Auxiliary material

Table of Contents

1. OVERVIEW OF POWER SYSTEM

1

ELECTRIC POWER SYSTEM

- An electric power system comprises of all electric power equipment from generating plants to electrical loads.
- Typically an electric power system has
- Electric power generating stations
- Interconnected transmission network (NITS)
- Distribution networks

2

ELECTRIC POWER SYSTEM

POWER SYSTEM IN GHANA

- Ghana operates a power system where generation, transmission and distribution have been segregated and operators are licensed by regulatory authorities.
- The regulatory authorities are
- Public Utilities Regulatory Commission (PURC): Economic Regulation
- Energy Commission (EC): Technical Regulation

3

ELECTRIC POWER SYSTEM

POWER GENERATION IN GHANA:

- HYDRO
- Akosombo Dam: 1020MW
- Kpong Dam: 160MW
- Bui Dam: 400MW

4

ELECTRIC POWER SYSTEM

POWER GENERATION IN GHANA: *cont.*

- THERMAL (GAS AND LCO- LIGHT CRUDE OIL)
- Tapco: 330MW
- Tico (Tarkoradi International Company): 220MW
- Cenit: 110MW
- MRP (Mines Reserve Plant): 80MW
- Tema Thermal:
- Asogli: 200MW

Total installed capacity is around 2,900 MW.
Peak demand is around 2,500 MW.

ELECTRIC POWER SYSTEM

POWER TRANSMISSION IN GHANA:

- Ghana Grid company (GridCo) is the only utility licensed to operate the transmission network in Ghana.
- It receives generated power from all generation companies and dispatch to distribution utilities and other bulk power consumers.

ELECTRIC POWER SYSTEM

DISTRIBUTION

- Ghana has two main distribution utilities:

- ECG: In charge of the Southern sector

- NEDCO: In charge of the Northern sector

ELECTRIC POWER SYSTEM

COMPONENTS OF THE POWER SYSTEM

- GENERATORS
- TRANSFORMERS
- TRANSMISSION LINES
- DISTRIBUTION FEEDERS
- LOADS

ELECTRIC POWER SYSTEM

COMPONENTS OF THE POWER SYSTEM *cont.*

The various components of the power system affect the performance of the power system under:

- **Steady state loading**: Involves transfer of power from generating stations to load centers under normal operating conditions.
- **Transient loading**: Involves the behaviour of the network under fault conditions.

ELECTRIC POWER SYSTEM

COMPONENTS OF THE POWER SYSTEM *cont.*

Factors that affect steady state loading are:

- Sending and receiving end voltages
- Capacity of generators
- Impedance of generators
- Impedance of transmission lines
- Configuration of transmission lines
- Size of transformers
- Impedance of transformers
- Vector group of transformers

ELECTRIC POWER SYSTEM

COMPONENTS OF THE POWER SYSTEM *cont.*

All the above factors together with the following factors determine transient behaviour of the power system.

- Grounding of the network
- Fault impedances

2. CONFIGURATION OF SUBSTATION EQUIPMENT

1

ELECTRIC POWER SYSTEM

SUBSTATION

- A substation is a part of the power system and not an entity on its own and therefore has one or more incomers and one or more outgoing lines or feeders.
- It is designed to ensure the following:
- Ease of isolation of potions of network. (For faults clearance or maintenance).
- Minimal interruption of service due to failure or isolation of portions of the network by providing contingencies.

2

ELECTRIC POWER SYSTEM

TYPES OF SUBSTATIONS

Substations may be categorized as follows:

- Transmission substation
- Sub-transmission substation
- Distribution substation
- Switching substation

3

ELECTRIC POWER SYSTEM

FUNCTIONS OF SUBSTATIONS:

Some of the functions of substations are:

- Voltage conversion
- Voltage regulation
- Interconnection of the power system
- Control of power flow (active and reactive)
- Measurement of power
- System protection and control
- System control and data acquisition (SCADA)

4

ELECTRIC POWER SYSTEM

SUBSTATION EQUIPMENT

The key equipment at substations are:

- Bus-bar
- Power Transformers
- Circuit breakers
- Disconnects or Isolators
- Instrument Transformers
- Lightning Arrestors
- Communication Equipment
- Voltage Regulation Equipment
- Control Room

5

ELECTRIC POWER SYSTEM

SUBSTATION BUS-BAR:

The substation bus is an important node in the power system. It is a termination point for incoming lines and a take off point for outgoing lines. Some factors that determine the type are:

- Load (present and future)
- Complexity of substation
- Importance of substation

6

ELECTRIC POWER SYSTEM

TYPES OF BUS-BAR ARRANGEMENTS

- **Single Bus** (With or without sectionalizer):
- Simple (operation and protection)
- Low cost
- Less space requirement
- Easy to expand
- Less reliable
- Must go off for maintenance
- Maintenance may affect protection

7

ELECTRIC POWER SYSTEM

TYPES OF BUS-BAR ARRANGEMENTS

- **Double Bus** (Breaker-and-a-half):
- Two normally energized bus bars
- Electrically connected between the two buses are 3 circuit breakers
- Connected between any two breakers is a feeder
- A feeder is therefore controlled by one and half breakers.

8

ELECTRIC POWER SYSTEM

TYPES OF BUS-BAR ARRANGEMENTS

- **Double Bus** (Breaker-and-a-half):
- Flexible operation
- High reliability
- Maintenance without complete shutdown
- High cost
- Complex protection

9

ELECTRIC POWER SYSTEM

TYPES OF BUS-BAR ARRANGEMENTS

- **Double Bus** (Double Circuit Breaker):
- Two normally energized bus bars
- Two circuit breakers connected between the two bus bars
- One circuit (feeder) between the two breakers

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ELECTRIC POWER SYSTEM

TYPES OF BUS-BAR ARRANGEMENTS

- **Double Bus** (Double Circuit Breaker):
- Flexible operation
- Very high reliability
- Maintenance without complete shutdown
- All switching with circuit breakers
- High Cost
- Two breakers per circuit

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3. INSTRUMENT TRANSFORMERS

1

INSTRUMENT TRANSFORMERS

- **CURRENT TRANSFORMER (CT)**

  CT is an **instrument transformer.** The primary of a CT is connected in series with the power system. CTs transform high system currents to more manageable levels and feed relays and meters.

  CTs are required in a power system because of the following:

- The need to isolate meters and relays from the high voltage of the power system.
- The need to transform high load currents to values that can easily be handled by relays and meters.

2

INSTRUMENT TRANSFORMERS

- CT cont.

There are two main types of CTs. These are:

- **Wound primary type**: Primary and secondary windings are wound on an iron core but insulated from each other. The primary may be one or multi turns. They can be for indoor or outdoor use.
- **Ring/Window/Toroid type**: Only the secondary winding is wound on the core. A window is provided for the primary which is either a bus-bar or a conductor.

3

INSTRUMENT TRANSFORMERS

- **CT Specification:**

  CTs are specified by the following parameters:

- **Nominal System Voltage**

  This usually indicates the maximum allowable system voltage. Every CT is designed with insulation to withstand a specific voltage. Eg. For ECG's 11kV and 33kV networks, the maximum voltages are 12kV and 36kV respectively.

4

INSTRUMENT TRANSFORMERS

- CT *cont.*

- **Ratio**: This defines the **rated primary and secondary currents**. The rated secondary current is either 5A or 1A.
  E.g. 200/5A or 200/1A for 1 core CT;
  1600-800/5/5A for 2 core dual ratio CT.

5

INSTRUMENT TRANSFORMERS

- CT *cont.*

- **Class**: This defines the accuracy of the CT. E.g. 0.1, 0.2, 0.5, 1.0 for metering CTs and 5P, 10P for protection CTs.
  The number in the class signifies the percentage error of the CT. The letter 'P' stands for protection class.

6

INSTRUMENT TRANSFORMERS

- CT *cont.*

  Burden: This defines the maximum load that can be connected to the secondary of the CT for the CT to remain accurate as specified. It is usually given in VA but can be expressed in ohms.
  It is made up of the impedance of the secondary leads and the impedance of the equipment connected to the secondary.

7

INSTRUMENT TRANSFORMERS

- CT *cont.*

- **Accuracy Limit Factor (ALF):** This is specified for protection CTs. Protection CTs are required to maintain their accuracy up to several times the rated primary current.
  The primary current at which the limits of error starts to be exceeded is known as the accuracy limit primary current.
  ALF is the ratio of the accuracy limit primary current to the rated primary current. This can be 5, 10, 15, 20 or 30. A typical protection CT rating is 100/5A, 5P20, 30VA

8

INSTRUMENT TRANSFORMERS

- CT *cont.*

- **Security Factor (FS):** This is specified for metering CTs. Metering CTs are required to saturate under fault conditions in order to protect the sensitive meters connected to them from damage.

  The FS is the ratio of the accuracy limit primary current to the rated primary current. This is usually specified as <5 or <10 for metering CTs.

9

INSTRUMENT TRANSFORMERS

- CT *cont.*

- **Short Time Rating:**

  This defines the maximum fault current the CT can tolerate within a short time, usually 3 sec or 1 sec.

  For ECG's 11kV and 33kV networks, the short time ratings are 25kA and 31.5kA respectively.

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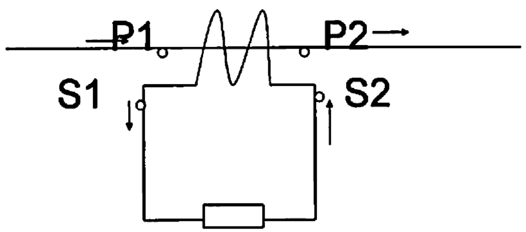
INSTRUMENT TRANSFORMERS

- CT *cont.*



When the primary current flows into P1 and out of P2, the secondary current flows out of S1 into S2

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INSTRUMENT TRANSFORMERS

CT SATURATION

- Occurs when excessive current than the CT can handle flows in the primary.
- The presence of DC in the primary current also causes saturation.
- Little or no current flows in the secondary under saturation.
- The voltage in the secondary of CT just before saturation is called the knee point voltage.
- It is the point on the magnetization curve at which a 10% increase in voltage results in a 50% increase in current.

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INSTRUMENT TRANSFORMERS

- CT *cont.*

WARNING

Under no circumstance should the secondary of a CT be open when the primary is energized.

The high voltages that result can damage insulation and cause fire and be dangerous to personnel.

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INSTRUMENT TRANSFORMERS

- **VOLTAGE TRANSFORMER (VT)**

VT is an instrument transformer connected in **parallel** with the power system to transform the system voltages to more manageable values and feeds relays and meters.

There are two types of VTs.

✓ **Electromagnetic (Inductive) type**: Single phase or 3-phase units with primary and secondary windings wound on an iron core.

✓ **Capacitor (CVT) type**: Single phase units made basically of a capacitance potential divider for high voltage power systems.

The inductive type is more accurate than the CVT.

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INSTRUMENT TRANSFORMERS

- VT *cont.*

The VT is specified by the ratio, burden, accuracy class and voltage factor.

Ratio: The ratio indicates the nominal line voltages of the primary and secondary.

E.g. 33,000/√3 : 110/√3 , 11,000 /√3 : 110/√3

The company has a standard VT secondary voltages of 110V.

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INSTRUMENT TRANSFORMERS

- VT *cont.*

Burden: This defines the maximum load that can be connected to the secondary of the VT for it to remain accurate as specified. It is usually given in VA but can be expressed in ohms. Substation VTs are usually connected to the bus and the burden must be specified properly.

Class: Specifies the ratio error of the VT. E.g. 0.1, 0.2, 0.5, 1.0 for metering VTs and 3P, 6P for protection VTs.

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INSTRUMENT TRANSFORMERS

- VT *cont.*

Voltage factor: This is the maximum voltage the VT is rated to carry. It is expressed in per unit of rated voltage. The continuous rating is usually 1.2 while the short time rating depends on the system grounding.

Isolated neutral systems: Vf = 1.9 for 8 hours.

Effectively earthed systems: Vf = 1.5 for 30s.

Non-effectively earthed systems: Vf = 1.9 for 30s.

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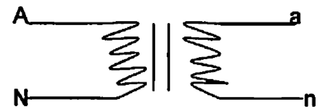
INSTRUMENT TRANSFORMERS

- VT *cont.*



VT secondary should not be short-circuited when the primary is energized.

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INSTRUMENT TRANSFORMERS

- VT *cont.*

To protect the VT against damage from short circuits, fuses or MCBs should be installed in the secondary of VTs.

Primary fuses, though frequently used, do not protect VTs against secondary short circuits.

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4. OVERVIEW OF PROTECTION RELAY SYSTEM

1

THE NEED FOR PROTECTION

- FAULT:
  A fault is an **unintentional** and **undesirable** creation of a conducting path or blockage of current.

  There are 3 types:
- Short circuit: Results when there is an insulation failure between two phases e.g. in cables, overhead lines and transformers.
- Earth (leakage) fault: A fault to earth as a result of insulation failure between phase and earth e.g. insulation flashovers, conductors touching ground, etc.
- Open circuit: Results when there is a break in the circuit e.g. broken jumpers, broken conductors, etc.

2

THE NEED FOR PROTECTION

- FAULT: *cont.*

  Short circuits and earth faults are the most harmful to the system. They may result in the following:
- damage to faulted equipment
- damage to healthy equipment due to thermal and mechanical stress
- collapse of entire system
- harm to people

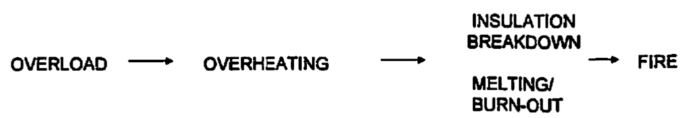
3

THE NEED FOR PROTECTION

- **DAMAGE TO EQUIPMENT**:
  Every power system equipment has a short time rating. The short time rating is the maximum current the equipment can carry safely in 1 second or 3 seconds.

To avoid damaging the equipment, its short time rating should be:
- More than the continuous rating of the equipment
- More than or equal to the maximum fault level of the power system in which it will be connected.

  When the short time rating is exceeded, overheating results leading to circuit burn-outs or insulation failure which may eventually lead to fire.



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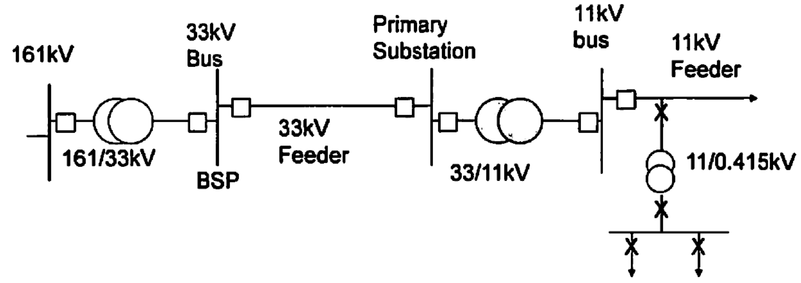
THE NEED FOR PROTECTION

- SYSTEM COLLAPSE

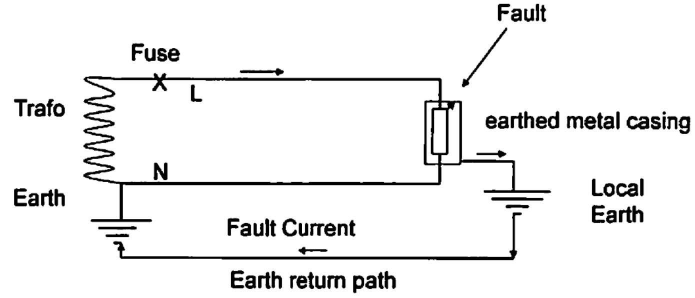


A fault on a downstream feeder can cause the entire system to collapse if not isolated quickly.

