

### 3.0 BREAKER ELECTRICAL OPERATION

#### Learning Objectives

As a result of this lesson you will be able to:

1. Recognize and understand the function of electrical components used in the circuit breaker control circuit
2. Describe the function of the anti pump circuit
3. Understand the operation of the auxiliary switch “a” and “b” contacts
4. Understand the function of the protective relays and how they interface with the medium voltage circuit breaker to automatically trip (open) in the event of abnormal condition
5. Name the two common protection relays used on medium voltage breakers

### 3.1 BASIC ELECTRICAL OPERATION

Medium voltage circuit breakers (air-magnetic, SF6, or vacuum type) are designed to operate electrically. This is accomplished by electrical components on the circuit breaker operating mechanism. These electrical components operate cams, wheels, rollers, and latches to charge, close and open the breaker.

Electric operation:

- The secondary disconnect provides power to the breaker electrical components after the breaker is racked into the connect position in the switchboard cubicle.
- The charging spring normally charges automatically when the breaker is in the switchboard and the control fuses are installed.
- The breaker can now be closed and opened from a local control switch on the breaker cubicle door (Figure 3-1) or from a remote location (Control Room).

### 3.2 ELECTRICAL COMPONENTS

Each breaker manufacturer operating mechanism design is different, but the electrical components required to operate the breaker all have similarities. Therefore, basic schematics for the control circuit for each manufacturer generally are similar as well.

Charging motors, close coils, trip coils and associated switches are required to operate the breaker and the operating sequences are essentially the same for each manufacturer. Basic schematics for the control circuit for each manufacturer generally is the same regardless of the breaker size and the charge, close, and trip control pins on the secondary will nearly always be the same for all plant breakers (i.e. if a DHP breaker charges on pin 5 and 6 all DHP's). The auxiliary switch arrangements can be different and should always be verified prior to swapping cubicles.

The following components are usually part of all stored energy breaker electrical circuits:

- 3.2.1 Secondary Disconnect: normally a plastic insulated block with silver-plated copper fingers (male) or plates, which connect to a switchboard, or a mounted insulated block with silver-plated copper female receptacle pins or flat plates.
- 3.2.2 Charging Motor: an electrical motor similar to a hand drill, which moves the closing spring to a primed position (Figure 3-2).
- 3.2.3 Close Coil: operates the close latch.
- 3.2.4 Trip Coil: operates the trip latch.
- 3.2.5 Y Relay/ Anti Pump coil: locks out the control circuit if the close operation is not completed.
- 3.2.6 Auxiliary Switch (aux switch): a set of closed contacts and a set of open contacts which are connected to the main operating shaft by a link and changes position with the operation of the breaker main contacts. The aux switch contacts, which are open when the breaker is open, are called **“a contacts”** and the contacts that are **closed** when the breaker is open are called **“b contacts”**. The “a contacts” are in the same position as the breaker main contacts.
- 3.2.7 Position Operated Switches: interlock the breaker to allow it to operate only in the proper location, or change position and cut off a device.
  - Motor Cut Off Switch: normally operated from a timing cam, which operates the switch to open the normally closed contacts and de-energizing the motor when the breaker is charged. It can also have a set of normally open contacts, which close and complete the circuit to the close coil.

- Latch Check Switch: closes when a specific latch is in the proper position for the breaker to operate.

### 3.3 ELECTRICAL OPERATING SEQUENCE

The operating control voltage in most power plants is 125VDC or 220VDC and is provided to the breaker through the secondary disconnect. The secondary disconnect is also the interface for the auxiliary contacts on the breaker to the switchboard, and provides indication to the system on the breaker position.

A typical wiring diagram with DC control for the Westinghouse DHP is shown in Figure 3-3. We will be using this diagram to discuss the following electrical operating sequence of a circuit breaker.

#### 3.3.1 Electrical Charging:

The charging motor is energized automatically when breaker is racked in. In the schematic shown the motor is energized from pin 5 and 6 (Figure 3-3) on the secondary disconnect. The motor compresses the closing spring or springs and at the fully charged position the following occurs:

- The charging motor is in the skip tooth position of the ratchet wheel and stops pushing the mechanism.
- The closing prop/latch is engaged.
- The timing cam is in a position, which allows the motor, cut off bracket or actuator to move. This will actuate the switch contacts (Figure 3-2):
  - LSb, which opens the circuit to the charging motor disconnecting power to the charging motor. And
  - LSa, which closes indicating that the motor has completed its charge.
- The trip latch moves to a set position in preparation for closing the breaker.
- The trip latch moving to the set position actuates the latch check switch LCS closing the contact and completing the circuit to the spring release coil (Close Coil).

