Unrestrained Low-Impedance Bus Differential – Should I Use It?

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Agenda

• Introduction

• History of low impedance bus differential and the evolution of the unrestrained element

• Modern Unrestrained Low Impedance Bus Differential

• Case Study: Unexpected Operation of a 115 kV Unrestrained Bus Differential Element during an external Fault

• Conclusions
Introduction

• Restrained percent differential element – the cornerstone of low-impedance bus differential (LIBD) protection
• LIBD popular with modern microprocessor based relays
  • Offer advantages over microprocessor based high impedance BD
    • Typically faster
    • More functionality (multi-function)
    • Over-current
    • Directional control
    • Metering
    • Unrestrained (AKA: high-set or instantaneous) BD
Introduction

- History of BD and the evolution of modern unrestrained BD
  - Possibly came from transformer differential
- Case study of an actual unrestrained bus differential element mis-operation
  - Illustrates the application concerns
    - Security
    - Applicability of the element
    - Speed advantage may not justify risk
    - Cautions associated with using it
      - Manufacturer’s instruction manual may not provide complete advice
      - User must consider all possible causes of CT saturation
History of Low Impedance Bus Differential & Evolution of Unrestrained Element

- Earliest BD was electro-mechanical TOC
  - Low impedance
  - Unrestrained
  - Slow
  - Prone to false trips
    - CT errors
    - Drove development of CT standards
History of Low Impedance Bus Differential & Evolution of Unrestrained Element

- Electro-mechanical high impedance bus differential relay developed next
  - Utilizes a voltage coil to measure error voltage
  - Avoid circulating error currents in its operating winding
    - CT excitation characteristic provides “restraint”
  - Very successful
Electro-mechanical low impedance restrained BD developed
- Improve security during external faults
- Each winding current is passed through restraint coils
- Differential current is passed through an operate coil
- Trips when operate torque exceeded restraint torque
- No intentional delay
  - But operating time is highly variable with rest torque
  - Operating times from 0.07 – 0.7 seconds
  - No unrestrained direct tripping units
Several analog electronic high impedance BD relays offered
  • Some still available
  • Authors found only one restrained electronic BD
    • Medium impedance
    • No unrestrained unit
Modern microprocessor Multi-function low impedance BD relays
  • Over-current, metering, waveform & event capture
  • Unrestrained element shows up
  • Why?
    • Author’s believe it came from the restrained transformer differential
      • Required to trip during in-rush
      • No similar “hole” in tripping for BD
Unrestrained element
  • What problem are we trying to solve?
    • Speed
      • Microprocessor restrained BD is fast
      • Consistent operating time (12-20 mS)
      • Unrestrained element 2-4 mS faster
        • Not significant in most applications
      • Incur false trip risk during severe CT saturation
        • Good CTs can saturate under the right conditions
        • DC offset
        • Remnant flux
  • No way to make secure and keep speed advantage
Case Study

Unexpected Operation of a 115 kV Unrestrained Bus Differential Element during an external Fault

Location of first fault (B-G)

Location of second fault (B-C-G)

Second yard owned by another utility
Case Study

West bus primary low imp BD mis-operated for second fault
- Unrestrained element operated
- Restrained element did not operate
- Secondary high imp BD did not operate

All 4 B & C-phase CTs saturated (no waveform of sec 87B but..)

Bkr open during event
Case Study

Waveform traces clearly show saturation of 115 kV CTs as fault evolves from low-high side

Low side fault evolves to high side fault
Case Study

B-phase restrained element picks up (B87R PKP) but does not trip (B87R)

- Directional (B DIR) and saturation (B SAT) elements block

B-phase unrestrained operates on evolved fault
Case Study

Why did the CT saturation cause a false trip?
- Manufacturer’s instruction manual calcs were followed to calculate pickup of unrestrained element
  - Consider the ratio and class of CTs (1200/5, C800)
  - Considered affect of X/R ratio and available fault current
  - Yet saturation was worse than predicted
- Extensive testing of CTs and CT circuits
  - Everything tested OK
- Extensive relay testing
  - Owner injected 90 A and relay remained stable
  - Manufacturer repeated factory acceptance tests – OK
- Relay replaced “just in case”
Case Study

Why did the CT saturate?
• Culprit is believed to be remnant flux
  • In core due to first fault
  • Second fault saturated the CT
    • Can not change flux instantaneously
• No discussion of this in manufacturer’s manual
Case Study

Remedial actions taken
• Relay replaced
• Unrestrained element tripping disabled
  • No clear advantage to using it
  • No way to be absolutely sure of security

Original logic – Trip with overall function operation

Revised logic – Trip with restrained element operation only
Conclusions

• LIBD popular with modern microprocessor based relays
  • Offer advantages over microprocessor based high impedance BD
• Unrestrained BD can cause false trips if not properly applied
  • May not be possible to assure absolute security
  • No clear history of successful unrestrained BD prior to microprocessor relays
    • May have come from transformer differential
  • Case study of mis-operation supports risk assessment
    • Good CTs can still saturate unexpectedly
    • 2-4 mS speed increase may not justify risk
  • Following manufacturer instruction manual will not necessarily assure security
Thank You

Questions?