Protection Coordination

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8:30 - 12:30

Florida Electric Cooperatives Association
Clearwater, Florida
Seminar Objective

• Distribution Circuit Protection
  – Fuse to Fuse Coordination
  – Recloser to Fuse Coordination
  – Breaker to Recloser Coordination

• Transmission Line Protection
  – Distance Protection
  – Pilot Protection Schemes
  – Current Differential Protection
Art & Science of System Protection

• Not an exact science, coordination schemes will vary based on:
  – Company Philosophy
  – Protection engineer preference
  – System requirements
Coordinating Devices

Basic concept: All protective devices are able to detect a fault do so at the same instant.

If each device that sensed a fault operated simultaneously, large portions of the system would be de-energized every time a fault needed to be cleared. This is unacceptable.

A properly designed scheme will incorporate time delays into the protection system, allowing certain devices to operate before others.
Coordinating Devices

Timing of device operation is verified using time-current characteristics or TCCs – device response curves plotted on log-log graph paper.

Devices have inverse TCCs. They operate quickly for large magnitude overcurrents, and more slowly for lower-magnitude overcurrents.

Operating time is plotted on the vertical axis, and current magnitude is plotted on the horizontal scale.
Coordinating Devices

Four different TCCs are shown on the left. Device “D” is the fastest to operate, and device “A” is the slowest.

For a given current value, the operating time can be found.
Coordinating Devices

In this example, Device A is clearly faster than Device B for low (400-700 A) fault currents.

Device B is clearly faster for high (>1000 A) fault currents, but in the 700-1000 A region, timing is uncertain.
Coordinating Devices
Expulsion Fuse to Expulsion Fuse

Minimum Melt
Average Melt + tolerance

Total Clear
Average Melt + tolerance + arcing time

Curves are developed at 25°C With no preloading

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In this example, the red TCCs represent the downstream (protecting) fuse, and the blue TCCs represent the upstream (protected) fuse.

The protected fuse should not be damaged by a fault in the protecting fuse’s zone of protection.
Four factors need to be considered:

1. Tolerances.

2. Ambient temperature.

3. Preloading effects.

4. Predamage effects.
Consideration of these four factors can be quite involved.

Practically, the “75% Method” can be used: the maximum clearing time of the protecting link shall be no more than 75% of the minimum melting time of the protected link.
Coordinating Devices
Expulsion Fuse to Expulsion Fuse

Minimum melting time of protected link at 5 kA is 0.3 seconds.

Total clearing time of the protecting link at 5 kA is 0.22 seconds.

$0.22 < 0.3 \times 75\% = 0.225$, so coordination is assured for current magnitudes $\leq 5$ kA.
Utility Distribution Feeders
Multiple Feeder Segments

Segments are defined as sectionalizable pieces of a feeder that can be automatically or manually separated from the rest of the feeder.

Segments are delineated by reclosers, fuses, sectionalizers or switches.

Two primary concerns: number of customers per segment and time to isolate segment.
Utility Distribution Feeders
Number of Customers per Segment

The number of customers per segment has a major impact on reliability indices.

As the number of segments per feeder increases, reliability can also be adversely impacted, and construction cost will increase.

An optimum point must be sought to determine the best segment size.
Utility Distribution Feeders
Present and Future Load Requirements

Even the best load forecasts are full of errors.

You must continuously monitor your fuse coordination due changes in the load.

It is impossible to predict everything, so versatility is the key.
Coordination Goal

1. Maximum Sensitivity.
2. Maximum Speed.
4. Maximum Selectivity.
Basic Coordination Strategy

1. Establish a coordination pairs.

2. Determine maximum load of each segment and the pickup of all delayed overcurrent devices.

3. Determine the pickup current of all instantaneous overcurrent devices, based on short-circuit studies.

4. Determine remaining overcurrent device characteristics starting from the load and moving to the source.
### Coordination for Underground Distribution Circuits

<table>
<thead>
<tr>
<th>Transformer Size Rated KVA</th>
<th>BAYONET Fuse</th>
<th>Minimum Isolation Link Fuse</th>
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<td>15 T</td>
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* Fault Sensing - 350C (All others are Load Sensing - 358C)
## Coordination for Overhead Distribution Circuits

