SECTION 8: SYSTEM PROTECTION

ESE 470 – Energy Distribution Systems

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Introduction

System Protection

- Fault current may far exceed maximum current ratings for power system equipment
  - Thermal or mechanical damage may occur
- Goal of system protection equipment is to isolate equipment after a fault as soon as possible
  - HV and EHV systems – less than three cycles
  - LV systems 5 – 20 cycles
- Remove faulted equipment from the system until the fault is cleared
  - Want to remove as little of the system as possible

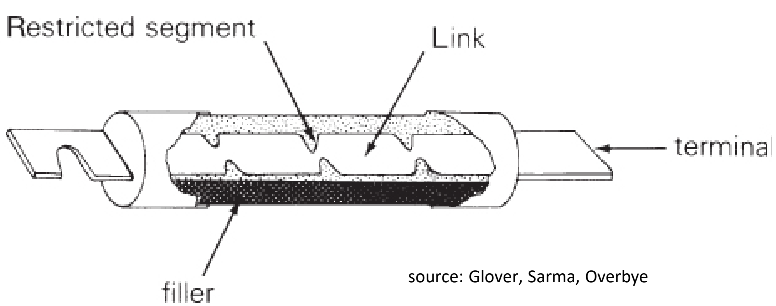
System Protection Equipment

- Protection equipment detects and isolates faults
  - Instrument transformers
  - Relays
  - Circuit breakers
  - Reclosers
  - Fuses
  - Surge arresters
- Transmission networks (HV and EHV) protected primarily by circuit breakers in conjunction with instrument transformers and relays
- Lower-voltage distribution networks mostly employ fuses and reclosers for protection

Fuses, Reclosers & Surge Arresters

Fuses

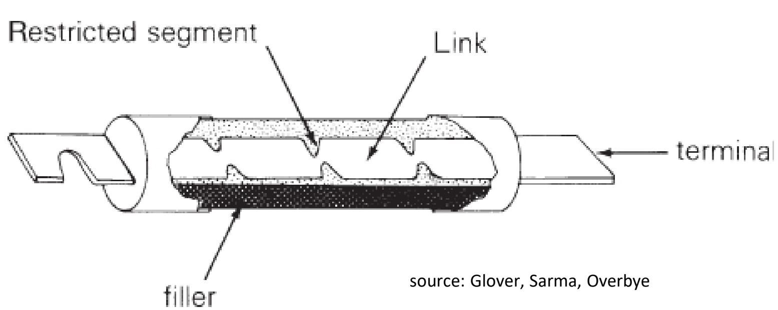
- The simplest type of system protection equipment is the fuse
  - Designed to create an open circuit in response to an overcurrent event
  - ***Fusible link*** melts in response to excessive current



source: Glover, Sarma, Overbye

Fuses

- Fuses are small, simple, and inexpensive, but …
- If a fuse opens, it must be replaced to restore service once the fault is cleared
  - Manual intervention is required
- Fuses are typically cylindrical in shape
  - Conductive fusible links, e.g. silver
  - Arc-suppressing filler material, e.g. sand

