Introduction to Protection Basics and Terminology

31st Annual Hands-On Relay School
17-March-2014

Brent Carper, PE
Engineering Manager – Relay Application Innovation, Inc.
Adjunct Professor – Washington State University
Brent.C@RelayApplication.com
Agenda

Hands-On Relay School Schedule & Logistics

What is Protective Relaying?
- What: What are we protecting
- Why: Why do we need protection
- When: Speed, selectivity, dependability
- Where: The equipment used to perform protection
- How: Applying protective relaying

Fundamentals of Protection
- Zones of Protection
- Coordination
- Reliability
- Compliance
Agenda

Tools of Protection
- Basic Power Equations
- 3-Phase Power Equations
- Per Unit System
- Phasors
- Symmetrical Components

Relay Types
- Classifications
- Construction
- Considerations
- ANSI Device Numbers
Agenda

Application Examples:

- **Distribution:**
  - Phase and Ground Overcurrent (50/51)

- **Transmission:**
  - Directional Overcurrent (67), Distance (21), Differential (87), Pilot Wire (85)

- **Equipment:**
  - Differential Relays (87), Sudden Pressure (63SPR)

- **Generation:**
  - Negative Sequence (46), Reverse Power (32), Loss of Excitation (40), Volts/Hz (24), Out of Step (78), Loss of Field (40), Stator Ground (64)

- **Other:**
  - Auto Reclosing (79), Synch Check (25), Lockout (86), Breaker Failure (50/62BF)

- **Other:**
  - Undervoltage (27), Overvoltage (59), Over/Under Frequency (81)
Basic Track – Monday

Introduction to System Protection Lecture Series (Smith CUE 203)

7:45am  Introduction to Protection Basics and Terminology
9:15am  Introduction to CT Basics and Testing
9:40am  Break
10:00am Introduction to CT Basics and Testing (cont.)
10:45am Introduction to Substation Print Reading
12:00am Lunch (on your own)

Introduction to System Protection Lecture Series (Sloan 175)

1:00pm Basics of Relay Test Equipment
1:45pm Introduction to Troubleshooting
3:00pm Break

Hands-On Lab (EE/ME B54)

3:10pm ABB CA relay
5:00pm Adjourn
Basic Track – Tuesday

Open Concurrent Lecture Series (Smith CUE)
- 7:30am  Concurrent Open Lecture #1
- 8:40am  Concurrent Open Lecture #2
- 9:40am  Break
- 9:50am  Concurrent Open Lecture #3
- 11:00am Concurrent Open Lecture #4
- 12:00pm Lunch (on your own)

Hands-On Lab (EE/ME B54)
- 1:00pm  ABB CO relay
- 3:00pm  Break
- 3:10pm  ABB RC relay
- 5:00pm  Adjourn
- 6:30pm  Supplier’s Showcase (University Inn, Moscow)
Basic Track – Wednesday

Hands-On Lab (EE/ME B54)

- 7:30am  GE JBCG
- 10:00am  Break
- 10:10am  GE JBCG (cont.)
- 12:00pm  Lunch (on your own)
- 1:00pm  Basler BE1-27/59 relay
- 3:00pm  Break
- 3:10pm  Basler BE1-81O/U relay
- 5:00pm  Adjourn
- 6:00pm  Social, no-host bar (University Inn, Moscow)
- 6:30pm  Banquet and Entertainment (University Inn, Moscow)
Basic Track – Thursday

**Hands-On Lab (EE/ME B54)**

- 7:30am ABB HU
- 10:00am Break
- 10:10am ABB HU (cont.)
- 12:00pm Lunch (on your own)
- 1:00pm SEL-551
- 3:00pm Break
- 3:10pm SEL-551 (cont.)
- 5:00pm Adjourn
Basic Track – Friday

Conclusions (Smith CUE 203)

7:30am  Closing Remarks
7:45am  Feature Presentation: Thanksgiving 2012 at Thermalito Powerplant
9:00am  Break
9:15am  Feature Presentation: Integration of Wind Resources into the BPA Grid
10:30am  Adjourn
What is Protective Relaying?

What: What are we protecting?
What is Protective Relaying?

Why: Why do we need protection?
What is Protective Relaying?

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What is Protective Relaying?

Why: Why do we need protection?
What is Protective Relaying?

When: Speed, selectivity, dependability.

Protection must:

- Detect an abnormal system condition
- React quickly
- Respond properly

Not as easy as it sounds!