#### 3.3.2 Electrical Closing:

- The close coil (Commonly called a “X coil” or spring release coil) is energized by applying power to pin 6 and 7 (Figure 3-3) on the secondary disconnect.

When the close coil is energized it will disengage the closing prop from the closing spring allowing the spring energy to move the contacts and close the breaker.

- **Y Relay (Anti Pump):** The Y relay is a parallel circuit to the spring release coil. The anti pump relay is energized at the same time as the close coil, this will open the normally closed Y contact in the close circuit.

**The purpose of the Y Relay:** If the breaker does not close on the first attempt, and the close coil remains energized, the “Y Relay” provides a lock out to prevent the breaker from attempting another close. If the close signal is initiated but not removed the breaker has the potential to cycle through an endless close, trip, charge, close and trip cycle (Pumping). The Y coil opens the Y contact in the close circuit and as long as the close signal is present the breaker can’t re-close.

### 3.3.3 Tripping:

When the breaker closes the circuit to the trip coil is completed by a set of “a” contacts in the Auxiliary switch which changes position with the breaker. The close operation compresses or extends the breaker opening springs to provide tripping energy.

The trip coil is energized by applying power to pin 9 and 10 on the secondary disconnect. This pulls the trip latch, which allows the operating mechanism to collapse, and the contacts to open.

The trip coil is used to trip the breaker on normal trip from the control panel but is also used to trip the breaker during fault from the switchboard overload relays.

## 3.4 PROTECTIVE RELAYS

Circuit breakers designed to operate below 600 volts use trip-units and/or series connected elements built directly into the circuit and are internal to the breaker. This design becomes impractical when dealing with higher voltages. Hence the protective relay is incorporated.

By using transformers to reduce large currents and high voltages to lower ranges (usually 0-5 amps and 120 volts), very simple motors or electronic circuits can be used to externally control circuit breakers. This overview will scratch the surface of electrical circuit protection design deeply enough to provide a basic

understanding of how these devices work and how they are applied to their appropriate systems.

The primary purpose of the protective relay is minimizing damage to equipment and interruptions to power systems when electrical failures occur. When the word “protective” is used, it means that, together with other equipment, relays help to minimize damage and improve service. The function of protective relay equipment is to quickly reenergize any element of a power system when it operates in an abnormal manner, which can damage or interfere with the effective operation of the system. Protective relay equipment normally is used to control circuit breakers, which in turn disconnect the faulty element of the system. Another important function of protective relaying is to indicate the location and type of failure.

### 3.4.1 Types of Protective Relays

- **Electromechanical/Induction:**  
Most relays of this type use either electromagnetic attraction or electromagnetic induction principle for their operation. The electromagnetic, such as plunger type are instantaneous –type relays used for detecting over current conditions. The induction-type relays provide over current protection with time delays. Two or three input induction relays are used for directional or distance protection. Balanced-beam relays are used for differential protection. For general discussion, electromechanical relays can be classified into instantaneous (magnetic attraction) and time-delay (torque-controlled) units.
  - **Instantaneous units:** This type of relay unit may consist of a solenoid and plunger or a solenoid and a hinged armature. Magnetic attraction is the operating force.
  - **Time-delay units:** This type of unit consists of an induction-disk or induction-cup that has a magnetic field applied to it by two poles of an electromagnet which produce eddy currents in the disk or cup generating torque on the moveable rotor. A very simple motor.
- **Solid-state:** These relays use electronic components to provide protective functions similar to those provided by electromechanical relays. This style of relay employs discrete solid-state electronic components and has no moving parts. Most versions of solid-state relays are simple devices that provide a single function, such as voltage, current, frequency, or phase angle measurement similar to electromechanical relays.

- Microprocessor (Numerical): These devices provide multiple protective functions in a single unit, thus reducing product and installation costs significantly. The basic protection principles remain the same. Microprocessor relays are also referred to as numerical relays because they calculate algorithms numerically. Basic construction consists of a microprocessor, an AC signal data acquisition system, and memory components containing the relay algorithms, contact inputs to control the relay, and contact outputs to control other equipment. The algorithms and settings contained in the relay memory define the protection characteristics.