<table>
<thead>
<tr>
<th>Transformer Size (KVA/phase)</th>
<th>7.2-kV Transformer Fuse</th>
<th>Minimum Backup Lateral Fuse</th>
<th>Maximum Total Downstream Connected KVA (KVA/phase)</th>
<th>Maximum Downstream Coordinating Fuse</th>
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# Fuse Peak Load Capability

<table>
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<tr>
<th>LATERAL FUSE SIZE</th>
<th>S&amp;C POSITROL FUSE LINKS CHART</th>
<th>COOPER FUSE LINKS CHART</th>
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<td></td>
<td>CONTINUOUS CAPABILITY</td>
<td>EMERGENCY CAPABILITY (8hre)</td>
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**NOTE:** Fuse link should not be loaded to their 8-hour peak-load capability values more than 10 times over the life time of the fuse link. (Data Bulletin 350-190 of S&C Electric Company)
<table>
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<tr>
<th>DOWNSTREAM FUSE</th>
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**Diagram Note:** Need to coordinate upstream fuse with largest downstream.
Fuse Blow Vs. Fuse Save

• Fuse Blow
  – Eliminates Instantaneous trip of the breaker or recloser (1st) by having the fuse blow for all permanent and temporary faults.
  – Minimizes momentary interruptions and increases SAIDI. Improves power quality but decreases reliability.

• Fuse Save
  – Minimizes customer interruption time by attempting to open the breaker or recloser faster than it takes to melt the fuse.
  – This saves the fuse and allows a simple momentary interruption.
Fuse Blow

Lateral experiences sustained interruption

FUSE is BLOWN
Fuse Blow

– Used primarily to minimize momentary interruptions (reduces MAIFI)
– Increases interruption duration (SAIDI)
– Very successful in high short circuit areas
– More suitable for industrial type customers having very sensitive loads
Fuse Save

Entire Feeder trips
Momentary occurs

FUSE is SAVED

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Fuse Save

- Minimize customer interruption time
- Reduce SAIDI
- Increase MAIFI
- May not work in high short circuit areas
- Work well in most areas
- Not suitable for certain industrial customers that cannot tolerate immediate reclosing
- Works best for residential and small commercial customers
Both (Fuse Save & Fuse Blow)

• Many utilities use both schemes for a variety of reasons
  – Fuse Blow for high short circuit current areas and Fuse Save where it will work.
  – Fuse Save on overhead and Fuse Blow on underground taps.
  – Fuse Save on rural and Fuse Blow on urban
  – Fuse Save on stormy days and Fuse Blow on nice days.
  – Fuse Save on some circuits and Fuse Blow on others depending on customer desires
Fast Bus Trip
SEL-351S
Protection and Breaker Control Relay
Modern Microprocessor Relay
Protection and Breaker Control Relay

Extremely versatile, many applications
Most commonly used on distribution feeders
Communicates with EMS system (DNP 3.0 Protocol)
Key element of “Substation Integration”
Provides many “traditional” features
Provides new capabilities
SEL-351S
Protection and Breaker Control Relay

Protection Features:

Performs at least 18 different protection functions.
SEL-351S
Protection and Breaker Control Relay

Protection Features:

- Bus Undervoltage (27)
- Phase Overvoltage (59P)
- Ground Overvoltage (59G)
- Sequence Overvoltage (59Q)
- Overfrequency (81O)
- Underfrequency (81U)
Protection Features (continued):

Phase Directional Overcurrent (67P)
Ground Directional Overcurrent (67G)
Sequence Directional Overcurrent (67Q)
Instantaneous Phase Overcurrent (50P)
Instantaneous Ground Overcurrent (50G)
Instantaneous Sequence Overcurrent (50Q)
Protection Features (continued):

- Time Phase Overcurrent (51P)
- Time Ground Overcurrent (51G)
- Time Sequence Overcurrent (51Q)
- Directional Neutral Overcurrent (67N)
- Instantaneous Neutral Overcurrent (50N)
- Time Neutral Overcurrent (51N)
SEL-351S
Protection and Breaker Control Relay

Breaker Control Features:

Synchronism Check (25)
Automatic Circuit Reclosing (79)

TRIP/CLOSE Pushbuttons
Enable/Disable Reclosing
Enable/Disable Supervisory Control
Other Features:

- Event Reporting and Recording
- Breaker Wear Monitor
- Station Battery Monitor
- High-Accuracy Metering
- Fault Locator
SEL-351S
Protection and Breaker Control Relay