- How do we “detect” something happening miles away?
- How do we react quickly enough? Electricity is traveling at (almost) the speed of light.
- How do we ensure that the response action is correct? An incorrect response could make the abnormal condition worse.
What is Protective Relaying?

When: Speed, selectivity, dependability.

Protection must:
- Detect an abnormal system condition
- React quickly
- Respond properly

In general:
- “abnormal” means a Fault
- “quickly” means Milliseconds
- “properly” is accomplished by:
  - Engineering (relay application, coordination, redundancy and backup)
  - Testing, Commissioning, Maintenance, Verification, Event Analysis
What is Protective Relaying?

Where: The equipment used to perform protection.
What is Protective Relaying?

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Where: The equipment used to perform protection.
What is Protective Relaying?

Where: The equipment used to perform protection.

Relays are just one component of the “Protection System”

- Relays
- Circuit Breakers (or switches)
- Input Sources (CTs, PTs, sensors)
- DC System (battery)
- Interconnection (wiring, controls, integration)

*The best Relay Techs (and engineers) have expertise on the “Protection System”, not just the relays!*
What is Protective Relaying?

How: Applying protective relaying.

1. Engineering
   - Applications, zones of protection, fault studies, schematic design
   - Relay settings and logic

2. Construction and Commissioning
   - Testing the application (not the settings)
   - Calibration of E/M relays
   - Functional testing

3. Maintenance for Reliability
   - Periodic in-service load readings, relay I/O testing, E/M relay calibration, trip checks, breaker monitoring and maintenance, battery system maintenance
   - Event analysis
   - Managing changes, managing relay firmware, verifying settings
   - Cyber security
What is Protective Relaying?

How NOT to apply protective relaying...
What is Protective Relaying?

The best Relay Techs (and engineers) have expertise on the “Protection System”, not just the relays!

The best Relay Techs (and engineers) do not become famous, and do not end up on YouTube!
Zones of Protection
Zones of Protection

Feeder Protection
Zones of Protection

Feeder Protection
Motor Protection
Zones of Protection

Feeder Protection
Motor Protection
Line Protection
Zones of Protection

Feeder Protection
Motor Protection
Line Protection
Transformer Protection
Zones of Protection

Feeder Protection
Motor Protection
Line Protection
Transformer Protection
Bus Protection
Zones of Protection

Overlapping Zones of Protection

Feeder Protection
Motor Protection
Line Protection
Transformer Protection
Bus Protection
Generator Protection
Zones of Protection, Backup, and Coordination
Zones of Protection, Backup, and Coordination

Zone 1 = Instantaneous
Zones of Protection, Backup, and Coordination

Zone1 = Instantaneous
Zone2 = Time Delayed
Zones of Protection, Backup, and Coordination

Overcurrent and Impedance protection provides backup by “overreaching” on both transmission and distribution systems. Overreach must be coordinated using time delay.

Zone1 = Instantaneous
Zone2 = Time Delayed
Zone3 = Time Delayed
Coordination

Reach
- Overcurrent: Determined by the pickup setting (tap)
- Impedance: Determined by the electrical distance (mho circle)

Instantaneous
- There is no such thing as “instantaneous”
- No intentional time delay – as fast as possible

Time Delay
- Definite Time (fixed time delay)
- Inverse Time (delay depends on the magnitude and a curve)
Coordination – Time Overcurrent
Coordination – Time Overcurrent
Reliability

Dependability = Trips every time
Security = Never false trips

Increase Dependability by:
- Increasing sensitivity, increasing number of elements/relays used
- Redundant relays, dual batteries, dual trip coils
- Digital relay self monitoring
- Maintenance, reviewing events

Increase Security by:
- Correct application and good design engineering
- Minimizing “features”, maintaining simplicity
- Calibration (e/m and static), and Firmware (digital)
Reliability?
Compliance

North American Electric Reliability Corporation (NERC) Protection and Control (PRC) Reliability Standards

- PRC-001 System Protection Coordination
- PRC-002,012 Disturbance Monitoring
- PRC-004 Protection System Misoperations
- PRC-005 Protection System Maintenance and Testing
- PRC-006,008,010,011,015,016,017,021,022 Load Shedding and RAS Schemes
- PRC-23 Transmission Relay Loadability

NERC compliance is the best thing to happen to Relay Techs in 136 years of electric power! NERC PRC-005 has made relay testing and commissioning one of the very most critical and important functions in the utility industry.
Basic Electrical Theory

