



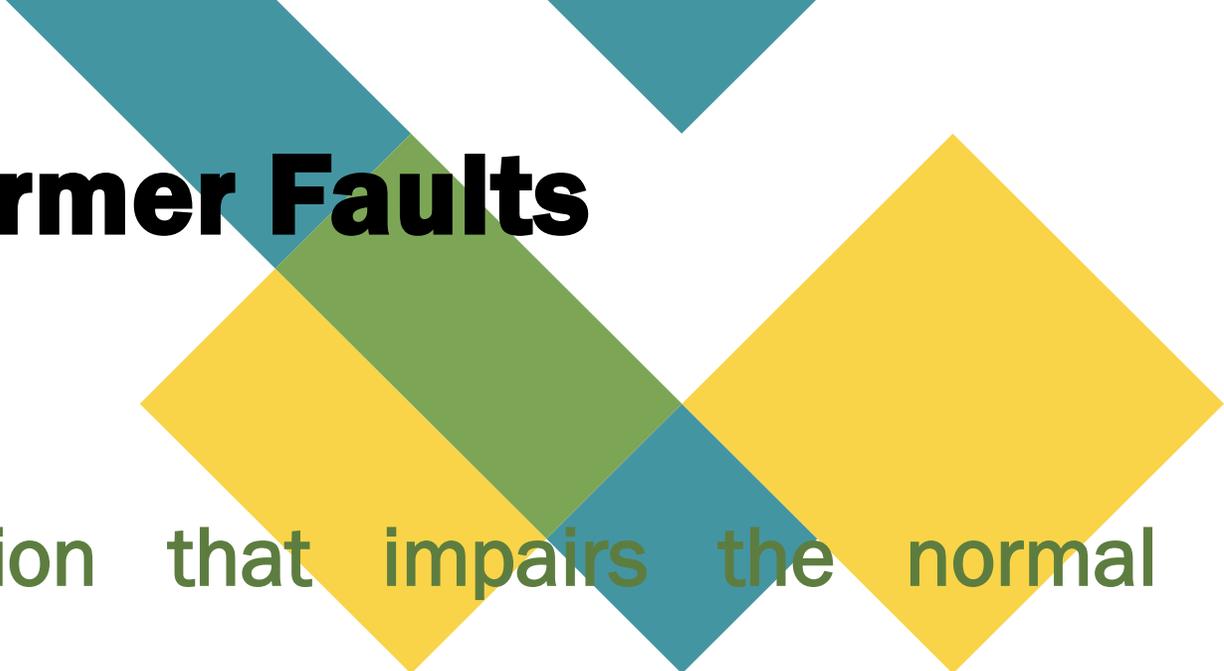
Protection Systems in Transformers

Why Do Transformers Need Protection?



- **Critical Component:** Transformers are the most expensive and crucial equipment in a substation.
- **Cost of Failure:** A failure can result in huge financial losses (repair/replacement) and massive grid blackouts.
- **Safety:** Protection systems prevent catastrophic failure (like fire or explosion) that could endanger personnel and surrounding equipment.
- **Speed:** Protection must isolate a fault in milliseconds before damage becomes permanent.

Introduction to Transformer Faults



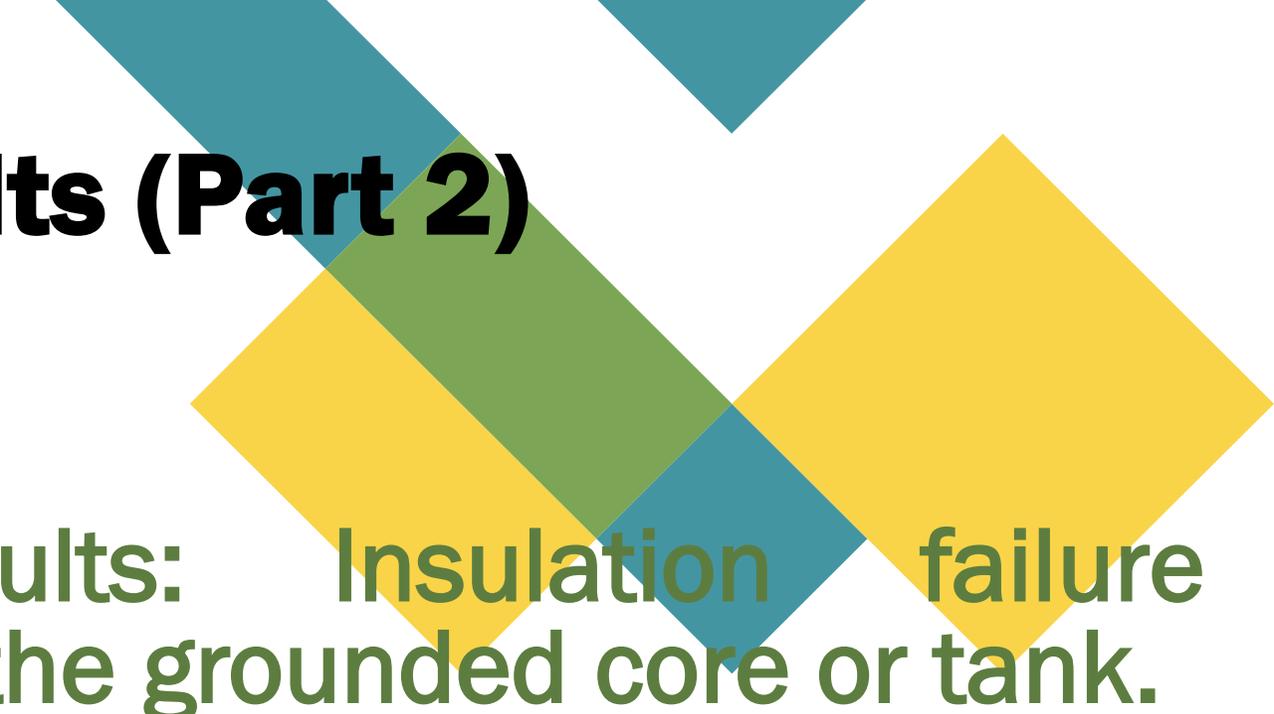
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- **Fault:** Any undesirable condition that impairs the normal operation of the transformer.
 - **Internal Faults:** Occur inside the transformer tank (e.g., winding short circuits). These are the most dangerous.
 - **External Faults:** Occur outside the transformer, on the connected busbars or lines. The transformer must survive these without damage.

