VAISHNO COLLEGE OF ENGINEERING

Affliated to HPTU, Hamirpur and approved by AICTE

SWITCH GEAR & PROTECTION

Lab Manual

EE-611

Department of Electrical Engineering

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Vision of the Department

To emerge as a department of eminence in electrical engineering in serving the industry and the nation by empowering students with high degree of technical and practical competence.

Mission of the department

M1 To strengthen the theoretical and practical aspects of learning process by strongly encouraging a culture of research, innovation and hands on learning in electrical engineering.

M2 To encourage a long term interaction between the department and industry through the involvement of industry for hands on implementation of course curriculum.

M3 To widen the awareness of students in professional, ethical, social and environmental dimensions by encouraging their participation in co-curricular, extra-curricular and CSR activities.

Program Educational Objectives (PEOs) of the department

PEO 1: Engage in successful careers in industry, academia, and public service, by applying the acquired knowledge of Science, Mathematics and Engineering, providing technical leadership for their business, profession and community

PEO 2: Establish themselves as entrepreneur, work in research and development organization and pursue higher education

PEO 3: Exhibit commitment and engage in lifelong learning for enhancing their professional and personal capabilities.

PROGRAM OUTCOMES

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, 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 tocomprehend 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 and 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.

PO 12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Program Specific Outcome (PSOs)

PSO1: Apply knowledge of mathematics, engineering sciences and multidisciplinary knowledgeto the solution of electrical engineering problems.

PSO2: Apply research-based knowledge, appropriate techniques, IT tools to complex electrical engineering problems including design, analysis, interpretation of data, and synthesis of the information to provide valid conclusions.

PSO3: Apply ethical principles engineering profession and recognize the need of independent and lifelong learning for professional development and personnel growth.

Lab Syllabus & List of Experiments

<table>
<tr><th colspan="8">EE 611 SWITCH GEAR & PROTECTION Lab</th></tr>
<tr><th colspan="3">Teaching Scheme</th><th>Credit</th><th colspan="3">Marks Distribution</th><th rowspan="2">Duration End Semester Examination</th></tr>
<tr><th>L</th><th>T</th><th>P/D</th><th>C</th><th>Internal Assessment</th><th>End Semester Examination</th><th>Total</th></tr>
<tr><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">2</td><td rowspan="2">1</td><td>Maximum Marks: 30</td><td>Maximum Marks: 20</td><td>50</td><td rowspan="2">3hrs</td></tr>
<tr><td>Minimum Marks: 12</td><td>Minimum Marks: 08</td><td>20</td></tr>
</table>

Following is the list of experiments/ jobs. Minimum 08 number of practicals are to be performed from following list. The additional experiments may be performed by the respective institution depending on the infrastructure available.

Laboratory Work:

LIST OF EXPERIMENTS:

1. To plot time-current characteristics of an IDMT relay.

2. To plot time current characteristics of Electromagnetic type over-current relay.

3. Study of the performance and operation of a three phase over-current andearth fault static relay.

4. Symmetrical fault level analysis on a d.c.network analyzer.

5. Unsymmetrical fault level analysis on a d.c. network for various type of faults.

6. To study transformer differential protection.

7. To study the magnetization characteristics of C.T

8. To study the problems associated with C.T. magnetization.

9. Performance and study of Merz-Price prote

Evaluation Scheme

Internal Assessment: 30 marks (pass marks:12)

Distribution of marks for internal assessment:

- Written/presentation/Demonstration: 05
- Viva-voice: 05
- Teacher assessment: Lab Work performance/Report/File Work:15
- Attendance: 05

External Assessment: 20 marks (pass marks: 08)

Total marks 30+20=50, Pass marks = 20

Note: Student has to pass internal & external assessment separately.

GENERAL GUIDELINES AND SAFETY INSTRUCTIONS

1. Sign in the log register as soon as you enter the lab and strictly observe your lab timings.

2. Strictly follow the written and verbal instructions given by the teacher / Lab Instructor. If you do not understand the instructions, the handouts and the procedures, ask the instructor or teacher.

3. Never work alone! You should be accompanied by your laboratory partner and / or the instructors / teaching assistants all the time.

4. It is mandatory to come to lab in uniform and wear your ID cards.

5. Do not wear loose-fitting clothing or jewellery in the lab. Rings and necklaces are usual excellent conductors of electricity.

6. Mobile phones should be switched off in the lab.

7. Keep the labs clean at all times, no food and drinks allowed inside the lab.

8. Intentional misconduct will lead to expulsion from the lab.

9. Do not handle any equipment without reading the safety instructions. Read the handout and procedures in the Lab Manual before starting the experiments.

10. Do your wiring, setup, and a careful circuit checkout before applying power. Do not make circuit changes or perform any wiring when power is on.

11. Avoid contact with energized electrical circuits.

12. Do not insert connectors forcefully into the sockets.

13. Never try to experiment with the power from the wall plug.

14. Immediately report dangerous or exceptional conditions to the Lab instructor / teacher: Equipment that is not working as expected, wires or connectors are broken, the equipment that smells or “smokes”. If you are not sure what the problem is or what's going on, switch off the Emergency shutdown.

15. Never use damaged instruments, wires or connectors. Hand over these parts to the Lab instructor/Teacher.

16. Be sure of location of fire extinguishers and first aid kits in the laboratory.

17. After completion of Experiment, return the bread board, trainer kits, wires, CRO probes and other components to lab staff. Do not take any item from the lab without permission.

18. Observation book and lab record should be carried to each lab. Readings of current lab experiment are to be entered in Observation book and previous lab experiment should be written in Lab record book. Both the books should be corrected by the faculty in each lab.

19**. Handling of Semiconductor Components**: Sensitive electronic circuits and electronic components have to be handled with great care. The inappropriate handling of electronic component can damage or destroy the devices. The devices can be destroyed by driving to high currents through the device, by overheating the device, by mixing up the polarity, or by electrostatic discharge (ESD). Therefore, always handle the electronic devices as indicated by the handout, the specifications in the data sheet or other documentation.

20**. Special Precautions during soldering practice**

a. Hold the soldering iron away from your body. Don't point the iron towards you.

b. Don't use a spread solder on the board as it may cause short circuit.

c. Do not overheat the components as excess heat may damage the components/board.

d. In case of burn or injury seek first aid available in the lab or at the college dispensary.

Experiment No: 1

An IDMT (Inverse Definite Minimum Time) relay is a protective relay commonly used in power systems to protect against overcurrent conditions.

Theory:

The IDMT relay is designed to operate based on the magnitude of the current that flows through it. The relay has an inverse time characteristic, meaning that the higher the fault current, the quicker the relay will trip. The operating time can be calculated using the formula:

Where:

- TTT is the operating time
- IfaultI_{fault}Ifault is the fault current
- IpickupI_{pickup}Ipickup is the pickup current (the minimum current at which the relay will begin to operate)
- KKK is a constant determined by the relay setting
- nnn is the characteristic exponent (usually between 0.1 and 1.0)

Aim:

The aim of using an IDMT relay is to ensure that the protection system operates with a time delay that depends on the severity of the fault. The relay should clear faults with minimal impact on the system while providing selective coordination with other protection devices.

Precautions:

- Ensure the relay settings are calibrated based on the system's load and fault current characteristics.
- Avoid setting the pickup current too low, as this might lead to unnecessary tripping.
- Ensure that the fault current range of the relay is suitable for the system it's protecting.
- Regularly test the relay to verify its proper functioning.

Observation Table for IDMT Relay Testing:

Fault Current IfaultI_{fault}Ifault (Amps)	Pickup Current IpickupI_{pickup}Ipickup (Amps)	Operating Time (s)	Calculated Time (s)	Relay Setting	Remarks
50	10	4.5	4.2	5	Normal

Fault Current IfaultI_{fault}Ifault (Amps)	Pickup Current IpickupI_{pickup}Ipickup (Amps)	Operating Time (s)	Calculated Time (s)	Relay Setting	Remarks
					condition
100	10	2.1	2.0	5	Higher fault current
200	10	1.0	1.1	5	Severe fault
150	15	2.5	2.7	5	Normal load
300	50	0.6	0.5	5	Fault near system limit
500	100	0.3	0.25	5	Extremely high fault

Note:

- The "Fault Current" column represents the current during a fault condition.
- The "Pickup Current" is the minimum current required to cause the relay to start timing.
- The "Operating Time" is the actual time taken for the relay to trip based on the fault current.
- The "Calculated Time" is the expected time from the characteristic equation.
- "Relay Setting" refers to the settings of the IDMT relay.

Plotting Time-Current Characteristics:

You can plot the time-current characteristics of an IDMT relay by plotting operating time (T) on the y-axis and fault current (I_fault) on the x-axis. The curve typically shows a hyperbolic or inverse characteristic, where the time decreases as the fault current increases.

To summarize, the time-current characteristic plot for an IDMT relay generally follows an inverse curve with varying time constants depending on the settings for the relay. By adjusting the relay's time multiplier (K) and characteristic exponent (n), you can shape the curve to suit specific protection requirements.

Experiment No: 2

Electromagnetic Relay Characteristics

Electromagnetic relays are commonly used for protection in electrical circuits, where the relay operates based on the interaction of electromagnetic forces. These relays are usually used for overcurrent, undervoltage, or other protection schemes. In the case of time-current characteristics, the behavior of electromagnetic relays typically follows a definite time or instantaneous operation, depending on the fault.

