# First Course on Power Systems

## Module 13: Protection of Power Systems: Transmission Line Faults and Over-votages

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**Reference Textbook:**
**First Course on Power Systems by Ned Mohan, www.mnpere.com**

# Protection of Power Systems

- Protection against Short-Circuit Faults
- Causes of Over-Voltages
- Insulation to Withstand Faults
- Surge Arresters and Insulation Coordination

# Protection Against Short-Circuit Faults

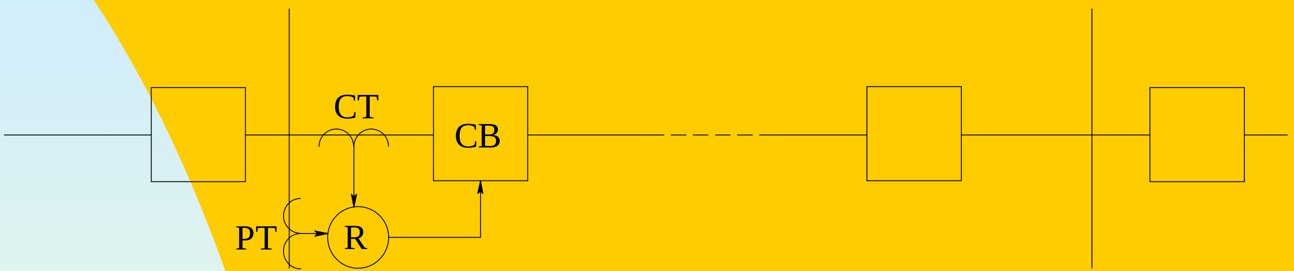
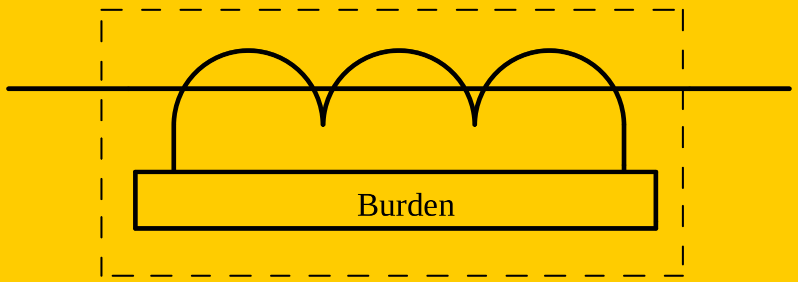



Fig. 13-14 Protection equipment.

- **Current and voltage transformers**
- **Relays**
- **Circuit Breakers**

# Current Transformers (CT)

(a)

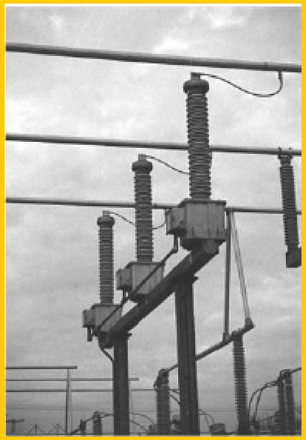



(b)

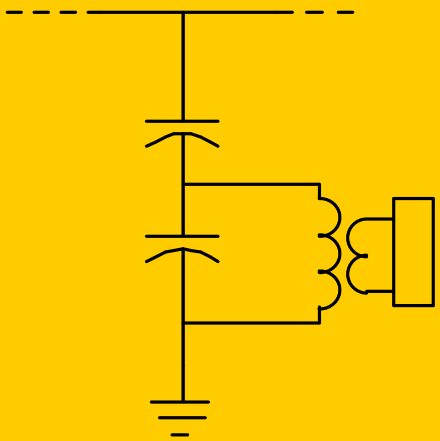
Fig. 13-15 Current Transformer (CT) [5].

- **The current transformer (CT) is a transformer in which the power system current flows through its primary which usually has a single turn.**
- **The secondary generally has a large number of turns and produces a much smaller current, primary current divided by the turn-ratio, which flows through a small load referred to as "burden".**
- **The current-sense signal associated with it is used in the relay logic.**

# Capacitor-Coupled Voltage Transformers (CCVT)



(a)



(b)

Fig. 13-16 Capacitor-Coupled Voltage Transformer (CCVT) [5].