Ohm’s Law
Kirchhoff’s Current Law
Kirchhoff’s Voltage Law
Basic Power Equations

\[ \vec{V} = \vec{I} \times \vec{Z} \quad \vec{Z} = R + jX \]
\[ S(VA) = \vec{V} \times \vec{I}^* = P + jQ \]

\[ P(W) = V \times I \times \cos \theta = V \times I \times PF = \frac{V^2}{R} = I^2 \times R \]
\[ Q(VAr) = V \times I \times \sin \theta \]

\[ S(VA) = \sqrt{P^2 + Q^2} \]

\[ PF = \frac{P(W)}{S(VA)} \]
3-Phase Power Equations

\[ P_{\text{3phase}} = 3 \times P_{\text{1phase}} \]
\[ P_{\text{3phase}} = 3 \times V_{\text{LN}} \times I_{\text{1phase}} \]
\[ P_{\text{3phase}} = 3 \times \frac{V_{\text{LL}}}{\sqrt{3}} \times I_{\text{1phase}} \]
\[ P_{\text{3phase}} = \sqrt{3} \times V_{\text{LL}} \times I_{\text{1phase}} = \sqrt{3} \times V \times I \]

Example: Calculate the full load current of a 115/12.47kV, 20/30/40MVA transformer.

Solution: \[ I = \frac{P}{\sqrt{3} \times V_{\text{LL}}} = \frac{40\text{MVA}}{\sqrt{3} \times 115\text{kV}} = \frac{40,000}{\sqrt{3} \times 115} = 200.8 \text{ Amps on the High Side} \]
\[ I = \frac{P}{\sqrt{3} \times V_{\text{LL}}} = \frac{40\text{MVA}}{\sqrt{3} \times 12.47\text{kV}} = \frac{40,000}{\sqrt{3} \times 12.47} = 1852.0 \text{ Amps on the Low Side} \]

Math Check: \( N = 115\text{kV}/12.47\text{kV}=9.22, 1852.0\text{A}/200.8\text{A}=9.22 \checkmark \)

Sanity Check: Full load is normally <3000 amps \( \checkmark \)
Per Unit System

Per Unit:

- Simplifies calculations in power systems.
  - Allows a 1-phase equivalent circuit for a 3-phase system (no more $\sqrt{3}$ errors).
  - Eliminates transformers from calculations.
  - Because of this, it is very common for equipment parameters to be in Per Unit (example: 20MVA transformer with 8.5% Z).

Example: 115/12.47kV, 20/30/40MVA transformer with 8.5% Z.

What is the voltage regulation at full load?
What is the maximum fault current on the low side?

First... Let’s understand what %Z is...
How is transformer %Z determined?

- Short one side of the transformer.
- Slowly increase the voltage on the other side until the current reaches the rated base amps.

Example: 115/12.47kV, 20/30/40MVA transformer.

\[ I_{\text{rated}} = \frac{P}{\sqrt{3} \times V_{\text{LL}}} = \frac{20\text{MVA}}{\sqrt{3} \times 115\text{kV}} = 100.4 \text{ Amps} \]

The test determines the required voltage to get 100.4 Amps is 9,775V

\[ Z = \frac{V}{I} = \frac{9,775}{100.4} = 97.36 \text{ ohms} \]

\[ \%Z = \frac{9,775}{115,000} = 0.085 = 8.5\%Z \]

How will we use “ohms” in calculating fault current on the low side under normal conditions? Voltage regulation? Etc.

1-phase or 3-phase, \( \sqrt{3} \), voltage ratio, current ratio... Pretty tricky!
What is the voltage regulation at full load?

- 8.5%
- \( V_{\text{full-load}} = 12.47kV \times (1-0.085) = 11.41kV \)

What is the maximum fault current on the low side?

- \( P_{\text{fault}} = \frac{20\text{MVA}}{8.5\%} = \frac{20\text{MVA}}{0.085} = 235\text{MVA} \)
- \( I_{\text{fault}} = \frac{P_{\text{fault}}}{\sqrt{3} \times V_{\text{LL}}} = \frac{235\text{MVA}}{\sqrt{3} \times 12.47kV} = 10,894 \text{ Amps} \)
- Or, in one step... \( I_{\text{fault}} = \frac{P}{\sqrt{3} \times V_{\text{LL}} \times \%Z} = \frac{20\text{MVA}}{\sqrt{3} \times 12.47kV \times 0.08} = 10,894 \text{ Amps} \)
- Remember... %Z is on the transformer BASE rating (20MVA), not the top rating (40MVA)!
Per Unit System

Use Per Unit to evaluate Arc Flash Hazard:

Where are you at more risk for Arc Flash?