Common Internal Faults (Part 1)



- **Winding Short Circuits (Inter-turn Faults):** Insulation failure between adjacent turns of the same winding.
 - *Effect:* Causes massive short-circuit current, intense localized heating, and rapid oil decomposition.
- **Phase-to-Phase Faults:** Insulation failure between two different phase windings.

Common Internal Faults (Part 2)



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- **Winding-to-Ground Faults:** Insulation failure between a winding and the grounded core or tank.
 - *Effect:* High current flow through the ground connection.
 - **Core Faults:** Failure of the core lamination insulation, leading to excessive eddy currents and overheating.

Common External Faults



- **Line-to-Ground Faults:** Occurring on the transmission line connected to the high-voltage side.
- **Busbar Faults:** Short circuits on the metal conductors (busbars) in the substation.
- **The Challenge:** The transformer's protection must be able to differentiate between these external faults and internal ones.

Introduction to Overloads and External Heating



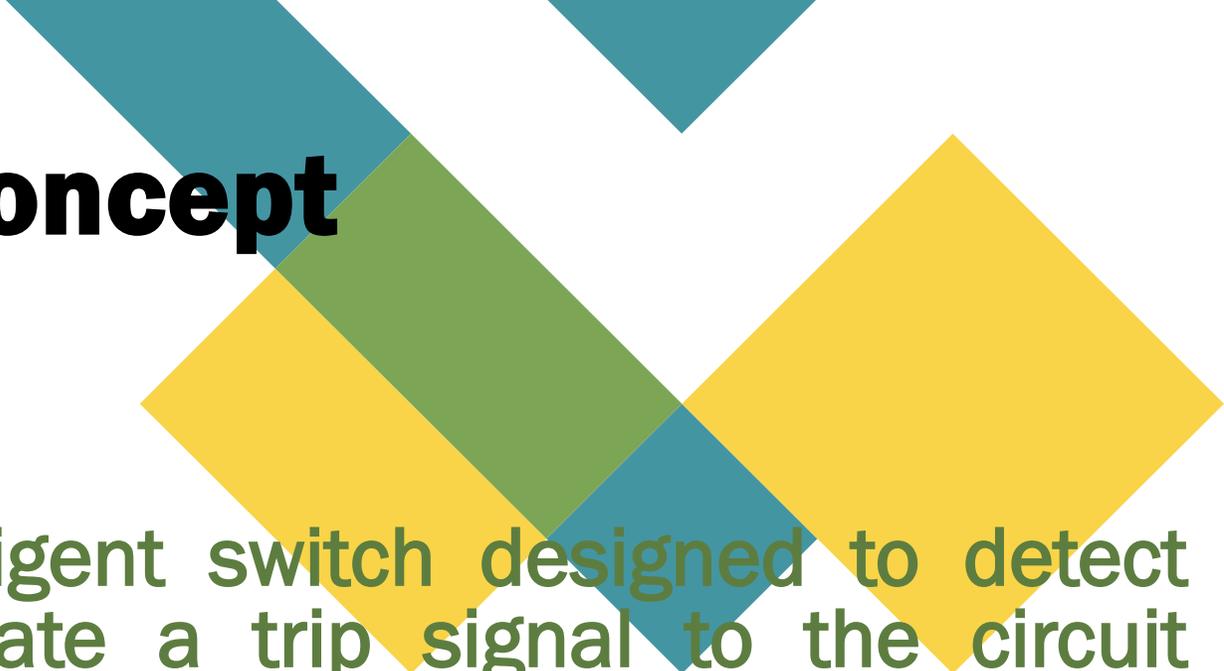
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- **Overloading:** Operating the transformer above its rated capacity.
 - *Effect:* Leads to slow, progressive overheating of the windings and insulation.
 - **External Heating:** High ambient temperature or poor ventilation.
 - **Protection Response:** Protection systems for overheating typically give an alarm first, and then trip the circuit breaker if the condition persists.

Classification of Protection Schemes



- **Electrical Protection: Detects electrical abnormalities (current, voltage, impedance).**
 - *Example:* Differential protection, overcurrent protection.
- **Non-Electrical Protection: Detects physical abnormalities (gas, pressure, temperature).**
 - *Example:* Buchholz relay, winding temperature indicator.

The Protective Relay Concept



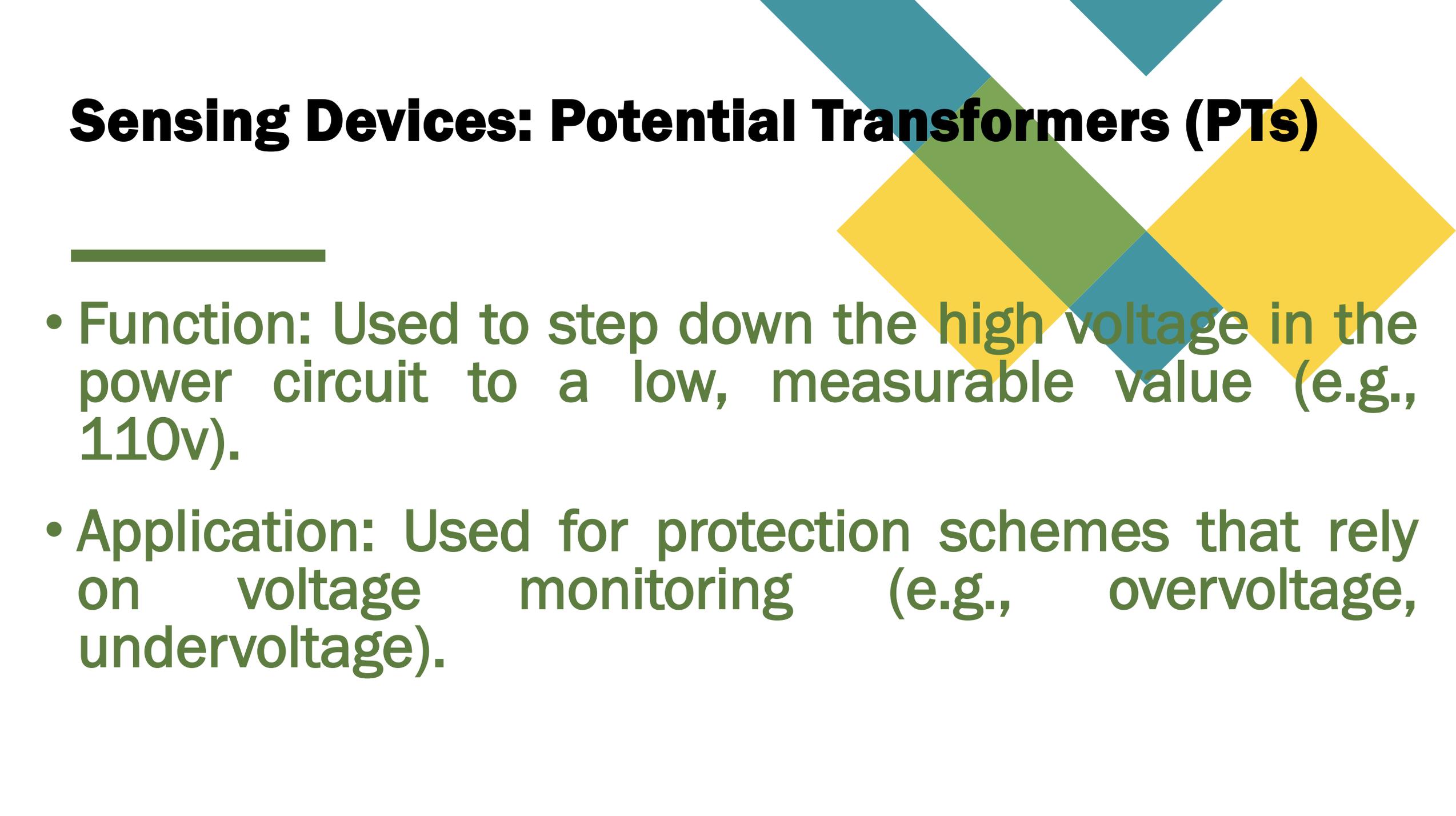
- **Definition:** A relay is an intelligent switch designed to detect abnormal conditions and initiate a trip signal to the circuit breaker.
- **Operation Sequence:**
 - **Sensing:** Current or voltage transformers sense an abnormality.
 - **Detection:** The relay compares the sensed values against its settings.
 - **Tripping:** If abnormal, the relay sends a signal to the circuit breaker to open and isolate the fault.