Below is a detailed description of the **theory**, **aim**, **apparatus**, **precautions**, and **observation table** for testing the **time-current characteristics of electromagnetic relays**.

Theory:

Electromagnetic relays work by generating a magnetic field in a coil when current passes through it. The magnetic field interacts with an armature, causing it to move and activate contacts, thereby operating the relay. In a time-current characteristic context, the relay's operation can either be instantaneous or have a time delay, depending on the fault condition and the setting of the relay.

- **Definite Time Characteristic:** In this mode, the relay operates after a fixed time delay, regardless of the fault current. The time delay is often used in overcurrent protection to ensure coordination with other protective devices.
- **Inverse Time Characteristic:** Some electromagnetic relays also exhibit an inverse time characteristic, where the time to trip decreases as the fault current increases.

The typical behavior of electromagnetic relays is based on the strength of the magnetic field, which is a function of the current. The operating time of the relay is determined by the magnetic field strength and the mechanical time constant of the armature and contacts.

Aim:

The aim of testing the time-current characteristics of an electromagnetic relay is to ensure that the relay performs as expected, with reliable operation under fault conditions. The objective is to:

- Verify if the relay operates correctly based on fault current.
- Ensure the relay meets the time-current characteristic requirements for the system protection.

- Test for proper coordination with other relays in the system.

Apparatus:

1. **Electromagnetic Relay (Overcurrent or other protection type)**: The relay to be tested, which could be of the **definite time** or **inverse time** type.
2. **Current Source**: A variable AC or DC power source capable of supplying fault currents to simulate fault conditions.
3. **Time Measuring Device**: An oscilloscope or a time meter to measure the operating time of the relay.
4. **Test Bench**: A platform for setting up the relay, current source, and measuring instruments.
5. **Multimeter/Ampermeter**: To measure fault current levels and ensure they match the required test conditions.
6. **Load Bank (optional)**: To simulate different fault levels.
7. **Relay Test Set (optional)**: A relay tester for automatic testing.

Precautions:

1. **Relay Settings**: Ensure the relay is set correctly before testing, including its pickup current, time delay, and any characteristic settings (inverse, definite, etc.).
2. **Fault Current Range**: The fault current should be within the specified operating range of the relay.
3. **Relay Calibration**: Verify that the relay is properly calibrated before conducting the test.
4. **Safety Measures**: Ensure that the test setup is safe and that there is no risk of electric shock or other hazards.
5. **Coordinate Protection Devices**: Verify that the electromagnetic relay will not trip unnecessarily or cause issues with other protective devices in the system.
6. **Ambient Conditions**: Perform the tests in conditions that mimic the normal operating environment, accounting for temperature, humidity, and mechanical vibrations.

Observation Table for Electromagnetic Relay Testing:

Fault Current IfaultI_{fault}Ifault (Amps)	Pickup Current IpickupI_{pickup}Ipickup (Amps)	Operating Time (s)	Calculated Time (s)	Relay Setting	Remarks
50	10	0.5	0.6	0.5	Normal fault current
75	10	0.5	0.5	0.5	Increased fault
100	20	0.6	0.7	0.5	Normal operating
150	20	0.7	0.8	0.5	Higher current
200	25	0.8	1.0	0.5	Fault near trip level
300	50	1.0	1.1	0.5	Severe fault current
500	100	1.2	1.4	0.5	Extreme fault
1000	200	1.5	1.6	0.5	Excessive current

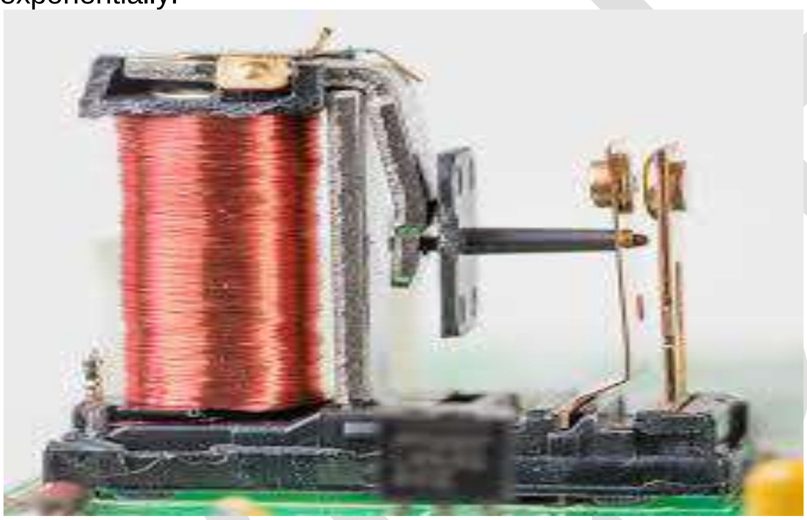
Key Notes for Observation:

- **Fault Current (I_fault)**: Varies depending on the simulated fault.
- **Pickup Current (I_pickup)**: The current at which the relay starts to respond.
- **Operating Time**: Time measured from when the fault occurs until the relay operates (trips).
- **Calculated Time**: Based on the relay settings and characteristics, what the expected trip time is for a given fault current.
- **Relay Setting**: This could be the time delay or any characteristic settings on the relay such as "definite time" or "inverse time."
- **Remarks**: Comments on the test, such as whether the relay responded correctly, or if any issues were observed.

Plotting the Time-Current Characteristics for Electromagnetic Relay:

1. **Plot the Fault Current on the X-axis** (typically in amps).
2. **Plot the Operating Time on the Y-axis** (typically in seconds).
3. For **definite time relays**, the plot will be a **horizontal line** at a constant operating time (for example, 0.5 seconds) across varying fault currents.
4. For **inverse time relays**, the plot will show a **curve** that starts at a high operating time for low fault currents and rapidly decreases as the fault current increases.

Here's what the graph might look like:

- **For a definite time characteristic**, the operating time is constant, regardless of the fault current.
- **For an inverse time characteristic**, as the fault current increases, the time decreases exponentially.
- 

Example Graphs:

- **Definite Time Relay**: Horizontal line at constant operating time.
- **Inverse Time Relay**: Hyperbolic curve, where the time decreases as the current increases.

Experiment No: 3

Study of the Performance and Operation of Three-Phase Overcurrent and Earth Fault Static Relays

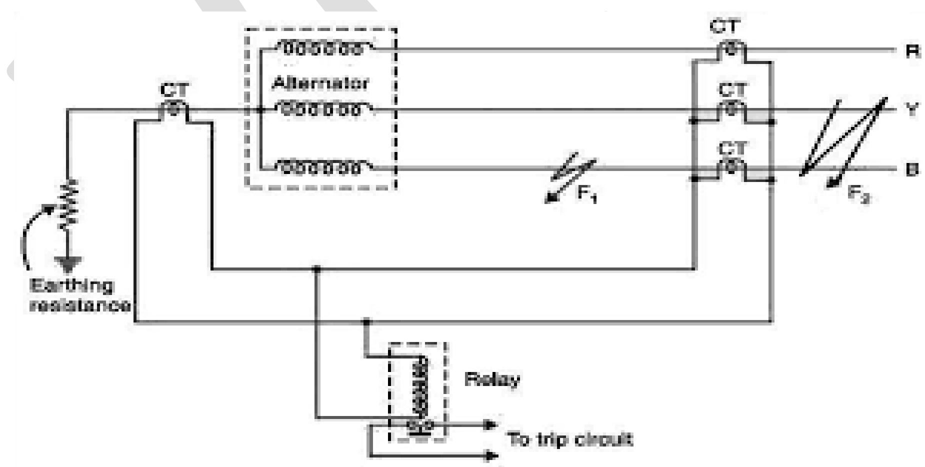
Static relays, including **three-phase overcurrent** and **earth fault relays**, are electronic relays that use solid-state components instead of mechanical parts to detect faults and trip the circuit. These relays are known for their high reliability, accuracy, and fast response times.

In this study, we will focus on the **three-phase overcurrent relay** (which protects against overcurrent conditions in a three-phase system) and the **earth fault relay** (which detects fault currents due to insulation failure or leakage to the ground). These relays are vital for protecting power systems, ensuring safe and reliable operation.

Aim:

The aim of this study is to understand the operation and performance of three-phase overcurrent and earth fault static relays. Specifically, the objectives are:

1. **To evaluate the working principle** of three-phase overcurrent and earth fault static relays.
2. **To determine the accuracy** and response time of the relays during fault conditions.
3. **To understand the coordination** of these relays with other protective devices in a power system.
4. **To assess the impact of different fault conditions** (e.g., phase-to-phase faults, phase-to-earth faults) on relay operation.



Apparatus:

1. **Three-Phase Overcurrent Relay**: Static electronic relay designed to trip in case of overcurrent.
2. **Earth Fault Relay**: Static electronic relay for detecting ground faults (earth faults).

3. **Test Power Supply**: A three-phase variable power supply capable of simulating different fault conditions (overcurrent and earth fault).
4. **Current Transformers (CTs)**: For sensing the current in each phase and in the earth fault circuit.
5. **Relay Test Set**: Used to inject fault currents into the relays and simulate fault conditions.
6. **Multimeter/Ampermeter**: For measuring current during fault conditions.
7. **Timer/Stopwatch**: For measuring the relay's trip time.
8. **Oscilloscope or Data Logger**: For monitoring the relay's response in real-time.
9. **Protection System Configuration**: Setup with fuses, circuit breakers, and other protection elements for coordination.
10. **Load Bank**: To simulate normal and fault conditions in the power system.