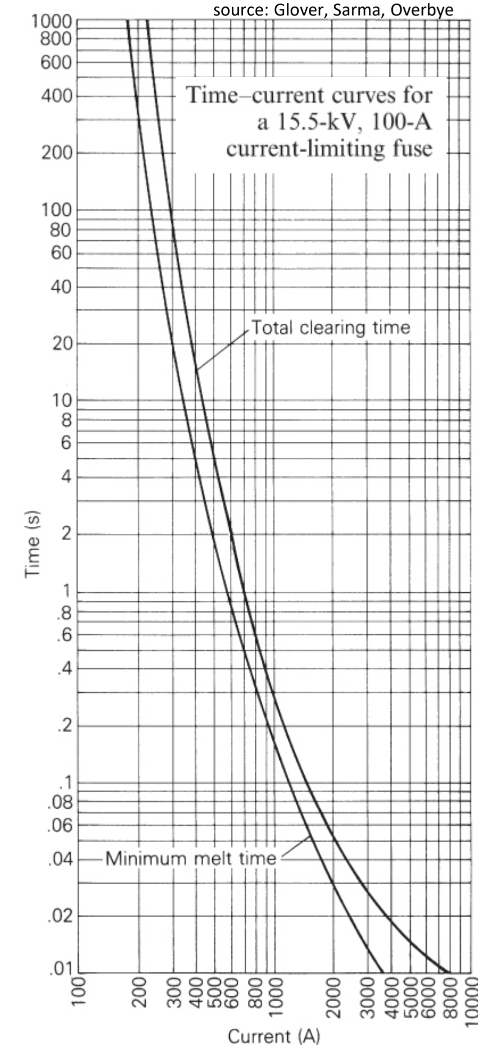


source: Glover, Sarma, Overbye

Fuse Ratings

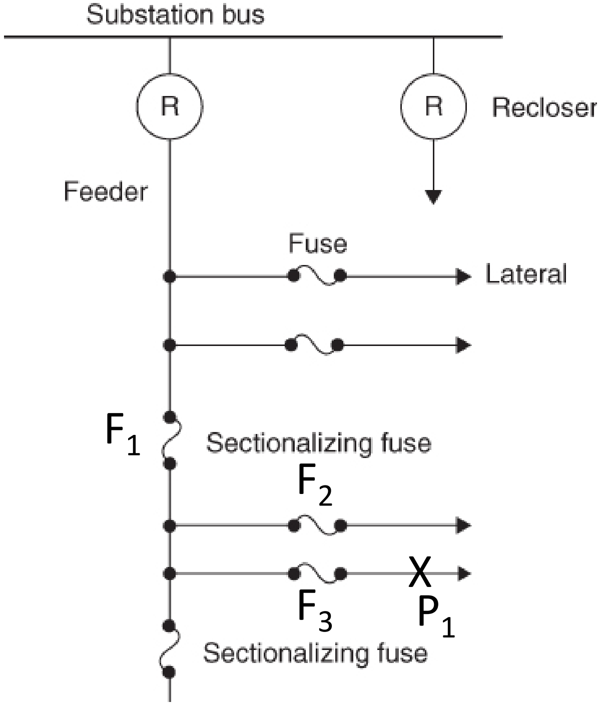
- **Voltage rating**
  - The maximum voltage a fuse can withstand after opening
- **Continuous current**
  - Maximum current the fuse can carry without opening
- **Interrupting current**
  - Maximum current a fuse can safely interrupt
- **Time response**
  - Fuse melt time is proportional to current magnitude relative to the fuse current rating
  - Described by time-current curve

source: Glover, Sarma, Overbye



Fuse Timing

- For a given overcurrent magnitude, some fuses will open faster than others
- In ***radial*** networks, fuses can be ***time coordinated***
  - Fuses further downstream – closer to the fault – will open first
    - Minimize loss of service
- For example, for a fault at P_1:
  - F_3 should open, F_1 should not
- More complicated for non-radial systems



source: Glover, Sarma, Overbye

Reclosers

- Another type of system protection is the ***recloser***
  - Like fuses, common at the distribution level
  - Internal control circuitry
  - Interrupts (opens) a circuit on a fault condition
  - Automatically recloses after some time delay
    - Opens again if fault persists
  - Attempts to reclose again after additional delay
    - Preprogrammed to attempt to reclose several (e.g. three) times
  - If fault does not self-clear, recloser will remain open
    - Manual intervention – possibly remote – required

Reclosers

- Useful for temporary faults
  - Wind shorting phases
  - Falling tree limbs
  - Animals
  - Lightening, etc.
- Most faults on overhead lines are self-clearing
- Unlike fuses, manual intervention is not required unless fault does not self-clear

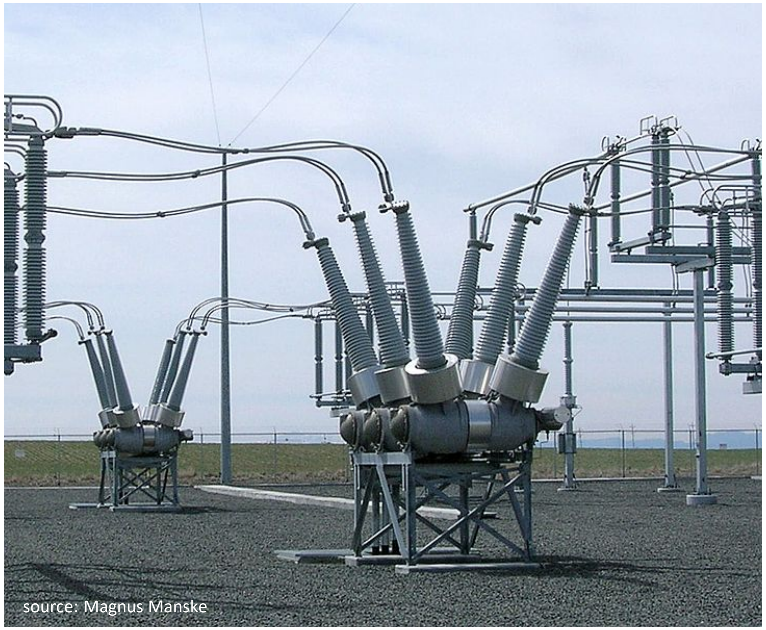
Surge Arresters

- ***Surge arresters*** protect against very high overvoltage events
  - E.g., ***lightening strikes***
- Low-impedance path to ground for high voltage
- High impedance for normal voltage levels
- Located at substations and on transmission/ distribution lines