Functional Overview

SEL-351S Relay

- SELloc® Control Equations
- Event Reports
- Sequential Events Recorder
- Breaker Wear Monitor
- Station Battery Monitor
- DNP 3.0 Level 2 Slave Protocol
- Memosys™ Communications
- Comm. Assisted Tripping
- High-Accuracy Metering
- Remote and Local Control Switches
- Local Display and Operator Controls
- Load Profile
- Fault Locator
- Sensitive Earth Fault Protection
- Sensitive Directional Earth Fault (Petersen Coil) Protection
- Voltage Sag/Swell Interruption Records

*Optional Functions
• **Advantages of microprocessor relays**
  - Extremely flexible
  - Have many different elements (UF, UV, Directionality, etc…)
  - One relay can protect on zone of protection
  - Inexpensive and require much less maintenance
  - Alarm if they fails and don’t need calibration
  - Provide fault information
  - Provide oscillography and SER data
  - Can provide analog data to SCADA

• **Disadvantages of microprocessor relays**
  - Can be very complex to program due to given flexibility
  - Require more training to Relay Technicians
  - Require more training to Relay Engineers
Relays

• Basic relay settings:
  ▪ Phase overcurrent elements must be set above maximum possible loads
  ▪ Ground overcurrent elements must be set above maximum anticipated unbalanced loads
  ▪ Must be coordinated with downstream protective devices
  ▪ Under Frequency elements must be set according to the predetermined set point

• TAGGING
  ▪ NORMAL mode – 2 reclosing attempts
  ▪ WORK mode – HOT LINE TAG
  ▪ COLD mode
Relay Curves

![Graph showing relay curves for different inverse characteristics. The graph plots the time in seconds on the y-axis against the multiple of pick up on the x-axis. Curves represent Moderately Inverse, Inverse, Very Inverse, and Extremely Inverse.]
In this example

Multiple of Pickup = 3.

- TD = 0.5    Time = 0.3s
- TD = 2      Time = 1.1s
- TD = 6      Time = 3.4s
- TD = 15     Time = 7.0s
In this example,

**Pickup = 600 A.**
**Fault Current = 1800 A.**

- TD = 0.5  Time = 0.29s
- TD = 2    Time = 1.16s
- TD = 6    Time = 3.48s
- TD = 15   Time = 8.72s

**Pickup = 900 A.**
**Fault Current = 1800 A.**

- TD = 0.5  Time = 0.69s
- TD = 2    Time = 2.78s
- TD = 6    Time = 8.33s
- TD = 15   Time = 20.8s
Pickup Current of Delayed Ground OC Devices

Source Side
Backup

Load Side
Primary

$|I_{MU}| < |I_{PU}| < |I_{MIN}|$ Fault

$|I_{MU}| = \text{Maximum Unbalance}$
Pickup Current of Delayed Phase OC Devices

Source Side

Load Side

$I_{ML} < I_{PU} < I_{min \, \phi-\phi \, \text{Fault}}$

Phase to Phase Fault

$I_{ML} = \text{Maximum Load}$
Typical Pickup Setting

$T_B > T_R + CTI$

Recloser Ct ratio  600:1

$I_{PU} = 1 \text{ A}$

$I_{PU \ Primary} = 600 \text{ A}$

Breaker Ct ratio 240:1

$I_{PU} = 3.75 \text{ A}$

$I_{PU \ Primary} = 900 \text{ A}$

CTI = Coordination Time Interval (Typically 0.2-0.5sec)
Trip Logic

\[
TR = OC + PB9 + 51P1T + 51G1T \times (LT6 + LT7) + (50P3 + 50G3) \times LT7 + (50P2 + 50G2) \times SH1
\]

OC: OPEN COMMAND (SCADA TRIP)
PB9: FRONT PUSH BUTTON
51P1T: PHASE TIME OC ELEMENT
51G1T: GROUND TIME OC ELEMENT
LT6: TAGGING IS IN NORMAL MODE
LT7: TAGGING IS IN WORK MODE
50P2/50P3: PHASE INSTANTANEOUS OC ELEMENT
50G2/50G3: GROUND INSTANTANEOUS OC ELEMENT
SH1: RECLOSING SHOT #1 (FIRST RECLOSE ATTEMPT)

CTR = 600.0
INSTANTANEOUS ENABLED ONLY AFTER FIRST RECLOSE ATTEMPT
50P2P = 2.5 (1500 AMPS PRIMARY)
50G2P = 1.6 (960 AMPS PRIMARY)