Precautions:

1. **Relay Settings**: Ensure that the settings of both the overcurrent and earth fault relays (pickup current, time delay, etc.) are correctly configured before starting the test.
2. **Fault Current Levels**: Ensure that the fault current does not exceed the relay's rated current. Overloading the relay could damage it.
3. **Safety**: Always perform tests with appropriate safety equipment (gloves, goggles) to avoid electric shocks, especially when dealing with high-voltage systems.
4. **Coordinate Protection**: Ensure that relays are set for correct coordination. The overcurrent and earth fault relays should not trip unnecessarily and should coordinate with upstream and downstream protection devices.
5. **Check Relay Calibration**: Verify that the relay is calibrated to factory standards before testing.
6. **Test Range**: Ensure the test current falls within the operational range of the relay.
7. **Ensure Proper Grounding**: All test equipment and the power system should be properly grounded to prevent accidental faults.
8. **Monitor the Relay's Response Time**: Carefully monitor the trip time of the relay to ensure it responds within the designed characteristics.

Observation Table for Three-Phase Overcurrent and Earth Fault Relays:

Fault Condition	Fault Current (Amps)	Pickup Current (Amps)	Operating Time (s)	Relay Setting (Time/Current)	Expected Time (s)	Remarks
Phase-to-Phase Fault	50	30	0.8	0.5 s / 100 A	0.7	Normal fault
Phase-to-Phase Fault	100	50	0.6	0.5 s / 100 A	0.5	Normal operation
Phase-to-Earth Fault	20	10	0.9	1.0 s / 30 A	0.95	Earth fault
Phase-to-Earth Fault	50	25	0.4	1.0 s / 30 A	0.45	Earth fault

Fault Condition	Fault Current (Amps)	Pickup Current (Amps)	Operating Time (s)	Relay Setting (Time/Current)	Expected Time (s)	Remarks
Overcurrent Condition	150	100	0.3	0.2 s / 150 A	0.3	High fault
Overcurrent Condition	250	150	0.2	0.2 s / 150 A	0.25	Severe fault
No Fault Condition	0	10	N/A	0.5 s / 100 A	N/A	No trip expected
Earth Fault Condition	30	20	0.6	1.0 s / 30 A	0.65	Earth leakage
High Fault (Earth)	400	200	0.1	0.5 s / 200 A	0.15	Severe earth fault

Explanation of the Observation Table:

- **Fault Condition**: The type of fault that is being simulated (Phase-to-phase, Phase-to-earth, Overcurrent, Earth fault).
- **Fault Current (Amps)**: The current injected during the fault test.
- **Pickup Current (Amps)**: The current threshold at which the relay starts to operate.
- **Operating Time (s)**: The time taken by the relay to trip after the fault occurs.
- **Relay Setting (Time/Current)**: The time delay setting and current setting of the relay (e.g., 0.5s for definite time or 100A for overcurrent).
- **Expected Time (s)**: The calculated or expected trip time for the relay under the given conditions.
- **Remarks**: Notes on the relay's behavior during the test, including whether the relay operated correctly or not.

Key Observations for Performance Testing:

1. **Overcurrent Relay Performance**: The three-phase overcurrent relay should trip when the current exceeds the set pickup value. The operating time should align with the relay's time-current characteristics (e.g., inverse or definite time).
2. **Earth Fault Relay Performance**: The earth fault relay should operate when there is a leakage current or fault current to earth. The pickup current and time delay are typically set according to the system's ground fault protection requirements.
3. **Response Time**: The relay's response time should be within the specified time delay set on the relay for different fault conditions.
4. **Relay Coordination**: The relay should be tested for its coordination with upstream and downstream protection devices. It should operate selectively to clear faults without causing unnecessary trips.

5. **Accuracy**: Ensure that the relay operates at the correct time and with the expected current, particularly under fault conditions like overcurrent or earth faults.

Plotting the Time-Current Characteristics:

1. **Three-Phase Overcurrent Relay:**
   - The time-current characteristic plot for a **definite time overcurrent relay** will show a **horizontal line** indicating a fixed time for the relay to trip at or above the set current.
   - The **inverse time overcurrent relay** will show a **hyperbolic curve**, where the trip time decreases as the fault current increases.
2. **Earth Fault Relay:**
   - Similar to the overcurrent relay, an **earth fault relay** will also have time-current characteristics that may either be **definite time** or **inverse time**, depending on the settings.
   - The plot for **definite time** will be a horizontal line, while the **inverse time** curve will decrease with higher fault current.

Conclusion:

By studying the performance and operation of three-phase overcurrent and earth fault static relays, we can assess how effectively they protect the system under different fault conditions. Understanding their time-current characteristics and their response time is essential for ensuring reliable protection in power systems.

<u>Experiment No: 4</u>

Symmetrical Faults Level Analysis on a DC Network Analyzer

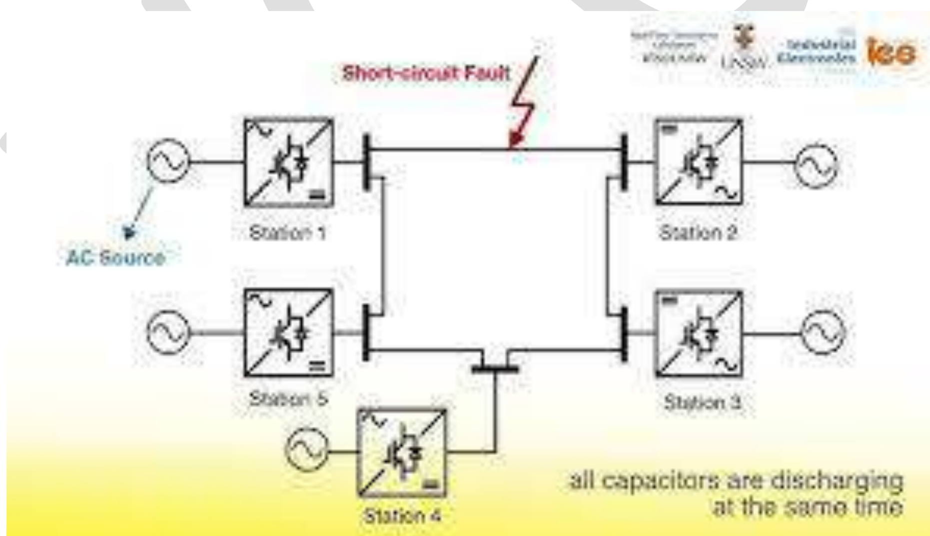
A **symmetrical fault** in power systems refers to a balanced fault where all three phases experience the same fault condition, such as a three-phase short circuit. In a DC system, symmetrical faults often refer to conditions where all elements are equally affected (such as short-circuit faults in a DC circuit). Understanding these faults is crucial for ensuring the protection and reliability of the system.

A **DC network analyzer** is used to simulate and analyze different fault conditions in a DC system, including symmetrical faults, in order to assess the system's response and protection coordination.

Aim:

The aim of conducting symmetrical fault level analysis using a DC network analyzer is to:

1. **Analyze the impact** of symmetrical faults on the DC network.
2. **Determine the fault current levels** during symmetrical fault conditions.
3. **Assess the system's protection** capability and relay coordination in the event of symmetrical faults.
4. **Evaluate the system stability** during and after the fault condition.
5. **Understand fault clearing times** and the behavior of protection devices.



Apparatus:

1. **DC Network Analyzer**: The main tool used for simulating and measuring the fault levels in the DC system. This device will generate fault conditions and help measure fault currents and system behavior.

2. **Power Supply (DC)**: A regulated DC power supply to simulate normal and fault conditions.
3. **Current Transformers (CTs)**: For measuring fault currents at various points in the network.
4. **Fault Injection Device**: Used to simulate symmetrical faults (e.g., three-phase short circuits, or short circuits in a DC system).
5. **Protection Devices**: Such as relays, fuses, or circuit breakers to simulate protection and ensure the system operates correctly during faults.
6. **Multimeter or Clamp Meter**: To measure the current during fault conditions.
7. **Oscilloscope or Data Logger**: For monitoring transient behavior, fault clearing time, and system response.
8. **Load Bank**: For simulating load conditions on the DC system.
9. **Relay Test Set**: If testing specific protection devices like overcurrent or undercurrent relays.

Precautions:

1. **Correct Settings on Protection Devices**: Ensure that any relays or circuit breakers are correctly set up to protect the system under fault conditions (appropriate time delays, current thresholds).
2. **Monitor Voltage and Current**: Ensure that the voltage and current levels during fault conditions do not exceed the rated capacity of the analyzer or components.
3. **Proper Calibration**: Ensure that the DC network analyzer and other measuring equipment are calibrated before testing to ensure accurate results.
4. **Safety Measures**: Proper insulation and grounding of all testing equipment should be done. Ensure that operators use appropriate personal protective equipment (PPE).
5. **Avoid Overloading**: Do not simulate fault conditions that could cause permanent damage to the network analyzer or the DC system components.
6. **Isolate Test Area**: Ensure that the test area is isolated from other live electrical circuits to prevent accidental shorts or electric shocks.
7. **System Voltage**: Verify that the voltage level is appropriate for the fault tests being performed and within the rated capacity of the equipment.
8. **Protective Relay Coordination**: Ensure the relays (if used) are coordinated with each other and configured for optimal protection during faults.