Sensing Devices: Current Transformers (CTs)



- **Function:** Used to step down the high current in the power circuit to a low, measurable value suitable for relays and meters.
- **Placement:** CTs are installed on the primary and secondary sides of the power transformer.
- **Principle:** They provide isolation and scaling for the relay circuitry.

Sensing Devices: Potential Transformers (PTs)



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- **Function:** Used to step down the high voltage in the power circuit to a low, measurable value (e.g., 110v).
 - **Application:** Used for protection schemes that rely on voltage monitoring (e.g., overvoltage, undervoltage).

Non-Electrical Protection: The Importance of Oil



- **Oil-Immersed Transformers:** Most large transformers use mineral oil for cooling and insulation.
- **Fault Signature:** Internal faults cause intense heat, which decomposes the oil, producing gases (like hydrogen, carbon monoxide).
- **Gas Detection:** Detecting these gases is a highly reliable way to find incipient (developing) internal faults.

The Buchholz Relay: Introduction



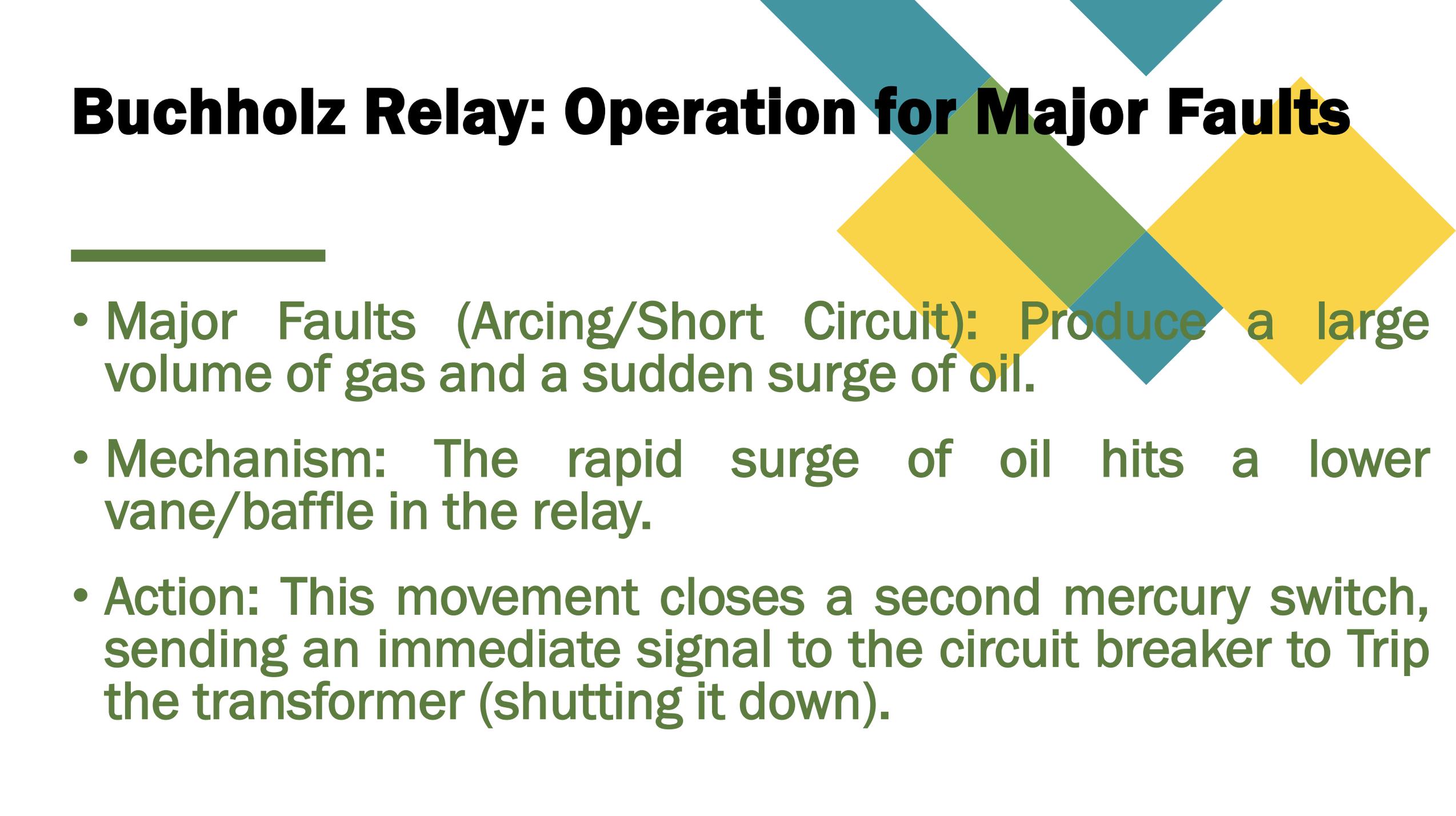
- **Location:** Installed in the pipe connecting the main transformer tank and the conservator tank (the small storage tank above the main tank).
- **Function:** A gas-actuated relay that protects against most types of internal faults, especially early-stage ones.
- **Nature:** It is the primary non-electrical protection device.