### 3.4.2 Instrument transformers:

Instrument transformers are an essential part of an electrical relaying system. The quality of instrument transformers will directly affect the overall accuracy and performance of these systems. Instrument transformer performance is critical in protective relaying, since the relays can only be as good as the instrument transformers. The basic function is to change the magnitude (but not the nature) of primary voltage and current to secondary values to 120 volts and 5 or 1 amp where relays can be applied.

When relays compare the sum or difference of two or more currents or the interaction of voltages and currents, the relative direction of the current must be known. The direction of current flow can be determined by knowing the instrument transformer polarity. Polarity markings are normally shown on instrument transformers.

- Current Transformers: Current transformers are designed for connection in the primary circuit (either in series or around the primary circuit). The secondary current of the transformer bears a known relationship with the primary current. Any change in the primary current is reflected in the secondary circuit. Relays are connected to the secondary terminals of the CT's. CT's are made in many different ratios, different voltage insulation systems, and for different environmental conditions such as indoor or outdoor use.
  - Accuracy class: Separate accuracy standards (ANSI) are established for metering CT's and for relaying CT's. Relaying CT's are required to carry a much greater burden (load) as compared to metering CT's.

- Single and multi-ratio: CT's may have two secondary terminals providing a single primary-to-secondary ratio or they may have multiple secondary terminals (usually 5) allowing multiple options for the required ratio.
- Voltage Transformers: The purpose of the VT is to provide an isolated secondary voltage that is an exact proportionate representation of primary voltage. ANSI standards for accuracy are also established for VT's.

### 3.4.3 Relay system characteristics

There are four basic characteristics required for a relay to perform its function properly.

- Sensitivity: The relay must be sensitive enough to operate under the minimum conditions expected.
- Selectivity: Selectivity of a protective relay is its ability to recognize a fault in a particular zone of protection and trip a minimum number of circuit breakers to clear that fault. When the relay detects fault conditions that don't apply to its zone it should not operate. An example of an inherently selective scheme is differential relaying. The zone of protection is clearly defined. Faults can occur upstream or downstream of the zone with no action taken by the differential relay. Other relays should be designated for those specific conditions.
- Speed: High speed indicates that the operating time usually does not exceed 50 ms (three cycles on a 60 Hz system). The term instantaneous indicates that no intentional delay is introduced in the operation. Speed is essential in clearing a malfunctioning portion of a power system since it has a direct bearing on the damage done by a short-circuit and consequently, the cost and the delay in making repairs. The speed of operation also has a direct effect on the general stability of the power system.
- Reliability: System reliability consists of two elements, dependability and security. Dependability is the degree of certainty of correct operation in response to system trouble, whereas security is the degree of certainty that a relay will not operate incorrectly. Unfortunately, increasing security tends to decrease dependability and vice versa. Modern relaying systems are highly reliable and provide a practical compromise between security and dependability. Most older systems have stood the test of time and adjustments to their protection are made as required.

### 3.4.4 Common Switchboard protective relay functions

- Over current relays: When excessive current flows in a circuit, it is necessary to trip the circuit breaker protecting that circuit. This type of protection is usually provided by either time delay or instantaneous over current relays. The instantaneous relay, although inherently fast, requires a short time to operate, whereas time-delay relays have intentional time delay built into them to provide coordination with other over current relays for selectivity. The selectivity is obtained by adjustment of current setting and time, using the most applicable of several time characteristics. The relay time characteristics differ by the rate at which the time of operation of the relay decreases as the current increases. This can be represented graphically by the relays TCC curve (Time Current Characteristic). Some common relay TCC curve families are identified as inverse, very inverse, extremely inverse, and definite time. There are many more and custom curves can be developed in microprocessor type relays.
- Over-under voltage relays: Over-under voltage relays have characteristics similar to the over current relays. The actuating quantity in the operating element is voltage instead of current. Voltage relays often combine the under-over voltage elements in one relay, with contacts for either and under voltage or over voltage condition. These relays may be used to trip the breaker or sound an alarm when the supervised voltage exceeds a predetermined limit or falls below a predetermined value.
- Directional relays: Directional relays are used when it is desirable to trip the circuit breaker for current flow in one direction only. This is achieved by making the relay distinguish certain differences in phase angle between current and reference voltage or current. The directional relay has a current winding and directional winding. The current winding is connected to the CT and the directional winding is connected to the VT's to provide the circuit voltage for polarizing the unit. The trip contacts of the relay will only operate when there is sufficient current magnitude and the phase angle relationship between this current and the polarizing voltages are within the predetermined range. The directional relay thus establishes one boundary of the protected zone. Directional relaying is often used where coordination becomes a problem, such as in a tie circuit between two supplies.