1. Working on 14.4kV terminals of a 50/62/75MVA 9%Z substation transformer
2. Working on 480V terminals of a 2,500kVA 5.5%Z distribution transformer

Note: (Substation transformer is $75,000/2,500 = 30x$ larger in MVA)

(Substation voltage is $14,400/480 = 30x$ larger in kV)

Solution:

$$\frac{P_{\text{fault}}}{\sqrt{3} \times V_{\text{LL}}} = \frac{50\text{MVA}}{\sqrt{3} \times 14.4\text{kV} \times 0.09} = 22,274 \text{ Amps}$$

$$\frac{P_{\text{fault}}}{\sqrt{3} \times V_{\text{LL}}} = \frac{2,500\text{kVA}}{\sqrt{3} \times 480\text{V} \times 0.055} = 54,673 \text{ Amps}$$

Arc energy is $I^2t$.

$$(54.7\text{kA}/22.3\text{kA})^2 = 6x$ the arc flash energy at the distribution transformer!

Could you have done this with Ohms? It would have been difficult.
Phasors: Balanced System
Phasors: Three Phase Fault (3L, 3LG, 3-P)
Phasors: Single Line to Ground Fault (SLG, 1LG, L-G)
Phasors: Line to Line Fault (LL, 2L, L-L)
Phasors: Line to Line to Ground Fault (LLG, 2LG, L-L-G)
Phasors

Balanced Systems:
3-Phase Load
3-Phase Fault

Unbalanced Systems:
Line-to-Ground Fault
Line-to-Line Fault
Line-to-Line-to-Ground Fault
Open Phase (open pole, open conductor)
Unbalanced Load
Symmetrical Components

Positive Sequence

Negative Sequence

Zero Sequence

a = b = c
Symmetrical Components

$V_a I_a + V_c I_c = a = b = c$

Positive Sequence

Negative Sequence

Zero Sequence
## Symmetrical Components

<table>
<thead>
<tr>
<th>System</th>
<th>Positive (+,1)</th>
<th>Negative (-,2)</th>
<th>Zero (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Phase Load</td>
<td>☑</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Phase Fault</td>
<td>☑</td>
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<tr>
<td>Line-to-Line Fault</td>
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<tr>
<td>Line-to-Ground Fault</td>
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<tr>
<td>Line-to-Line-to-Ground Fault</td>
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<tr>
<td>Open Phase</td>
<td>☑</td>
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<tr>
<td>Unbalanced Load</td>
<td>☑</td>
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</tbody>
</table>
Relay Classifications

Current and Voltage

- Relay measures:
  - Current and voltage magnitude and phase angle

- Relay determines:
  - Impedance, frequency, sequence quantities, harmonics, power, direction, difference, etc.
Relay Classifications

Overcurrent Relay
- Current Magnitude

Distance Relay
- Uses voltage and current magnitude and phase angle difference to determine impedance

Ground Relay
- Measures ground (zero sequence) current or voltage directly based on CT/PT wiring connections
- Determines zero sequence internally

Negative Sequence Relay
- Determines sequence component of current or voltage
Relay Classifications

Differential Relay
- Determines difference between measurements
- Common for busses, transformers, and generators
- Can be used for transmission lines

Synch Check Relay
- Determines the magnitude difference between two voltages
- Determines the phase angle difference between two voltages
- Determines the rate of change of the phase angle difference (slip)

Pilot Relay
- Uses a communications channel to share relay measured quantities with the remote end, or to trip remote end
- Provides high-speed protection for the entire line length
- Solve coordination issues
Relay Classifications

Auxiliary Relay
- Responds to control system voltage/current based on other relays and devices (not connected to respond to Power System voltage/current)
- Lockout Relay, Interposing Relay, Tripping Relay, Reclosing Relay

Other Relays & Devices
- Respond to pressures, temperatures, levels, and other non-electrical quantities.
Official Definitions

Relay

“An electric device that is designed to respond to input conditions in a prescribed manner and, after specified conditions are met, to cause contact operation or similar abrupt change in associated electric control circuits. Inputs are usually electric, but may be mechanical, thermal, or other quantities or combinations of quantities. Limit switches and similar simple devices are not relays.” (IEEE C37.90)

Protective Relay

“A relay whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action.” (IEEE 100).

