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

The Aftermath
Results of Transformer Fire

Generator Fault
Expensive Consequences for Protection Failure

What Events Require Protective Actions

- Faults
- Abnormal operation
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
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

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
Constraints

- Must be able to detect faulted or abnormal conditions—*sensitivity*
- Accurately identify if a problem, and only react if there is a problem—*selectivity*
- Must also 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)
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

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
Modern Relays

- 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
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?

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

- Overlapping zones of protection are common

Overlapping Zones

- 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
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