Performance of Relaying During Wide-Area Stressed Conditions

IEEE Power Systems Relaying Committee

C12 Working Group Report

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C12 Working Group

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C12 WG Report Organization

- Description and detailed analysis of causes that lead to wide area disturbance
- Relay behavior under stressed conditions
- Field experience and examples
- Solutions to mitigate undesired operations
- Full report available on the PSRC website (Published Reports): http://www.pes-psrc.org/

Blackouts

- Increase in frequency of major, costly, blackouts since ‘94
- Power system is very complex and man-made
  - General understanding of blackouts caused by natural disasters
  - Human created system-wide outages should be preventable
    - Blackouts are symptoms (result?) of our decisions
- Analysis of disturbances reveals some common threads:
  - Protection equipment has had major impact on disturbance propagation: Address solutions to prevent propagation!
  - Propagation of the blackout can be arrested
  - Restoration time can be reduced
- It is not possible to avoid multiple contingency initiated blackouts, however:

The probability, size and impact of wide area blackouts can be reduced!

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Undesired/Unexpected Relay Operation During a Disturbance

- Sometimes contributes to the propagation.
  - Aug. 14, 2003 - Overreaching zone (Z3) operation on one 345 kV line tripped first followed by 14 line trips on over-reaching Zones.
- Sometimes prevents further propagation of a disturbance.
  - Island created during disturbance survived (New England and the Maritime provinces).

Factors Influencing Relay Performance During a Wide Area Disturbance

- Conditions not considered in the relay settings criteria
  - Multiple contingencies, severe overload condition, system voltage and frequency excursions beyond the normal operating range.
- Hidden failures in the scheme

Causes of Wide Area Disturbance

- Involves a combination of:
  - Voltage instability/ voltage collapse
  - Angular instability
  - Voltage/ Frequency excursions
  - Small Signal Instability
  - High equipment loading and high power transfers; High system unbalance

Protection Behavior During Stressed Conditions

- The report addresses issues with:
  - Transmission line protection
  - Transformer protection
  - Generator Protection
  - Bus Protection
  - Shunt Reactor/Capacitor Protection
  - Feeder Protection
  - Motor Protection

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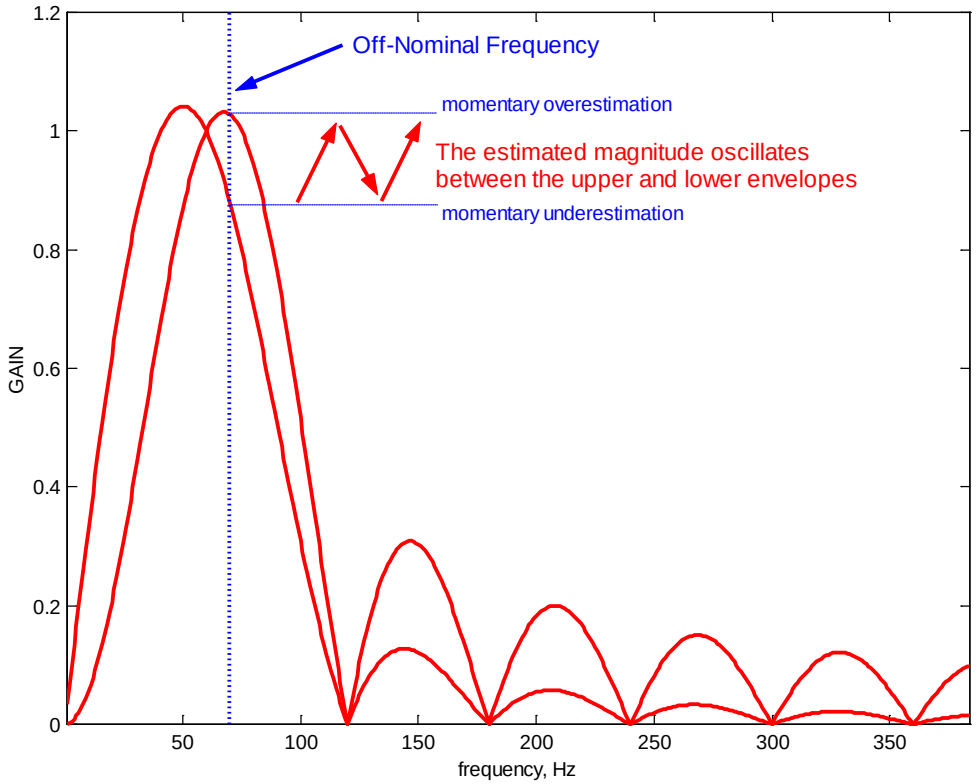
Impact of Frequency Excursion

