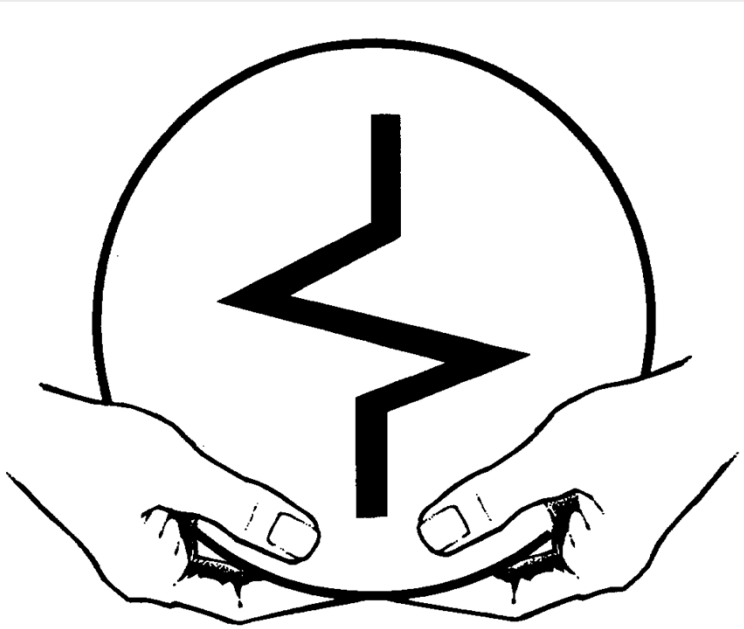
Introduction to System Protection - Protection Basics and Terminology

Hands-On Relay School



Jon F. Daume
Bonneville Power Administration (Retired)

March 14, 2011

Your guide to System Protection

Relays for DUMMIES

3rd Edition

A Reference for the Rest of Us!

Hands-On Relay School
March 14, 2011

Purpose of Protective Relays

Transmission line fault protection

Detect and isolate equipment failures

Improve system stability

Protect against overloading

Protect against abnormal conditions

- Voltage, frequency, current

Protect public

Fault Causes

- Lightning
- Wind and ice
- Vandalism
- Contamination
- External forces
  - Cars, tractors, balloons, airplanes, trees, critters, flying saucers, etc.
- Equipment failures
- System disturbances
  - Overloads, system swings

Fault Types

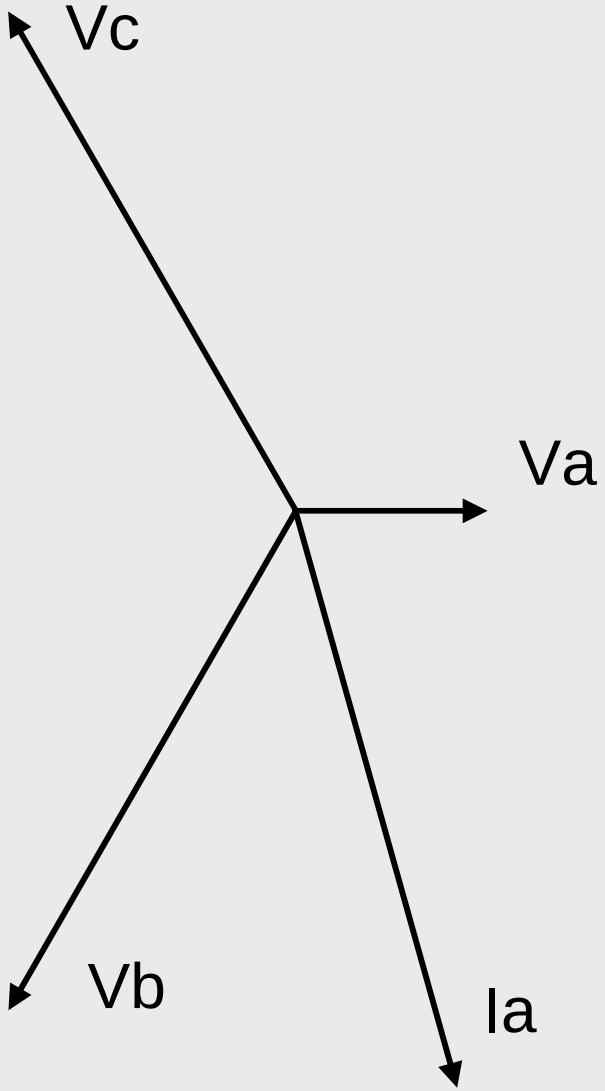
One line to ground (most common)