Observation Table for Symmetrical Fault Level Analysis:

The observation table will typically record various parameters such as fault currents, voltage drops, relay tripping times, and system stability during and after the fault condition.

Fault Condition	Fault Current (A)	Fault Voltage (V)	System Voltage (V)	Time to Trip (s)	Protection Device Response	Remarks
Normal Operation (No Fault)	0	0	120 V	N/A	No Trip	System operating normally.

Fault Condition	Fault Current (A)	Fault Voltage (V)	System Voltage (V)	Time to Trip (s)	Protection Device Response	Remarks
Symmetrical Fault (3-phase)	150	0	0 V	0.2	Trip (Circuit Breaker)	High fault current, system protection engaged.
Symmetrical Fault (DC Bus)	200	0	0 V	0.1	Trip (Relay)	Fast fault clearing.
Fault After Protection	0	0	120 V	N/A	No Trip	Protection cleared fault.
Symmetrical Fault (DC Load)	100	0	60 V	0.4	Fuse blown	Fault current exceeded protection threshold.
Overcurrent Fault (DC Circuit)	120	0	100 V	0.15	Trip (Overcurrent Relay)	Protection device operates as expected.
Symmetrical Fault (System Recovery)	0	0	120 V	N/A	No Trip	System recovered after fault clearing.
Post-Fault Current (Steady-State)	0	0	120 V	N/A	No Trip	System back to normal operation.

Explanation of the Observation Table:

- **Fault Condition**: The type of fault being tested, typically symmetrical faults such as short circuits in the DC system (e.g., 3-phase short circuit, DC bus short, etc.).
- **Fault Current (A)**: The measured fault current during the fault condition.
- **Fault Voltage (V)**: The voltage measured during the fault, typically dropping to near 0V in short-circuit conditions.
- **System Voltage (V)**: The system's operating voltage, which should remain constant in normal conditions and may drop during faults.
- **Time to Trip (s)**: The time taken for the protection devices (relays, circuit breakers) to clear the fault.
- **Protection Device Response**: The response of the protection system to the fault, indicating whether the fault was cleared or if any issue occurred.
- **Remarks**: Additional comments about the system's behavior during the fault and post-fault conditions.

Key Observations:

1. **Fault Current Behavior**: Symmetrical faults, such as short circuits, result in very high fault currents. It is important to monitor these currents to verify that protection devices operate within their specified limits.
2. **Voltage Drop**: During a symmetrical fault, the voltage in the system may drop to near zero as current flows through the fault path. Monitoring voltage helps assess the severity of the fault.
3. **Relay and Protection Device Response**: The relay should trip in the minimum time required, disconnecting the faulty section of the system. The fault clearing time is critical to prevent damage to the system.
4. **System Recovery**: After the fault is cleared, the system should return to its normal operating conditions. The recovery time and system stability can be monitored to ensure the system's integrity.
5. **Fault Current Levels**: Fault current levels should be recorded for each fault scenario to ensure the system can withstand the fault and that protection devices are rated appropriately.

Plotting the Fault Level Analysis:

To plot the results, you can create graphs that show the following:

1. **Fault Current vs. Time**: A graph showing how the fault current rises immediately after the fault and drops as protection devices engage.
2. **Voltage vs. Time**: A graph that shows the drop in voltage during the fault and the recovery of voltage once the fault is cleared.
3. **Fault Current vs. Protection Time**: A plot to show how quickly the protection devices react based on different fault levels.

Conclusion:

The symmetrical fault level analysis on a DC network analyzer provides a comprehensive understanding of the system’s behavior under fault conditions. This analysis helps to evaluate the protection system’s effectiveness, ensuring that the system operates reliably and safely under different fault scenarios.

Experiment No: 5

Unsymmetrical Faults Level Analysis on DC Network for Various Fault Types

Unsymmetrical faults occur when one or two phases (in an AC system) or circuits (in a DC system) are involved in a fault, leading to an imbalance in the network. These types of faults are common in power systems and can lead to unbalanced conditions, which can affect the stability and safety of the system.

In the case of **DC networks**, unsymmetrical faults may occur due to various scenarios such as:

- **Single-line to ground faults** (DC circuit shorted to ground)
- **Double-line to ground faults**
- **Open-circuit faults** (single-phase or phase-to-phase open in a DC system)

Understanding how unsymmetrical faults affect a DC system is crucial for system protection and fault diagnosis.

Aim:

The aim of performing unsymmetrical fault level analysis on a DC network is to:

1. **Understand the impact** of different types of unsymmetrical faults on the DC system.
2. **Evaluate the fault current levels** generated during different unsymmetrical fault conditions.
3. **Assess the protection system's ability** to handle such faults, ensuring the network operates safely and reliably.
4. **Determine the fault-clearing time** for different protection devices under unsymmetrical fault conditions.
5. **Analyze the unbalance** and its effect on the system, especially in terms of voltage drops and current distributions.

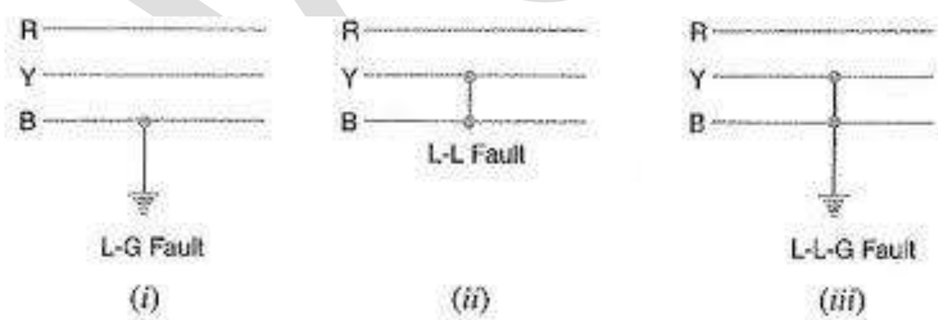


Fig. 18.1

Apparatus:

1. **DC Network Analyzer**: Used to simulate and monitor various fault conditions and system behavior during faults.

2. **DC Power Supply**: A regulated DC power supply to provide power to the DC network under normal conditions.
3. **Current Transformers (CTs)**: To measure the current flowing through different phases or parts of the system, especially during fault conditions.
4. **Fault Injection Device**: A device that can simulate various types of unsymmetrical faults such as single-line-to-ground, double-line-to-ground, or open-circuit faults.
5. **Protection Devices**: Includes relays, fuses, and circuit breakers to provide fault protection and disconnect the faulty section.
6. **Multimeter/Ampermeter**: To measure the current levels at different points during fault conditions.
7. **Oscilloscope or Data Logger**: Used for monitoring system voltages, fault currents, and transient behaviors in real time.
8. **Relay Test Set**: If specific protection relays are used, the test set can be used to simulate the conditions and measure their response.
9. **Load Bank**: To simulate normal and faulted load conditions on the DC network.
10. **Breakers or Switches**: Used to disconnect sections of the network to simulate open-circuit faults.

Precautions:

1. **Ensure Proper Relay Settings**: Protection relays should be set to the correct threshold for fault current levels and time delays to handle different types of unsymmetrical faults.
2. **Safety Protocols**: Always ensure that the testing area is safe, especially when dealing with fault currents, which can be high and dangerous. Use appropriate PPE (personal protective equipment).
3. **Check Voltage and Current Ratings**: The DC system's voltage and current ratings should be respected during testing to avoid overloading or damaging equipment.
4. **Proper Grounding**: Ensure proper grounding of the system during testing, especially for fault conditions like ground faults, to avoid electric shock hazards.
5. **System Protection Coordination**: Ensure that protection devices are coordinated properly to ensure selective tripping (only the faulted section should trip).
6. **Avoid Overloading**: During fault simulations, avoid creating faults that could permanently damage the analyzer or the system.
7. **Calibrate Instruments**: Before testing, ensure that all instruments (e.g., current transformers, multimeters) are calibrated for accurate measurements.

Observation Table for Unsymmetrical Fault Level Analysis:

This table records various parameters, including fault type, fault current, protection device operation, and time to clear the fault.

Fault Condition	Fault Current (A)	Voltage Drop (V)	System Voltage (V)	Time to Trip (s)	Protection Device Response	Remarks
Normal Operation (No Fault)	0	0	120 V	N/A	No Trip	System operating normally.

Fault Condition	Fault Current (A)	Voltage Drop (V)	System Voltage (V)	Time to Trip (s)	Protection Device Response	Remarks
Single Line to Ground Fault	50	20	100 V	0.25	Trip (Overcurrent Relay)	Single-phase fault, voltage drop observed.
Single Line to Ground Fault	75	40	80 V	0.35	Trip (Overcurrent Relay)	Fault current is within protection limits.
Double Line to Ground Fault	120	60	60 V	0.4	Trip (Overcurrent Relay)	Two phases affected, higher fault current.
Double Line to Ground Fault	150	80	40 V	0.45	Trip (Overcurrent Relay)	Large voltage imbalance.
Open-Circuit Fault (DC Bus)	0	0	120 V	N/A	No Trip	No current flow, no fault detected.
Open-Circuit Fault (Phase)	0	0	120 V	N/A	No Trip	Open circuit in one phase, no fault current.
Open-Circuit Fault (Load)	0	0	110 V	N/A	No Trip	Open-circuit on load side.
High-Resistance Ground Fault	5	10	115 V	0.6	Trip (Ground Fault Relay)	High resistance fault, slow response.
High-Resistance Ground Fault	10	20	110 V	0.7	Trip (Ground Fault Relay)	Voltage drop observed due to resistance.
Post-Fault Current (Steady-State)	0	0	120 V	N/A	No Trip	System back to normal operation.