- Off–nominal frequency operation affects most of the microprocessor-based relays
- Relays make use of fundamental frequency components for their protection function
- Phasor estimation techniques in Microprocessor-based relays work well at nominal frequency

Phasor Estimation Off-Nominal Frequency Response

- Frequency Tracking algorithms are slow or may stop tracking during a disturbance
- Effect on Current differential schemes are inconsequential



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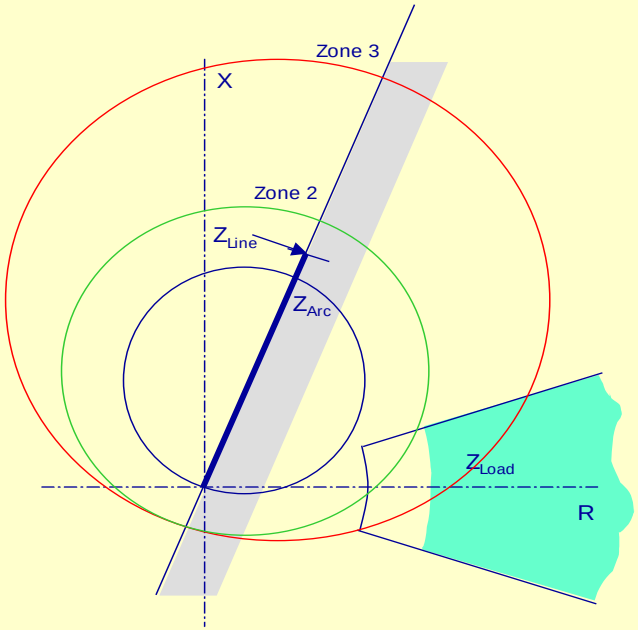
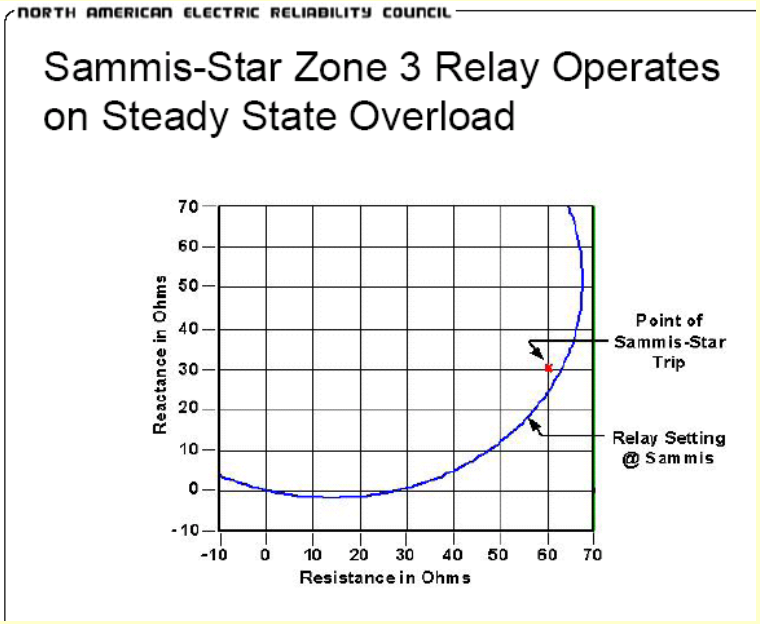
Transmission Line Protection