Three phase (rare but most severe)

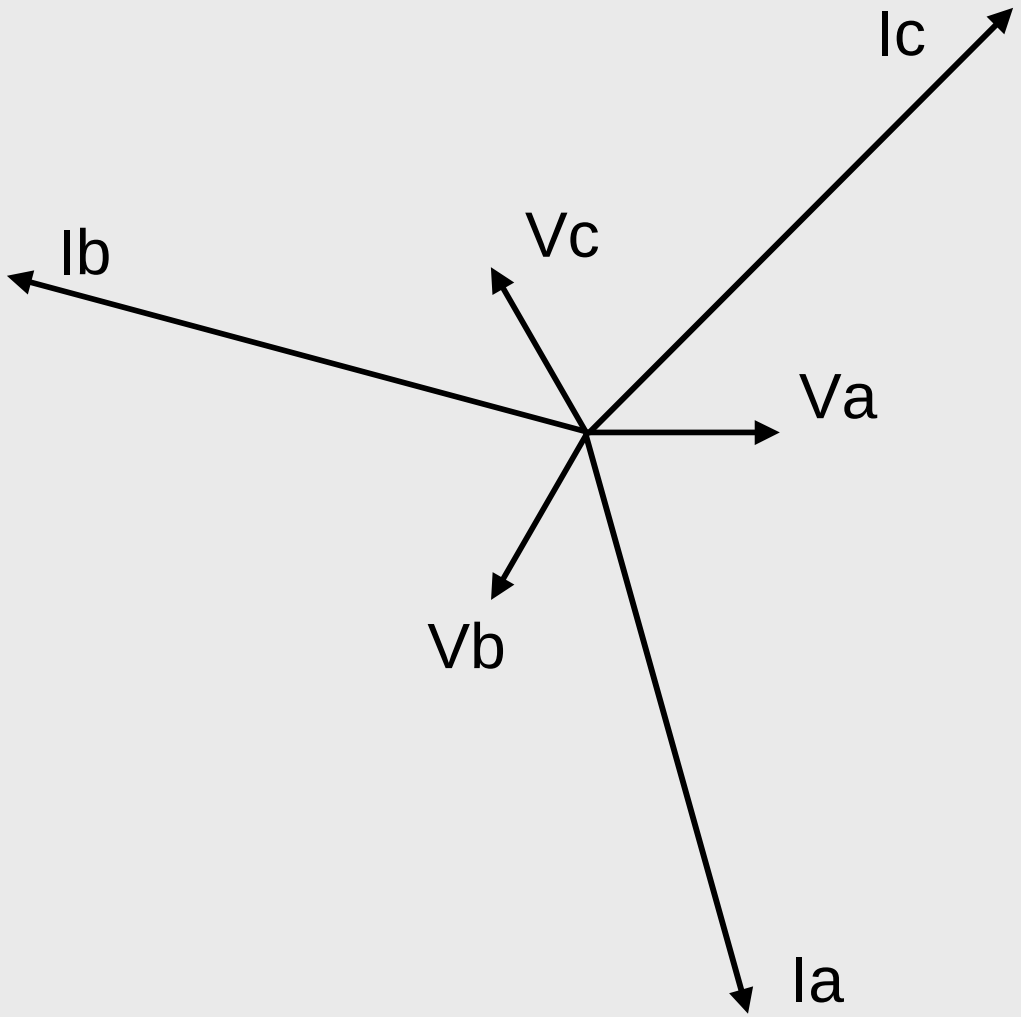
Phase to phase

Phase to phase to ground

