnormal conditions. The basic electrical quantities which are likely to change during abnormal conditions are current, voltage, phase-angle (direction) and frequency. Protective relays utilize one or more of these quantities to detect abnormal conditions on a power system.

Protection is needed not only against short circuits but also against any other abnormal conditions which may arise on a power system. A few examples of other abnormal conditions are over speed of generators and motors, overvoltage, under frequency, loss of excitation, overheating of stator and rotor of an alternator etc. Protective relays are also provided to detect such abnormal conditions and issue alarm signals to alert operators or trip circuit breaker.

A protective relay does not anticipate or prevent the occurrence of a fault; rather it takes action only after a fault has occurred. However, one exception to this is the Buchholz relay, a gas actuated relay, which is used for the protection of power transformers. Sometimes, a slow breakdown of insulation due to a minor arc may take place in a transformer, resulting in the generation of heat and decomposition of the transformer’s oil and solid insulation. Such a condition produces a gas which is collected in a gas chamber of the Buchholz relay. When a specified amount of gas is accumulated, the Buchholz relay operates an alarm. This gives an early warning of incipient faults. The transformer is taken out of service for repair before the incipient fault grows into a serious one.

Thus, the occurrence of a major fault is prevented. If the gas evolves rapidly, the Buchholz relay trips the circuit breaker instantly.

Protective relaying is teamwork of the following Components for the protection of equipment these include: protective current transformers and voltage transformers, protective relays, time-delay relays, auxiliary relays, secondary circuits; trip circuits, auxiliaries and accessories, etc. Each component is important.

1.1 Nature and causes of Faults

Equipment	Cause of fault	% of Total Faults
1. Overhead lines	Lightning strokes Storms, earthquakes, icing Birds, trees, kites aeroplanes, snakes, etc. Internal over-voltages.	30—40
2. Underground cables	Damage during digging Insulation failure due to temperature rise Failure of joints	8—10
3, Alternators (Generator)	Stator faults Rotor faults Abnormal conditions Faults in associated equipment Faults in protective system	6—8
4. Transformers	Insulation failure Faults in tap-changer Faults in bushing Faults in protection circuit Inadequate protection Overloading, over voltage.	10—12
5. CT, PT	Over-voltages Insulation failures Breaking of conductors Wrong connections	15—20
6 Switchgear	Insulation failure Mechanical defect Leakage of air/oil/gas Inadequate rating Lack of maintenance.	10—12

Statistics of fault on overhead lines

Types of fault	% of occurrence
Line to ground faults	80-90%
Double line faults	6-10%
Double line to ground faults	3-7%
Triple line faults	2% or less

1.2 TYPES OF FAULTS

Two broad classifications of faults are

- Symmetrical faults
- Unsymmetrical faults

Symmetrical Faults

A three-phase (3-Ǿ) fault is called a symmetrical type of fault. In a 3-Ǿ fault, all the three phases are short circuited. There may be two situations—all the three phases may be short circuited to the ground or they may be short-circuited without involving the ground. A 3-Ǿ short circuit is generally treated as a standard fault to determine the system fault level.

Unsymmetrical Faults

Single-phase to ground, two-phase to ground, phase-to-phase short circuits; single phase open circuit and two-phase open circuit are unsymmetrical types of faults.

Single-phase to Ground (L-G) Fault

A short circuit between any one of the phase conductors and earth is called a single phase to ground fault. It may be due to the failure of the insulation between a phase conductor and the earth, or due to phase conductor breaking and falling to the ground.

Two-phase to Ground (2L-G) Fault

A short circuit between any two phases and the earth is called a double line to ground or a two-phase to ground fault.

Phase-to-Phase (L-L) Fault

A short circuit between any two phases is called a line to line or phase-to-phase fault.

Open-circuited Phases

This type of fault is caused by a break in the conducting path. Such faults occur when one or more phase conductors break or a cable joint or a joint on the overhead lines fails. Such situations may also arise when circuit breakers or isolators open but fail to close one or more phases. Due to the opening of one or two phases, unbalanced currents flow in the system, thereby heating rotating machines. Protective schemes must be provided to deal with such abnormal situations.

Winding Faults

All types of faults discussed above also occur on the alternator, motor and transformer windings. In addition to these types of faults, there is one more type of fault, namely the short circuiting of turns which occurs on machine windings.

Simultaneous Faults

Two or more faults occurring simultaneously on a system are known as multiple or simultaneous faults. In simultaneous faults, the same or different types of faults may occur at the same or different points of the system. An example of two different types of faults occurring at the same point is a single line to ground fault on one phase and breaking of the conductor of another phase, both simultaneously present at the same point. The simultaneous presence of an L-G fault at one point and a second L-G fault on another phase at some other point is an example of two faults of the same type at two different points. If these two L- G faults are on the same section of the line, they are treated as a double line to ground fault. If they occur in different line sections, it is known as a cross-country earth fault. Cross-country faults are common on systems grounded through high impedance or Peterson coil but they are rare on solidly grounded systems **.**

1.3 EFFECTS OF FAULTS

The most dangerous type of fault is a short circuit as it may have the following effects on a power system, if it remains uncleared.

- Heavy short circuit current may cause damage to equipment or any other element of the system due to overheating and high mechanical forces set up due to heavy current.
- Arcs associated with short circuits may cause fire hazards. Such fires, resulting from arcing, may destroy the faulty element of the system. There is also a possibility of the fire spreading to other parts of the system if the fault is not isolated quickly.
- There may be reduction in the supply voltage of the healthy feeders, resulting in the loss of industrial loads.
- Short circuits may cause the unbalancing of supply voltages and currents, thereby heating rotating machines.
- There may be a loss of system stability. Individual generators in a power station may lose synchronism, resulting in a complete shutdown of the system. Loss of stability of interconnected systems may also result. Subsystems may maintain supply for their individual zones but load shedding would have to be resorted in the sub-system which was receiving power from the other subsystem before the occurrence of the fault.
- The above faults may cause an interruption of supply to consumers, thereby causing a loss of revenue.

High grade, high speed, reliable protective devices are the essential requirements of a power system to minimise the effects of faults and other abnormalities

1.4 ZONES OF PROTECTION

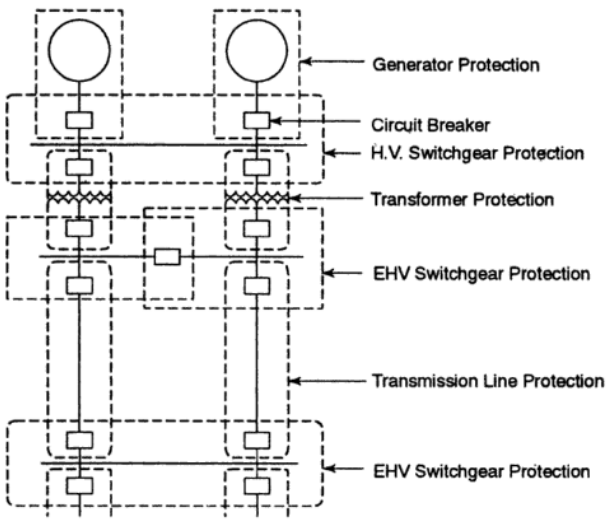
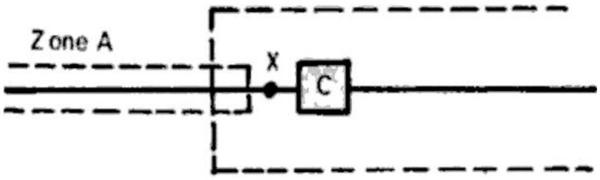


FIGURE 1.1 Zones of protection

The protected zone is that part of a power system guarded by a certain protection Scheme and usually contains one or at the most two elements of the power system. The zones are arranged to overlap so that no part of the system remains unprotected. Figure (1.1) shows a typical arrangement of overlapping zones of protection.