Buchholz Relay: Operation for Minor Faults



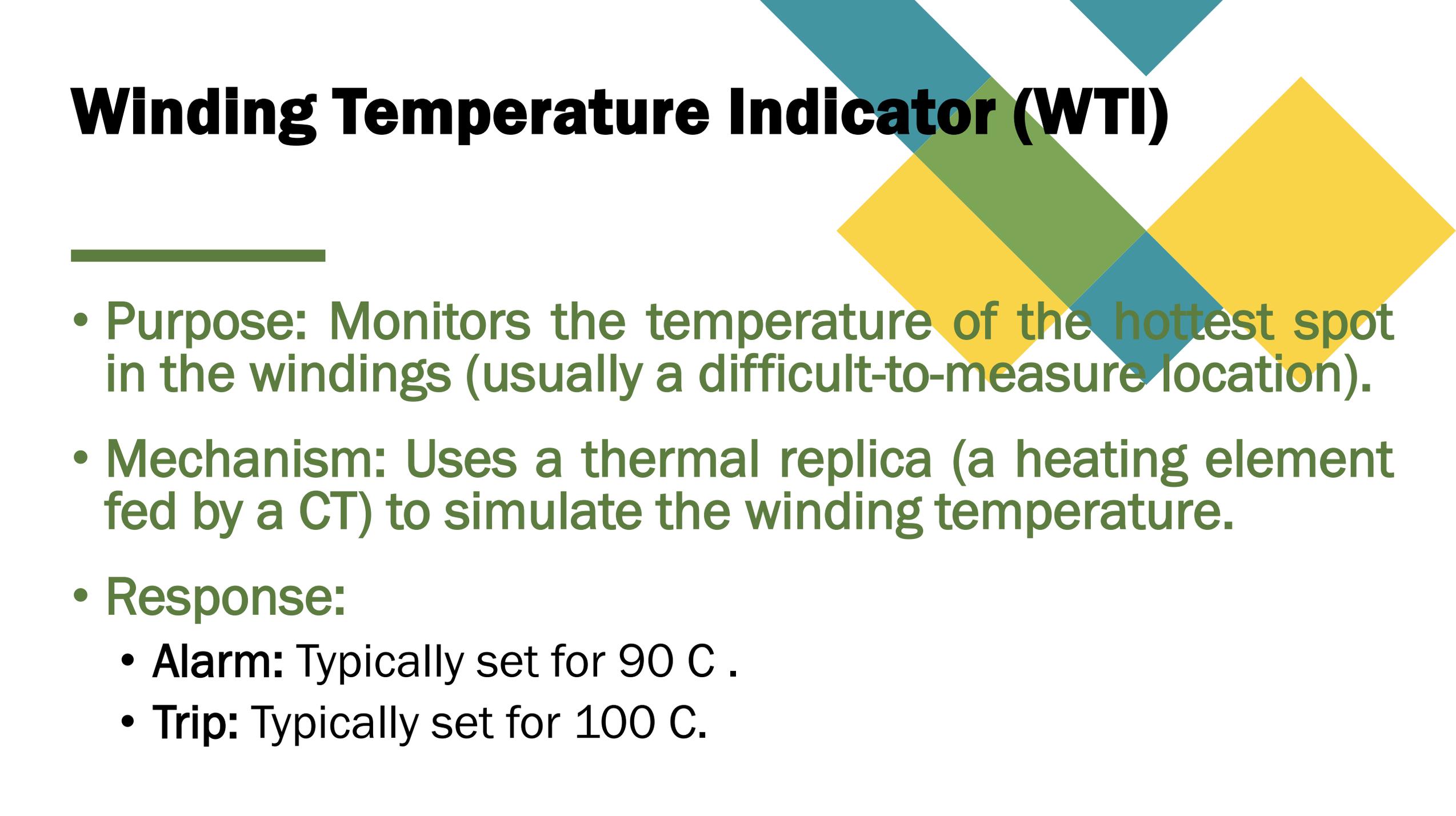
- Minor Faults (Slow Heating): Produce small amounts of gas bubbles.
- Action: Gas rises and collects in the upper part of the Buchholz relay chamber, displacing oil.
- Mechanism: The oil level drop tilts an upper float, closing a mercury switch and generating a Warning Alarm (Alerting the operator).

