**Relion. Thinking beyond the box.**

Designed to seamlessly consolidate functions, Relion relays are smarter, more flexible and more adaptable. Easy to integrate and with an extensive function library, the Relion family of protection and control delivers advanced functionality and improved performance.
ABB is pleased to provide you with technical information regarding protective relays. The material included is not intended to be a complete presentation of all potential problems and solutions related to this topic. The content is generic and may not be applicable for circumstances or equipment at any specific facility. By participating in ABB’s web-based Protective Relay School, you agree that ABB is providing this information to you on an informational basis only and makes no warranties, representations or guarantees as to the efficacy or commercial utility of the information for any specific application or purpose, and ABB is not responsible for any action taken in reliance on the information contained herein. ABB consultants and service representatives are available to study specific operations and make recommendations on improving safety, efficiency and profitability. Contact an ABB sales representative for further information.
Line Current Differential Protection

Roger Hedding

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Roger graduated from Marquette University and joined Westinghouse Electric Corp. After receiving a Masters degree in Electrical Engineering from the University of Pittsburgh, Roger became a District Engineer, and eventually moved to Milwaukee where he currently resides.

As a Senior Consultant he guides the applications and development of relay products for the North American market. Roger is a IEEE senior member, and Past Chair of the IEEE Power Systems Relay Committee. Roger has authored or co-authored many papers in power systems protection.
Learning objectives

- What is a current differential relay?
- What is a line current differential relay?
- What are the application issues of line current differential relays vs line distance relays?
Line differential protection

Agenda

- Introduction
- Differential Relay
- Line Current Differential Relay
- Application Issues
- Communications
- Summary
Simple line differential protection

Application
Multi-terminal differential protection

- Unit Protection
- Task – To Determine if fault is within protected zone or outside the protected zone
- Protected Zone
  - Transmission Line Terminals
  - Power Transformer Terminals
- Measures Currents at the terminals of the protected circuit
- Transmits information about the currents to the remote end(s)
- Compares the currents using classical current differential principles
- Supplemented by additional criteria
- High Dependability – Operates for all faults which it is designed to operate
- Highly Security – Doesn’t operate for faults for which it should not operate
- Good performance during evolving faults, and cross country faults
- Immune to power swings, mutual coupling, and series impedance unbalances
- With sample data its easy to calculate
  - Sequence components
  - Harmonic Currents

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Slide 8
Line current differential
Basics
Current only scheme

- No dependence on VTs
  - Relief from Fuse fail, CCVT, Power swings
- Can be very sensitive in detecting ground faults- Not matched by distance relays
- Segregated phase
  - Ideal for evolving faults
  - and cross country faults
  - Single pole tripping
  - Series compensated lines
- Communication dependent
Types of current only schemes

- Current Differential
  - Analog
  - Digital

- Phase Comparison
  - Segregated
  - Combined Sequence
  - Not used much anymore
Current differential relay

Local end

Protected Equipment

Remote end

$I_L$ $I_R$ $I_L + I_R$
Normal operations or external faults

\[ I_L = -I_R \]
\[ I_L + I_R = 0 \]  \[\Rightarrow\] Should NOT TRIP!

Local end  \[\rightarrow\]  Remote end
Internal faults

\[ I_L + I_R \neq 0 \]

\[ \Rightarrow \text{Should TRIP!} \]

Local end + Remote end
Operating and restraint regions

\[ \frac{I_L}{I_R} = x + jy = -1 \]

Restraint point

-1
Operating and restraint regions

- High security for external faults
- High sensitivity for internal faults
Operating and restraint regions

Add restraint windings in addition to the original operating winding

Local end

Remote end

Protected Equipment

I_L

I_R

I_L + I_R

Relay
Operating (trip) condition

Local end

Protected Equipment

Remote end

\[ |I_L + I_R| \geq K(|I_L| + |I_R|) \]

or

\[ |I_L + I_R| \geq K(|I_L - I_R|) \]

or

\[ |I_L + I_R| \geq K|I_{\text{max}}| \]
Operating and restraint regions

Differential Current

Operate Current (p.u. of Ibase)

Operate Conditionally

Restrain

Restraint Current (p.u. of Ibase)
Line current differential relays

- Two terminals physically separated
- Two relays
- Communication between two terminals
Line current differential relays

\[
\frac{1}{2}(I_L + I_R)
\]
Normal conditions or external faults
Internal faults

Ref. File: Abcf1L.PH at 60 Hz
10/05/2000 12:00:48.48700
REL352 File

Sec. File: Abcf1r.OPH at 60 Hz
10/05/2000 12:01:11.10500
REL352 File

YScale = 100.0 V
IScale = 53.43 A
Line differential protection Characteristic
Line current differential relays
First generation

- Reduce communication requirements
- Sequence filter
HCB pilot wire relay
Pilot wire relays