A power system contains generators, transformers, bus bars, transmission and distribution lines, etc. There is a separate protective scheme for each piece of equipment or element of the power system, such as generator protection, transformer protection, transmission line protection, bus bar protection, etc.

Neighboring zones overlap so that no 'dead spot' are left in the protected system



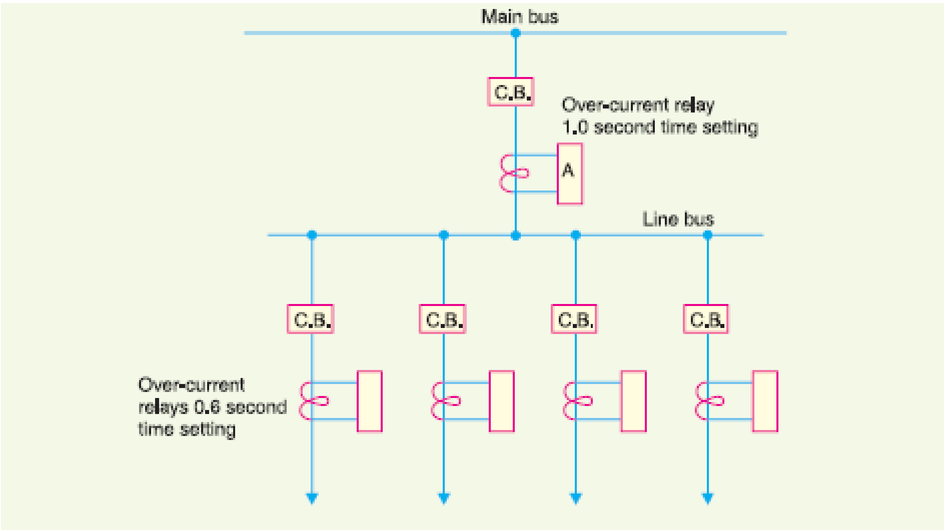
It can be seen that for a fault at X the circuit breakers of 'Zone B' including breaker C will be tripped; however, this does not interrupt the flow of fault current from 'Zone A', the relaying equipment of 'Zone B' must also trip certain breaker in zone 'Zone A'

This is all right for fault at X, but for faults in zone B to the right of breaker C the operation of breakers in zone A is not useful. How far this unnecessary operation can be tolerated will depend on the particular application.

1.5 PRIMARY AND BACK-UP PROTECTION

Primary protection (Main protection) is the essential protection provided for protecting an equivalent/machine. As a precautionary measure, an addition protection is generally provided and is called 'Back-up Protection'. The primary protection is the first to act and the Back-up Protection is the next in the line of defense-meaning, if primary protection fails, the back-up protection comes into action and removes the faulty part from the healthy system. Back-up protection is provided for the following reasons:

If due to some reason, the Main protection fails, the Back-up protection serves the purpose of protection. Main protection can fail due to failure of one of the components in the protective system such as relay, auxiliary relay CT, PT, trip circuit, circuit-breaker, etc. If the primary protection fails, there must be an additional protection; otherwise the fault may remain uncleared, resulting in a disaster.



Back-up protection. It is the second line of defence in case of failure of the primary protection.
It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus referring to above Fig., relay *A* provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay *A* on the group breaker will operate after a definite time delay and clear the entire group of lines. It is evident that when back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly. Therefore, greater emphasis should be placed on the better maintenance of primary relaying.

As a measure of economy, Back-up protection is given against short-circuit protection and generally not for other abnormal conditions. The extent to which back-up protection is provided, depends upon economic and technical considerations

The back-up relays are made independent of those factors which might cause primary relays to fail. A back-up relay operates after a time delay to give the primary relay sufficient time to operate. When a back-up relay operates, a larger part of the power system is disconnected from the power source, but this is unavoidable.

The methods of back-up protection can be classified as follows:

1. **Relay Back-up.** Same breaker is used by both main and back-up protection, but the protec-

tive systems are different. Separate trip coils may be provided for the same-breaker.

2. **Breaker Back-up**. Different breakers are provided for main and back-up protection, both the breakers being in the same station
3. **Remote back-up**. The main and Back-up protections provided at different stations and are completely independent.

1.6 DESIRABLE QUALITIES OF PROTECTIVE RELAYING

Protective relaying should have certain qualities. Some of these quantities cannot be expressed in form of a mathematical expression, however, they are important. The qualities of protective relaying are named as

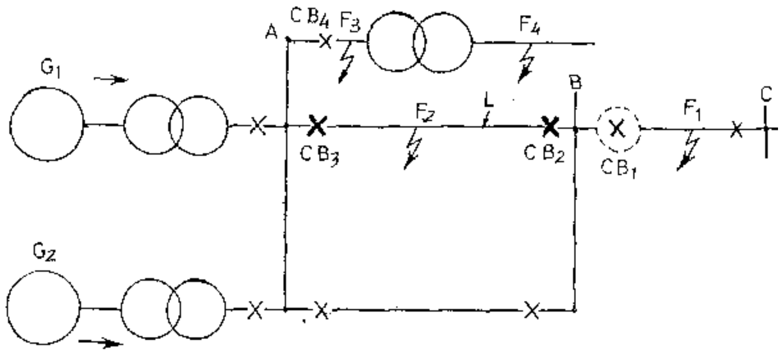
- Selectivity & discrimination.
- Fast Operation.
- Sensitivity.
- Stability.
- Reliability.
- Adequateness.

The qualities should be carefully considered while selecting protection schemes for power system protection. Cost is also equally important. A better protective system costs more

Selectivity & discrimination.

This is the property by which only the faulty element of the system is isolate and remaining healthy section should are left intact.
Discrimination is 'the act Discriminating' or 'distinguishing the difference between' the following:
Normal Condition & Abnormal condition

The protective system should operate only during abnormal conditions and should not operate under normal condition. In other words, the protective relaying system should discriminate between normal condition and abnormal condition. It should select and disconnect only faulty part without disconnecting the remaining healthy part.



Explaining Selectivity ('χ' mark indicate CB)

Protective relaying should be inoperative and stable during faults and abnormal conditions beyond its protective zone. It should not operate for faults, abnormal conditions beyond its protective zone. Referring to below Fig, if a fault occurs on transmission line, the protective relaying should isolate only the faulty line without tripping the neighbouring line or the transformer. For fault F1, only circuit-breaker CB1 should open. For fault F2, both CB2 and CB3 should open.

If protective relaying is not selective, and operates for faults beyond its protective zones, a larger portion of the system gets disconnected unnecessarity, causing embarrassment to supplier and consumers

Fast Operation

A protective system should be fast enough to isolate the faulty element of the system as quickly as possible to minimise damage to the equipment and to maintain the system stability.

Fault clearing time is the time between the instant of fault and instant of final are interruption (in circuit breaker).
Fault clearing time is the sum of relay-time and circuit breaker-time.

Remember the time events

Fault Clearing Time = [Relay Time] + [Breaker Time]

Fault Instant to Closing of relay contacts	+	Closing of relay contacts to Final Arc-extinction in C.B.

The relay-time is the time between the instant of occurrence of fault and the instant of closure of relay contacts. Or, it is the time between the instant when the operating quantity reaches the pick-up value and the instant of closure of relay contacts.

The circuit breaker time is the total of time taken by operating mechanism to open to circuit breaker contacts and the arching time. It is also called total break time.