Buchholz Relay: Operation for Major Faults



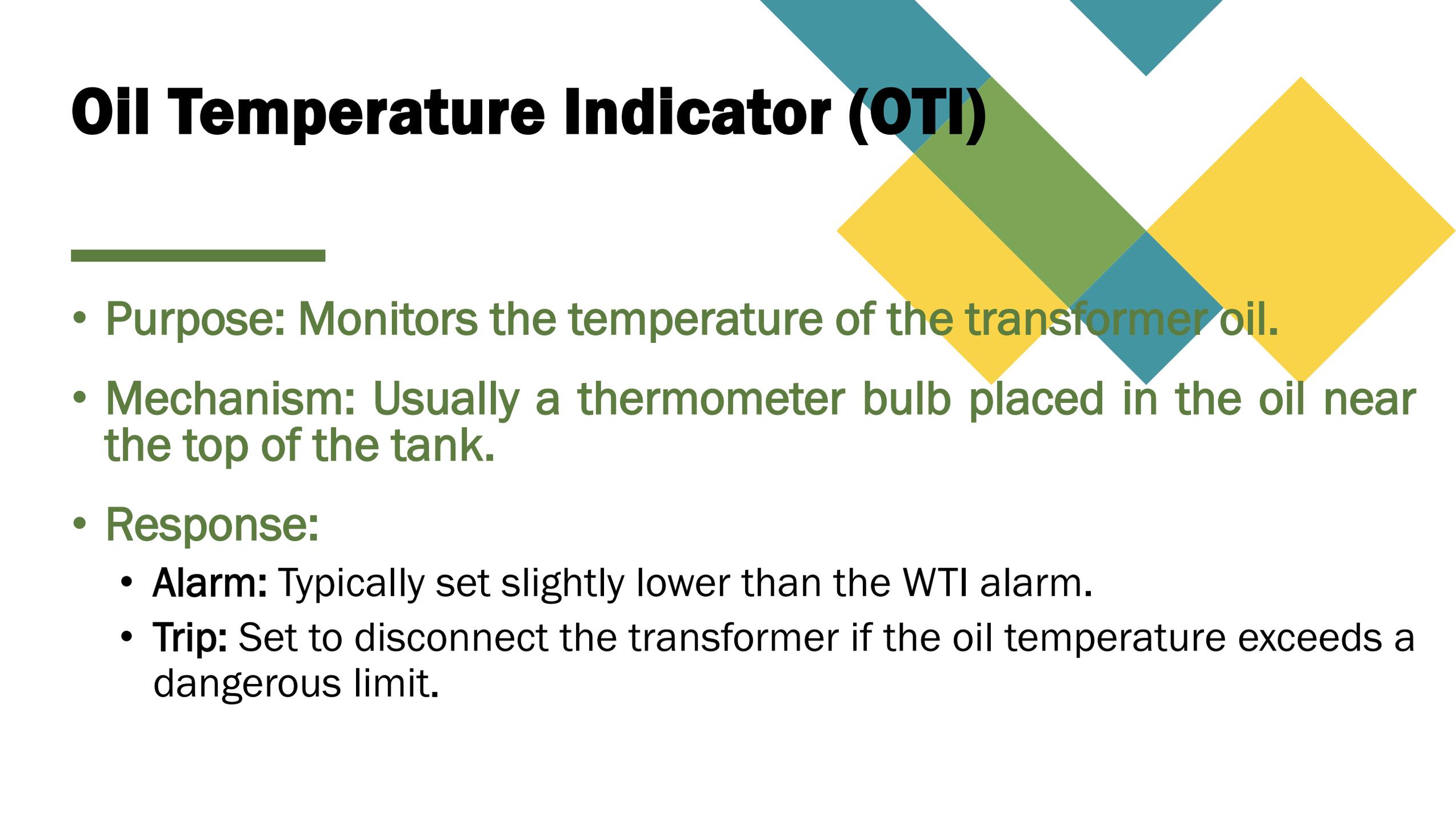
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- Major Faults (Arcing/Short Circuit): Produce a large volume of gas and a sudden surge of oil.
 - Mechanism: The rapid surge of oil hits a lower vane/baffle in the relay.
 - Action: This movement closes a second mercury switch, sending an immediate signal to the circuit breaker to Trip the transformer (shutting it down).

Winding Temperature Indicator (WTI)



- **Purpose:** Monitors the temperature of the hottest spot in the windings (usually a difficult-to-measure location).
- **Mechanism:** Uses a thermal replica (a heating element fed by a CT) to simulate the winding temperature.
- **Response:**
 - **Alarm:** Typically set for 90 C .
 - **Trip:** Typically set for 100 C.

Oil Temperature Indicator (OTI)



- **Purpose:** Monitors the temperature of the transformer oil.
- **Mechanism:** Usually a thermometer bulb placed in the oil near the top of the tank.
- **Response:**
 - **Alarm:** Typically set slightly lower than the WTI alarm.
 - **Trip:** Set to disconnect the transformer if the oil temperature exceeds a dangerous limit.

Pressure Relief Device (PRV)



- Purpose: Protects the tank against excessive internal pressure build-up.
- Cause of Pressure: Severe internal arcing instantly vaporizes the oil, creating a massive pressure wave.
- Mechanism: A spring-loaded valve or diaphragm that rapidly opens when internal pressure exceeds a safe limit. This prevents the tank from rupturing.

Electrical Protection: Differential Protection



- The Primary Electrical Method: Highly sensitive and fast for internal winding faults.
- Principle: Based on Kirchhoff's Current Law—the current entering a healthy zone must equal the current leaving it.
- Zone of Protection: The relays compare the current entering the primary winding with the current leaving the secondary winding.

Differential Protection: Components



- **Two Sets of CTs:** One set on the primary side (CT_1) and one set on the secondary side (CT_2).
- **Relay Coil:** The relay's operating coil (differential coil) is connected between the secondary circuits of the two CTs.

Differential Protection: Operation (Normal/External Fault)

- Normal Operation: I_p is proportional to I_s . The two CTs are matched, so the secondary currents are equal and 180° out of phase.
 - *Result:* Current through the relay coil is zero (or very close to zero). Relay **DOES NOT** trip.
- External Fault: A fault occurs outside the protected zone. The ratio I_p/I_s remains constant, and currents in the CT secondaries remain balanced. Relay **DOES NOT** trip.

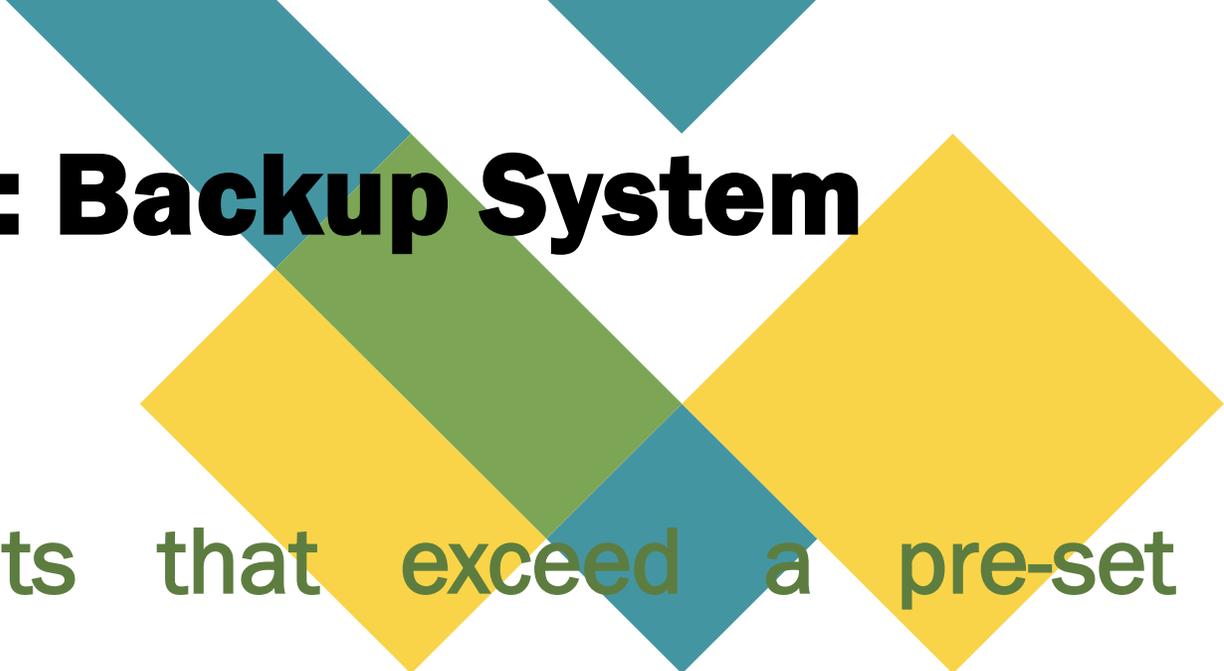
Differential Protection: Operation (Internal Fault)

