Low Impedance Differential Protection: New Challenges and Advanced Solutions

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Presentation Outline

- Introduction to differential protection
- Typical challenges and solutions
  - CT saturation, fault clearing, etc.
- New challenges and solutions
  - SV relays, renewables, GIC, etc.
- Conclusions
Introduction

- **Slope characteristics**

\[ I_0 = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 \]
for all a, b, c phases

\[ I_r = \frac{|I_1| + |I_2| + |I_3| + |I_4| + |I_5| + |I_6|}{x} \]
for all a, b, c phases

- **Main Challenges**
  - Lack of security under load conditions
  - Lack of security under external fault conditions
**Introduction**

- Dual slope characteristics

\[
I_0 = I_1 + I_2 + I_3 + I_4 + I_5 + I_6
\]

for all a, b, c phases

\[
I_r = \left( |I_1| + |I_2| + |I_3| + |I_4| + |I_5| + |I_6| \right) / x
\]

for all a, b, c phases
Introduction

- Dual slope characteristics with **high current setting**

\[ I_0 = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 \]
for all a, b, c phases

\[ I_r = \left( |I_1| + |I_2| + |I_3| + |I_4| + |I_5| + |I_6| \right) / x \]
for all a, b, c phases

- High current setting provides tripping options, independent of the slope pickup, during heavy fault conditions.
Introduction

- Difficult faults
  - CT saturations during close-in external faults
  - Subsidence currents present after clearing external faults
Phase Angle Comparison Method

- Compares phase angles of currents

This function may block the operation during high impedance internal faults if there is only one active source.
Rate of Change of Differential Method

- Compares rates of change of operating and restraint currents

\[ \frac{dI_0}{dt} > \frac{dI_r}{dt} > 0 \quad \text{Internal fault} \]

other cases \quad \text{External fault}
Advanced Filtering

Before

After
Overall Differential Protection Scheme

- 87 Logic (high level)

- Algorithm for detection of CT saturations
  - Harmonic based algorithm
Example Network

- 230 kV test network
CT Saturation During External Faults

- External fault
  - Phase B-G

![Diagram showing a power system with external fault]

- Protected Bus
- 200 km T-Line (open ended)
- 100 km T-Line
CT Saturation During External Faults

- External fault
  - Phase B-G
CT Saturation During External Faults cont.

- Variations of phase currents
CT Saturation During External Faults cont.

- Variations of operating and restraint currents
High Impedance Fault

- Internal Fault
  - Phase A-G with 200 ohms fault resistance
High Impedance Fault cont.

- Variations of operating and restraint currents
High Impedance Fault cont.

- Variations of phase currents
High Impedance Fault cont.

- Variations of operating and restraint currents
Differential Protection Basics: Summary

- Typical Challenges
  - Loading
  - CT saturation
  - External fault clearing
  - High impedences faults

- Solutions are available to address above challenges.
New Considerations

- SV Relays
- Impact of GIC
- Impact of inverter connected renewables
Challenges Associated with SV Relays

- IEC 61850 9-2 type applications
Challenges Associated with SV Relays

- **Time synchronization**
  - Accurate time synchronization (MUs and Relays) is critical for correct operation of the differential protection scheme.
  - 1 millisecond deviation introduces 21.6 degree error

- **Solutions**
  - Precision Time Protocol (PTP)- IEEE 1588
    - Flexible and accurate
  - IRIG-B
Challenges Associated with SV Relays

• **Signaling/processing**
  • Processing delays
    • Data is coming into a SV relay from different merging units
  • Network delays

• **Solutions**
  • Proper data/sample buffering and alignment at subscriber level (at SV Relay).
    • Overall response time of the protection is affected due to sample/signal buffering/alignment.
Challenges Associated with SV Relays

• **Missing data/samples**
  - Missing data /samples may lead to misoperate the relay.
  - Sample/data missing could happen due to different reasons in different ways.
    - Eg: randomly missing few samples, continuously missing few samples, etc.

• **Solutions**
  - Blocking during sample/data missing conditions.
    - Relay may not need to block for all conditions.
    - Advanced extrapolation techniques can be applied to ensure correct operating during sample missing conditions.
      - This may delay the response of the relay (acceptable)
Challenges Associated with SV Relays

- **Off-nominal frequency response**
  - Typically, merging units operate based on fixed frequency sampling rate.
  - Differential relay typically use different frequency tracking techniques.
    - **Method-1**: Adjust the sampling rate based on actual frequency
    - **Method-2**: Frequency correction without adjusting the sampling (fixed frequency sampling)

- **Solutions**
  - Relays/algorithms operate based on adjustable sampling rates needs to be modified to correct off-nominal frequency issues.
Challenges Associated with SV Relays: Summary

• Challenges Discussed
  • Accurate time synchronization
  • Signaling
  • Data/sample missing
  • Off-nominal frequency response

• Methods and techniques are available to overcome above challenges.
Impact of GIC

• Impact of Geomagnetically Induced Currents (GIC)
  • During GIC conditions, transformers could introduce harmonics on electrical signals.
  • Overall operation of differential protection could be affected.
    • Differentiation of inrush vs GIC (87T)
    • Differentiation of CT saturation vs GIC

• Solutions
  • Use of alternative inrush and CT saturation detection methods
  • Enhanced inrush detection methods

• NERC- TPL-007-3 – Transmission System Planned Performance for Geomagnetic Disturbance Event
Impact of Renewables

- Impact of inverter connected renewables
  
  - Lack of fault current magnitudes/duration

![Image of renewable energy sources]
Impact of Renewables

- Impact on differential protection during faults

![Graph showing operate and restrain regions for differential protection]

- Solution
  - Adjust the $I_{0\text{min}}$ (may not be suitable for very weak systems)
Impact of Renewables

- Impact of inverter connected renewables
- Impact of sub harmonics conditions
Impact of Renewables

• Impact of sub harmonics
  • Control modes would reflect into electrical networks as complimentary frequencies.
    • Eg. 45 Hz control mode may reflect into electrical calculations as 15 Hz and 105 Hz.
  • This is visible on electrical signals as a harmonic condition.
  • The operation of differential protection will be affected.
    • Differentiation of inrush vs Sub Harmonics (87T)
    • Differentiation of CT saturation vs Sub Harmonics

• Solution
  • Advanced filtering method can be used to remove the impact of sub harmonics (may not be adequate for all conditions)
Conclusions

• Key challenges associated with differential protection are discussed.
  • Relay technologies
  • New application considerations

• Possible solutions to overcome these challenges are discussed.
  • Some of these challenges are applicable for other protection elements (distance, generator, etc.) as well.

• Challenges associated inverter connected generators need further attention.
Questions?