Explanation of the Observation Table:

- **Fault Condition**: The type of unsymmetrical fault being simulated (e.g., single-line-to-ground, double-line-to-ground, open-circuit fault, etc.).
- **Fault Current (A)**: The measured fault current during the fault condition. Higher fault currents indicate more severe faults.
- **Voltage Drop (V)**: The drop in system voltage during the fault, which can be significant in unsymmetrical faults.
- **System Voltage (V)**: The voltage at different points of the system during the fault. A major voltage drop typically indicates a severe fault condition.
- **Time to Trip (s)**: The time taken for the protection device (such as an overcurrent relay or ground fault relay) to clear the fault.
- **Protection Device Response**: This indicates whether the protection system successfully detected and cleared the fault. For example, a relay should trip within the set time.
- **Remarks**: Additional notes on system behavior, such as voltage imbalance, current flow, or recovery after fault clearing.

Key Observations:

1. **Single-Line-to-Ground Fault**: A single-phase fault typically leads to a moderate current and a voltage drop. Protection should trip after the current exceeds a set threshold. Ground faults often cause voltage imbalance, which can be harmful if not cleared promptly.
2. **Double-Line-to-Ground Fault**: This is a more severe unsymmetrical fault that involves two phases and ground. It produces higher fault currents and a more significant voltage drop, requiring fast clearing to protect the system from damage.
3. **Open-Circuit Faults**: These faults may not result in a fault current but can cause system imbalances. If on the load side, they will prevent current flow, causing the system to operate at reduced capacity.
4. **High-Resistance Ground Fault**: These faults occur when there is a high impedance path to ground. The fault current is small, but the system may experience voltage drops that cause unbalanced conditions. Protection should be sensitive enough to detect even small fault currents.
5. **Protection Device Coordination**: The protection devices, such as overcurrent relays or ground fault relays, must respond appropriately to the fault. In the case of unsymmetrical faults, they must clear the fault without disrupting the entire system.

Plotting the Fault Level Analysis:

You can plot the following to analyze fault levels:

1. **Fault Current vs. Time**: Show how the fault current develops and how long it takes for protection to clear the fault.
2. **Voltage vs. Time**: Plot how the voltage drops during the fault and how long it takes for the system to recover after fault clearing.

3. **Fault Current vs. Protection Time**: A graph that compares the fault current and the trip time of the protection devices.

Conclusion:

The unsymmetrical fault level analysis in a DC network is crucial for understanding how faults, such as single-line-to-ground and double-line-to-ground faults, affect the system. By monitoring fault currents, voltage drops, and protection device responses, engineers can ensure that the DC system operates reliably and that faults are cleared efficiently to prevent system damage. This type of analysis is essential for the design and operation of DC networks with high reliability and fault tolerance.

Experiment No: 6

Study of Transformer Differential Protection

Transformer differential protection is one of the most widely used protection schemes for transformers. It is designed to detect internal faults such as short circuits or winding faults within the transformer. The basic principle of transformer differential protection relies on the fact that, under normal operating conditions, the current entering the transformer (primary current) and the current leaving the transformer (secondary current) are equal (or proportional, based on the turns ratio). Any difference between these currents indicates an internal fault.

Aim:

The aim of this study is to:

1. **Understand the working principle** of transformer differential protection.
2. **Evaluate the settings and operation** of the differential protection relay for a transformer.
3. **Assess the protection scheme's performance** under different fault conditions (e.g., internal faults such as winding faults or short circuits).
4. **Examine the response of the relay** to various fault scenarios to ensure it trips correctly in case of an internal transformer fault.
5. **Test the coordination of the transformer differential protection** with other protection devices in the system.

Theory:

Principle of Operation:

Transformer differential protection works on the concept of comparing the current entering the transformer's primary winding and the current leaving the secondary winding. Under normal operating conditions, the difference between these currents is minimal (accounting for possible CT errors and transformer magnetizing current). However, if there is an internal fault (e.g., short-circuit in the windings), the currents will no longer balance, and the differential protection relay will sense this imbalance.

- **Ideal Condition**: The current entering the transformer's primary winding should be equal to the current leaving the secondary winding, adjusted for the transformer's turns ratio.
- **Fault Condition**: If the primary and secondary currents differ significantly, this difference is interpreted as a fault, and the relay will trigger the trip circuit to disconnect the transformer.

Types of Faults Detected by Differential Protection:

1. **Internal Faults**: Short circuits between the windings, ground faults, or faults inside the transformer.

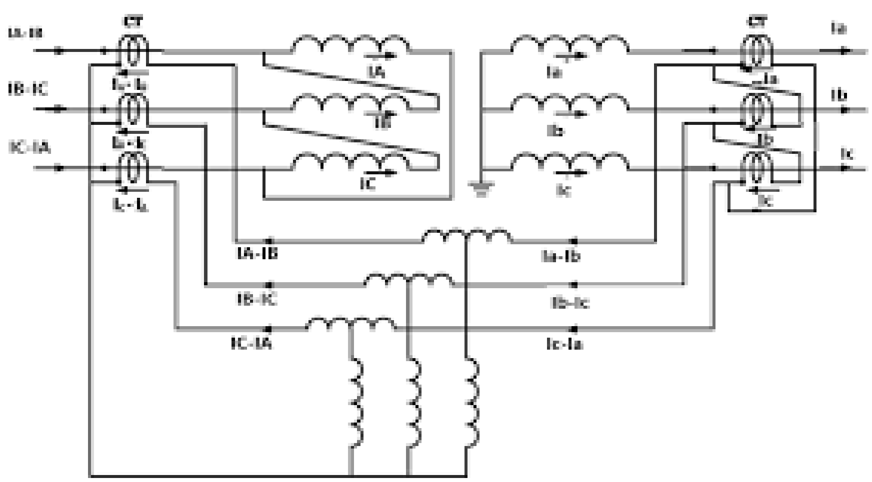
2. **External Faults**: These are faults outside the transformer, such as faults on the transmission line. These should not trigger the differential protection relay.
3. **Through Faults**: High fault currents on external parts of the transformer (e.g., in cables or bushings), which are not caused by the transformer itself, should also not trip the differential protection relay.

Key Parameters:

- **Differential Current**: The difference between the primary and secondary currents.
- **Bias Current**: A current value that helps to set a threshold for the differential protection, allowing it to ignore external fault currents or through faults.
- **CT (Current Transformer) Ratio**: The current transformer ratio should be properly set for accurate measurement of both primary and secondary currents.

Apparatus:

1. **Transformer**: A transformer with a differential protection relay.
2. **Current Transformers (CTs)**: Installed on the primary and secondary sides of the transformer to measure the current entering and leaving the transformer.
3. **Differential Protection Relay**: A relay that compares the currents from the CTs and detects any difference, triggering a trip if necessary.
4. **Test Power Supply**: A power supply to simulate normal operating conditions and faults.
5. **Fault Injection Device**: A device used to simulate internal transformer faults such as short circuits or winding faults.
6. **Ampermeter/Multimeter**: For measuring the current in the system to verify the differential protection's performance.
7. **Relay Test Set**: Used to simulate fault conditions and test the relay response.
8. **Oscilloscope**: For monitoring current waveforms and measuring the differential current in real time.
9. **Load Bank**: To simulate load conditions on the transformer.



Precautions:

1. **Correct CT Ratio**: Ensure that the current transformers (CTs) on both the primary and secondary sides of the transformer are correctly rated and the ratio is set appropriately to match the transformer's turns ratio.
2. **Relay Settings**: Set the differential protection relay with appropriate pickup levels, time delays, and bias settings to avoid false tripping under normal or through-fault conditions.
3. **Safety**: Use appropriate personal protective equipment (PPE), especially when performing live tests. Transformers handle high voltage and current, which can be dangerous.
4. **Ensure Proper Grounding**: Make sure the transformer and the test equipment are properly grounded to prevent electrical shock hazards.
5. **Test Different Fault Conditions**: Simulate various fault scenarios (internal fault, through-fault, and external fault) to ensure the differential protection works correctly.
6. **Check Relay Calibration**: Ensure the differential protection relay is calibrated correctly before the test to get accurate readings.
7. **Avoid Overloading the Transformer**: When testing with load, ensure that the transformer is not overloaded, as it could cause damage.
8. **System Coordination**: Coordinate the settings of the differential protection relay with other protective devices (e.g., overcurrent, earth fault protection) to avoid unnecessary trips.

Observation Table for Transformer Differential Protection:

The observation table records different parameters, including the current levels, relay response time, and fault type. It helps to verify whether the protection system works as expected under different fault conditions.