Circuit Breakers & Relays

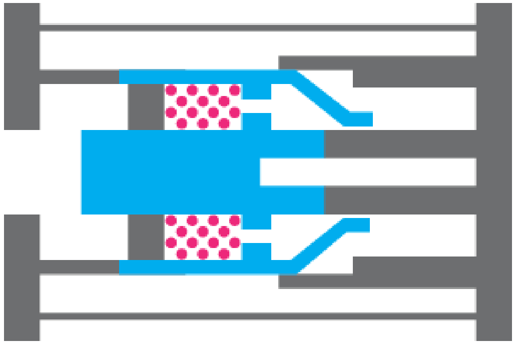
Circuit Breakers

- The other main category of system protection devices is ***circuit breakers***
  - Interrupt and reclose a circuit when commanded to by external control circuitry
- Circuit breakers are used in conjunction with external control circuitry
  - Instrument transformers
    - Voltage transformers
    - Current transformers
  - Overcurrent relays
- Located at substations and generation facilities

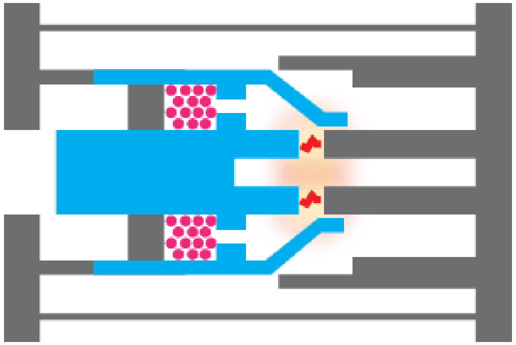


Circuit Breakers

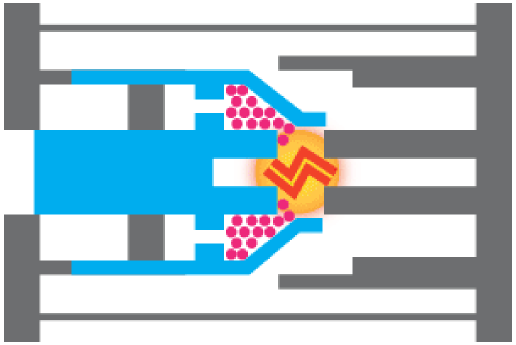
1. Closed under normal operating conditions



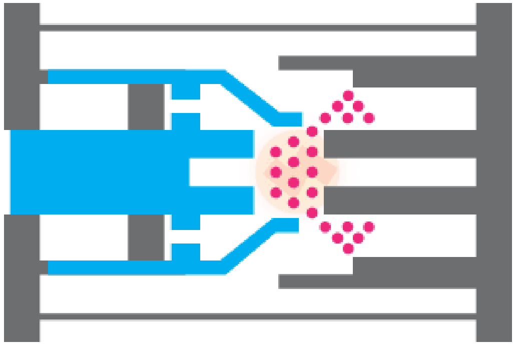
2. Opens in response to overcurrent



3. Arc wants to persist across gap between contacts



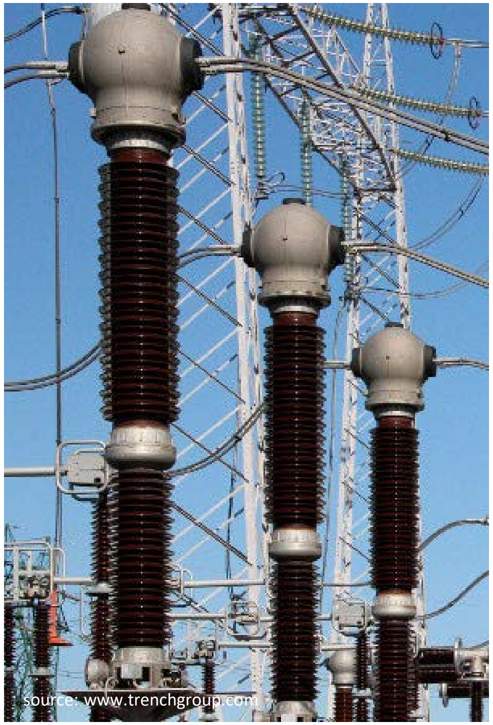
4. Compressed gas extinguishes the arc



Images source: http://spectrum.ieee.org, Erik Vrielink

Instrument Transformers

- Transformers used for measuring power-system quantities – voltage or current
  - Voltage transformers (VT)
  - Current transformers (CT)



Overcurrent Relays

- ***Overcurrent relays***
  - Detect faults based on input from a current transformer
  - Sends a control signal to circuit breaker to interrupt the circuit