INSTANTANEOUS ENABLED ONLY DURING WORK/HOT LINE TAG
50P3P = 1.35 (810 AMPS PRIMARY)
50G3P = 0.50 (300 AMPS PRIMARY) – NORMAL UNBALANCE GROUND CURRENT ~20 TO 30 AMPS
SEL-351S
History Summary (HIS Command)

Sample output:

<table>
<thead>
<tr>
<th>#</th>
<th>DATE</th>
<th>TIME</th>
<th>EVENT</th>
<th>LOCAT</th>
<th>CURR</th>
<th>FREQ</th>
<th>GRP</th>
<th>SHOT</th>
<th>TARGETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01/28/14</td>
<td>08:22:32.327 BG</td>
<td></td>
<td>5.32</td>
<td>1910</td>
<td>59.98</td>
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<td>1</td>
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<tr>
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<td>01/28/14</td>
<td>08:22:31.685 BG T</td>
<td></td>
<td>1.11</td>
<td>3986</td>
<td>59.98</td>
<td>1</td>
<td>0</td>
<td>10000110 01001010</td>
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<tr>
<td>3</td>
<td>01/10/14</td>
<td>06:49:52.171 ER</td>
<td></td>
<td>Dell</td>
<td>$$$$$$$</td>
<td>160</td>
<td>59.99</td>
<td>1</td>
<td>0</td>
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<tr>
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<td>09:39:00.251 ABG</td>
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# Sequence of Events Recording (SER)

<table>
<thead>
<tr>
<th>#</th>
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<th>Time</th>
<th>Element</th>
<th>State</th>
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</thead>
<tbody>
<tr>
<td>54</td>
<td>01/28/14</td>
<td>08:22:31.677</td>
<td>50P2</td>
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<tr>
<td>53</td>
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<td>08:22:31.677</td>
<td>50G4</td>
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</tr>
<tr>
<td>52</td>
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<td>08:22:31.677</td>
<td>50G3</td>
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<td>50G2</td>
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<tr>
<td>50</td>
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<td>08:22:31.681</td>
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</tr>
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<tr>
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<tr>
<td>45</td>
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<tr>
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<td>79CY</td>
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<td>08:22:32.152</td>
<td>50G1</td>
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</tr>
<tr>
<td>24</td>
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<td>OUT101</td>
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</tr>
<tr>
<td>23</td>
<td>01/28/14</td>
<td>08:22:32.239</td>
<td>TRIP</td>
<td>Deasserted</td>
</tr>
<tr>
<td>22</td>
<td>01/28/14</td>
<td>08:22:32.239</td>
<td>CLOSE</td>
<td>Asserted</td>
</tr>
<tr>
<td>21</td>
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<td>08:22:32.256</td>
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</tr>
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<td>18</td>
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<tr>
<td>17</td>
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<tr>
<td>16</td>
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<td>Asserted</td>
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<tr>
<td>15</td>
<td>01/28/14</td>
<td>08:22:32.327</td>
<td>CLOSE</td>
<td>Deasserted</td>
</tr>
<tr>
<td>14</td>
<td>01/28/14</td>
<td>08:22:32.327</td>
<td>50G2</td>
<td>Asserted</td>
</tr>
<tr>
<td>13</td>
<td>01/28/14</td>
<td>08:22:32.327</td>
<td>IN102</td>
<td>Asserted</td>
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<td>12</td>
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<td>51P1</td>
<td>Asserted</td>
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<td>01/28/14</td>
<td>08:22:32.331</td>
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<td>10</td>
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<td>08:22:32.339</td>
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</tr>
<tr>
<td>9</td>
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<td>8</td>
<td>01/28/14</td>
<td>08:22:32.344</td>
<td>50G4</td>
<td>Deasserted</td>
</tr>
</tbody>
</table>
SEL-351S
Metering Data (MET Command)

Sample output - Metering Data (MET):

```
->MET <ENTER>

FEEDER 1
STATION A

Date: 02/01/97   Time: 15:00:52.615

I MAG (A)  195.146  192.614  198.090  0.302  4.880
I ANG (DEG)  -8.03   -128.02  111.89  52.98  81.22

V MAG (KV)  11.691  11.686  11.669  11.695
V ANG (DEG)  0.00   -119.79  120.15  0.05

MW        2.259  2.228  2.288  6.774
MVAR      0.319  0.322  0.332  0.973
PF        0.990  0.990  0.990  0.990

I1  3I2  3I0  V1  V2  3V0
MAG   195.283  4.630  4.880  11.682  0.007  0.056
ANG (DEG)  -8.06  -103.93  81.22  0.12  -80.25  -66.83

FREQ (Hz)  60.00  VDC (V)  129.5

->
```
# SEL-351S