- Internal Fault: A fault occurs inside the protected zone.
 - The current entering the primary is no longer equal to the current leaving the secondary.
 - *Result:* The secondary currents of CT₁ and CT₂ are unbalanced. This difference current flows through the relay coil.
 - *Action:* If the difference current is large enough, the relay instantly trips the circuit breakers on both sides.

The Stabilizing Feature: Biased Differential Protection

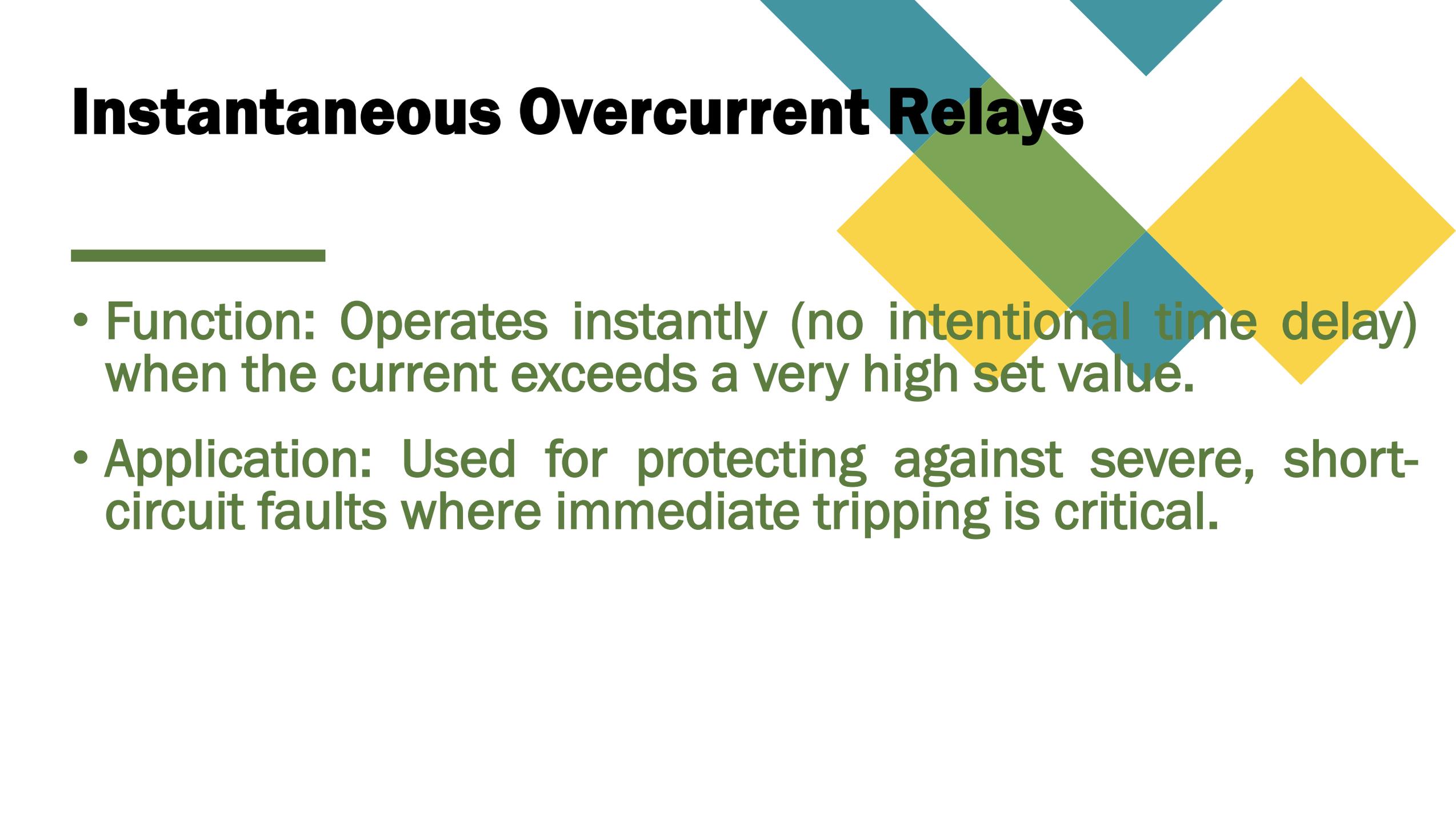
- Purpose: To prevent "false trips" due to minor mismatches or large external fault currents.
- Biasing Coil (Restraining Coil): An additional coil connected to circulate the average current from both CTs.
- Principle: The tripping current must be large enough to overcome the restraining force of the bias coil. The higher the through-fault current (external fault), the higher the restraining force.

Overcurrent Protection: Backup System



- **Definition:** Detects currents that exceed a pre-set maximum value.
- **Role:** Acts as the backup protection in case the primary differential system fails or is taken out of service.
- **Characteristic:** Slower than differential protection because it must have a time delay to allow downstream relays to operate first.

Instantaneous Overcurrent Relays



- **Function:** Operates instantly (no intentional time delay) when the current exceeds a very high set value.
- **Application:** Used for protecting against severe, short-circuit faults where immediate tripping is critical.