- Voltage or current balance relays: Voltage or current balance relays compare the magnitudes of voltage or current present on each phase of a three-phase system. Voltage balance relays can detect a change in the phase sequence (phase reversal), loss of a phase, or an abnormal reduction in a phase voltage due to a system fault or supply problem. Current balance supervision between phases of a motor is used to protect the machine against overheating when phase currents become unbalanced due to short-circuits or an open fuse.
- Differential relays: Differential relaying provides selectivity by providing a zone of protection with a circuit of interconnected CT's. CT's having the same ratio are installed in all the connections to the component to be protected and the secondary of the CT's are connected in parallel to the relay. As long as the current flow through the protected component is unchanged in magnitude and phase, the relay does not pick up. Such a condition would occur for a short-circuit fault outside the zone of relay protection. Should a fault occur inside the zone of relay protection (that is between the CT's), the differential relay would receive current in the operating coil. Differential relays are designed to provide fast selective short-circuit protection.

### 3.4.5 Relays as applied to the Switchboard

#### 3.4.5.1 Main Breaker protection

- Phase and ground time-over current
- Phase and ground instant over current
- Phase and ground directional over current
- Voltage protection
- Over/under voltage
- Unbalance/phase loss/phase sequence

#### 3.4.5.2 Feeder circuit protection

- Phase and ground time-over current
- Phase and ground instant over current

#### 3.4.5.3 Relay coordination

- Breakers closest to a fault should be cleared before up-stream breakers.

#### 3.4.5.4 Bus differential protection

- Over current
- High impedance

#### 3.4.5.5 Transformer protection

- Differential
- Sudden pressure
- Backup over current

#### 3.4.5.6 Motor circuit protection

- Usually in MCC
- Thermal capacity
- Phase and ground fault
- Overload
- Locked rotor/mechanical jam/ instantaneous short circuit
- RTD inputs
- Phase sequence
- Negative sequence current
- Load loss

#### 3.4.6 Circuit breaker control

- Electro-mechanical and Solid-state relays: Trip output contacts are connected in the DC trip circuit of the relay or to the operating coil of a lockout device which is in turn connected to the breaker trip circuit.
- Microprocessor relays: Microprocessor relays have multiple output contacts allowing direct trip control of the breaker for certain protection elements and/or lockout trip control for other selected elements. Outputs contacts may be connected in the closing circuit of the breaker allowing local or remote closing operations through the relay. These relays are also equipped with input sensing circuits that can be connected to breaker auxiliary contacts or cell switches so the relay can monitor the breaker status (open/closed, connected/disconnected). Numerous inputs are accommodated in this type of relay allowing tremendous flexibility of control over a circuit breaker. Custom logic can be applied in the relay software for automatic operation of multiple circuit breakers.
- Relay settings: The individual elements that make up a protective relay are adjustable. This is where sensitivity and selectivity are applied. The level of protection or pickup point is defined by a setting. If applicable a time delay may also be selected. Pickup settings options are usually one of two formats, secondary values or per-unit values.
- Secondary values: The actual current or voltage that will be measured at the relay terminals.

- Example: An electromechanical time over current relay has a 300:5 CT connected to it. The pickup setting 3.3 is the current that will be measured at the relay terminals when 180 amps of primary current passed through the CT. At that time the induction disc will start to move.
- Per-unit values: A percentage of the CT rating.
  - Example: A microprocessor relay has a 300:5 CT connected to it. The per-unit value of the above setting (180 amps primary) is 0.6 x CT.  
 $0.6 \times 300 = 180 \text{ amps primary}$   
 $0.6 \times 5 = 3 \text{ amps secondary}$

#### 3.4.7 Actually setting the relay:

- Electromechanical: Manually place screw in the desired tap on the relay. Turn time-dial to the desired delay band.
- Solid-state: Usually setting a dial on the face for the relay for the pickup and delay.
- Microprocessor: The easiest method is connecting a laptop to the relay with required communication cable and utilizing the manufacturer's software to install protection and logic settings. Settings files may be developed with OEM software without being connected to a relay. These files can then be installed directly into the relay without having to enter settings for each element individually.