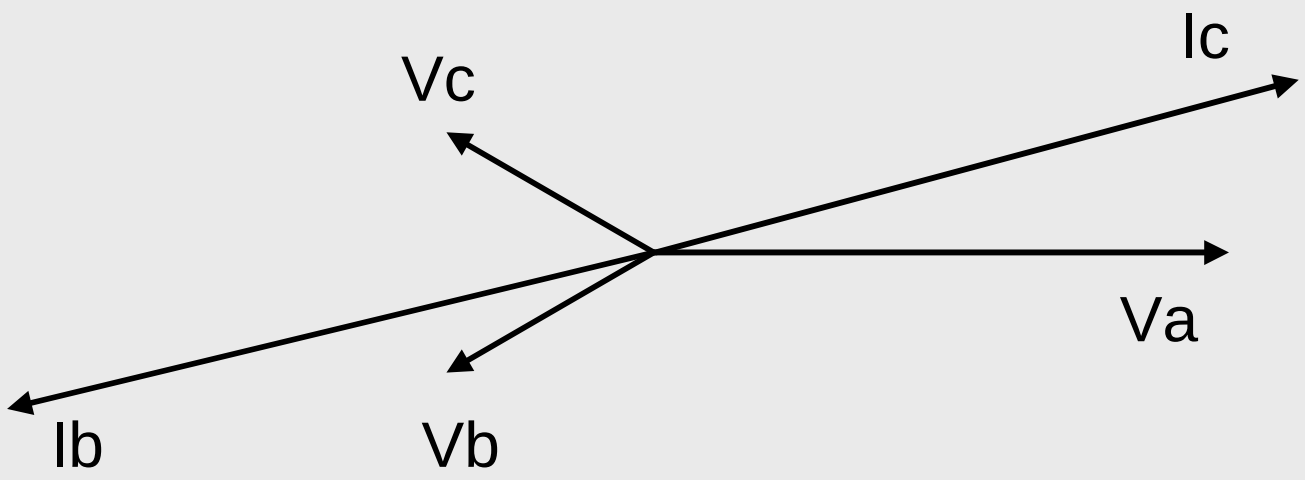
Single Line to Ground Fault



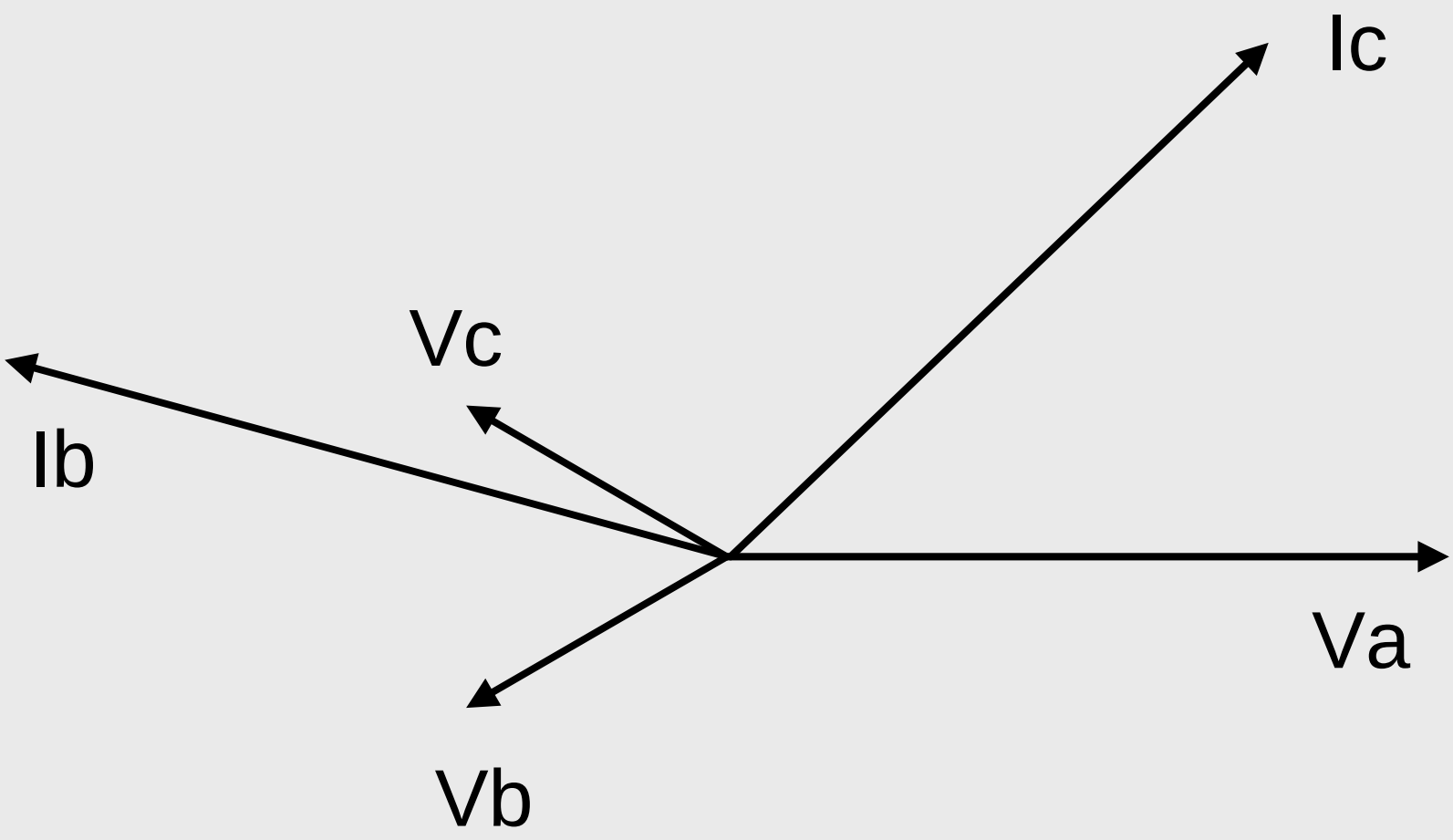
Three Phase Fault