- Distance or Current differential/comparison scheme
- Relay may operate for faults outside the protected zone or its intended application
  - Power swings
  - Heavy loads
  - Frequency excursion
  - Voltage instability
  - Combination of the above

Heavy Overloads

- May result in faults lines sagging into trees or equipment damage
- Distance relays pick up if overloads not relieved - Zone 3 tripping as the relay detects this as three phase fault
- Thermal line protection may trip but not widely used in the US





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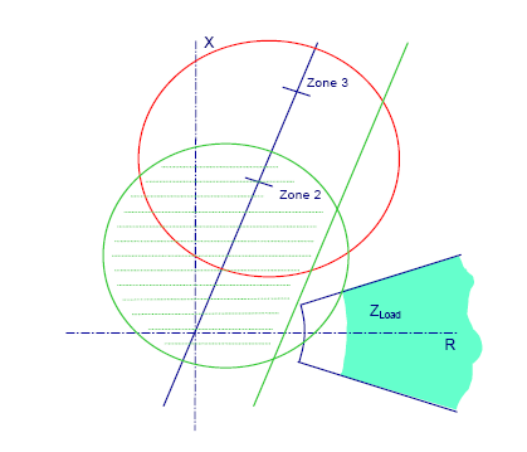
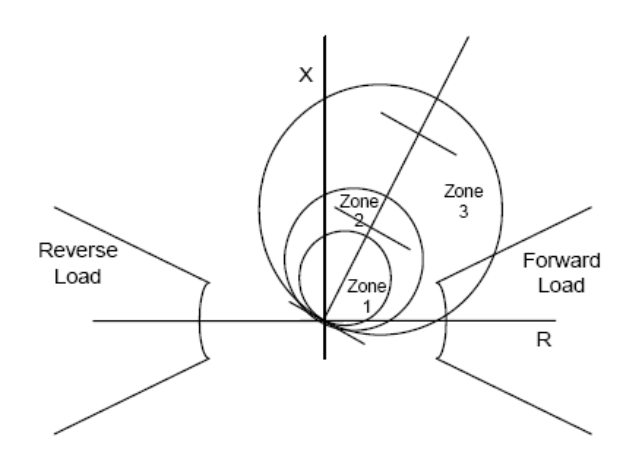
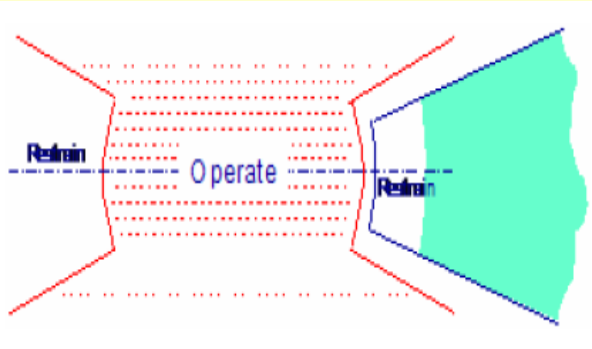
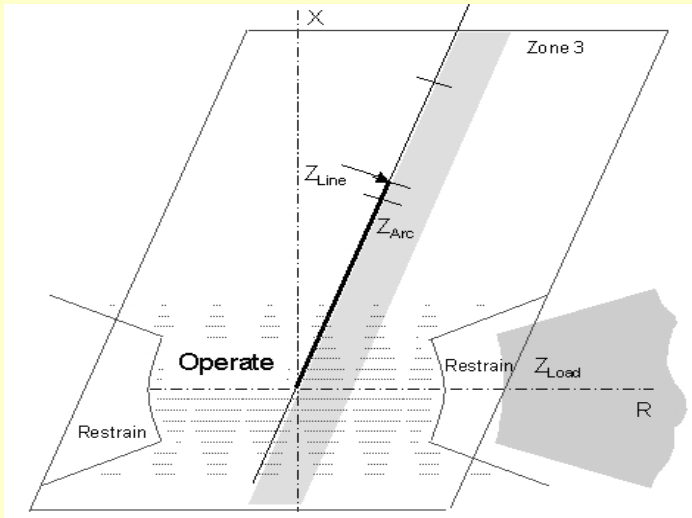
Load Encroachment Logic