#### 3.4.8 Summary

Without the protective relay, the medium voltage circuit breaker is nothing more than a switch. It needs to be told when to close and when to open. Technology offers us many new and innovative ways to do just that. Despite all these terrific ideas we still have relays that are 30-40 years old that need to remain in service. There is quite a broad range of protective devices one may encounter in a medium voltage switchboard. What we have shown today is only the tip of the iceberg. Protective relaying is a science all its own.

#### 3.4.9 ANSI protective relay designation numbers

There are nearly 100 ANSI relay code numbers, the following table lists relays that could be found on medium voltage breaker protection scheme.

**TABLE 3-1**

CODE	FUNCTION
21	<b>Distance Relay</b> is a relay that functions when the circuit admittance, impedance, or reactance increases or decreases beyond predetermined limits.
25	<b>Synchronizing or Synchronism-Check Device</b> is a device that operates when two a-c circuits are within the desired limits of frequency, phase angle, or voltage, to permit or to cause the paralleling of these two circuits.
27	<b>Undervoltage Relay</b> is a relay that functions on a given value of under-voltage.
32	<b>Directional Power Relay</b> is a device that functions on a desired value of power flow in a given direction or upon reverse power resulting from arc back in the anode or cathode circuits of a power rectifier.
40	<b>Field Relay</b> is a relay that functions on a given or abnormally low value or failure of a machine field current, or on excessive value of the reactive component of armature current in an a-c machine indicating abnormally low field excitation.
46	<b>Reverse Phase or Phase Balance Current Relay</b> is a relay that functions when the polyphase currents are of reverse-phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.
47	<b>Phase-Sequence Voltage Relay</b> is a relay that functions upon a predetermined value of polyphase voltage in the desired phase sequence.
49	<b>Machine or Transformer Thermal Relay</b> is a relay that functions when the temperature of a machine armature or other load-carrying winding or element of a machine or the temperature of a power rectifier or power transformer (including a power rectifier transformer) exceeds a predetermined value.
50	<b>Instantaneous Overcurrent or Rate -of-Rise Relay</b> is a relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise, thus indicating a fault in the apparatus or circuit being protected.
51	<b>A-C Time Overcurrent Relay</b> is a relay with either a definite or inverse time characteristic that functions when the current in an a-c circuit exceed a predetermined value.
62	<b>Time-Delay Stopping or Opening Relay</b> is a time-delay relay that serves in conjunction with the device that initiates the shutdown, stopping, or opening operation in an automatic sequence or protective relay system.
63	<b>Liquid or Gas Pressure or Vacuum Relay</b> is a relay that operates on given values of liquid or gas pressure or on given rates of change of these values.
67	<b>A-C Directional Overcurrent Relay</b> is a relay that functions on a desired value of a-c over-current flowing in a predetermined direction.
79	<b>A-C Reclosing Relay</b> is a relay that controls the automatic reclosing and locking out of an a-c circuit interrupter.
81	<b>Frequency Relay</b> is a relay that functions on a predetermined value of frequency

	(either under or over or on normal system frequency) or rate of change of frequency.
85	<b>Carrier or Pilot-Wire Receiver Relay</b> is a relay that is operated or restrained by a signal used in connection with carrier-current or d-c pilot-wire fault directional relaying.
86	<b>Locking-Out Relay</b> is an electrically operated hand, or electrically reset relay or device that functions to shut down or hold equipment out of service, or both, upon the occurrence of abnormal conditions.
87	<b>Differential Protective Relay</b> is a protective relay that functions on a percentage or phase angle or other quantitative difference of two currents or of some other electrical quantities.