The fault clearing time is significant due to the following reasons:

1. Rapid fault clearing minimizes the damage. During short circuit tests on bus bars, with fault duration of 0.07 second, with 60 kA R.M.S. value of current, no damage was observed after the tests. With fault duration of 7 seconds, however, the bus bars were completely destroyed.

2. Rapid fault clearing improves power system stability. For the reason, the slow relays and slow circuit breakers should not be preferred for protection, where stability is important. This applies to protection of EHV transmission lines, protection of large machines like important generator, large transformer, large-motors, etc., and protection in important generating stations and receiving stations

Though fast fault clearing is desirable, time lag is purposely provided in majority of protection systems for the following purposes:

- To permit discrimination between main and back-up protection.
- To prevent the operation of relay during transients, starting currents, permissibly load fluctuations, etc.

The relay-time of fast relays is of the order of a few cycles and that of inverse time relays can be adjusted between about 6 seconds to 60 seconds. The circuit-breaker time of slow circuit- breakers is of the order of 5 cycles and that of fast circuit-breakers is of the order of 2 cycles to 3 cycles.

Sensitivity

A protective relay should operate when the magnitude of the current exceeds the preset (Pick-up) value. This value is called the pick-up current. The relay should not operate when the current is below its pick-up value. A relay should be sufficiently sensitive to operate when the operating current just exceeds its pick-up value.

Reliability

A protective relay must operate reliably when a fault occurs. The reliability of a protective relay should be very high, a typical value being 95%.

Reliability means trustworthiness. The protective relaying should not fail to operate in the event of faults in the protected zone. Secondly, there should not be any fault in the components of protective system. Protective system should not operate unnecessarily. Reliability of protective systems is assessed from statistical data.

The protective system is teamwork of several components. A failure or defect in any one of them can result in failure of protection system. Hence the basic requirement of reliable protection is reliability of each component including circuit-breaker, relays, CT's, PT's secondary cables, trip circuit, battery system accessories, etc.

To achieve a high degree of reliability, greater attention should be given to the design, installation, maintenance and testing of the various elements of the protective system. Robustness and simplicity of the relaying equipment also contribute to reliability.

Stability

This is the ability of the protective system to remain inoperative under all load conditions, and also in case of external faults. The relay should remain stable when a heavy current due to an external fault is flowing through it

OR

A protective system should remain stable even when a large current is flowing through its protective zone due to an external fault, which does not lie in its zone. The concerned circuit breaker is supposed to clear the fault. But the protective system will not wait indefinitely if the protective e scheme of the zone in which fault has occurred fails to operate. After a preset delay the relay will operate to trip the circuit breaker.

Adequateness

There can be many abnormal conditions and providing protection against every abnormal condition is economically impossible. However, the protection provided for any machine, should be adequate.

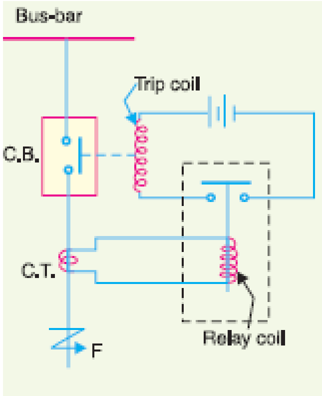
The adequateness of protection is judged by considering the following aspects :

- Rating of the protected machine.
- Location of the protected machine.
- Probability of abnormal condition due to internal and external causes.
- Cost of the machine, important.
- Continuity of supply as affected by failure of machine.

for low voltage machine/equipment, at the remote end of the system, an elaborate and costly protective system is not necessary. For example, distribution transformers below, say 500 kVA arc protected simply by drop-out fuses. Motors below 100 kW are protected by thermal over-load relays and HRC fuses. In these cases, the cost of CT's and protective relays, circuit-breakers, etc. is not generally justified. Whereas for a large machine, say generator, a very complex protective scheme is necessary. The adequateness of protection should be assessed while planning the protection scheme. Each installation generally needs particular attention, as the protective relaying needs are influenced by local conditions

1.7 Protective Relays

A protective relay is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system. The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency and phase angle. Through the changes in one or more of these quantities, the faults signal their presence, type and location to the protective relays. Having detected the fault, the relay operates to close the trip circuit of the breaker. This results in the opening of the breaker and disconnection of the faulty circuit. A typical relay circuit is shown in Fig. 21.1. This diagram shows one phase of 3-phase system for simplicity. The relay circuit connections can be divided into three parts viz.



(i) First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.

(ii) Second part consists of secondary winding of C.T. and the relay operating coil.

(iii) Third part is the tripping circuit which may be either a.c. or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts. When a short circuit occurs at point F on the transmission line, the current flowing in the line increases to an enormous value. This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system. In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system.

1.8 Instrument transformers. The lines in sub-stations operate at high voltages and carry current of thousands of amperes. The measuring instruments and protective devices are designed for low voltages (generally 110 V) and currents (about 5 A). Therefore, they will not work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing instrument transformers on the power lines. The function of these instrument transformers is to transfer voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays. There are two types of instrument transformers viz.

(i) Current transformer (C.T.)

(ii) Potential transformer (P.T.)

(i) Current transformer (C.T.). A current transformer in essentially a step-up transformer which steps down the current to a known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large number of turns of fine wire and provides for the measuring instruments and relays a current which is a constant fraction of the current in the line. Suppose a current transformer rated at 100/5 A is connected in the line to measure current. If the current in the line is 100 A, then current in the secondary will be 5A. Similarly, if current in the line is 50A, then secondary of C.T. will have a current of 2·5 A. Thus the C.T. under consideration will step down the line current by a factor of 20.

(ii) Voltage transformer. It is essentially a step down transformer and steps down the voltage to a known ratio. The primary of this transformer consists of a large number of turns of fine wire connected across the line. The secondary winding consists of a few turns and provides for measuring instruments and relays a voltage which is a known fraction of the line voltage. Suppose a potential transformer rated at 66kV/110V is connected to a power line. If line voltage is 66kV, then voltage across the secondary will be 110 V.

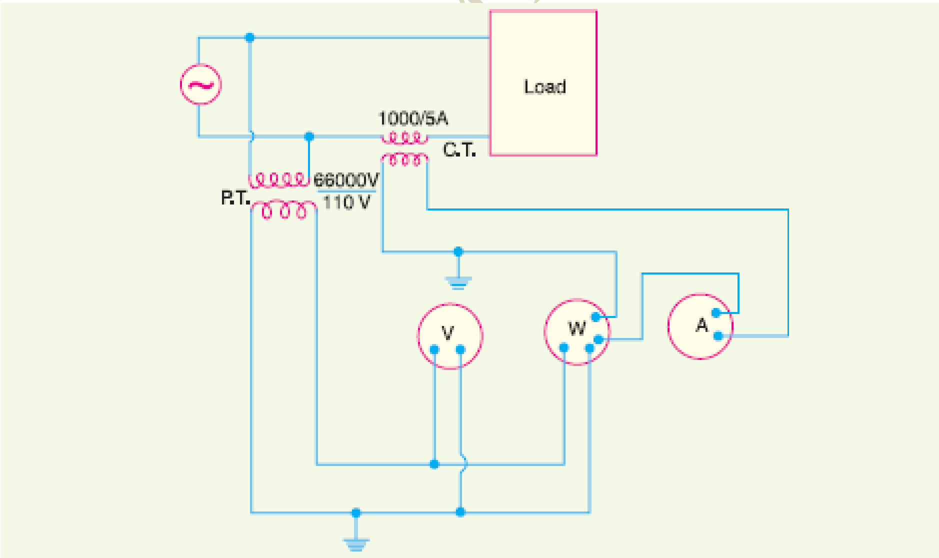


Fig. above shows the use of instrument transformers. The *potential transformer rated 66,000/110V provides a voltage supply for the potential coils of voltmeter and wattmeter. The current transformer rated 1000/5 A supplies current to the current coils of wattmeter and ammeter. The use of instrument transformers permits the following advantages:

(a) They isolate the measuring instruments and relays from high-voltage power circuits.