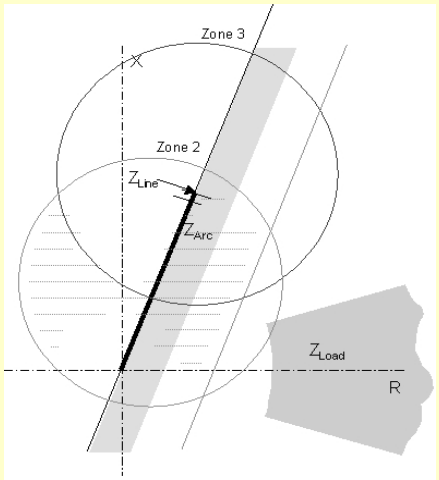






Methods Available to prevent relay operation for loads





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Zone 3 Summary

- Zone 3 cannot be arbitrarily removed without reviewing concrete protection applications and alternatives
- Protection applications and settings should not interfere with operation
  - Conductor thermal ratings, sagging, and re-rating
- New installations or upgrades using microprocessor relays can minimize effects of load encroachment
- Where conflict between impedance set points and load encroachment use alternative protection methods
  - Direct Transfer Trip
  - Line differential relays
- Use of adaptive protection or multi-setting groups

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Power Swing Detection and Application of Relays

- Slow variation of voltage and current instead of a step change during faults
- Three phase balanced phenomenon
- Power swings may cause unwanted relay operations at locations that can lead to cascading outages
- Relay applications on transmission lines for power swing blocking and out of step conditions are covered in depth in the report produced by IEEE PSRC after the August 14, 2003 event. Available on line at http://www.pes-psrc.org/

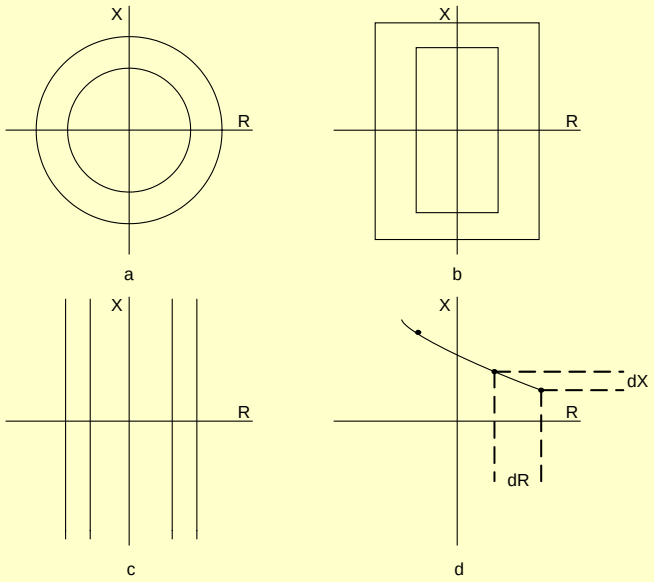
Power Swing Blocking Relay (PSB)