Phase to Phase Fault



Two Phase to Ground Fault



Balanced & Unbalanced Systems

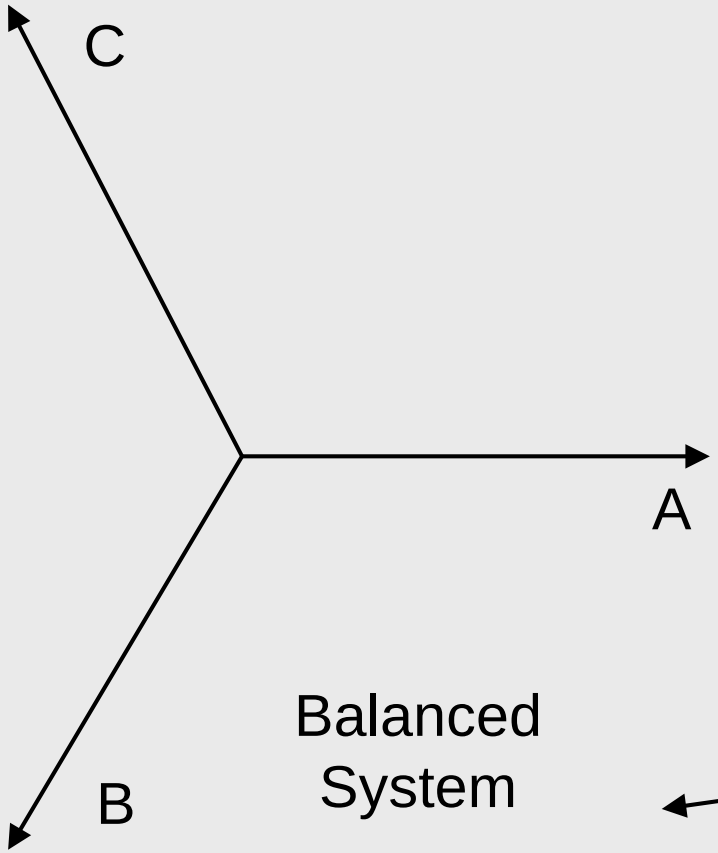
Balanced System:

- 3 Phase load
- 3 Phase fault

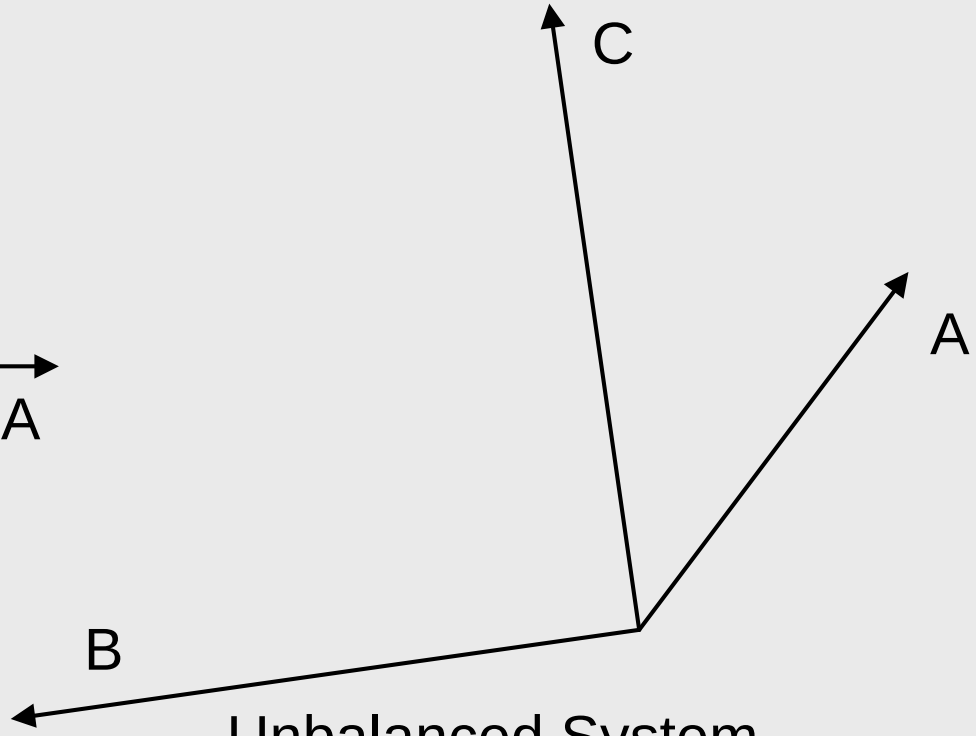
Unbalanced System:

- Phase to phase fault
- One line to ground fault
- Phase to phase to ground fault
- Open pole or conductor
- Unbalanced load

Balanced & Unbalanced Systems



Balanced System



Unbalanced System

Sequence Quantities
(Symmetrical Components)

Condition	+	-	0
3 Phase load	✔	-	-
3 Phase fault	✔	-	-
Phase to phase fault	✔	✔	-
One line to ground fault	✔	✔	✔
Two phase to ground fault	✔	✔	✔
Open pole or conductor	✔	✔	✔
Unbalanced load	✔	✔	✔

Relay Types

- Non-directional
  - Detect fault in any direction
    - Operate when quantity exceeds pickup value
    - Used on distribution lines
    - Can be used on radial systems
- Directional
  - Only trip for faults in front of relay (on line)
    - Use voltages, currents, angles to determine fault direction
    - Operate when quantities exceed pickup value and correct direction is determined
    - Relay of choice for HV and EHV transmission

Relay Types

- Current, voltage, frequency
  - Operates if input meets setting
- Distance
  - Uses voltage and current to measure impedance to fault
- Differential
  - Looks at imbalance between inputs
  - Common for power transformers and generators
  - Can be used for transmission lines

Relay Types

- Recloser
  - Relay to automatically reclose circuit breaker following a relay operation to restore circuit
- Pilot scheme
  - Uses communications to transmit relay information or trip to remote terminal
  - Provides high speed tripping for entire protection zone
  - Radio, fiber optics, hard wire, carrier current can be used for pilot channel
  - Most common on HV, EHV lines