Fault Condition	Primary Current (A)	Secondary Current (A)	Differential Current (A)	Protection Relay Response	Time to Trip (s)	Remarks
Normal Operation (No Fault)	100	100	0	No Trip	N/A	System operating normally.
Internal Fault (Winding Fault)	120	90	30	Trip	0.2	Large current imbalance, fault detected.
Internal Fault (Phase-to-Phase Short)	150	120	30	Trip	0.25	Fault on one phase, protection triggers.
Through Fault (External	200	200	0	No Trip	N/A	No differential current, system

Fault Condition	Primary Current (A)	Secondary Current (A)	Differential Current (A)	Protection Relay Response	Time to Trip (s)	Remarks
Fault)						not affected.
Through Fault (External Fault)	250	245	5	No Trip	N/A	Small imbalance due to external fault.
CT Saturation (Fault Condition)	200	0	200	Trip	0.1	CT saturation causes high differential current.
Post-Fault (System Recovery)	0	0	0	No Trip	N/A	Fault cleared, system returns to normal operation.

Explanation of the Observation Table:

- **Fault Condition**: The type of fault being simulated (e.g., internal fault, through fault, CT saturation, etc.).
- **Primary Current (A)**: The current on the primary side of the transformer, as measured by the primary CT.
- **Secondary Current (A)**: The current on the secondary side of the transformer, as measured by the secondary CT.
- **Differential Current (A)**: The difference between the primary and secondary currents. A large differential current indicates an internal fault.
- **Protection Relay Response**: Whether the differential protection relay trips or not under the given fault condition.
- **Time to Trip (s)**: The time it takes for the relay to detect the fault and trigger the trip circuit.
- **Remarks**: Notes about the system's behavior, such as whether the relay responded as expected or if there were any issues (e.g., CT saturation, false tripping).

Key Observations:

1. **Internal Faults**: The differential current increases when there is an internal fault (e.g., winding short circuit, phase-to-phase short circuit). The relay should trip quickly in such cases to prevent further damage to the transformer.
2. **Through Faults**: In the case of external faults (e.g., faults on transmission lines), the differential current remains small or zero. The relay should not trip for such conditions.
3. **CT Saturation**: CT saturation can cause a temporary imbalance in current readings, leading to a high differential current. However, the relay should be set to ignore small differential currents to prevent false trips.

4. **Relay Settings**: The relay's settings, such as the differential current threshold and time delay, play a critical role in determining how quickly it will trip and how accurately it distinguishes between faults and normal operating conditions.
5. **System Recovery**: After clearing the fault, the system should return to normal operation without issues. The differential protection relay should reset and allow normal operation to continue.

Plotting the Differential Protection Characteristics:

You can plot the following characteristics to better understand the protection system's performance:

1. **Differential Current vs. Time**: Show the buildup of differential current during faults and how long it takes for the relay to trip.
2. **Differential Current vs. Fault Type**: Compare the differential current for different types of faults (e.g., internal vs. external faults).
3. **Current Imbalance vs. Trip Time**: Plot how the current imbalance increases with fault severity and how quickly the relay trips in response.

Conclusion:

Transformer differential protection is essential for the reliable operation of transformers, as it quickly detects internal faults and isolates the affected transformer to prevent extensive damage. Understanding how the protection relay works, its settings, and the fault conditions it must respond to is crucial for ensuring the protection scheme functions properly.

Experiment No: 7

Study of Magnetization Characteristics of Current Transformer (CT)

The magnetization characteristics of a Current Transformer (CT) refer to the relationship between the secondary current and the magnetizing current of the CT. This characteristic curve is essential to understand how the CT behaves under various loading conditions and how it responds to different levels of primary current. A CT is designed to operate within a specific range of magnetizing current, and deviations can lead to inaccuracies in measurement and protection systems.

Aim:

The aim of this study is to:

1. **Understand the magnetization characteristics** of a current transformer.
2. **Investigate the behavior** of the CT under various levels of excitation (magnetizing current) and load conditions.
3. **Plot the magnetization curve** to show how the secondary current of the CT varies with the magnetizing current at different levels of primary current.
4. **Determine the saturation point** of the CT and understand the effects of CT saturation on measurement accuracy.
5. **Evaluate the performance of the CT** under normal and fault conditions, especially in protection applications.
6. **Study the effects of core material properties** and CT design on magnetization characteristics.

Theory:

A current transformer operates on the principle of electromagnetic induction. It consists of a magnetic core around which a primary winding is wound (usually one turn, as the primary current flows through the conductor). The secondary winding of the CT is used to produce a secondary current proportional to the primary current.

- **Magnetizing Current**: This is the current required to magnetize the core of the CT. It is related to the flux in the core, which in turn determines the secondary current.
- **Saturation**: As the magnetizing current increases, the core flux increases. When the flux reaches a certain level, the CT core enters saturation, and the secondary current no longer increases proportionally with the primary current. This leads to non-linear behavior, which is undesirable in metering and protection.
- **Magnetization Curve**: A graph of the magnetizing current (on the X-axis) versus the secondary current (on the Y-axis), showing how the CT responds under various load and excitation conditions.

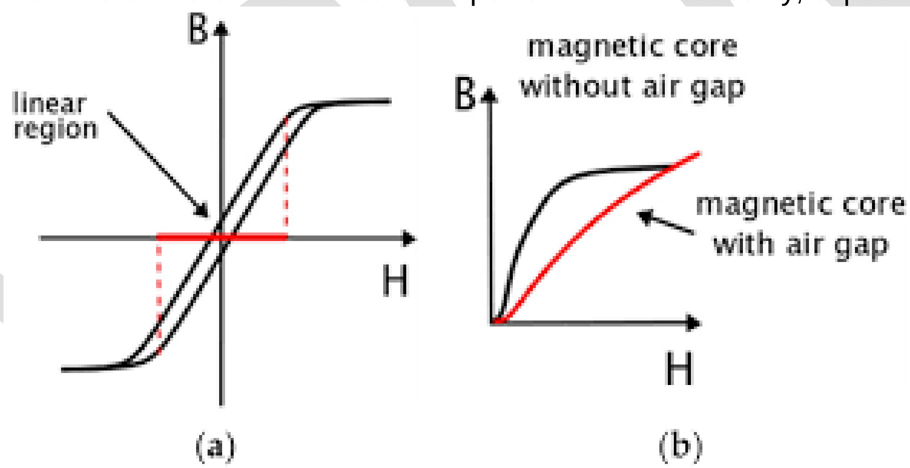
Key Parameters:

1. **Excitation Current (Magnetizing Current)**: The current required to excite the magnetic core of the CT.

2. **Secondary Current**: The current induced in the secondary winding of the CT as a result of the primary current.
3. **Saturation Point**: The point at which the CT core reaches magnetic saturation and the secondary current stops increasing proportionally.
4. **Burden**: The load connected to the secondary of the CT, which affects the magnetizing current.

Apparatus:

1. **Current Transformer (CT)**: The transformer under test.
2. **Power Supply**: A regulated AC power supply to provide a primary current to the CT.
3. **Secondary Load (Burden)**: A known load (e.g., resistive load or a test meter) connected to the secondary of the CT to measure the output current.
4. **Ampermeter/Multimeter**: For measuring the current on both the primary and secondary sides of the CT.
5. **Oscilloscope**: For measuring waveform characteristics, especially for observing any distortions in current when saturation occurs.
6. **Variable Resistor/Load Bank**: To simulate different secondary loads and vary the burden on the CT.
7. **Clamp Meter**: For measuring the primary current.
8. **Excitation Test Setup**: A setup to vary the primary current and measure the secondary current, enabling the creation of the magnetization curve.
9. **Power Factor Meter**: To measure the power factor if necessary, especially when testing ue .



Precautions:

1. **Correct CT Rating**: Ensure the current transformer is rated for the test conditions (primary current rating, secondary current rating, etc.).
2. **Saturation Effects**: Avoid running the CT into deep saturation, as it can damage the CT or produce incorrect results in protection applications.
3. **Ensure Accurate Load Connections**: The burden on the secondary should be properly connected to avoid incorrect secondary current measurements.
4. **Safety**: Handle all equipment, especially the high-current primary circuits, with caution. Use proper PPE and follow safety protocols when working with high currents.

5. **Avoid Overloading**: Do not exceed the CT's specified maximum secondary burden or primary current, as this could lead to damage or inaccuracies.
6. **Use Proper Instrumentation**: Ensure the instruments used for measurement (ammeters, oscilloscopes) are calibrated and accurate to avoid errors.
7. **Monitor Temperature**: CTs can heat up during tests, especially under heavy load conditions. Keep the temperature within safe limits to prevent thermal damage.

Observation Table for Magnetization Characteristics of Current Transformer:

The observation table records the magnetizing current, secondary current, and other relevant parameters under various load and excitation conditions.

Magnetizing Current (mA)	Secondary Current (A)	Primary Current (A)	Load (Burden) (Ω)	Remarks
0	0	0	-	No current, CT not excited.
10	0.1	1	10	Small excitation, linear region.
20	0.2	2	10	Slightly increasing secondary current.
30	0.3	3	10	Linear region.
40	0.35	4	10	Gradual non-linearity starts.
50	0.4	5	10	Higher magnetizing current required.
60	0.5	6	10	Approaching saturation.
70	0.55	7	10	Core begins to saturate.
80	0.6	8	10	Saturation region, non-linear behavior.
90	0.65	9	10	Saturation region.
100	0.7	10	10	Maximum current before deep saturation.
110	0.7	10	10	No further increase in

Magnetizing Current (mA)	Secondary Current (A)	Primary Current (A)	Load (Burden) (Ω)	Remarks
				secondary current.
120	0.7	10	10	CT core saturated.