5

THE NEED FOR PROTECTION

- **HUMAN SAFETY**

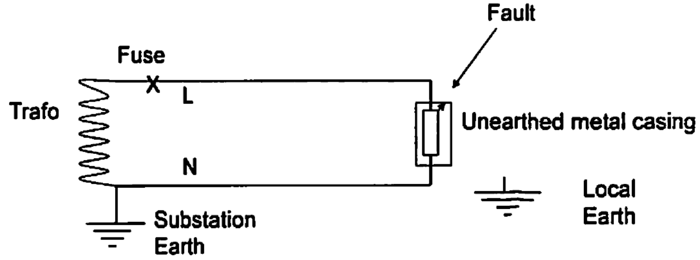


A return path exists for fault current to flow for protection to work.

6

THE NEED FOR PROTECTION

- Human Safety



Full voltage exist between faulted metal casing and earth. This poses danger to a person who touches the metal casing.

7

THE NEED FOR PROTECTION

- Protection System Reliability:
- Sensitivity: Measure small quantities of fault levels
- Selectivity: Respond to only faults in its zone of operation
- Stability: Remain inoperative for faults outside its zone of operation
- Speed: Act as fast as possible
- Security: Provide back-up and assurance that it will not operate when there is no fault

8

5. CONFIGURATION OF PROTECTION RELAY SYSTEM

1

CONFIGURATION OF PROTECTION SYSTEMS

PURPOSE:

The purpose of a protection system is to detect a fault on the power system and then instruct the appropriate circuit breaker to trip and isolate the faulty item of plant. This process must be accomplished as fast as possible.

2

CONFIGURATION OF PROTECTION SYSTEMS

- **Protection System**

  A number of devices working together to detect faults in the power system and instructing the appropriate CB to trip and isolate the faulty item of plant.

3

CONFIGURATION OF PROTECTION SYSTEMS

- **COMPONENTS**:
- **Transducers** – CTs and VTs
- **Relays** – Detect faults in the system
- **Circuit Breakers** – Do the actual job of interrupting the flow of current to the fault.

4

CONFIGURATION OF PROTECTION SYSTEMS

- **RELAYS**

  Devices that use currents, voltages and other inputs to determine if a fault exists in the system.

  RELAY TYPES:

  - Overcurrent /Earth Fault
  - Differential
  - Distance
  - Over-voltage
  - Under-voltage

5

CONFIGURATION OF PROTECTION SYSTEMS

- **RELAYS** *cont.*

  RELAY GENERATIONS:

  There are 3 generations of relays:

  - Electromechanical
  - Static
  - Numerical

  All relays are made up of 3 main modules. These are input, decision and output modules.

6

CONFIGURATION OF PROTECTION SYSTEMS

- **RELAYS** *cont.*

  Input module: This module performs two functions.

  - Receives input from the electrical system mainly in the form of currents and voltages.
  - Receives and stores relay settings. This function is achieved by the use of taps and dials in electromechanical relays, selector switches in static relays and push buttons and communication ports in numerical relays.

7

CONFIGURATION OF PROTECTION SYSTEMS

- **RELAYS** *cont.*

  - **Decision module:** This module monitors the input data provided by the relay settings and the system data provided by the currents and voltages and makes a decision. When the system data exceeds the threshold determined by the relay settings, a trip decision is made.

    In electromechanical relays, the decision module consists of disks that work by induction, solenoids, plungers etc.

    In static relays, the comparison is done by the use of solid state electronic devices such as diodes, capacitors and resistors.

    In numerical relays, microprocessors are used.

8

CONFIGURATION OF PROTECTION SYSTEMS

- **RELAYS** *cont.*
- **Output module:** Any trip decision made by the decision module is communicated to the output module. The output module then functions to operate a circuit breaker to isolate the faulty system component.

  This module also functions to send the fault information to local and remote points in the form of visible and audible alarms.

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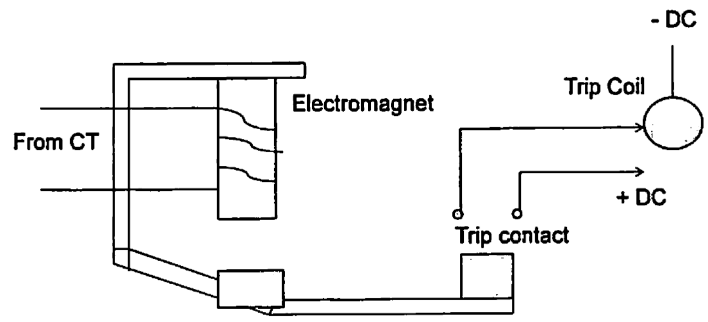
CONFIGURATION OF PROTECTION SYSTEMS

- **OVERCURRENT RELAY**



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CONFIGURATION OF PROTECTION SYSTEMS

FAIL-SAFE SYSTEM

- A protection system is configured as a fail-safe system when a trip decision is based on two separate output decisions.
- It is a dual serial system designed to prevent mal-operation of protection systems.
- It comprises of either a fault detection module and a trip decision module or two trip modules connected in series.

11

CONFIGURATION OF PROTECTION SYSTEMS

BLIND SPOTS

- Protection zones of operation are determined by the position of current transformers.
- The region behind the CT is called its blind spot.
- A fault in the blind spot of a CT falls out of its zone of protection and cannot be detected by it.
- Blind spots can be eliminated by positioning CTs behind its circuit breaker.
- Where blind spots exist, faults in it can only be cleared by backup protection.

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6. TYPES OF PROTECTION SYSTEMS

1

TYPES OF PROTECTION SYSTEMS

OBJECTIVE :

The main objective of any protection relaying system is to ensure the integrity of the power system and preserve the system from **damage or collapse.**

2

TYPES OF PROTECTION SYSTEMS

This main objective is achieved through the use of:

- Fault clearance systems
- Prevention of fault cascading
- Auto-reclosing

3

TYPES OF PROTECTION SYSTEMS

FAULT CLEARANCE:

- Every protection zone has a main protective relay assigned the primary role of responding to faults in the zone.
- Another relay is assigned a backup role in case of failure of the main relay.
- The backup role could also be provided by another function in the same relay.
- As a rule, every protection relay has at least one backup protection.

4

TYPES OF PROTECTION SYSTEMS

PREVENTION OF FAULT CASCADING:

- Clearance of power system faults may result in instability of the system due to the following:
- - Loss of synchronism
- - Over/under frequency
- - Over/under voltage
- - Overloading of system equipment

5

TYPES OF PROTECTION SYSTEMS

PREVENTION OF FAULT CASCADING:

Fault cascading is prevented by the use of:

- Power swing blocking systems
- Automatic frequency load shedding (AFLS)

6

TYPES OF PROTECTION SYSTEMS

AUTO-RECLOSING:

- The purpose of auto-reclosing is to quickly restore faulted overhead lines back into service to ensure system stability.
- Protection relays are made to issue close commands to circuit breakers after fault trip operations.
- The dead time is made as small as possible to minimize the outage duration.
- Where single pole tripping is possible, single pole auto-reclosing is done.

7

TYPES OF PROTECTION SYSTEMS

OPERATING TIME CHARACTERISTICS

- Inverse time: Shorter time delays for higher currents.
- Definite time: Fixed time delay for all magnitudes of fault currents.
- Instantaneous: No time delay for certain level of fault current.

8

TYPES OF PROTECTION SYSTEMS

ANSI PROTECTION DEVICE NUMBERS

- INSTANTANEOUS OVERCURRENT – 50
- TIME DELAY OVERCURRENT – 51
- INSTANTANEOUS EARTH FAULT – 50N
- TIME DELAY EARTH FAULT – 51N
- DIRECTIONAL OVERCURRENT – 64
- DIRECTIONAL EARTH FAULT – 64N
- DISTANCE PROTECTION – 21
- DIFFERENTIAL PROTECTION – 87
- **CIRCUIT BREAKER - 52**

9

TYPES OF PROTECTION SYSTEMS

OVERCURRENT PROTECTION

- The most widely used protection system.
- Applicable in generation, transmission and distribution.
- Simple, cheap and easy to use.
- Does not require a voltage input.
- Difficult to coordinate in interconnected ring networks.
- Useful as a backup for other forms of protection.

10

TYPES OF PROTECTION SYSTEMS

OVERCURRENT PROTECTION

- Overcurrent protection devices protect power system equipment against **excess current.**
- An overcurrent condition occurs when the current in amperes is greater than the rated current carrying capacity of the equipment as a result of **over-loading** or **faults**.

11

TYPES OF PROTECTION SYSTEMS

DIRECTIONAL PROTECTION

- A tool to determine direction of faults in interconnected networks.
- Uses the phase angle between voltage and current to determine direction of fault.
- Requires voltage input from a VT to operate.
- Types include directional overcurrent and directional earth fault.
- More expensive than non-directional overcurrent

12

TYPES OF PROTECTION SYSTEMS

DISTANCE (IMPEDANCE) PROTECTION

- Used for the protection of transmission lines and interconnected sub-transmission networks.
- Uses the impedance of the protected line to determine whether a fault exist on the line or not.
- The relay compares the fault impedance to the impedance of the protected zone of the line and trips when the fault is in the protected zone.
- Availability of communication between relays at both ends of the line improves reliability.
- Requires inputs from CTs and VTs and is directional by nature.

13

TYPES OF PROTECTION SYSTEMS

DIFFERENTIAL PROTECTION

- It is a unit protection for generators, transformers, lines, buses, etc.
- The zone is determined by the location of the current transformers.
- It operates by summing currents from the CTs. A zero sum means no fault in protected zone and a differential current means fault in protected zone.
- It operates without any time delay as delays could result in catastrophic damage to the unit.

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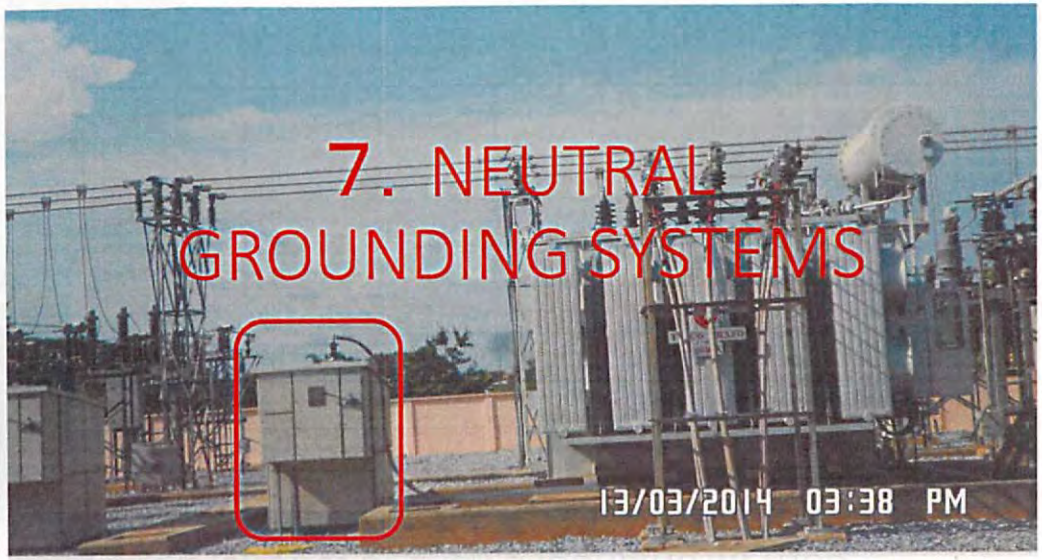


OVERVIEW

- INTRODUCTION
- OBJECTIVES OF NEUTRAL GROUNDING
- CLASSIFICATIONS OF NEUTRAL GROUNDING
- CHARACTERISTICS OF EACH GROUNDING METHOD
- FAULT TYPE AND VECTOR DIAGRAMS
- VOLTAGE PROFILE UNDER FAULT CONDITIONS
- NEUTRAL GROUNDING SYSTEM AND WAVEFORMS
- SYSTEM GROUNDING IN ECG – CASE STUDIES

INTRODUCTION

- Most of the faults in the power network are earth faults
- Users of electricity should not be exposed to hazardous voltages
- Power supplied to consumers should be safe
- Staff and public should be safe when they are around electrical installations.

SYSTEM GROUNDING

- Intentionally connecting the network to ground directly or through an impedance.

OBJECTIVES OF NEUTRAL GROUNDING

- to minimize potential transient over voltages
- personnel safety requirements
- detection and isolation of fault
- reduce the inductive interference to the communication wires.

CLASSIFICATIONS OF NEUTRAL GROUNDING

- Ungrounded system
  - For relatively low-voltage, small-scale power systems
  - single line ground fault often becomes extinct
  - Earth fault current is small or insignificant
- Impedance/Resistance grounded system
  - System is grounded through a resistor, reactor or earthing transformer
  - Earth fault currents are significant and so detection by protection relays is improved.
  - Earth fault currents are limited to several hundred amperes
- Solidly grounded system
  - System is connected directly to ground without any intentional impedance connected
  - Sensitivity of protection relays is high
  - Earth fault current is several thousand amperes

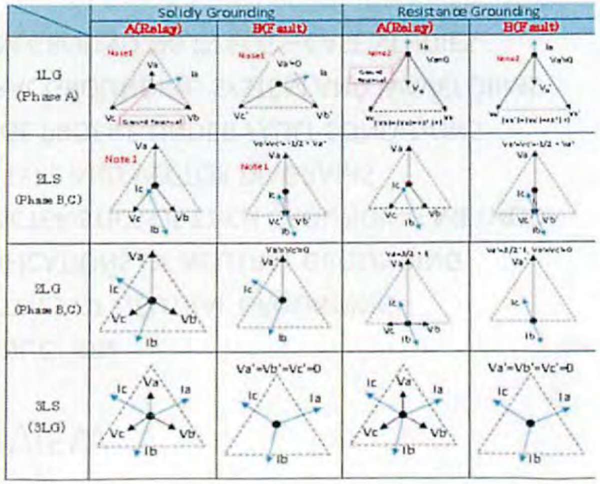
Neutral Grounding Resistor

Earthing transformer

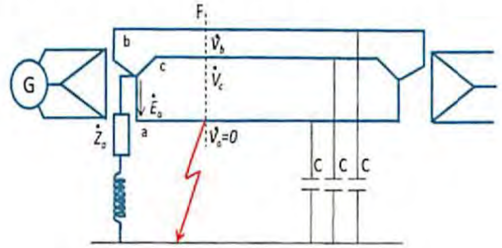
CHARACTERISTICS OF EACH GROUNDING METHOD

	Item \ Grounding system	Solidly grounded system	Resistance grounded system	Ungrounded system
Influences of single line ground fault	Sound phase voltage (see section 3.3)	Does not rise	Rises to the value of voltage between lines	Rises to the value of voltage between lines
	Line Voltage (see section 3.3)	Drops	No change	No change
	Possibility of abnormal voltage ※2	Minimum	Low	Yes (The sound phase voltage could rise up to about 2.7 times the phase voltage)
	Ground fault current	Very high(MAX)	Ground fault current is set based on the neutral point resistance value	Low
	Relay sensitivity	Most sensitive (Easy to detect and selectively locate faults)	No problem if the charging current to ground is up to about the NGR capacity	Least sensitive
	Telecommunication lines induction	High	Low	Almost none
	Whether outage takes place	Yes (However, influences are minimized by using high-speed, single-phase reclosing)	Yes	Yes
	Influences to customers	Medium	Yes if the power is supplied via the fault transmission line	Medium
Application examples in Ghana	Applicable voltage grade	330kV, 225kV, 161kV, 69kV, 433V(low voltage)	33kV, 11kV	None
	Applicable relay system	Pilot relay system Directional distance relay system	Directional distance relay system Ground fault over-current relay system	–