Fuse

“An overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of the overcurrent through it” (IEEE 100)
Protective Relays
Auxiliary Relays
Not Relays

Not Relays...
but an important protective devices.
Transformer Sudden Pressure Relay (aka Rapid Pressure Rise Relay) and associated Seal-In Relay. Protective Relays? Auxiliary Relays? *This is an example of a “gray area”.*
Relay System
Relay Construction

Relay Types:
- Electromechanical (E/M)
- Solid State (Analog, Static)
- Digital (Microprocessor, Numerical, IED, Computerized)

Relay Construction:
- Single-Function / Multi-Function
- Single-Phase / Poly-Phase (multi-phase)
- Drawout Case / Fixed
- Rack Mount / Panel Mount
- Projection Mount / Flush Mount / Semi-Flush Mount
- Front Connected, Back Connected
Relay Considerations

Understand the pros and cons of:
- Electromechanical, Static, and Digital
- Different relay types and designs

Things to consider in relay applications:
- Life
- Reliability
- Redundancy/Backup
- Simplicity in function
- Power draw (on the battery)
- Cost
- Calibration/Maintenance
- Speed
- Accuracy
- Flexibility
- Burden (AC current/voltage inputs)
- Information and data recording
- Integration
<table>
<thead>
<tr>
<th>Device Number</th>
<th>Device Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Master Element</td>
</tr>
<tr>
<td>21</td>
<td>Distance Relay</td>
</tr>
<tr>
<td>25</td>
<td>Synchronizing or Synch Check Relay</td>
</tr>
<tr>
<td>27</td>
<td>Undervoltage Relay</td>
</tr>
<tr>
<td>30</td>
<td>Annunciator Relay</td>
</tr>
<tr>
<td>32</td>
<td>Directional Power</td>
</tr>
<tr>
<td>43</td>
<td>Selector Switch</td>
</tr>
<tr>
<td>50</td>
<td>Instantaneous Overcurrent Relay</td>
</tr>
<tr>
<td>51</td>
<td>AC Time Overcurrent Relay</td>
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<tr>
<td>52</td>
<td>AC Circuit Breaker</td>
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<tr>
<td>59</td>
<td>Overvoltage Relay</td>
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<tr>
<td>62</td>
<td>Time Delay Relay</td>
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<td>63</td>
<td>Pressure Switch</td>
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<td>64</td>
<td>Ground Detector Relay</td>
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<tr>
<td>67</td>
<td>AC Directional Overcurrent Relay</td>
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<td>69</td>
<td>Permissive Control Device</td>
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<td>71</td>
<td>Level Switch</td>
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<td>74</td>
<td>Alarm Relay</td>
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<tr>
<td>79</td>
<td>Reclosing Relay</td>
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<tr>
<td>81</td>
<td>Frequency Relay</td>
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<tr>
<td>85</td>
<td>Carrier or Pilot Wire Relay</td>
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<tr>
<td>86</td>
<td>Lockout Relay</td>
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<tr>
<td>87</td>
<td>Differential Relay</td>
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<tr>
<td>88</td>
<td>Auxiliary Motor</td>
</tr>
<tr>
<td>89</td>
<td>Line Switch</td>
</tr>
<tr>
<td>90</td>
<td>Regulating Device</td>
</tr>
<tr>
<td>94</td>
<td>Tripping or Trip Free Relay</td>
</tr>
</tbody>
</table>
ANSI Device Numbers – IEEE C37.2

Use of Prefixes:

01 = Master Element
   ▪ 101 = Breaker Control Switch in Breaker Mechanism
   ▪ 201 = Breaker Control Switch in Control House
   ▪ 301 = SCADA Breaker Control

21 = Distance Relay
   ▪ 121 = Zone 1 Distance Relay (set at 80% of line impedance)
   ▪ 221 = Zone 2 Distance Relay (set at 120% of line impedance)
   ▪ 321 = Zone 3 Distance Relay (set at 200% of line impedance)
   ▪ 421 = Zone 4 Distance Relay (set as a reverse zone for a pilot scheme)
ANSI Device Numbers – IEEE C37.2

Use of Suffixes:

87 = Differential Relay
- 87B = Bus Differential
- 87L = Line Current Differential
- 87T = Transformer Differential

