Power Systems Protection

- What exactly are we protecting?
  - » A
  - » B
  - » C
  - » D
  - » E
  - » F

Impacts on the Power System

- Local protection
  - » Protection of immediate equipment
  - » Minimize disruption of loads
    - – Duration or interruption or abnormal condition
- Larger system issues?
  - » Impacts on stability of larger system
  - » Potential for distant impact
- Power Quality

Some Consequences To Avoid: Substation Fire … Evening News

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The Aftermath

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Results of Transformer Fire

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Generator Fault

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Expensive Consequences for Protection Failure

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What Events Require Protective Actions

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- Faults
- Abnormal operation

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What Actions Taken?

- 1
- 2
- 3

What is a Protection System?

- Current and voltage transformers
- Relay
- Circuit breaker
- Control wiring or substation network
- Communication system
- Coordinate with: Other relays, fuses, active controls

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Protective Relay

- Piece of equipment whose function is to:
  - » Detect defective or abnormal system conditions or detect defective apparatus
  - » Initiate proper control response
- Common responses
  - » Trip circuit breaker
  - » In some cases close breaker
  - » In some cases only issues alarm
- Generally a reactionary device

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Relay Types?

- Legacy Relays:
  - » Electromechanical (1900-present)
    - – Single function and mission
  - » Discrete digital and analog electronics (1970-1990s)
    - – Multifunction, single mission
- Modern Relays
  - » Microprocessor based
    - – Multiple function and mission

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Constraints

- Must be able to detect faulted or abnormal conditions—*sensitivity*
- Accurately identify it a problem, and only react if there is a problem—*selectivity*
- Must also be operate for a long time without acting, and then act properly—*reliability*
- React quickly to minimize damage—*speed*
- Tradeoff with—*cost*

Typical Response

- Detect that something has changed
- Identify what has happened
  - » Local measurements
  - » Communicated data
- Make decision (is this a problem or not)
  - » Generate trip signal
  - » 1-3 cycles to get to this point
- Breaker response (2-10 cycles)

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Impact of Response

- Faster response implies:
  - » Less disruption of loads
  - » Less energy at the point of fault --less damage
    - – Smaller fireball
  - » Faster reclosing -- Improved stability
- Coordination with other devices
  - » Intentional delay

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What are the inputs?

- Voltage
  - » Step down for relay input
- Current
  - » Step down for relay input
- Accuracy and Transient Response
- All three phases?
- GPS time stamp?
  - » Synchronized phasor measurements

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Modern Relays

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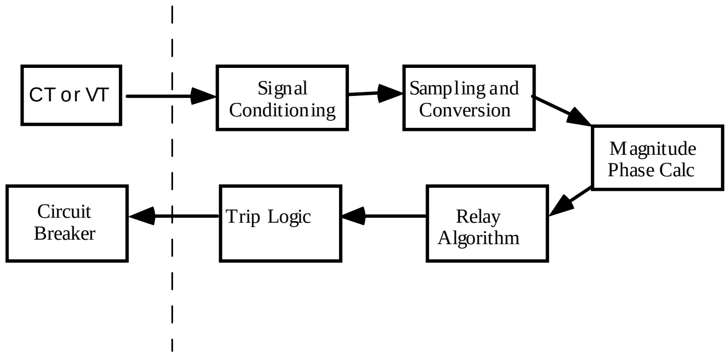
- Microprocessor based relays



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Modern Relays

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- Microprocessor based relays
- Sample measured data and compute:
  - » RMS voltage or current
  - » Travelling wave current or voltage
  - » Sequence components (especially 0 or 2)
  - » Phase Angle
  - » Impedance or Admittance
  - » Frequency
  - » Torque

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Evaluate Measured Data Based on Algorithm

- Time-overcurrent/Inverse time-overcurrent
- Over/under voltage
- Real or reactive power
- Impedance (distance protection)
- Frequency
- Reverse power
- Positive, Negative or Zero Sequence?

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Additional Calculations

- Harmonic content (often used for blocking)
- In some cases transient responses used
- Direction to fault
- Fault location
- Breaker failure
- Series faults (line open)
- Combined series/ground faults

Redundancy

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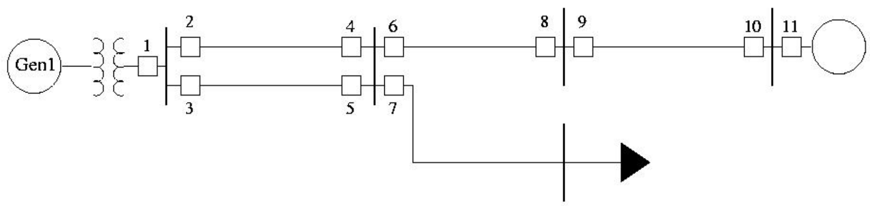
- Overlapping zones of protection are common



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Overlapping Zones

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- Backup in case relay or breaker fails
- Time delay if out of primary zone
- Often more sensitive in secondary zone
- Coordination is a key issue

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Role of Communication

- Line protection far faster when can compare with other end of line
- Can locate fault zone
- Need to have adequate back-up in case communication is lost
- Redundancy--does communication go as a result of the fault?

Cybersecurity

- Information technology (IT)
- Operation technology (OT)
  - » Industrial control systems
  - » Referred to as CS in Table 1.1
- Very different priorities
- NERC Critical Infrastructure Protection

Future Directions

- IEC 61850 Process Bus
  - » Measurements processed at measurement devices and broadcast on substation bus
  - » Relays (possibly more general purpose)
    - – Subscribe to measurements
    - – Provides more flexibility and speed
    - – Design concerns for reliability and security
- Phasor measurement based schemes