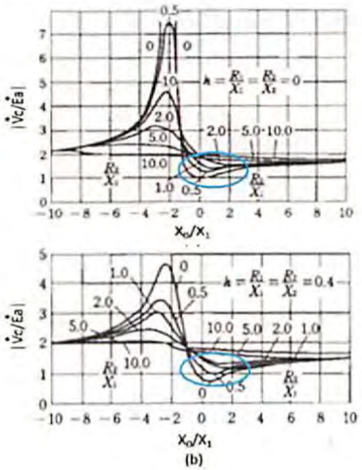
FAULT TYPE AND VECTOR DIAGRAMS



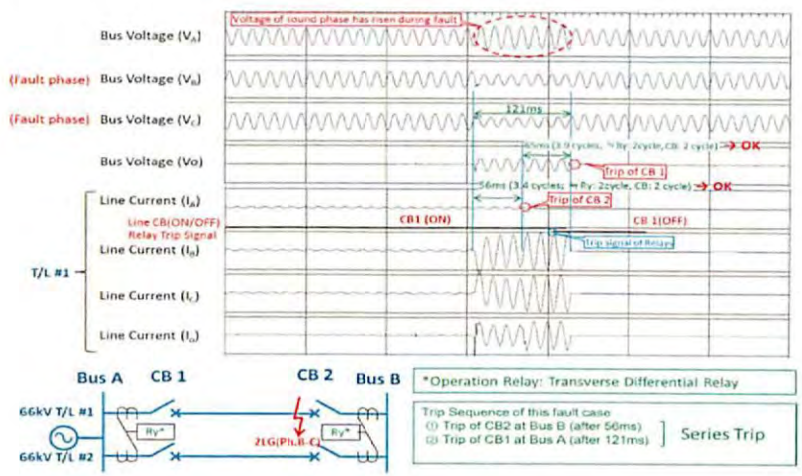
VOLTAGE PROFILE UNDER FAULT CONDITIONS



Voltage rise on healthy phase during single phase fault is limited to 1.3xPh-G voltage or 75% line voltage. Such systems are effectively grounded and fulfill $R0 \leq X1,\ X0 \leq 3X1$



NEUTRAL GROUNDING SYSTEM AND WAVEFORMS



CAUTION

- It the system is to be grounded, then the grounding should be good (preferably 1 ohm or better)
- Failure to ensure this will make the network behave as having a different type of grounding (high impedance grounding or isolated system) with its unintended implications such as:
  - Increased voltage rise under fault conditions
  - Diminished earth fault currents which make detection difficult
  - Uncoordinated tripping of circuit breakers

SYSTEM GROUNDING IN ECG – CASE STUDIES

- Kumasi "F"
- Nkawkaw
- Tema "H"
- Distribution transformer

KUMASI “F”

- System description
  - Station has 2x20/26MVA transformers
  - Transformers are Dyn1
  - Star point of the transformers are grounded through neutral ground resistors NGR (6.35ohm, 1000A for 30s)
- Phenomenon
  - 11kV feeders were not tripping for earth faults but when they trip, two feeders get tripped
- Problem
  - NGR grounding points were floating (not grounded)
- Solution
  - NGR grounding points were grounded

NKAWKAW

- System description
  - Station has 33/11kV, 10/13MVA transformer
  - Transformers are Dyn1
  - Earthing transformer is installed on the 33kV bus (XXohm, XXA for XXs)
- Phenomenon
  - Earth faults in the 33kV network is accompanied by flashovers in control wiring
- Problem
  - Earthing transformer earthing conductor is bonded to station transformer earthing and connected to earth electrode of resistance 70ohms
- Solution
  - Earthing transformer earthing and distribution transformer earthing were separated and earth electrode resistance was improved to less than 5ohms.

TEMA “H”

- Earthing transformers

DISTRIBUTION TRANSFORMERS

- Solid grounding

OUTLINE

- Objectives
- Introduction
- Transformer design
- Types of transformer protection
- Examples in ECG

OBJECTIVES

- To provide basic understanding of how electrical and mechanical protection are applied to protect power transformers

INTRODUCTION

Power transformer:

Transforms electric power from one voltage level to another for transmission or distribution

- It transforms power to facilitate transmission or distribution
- A 20/26MVA transformer costs around $600,000.00
- It takes about 18 weeks from order to delivery
- It costs around GhC 18,000.00 to install
- It takes 14 days to install

TRANSFORMER CONSTRUCTION

- Causes of transformer failures
  - Short circuit between windings (turn-to-turn, inter-turn)
  - Ground faults (winding-core, winding-tank)
  - Insulation failure between HV and LV windings
  - Breaking of windings
- The above causes of failures may be the result of
  - Insulation contamination
  - Excessive temperature
  - Electrodynamic forces
  - Voltage surges

TYPES OF TRANSFORMER PROTECTION

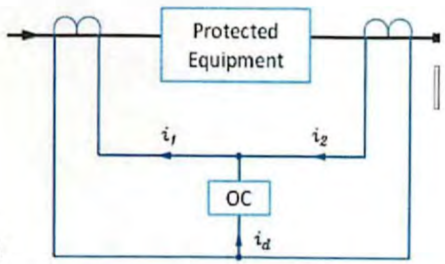
- Electrical protection
  - Differential protection
  - Overcurrent protection
  - Restricted earth fault protection
- Mechanical protection
  - Buchholz
  - Pressure relief
  - Temperature

ELECTRICAL PROTECTION

- Differential protection
- Overcurrent protection
- Restricted Earth Fault protection

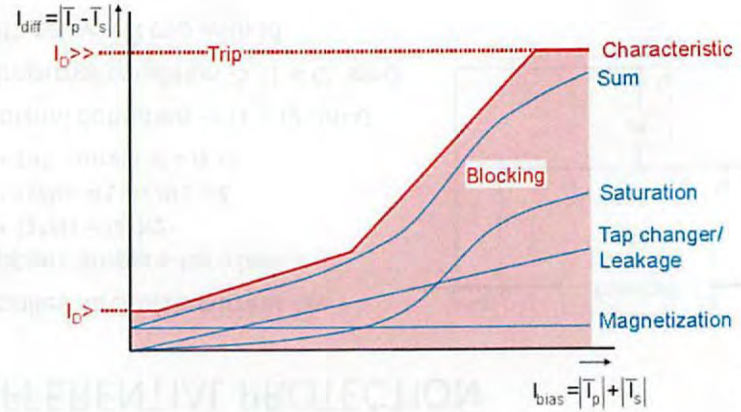
DIFFERENTIAL PROTECTION

- Applies Kirchoff's current law
- Applies ampere-turn law
  - I1*N1 = I2*N2
  - I1/N2 =i1 ; I2/N1 =i2
  - Diff. current id = i1-i2
- Normal condition -> i1 = i2, id=0
- Abnormal condition -> i1 ≠ i2, id>0
- Diff. relay will trip with id.



- The ff factors will affect stability of diff relays and may result in nuisance tripping:
  - CT mismatch
  - Transformer vector group
  - OLTC operation
  - Through faults
  - Magnetizing inrush (2nd harmonic current)
  - Over-excitation of transformer (5th harmonic current)
- These are resolved by
  - Vector group correction methods
  - Combining both restraint (i1+i2) and diff (i1-i1) current to produce operating characteristics of diff relays
  - Using 2nd harmonic and 5th harmonic filters

Operating characteristic



- Differential protection covers the zone between CTs
- Is reliable for detecting internal short circuits

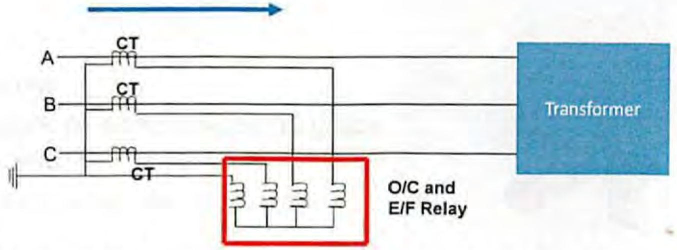
- Harmonic xtic
- Harmonic block diagram

OVERCURRENT PROTECTION

- It used as a back up protection
- In ECG is used as back up protection for 10MVA transformers or higher
- Is used as main protection for 5MVA and lower

CTs and Relay Connection

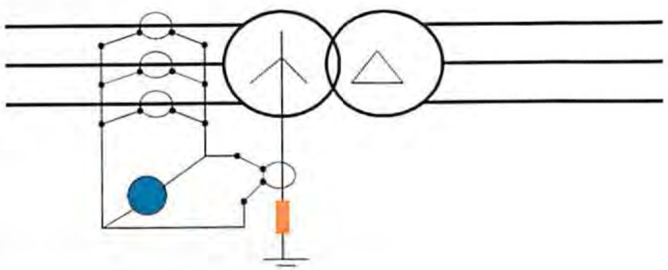
Diagram



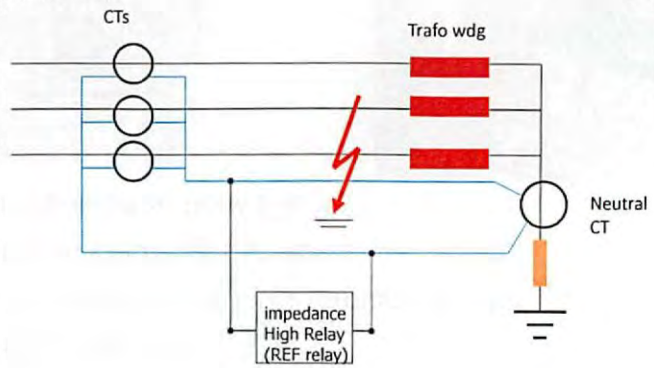
The relay measures the current from the CT. If the current exceeds the present threshold ($I_{s>}$, $I_{os>}$) a timer will time out (depending on the timing characteristics) and issue a trip signal to the breaker of the relay.

RESTRICTED EARTH FAULT PROTECTION

This is a unit protection scheme used to provide adequate protection for star winding earth faults with an Impedance earthed neutral.



Fault scenario

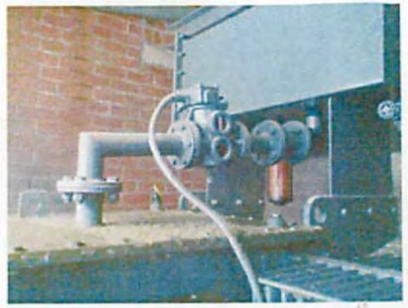


MECHANICAL PROTECTION

- Buchholz
- Pressure relief
- Explosion vent
- Temperature

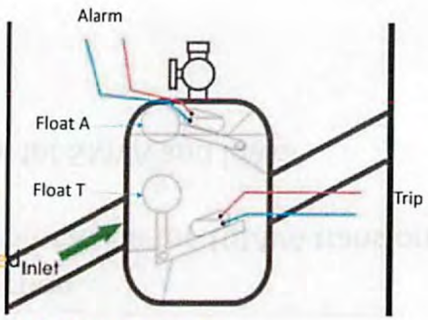
BUCHHOLZ RELAY

- Protects the transformer from damage due to
- Minor internal failure-gas build up
- Major failure-sudden flow of oil



BUCHHOLZ

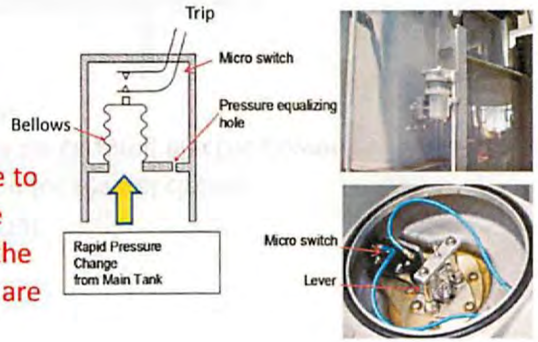
- Normal conditions:
  - Device is filled with oil
  - Both switches are open
- During minor faults:
  - Some oil decompose into gas
  - The is collected in buchholz
  - Float A falls and alarm activated
- During major faults
  - Sudden pressure causes rush of oil into conservator
  - Float T is pushed and trip circuit is activated to trip trafo CBs



PRESSURE RELIEF

- Functions:
  - It protects the transformer from high Internal pressure
  - This may be due to insulation failure inside the transformer

- Normal conditions
  - Pressure in main tank is consistent with specified
- Major fault condition
  - Rapid pressure increase due to Oil surge and/or gas release
  - Plunger shoots up to close the micro switch and trafo CBs are tripped.



9. PROTECTION SYSTEM FOR SUBSTATION

BUS PROTECTION SYSTEM

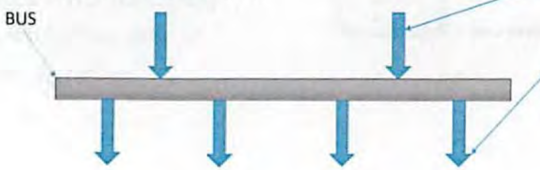
OUTLINE

- Introduction
- Importance of buses
- Bus configurations
- Characteristics of bus protection system
- Bus protection by bus configuration
- Measures against CT saturation

INTRODUCTION

- Busbar

Is an electrical conductor that
  - Makes common connection for several circuits
  - Serves as switching station for carrying electric power
  - Usually carries high current



IMPORTANCE OF BUSES

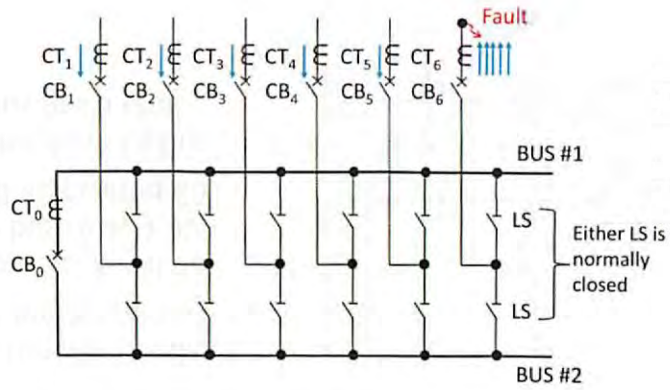
- Bus
  - Serves as switching station for transmitting electric power
  - Is the hub/connection point of several circuits
- Interruption to a bus due to fault implies:
  - Loss of supply to several feeders
  - Interruption of large fault currents
  - Voltage dips

BUS CONFIGURATIONS

- Double bus
- Breaker and half
- Main and transfer bus
- Single bus

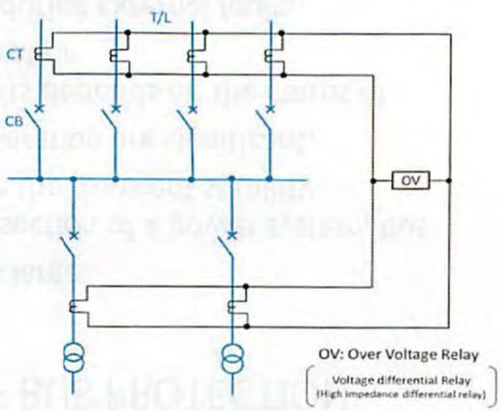
CHARACTERISTICS OF BUS PROTECTION SYSTEMS

- The number of terminals is large.
- With busses in the central section of a power system, bus faults significantly influence the transient stability
- Influences of erroneous operation are significant.
- CB to be tripped during faults depends on the status of switches in the bus configuration
- CT saturation often results during external faults.