Relay Types

- Phase relay
  - Relay measures phase current or voltage quantities
- Ground relay
  - Relay measures ground current or voltage quantity (zero sequence values)
  - Protects for one line to ground and phase to phase to ground faults
- Sequence relay
  - Relay measures symmetrical component sequence quantity (+, -, 0)

Relay Trip Times

- Instantaneous
  - Relay operates as soon as operating value is met
- Time delay
  - Relay operating time is delayed
    - Fixed delay determined by separate timing element (62)
    - Inverse delay determined by magnitude of operating quantity and relay operating curve
      - Delay decreases as operating value increases
- Actual clearing time includes relay operate time plus circuit breaker opening time

Relay Construction

- Electromechanical
  - Several individual relays required for complete fault protection
- Static or electronic
  - One or more relays required for complete fault protection
- Digital or microprocessor
  - Single device provides complete fault protection
  - Device may include additional features not available with electromechanical or electronic relays

Relay Basics

- Component relay
  - Individual boxes that provide phase or ground protection, reclosing, etc.
- Relay system
  - Bunch of single components designed to do a task
  - A multifunction device to do the same task or several tasks

Digital Relays

- Digital relays were introduced in early 1980's
- Additional digital relay features
  - Fault information and location
    - Voltage and current inputs required to locate fault
  - Remote communications
  - Self testing
  - Circuit breaker history and monitoring
  - Metering
  - Time tagging (GPS clock input)
- Concerns
  - Complicated to apply (many elements)
  - Single point of failure
  - Limited life expectancy

IEEE Device Numbers

Numbers 1 - 97 used

21 Distance relay

25 Synchronizing or synchronism check device

27 Undervoltage relay

32 Directional power relay

43 Manual transfer or selector device

46 Reverse or phase balance current relay

50 Instantaneous overcurrent or rate of rise relay (fixed time overcurrent)

(IEEE C37.2)

IEEE Device Numbers

51 AC time overcurrent relay

52 AC circuit breaker

59 Overvoltage relay

62 Time delay stopping or opening relay

63 Pressure switch

67 AC directional overcurrent relay

79 AC reclosing relay

81 Frequency relay

86 Lock out relay

87 Differential relay

(IEEE C37.2)

Relay Reliability

- Overlapping protection
  - Relay systems are designed with a high level of dependability
  - This includes redundant relays
  - Overlapping protection zones
- We will trip no line before its time
  - Relay system security is also very important
  - Every effort is made to avoid false trips

Relay Reliability

Relay dependability (trip when required)

- Redundant relays
- Remote backup
- Dual trip coils in circuit breaker
- Dual batteries
- Digital relay self testing
- Thorough installation testing
- Routine testing and maintenance
- Review of relay operations

Relay Reliability

- Relay security (no false trip)
  - Relay security failures have increased the impact of numerous system disturbances
  - Careful evaluation before purchase
  - Right relay for right application
  - Voting
    - 2 of 3 relays must agree before a trip
  - Thorough installation testing
  - Routine testing and maintenance
  - Review of relay operations

Protection Zone

- Portion of system protected by relay
- Usually determined by location of current transformers
- Common protection zones
  - Substation bus
  - Transmission line
    - May have multiple protection zones
  - Power transformer
  - Generator
- Common to have backup protection for zone

Instrument Transformers

- Used to transform line currents and voltages to relay values
  - Voltage and current transformers
- Transformer types
  - Magnetic
  - Capacitive
    - Capacitor voltage divider to measure voltages
  - Optical

Instrument Transformers

Transmission Lines

$Z_{secondary} = Z_{primary}$ x CTR / VTR

For distance relays

The PT location determines the point from which impedance is measured.