**Metering Data (MET Command)**

Sample output - Metering Demand (MET D):

```plaintext
$MET D <ENTER>

FEEDER 1   Date: 02/01/97   Time: 15:08:05.615
STATION A

<table>
<thead>
<tr>
<th></th>
<th>LA</th>
<th>LB</th>
<th>LC</th>
<th>LN</th>
<th>LG</th>
<th>SL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBMND</td>
<td>188.6</td>
<td>186.5</td>
<td>191.8</td>
<td>0.2</td>
<td>4.5</td>
<td>4.7</td>
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<tr>
<td>PEAK</td>
<td>188.6</td>
<td>186.5</td>
<td>191.8</td>
<td>0.3</td>
<td>4.5</td>
<td>4.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MWA</th>
<th>MWB</th>
<th>MNC</th>
<th>MW3P</th>
<th>MVARA</th>
<th>MVARB</th>
<th>MVARC</th>
<th>MVAR3P</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBMND IN</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>PEAK IN</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
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<td>2.2</td>
<td>6.6</td>
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<td>0.3</td>
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<td>0.9</td>
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<tr>
<td>PEAK OUT</td>
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<td>3.1</td>
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<td>9.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

LAST DEMAND RESET 01/27/97 15:31:51.238   LAST PEAK RESET 01/27/97 15:31:56.239

$->
```
SEL-351S
Metering Data (MET Command)

Sample output - Metering Energy (MET E):

```
$ MET E<br />
FEEDER 1  Date: 02/01/97  Time: 15:11:24.056
STATION A

IN    MWhA  MWhB  MWhC  MWh3P  MVARhA  MVARhB  MVARhC  MVARh3P
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
OUT   36.0  36.6  36.7  109.2  5.1   5.2   5.3   15.6

LAST RESET 01/31/97 23:31:29.064
```
**SEL-351S**  
**Metering Data (MET Command)**  