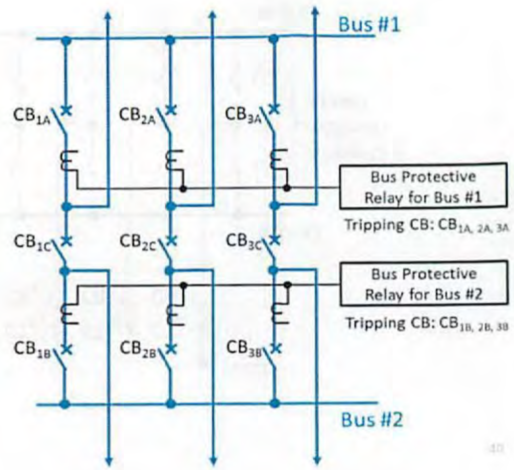


BUS PROTECTION BY BUS CONFIGURATION

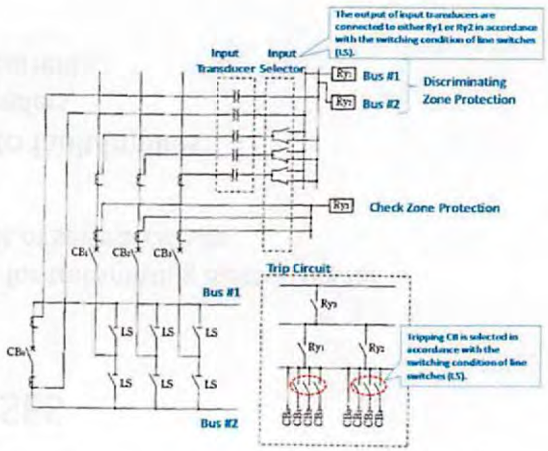
- Single Bus Protection by Voltage Differential Relay
- A fault on the bus will cause total current entering the bus differ from total current leaving the bus.
- Diff relay will trip associated circuit breakers



- Bus Protection for Breaker-and-a-Half Bus System
- Any fault on bus 1 will be cleared by bus relay 1 by opening all associated CBs
- Same will be done by bus relay 2 if bus has a fault



- Bus protection for double busbar
- The scheme shown has
- Discriminating zone protection
- Check zone protection



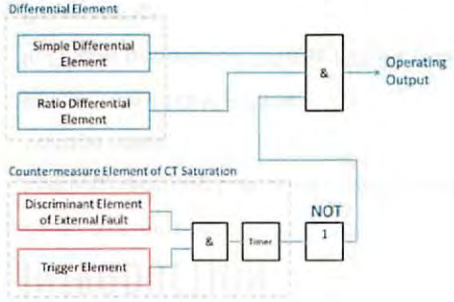
MEASURES AGAINST CT SATURATION

- CT saturation
- During saturation, CT's output does not replicate the input current

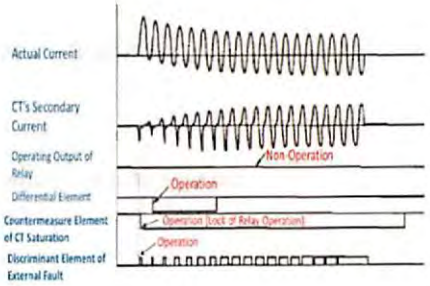
  In terms of transformed magnitude and wave shape
- This can cause differential relays to trip for faults outside the protection zone
- Countermeasures for CT saturation

Countermeasures for CT saturation

- Waveform discrimination method



Block diagram



Waveform

10. TRANSMISSION LINE PROTECTION SYSTEM

OBJECTIVE

Overview of transmission protection system

Outline of transmission protection system without signal transmission

Outline of transmission protection system with signal transmission

High speed reclosing

INTRODUCTION

Power transmission

Sending/receiving bulk power over long distances and high voltages

Voltage levels

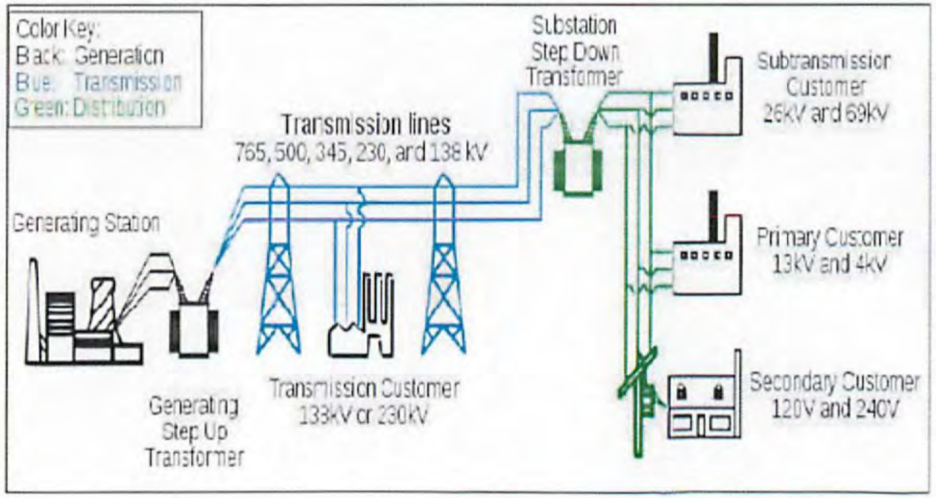
Range from 110kV – 750kV

In Ghana transmission voltage ranges from 69kV – 330kV

Power ratings

Distances of transmission range from tens to hundreds of km

Loosing a transmission line or delaying fault clearing could trigger system instability. Hence transmission protection is expected to operate very fast (from fraction of a cycle to a few cycles)



CATEGORIES OF PROTECTION SYSTEMS

Transmission line protection without signal transmission

Transmission line protection with signal transmission

High-speed reclosing system

TRANSMISSION LINE PROTECTION WITHOUT SIGNAL TRANSMISSION

Overcurrent relays

Directional Overcurrent relays

Distance relays

TRANSMISSION LINE PROTECTION WITH SIGNAL TRANSMISSION

This system requires communication between the relays at the ends of the line being protected. Communication may be via a pilot cable, power line carrier (PLC), microwave or optical fibre.

Such systems include:

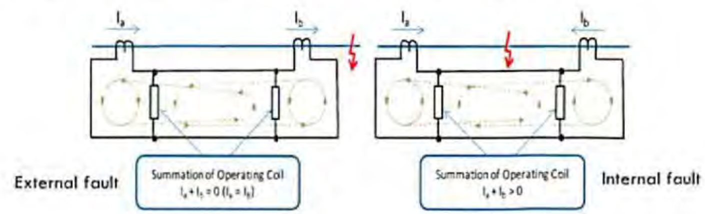
- Pilot wire protection system
- Current Differential
- Directional comparison
- Phase comparison

PILOT WIRE PROTECTION SYSTEM

First form of current differential protection for transmission lines and been in use since 1960s

Current measured at both ends of the line is superimposed on telecommunication lines and send to relays

Two types: current-circulation type and voltage-opposite type



CURRENT DIFFERENTIAL PROTECTION

This system uses optical fiber or microwave for communication instead of pilot wires

Current signals at each relay is converted to digital signal and transmitted

Signals received at each end are combined with local signals and analyzed. A trip is issued if difference current is above a preset value.

Two types: Frequency modulation and pulse code modulation

CURRENT DIFFERENTIAL PROTECTION

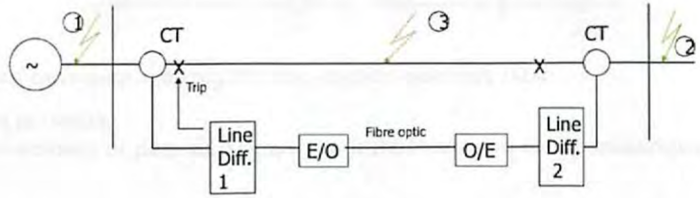


Fig 1.0

The relay will trip for fault (fault 3) in the protected zone but will not trip for faults outside the zone of protection (fault 1 and 2). Relay should remain stable for through faults.

SECOND SCENARIO

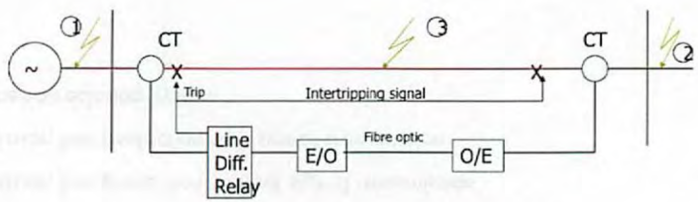
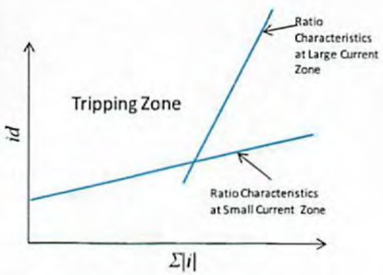


Fig 2.0

CHARACTERISTICS

Sources of error

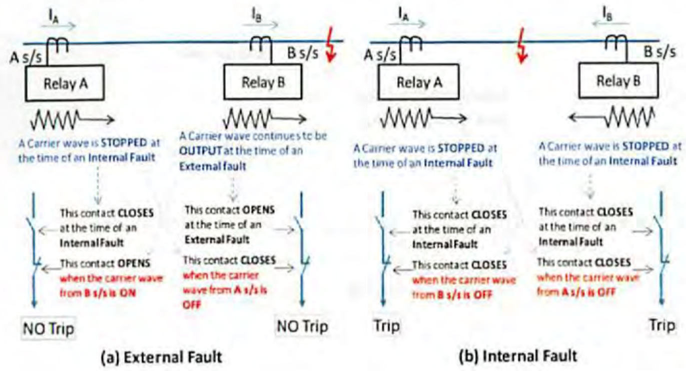
Fixed component errors	1. Internal charging current of transmission lines 2. Fixed component errors of relay unit
Proportionate component errors	1. Proportionate component errors of relay unit (part of analog input) 2. Errors of current transformers (CT) 3. Deviation in sampling synchronization and other communication system errors



$$|i_a + i_b| - k_1(|i_a| + |i_b|) > k_0$$

Id=Diff current   ∑ i=Diff current

DIRECTIONAL COMPARISON



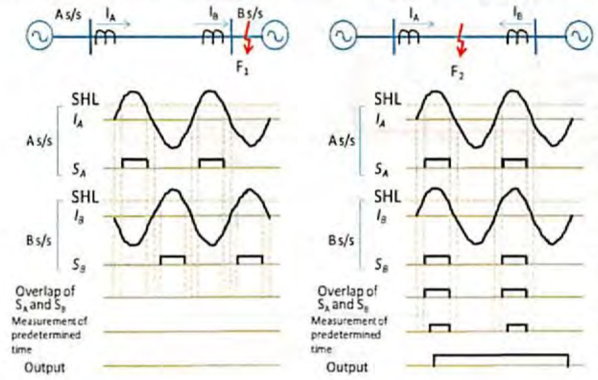
The protection relay system mutually compares operations of directional relays installed at electric power stations on both ends of a line.

During fault:

if both directional relays A and B see fault as internal then both relays send signals to permit tripping of circuit breakers A and B.

If relay A sees fault as internal but relay B sees fault as external, signal is sent to block tripping circuit breakers A and B.

PHASE COMPARISON



It compares the phases of currents at the respective ends of transmission lines utilizing transmission waves.

The currents IA and IB at opposite ends are in reverse-phase during external fault

IA and IB are in-phase at the time of internal fault.

square waves (SA, SB) of signal "1" are mutually transmitted current value is higher than a specified level

fault is judged as an internal fault and tripping is carried out when SA and SB overlap for the specified duration or more.

CATEGORIES OF PROTECTION SYSTEMS

Transmission line protection without signal transmission

Transmission line protection with signal transmission

High-speed reclosing system

11. OVERCURRENT AND EARTH FAULT PROTECTION

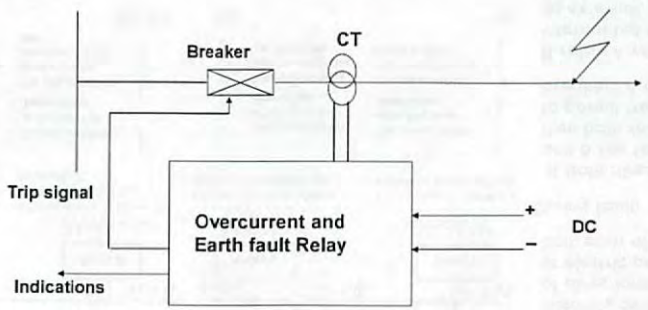
OVERCURRENT AND EARTH FAULT PROTECTION

Operation principle

- Measures the magnitude of current and issues trip command if:
- Current magnitude exceeds preset threshold
- Preset time delay has elapsed

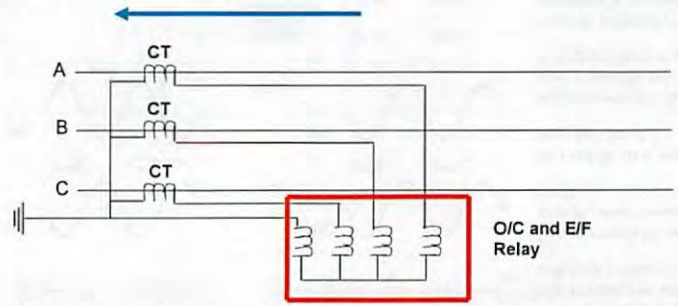
Overcurrent and earth fault relays are used for:

- Back-up protection for impedance protection or differential protection in transmission networks



Block diagram of overcurrent relay

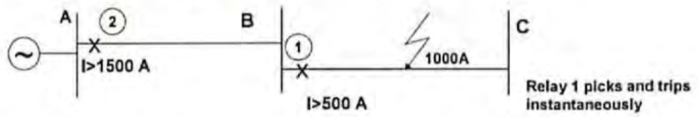
CTs and Relay Connection

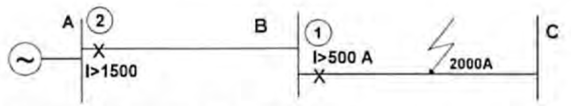


The relay measures the current from the CT. If the current exceeds the present threshold ($I_{s>}$, $I_{os>}$) a timer will time out (depending on the timing characteristics) and issue a trip signal to the breaker of the relay.