(b) The leads in the secondary circuits carry relatively small voltages and currents. This permits to use wires of smaller size with minimum insulation.

1.9 Auto-Reclosing

Faults on overhead lines fall into one of three categories:
A. transient
B. semi-permanent
C. permanent
80-90% of faults on any overhead line network are transient in nature. The remaining 10%-20% of faults are either semi-permanent or permanent

Most of the faults on over head lines are transient in nature. About 80% to 90% of faults are momentary and caused by tree branches, lightning, birds etc. These conditions results in arcing faults which lasts for very small duration and clears after that moment. The arc generated can be extinguished and the line can be re energized. For this momentary faults which recovers on its own normal circuit breaker operation of opening the faulty part is not advisable. Some provision should be permitted in circuit breakers to close the breaker contacts if the fault is cleared momentarily. This fact is employed as a basis for auto- reclosures.

In this scheme after the relays of both ends have picked up, the circuit breakers are tripped as for as possible at the same time and reclosed after time has be allowed for deionization. The fault disappears if it is transient and line is restored to normal service after the reclosure. If the fault is not cleared after the first reclosure a double or triple attempt of separation and reclosure is made. If the fault still persists, the breaker may permanently open till it is manually reset.

Auto reclosures may be single or three phase type. Mostly single phase auto reclosing breakers are preferred as most of the transmission faults are single phase to ground faults. Auto reclosures of single pole type improves the stability of the system as power remains transmitted through the remaining two healthy phases when fault on one phase occurs.

The breakers may be rapid auto reclosing type (about 20 cycles or 0.4 sec) or delayed auto reclosing (5 to 30s) type. For rapid reclosing type it is not required to check synchronism while reclosing however for delay reclosing synchronism should be checked before reclosing. For this purpose synchronous relays are employed

Use of an auto-reclose scheme to re-energise the line after a fault trip permits successful re-energisation of the line. Sufficient time must be allowed after tripping for the fault arc to de-energise prior to reclosing otherwise the arc will re-strike. Such schemes have been the cause of a substantial improvement in continuity of supply. A further benefit, particularly to EHV systems, is the maintenance of system stability and synchronism

The most important parameters of an auto-reclose scheme are:
1. dead time
2. reclaim time
3. single or multi-shot

These parameters are influenced by: **a.** type of protection **b.** type of switchgear **c.** possible stability problems **d.** effects on the various types of consumer loads

Dead Time

Several factors affect the selection of system dead time as follows:
a. system stability and synchronism
b. type of load
c. CB characteristics
d. fault path de-ionisation time

e. protection reset time

Reclaim time
Factors affecting the setting of the reclaim time are

- Type of protection
- Spring winding time

Number of Shots Factors affecting the setting of the reclaim time are

- Circuit breaker limitations
- System conditions

A typical single-shot auto-reclose scheme is shown in below Figure. The fig. shows a successful reclosure in the event of a transient fault,

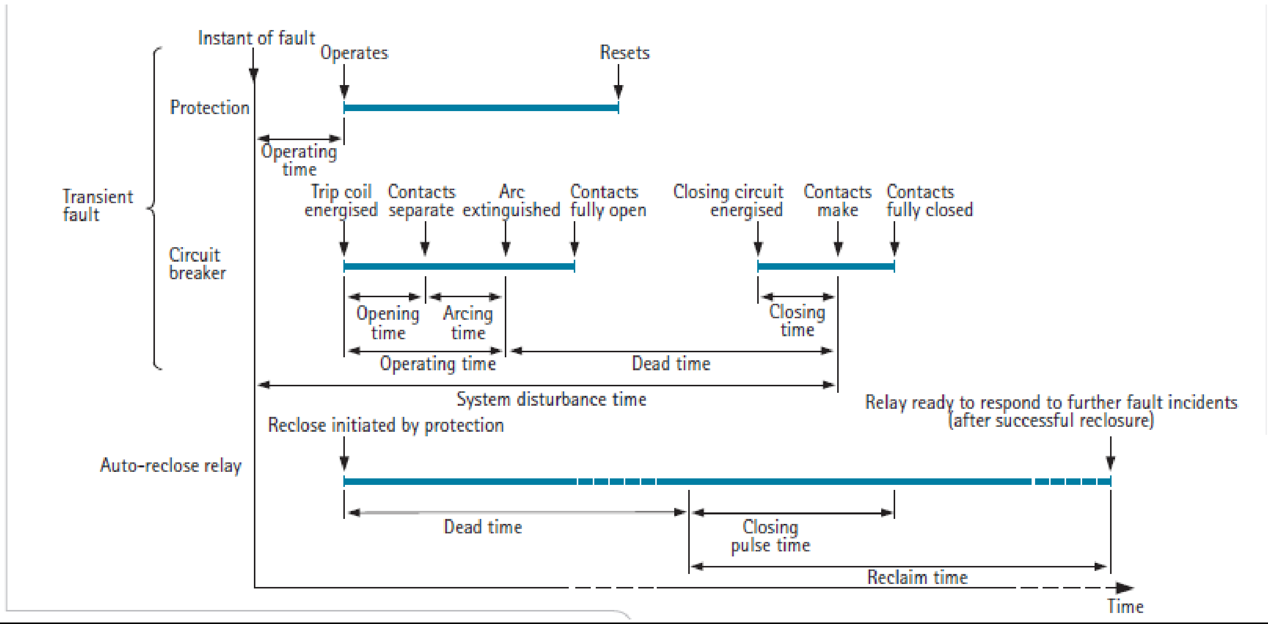


Figure: Single-shot auto-reclose scheme operation for a transient fault

On HV distribution networks, auto-reclosing is applied mainly to radial feeders where problems of system stability do not arise, and the main advantages to be derived from its use can be summarised as follows:

a. reduction to a minimum of the interruptions of supply to the consumer
b. instantaneous fault clearance can be introduced, with the accompanying benefits of shorter fault duration, less fault damage, and fewer permanent faults

As 80% of overhead line faults are transient, elimination of loss of supply from this cause by the introduction of auto-reclosing gives obvious benefits through:
a. improved supply continuity
b. reduction of substation visits

1.10 CLASSIFICATION OF PROTECTIVE RELAYS

Protective relays can be classified in various ways depending on the technology used for their construction, their speed of operation, their generation of development, function, etc., and will be discussed in more details in the following chapters.

Classification of Protective Relays Based on Technology

Protective relays can be broadly classified into the following three categories, depending on the technology they use for their construction and operation.

1. Electromechanical relays
2. Static relays
3. Numerical relays
4. Microprocessor-based relay
5. Microcontroller-based relay

Electromechanical Relays

Electromechanical relays are further classified into two categories, i.e.

(i) Electromagnetic relays, and
(ii) Thermal relays.

- **Electromagnetic relays**:
    - Operate on the electromagnetic principle i.e. an electromagnet attracts magnetic moving part or a force is exerted on a current carrying conductor when placed in the magnetic field or a force is produced by the principle of induction, etc. Moving iron, moving coil, attracted armature, induction disc and induction cup type relays come under this group of relays
- **Thermal relays**
    - Utilize the electro thermal effect of the actuating current for their operation.