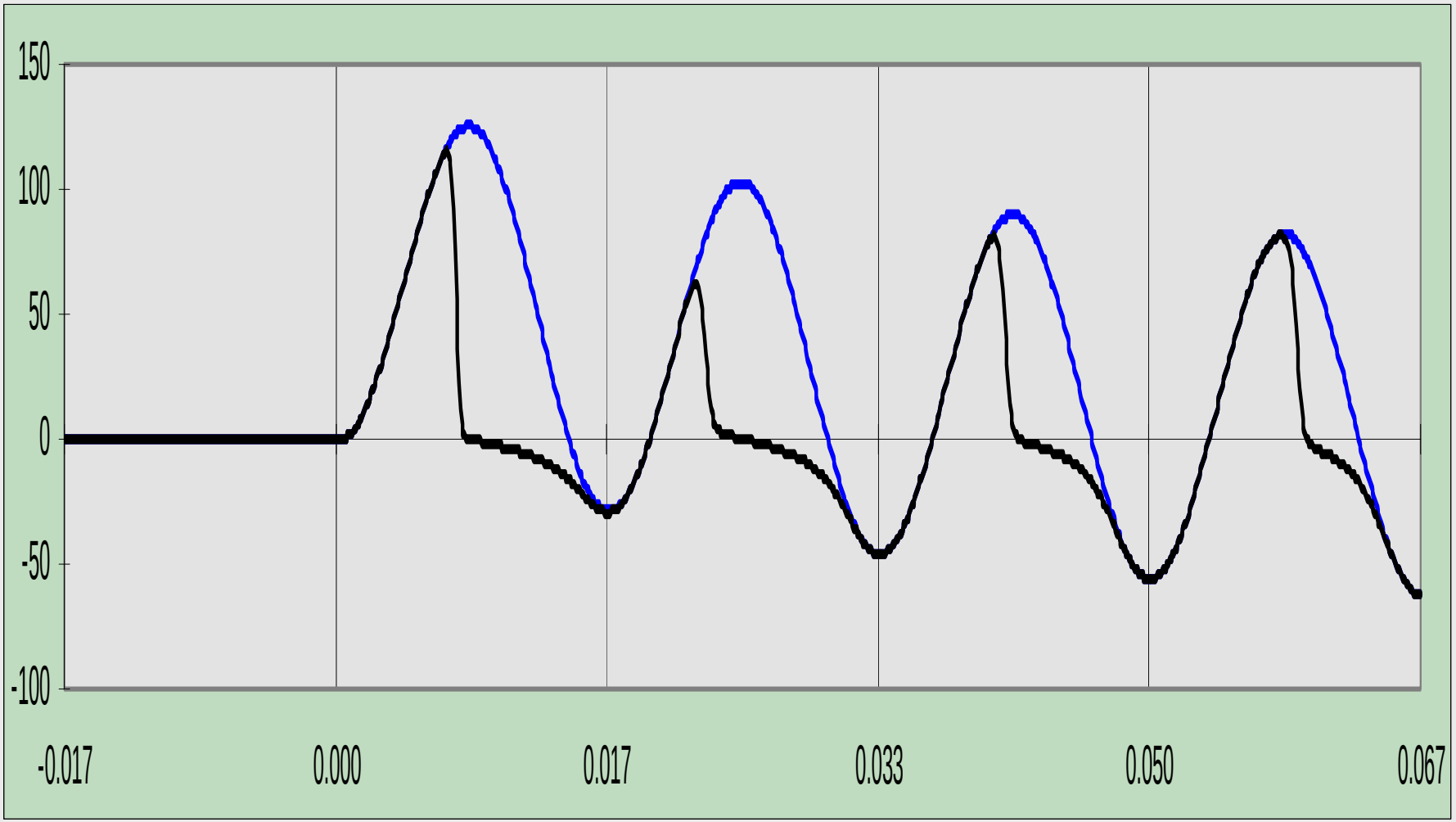
The CT location determines the fault direction.