50/51 = AC Time Overcurrent Relay
- 50/51A = A-phase
- 50/51B = B-phase
- 50/51C = C-phase
- 50/51N = Ground

50FD = Fault Detector
50BF = Breaker Failure
Applications: Distribution

Circuit Breaker with Relays – Pole-mounted Recloser – Fuses

Overcurrent Relays (50/51)
- Non-directional
- Phase and Ground relays (typically 4 relays)
- Instantaneous Overcurrent (50)
- Time Overcurrent (51)

Reclosing Relays (79)
- Fuse Saving / Fuse Blowing

HRS Basic Track:
- Tuesday PM: ABB CO (50/51) and ABB RC (79) w/ Breaker Simulator (52)
- Thursday PM: SEL-551 (50/51/79)
Applications: Distribution
Applications: Distribution

DEVICE NUMBER CHART

51 - OVERCURRENT RELAY, TYPE CO
51-N - GROUND OVERCURRENT RELAY, TYPE CO
52 - POWER CIRCUIT BREAKER
52-A - BREAKER AUXILIARY CONTACT
ICS - INDICATING CONTACTOR SWITCH
TC - BREAKER TRIP COIL
Applications: Transmission

Distance (21 or 21G)
Directional Overcurrent (67 or 67N)
Differential (87L)
Pilot Wire (85)
Reclosing (79)
Synch Check or Close Supervision (25/27DL/59HB)

Most common: 21P/67N/79

HRS Basic Track:
- Wednesday AM: GE JBCG (67N)
Applications: Transmission

Diagram showing a substation with components labeled CT (3), PT (3), 21, 50 BF, 67N, 52, 79, and a transmission line labeled 125 Volt Battery.
Applications: Transmission

- 21 Zone 1 85-90%
- 21 Zone 2 125-180%, Time Delay Trip
- 21 Zone 3 150-200%, Time Delay Trip
- 67 Ground Instantaneous Overcurrent
- 67 Ground Time Overcurrent
- 67 Ground Time Permissive Transfer Trip Overcurrent

Typical Relay Protection Zones
Applications: Distribution

PHASE SEQUENCE 1-2-3 OR 3-2-1

TRIPPING DIRECTION

52

IF POTENTIAL POLARIZATION IS USED, CONNECT A TO D & B TO C. IF POTENTIAL POLARIZATION IS NOT USED, CONNECT C TO D

67N

D TOC 10C

6 5 4 2 1

A

D

67N

67N

D

B

C

9

10

TO PHASE RELAYS

TO TRANSFORMER NEUTRAL

8

7

67N

D

IF CURRENT POLARIZATION IS NOT USED, DO NOT CONNECT TO STUD 7&8.
Applications: Equipment

Bus Differential (87B)
Transformer Differential (87T)
Transformer Overcurrent (50/51)
Transformer Overexcitation (24)
Transformer Sudden Pressure (63SPR)
Transformer Temperature (49T, 49Q)
Transformer Oil Level (71Q)
Breaker Failure (50/62BF)
Lockout (86B, 86T, 86BF)

HRS Basic Track:
- Monday PM: ABB CA (87T)
- Thursday AM: ABB HU (87T)
Applications: Equipment

Bus Differential – External Fault
Applications: Equipment

Bus Differential – Internal Fault
Applications: Equipment

Bus Differential – Zones of Protection
Applications: Equipment

Transformer Differential – External Fault
Applications: Equipment

Transformer Differential – Internal Fault
Applications: Equipment

Transformer Differential – Turn-to-Turn Fault

Differential does not detect a turn-to-turn fault!

Inrush is also a problem.
Applications: Generation

- Sequential Events Recorder
- Event Reports
- Two Inputs and Three Outputs Standard
- I/O Expansion*—Additional Contact Inputs, Contact Outputs, Analog Inputs, Analog Outputs, and RTD Inputs
- Battery-Backed Clock, IRIG-B Time Synchronization
- Instantaneous Metering, Demand Metering
- Off-Frequency Operation Time Accumulators
- Advanced SELogic® Control Equations
- IEEE C37.118 Synchronphasors
- Breaker Wear Monitor
- Event Messenger Compatible

* Optional
Applications: Reclosing (79)

Automatic reclosing:
- Restore service (distribution, transmission)
- Prevent system instabilities (transmission)

Temporary faults:
- Trees
- Lightning
- Overhead systems

First reclose = 80% success rate
Second reclose = 5% success rate
1LG faults are more likely to be temporary than 3-Phase faults.