Static Relays

These are solid state relays and employ semiconductor diodes, transistors, thyristors, logic gates, ICs, etc. The measuring circuit is a static circuit and there are no moving parts. In some static relays, a slave relay which is a D.C. polarised relay is used as the tripping device

Static relays contain electronic circuitry which may include transistors, ICs, diodes and other electronic components. There is a comparator circuit in the relay, which compares two or more currents or voltages and gives an output which is applied to either a slave relay or a thyristor circuit. The slave relay is an electromagnetic relay which finally closes the contact. A static relay containing a slave relay is a semi-static relay. A relay using a thyristor circuit is a wholly static relay. Static relays possess the advantages of having low burden on the CT and VT, fast operation, absence of mechanical inertia and contact trouble, long life and less maintenance. Static relays have proved to be superior to electromechanical relays and they are being used for the protection of important lines, power stations and sub-stations. Yet they have not completely replaced electromechanical relays. Static relays are treated as an addition to the family of relays. Electromechanical relays continue to be in use because of their simplicity and low cost. Their maintenance can be done by less qualified personnel, whereas the maintenance and repair of static relays requires personnel trained in solid state

Numerical Relays

A numerical relay is that in which the measured ac quantities are sequentially sampled and converted into numerical (digital) data form. A microprocessor or a microcontroller processes the data numerically (i.e., performs mathematical and/or logical operations on the data) using an algorithm to calculate the fault discriminants and make trip decisions.

At present microprocessor/ microcontroller-based numerical relays are widely used. These relays use different relaying algorithms to process the acquired information. Microprocessor/micro-controller-based relays are called numerical relays specifically if they calculate the algorithm numerically. The term 'digital relay' was originally used to designate a previous-generation relay with analog measurement circuits and digital coincidence time measurement (angle measurement) using microprocessors. Now' a days the term 'numerical relay' is widely used in place of 'digital relay'. Sometimes, both terms are used in parallel. Similarly, the term 'numerical protection' is widely used in place of 'digital protection'. Sometimes both these terms are also used in parallel.

The present downward trend in the cost of Very Large Scale Integrated (VLSI) circuits has encouraged wide application of numerical relays for the protection of modern complex power networks. Economical, powerful and sophisticated numerical devices (e.g. microprocessors, microcontrollers, DSPs, etc) are available today because of tremendous advancement in computer hardware technology. Various efficient and fast relaying algorithms which form a part of the software and are used to process the acquired information are also available today. Hence, there is a growing trend to develop and use numerical relays for the protection of various components of the modern complex power system. Numerical relaying has become a viable alternative to the traditional relaying systems employing electromechanical and static relays. Intelligent numerical relays using artificial Intelligence techniques such as Artificial Neural Networks (ANNs) and Fuzzy Logic Systems are presently under active research and development stage.

The main features of numerical relays are their economy, compactness, flexibility reliability, self-monitoring and self-checking capability, multiple functions, low burden on instruments transformers and improved performance over conventional relays of electromechanical and static types.

Microprocessor-based relay:

A microprocessor is used to perform all functions of a relay. It measures electrical quantities, makes comparisons, performs computations, and sends tripping signals. It can realize all sorts of relaying characteristics, even irregular curves which cannot be realised by electromechanical or static relays easily.

Microcontroller-based relay:

A microcontroller is used for performing all the function of the relay. It measures the electrical quantities by acquiring them in digital form through a data acquisition system, makes comparisons, processes the digital data to calculate the fault discriminants and make trip decisions. It can realised all sorts of relaying characteristics

Classification of Protective Relays Based on their Function

Protective relays can be classified into the following categories, depending on the duty they are required to perform:

- Over current relays
- Under voltage relays
- Impedance relays
- Under frequency relays
- Directional relays

These are some important relays many other relays specifying their duty they perform can be put under this type of classification. The duty which a relay performs is evident from its name. For example, an over current relay operates when the current exceeds a certain limit, an impedance relay measures the line impedance between the relay location and the point of fault and operates if the point of fault lies within the protected section. Directional relays check whether the point of fault lies in the forward or reverse direction

CLASSIFICATION OF PROTECTIVE RELAYS BASED ON SPEED OF OPERATION.

Protective relays can be generally classified by their speed of operation as follows:

- Instantaneous relays
- Time-delay relays
- High-speed relays
- Ultra high-speed relays

Instantaneous Relays

In these relays, no intentional time delay is introduced to slow down their response. These relays operate as soon as a secure decision is made.

Time-delay Relays

In these relays, an intentional time delay is introduced between the relay decision time and the initiation of the trip action.

High-speed Relays

These relays operate in less than a specified time. The specified time in present practice is 60 milliseconds (3 cycles on a 50 Hz system).

Ultra High-speed Relays

Though this term is not included in the relay standard but these relays are commonly considered to operate within 5 milliseconds

CLASSIFICATION OF PROTECTIVE SCHEMES

A protective scheme is used to protect an equipment or a section of the line. It includes one or more relays of the same or different types. The following are the most common protective schemes which are usually used for the protection of a modem power system.

- Over current protection
- Distance protection
- Differential protection

Over current Protection

This scheme of protection is used for the protection of distribution lines, large motors, equipment, etc. It includes one or more over current relays. An over current relay operates when the current exceeds its pick-up value.

Distance Protection

Distance protection is used for the protection of transmission or sub-transmission lines; usually 33 kV, 66 kV and 132 kV lines. It includes a number of distance relays of the same or different types. A distance relay measures the distance between the relay location and the point of fault in terms of impedance, reactance, etc. The relay operates if the point of fault lies within the protected section of the line. There are various kinds of distance relays. The important types are impedance, reactance and mho type. An impedance relay measure the line impedance between the fault point and relay location; a reactance relay measures reactance, and a mho relay measures a component of admittance **.**

Differential Protection

This scheme of protection is used for the protection of generators, transformers, motors of very large size, bus zones, etc. CTs are placed on both sides of each winding of a machine. The outputs of CT secondary are applied to the relay coils. The relay compares the current entering a machine winding and leaving the same. Under normal conditions or during any external fault, the current entering the winding is equal to the current leaving the winding. But in the case of an internal fault on the winding, these are not equal. This difference in the current actuates the relay. Thus, the relay operates for internal faults and remains inoperative under normal conditions or during external faults. In case of bus zone protection, CTs are placed on the both sides of the Bus bar.

1.11 Electromechanical Relays

Most of the relays in service on electric power system today are of electro-mechanical type.They work on the following two main operating principles:

(i) Electromagnetic attraction

(ii) Electromagnetic induction

Electromagnetic Attraction Relays

Electromagnetic attraction relays operate by virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a solenoid. Such relays may be actuated by d.c. or a.c. quantities. The important types of electromagnetic attraction relays are:

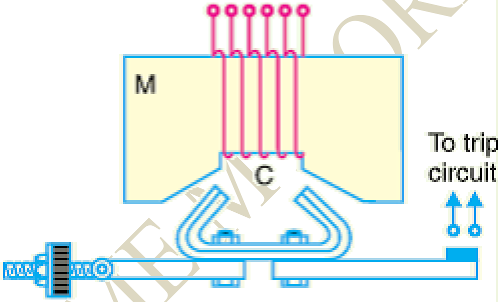
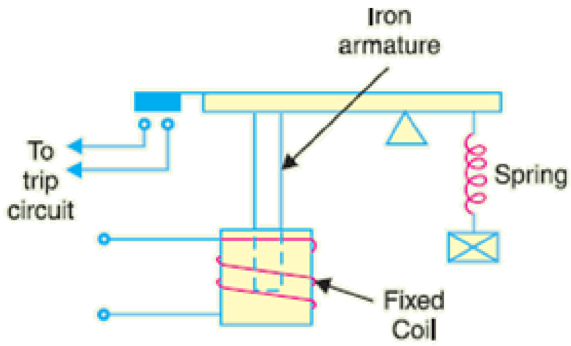


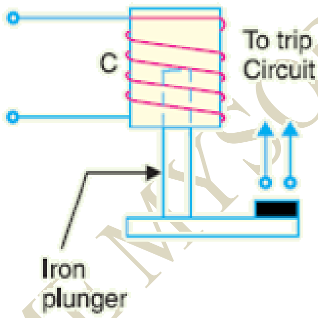
Fig. 21.3

(i) Attracted armature type relay. Fig. shows the schematic arrangement of an attracted armature type relay. It consists of a laminated electromagnet M carrying a coil C and a pivoted laminated armature. The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end. Under normal operating conditions, the current through the relay coil C is such that counterweight holds the armature in the position shown. However, when a short-circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards. The contacts on the relay armature bridge a pair of stationary contacts attached to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker and, therefore, in the disconnection of the faulty circuit. The minimum current at which the relay armature is attracted to close the trip circuit is called pickupcurrent. It is a usual practice to provide a number of tappings on the relay coil so that the number of turns in use and hence the setting value at which the relay operates can be varied.