- Electromechanical relays

source: Creative Commons, Wtshymanski

- Solid-state, digital relay

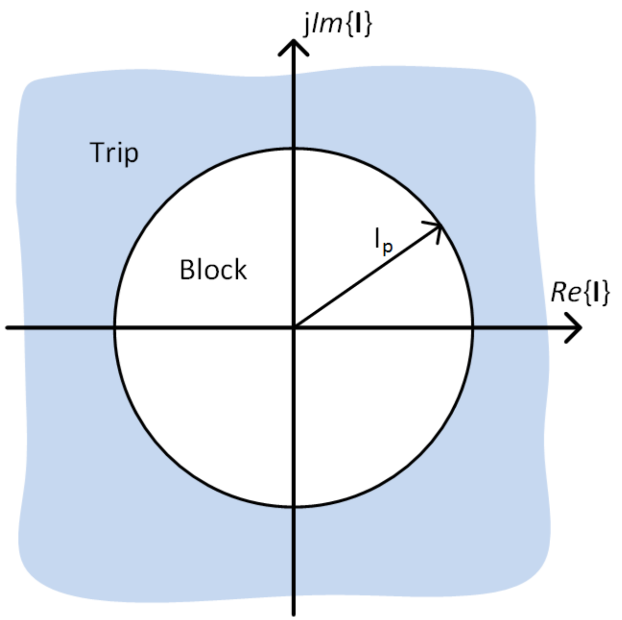
source: Creative Commons, Zen 38

Overcurrent Relays

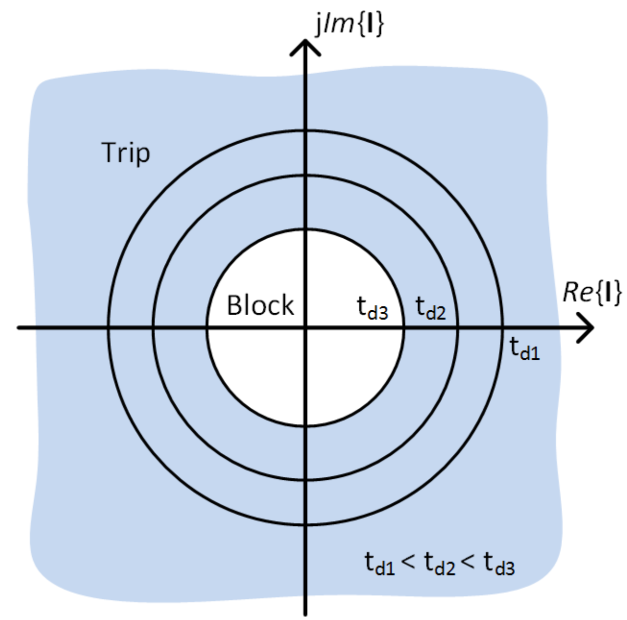
- Two main categories of overcurrent relays
  - ***Instantaneous*** overcurrent relays
    - Designed to trip very quickly when current exceeds the current limit, or ***pickup current***, I_p
  - ***Time-delay*** overcurrent relays
    - Designed to trip after some time delay when current exceeds pickup current, I_p
    - Amount of delay depends on amount that the current exceeds I_p
- Time-delay overcurrent relays have two adjustments
  - Pickup current
  - Time delay

Overcurrent Relays

- Trip and block regions for instantaneous and time-delay overcurrent relays
  - Instantaneous overcurrent relay:



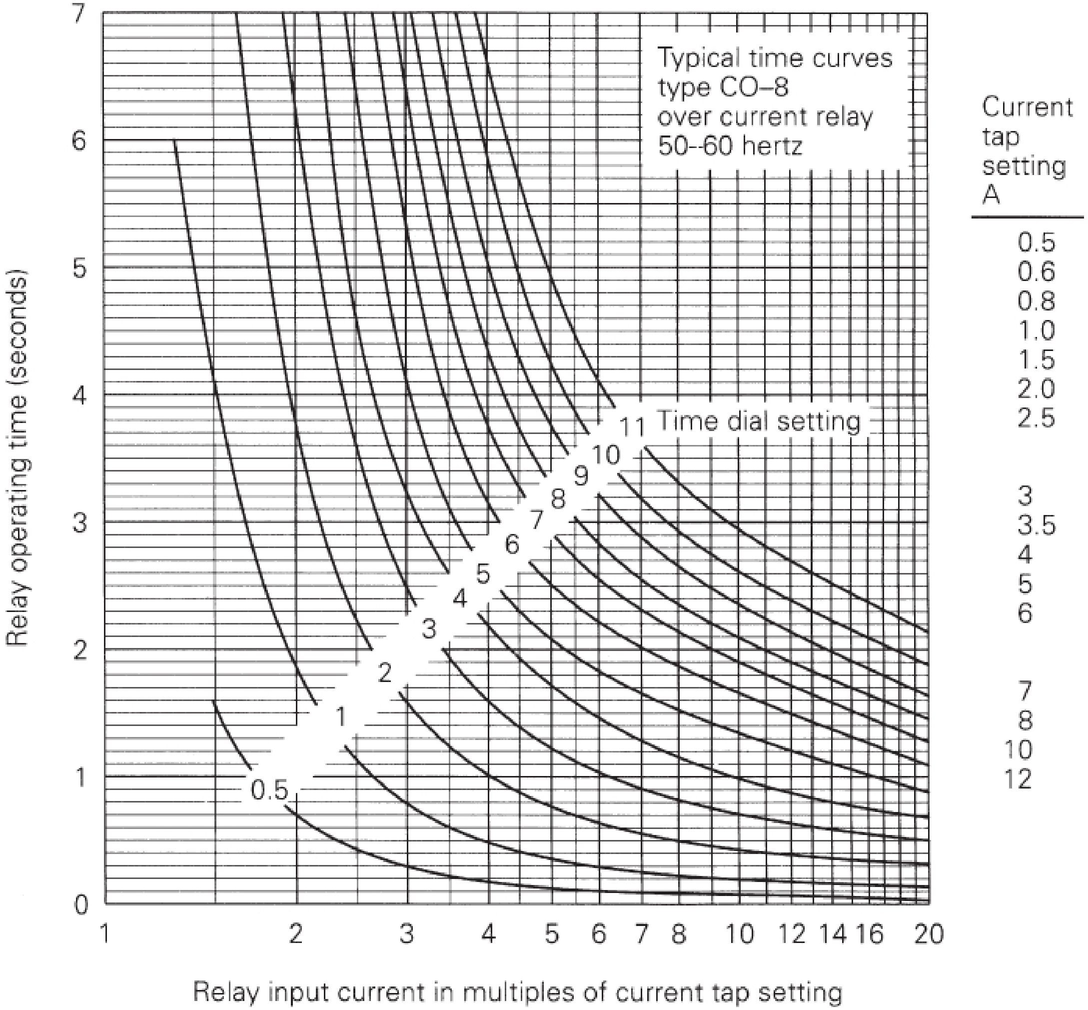
  - Time-delay overcurrent relay:



Time-Delay Overcurrent Relays

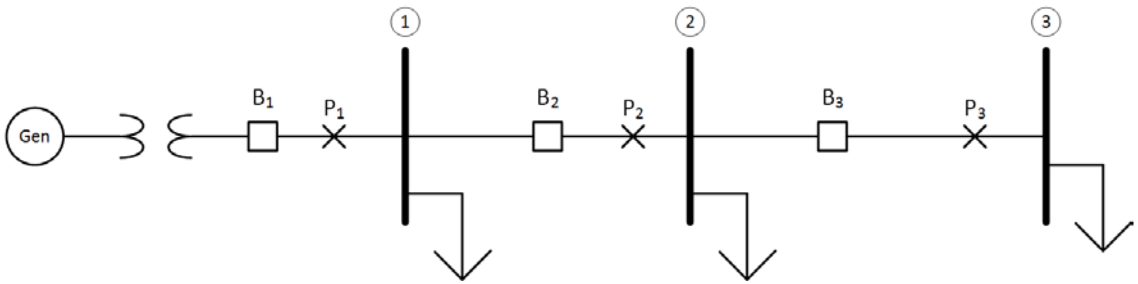
- Time-current curves for a typical electro-mechanical time-delay overcurrent relay

source: Glover, Sarma, Overbye



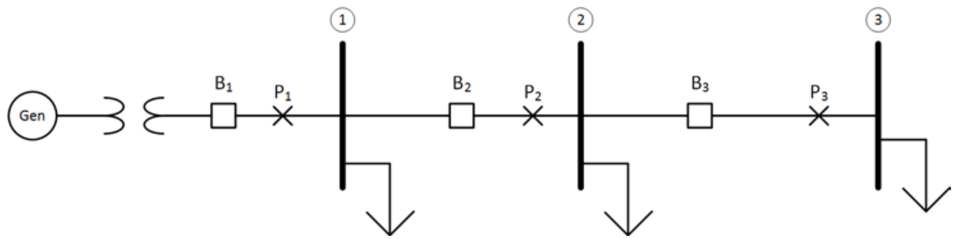
Time Coordination of Relays

- Consider the following simple radial system



- A fault at P_1 would cause breaker B_1 to open
  - Buses 1, 2, and 3 are all disconnected from the generator
- For a fault at P_2, both B_1 and B_2 would experience an overcurrent
  - Ideally, only B_2 would open, taking buses 2 and 3 offline, but leaving bus 1 in service

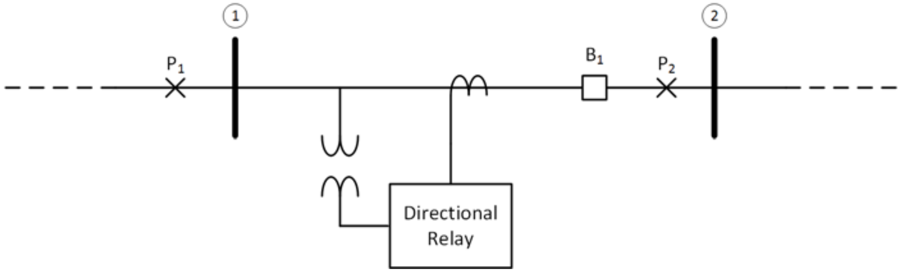
Time Coordination of Relays



- Time coordination of relays
  - Set time delay of B_3 to be less than that of B_2
  - Set time delay of B_2 to be less than that of B_1
- Downstream breakers, those closest to the fault, will trip first
  - Fault will be isolated before upstream breakers can trip
  - Loss of load is limited
- Practical number of time-coordinated relays on a radial system is limited to five or fewer
- Time coordination gets more complicated for non-radial systems