HRS Basic Track:
- Tuesday PM: ABB CO (50/51) and ABB RC (79) w/ Breaker Simulator (52)
- Thursday PM: SEL-551 (50/51/79)
Applications: Reclosing (79)

Transmission:

- High-speed reclose generally better for system stability, and may be necessary when close to generators.
- Must de-energize long enough for arc to deionize.
- Must delay long enough for remote end to clear.
- If not high-speed, then (59/27 or 25) close supervision may be necessary.
- Typically just one reclose.

Standard Reclosing = Attempts reclosing after every trip.

Conditional Reclosing = Attempts reclosing only for certain conditions.

- Example: Reclosing for SLG fault only; no reclosing for multi-phase faults.
- Example: Reclosing for a Zone 1 trip only; no reclosing on overreaching zones.
Applications: Reclosing (79)

Distribution:

- **Fuse Saving Scheme:**
  - First trip on 50 or a “fast curve” (faster than any downstream fuse)
  - Reclose
  - Block the 50 from retreating
  - At least two recloses; as many as four
  - Entire circuit (and all phases) will get “blinked” for every fault.
  - More common on rural circuits

- **Fuse Blowing Scheme:**
  - 50 not used, except for short reach or hot-line work tag
  - All tripping on 51, coordinated with the fuses
  - One or two recloses
  - Every fault results in an outage, but the outage is limited to just the lateral and phase that has the fault.
  - More common on urban circuits
Applications: Under/Over Voltage (27/59)

May be used for tripping, or as part of a scheme

Examples:

- Undervoltage Load Shedding Scheme (27)
- Overvoltage Protection (59)
- Generator ground fault protection (59N, 27TN)
- Week Infeed Logic (uses 59 with other distance and directional elements)
- Close supervision ($59B \times 27L + 59B \times 59L \times 25 = \text{Hot Bus and Dead Line, or if both are hot, then they must be in synch}$)

HRS Basic Track:

- Wednesday PM: Basler BE1-27/59
Applications: Under/Over Frequency (81)

Examples:
- Underfrequency Load Shedding Scheme (81U)
- Generator or motor protection (81O, 81U)

Comments:
- Uses voltage; typically one phase
- Must be blocked by a 27 or a 60
- Cannot be set to trip instantaneous as the frequency will appear to change during a fault as the voltage vector shifts.
- Usually set in Steps

HRS Basic Track:
- Wednesday PM: Basler BE1-81O/U
# Applications: Under/Over Frequency (81)

<table>
<thead>
<tr>
<th>81U</th>
<th>81O</th>
<th>Trip Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.4 Hz</td>
<td>60.6 Hz</td>
<td>10,800 cycles (3 minutes)</td>
</tr>
<tr>
<td>58.4 Hz</td>
<td>61.6 Hz</td>
<td>1,800 cycles (30 seconds)</td>
</tr>
<tr>
<td>57.8 Hz</td>
<td></td>
<td>450 cycles (7.5 seconds)</td>
</tr>
<tr>
<td>57.3 Hz</td>
<td></td>
<td>45 cycles</td>
</tr>
<tr>
<td>56.8 Hz</td>
<td></td>
<td>7.2 cycles</td>
</tr>
<tr>
<td>56.4 Hz</td>
<td>61.7 Hz</td>
<td>3 cycles</td>
</tr>
</tbody>
</table>
Tuesday – Open Concurrent Lectures

Lecture #1 (7:30am) and Lecture #3 (9:50am)
- Substation Commissioning Part 1 (CUE 119)
- Digital Logic for P&C (CUE 202)
- Phasor Diagrams (CUE 203)
- Transformer Protection (CUE 219)
- Symmetrical Components Part 1 (CUE 319)
- A Guide to DFR Event Analysis (CUE 419)

Lecture #2 (8:40am) and Lecture #4 (11:00am)
- Substation Commissioning Part 2 (CUE 119)
- Fault Location (CUE 202)
- Fault Analysis for Relay Technicians (CUE 203)
- Relay Communications Basics (CUE 219)
- Symmetrical Components Part 2 (CUE 319)
- Impact of DG on Distribution Systems (CUE 419)
Thank You

Brent Carper, PE
Engineering Manager – Relay Application Innovation, Inc.
Adjunct Professor – Washington State University
Brent.C@RelayApplication.com
509-334-9138