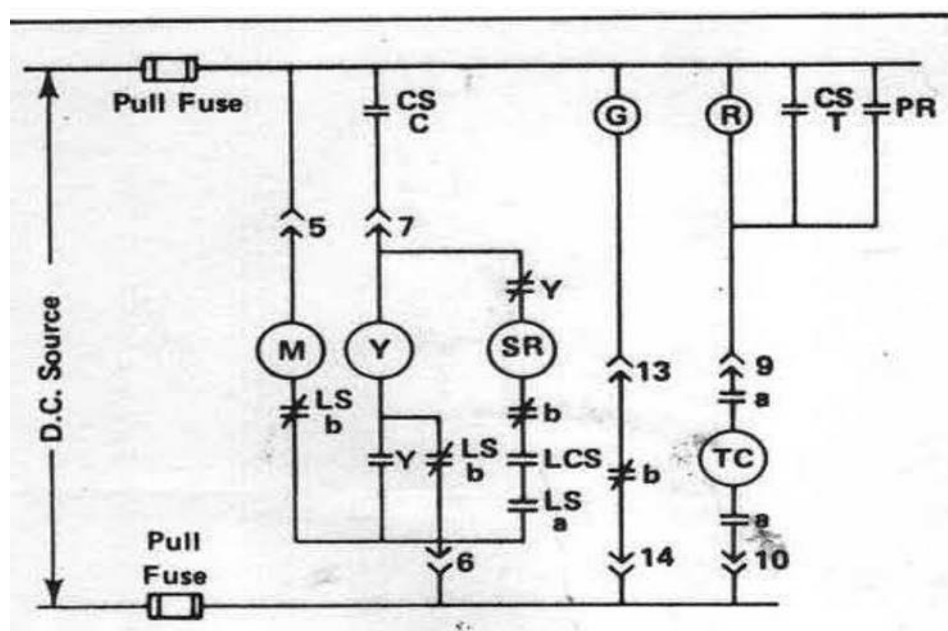
FIGURE 3-1 Cubicle breaker control switch





Figure 3-2 typical circuit breaker charging motor





CS- BKR Control Switch	TC-Trip Coil
Y- Control Relay (Anti-Pump)	PR- Protraction Relay
SR- Spring Release (Close)	G -Green indicating light
M- Spring Charging Motor	R-Red Indicating Light
LSb (NC)- Motor Cutoff Switch	LSa (NO)- Permissive Close
LC-Latch Check Switch	a- Auxiliary Switch Contact
b- Auxiliary Switch Contact	

Figure 3-3. Typical DC Control Scheme for Westinghouse DHP

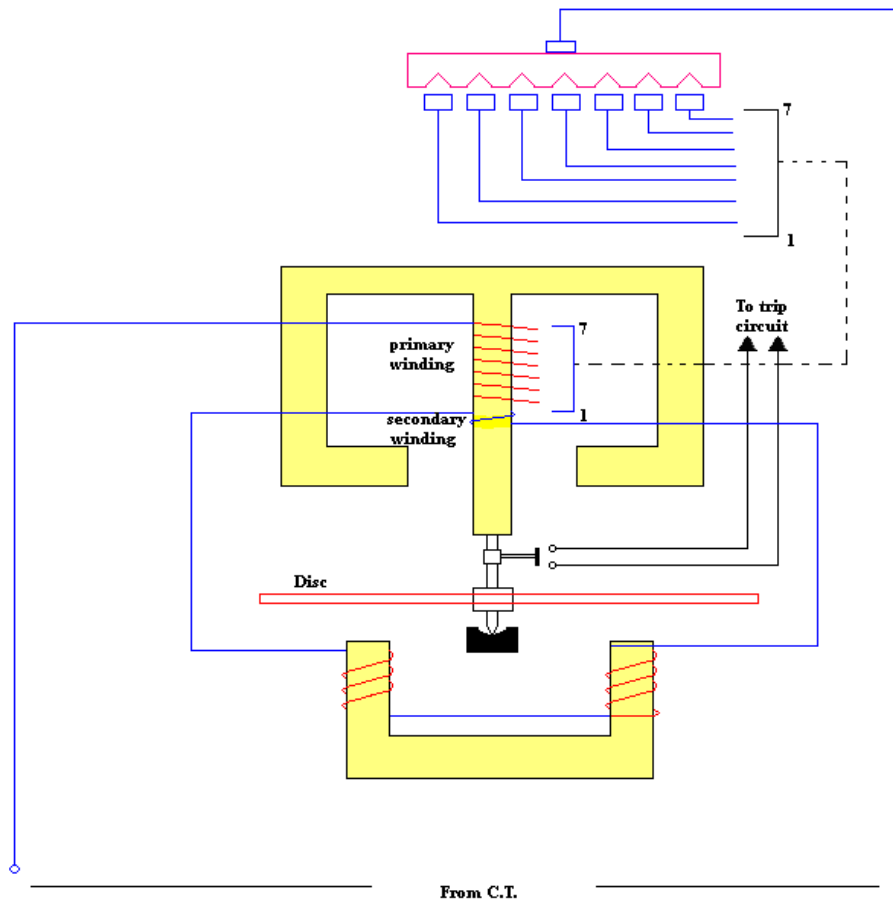


Figure 3-4 Typical Protective Relay