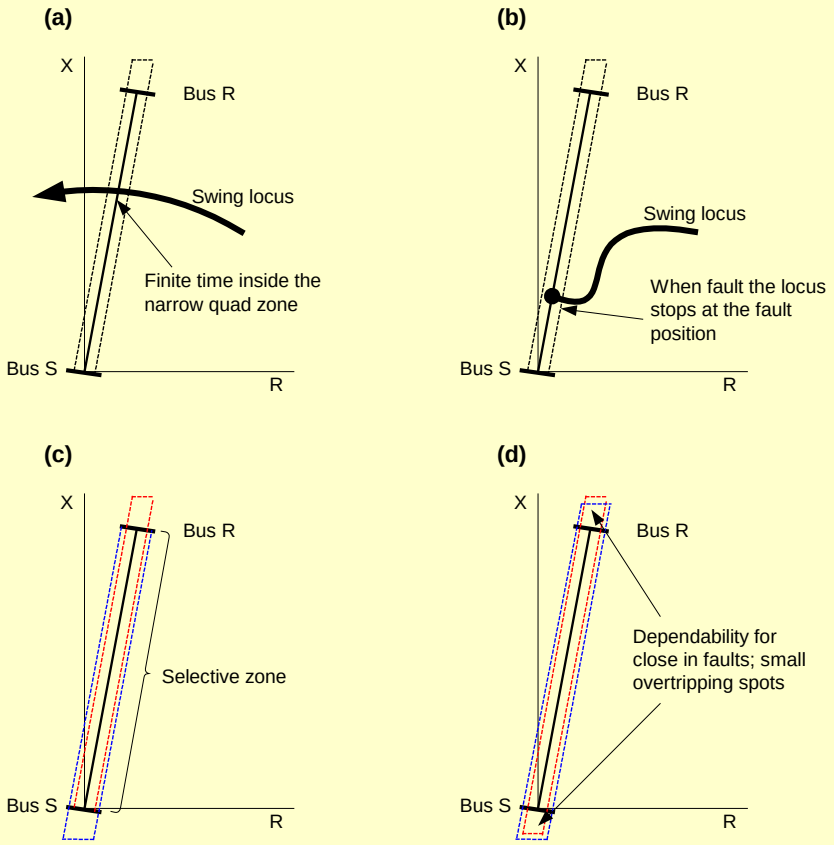
- PSB – discriminates between faults and power swings (stable and unstable)
- Blocks relay elements prone to operate during stable and unstable power swings
- Allows relay elements to operate during faults or for faults that evolve during out of step conditions

Out of Step Tripping Relay (OST)

- Discriminates between stable and unstable power swings
- Initiates system area separation at pre-determined points to maintain stability
- Protection philosophy is simple but proper implementation requires transient stability studies

Out of Step Relay Characteristics





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Effect of Frequency Excursion on Distance Protection

- Misoperations due to errors in impedance calculations are minimal
- Memory polarization is the main cause of undesired tripping
  - Operating quantity I x Z – V
  - Polarizing quantity k x V_{Memory}
  - Operating Criterion Angle(VOP – VPOL)< 90 deg