Directional Relays

- One goal of any system protection scheme is to remove as little of a system from service as possible in the event of a fault
  - Time coordination accomplishes this for radial systems
  - For more complicated networks, other tools are needed
- ***Directional relays***
  - Trip for fault current in one direction only
  - Current and voltage instrument transformers used to detect ***current magnitude*** and ***direction***
  - Exploits the fact that line impedance is inductive

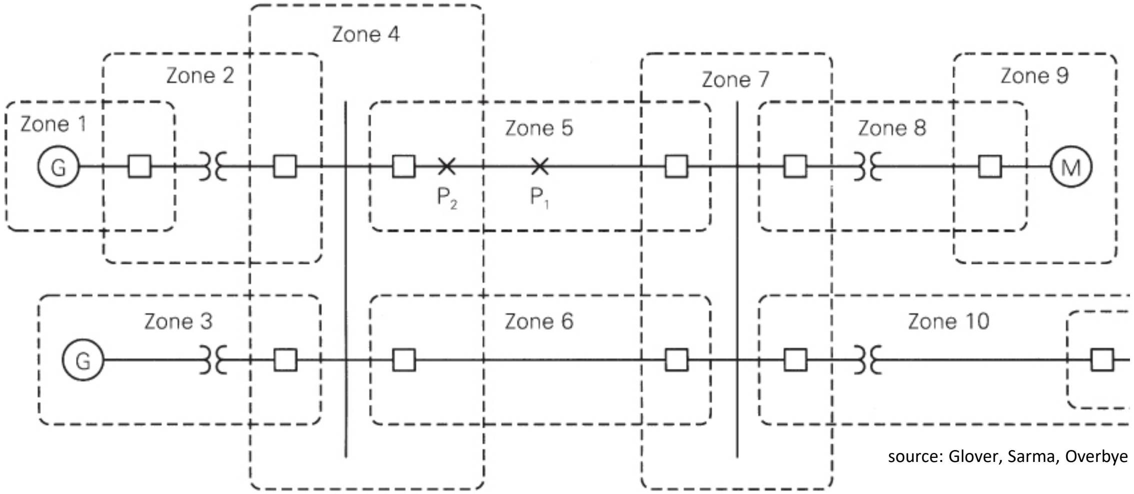


- For example, relay above could be configured to trip breaker B_1 for a fault at P_2, but not a P_1

Zones of Protection

Zones of Protection

- Time coordination works for simple radial distribution networks
- For more complicated networks, we use ***zones of protection***
- Power system divided into zones – one zone for each:
  - Generator
  - Bus
  - Transformer
  - Transmission/ distribution line
  - Load