Discrimination methods

- Current Discrimination- Fault current varies in the position of the fault due to impedance between source and fault. The relay picks and trips instantaneously



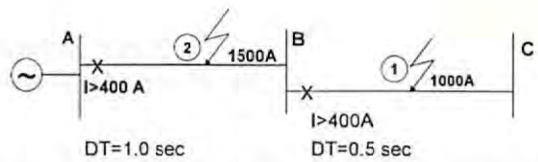


Relay 1 and 2 all pick and trip instantaneously.

Uncoordinated tripping are expected

Time Discrimination

Appropriate time delay is set on the relays protecting a power system. When the current threshold is exceeded,
the relay issues a trip signal to the breakers.



A very long-time will be used to clear fault section A-B

Discrimination By Both Time and Current

Here the relay operating time is inversely to the level of fault current and a function of both time and current.

The higher the fault, the quicker the operating time.

$$t_{trip} = \frac{ktd}{(\frac{If}{Is})^{\partial} - 1} \cdot I_m = (\frac{I_f}{I_s}) = \text{Current multiple and}$$

t_d = time dial, I_f = fault current, I_s = pick up or set current

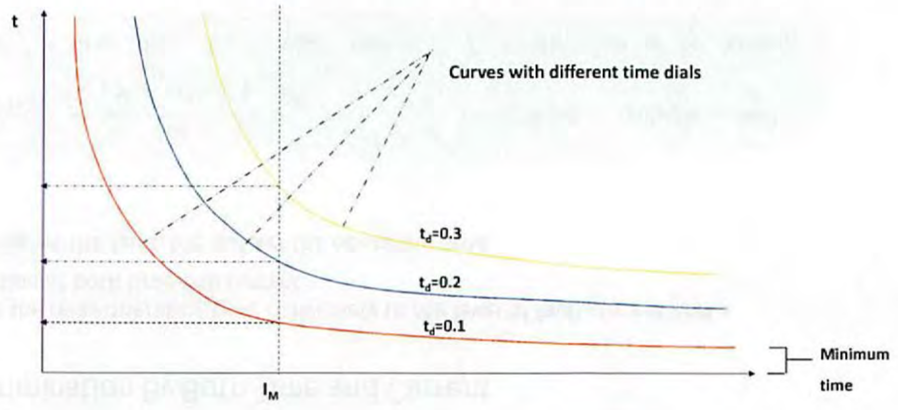
K, ∂ are constants associated with a particular characteristic of a curve.

IDMT refers to Inverse Definite Minimum Time.

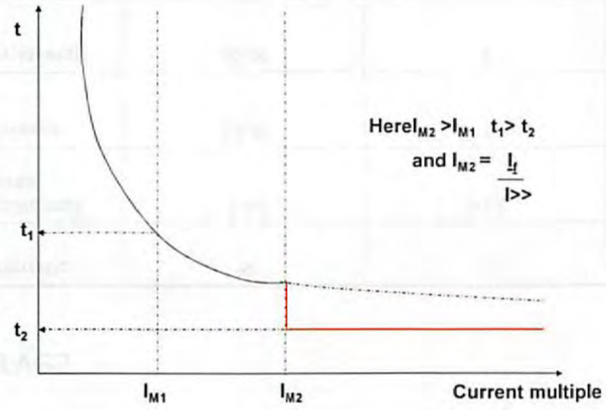
IEC Curves

Characteristic	*K*	*∂*	*Equation*
Standard/Normal Inverse	*0.14*	*0.02*	$\frac{0.14 \cdot t_d}{(I_M)^{0.02}-1}$
Very Inverse	*13.50*	*1*	$\frac{13.5 \cdot t_d}{(I_M)-1}$
Extremely Inverse	*80.00*	*2*	$\frac{80 \cdot t_d}{(I_M)^2-1}$
Long Time Inverse	*120.0*	*1*	$\frac{120 \cdot t_d}{(I_M)-1}$

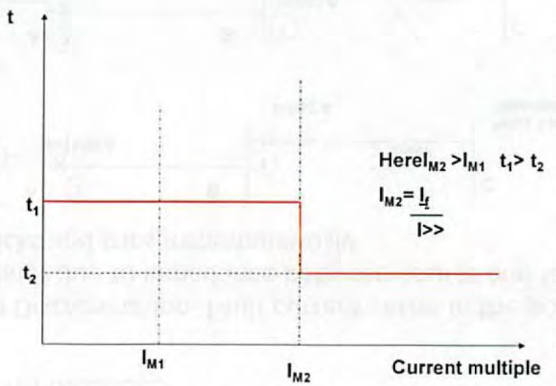
IDMT Curve (With No Instantaneous Setting)



IDMT Curve (With Instantaneous setting)

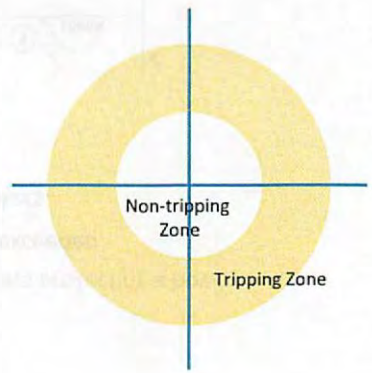


Definite Time Curve

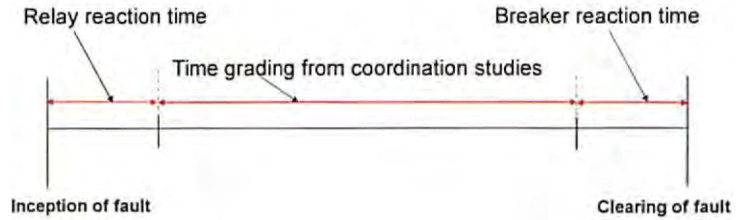


Properties of Overcurrent protection

- Overcurrent relays can not tell the direction of a fault
- Cheap
- Relatively slow reaction times
- Longer fault clearing times



Total operating time of a relay and CB



Note: Changing the Is or $I_>/I_{o>}$,t_d, curve type or network configuration (altering fault current) will cause uncoordinated trippings.

12. DIRECTIONAL OVERCURRENT AND EARTH FAULT PROTECTION

DIRECTIONAL OVERCURRENT AND EARTH FAULT RELAYS

They are similar to overcurrent relays but can detect direction of a fault.

Applicable for parallel/ mesh network with a single source

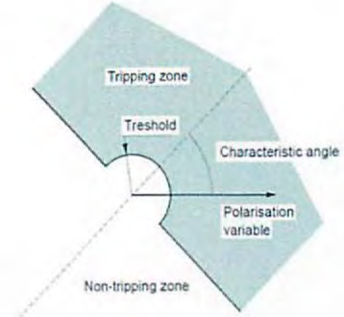
Here the current can flow towards the line or towards the busbar for certain power system configuration.

The directional control function is introduced using voltage input from VTs.

If a fault current falls within the operating area / trip zone the directional control will release the overcurrent element for operation.

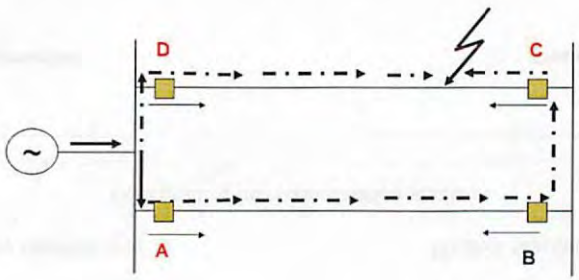
Various relay manufacturers have different methods of introducing the directional control function such as using faulted phase voltage, sound phase voltage etc. as polarizing voltage.

The maximum torque angle (MTA) is the angle of the operating current /fault current with respect to the polarizing voltage.

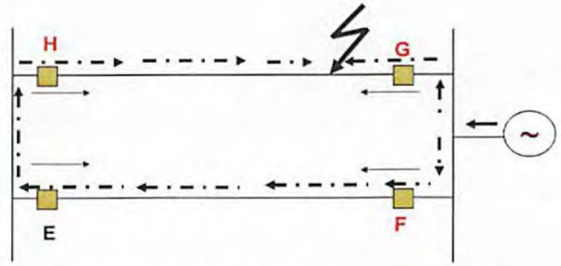


SCENARIO 1

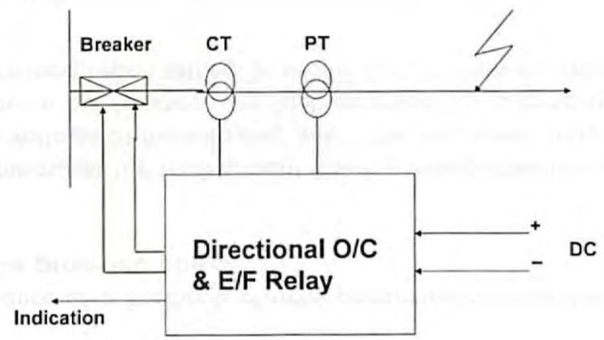
Relays at points A,C and D will trip and so they ought to be coordinated well . Relay B will not detect the fault current due to its directionality.



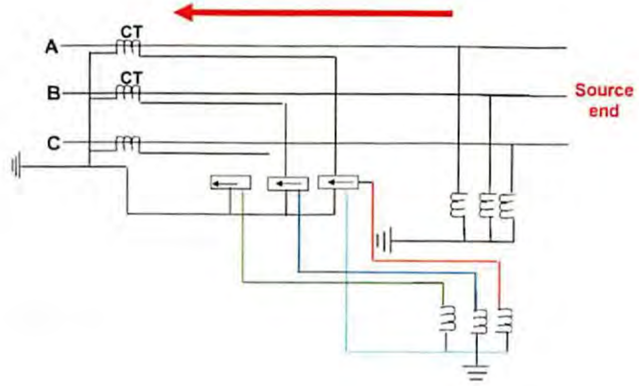
SCENARIO 2



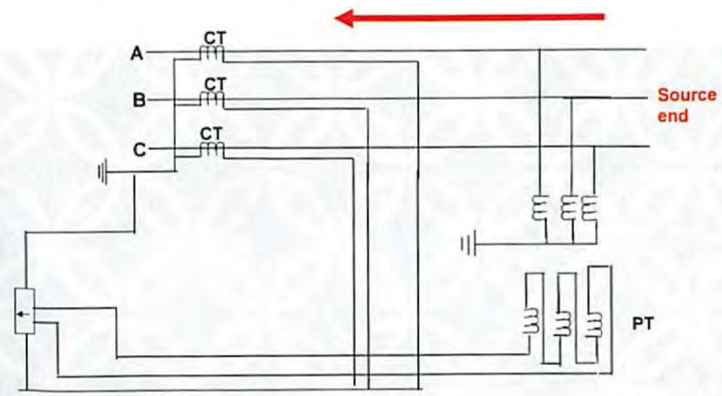
Relays F,G and H will trip but Relay E will not respond due to its directionality



TYPICAL CONFIGURATION FOR DIRECTIONAL O/C PROTECTION



TYPICAL CONFIGURATION FOR DIRECTIONAL EARTH FAULT



ADDITIONAL INFORMATION FOR DIRECTIONAL RELAY SETTING

Forward or reverse (angle for some relays) direction should be chosen depending on the staring point of the CTs.

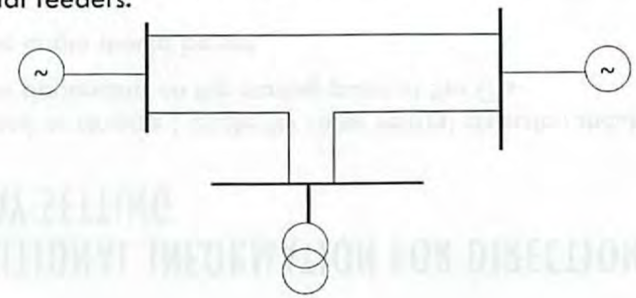
Torque angle should be set

1 3 . DISTANCE PROTECTION

DISTANCE PROTECTION

It is used mainly in multiple sources networks with mesh or parallel feeders.

It can also be used in single source network with parallel and radial feeders.



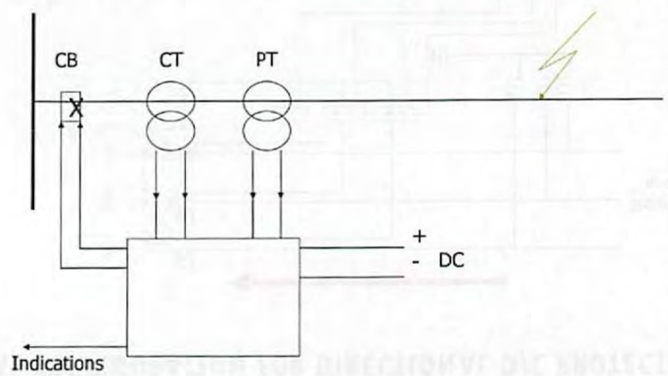
Distance relay is used in distance protection to determine the location or distance to a fault on a protected overhead line or cable.

The impedance of a feeder is directly proportional to the line length of the protected object.

The relay measures the fault current flowing through the line as well as the voltage at the relaying point. The measured impedance from the source bus to where the fault occurred (Z_f) is compared to a predetermined reach setting Zs and if $Z_f < Zs$, then the relay will trip.

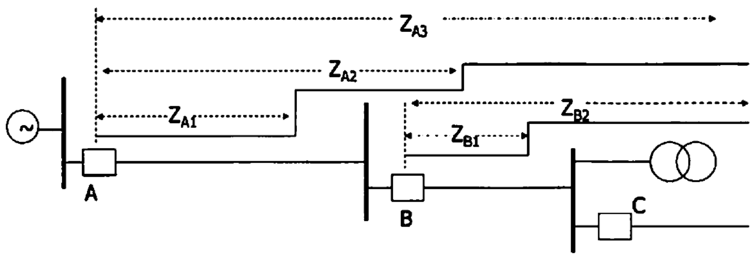
Note $Zs = V_s/I_s$ and $Z_f = V_f/I_f$ where $V_s > V_f$ and $I_f > I_s$

A typical distance scheme



PROTECTION ZONES

Correct coordination between different distance relays is achieved by using individual zonal reaches with the corresponding tripping times. There are at least two zones of protection. eg, zone 1, zone 2, zone 3 ,reverse zone.



Zone 1

This is usually set to protect about 80-85% of the line with <u>instantaneous tripping times.</u>

100% setting of the impedance of protected line is not appropriate since there could be CT or PT and construction parameter errors and this could cause the relay to be over reach (i.e tripping for fault on adjacent lines)

Zone 2

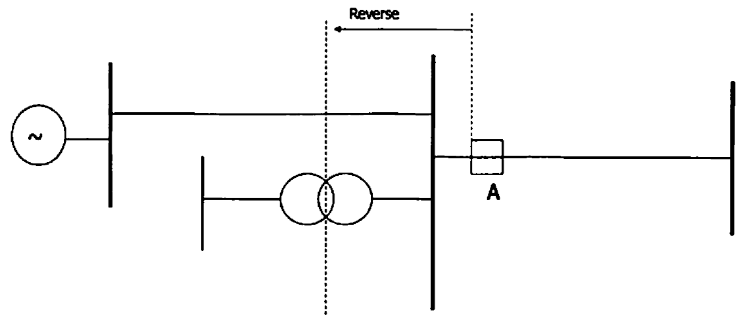
this is usually set to cover the remaining 20% of the first line and about 50% f the shortest adjacent line or is set to cover 120% of the first line (which ever is longer). The tripping time for zone 2 is typically between 0.4-0.5 seconds.