Problems

- Rise in station ground potential
- Induction from power line circuits
Pilot wire relays

Solutions

- Twisted wire pair
- Gaps/arrestors, etc.
- Drainage reactors
- Neutralizing reactors
- Insulating transformers
Non-metallic communications Issues

- Propagation delay-time synchronization
- Signal corruption
- Communication network
  - Bits, bauds, bandwidth, switching, Mux
- Backup protection
Numerical relay

- First generation of numerical relays transmitted Fourier coefficients across channel
- Newest relays transmit sampled data across channel
  - Can do harmonic analysis
  - Calculate sequence components
Channel requirement

- Segregated phase differential protection typically calls for larger information exchange - digital communication
  - Ideal against cross country faults, series compensated lines, single pole tripping etc.
Channel options

- Direct Fiber
  - Short Range 1 – 3 Km
  - Medium Range 3 – 50 Km
  - Long Range 51 – 160 Km
- G.703
- Fiber to multiplexer
- Use C37.94 standard
Line termination

- Single breaker
- Ring bus
- Breaker and one half
- Transformer
Single breaker

- $I_{LP}$
- $I_{LS}$
- Line Differential Relay
- $I_L$
Ring bus or breaker and 1/2

How to Connect CT’s?

Relay

I_h

I_l - I_h
Classical current transformer connection
Classical connection
Problems

- Individual current transformer information
  - Current transformer health
    - Open circuit
    - Shorted
    - Saturated
  - Metering information
- Larger restraint current requires operate current
  - Reduced sensitivity
Differential characteristic

Operate Current (p.u. of Ibase)

Restraint Current (p.u. of Ibase)

Operate

Ct’s separate

Restrain

Parallel Ct’s
Preferred dual breaker connection

Line Differential Relay

$I_L - I_H$

$I_H$

$I_L$
Transformer terminated line
Transformer inrush

Current Phase shift across transformer
Transformer inrush current
Low side faults on delta wye grounded transformer

Take care of in settings by giving vector group of winding configuration
Classical differential operation

Local (Inrush)

Remote = 0

Differential Element

Trip
Inrush characteristic

- 2nd Harmonic
- Over 7% of Fundamental (60 HZ) Current
Delta wye transformer
External ground fault
Transformer terminated line

Concerns

- External ground faults causing zero sequence current to flow only on one side of transformer (delta – wye)
  - Eliminate zero sequence current
  - Previously done by using auxiliary CT in zero sequence trap
  - Do numerically in relay
Tapped line
Secondary fault
Relative fault currents

- **Current magnitude**

- **Line fault**

- **Transformer secondary fault**
Small power transformer
Tapped line

- Time delay differential function for small differential current below a set limit
- Coordinate with downstream relays at tap
- Differential currents above limit with allow instantaneous operation
Tapped line

Protected Zone Instantaneous Coverage

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## Differential protection

Tap to small transformer

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### Protection Zone (High Speed Clearing)

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### Delayed Clearing

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### Summary of settings:

- Object: F50051-1, 87L in REL670
- Power/Current setting: 13 MVA, 18 MVA
- Time/time const (k) setting: 0.1, 0.2
- Characteristic: Norm inv, Norm inv
- High set value: 9999 MVA, 9999 MVA

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High impedance fault

High Resistance Fault
Negative sequence Fault discriminator

Negative Sequence From Fault
Negative sequence
Current fault discriminator

- If the two currents flow in the same direction, the fault is internal.
- If the two currents flow in opposite directions, the fault is external.
Capacitive current Compensation

Equivalent “PI” Network of Line

Make pick-up of differential above the capacitive current
Make a compensation in algorithm $I_c = \frac{V}{X_c}$
Charging current Compensation

- Measure fundamental frequency differential current under normal steady state conditions
- Normal means no start signals, neither internal or external fault,
- Subtract it making resulting differential current zero
- No need to raise minimum operate current
Three terminal line
Application

Protection Zone

RED670

Communications lines

RED670

Current from all terminals
Fault current can be fed from all line ends
Four communications modules
Practical use
Route switched networks
With delay symmetry

The echo method allows for route switching with equal delay times for send and receive
Route switched network
Without delay symmetry

GPS time synchronization

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Redundant communication channels
5-Terminal line
Master-master system
5-Terminal line
Master-slave system
Master-slave
Application example
Multifunction line current differential relay
Relion® RED670
Maximum power system reliability

Efficient substation automation for the protection, monitoring and control of high voltage overhead lines and cables

- Delivering significant savings in configuration, setting, erection, commissioning, maintenance, and space
- Improving availability with outstanding performance and efficient information management
- Enabling applications with multiple algorithms, multiple objects, integrated and distributed architectures
- Application flexibility makes them an excellent choice for both new and retrofit installations
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- **RTU 500 Series** – Proven, powerful and open architecture
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