**The capacitor-coupled voltage transformer (CCVT) uses the capacitive voltage-divider principle where the output voltage of this divider is isolated through a transformer for safety purposes.**

# Relays

- Relays decide if a fault has occurred and if it should be interrupted by the circuit breaker.
- It is important that relays operate, when they should, in order to protect power system but it is equally important that they don't operate falsely in order to avoid causing unnecessary power disturbances.
- In relays, three things are important:
  - Selectivity
  - Speed
  - reliability

# Differential Relays

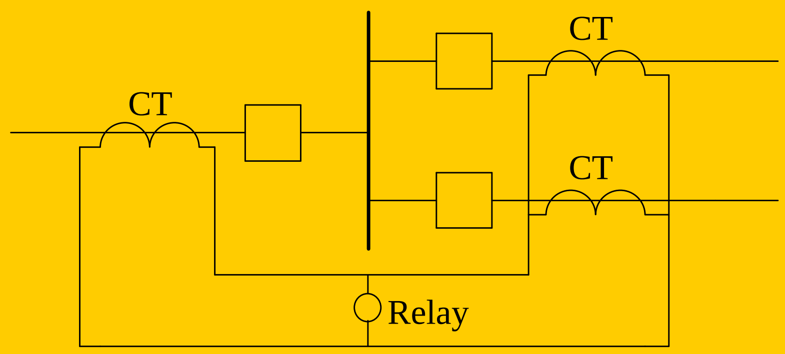



Fig. 13-17 Differential relay.

- These relays may be used, for example to protect a generator, a bus or a transformer against internal faults.
- Under normal conditions the differential current through the relay, which is the difference between the measured currents, is zero. This is not so under an internal fault condition, causing the fault current to trip the circuit breaker.

# Over-Current Relays

- In these relays, if the current being measured exceeds a minimum value that is greater than the maximum load current by a certain factor, the relay determines that a fault has occurred, giving a “trip” command to the circuit breaker to operate.
- Generally, such relays operate on a delay time basis where this delay time is a nonlinear function of the magnitude of the fault current; larger the current magnitude, shorter the delay time.

# Directional Over-Current Relays

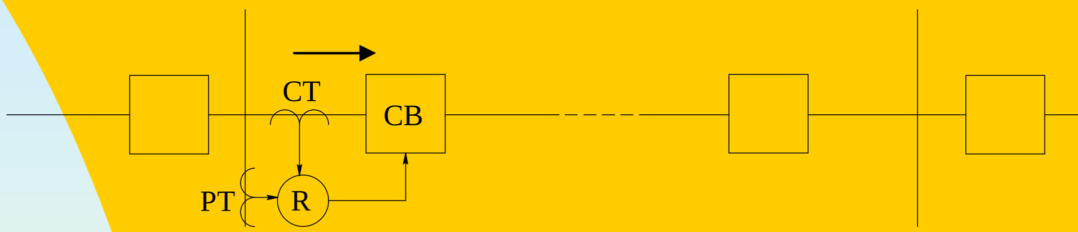



Fig. 13-18 Directional over-current Relay.

- **The protection offered by this relay is for faults only in one direction. For example, in the figure above, if the fault occurs right of its CT location, the current *I sensed by this relay would be lagging with respect to the* voltage at this location, causing the relay to trip the circuit breaker. Whereas for the fault left of its CT location, the current would be leading and the relay would be blocked from tripping the circuit breaker.**

# Ground Directional Over-Current Relays for Ground Faults

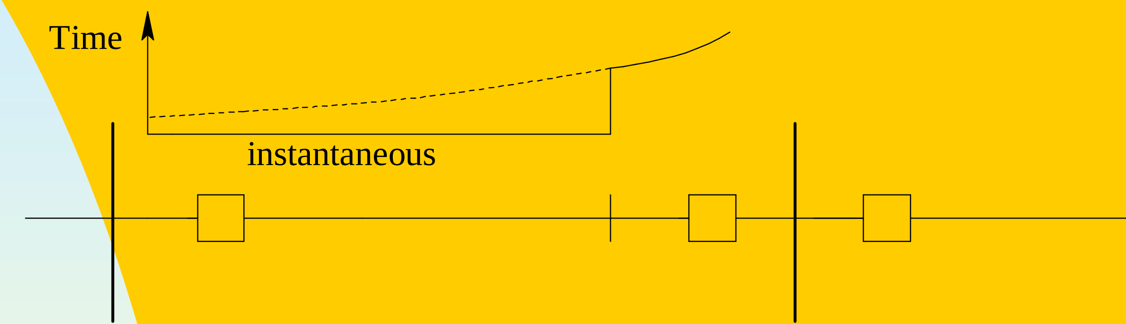



Fig. 13-19 Ground directional over-current Relay.