Zone 3

This is usually set to cover 100% of the first line and 120% of the adjacent shortest line but it should not see faults beyond any transformer at the remote end. The tripping time for zone 3 is at least 1.0 seconds.

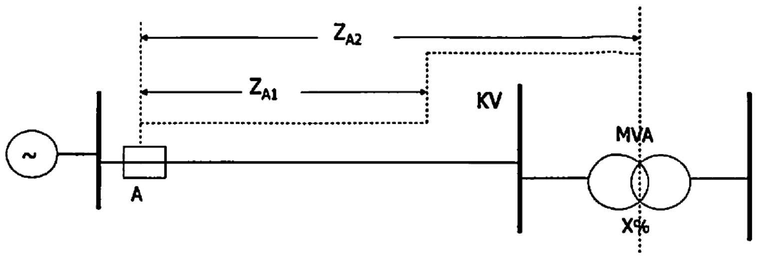
Reverse Zone

This is set to cover about 20% of the impedance in the reverse direction of the relay depending on its application (i.e for bus bar protection or transformer internal fault) protection.



Typical tripping times are instantaneous- 0.1 seconds

OTHER APPLICATIONS

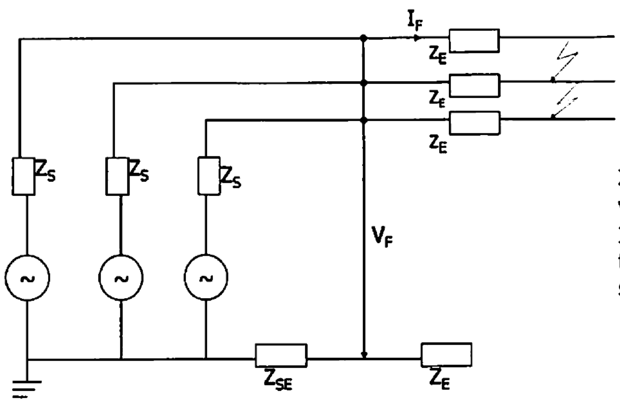


Here, Z_{A2} is used to protect the 100% of the line plus about 20% of the transformer impedance

Transformer impedance = $[(KV)^2 * X_t\%]/MVA_t$

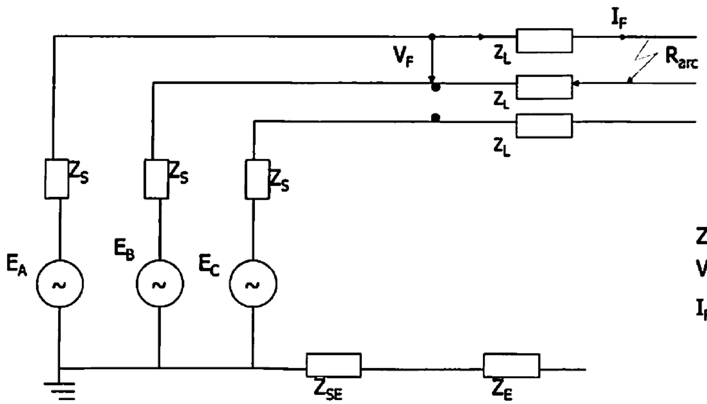
FAULT IMPEDANCE CALCULATION IN THREE PHASE SYSTEM

- Three phase balance fault



$Z_F = V_F/I_F$
V_F = L- N
I_F= current flowing towards the fault in that same phase

PHASE TO PHASE FAULTS.



$Z_F = V_F/2I_F$
V_F=Phase-phase voltage
I_F=fault current

PHASE TO EARTH FAULTS

The following must be considered when calculating the fault impedance for an earth fault.

-the voltage of the faulted phase will decrease

-fault current will only flow in the faulted phase

-the earth return impedance must be considered by using earth fault compensation factor to compensate for the difference between the earth return impedance and the phase impedance measured by the relay as:

$Ke = Z_E/Z_L = 1/3[(Z_O - Z_1)/Z_1]$

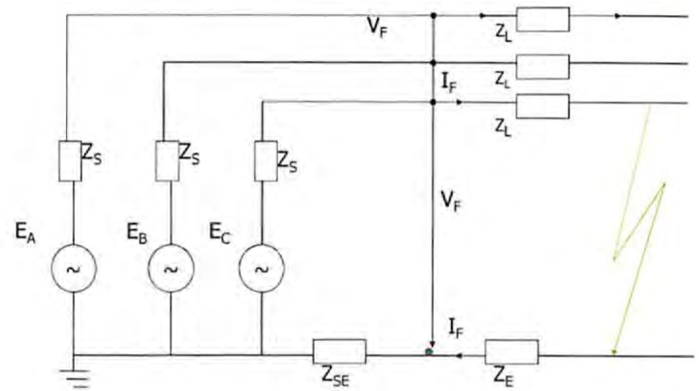
Z_E= earth impedance
(This data is obtained by measuring)

Z_L= Line impedance = $R_1 + jX_1$
(This data is obtained from the manufacturer)

Z_O= Zero sequence impedance = $R_0 + jX_0$
(This data is obtained by measuring)

Z_1= Positive sequence impedance.

$Z_F = V_F / [I_F * (1 + K_e)]$

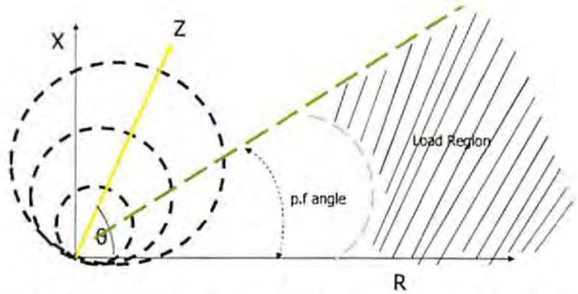


IMPEDANCE RELAY CHARACTERISTICS

Impedance relay measures the fault impedance and then determines if operation is repeated as defined by its R-X diagram.

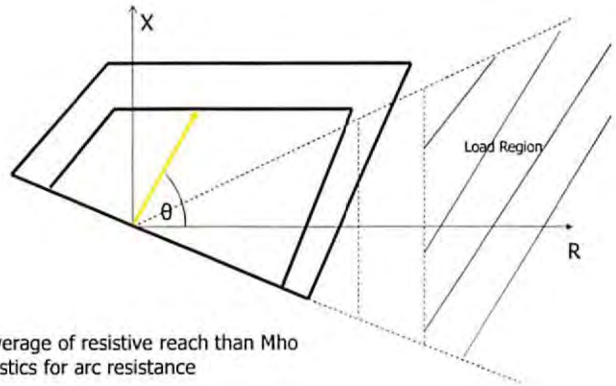
The boundaries of the R-X diagram can be repeated by different characteristics such as circular, mho, quadrilateral etc

MHO CHARACTERISTICS



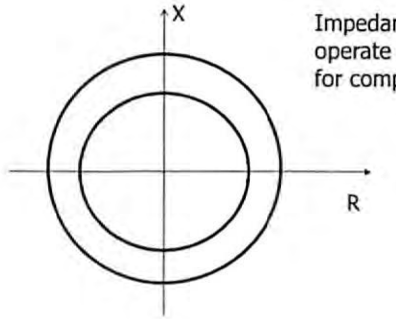
The impedance element is directional and will only operate for faults in forward direction

QUADRILATERAL CHARACTERISTICS

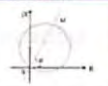
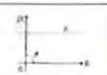
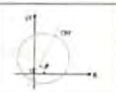
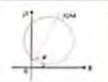
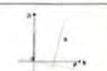
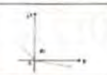


Better coverage of resistive reach than Mho characteristics for arc resistance

_CIRCULAR X'TIC



Impedance element in both directions can operate for faults in all directions but limited for compensating for arc resistances

Abbreviation	Name	Characteristic	Main Purpose
M	Mho		Zone 3 Directional Detection
X	Reactance		Zone 1,2
OM	Off-set Mho		Step Out Detection
FOM	Front Off-set Mho		Zone 4 (Remote Back up)
R	Ohm		Blinder
D	Directional		Directional Detection

θ Characteristic Angle, θ1, θ2 Operational Phase Angle

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CALCULATION OF LOAD REGION

Option 1

From basic ohms law, $S = (V)*(I) = \frac{(V) * (V)}{(Z)}$

▶ $S = \frac{(V)^2}{(Z)}$

Therefore, $Z_{min} = \frac{(V_{min})^2}{(S_{max})}$

Load Resistance $R_{min} = Z_{min} * \cos Ø$

Where Ø is the system power factor angle

CALCULATION OF LOAD REGION

Option 2

$$Z_{load/ph} = \frac{V_{ph\,(min)}}{I_{ph\,(max)}} = \frac{V_{L\text{-}L\,(min)}}{\sqrt{3} * I_{ph\,(max)}}$$

Load Resistance $R_{min} = Z_{min} * \cos Ø$

Where Ø is the system power factor angle

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RESISTIVE REACH/ ARC RESISTANCE (SC/PH)

R_{arc} (Ph-Ph Fault)= $(28700 * \text{Arc length})/(I_{min.sc}^{1.4} * 2)$

R_{arc} (Ph-Ph Fault)= $(28700 * \text{Arc length})/(I_{min.sc}^{1.4} * (1+K_e))$

The calculation depends on wind speed, air pressure, moisture infeed conditions.

In practice, a value= 2.5 x Zonal resistive reach is used.

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1 4 . RECLOSING

RECLOSING

- 80-90% of faults on overhead lines are transient
- Tripping a transmission line carrying bulk power can lead system instability
- Clearing the numerous transient faults very fast will lead to improved system reliability.
- Hence reclosing
- Reclosing is done at a high speed in many cases for overhead transmission lines.
- High-speed reclosing
  - enhances transient stability of electric power systems
  - High speed reclosing enhances automation of restoration work
  - Reduces outage duration.

- When a relay trips a CB due to a fault, a recloser closes the CB
- If fault is transient, opening the CB will extinguish the fault and closing the CB subsequently will restore supply.
- If fault persists, is tripped and left open.

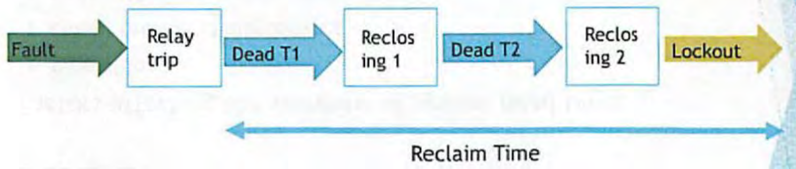
Reclosing Cycle

- **Dead time-** it is the time between the trip and reclosing.
- Factors affecting the selection of system dead time:
  - type of load
  - circuit breaker characteristics
  - fault path de-ionisation time.
  - system stability considerations.
  - protection reset time.

Reclaim Time:

- **Reclaim Time:** This is the time that if a fault condition clears midway through a sequence, the recloser times out before returning to the dormant mode.
- Factors affecting the setting of the reclaim time:
  - Number of shots
  - Relay operating characteristics (zone 1/ inst, zone 2 etc)
  - Circuit breaker limitations (ability to perform trip and close operations)
  - Statistical information on a particular network.

RECLOSING CYCLE



Reclosing schemes

- Pg 103

Reclosing system matrix

- Pg 104

15. DISTRIBUTION LINE PROTECTION SYSTEM FOR ECG PERSONNEL

Course Objectives

- Understand some basic distribution line short circuit and ground fault protection theory
- Understand Distribution Line protection coordination
- Understand distribution line protective relay functions and how to set them
- Appreciate Power System Fault Calculations

Content of Training

- Introduction to Power System Protection
- Outline of Distribution Line Protection System
- ✓ Typical Distribution Line Protection Schemes
- Concepts of faults and their effects on a network
- The role of Power System Protection
- Distribution System Grounding
- Relays and their functions
- Basic Distribution Line System protection schemes
- ✓ *Overcurrent and earth fault protection*
- ✓ *Negative sequence relaying protection*
- ✓ *Residual over voltage protection for ungrounded systems*
- ✓ *Auto-reclosers / relay reclosing functions*
- ✓ *Distance protection*

Introduction to Power System Protection

- Power System protection is the art and science of detecting problems with power system components and isolating these components
- Problems in the power includes:
- ➢ System faults (short circuits, grounds)
- ➢ Abnormal conditions
- ➢ Equipment failures
- Protective system consists of relays, associated communication systems, voltage and current sensing devices, CBs, station batteries and DC control circuitry

Outline of Distribution System

- Power distribution system comprises of:
- ❖ High Voltage distribution Feeders from primary substations
- ❖ High Voltage Customers
- ❖ Low Voltage distribution feeders from distribution transformers
- This course mainly discusses on protection of High Voltage distribution feeders
- The Electric Configuration widely adopted are:
- ❖ Three-phase, three lines systems or
- ❖ Three- phase, four lines systems
- ❖ Typical Voltages of 6.6kV, 11kV, 22kV, 33kV etc

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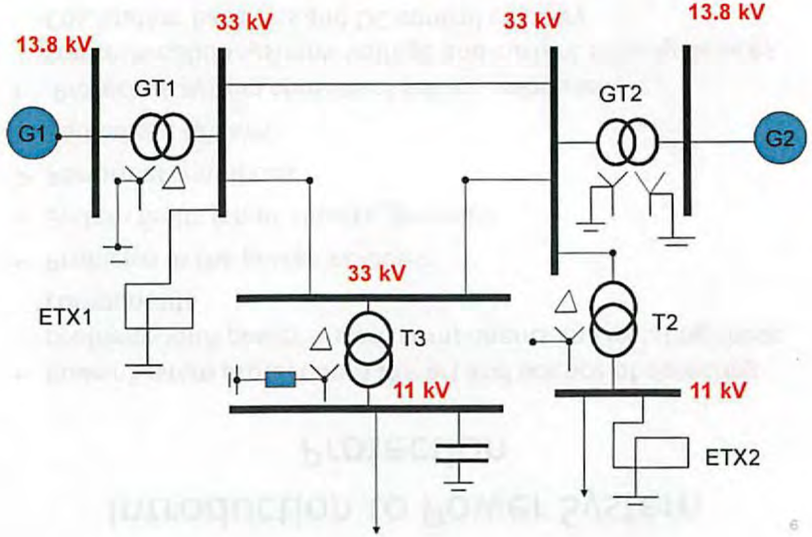
Typical Power System network



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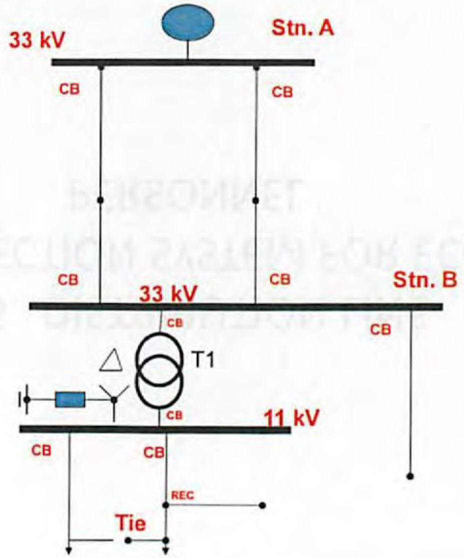
Typical Medium Voltage Distribution Network



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Typical Medium Voltage Distribution Line Protection Schemes

- ➢ Short-circuit protection:
  Overcurrent relays (50+51&79) , Distance relays
- ➢ Ground Fault protection:
  Earth fault (EF & 79)
  sensitive earth fault (SEF) and Distance relays
- ➢ Negative Sequence Relaying as Back-up for all Unbalanced faults
- ➢ Residual Overvoltage protection for Ungrounded systems
- ➢ Auto-reclosers and Sectionalizes

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Faults and their effects

- Short circuit faults result from breakdown of insulation between conductive parts which normally are at different potentials
- The magnitude of the fault current depends on the number of new generation sources in the system, the distance to these sources, fault resistance/arc resistance, and in the case of ground faults also on the neutral point treatment of the system (grounding methods)
- Fault magnitudes are estimated by the use of power system simulators and accurate network system parameters

Effect of faults on a system

- It will cause voltage and current disturbances, voltage collapse near fault locations
- The voltage gradients in the ground and across the earthing resistance create dangerous step and touch voltages near the fault
- The dynamic forces of the fault current, the electric arc at the fault location and thermal effects of current on the network elements in the current path all cause damage to plant equipment
- The voltage and current disturbances interrupt the transmission of power and thus also affect customers

Types of Faults

Faults can be broadly classified into two main areas namely:

➤ Active faults :-This is when actual current flows from one phase conductor to another (phase-phase) or alternatively from one phase conductor to earth (phase-to-earth).
This type of fault can further be classified into two areas namely the 'solid fault' and the 'incipient fault'.