Time-Delayed Overcurrent Relays



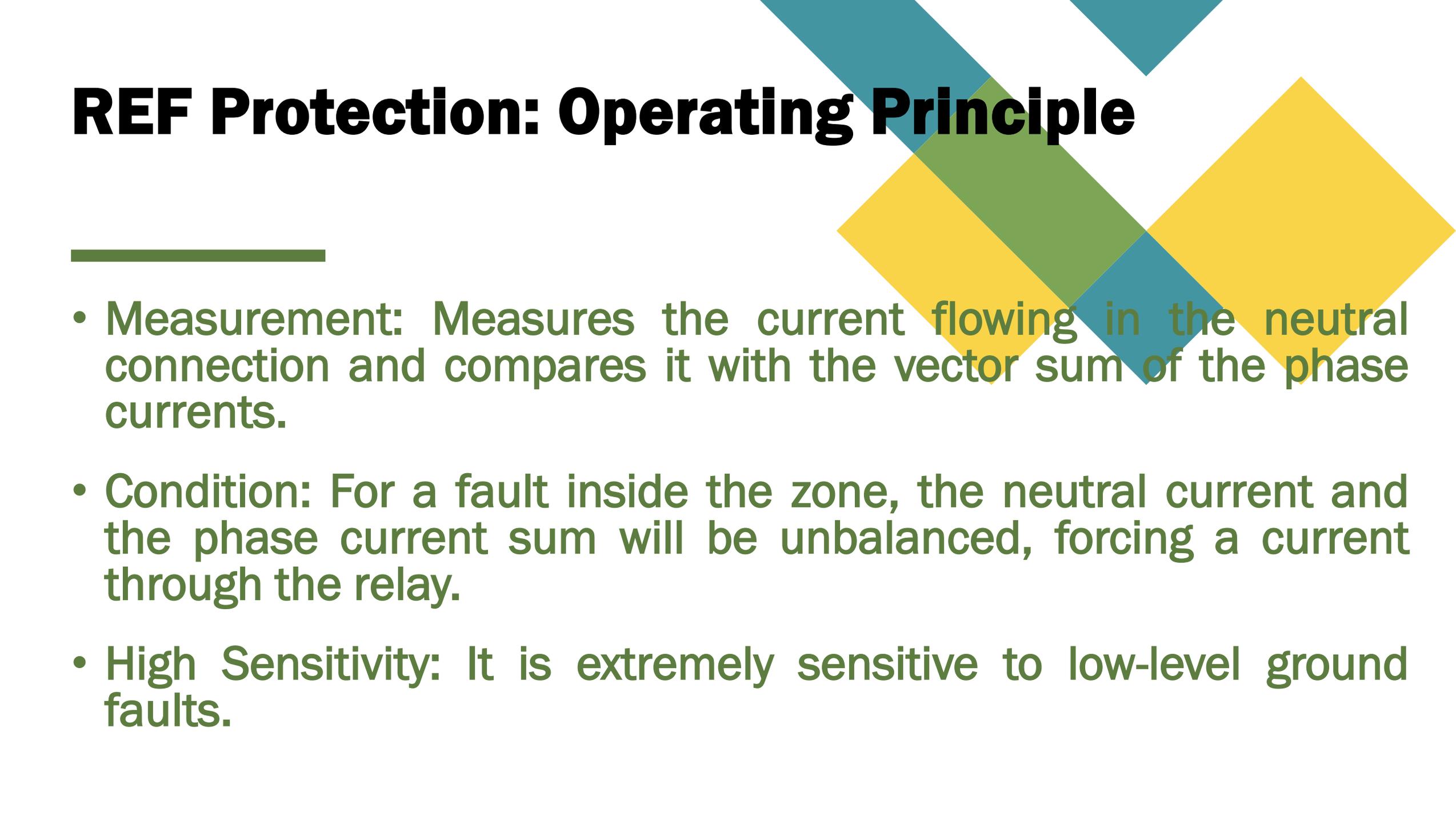
- **Function:** Provides an intentional delay before tripping, allowing coordination with other protective devices.
- **Types:**
 - **Definite Time:** Trips after a fixed time delay, regardless of how high the current is (above the pickup level).
 - **Inverse Definite Minimum Time (IDMT):** The tripping time is inversely proportional to the fault current magnitude.

Restricted Earth Fault (REF) Protection



- Purpose: Provides sensitive and fast protection specifically for earth faults (phase-to-ground faults) within the protected zone.
- Need: The main differential protection can sometimes be less sensitive to small earth faults, especially on Wye-connected windings.

REF Protection: Operating Principle



- **Measurement:** Measures the current flowing in the neutral connection and compares it with the vector sum of the phase currents.
- **Condition:** For a fault inside the zone, the neutral current and the phase current sum will be unbalanced, forcing a current through the relay.
- **High Sensitivity:** It is extremely sensitive to low-level ground faults.

Sudden Pressure Relay (SPR)



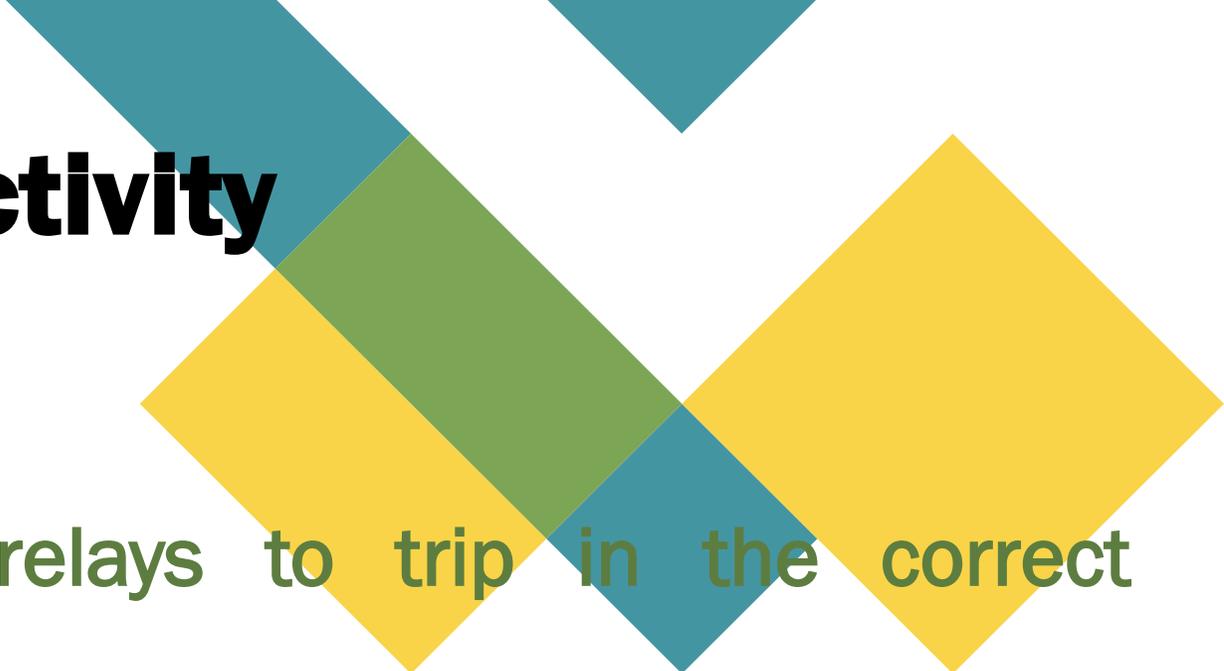
- **Application:** Used on sealed or nitrogen-blanketed transformers without a conservator tank.
- **Mechanism:** Monitors the rate of pressure change.
- **Action:** A sudden, rapid rise in pressure (indicating a fast internal fault) triggers an immediate trip. It is faster than the Buchholz relay for severe faults.