- **These are zero-sequence relays which as the figure above shows, act instantaneously in issuing a trip command to the circuit breaker if the fault is within 85% of the line; otherwise the time is increased as shown.**

# Impedance (Distance) Relays

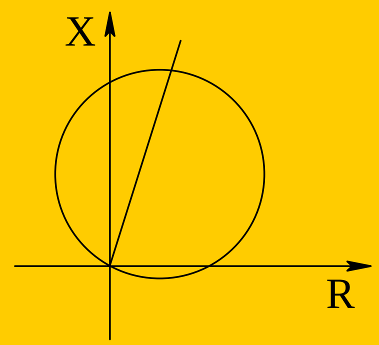



Fig. 13-20 Impedance (distance) relay.

- **By calculating the ratio of the measured voltage magnitude and the measured current magnitude, these bidirectional relays determine the impedance, and hence the name, which is an indication of the distance along the line that the fault has occurred.**
- **In an *$R - X$ plane shown in the figure above, if the* calculated impedance falls within the circle, the relay will trip; otherwise it is blocked.**

# Microwave Terminal for Pilot Relays

Fig. 13-21 Microwave terminal [5].

- Pilot relays use the communication channel, like the microwave shown in the figure above, the power-line carrier or the fiber-optics, to communicate between the two terminals of a transmission line being protected by such relays.
- If a fault occurs that is internal to the transmission line, the relays issue commands to circuit breakers at both ends of this line to interrupt the fault.

# Zones of Protection

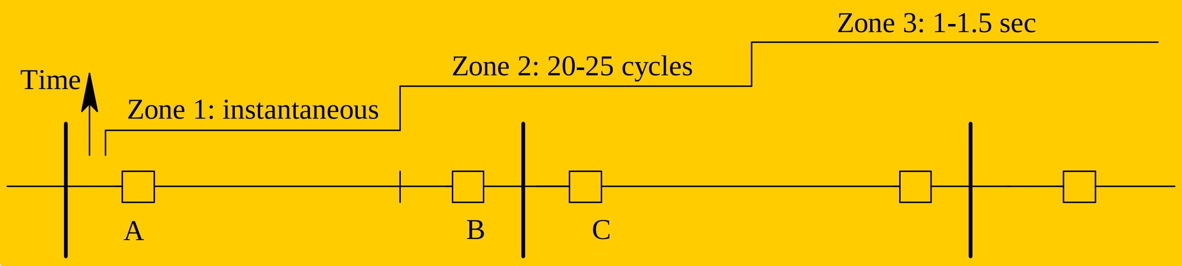



Fig. 13-22 Zones of protection.

- Each zone encompasses one or more power system equipment, and adjacent zones are overlapping so that no part of the power system is left unprotected.
  - The first zone for the relay at A encompasses for example 90% of the line. The remaining 10% is protected by the relay at B. If the fault occurs in A's first zone, the relay acts instantly without any time delay
  - The second zone for the relay at A encompasses for example 120% of the line, thus overreaching in the next section. If the fault occurs in the second zone assigned to it, it operates with a time delay of a few hundred msec, thus allowing it to coordinate with the relay that is its first zone.
  - The adjacent zone consisting of line CD is the third zone for the relay A for which it provides backup protection with a further time delay of 1 to 3 seconds.