❑ **Solid fault**:- It occurs as a result of an immediate complete breakdown of insulation (due to ageing, construction activities e.t.c) . This will result in a high fault current resulting in an electrical explosion.

❑ **Incipient fault**:- It starts as a small thing and gets developed into catastrophic failure (e.g. Corona discharge activity in a void in the insulation over an extended period can burn away adjacent insulation, eventually spreading further and developing into a solid fault. Other example is the pollution of insulators which can cause tracking across their surface. Once tracking occurs, any surrounding air will ionize which then behaves like a solid conductor consequently creating a Solid fault).

Types of Faults

➤ Passive faults :- They are not real faults but rather are conditions that stress the system beyond its system design capacity, so that ultimately active faults will occur.
Typical examples are as follows:

- ***Overloading*** leading to over heating of insulation (deteriorating quality, reduced life and ultimate failure).
- ***Overvoltage*** leading to stressing the insulation beyond its withstand capacities.
- ***Under frequency*** causing electrical plant to behave incorrectly.
- ***Power Swings*** leading to Generators going out-of-step or out-of-synchronism with each.

Transient and Permanent faults

- Transient faults:- Faults which do not damage the insulation permanently and allow the circuit to be safely re-energized after a short period. They occur mainly on outdoor equipment where air is the main insulating medium.

  Example is an insulation flashover following a lightning strike which would be cleared successfully by opening a circuit breaker , which could then be automatically closed.
- Permanent faults:- Faults which result in permanent damage to insulation. In this case, the equipment has to be repaired .

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The role of protection in distribution system

The fundamental role of protection are as follows:

- Detect faults
- Remove the faulty element from the power system
- Prevent damage to the power system and danger to personnel

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Requirement for achieving the above

- Reliability-To ensure operation of the protection system for all types of faults in all locations in the network. Back-up protection is provided by an upstream relay to ensure that the faulty element is removed from the system if the protection closest to the fault malfunctions
- Selectivity-To ensure that only the CBs necessary to isolate the fault are tripped, while all other CBs are unaffected. This is to minimise the number of customers that are affected by a fault. It is achieved by time grading, current grading, current/time grading, impedance grading, frequency grading (AFLS) & e.t.c
- Speed of Operation - High speed operation of the protection system is critical to the system stability, limiting the effects of a fault (damage to equipment by exceeding their thermal stress rating I^2t)

Typical fault clearing times (relay and CB reaction times) are in the area of (80- 150 ms) on transmission systems and may exceed 1s in distribution networks.

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Distribution System Grounding

Importance of grounding

- Improved ground fault detection
- It offers protection against temporary overvoltatages on healthy phases. Voltages on the healthy phases,

$$|V| = \sqrt{(0.866)^2 + [0.5 + \{\frac{(x_0/x_1)^{-1}}{(x_0/x_1)^2}\}^{-1}]^2}$$

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which can build up to 173% of the nominal phase voltage

- It improves public , employee and equipment safety

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Types of Grounding
(BSP grounding/Primary Station grounding)

- Earthing transformer earthing, Neutral Resistor Earthing and Solid Earth
- BSP Grounding

✓ It depends on the Bulk Supplier's transformer(s) vector groups

✓ For Star winding at HV side and Delta winding at LV side, earthing transformer is used to provide the grounding path for earth fault current

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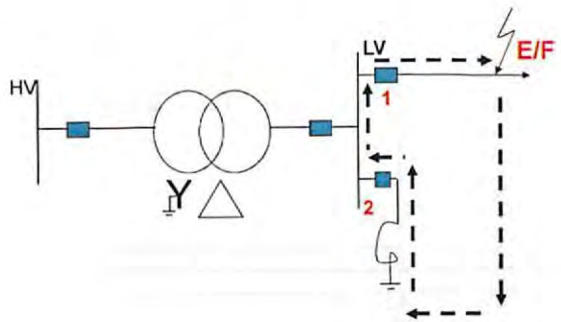
Arrangement 1



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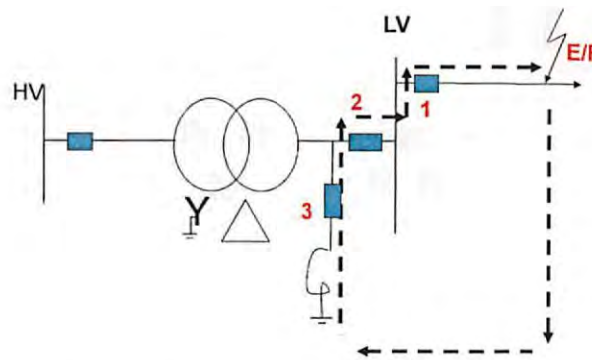
Arrangement 2



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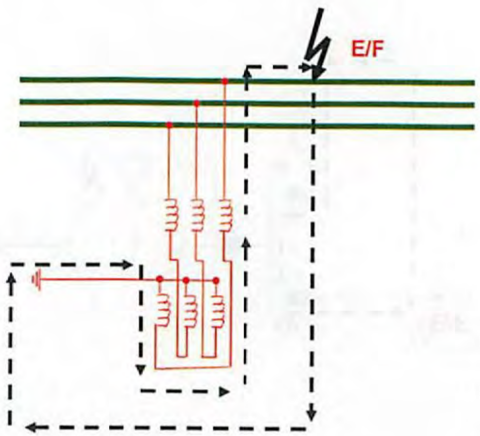
Earthing transformer windings



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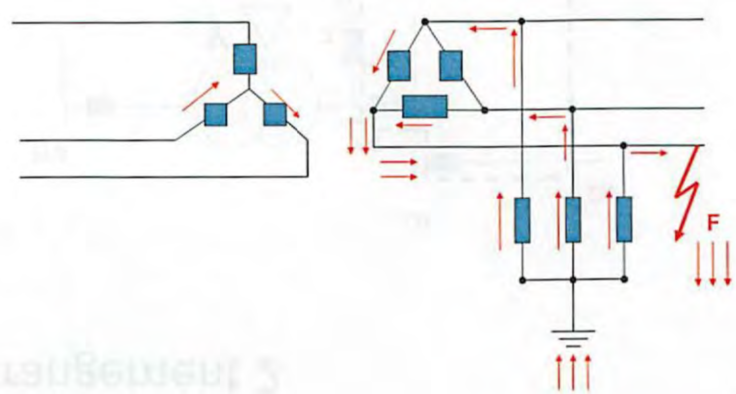
Earthing Transformer fault detection path



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Typical ECG'S SPECS

For 33kV

I_{ph}= 1060 A /phase for 10 sec

Z_0=19.4 Ω

For 11kV

I_{ph}=300A /phase for 10 sec

Z_0=21Ω

Thermal stress rating (I^2t) should be very high

*For star winding at HV side and star winding at LV side, no grounding is required at the distribution station's side

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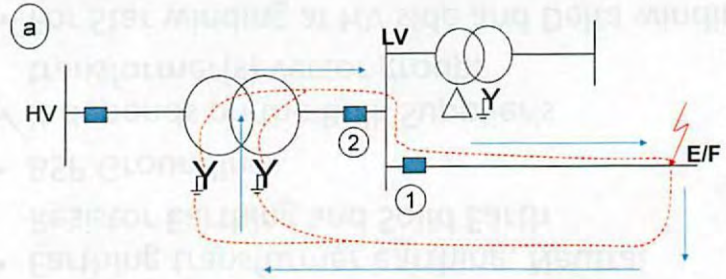
Scenario 1

Diagram



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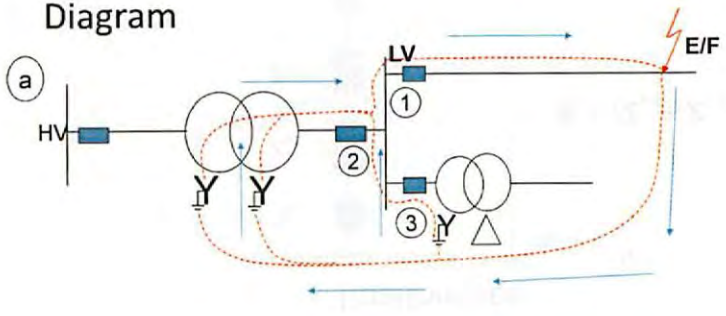
Scenario 2

Diagram



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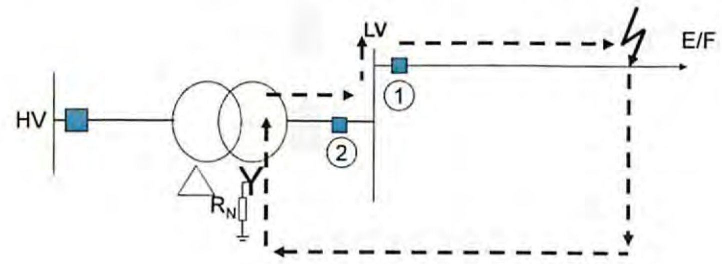
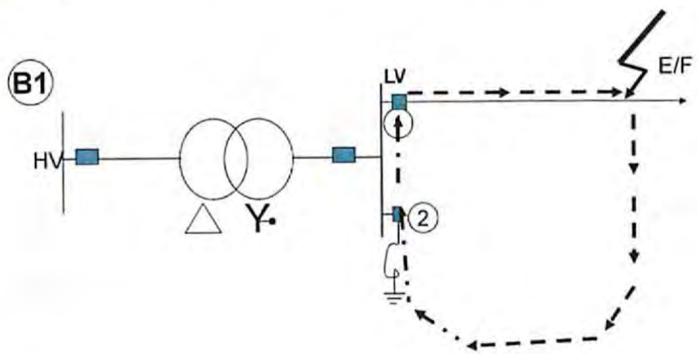
Neutral Resistor Grounding

a. Neutral Resistor Grounding (R_N=1000 A for 30 sec. R=6.35 Ω)



Earthing Transformer Grounding

Diagram



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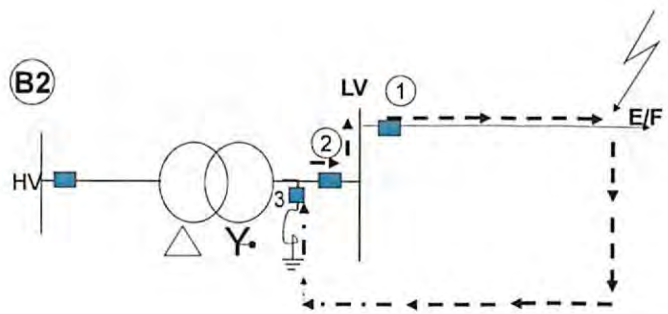
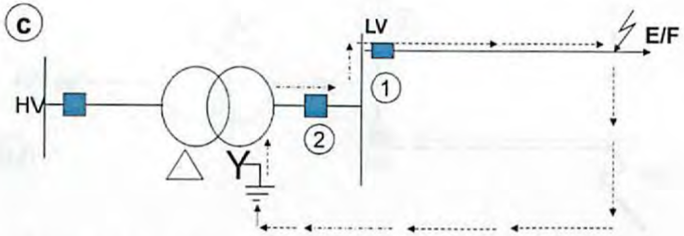
Earthing Transformer Grounding

Diagram



Solid grounding/earthing

Diagram



Note: In all the above scenarios, the earthing reactor /transformer relay is wired to trip the in-comer breaker.

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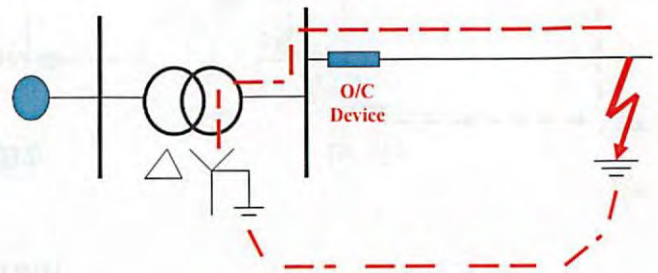
Earth fault analysis for a distribution system



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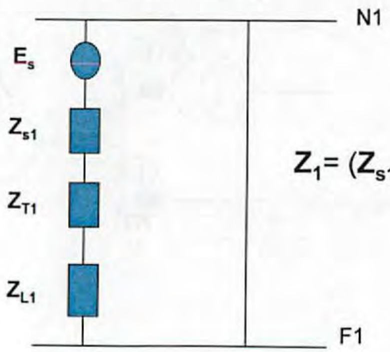
Sequence diagrams for earth fault calculation

Positive seq.



$$Z_1 = (Z_{s1} + Z_{T1} + Z_{L1})$$

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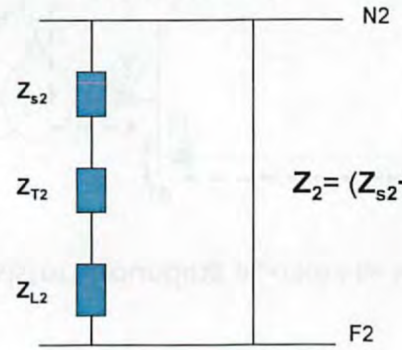
Sequence diagrams for earth fault calculation

Negative seq.

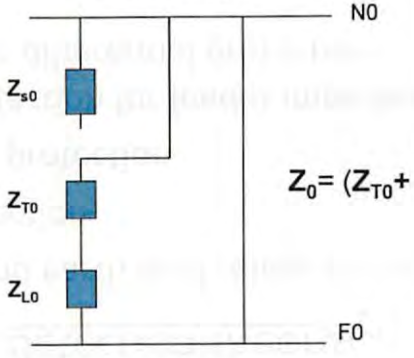


$$Z_2 = (Z_{s2} + Z_{T2} + Z_{L2})$$

32

Sequence diagrams for earth fault calculation

Zero seq.