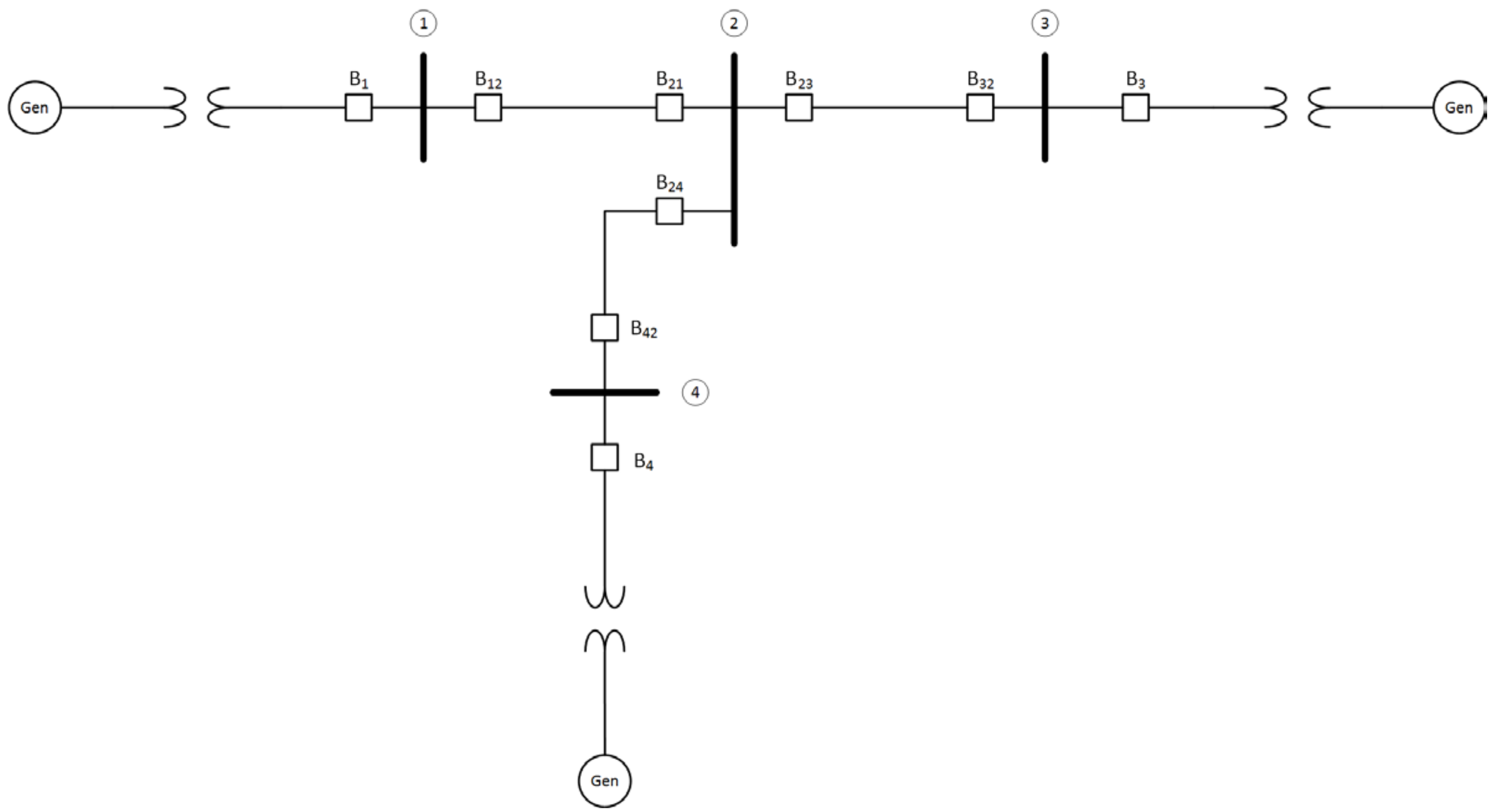
source: Glover, Sarma, Overbye

Zones of Protection

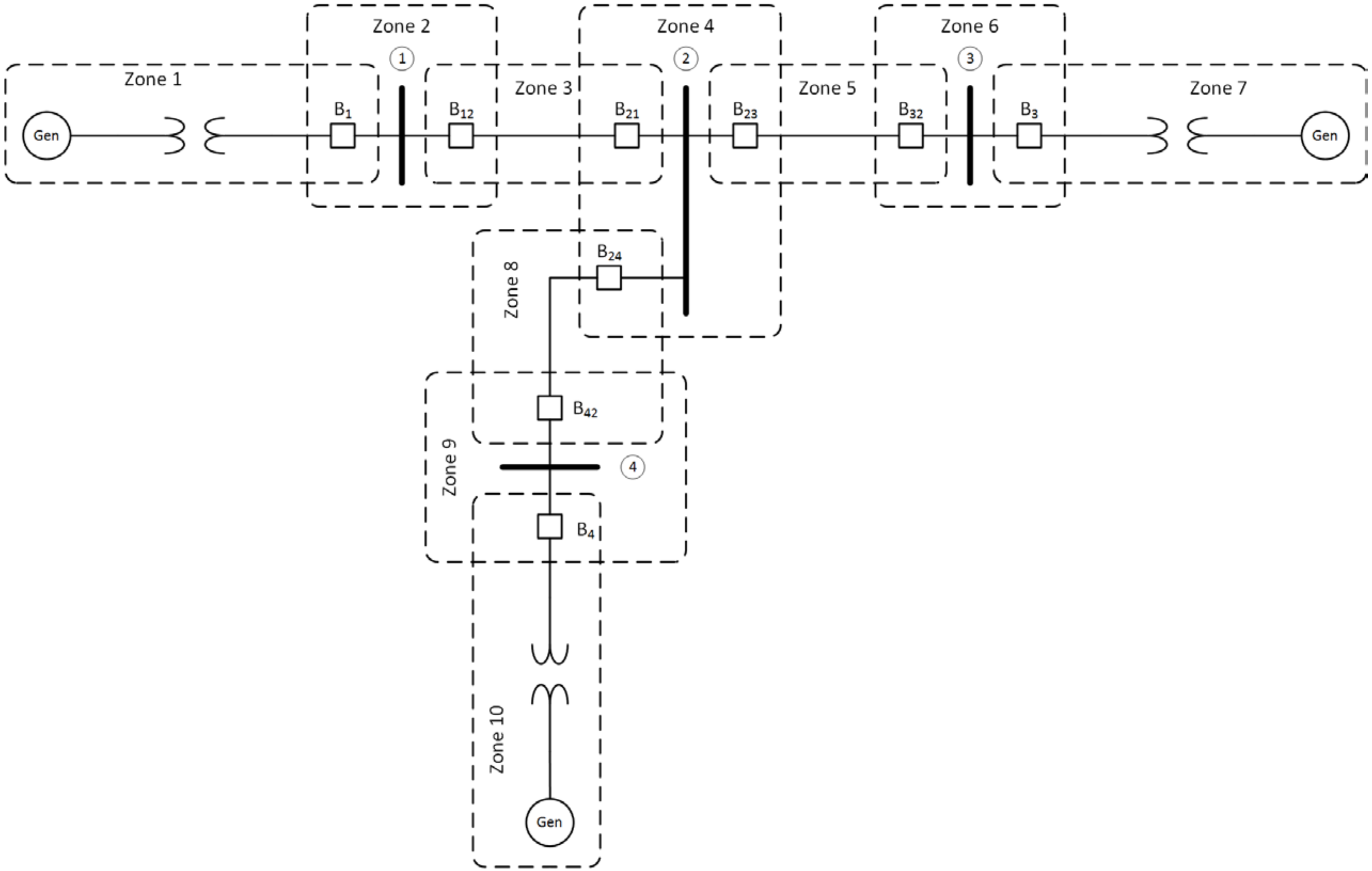
- When a fault is detected anywhere in a zone:
  - All breakers in that zone open
  - Entire zone is isolated
- Rules for defining zones of protection:
  - Zones must ***overlap***
    - No gaps between zones
  - Circuit breakers define zone boundaries
    - Breakers are located in the overlap regions
- All circuit breakers in a zone must be coordinated
  - Multiple relays and instrument transformers for each circuit breaker
  - Communication between multiple relays and circuit breakers within a zone is required