(*ii*) Solenoid type relay. Below Fig. shows the schematic arrangement of a solenoid type relay. It consists of a solenoid and movable iron plunger arranged as shown. Under normal operating conditions, the current through the relay coil *C* is such that it holds the plunger by gravity or spring in the position shown. However, on the occurrence of a fault, the current through the relay coil becomes more than the pickup value, causing the plunger to be attracted to the solenoid. The upward movement of the plunger closes the trip circuit, thus opening the circuit breaker and disconnecting the faulty circuit



(*iii*) Balanced beam type relay. Below Fig. shows the schematic arrangement of a balanced beam type relay. It consists of an iron armature fastened to a balance beam. Under normal operating conditions, the current through the relay coil is such that the beam is held in the horizontal position by the spring. However, when a fault occurs, the current through the relay coil becomes greater than the pickup value and the beam is attracted to close the trip circuit. This causes the opening of the circuit breaker to isolate the faulty circuit



Electromagnetic Induction Relays

Electromagnetic induction relays operate on the principle of induction motor and are widely used for protective relaying purposes involving a.c. quantities. They are not used with d.c. quantities owing to the principle of operation. An induction relay essentially consists of a pivoted aluminium disc placed in two alternating magnetic fields of the same frequency but displaced in time and space. The torque is produced in the disc by the interaction of one of the magnetic fields with the currents induced in the disc by the other.

To understand the production of torque in an induction relay, refer to the elementary arrangement shown in Fig.(*i*). The two a.c. fluxes ϕ_2 and ϕ_1 differing in phase by an angle **α induce** e.m.f.s' in the disc and cause the circulation of eddy currents i_2 and i_1 respectively. These currents lag behind their respective fluxes by 90º. Referring to Fig.(*ii*) Where the two a.c. fluxes and induced currents are shown separately for clarity,

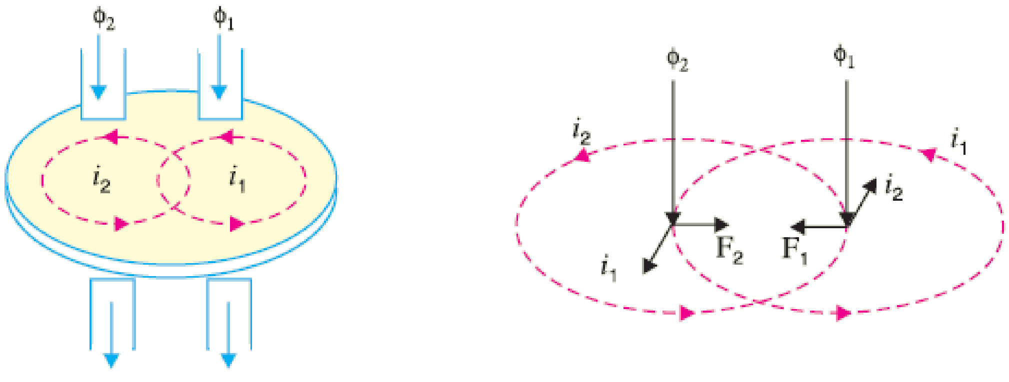
$$\text{let } \varphi_1 = \varphi_{1max} \sin \omega t$$

$$\varphi_2 = \varphi_{2max} \sin (\omega t + \alpha)$$

where φ1 and φ2 are the instantaneous values of fluxes and φ2 leads φ1 by an angle α.

Assuming that the paths in which the rotor currents flow have negligible self-inductance, the rotor currents will be in phase with their voltages.

$$\therefore\ i_1 \propto d\,(\varphi_{1max} \sin \omega\, t) / dt \quad \propto \varphi_{1\,max} \cos \omega\, t$$



(*i*) (*ii*)

$$\text{and} \quad i_2 \propto d\, \varphi_2 / dt \ \propto \varphi_{2max} \cos(\omega\, t + \alpha)$$

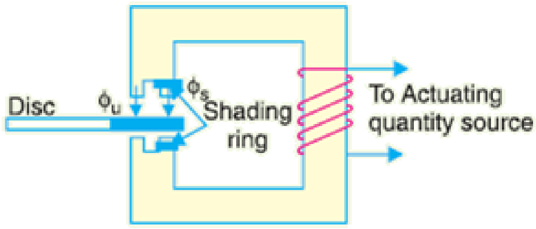
Now, $F_1 \propto \varphi_1\, i_2$ and $F_2 \propto \varphi_2\, i_1$
Fig. (*ii*) shows that the two forces are in opposition.
$\therefore$ Net force F at the instant considered is

$$\begin{aligned}
F &\propto F_2 - F_1 \\
&\propto \varphi_2\, i_1 - \varphi_1\, i_2 \\
&\propto \varphi_{2max} \sin(\omega\, t + \alpha)\ \varphi_{1max} \cos \omega\, t - \varphi_{1max} \sin \omega t\ \varphi_{2max} \cos(\omega\, t + \alpha) \\
&\propto \varphi_{1max}\, \varphi_{2max} [\sin(\omega\, t + \alpha) \cos \omega\, t - \sin \omega\, t \cos(\omega\, t + \alpha)] \\
&\propto \varphi_{1max}\, \varphi_{2max} \sin \alpha \\
&\propto \varphi_1\, \varphi_2 \sin \alpha \qquad \text{... (i)}
\end{aligned}$$

where φ_1 and φ_2 are the r.m.s. values of the fluxes
The following points may be noted from exp. (*i*):
(*a*) The greater the phase angle α between the fluxes, the greater is the net force applied to the Disc. Obviously, the maximum force will be produced when the two fluxes are 90o out of phase.
(*b*) The net force is the same at every instant. This fact does not depend upon the assumptions made in arriving at exp. (*i*).
(*c*) The direction of net force and hence the direction of motion of the disc depends upon which flux is leading.