Intertripping Scheme



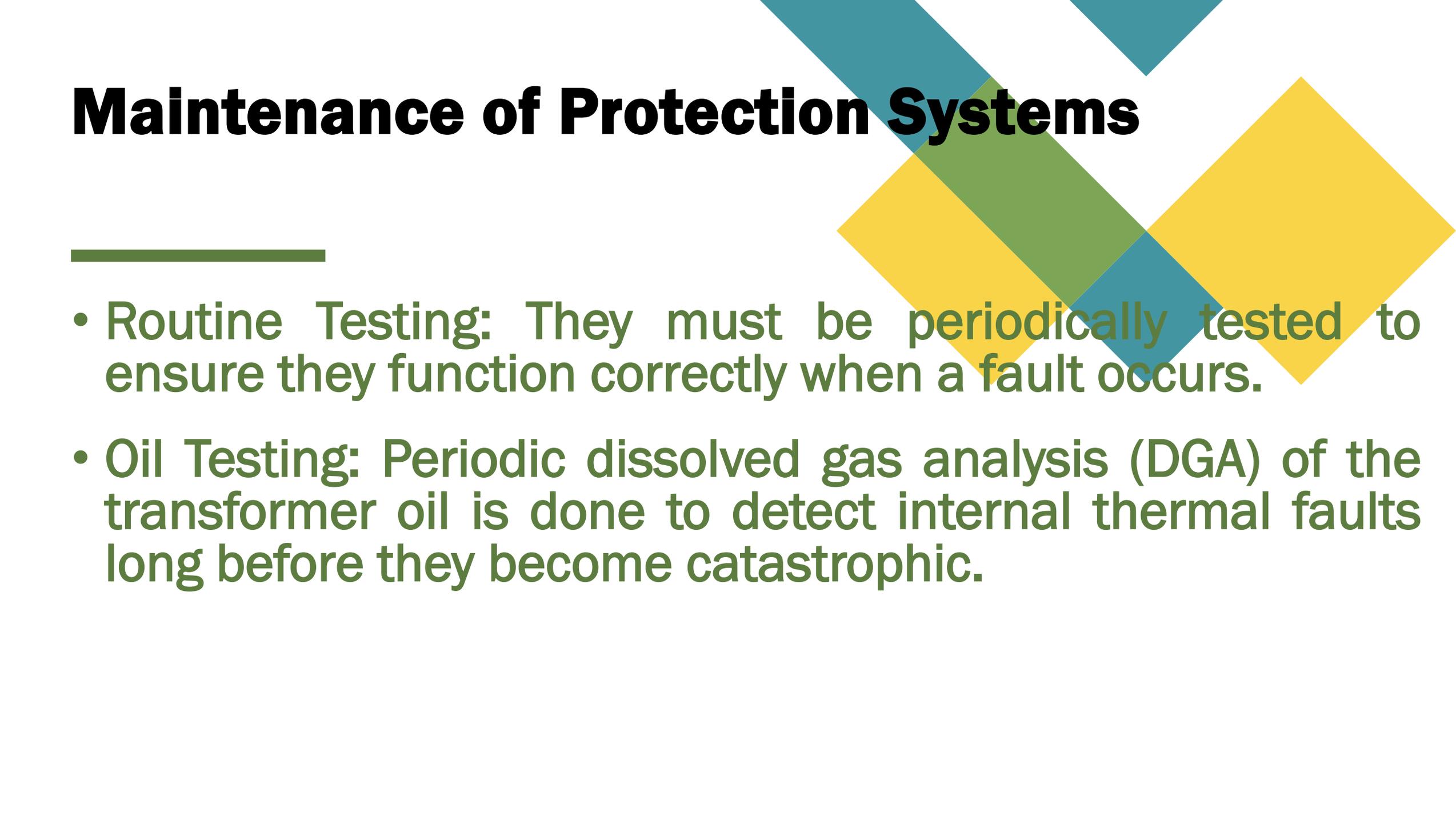
- Scenario: A fault is detected on the high-voltage side of the transformer.
- Need: The circuit breaker on the low-voltage side (feeder end) must also open simultaneously to completely isolate the transformer.
- Intertripping: A communication link (e.g., pilot wire or fiber optic) that sends a trip signal from one side's protection panel to the other side's circuit breaker.

Coordination and Selectivity



- Coordination: The ability of relays to trip in the correct sequence.
- Selectivity: The ability of the protection system to isolate only the minimum portion of the network necessary to clear the fault.
- Goal: A well-designed system ensures the nearest protective device trips first, minimizing disruption to healthy parts of the grid.

Maintenance of Protection Systems



- Routine Testing: They must be periodically tested to ensure they function correctly when a fault occurs.
- Oil Testing: Periodic dissolved gas analysis (DGA) of the transformer oil is done to detect internal thermal faults long before they become catastrophic.

The Digital Revolution in Protection



- **Modern Relays:** Digital/Microprocessor-based relays have largely replaced old electromagnetic relays.
- **Advantages:**
 - **Flexibility:** Easily programmable settings.
 - **Advanced Logic:** Can perform complex logic (like differential protection with tap changer compensation).
 - **Data Logging:** Records fault parameters (timing, currents, waveforms) for post-fault analysis.



Thank you

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