$Z_0 = (Z_{T0} + Z_{L0})$

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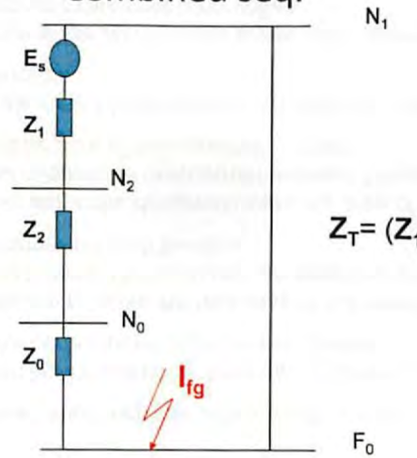
Sequence diagrams for earth fault calculation

Combined seq.



$Z_T = (Z_1 + Z_2 + Z_0)$

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Earth fault calculation

$$I_{fg} = \frac{3*V_{L-N}}{Z_1+Z_2+Z_0+3Z_F}$$

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From the equation above, I_{fg} depends on Z_E of the protected network

i.e

- **Fault impedance at the time of the fault (whether the conductor is lying on a rocky surface, on dry vegetation, on other surfaces)**
- **Substation grounding (whether the value is so high, grounding removed, etc)**
- **Arc resistance**

From these factors, it can be seen that earth fault detection is at times very difficult.

Relays and their functions

- Relays are devices, which monitor the conditions of an electrical system circuit and give instruction to CBs to open a circuit under unhealthy conditions.
- The basic parameters of a typical three- phase electrical system are: Voltage, current, frequency and power
- All these parameters have pre-determined values and /or sequence under healthy conditions
- Any shift from this normal behavior, could be the result of a fault condition either at the source or load end.
- Hence relays would have to detect the abnormal condition and send trip signal to CBs to isolate the faulted circuit or component.

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Types of Relays

By make

- ➢ Electromechanical
- ➢ Static (Analog & Digital)
- ➢ Numeric

By Function

- ➢ Overcurrent and Earth Fault relays
- ➢ Distance or Impedance relays
- ➢ Differential relays
- ➢ Auto-reclosing relays
- ➢ Frequency relays
- ➢ Over/Under voltage relays
- ➢ etc

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Overcurrent And Earth fault detection theory

Overcurrent and earth fault relays are used for:

✓Feeder protection

✓Transformer protection

✓Back-up protection for feeder impedance protection or differential protection

Please refer to

" 1 1 . OVERCURRENT AND EARTH FAULT PROTECTION"

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Theory of Directional Overcurrent & Earth fault relaying

➢*Applicable for parallel/ mesh network with a single source*

➢*Here the current can flow in both directions either towards the line or towards the busbar for certain power system configuration.*

➢*It is therefore necessary to make the response of the relay directional by introducing a directional control function with an additional voltage input from a voltage transformer on such feeders.*

➢*If a fault current falls within the designed operating area of the relay, the directional control will release the overcurrent element for operation. (*Relays are tested to be sure of their operating areas)*

➢*Various relay manufacturers have different methods of introducing the directional control function.*

➢*The maximum torque angle (MTA) is the angle of the operating current /fault current with respect to the polarizing voltage.*

Please refer to

" 1 2 . DIRECTIONAL OVERCURRENT AND EARTH FAULT PROTECTION"

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Some Factors to consider in setting Overcurrent and Earth Fault relays

- Type of conductor, Transformer or cable to be protected
- Conductor or cable current ampacity, Transformer rating
- Thermal stress rating of protected component (tI^2)
- Rating of power transformer or equipment to be protected
- Coordination between upstream and downstream relays
- Types of relays to be coordinated
- Imbalance in the system, in the case of Earth fault and negative sequence relay settings
- CT Ratio
- Relay setting format requirement (pu, secondary or primary)
- Type of power system neutral grounding for the case of E/F
- Relay manual

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Example

- Draw a typical distribution network and come out with coordination settings for at least two protection points.

Demonstration from Excel coordination software

Typical O/C & E/F Relay Settings

- Relay Type: P122
- CT Ratio : 400/5A
- I> = 420 A , 1.05pu (1.05In)
- Td = 0.1, Curve = SI
- I>> = 1200A , 3.0pu (3In)
- DT = 0.05 sec.
- Io> = 20 A, 0.05pu (0,05In)
- Td = 0.1, Curve = EI
- Io>> = 600A, 1.5 pu (1.5In)
- DT = 0.0 sec.

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Additional Information for directional relay setting

- Forward or reverse (angle for some relays) direction should be chosen depending on the staring point of the CTs.
- Torque angle should be set

Negative Sequence Relaying

- This scheme is used for the detection of all unbalanced faults in a network (i.e. phase-phase, phase-earth, double phase-earth faults) as this component of fault current appears in all unbalanced faults conditions in a network.
- It can be used as back-up protection for all unbalanced faults for feeders (broken conductors ,load unbalances) and transformers.
- It can again be used in place of residual overvoltage protection for ungrounded system.
- Its tripping times can be definite times or IDMT depending on the Utility's protection policy.

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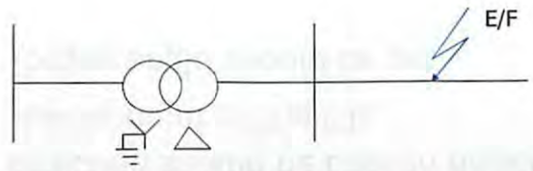
Neutral Displacement/ Residual Overvoltage Protection

- It is applied for the detection of earth fault in ungrounded system.



There is no ground path for zero sequence current to flow but there will be voltage displacement on individual phases. Healthy phases will experience voltage increases whiles the faulted phase will experience decrease in voltage.

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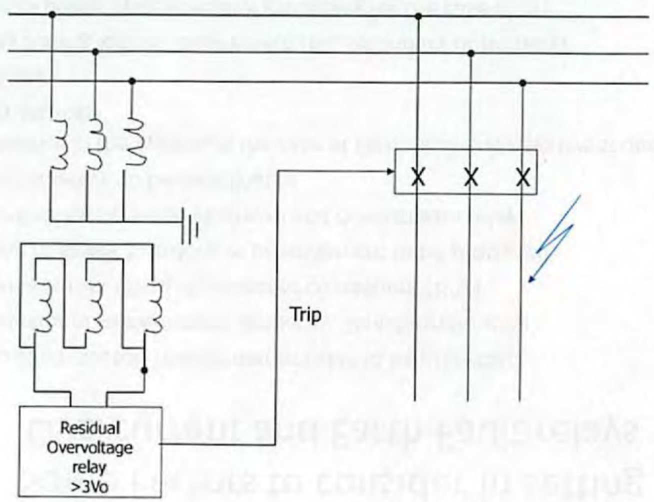
Earth fault on an ungrounded system



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- For balanced fault,

  $3V_o = \tilde{V}_A + \tilde{V}_B + \tilde{V}_C = 0$
- For unbalanced fault (earth fault),

  $3V_o = \tilde{V}_A + \tilde{V}_B + \tilde{V}_C > 0$
- Typical pick-up setting can be from 30 - 50V (depending on the utility philosophy) with a definite time delay.
- The definite time delay must coordinate with earth fault relays downstream the network.

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Auto-reclosers

- 80-90% of faults on any overhead line are transient whiles the remaining faults are either semi-permanent or permanent.
- Auto reclosers are circuit breakers of relatively lower normal current and short circuit current capability for clearing faults.
- They have overcurrent and earth fault sensing devices and reclosing controls as part of the unit contain within it.
- They are mostly used in the protection of overhead lines and sometimes for transformer protection.

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- A fault will trip the recloser but if the fault is temporary in nature and no longer exists, the tripping operation does not take place and the recloser returns to its normally closed position, ready for another incident. If the fault persists, the recloser will close and the operation will be repeated until the recloser locks out.

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- **Dead time-** it is the time between the trip and automatic closing operation or reclosing. Up to three dead times can be individually set.
- Factors affecting the selection of system dead time:

-type of load (industrial, commercial, domestic)
-circuit breaker characteristics
-fault path de-ionisation time.
-protection reset time.

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Reclaim Time:

- **Reclaim Time:** This is the time that if a fault condition clears midway through a sequence, the auto-recloser times out a reclaim time before returning to the dormant mode.
- Factors affecting the setting of the reclaim time:

-Number of shots-
-Relay operating characteristics (IDMT, DTL, Instantaneous)
-Circuit breaker limitations (ability to perform trip and close operations)
-Statistical information on a particular network.

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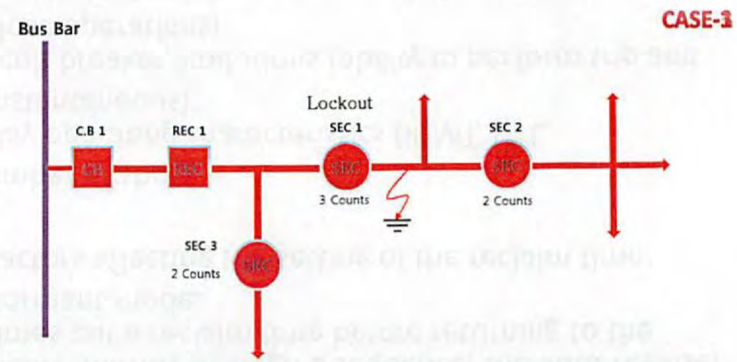
Illustration of reclosing cycle

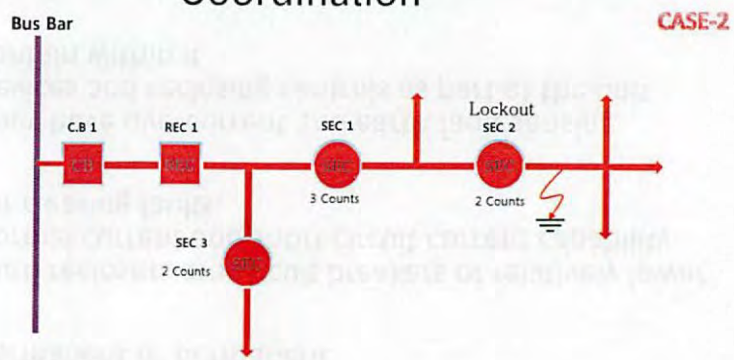
- *Demonstration from Excel software*

Example of Recloser & Sectionalizers



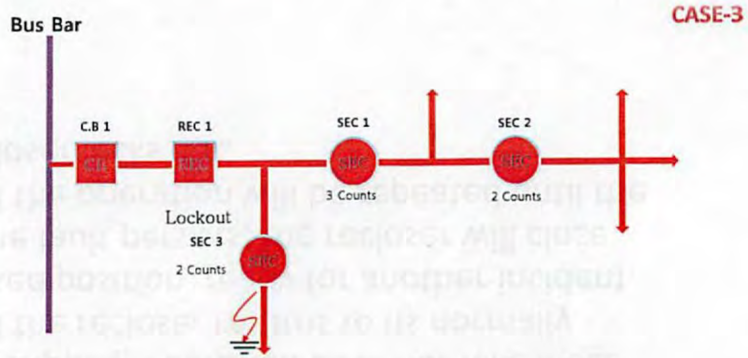
>> Reset

Example of Recloser & Sectionalizers Coordination



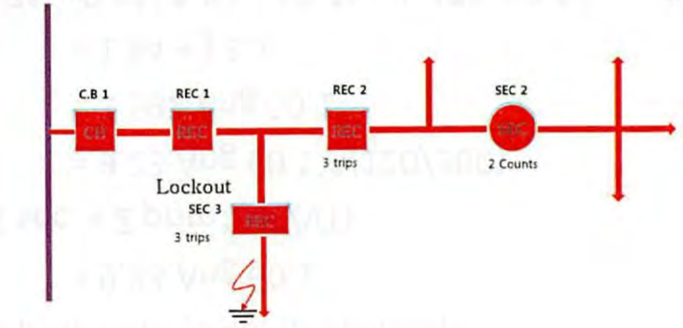
>> Reset

Example of Recloser & Sectionalizers Coordination



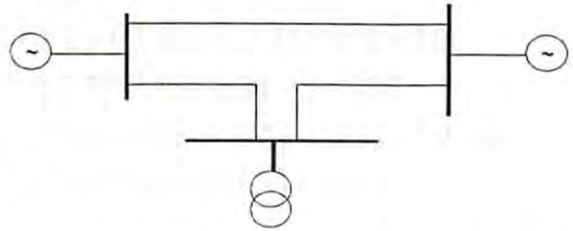
>> Reset

Example of Reclosers & Sectionalizer coordination



Distance Protection

- It is used mainly in multiple sources networks with mesh or parallel feeders.
- It can also be used in distribution network with single source. It can be used on both radial and parallel feeders



Please refer to "13. DISTANCE PROTECTION"

Example of Distance relays

- Digital Relays: SD36, Optimho
- Numeric Relays: Micom(P441,P433,P442),Reflex
- LED Indications;

❖Z1 zone one tripping

❖Z2 zone two tripping

❖Z3 zone three tripping

Programming of a typical Distance relay

- Type of relay
- Relay manual
- Gather necessary Data: CT & VT, Line impedance etc.
- Zones to programme
- Program LEDs and output contacts
- Testing relay functions

Calculation of Impedance Relay Setting Example

- A Distance relay on the feeder at bus A in fig. 1 is set to protect a 10Km, 33kV line.

Zone 1 is to be set at 80% of the line,
Zone 2 is to be set at 120% of the line,
Zone 3 set at 250% of the line impedance.
The following apply:
R= 0.46 ohms/Km, X=0.8 ohms/Km,
Ifl=450 A, CT = 600/5A, VT=33000/110,
Ko=0.53 Ang. -19˚

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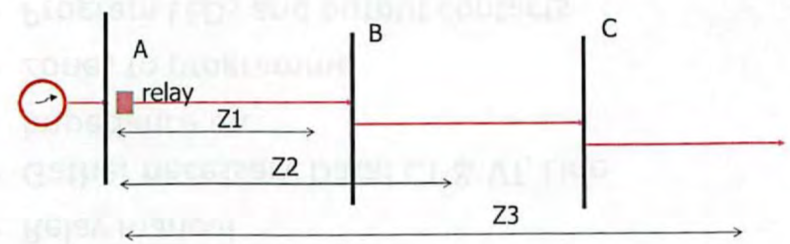
Fig. 1 SLD for Example 1



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Solution

Z prim= 10*(0.46+j0.8)=4.6+j8
= 9.23 Ang 60.1˚
Z sec. = Z prim*(CT/VT)
= 9.23 Ang 60.1˚*(120/300)
= 3.692 Ang 60.1˚
= 1.84 + j 3.2
Z1 = 0.8*(1.84 + j 3.2) = 1.472 +j2.56

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Solution

t1 = 0 sec, x1=2.56, r1=1.472
Z2 = 1.2*(1.84 +j 3.2) = 2.21 +j 3.84
t2 = 0.5 sec, x2=3.84, r2=2.21
Z3 = 2.5* (1.84 +j 3.2) = 4.6 + j 8
t3 = 1.0 sec, x3=8, r3=4.6
A Quad characteristic is chosen and the above setting set with Ko= 0.53Ang -19˚

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Solution

I fl = 450A

S max= 1.732*450*33 = 26MVA

Z min = (33kV)^2/26*10^6

= 42 ohms, Assume P F of 0.85

R min = 42* 0.85 = 41.99 ohms

R min. sec. = 41.99*(120/300) = 16.8 ohms

Note: Consider a typical Distance relay & set