The following three types of structures are commonly used for obtaining the phase difference in the fluxes and hence the operating torque in induction relays :
(*i*) shaded-pole structure
(*ii*) watthour-meter or double winding structure
(*iii*) induction cup structure

(*i*) Shaded-pole structure. The general arrangement of shaded-pole structure is shown in below Fig. It consists of a pivoted aluminium disc free to rotate in the air-gap of an electromagnet. One half of each pole of the magnet is surrounded by a copper band known as shading ring. The alternating flux φs in the shaded protion of the poles will, owing to the reaction of the current induced in the ring, lag behind the flux φu in the unshaded portion by an angle α. These two a.c. fluxes differing in phase will produce the necessary torque to rotate the disc. As proved earlier, the driving torque T is



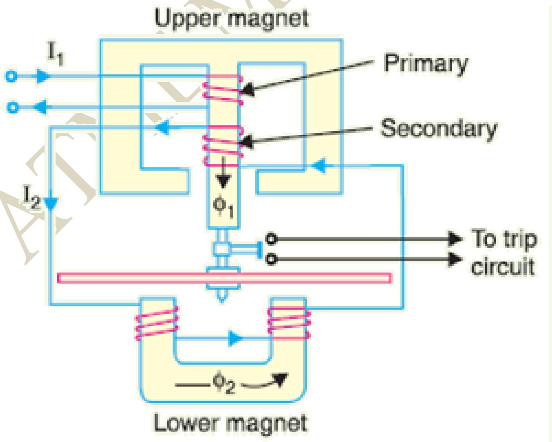
$$T \propto \varphi s\ \varphi u \sin \alpha$$

Assuming the fluxes φs and φu to be proportional to the current I in the relay coil,

$$T \propto I^2 \sin \alpha$$

This shows that driving torque is proportional to the square of current in the relay coil

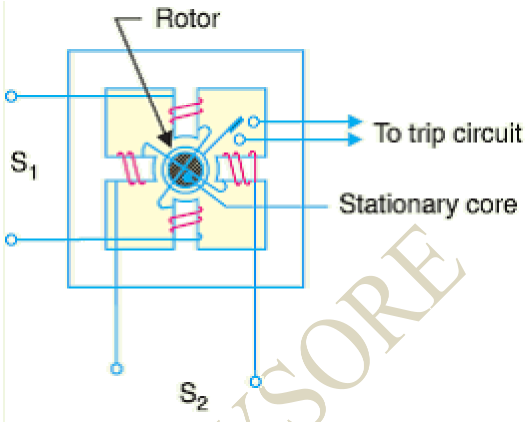
(*ii*) Watthour-meter structure. This structure gets its name from the fact that it is used in watthour meters. The general arrangement of this type of relay is shown in Fig. It consists of a pivoted aluminium disc arranged to rotate freely between the poles of two electromagnets. The upper electromagnet carries two windings ; the pirmary and the secondary. The primary winding carries the relay current *I*1 while the secondary winding is connected to the winding of the lower magnet. The primary current induces e.m.f. in the secondary and so circulates a current *I*2 in it. The flux φ2 induced in the lower magnet by the current in the secondary winding of the upper magnet will lag behind φ1 by an angle α. The two fluxes φ1and φ2 differing in phase by α will produce a driving torque on the disc proportional to φ1φ2 sin α.



An important feature of this type of relay is that its operation can be controlled by opening or closing the secondary winding circuit. If this circuit is opened, no flux can be set by the lower magnet however great the vaule of current in the pirmary winding may be and consequently no torque will be produced. Therefore, the relay can be made inoperative by opening its secondary winding circuit

Induction cup structure. Fig. shows the general arrangement of an induction cup structure. It most closely resembles an induction motor, except that the rotor iron is stationary, only the rotor conductor portion being free to rotate. The moving element is a hollow cylindrical rotor which turns on its axis. The rotating field is produced by two pairs of coils wound on four poles as shown.

The rotating field induces currents in the cup to provide the necessary driving torque. If $\varphi 1$ and $\varphi 2$ represent the fluxes produced by the respective pairs of poles, then torque produced is proportional to $\varphi 1 \varphi 2 \sin \alpha$ where α is the phase difference between the two fluxes. A control spring and the back stop for closing of the contacts carried on an arm are attached to the spindle of the cup to prevent the continuous rotation. Induction cup structures are more efficient torque producers than either the shaded-pole or the watthour meter structures. Therefore, this type of relay has very high speed and may have an operating time less then 0·1 second



1.12 Time–current Characteristics, Current Setting, Time Setting

Relay Definitions

- Operating force or torque: A force or torque which tends to close the contacts of the relay.

- Restraining (Control) force or torque: A force or torque which opposes the operating force/ torque.

- Actuating quantity: An electrical quantity (current, voltage, etc) to which relay responds

- PICK-UP:

  When the relay operates, we say, the relay has picked-up. It simply means that the relay with normally open contacts, has closed its contacts.

  The pick-up value or pick-up level is the minimum value of operating quantity at which the relay is one the verge of operation, e.g., consider an over current relay. The current injected in the relay coil is very gradually increased. At a current value of 2.51 amperes, the relay has not operated, at a value at a value of 2.52 amperes, the relay begins to operate. Then, 2.52 amperes is the pick-up value.

  In induction disc relays, the pick-up value corresponds to plug-setting (described later). If plug setting is 2.5 A, the relay starts operating at 2.5 A. If plug setting is 3.5 A, relay starts operating at 3.5 A and so on. However, in such relays the pick-up value is not exact, within about 5% of plug setting. The relay may not pick-up exactly at the plug setting value due to errors introduced by dust, friction, adjustment errors; and because operating torque is minimum at pick-up value.

- RESET OR DROP-OFF LEVEL:

  Now, we are talking about the relay which has already operated, and the actuating current is still flowing in the relay coil. As the operating quantity is gradually reduced, at some maximum value, the relay value, the relay contacts which have closed, start opening. This condition is called Reset or Drop off.

  The value of operating quantity at which the relay (normally open) contacts which were closed due to relay operation, start opening and coming to original state (open).

- Plug Setting and Time Setting in Induction Disc Relays

  In these relays, there is a facility for selecting the plug setting and time setting such that the same relay can be used for a wide range of current, time and characteristics.

- Time Setting in Induction Disc Relays

Time multiplier setting is generally in the form of an adjustable back-stop which decides the arc-length through which the disc travels, by reducing the length of travel, the time is reduced. The time multiplier setting is marked from about 0.1 to 1, with major divisions marked in between. If relay takes a certain time, say S seconds with time multiplier setting 1, the same relay will take time equal to T x S seconds for time multiplier setting T, other conditions remaining the same.

I.e. Actual Operating Time of Relay = Time multiplier setting x Trip Time (Time required to close the contacts)

- Plug Setting in Induction Disc Relays

It should be possible to use the same relay for a certain range of current/voltage. Hence a plug setting bridge is provided with electromagnetic relays. The plug setting refers to the reference value of operating quantity at which the relay starts operating. If by inserting the plug, setting of 2.5 is selected, the relay will start operating when the current in relay coil (secondary current of (CT) is about 2.5 A or more. Plug setting determines the number of turns tapped from the relay coil. The current-time characteristic for various plug setting is generally same, provided time setting remains unchanged. Such performance is achieved by matching the plug-setting and corresponding number of turns tapped from the coil such that the Ampere-turns remains same for various plug-settings

The arrangement is such that for various plug settings, the ampere-turns (amperes of plug setting x turns of coil corresponding to the plug setting) are constant for various plug settings. Thereby, the relay characteristics remains the same for various plug settings, for a given time setting. Actually, the relay should start operating at current equal to plug setting. However, due to friction, dust etc, the operations may not take place at exact plug setting value.

The relay characteristic is plotted with multiples of plug setting as an abscissa (log scale) and time in seconds (log scale) as ordinate. Suppose, current injected in relay coil is 10 Amp and plug setting is 2.5 Amp, then plug setting multiplier will be 10 / 2.5 = 4.

Plug-setting multiplier and represents the number of times the relay current is in excess of the current setting

PSM= Current injected in relay coil (secondary current of (CT)) / plug setting

Or

PSM=Primary fault current / (Relay Setting Current* C.T ratio)

Plug setting bride is provided with induction disc relays and it provides a wide range of current settings. The plug setting refers to the magnitude of current at which the relay starts to operate. The plug setting bridge comprises connections tapped from relay coil. By inserting the plug, in a particular gap in the bridge, a certain number of turns of the relay coil are brought into circuit

Fig. 1 illustrates typical characteristics of induction disc relays, on log scales.