Zones of Protection – Example 10.7

- Define zones of protection for the following power system:



Zones of Protection – Example 10.7



Distance Relays

Distance Relays

- An alternative to time coordination, directional relays, and protective zones, is the use of ***distance*** (***impedance***) ***relays***
- ***Distance relays***
  - Trip a breaker when a ***voltage-to-current ratio*** (line impedance to the fault) falls *below* some threshold

- Near a fault
  - Current increases drastically due to the fault
  - Voltage decreases drastically
  - Voltage-to-current ratio drops significantly

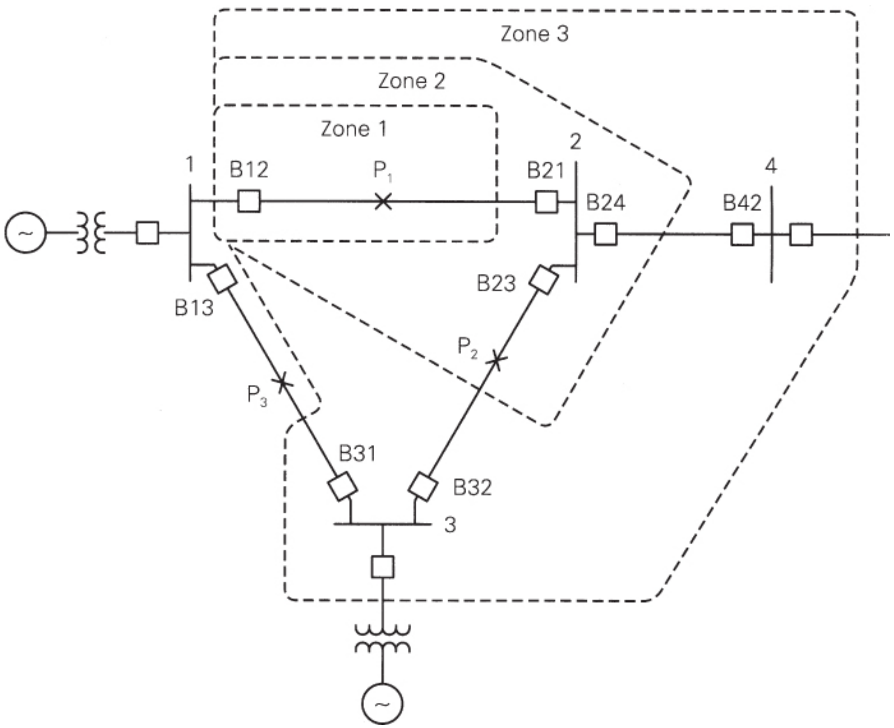
- Further from a fault
  - Same fault current increase is experienced
  - Voltage drops less or not at all
  - Voltage-to-current ratio decreases, but not as much

Distance Relays

- Distance relays are adjusted for a certain ***reach***
  - ***Reach***: percentage of the line over which a relay will respond to a fault
- Distance relays often used in conjunction with ***directional relays***
  - Monitoring for faults a certain distance down a line in only one direction
- Typical configuration is for a circuit breaker to be controlled by three directional impedance relays per phase
  - Three protective zones for each breaker
  - Each zone has progressively longer reach and time delay

Distance Relays

- For example, protective zones for breaker B12:
  - B12 trips instantly for fault at P_1 (Zone 1)
  - Reach of Zone 1 is 80% of line 1-2
    - Prevents mistaking faults on other lines near bus 2 for faults on line 1-2
- Consider a fault at P_2
  - Zone 2 for B12
    - Medium time delay
  - Zone 1 for B23 and B32
    - No time delay
  - B23 and B32 will trip
    - If B23 fails, B12 will trip after some delay



Distance Relays

- Note that zones for extend in one direction only
  - Away from bus 1
  - ***Directional distance relays***
- Now consider a fault at P_3
  - Approximately same impedance as P_1, but opposite direction
  - Not in any B12 zone
  - B12 will never trip for a fault at P_3
- P_3 would be in Zone 1 for B13 and B31