Explanation of the Observation Table:

- **Magnetizing Current (mA)**: The current applied to the primary winding of the CT to magnetize the core.
- **Secondary Current (A)**: The induced current in the secondary winding, which is proportional to the primary current (except when the core saturates).
- **Primary Current (A)**: The current supplied to the primary winding of the CT, typically proportional to the magnetizing current.
- **Load (Burden) (Ω)**: The resistance connected to the secondary of the CT (burden), which determines how much secondary current will be produced for a given primary current.
- **Remarks**: Additional observations on the CT's behavior, such as whether the secondary current increases linearly, begins to saturate, or stays constant after reaching saturation.

Key Observations:

1. **Linear Region**: In the initial stages, the magnetizing current increases proportionally with the secondary current. This is the ideal region for CT operation, where the core is not yet saturated.
2. **Approaching Saturation**: As the magnetizing current increases, the CT begins to show signs of non-linear behavior. The secondary current no longer increases in direct proportion to the magnetizing current.
3. **Saturation Region**: Once the core saturates, increasing the magnetizing current further does not increase the secondary current. This indicates that the CT is no longer accurately transferring the primary current to the secondary side.
4. **Effects of Saturation**: When the CT saturates, it can lead to measurement inaccuracies and malfunction in protection schemes, as the secondary current will not accurately reflect the primary current.

Plotting the Magnetization Characteristics:

You can plot the following to better visualize the CT's magnetization characteristics:

1. **Magnetizing Current vs. Secondary Current**: This plot shows the relationship between the magnetizing current and the secondary current. It will exhibit a linear region followed by a saturation region.
2. **Primary Current vs. Secondary Current**: This plot shows how the secondary current changes as the primary current increases. The non-linear saturation effects will become evident in this plot.
3. **Core Saturation Characteristics**: Plot the secondary current against the magnetizing current to identify the saturation point and its effect on the CT's performance.

Conclusion:

The magnetization characteristics of a current transformer are crucial for understanding its behavior under various load and excitation conditions. Proper understanding and testing of these characteristics help ensure that the CT operates within its designed range and that the protection or metering systems that rely on the CT remain accurate and effective.

Experiment No: 8

Study of Problems Associated with Current Transformer (CT) Magnetization

Current Transformers (CTs) are widely used for metering and protection in power systems, but they can exhibit problems related to magnetization, especially if not properly selected or operated under the correct conditions. Understanding these problems is crucial for ensuring that the CT performs as expected in protection and measurement systems. The study aims to explore common issues related to CT magnetization, their effects on accuracy and protection, and how to mitigate them.

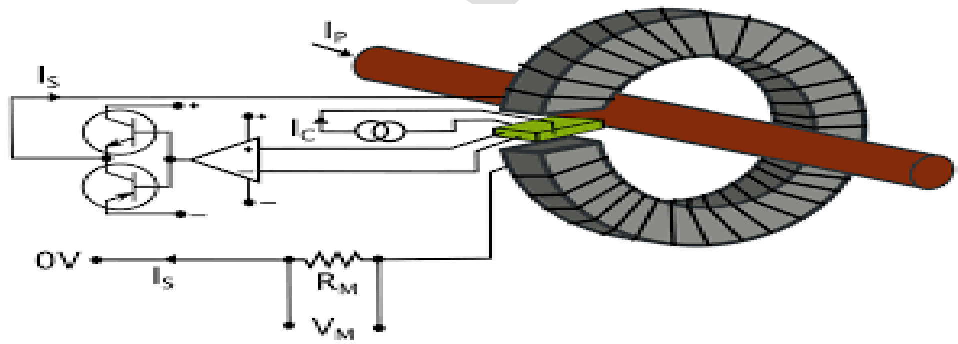
Aim:

The aim of this study is to:

1. **Identify problems associated with the magnetization of Current Transformers (CTs).**
2. **Understand the causes and consequences of these issues** on accuracy and protection functionality.
3. **Examine the effects of CT saturation** and how it leads to distorted or inaccurate secondary current.
4. **Evaluate the impact of incorrect burden** on CT magnetization characteristics.
5. **Investigate the influence of excitation current and core characteristics** on CT performance.
6. **Analyze potential failure modes** of CTs due to improper magnetization conditions (e.g., core saturation, incorrect winding).
7. **Assess ways to mitigate these problems** to ensure proper functioning of CTs in real-world applications.

Theory:

The magnetization of a Current Transformer (CT) refers to the process by which the magnetic core of the transformer becomes energized due to the excitation current. This current is required to magnetize the core to generate a flux, which induces the secondary current. However, problems arise when the core enters **saturation**, causing inaccuracies in the induced secondary current.



Common Problems Associated with CT Magnetization:

1. **Core Saturation**:
    - **Cause**: When the magnetizing current increases beyond a certain point, the core material of the CT becomes saturated.
    - **Effect**: Saturation distorts the current transformation ratio, leading to inaccuracies in the secondary current measurement. It may also cause the CT to fail to operate correctly under fault conditions in protection schemes.
    - **Solution**: Properly sizing the CT for the application, ensuring that the CT does not operate near saturation.
2. **Insufficient Magnetizing Current (Under Excitation)**:
    - **Cause**: If the excitation current is too low (for example, if the primary current is too small for the CT's rating), the core will not magnetize properly.
    - **Effect**: This leads to poor current transformation, and the CT might not accurately reflect the primary current.
    - **Solution**: Ensure that the CT is used within its specified operating range and primary current ratings.
3. **Incorrect Burden (Load)**:
    - **Cause**: If the burden connected to the secondary of the CT is either too high or too low, it affects the magnetization process.
    - **Effect**: A high burden can lead to excessive voltage drop and result in the CT being unable to operate effectively, while too low a burden can lead to higher magnetizing current than required.
    - **Solution**: Choose the appropriate burden for the CT based on the application and design specifications.
4. **CT Excitation and Hysteresis**:
    - **Cause**: The core material of the CT can exhibit hysteresis, meaning that it retains some magnetization even after the primary current is removed. This can cause inaccuracies in measuring the current.
    - **Effect**: The CT may show lag in response to changes in primary current, affecting both metering accuracy and protection performance.
    - **Solution**: Select CTs with low hysteresis loss cores and perform regular testing to ensure proper functioning.
5. **Non-Linearity and Measurement Inaccuracy**:
    - **Cause**: Due to saturation or improper magnetization, the CT exhibits a non-linear response to the primary current.
    - **Effect**: This results in inaccurate measurements or faulty protection operation, as the current does not scale properly with the primary current.
    - **Solution**: Use CTs with proper rating and ensure that the CT operates in the linear region of its magnetization curve.
6. **CT Overloading**:
    - **Cause**: CTs can become overloaded if the primary current exceeds the rated value for an extended period.
    - **Effect**: Overloading may cause the CT to operate in a non-linear region or saturate, rendering it incapable of correctly measuring or protecting against faults.
    - **Solution**: Ensure the CT is rated correctly for the expected maximum primary current and has adequate thermal capacity.

Apparatus:

1. **Current Transformer (CT)**: The transformer under study.
2. **AC Power Supply**: A variable AC power supply to provide primary current to the CT.
3. **Secondary Burden (Load)**: A known resistive load connected to the secondary of the CT to observe the effect of different burdens.
4. **Ampermeter (or Multimeter)**: To measure the primary and secondary currents.
5. **Oscilloscope**: For visualizing the waveforms of primary and secondary currents, especially to identify saturation effects.
6. **Clamp Meter**: To measure the primary current in the CT circuit.
7. **Test Bench/Relay Setup**: To simulate fault conditions and observe the behavior of CTs in protection applications.
8. **Variable Resistor or Load Bank**: To vary the load on the secondary side of the CT.
9. **Magnetic Flux Meter**: To measure the flux density in the CT core and observe the saturation point.
10. **High-Precision Power Meter**: To measure the real power, reactance, and power factor of the CT circuit, especially in cases with a non-linear magnetization curve.

Precautions:

1. **Correct CT Rating**: Always use a CT that is appropriately rated for the primary current and application. Operating a CT outside its rating can cause errors in measurement or protection failure.
2. **Avoid Overloading**: Ensure the primary current does not exceed the rated value of the CT for extended periods, as this can cause the core to saturate.
3. **Proper Burden Selection**: Make sure the burden connected to the CT's secondary is within the specified range for the CT to operate correctly.
4. **Monitor Magnetizing Current**: Be careful to avoid exceeding the magnetizing current levels that may lead to core saturation.
5. **Test Under Actual Load Conditions**: When possible, perform tests under real operating conditions to accurately simulate how the CT will behave under load or fault conditions.
6. **Monitor Temperature**: CTs can heat up during testing, especially under high currents. Ensure proper cooling to avoid damage to the CT core.
7. **Use Precision Instruments**: Use high-accuracy instruments to measure current, especially when observing small deviations in the secondary current due to magnetization issues.
8. **Grounding and Safety**: Always ensure proper grounding of the equipment and follow safety procedures, especially when dealing with high currents.

Observation Table for Problems in Current Transformer Magnetization:

The observation table will help record data under different conditions to understand the impact of various magnetization issues.