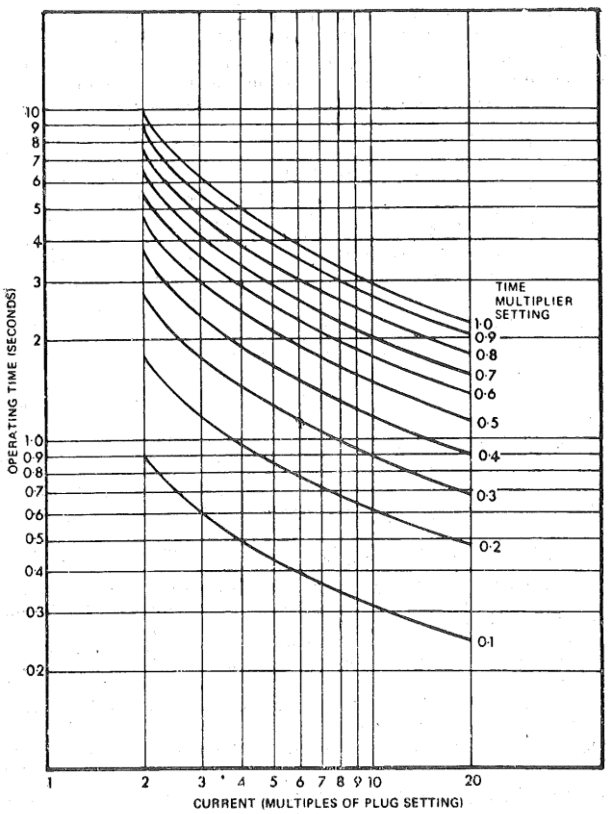


Fig 1, Inverse Characteristics of induction disc relay on log scale

The time / current Characteristics of induction disc relay is Inverse Characteristics, the time reduces as current increases.

Effect of Time-setting

By reducing the time multiplier, the characteristic is shifted to lower side, indicating that operating time is reduced (Fig. 1)

- Operating time: It is the time which elapses from the instant at which the actuating quantity exceeds the relays pick-up value to the instant at which the relay closes its contacts.

- Burden (Power consumption): The power consumed by the relay circuitry at the rated current or voltage is known as its burden expressed in volt ampere in a.c and in watts in d.c circuit

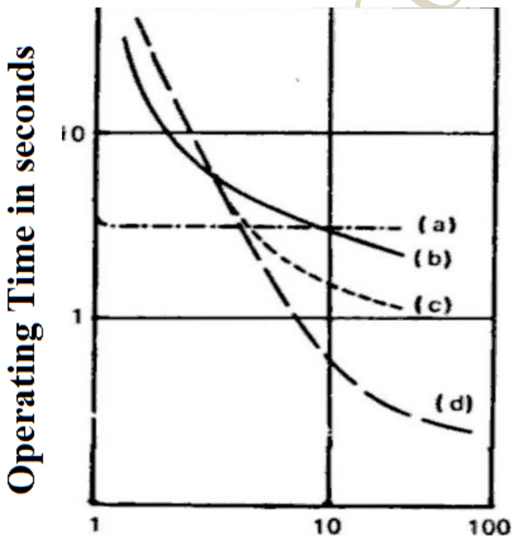
➢ <u>Directional or reverse power relay</u>: A directional relay is able to detect whether the point of fault lies in the forward or reverse direction with respect to the relay location. It is able to sense the direction of power flow, i.e. whether the power is flowing in the normal direction or the reverse direction

The operating time of all over current relays tends to become asymptotic (Straight Line) to a definite minimum value with increase in the value of current. This is inherent in electromagnetic relays due to saturation of the magnetic circuit. So by varying the point of saturation different characteristics are obtained; these are:

- Definite time.
- Inverse characteristics
- Inverse definite minimum time (IDMT).
- Very inverse.
- Extremely inverse

These characteristics are obtained by induction disc and induction cup relays.

The torque of these relays as shown earlier is proportional to $Ø_1 * Ø_2 * \text{Sin}\alpha$ where $Ø_1$ and $Ø_2$ are the two fluxes cutting the disc or cup and α is the angle between them. Where both fluxes are produced by the same quantity, as in current or voltage operated relays, then below saturation the torque is proportional to I^2, the coil current, or $T=KI^2$. If the core is made to saturate at very early stage with the result that by increasing I, K decreases so that the time of operation remains same over the working range, the characteristics is shown by curve (a) in fig1 and is known as definite minimum time characteristics i.e. (DMT) irrespective of the magnitude of the current above the pickup value, the operating time is the same (i.e. the time of operation is almost definite), however, DMT relay has also a slightly inverse characteristics.



Multiples of plug setting

FIGURE 1 Characteristics of various overcurrent relays: (a) definite time ;(b) IDMT; (c) Very inverse; (d) extremely inverse

In the case of inverse time characteristics, the relay operating time decreases as the current above the pickup value increases (i.e. time is inversely propositional to current)

Now if the core is made to saturate at a later stage the characteristics assume the shape of curve (b) Fig 1, known as IDMT (inverse definite minimum time (IDMT) characteristic)
The characteristics of DMT & of inverse time characteristics type is called inverse definite minimum time (IDMT) characteristics as show in fig
In case of inverse definite minimum time (IDMT) Relay, the operating characteristics will be inverse time

characteristics at lower value of the fault current and DMT characteristics at higher values of fault current.
Now if the core saturation occurs at a still later stage the characteristics assume the shape show by the curve (C) in fig 1 known as very inverse. The time-current characteristic is inverse over a greater range and after saturation tend to definite time.
The curve (d) in fig 1 shows extremely inverse characteristics i.e. the saturation occurs at a very late stage and the equation of the curve is roughly of the form $I^2t=k$ where I is the operating current and t is the time of operation.

Example Determine the time of operation of a 5-ampere, 3-second overcurrent relay having a current setting of 125% and a time setting multiplier of 0·6 connected to supply circuit through a 400/5 current transformer when the circuit carries a fault current of 4000 A. Use the curve (TMS = 1) shown in Fig. 21.16.

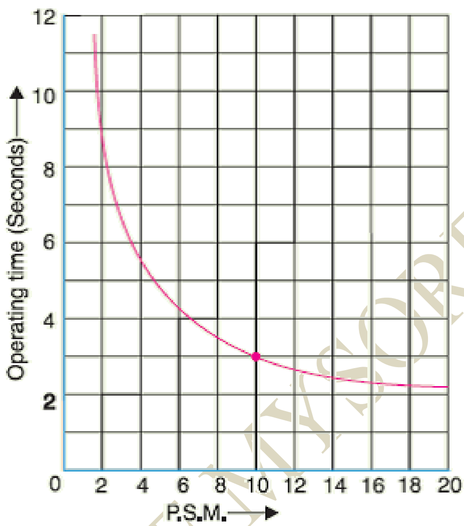


Fig. 21.16

Solution.
Rated secondary current of C.T. = 5 A

Pickup current = 5 × 1·25 = 6·25 A

Fault current in relay coil = 4000 * 5/400 = 50 A

∴ Plug-setting multiplier (P.S.M.) = 50 /6.25 = 8

Corresponding to the plug-setting multiplier of 8 (See Fig. 21.16), the time of operation is 3.5seconds.
∴ Actual relay operating time = 3·5 × Time-setting multiplier = 3·5 × 0·6 = **2·1 seconds**

Course outcomes : Interpret performance of protective relays, components of protection scheme and relay terminology & over current protection

Further Readings
1. http://nptel.ac.in/downloads/108101039/
2. https://www.electrical4u.com/protection-system-in-power-system/
3. http://electrical-engineering-portal.com