# Protection of Generator and its Step-up Transformer

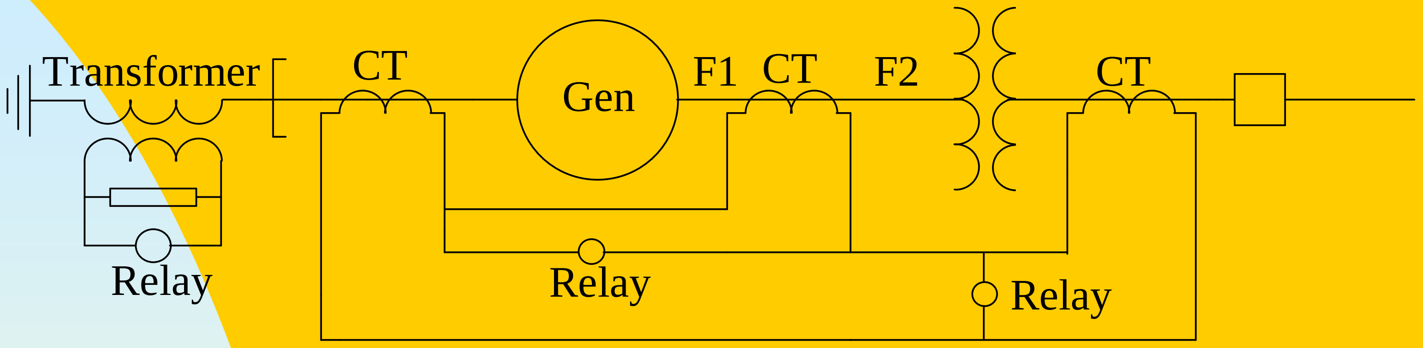



Fig. 13-23 Protection of generator and the step-up transformer.

- **Figure above shows the relaying scheme for protecting a generator and the step-up transformer associated with it. The generator neutral is grounded through an impedance that is connected to the secondary of a transformer, as shown. If a fault is detected, the circuit breaker is tripped, the field-excitation is removed and steam is vented out.**

# Circuit Breakers

Fig. 13-25 $SF_6$ circuit breaker [5].

- Circuit breakers, commanded by relays, interrupt the flow of current and break the circuit in order to protect power equipment from short-circuit faults.
- There are circuit breakers available that can operate in two cycles and further improvements are continuously being made.
- Various different principles are used to elongate and cool the arc established by the parting contacts as they try to interrupt the current through them; this process is helped in case of ac circuits where current goes to zero naturally every half-cycle.
- Circuit breakers use a method of arc interruption based on their voltage level. At 345-kV and above, most circuit breakers use sulfur hexafluoride gas-puffer.

# Illustration of Current Offset in R-L Circuits

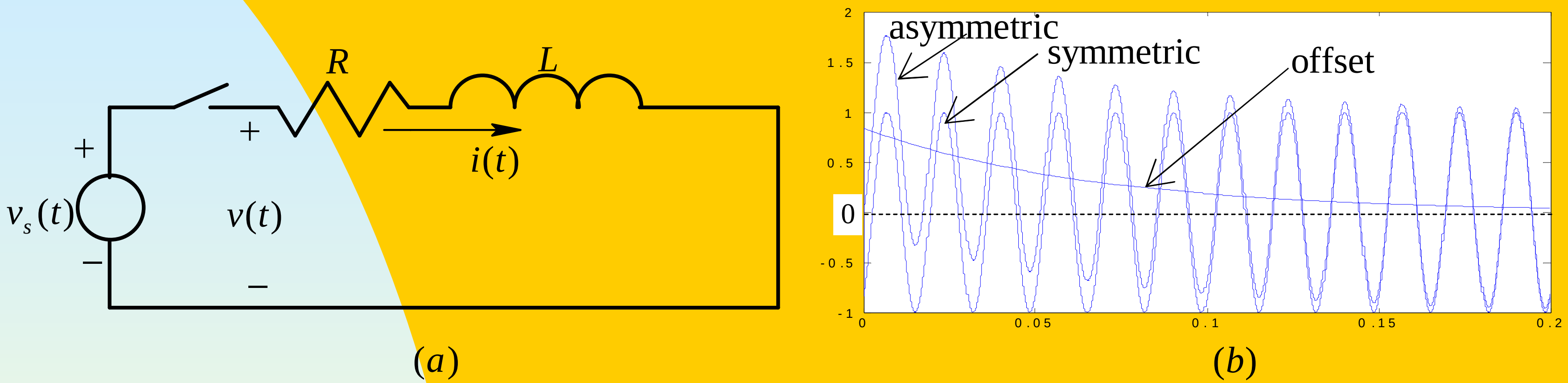



Fig. 13-26 Current in an *RL* circuit.

- **With fast circuit breakers it is important to take into account the initial current offset that results in *asymmetrical current*.**
- **The asymmetrical current can be higher than the symmetrical current by a factor depending on the reactance over the resistance ratio, *X / R , of the network.***