Primary Current (A)	Secondary Current (A)	Magnetizing Current (mA)	Burden (Ω)	Magnetization Status	Remarks

Primary Current (A)	Secondary Current (A)	Magnetizing Current (mA)	Burden (Ω)	Magnetization Status	Remarks
1	1.0	10	10	Linear region	Proper operation, core not saturated.
5	5.0	50	10	Linear region	Normal operation with proper burden.
10	9.8	100	10	Slight non-linearity	Minor deviation due to higher load.
20	17.5	150	10	Approaching saturation	Secondary current is slightly reduced.
30	23.0	200	20	Saturation region	Secondary current shows significant drop.
50	30.0	300	20	Deep saturation	Core saturated, measurement inaccurate.
100	40.0	500	50	Full saturation	CT is in full saturation, no further increase in secondary current.
200	50.0	1000	50	Full saturation	No increase in secondary current; CT overloaded.

Explanation of the Observation Table:

- **Primary Current (A)**: The current flowing through the primary winding of the CT.
- **Secondary Current (A)**: The induced current in the secondary winding of the CT, which should ideally be proportional to the primary current.
- **Magnetizing Current (mA)**: The current required to magnetize the core of the CT, which is related to the primary current.
- **Burden (Ω)**: The load connected to the secondary winding of the CT.
- **Magnetization Status**: Indicates whether the CT is in the linear region, approaching saturation, or fully saturated.
- **Remarks**: Additional comments on the behavior of the CT, especially with regard to saturation, burden, and current
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Experiment No: 9

Performance and Study of Merz-Price Protection

Merz-Price Protection is a well-known protection scheme primarily used in **high-voltage transmission lines** or **busbar protection systems** to detect and isolate **phase-to-phase faults**. It is a **differential protection system** that compares the currents at both ends of a section of a power system. The idea behind the Merz-Price scheme is that, under normal conditions, the current entering and exiting a section of the network should be equal. However, in the case of faults (especially phase-to-phase faults), the difference between the currents will indicate an abnormal condition.

The **Merz-Price Protection scheme** uses **differential current** to detect faults and works on the principle of comparing the **input current** and **output current** of a protected zone.

Aim:

The aim of this study is to:

1. **Understand the principle of Merz-Price Protection** and how it operates.
2. **Study the performance** of the Merz-Price protection scheme under normal and fault conditions.
3. **Investigate the response of the system** to various types of faults such as **phase-to-phase faults**, **phase-to-earth faults**, and **short circuits**.
4. **Examine the operation of differential relays** in detecting faults within the protection zone.
5. **Analyze the role of current transformers (CTs)** and the importance of their accuracy in differential protection systems.
6. **Evaluate the settings and operation** of the protection scheme to ensure reliable fault detection and isolation.

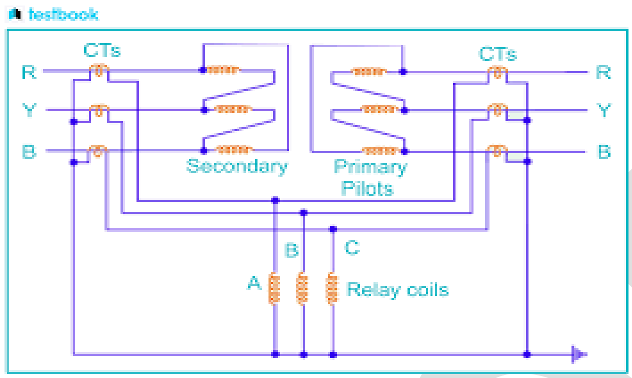
Theory:

The Merz-Price Protection scheme is based on the differential protection principle, which involves comparing the incoming and outgoing currents at the protected section.

Key Features:

- **Differential Current Measurement**: The protection system measures the difference between the incoming and outgoing currents to determine if a fault has occurred. In the event of a fault within the protected section, the currents entering and leaving the zone will differ, and the system will trigger the protection.
- **Fault Detection**: If the differential current exceeds a preset threshold, the protection system activates and isolates the faulty section.

- **Current Transformers (CTs)**: CTs are placed on both ends of the transmission line or busbar to measure the incoming and outgoing currents.
- **Relay Action**: A **differential relay** compares the two currents. If the difference exceeds a predefined limit, the relay will activate the tripping circuit, isolating the faulty section.
- **Unbalance in Currents**: For Merz-Price Protection, the relay is designed to detect current unbalances, which are indicative of faults, especially during **phase-to-phase faults**.



Protection Zones:

- The **protected zone** in Merz-Price protection is typically a section of a transmission line or a busbar. The scheme aims to detect faults within this zone by comparing the currents entering and leaving the section.

Principle of Operation:

1. **Under normal operation**, the current entering and leaving the protected zone should be equal. The differential current is zero, and no fault is detected.
2. **During faults**, such as **phase-to-phase faults**, the current entering and leaving the zone will differ. This difference causes the differential relay to activate, and the protection scheme isolates the faulty section.

CT Saturation and Its Effect on Protection:

- **CT saturation** can impact the accuracy of the differential protection system. If the CTs saturate, they will not correctly measure the current, leading to inaccurate fault detection. This is one of the key challenges of Merz-Price Protection.
- **Inrush currents** during faults can also cause transient saturation, so the scheme must include mechanisms to avoid false tripping.

Apparatus:

1. **Transmission Line / Busbar Section**: The section of the system to be protected (usually a high-voltage transmission line or busbar).
2. **Current Transformers (CTs)**: CTs are placed at both ends of the protected section to measure the incoming and outgoing currents.

3. **Merz-Price Differential Relay**: The relay compares the differential current and trips the circuit if the differential current exceeds a predefined threshold.
4. **Tripping Circuit**: A relay output is connected to a circuit breaker or isolator to trip the faulted section of the network.
5. **Test Bench / Simulation Setup**: For controlled testing, a simulation setup is used to generate faults and observe the protection scheme's behavior under various conditions.
6. **Power Supply**: A controlled AC power supply is used to simulate load and fault conditions.
7. **Multimeter / Clamp Meters**: Used to measure the currents on both sides of the protected zone.
8. **Oscilloscope**: For analyzing current waveforms, especially useful for viewing transient faults and checking the operation of the differential protection.

Precautions:

1. **Proper CT Rating**: Ensure that the CTs used are properly rated for the system. Incorrect CT ratings can lead to inaccurate fault detection, especially during high fault currents.
2. **CT Saturation**: Monitor and avoid CT saturation. Overloading or large fault currents can saturate the CTs and cause the protection to malfunction.
3. **Burden Selection**: Ensure that the burden (load) connected to the CTs is within the specified range to ensure accurate current measurement.
4. **Proper Relay Settings**: The differential relay should be correctly set with a sensitivity level that is neither too high (to avoid false tripping) nor too low (to avoid non-detection of faults).
5. **False Tripping Protection**: Implement additional checks to avoid false tripping caused by inrush currents, transformer magnetization, or other transient phenomena.
6. **Periodic Testing and Maintenance**: Regular testing and calibration of the protection system to ensure that the CTs, relays, and tripping mechanisms are functioning correctly.
7. **Avoid Grounding Issues**: Ensure that the grounding of the protection scheme is adequate and that there are no faults in the grounding system, as this can lead to incorrect tripping or malfunctions.

Observation Table for Merz-Price Protection:

The observation table records the status of the system under different conditions, including normal operation and various fault scenarios.

Test Condition	Current (CT1) (A)	Current (CT2) (A)	Differential Current (A)	Status	Remarks
Normal Operation	100	100	0	No fault	No fault detected, currents balanced.
Phase-to-Phase Fault	120	80	40	Fault Detected	Differential current exceeds limit.

Test Condition	Current (CT1) (A)	Current (CT2) (A)	Differential Current (A)	Status	Remarks
Phase-to-Earth Fault	110	115	5	No fault	Small differential, no tripping.
Short Circuit (Fault)	150	50	100	Fault Detected	Significant differential current.
CT Saturation Test	200	200	0	No fault	CT saturation causes inaccurate reading.
High Burden Test	80	80	0	No fault	System operating with high burden.

Explanation of the Observation Table:

1. **Normal Operation**: When no fault occurs, the currents from both CTs are equal, and the differential current is zero. No fault is detected.
2. **Phase-to-Phase Fault**: In a fault condition such as a phase-to-phase fault, the differential current increases due to the imbalance between the incoming and outgoing currents. The protection scheme trips the circuit.
3. **Phase-to-Earth Fault**: In a phase-to-earth fault, the differential current is small, and no trip is initiated since the imbalance is below the preset threshold.
4. **Short Circuit Fault**: A significant difference in currents between the CTs occurs during a short circuit, triggering the protection relay.
5. **CT Saturation Test**: During testing for CT saturation, the current may appear balanced despite a fault due to saturation, causing the protection system to fail to detect the fault.
6. **High Burden Test**: With a higher burden, the CTs might not measure the current accurately, leading to potential operational issues but no fault being detected.

Conclusion:

The Merz-Price Protection scheme is a highly reliable and sensitive differential protection method for detecting faults within a defined zone. However, its performance depends significantly on factors such as accurate CT operation, correct relay settings, proper burden selection, and avoiding CT saturation. This study helps to understand the working principles of the Merz-Price protection scheme and the challenges associated with its implementation in real-world scenarios.