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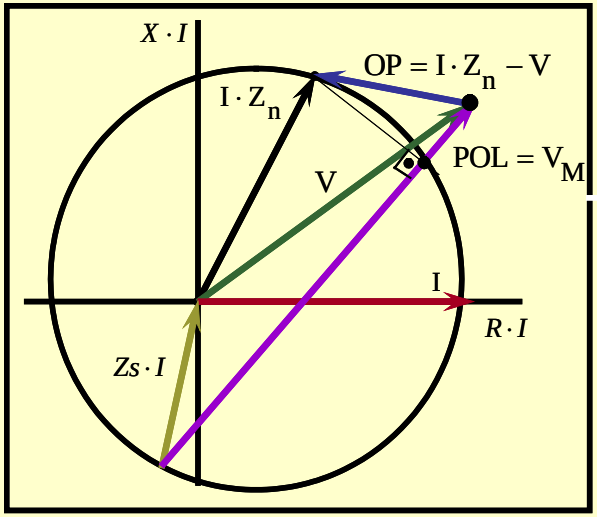
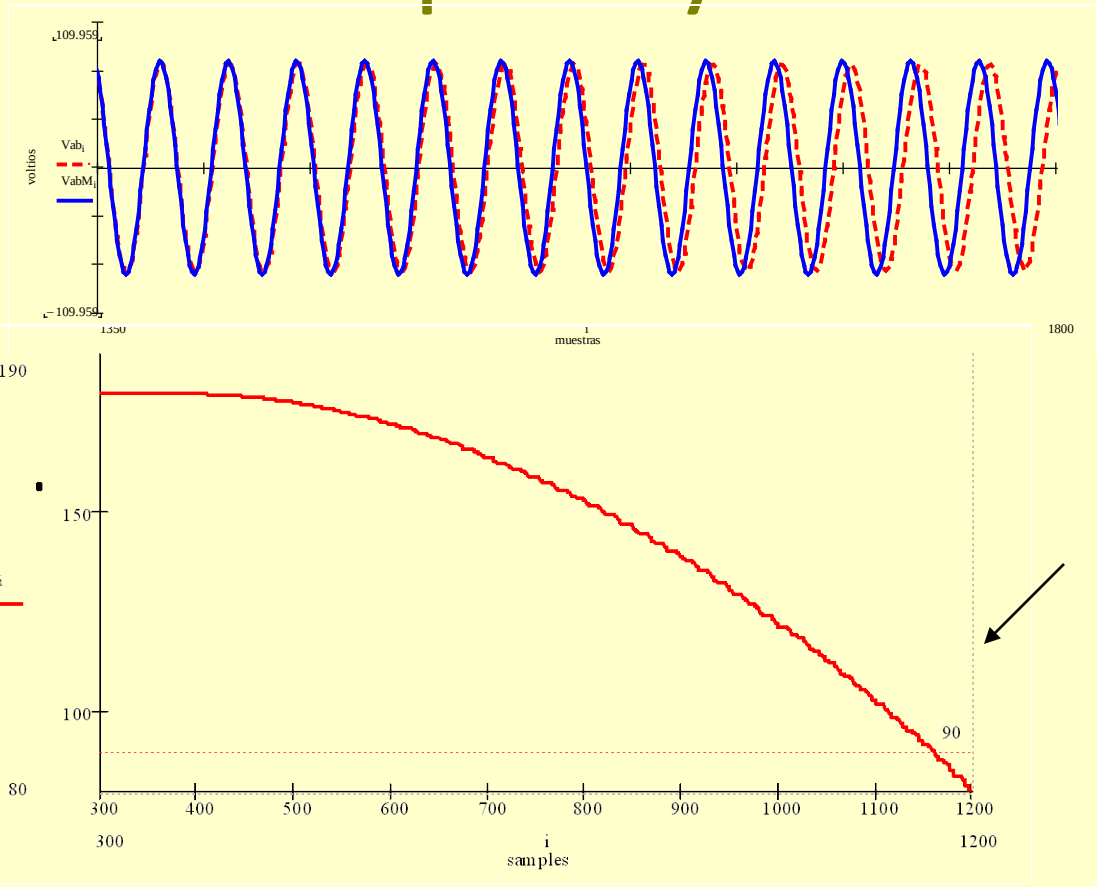
Distance Relay Operation During Off-Nominal Frequency





Change in Phase Angle between V_{OP} and V_{POL}

Solutions - Frequency Tracking and Compensation

- Numerical relays adapt estimation algorithms to maintain accuracy during slow changes in frequency
- Suggested methods for memory polarized relays: Memory voltage is used
  - Only during fault conditions with the use of fault detectors
  - Only if the available voltage is below a certain level

Other Transmission Schemes and Applications

- Current differential
  - Asymmetric Channel delays may cause misoperation
  - Harmonics or frequency deviation may affect depending on the filtering technique used
  - Generally not affected by other stressed conditions
- Parallel lines
- Multi-Terminal and tapped lines
- Series compensated lines
- High speed communication scheme considerations

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Improving Protection Performance

- Protection coordination studies across regions and within in the region
- Coordination with equipment control and protection
  - Study and review protection designs on a regular basis, as system conditions change
- Avoid hidden failures by adequate testing of not only individual relays, but also overall relay applications
- Increase the security of protection design in the areas vulnerable to blackouts
  - Voting schemes are implemented by some utilities

Conclusions

- Protective systems are often involved in major wide area disturbances, sometimes preventing further propagation and sometimes contributing to the spread
- The report identifies key system conditions that affect the protection performance, describes proven methods and recommendations to improve the protection performance

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Questions?