CT location generally determines zone of protection

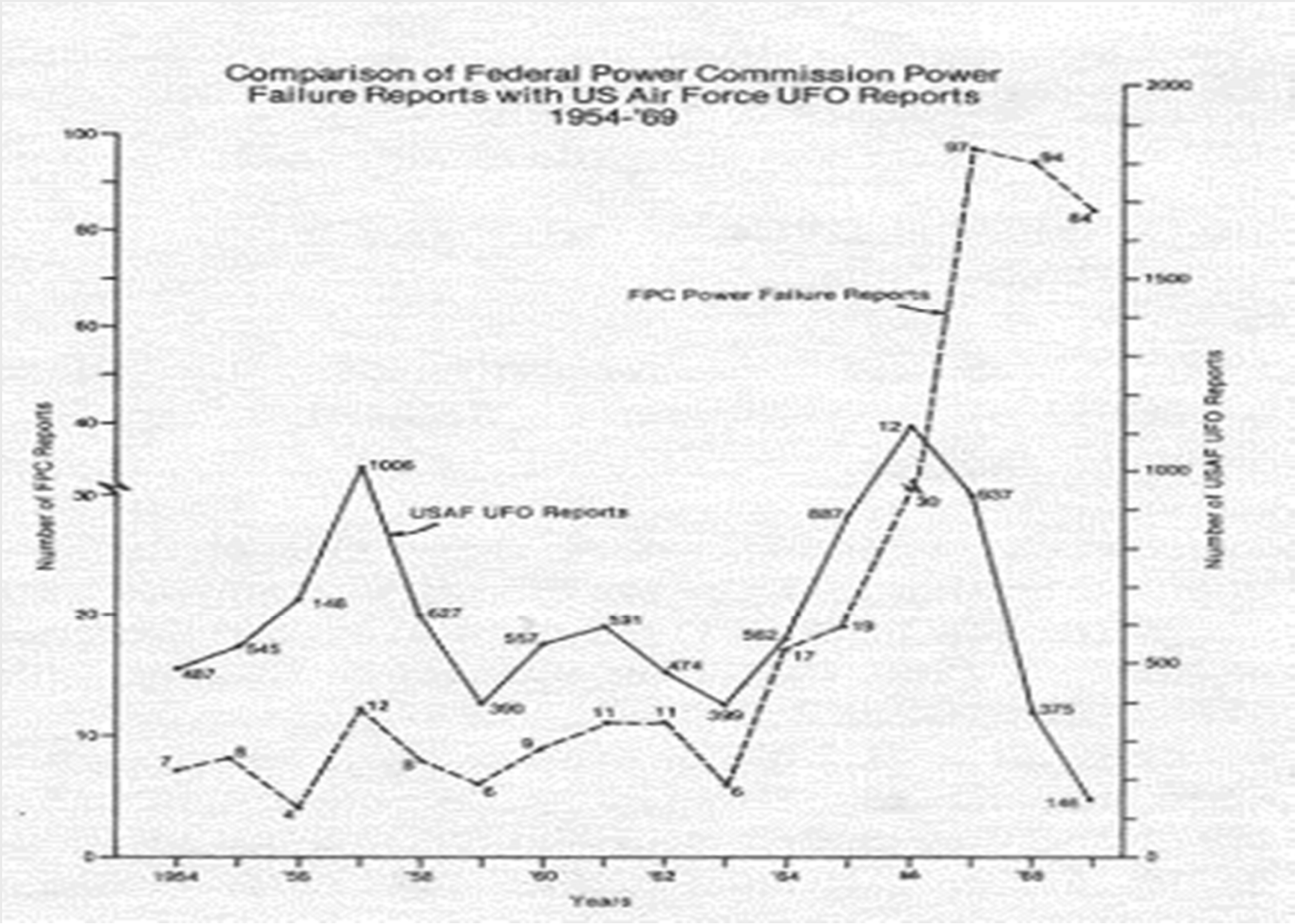
CT Selection

- C800 Current Transformer
  - Will support 800 volts @ 100 amps on CT secondary before saturation (20 times rated secondary current)
  - Consider burden of relays and cable impedance
- CT Accuracy decreases when less than full winding used
  - At half ratio, CT is C400
- CT Saturation:
  - Saturation most severe with high magnitude faults

Saturated Current



UFOs vs. Power Outages



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