**Sample output - Metering Max/Min (MET M):**

```
->MET M <ENTER>

<table>
<thead>
<tr>
<th>FEEDER 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION A</td>
<td>Date: 02/01/97</td>
<td>Time: 15:16:00.239</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>Date</td>
<td>Time</td>
<td>Min</td>
</tr>
<tr>
<td>IA(A)</td>
<td>196.8</td>
<td>02/01/97</td>
<td>15:00:42.574</td>
<td>30.0</td>
</tr>
<tr>
<td>IB(A)</td>
<td>195.0</td>
<td>02/01/97</td>
<td>15:05:19.558</td>
<td>31.8</td>
</tr>
<tr>
<td>IC(A)</td>
<td>200.4</td>
<td>02/01/97</td>
<td>15:00:42.578</td>
<td>52.2</td>
</tr>
<tr>
<td>IN(A)</td>
<td>42.6</td>
<td>02/01/97</td>
<td>14:51:02.328</td>
<td>42.6</td>
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<tr>
<td>IC(A)</td>
<td>42.0</td>
<td>02/01/97</td>
<td>14:50:56.294</td>
<td>42.0</td>
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<tr>
<td>VA(kV)</td>
<td>11.7</td>
<td>02/01/97</td>
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<tr>
<td>VE(kV)</td>
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<td>02/01/97</td>
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<td>2.4</td>
</tr>
<tr>
<td>VC(kV)</td>
<td>11.7</td>
<td>02/01/97</td>
<td>15:00:42.578</td>
<td>3.1</td>
</tr>
<tr>
<td>VS(kV)</td>
<td>11.7</td>
<td>02/01/97</td>
<td>15:01:01.576</td>
<td>3.4</td>
</tr>
<tr>
<td>NW3P</td>
<td>6.9</td>
<td>02/01/97</td>
<td>15:00:44.095</td>
<td>0.4</td>
</tr>
<tr>
<td>MVAR3P</td>
<td>1.0</td>
<td>02/01/97</td>
<td>15:00:42.578</td>
<td>0.1</td>
</tr>
<tr>
<td>LAST RESET: 01/27/97 15:31:41.237</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
Differential Relays

Protection of a Delta-Wye Transformer

A
\[ I_a - I_b \]
\[ I_b - I_c \]
\[ I_c - I_a \]

B
\[ I_a - I_b \]
\[ I_b - I_c \]
\[ I_c - I_a \]

C
\[ I_a - I_b \]
\[ I_b - I_c \]
\[ I_c - I_a \]

Ia
Ib
Ic

Power System Protection

-64- Ralph Fehr, Ph.D., P.E. – October 28, 2013
Distance Relays
Protection Features

– Four zones of distance protection
– Pilot schemes
– Phase/Neutral/Ground TOCs
– Phase/Neutral/Ground IOCs
Distance Relays
Protection Features - continued

- Negative sequence TOC
- Negative sequence IOC
- Phase directional OCs
- Neutral directional OC
- Negative sequence directional OC
- Phase under- and overvoltage
- Power swing blocking
- Out of step tripping
Distance Relays
Control Features

- Breaker Failure (phase/neutral amps)
- Synchrocheck
- Autoreclosing
Distance Relays
Metering Features

– Fault Locator
– Oscillography
– Event Recorder
– Data Logger
– Phasors / true RMS / active, reactive and apparent power, power factor
Distance Relays

Zones of Protection

Zone 1 – fastest (80% of line)
Zone 2 – slower (120% of line)
Zone 3 – (backwards Use in Pilot Protection for current Reversal logic)

Distance Relay at Bus 1 to protect Line A
Zone 1: Under reaches the remote line end Typically 0.7 $Z_{1L}$ to 0.9 $Z_{1L}$
With no intentional time delay.

Zone 2: Over reaches the remote line end Typically 1.2 $Z_{1L}$
with definite time delay.

Zone 3: Over reaches the longest adjacent line
with definite time delay greater than Zone2.
Unconventional Zone 2 & Zone 3 Settings

Be Mindful when Applying General Rules
Step Distance Relay Coordination Exercise

Setting the relay at breaker 3 protecting Circuit 2.

Set the Zones of Protection.

The maximum expected load is about 600A.

CTR = 1200:5 or 240:1

PTR = 600:1

IEEE/FECA Protection Coordination  June 2014  Serge Beauzile
Distance Relay Coordination Exercise

Circuit 2 & Circuit 5 Impedances

\[ Z_1 = 35.11 \ 83.97^\circ \ \Omega \ \text{primary} \]
\[ Z_0 = 111.58 \ 81.46^\circ \ \Omega \ \text{primary} \]

Circuit 3 & Circuit 6 Impedances

\[ Z_1 = 17.56 \ 83.72^\circ \ \Omega \ \text{primary} \]
\[ Z_0 = 53.89 \ 81.56^\circ \ \Omega \ \text{primary} \]

Circuit 1 & Circuit 4 Impedances

\[ Z_1 = 35.21 \ 83.72^\circ \ \Omega \ \text{primary} \]
\[ Z_0 = 187.80 \ 81.56^\circ \ \Omega \ \text{primary} \]
Distance Relay Coordination Exercise

Zone 1 Reach = 0.8 * (35.11  83.97°) Ω primary  

Zone 2 Reach = 1.2 * (35.11  83.97°) Ω primary

Check Zone 2 reach does not overreach = Circuit 2 Impedance + (Zone 1 of Circuit 3) or (Zone 1 of Circuit 6).

General rule = protected Circuit Impedance + Zone 1 of the Shortest Circuit past the protected circuit.

Check for Zone 2 Overreach = 35.11. + (0.8 * 17.56) = 49.16 Ω primary

Zone 2 Reach = 42.13 < 49.16 no overreach

Zone 4 Reach = (35.11  83.97°) + (17.56  83.72°) ( Ω primary) Zone 4 Reach = 52.55  83.35°) Ω primary
Primary / Secondary Impedance

Relay Input

\[ V_{sec} = \frac{V_{pri}}{VTR} \]
\[ I_{sec} = \frac{I_{pri}}{CTR} \]
\[ Z_{sec} = \frac{V_{sec}}{I_{sec}} \]

\[ Z_{sec} = \frac{V_{pri}}{VTR} \div \frac{I_{pri}}{CTR} \]
\[ Z_{sec} = \frac{V_{pri}}{I_{pri}} \times \frac{CTR}{VTR} \]

\[ Z_{sec} = Z_{pri} \times \frac{CTR}{VTR} \]
Zone 1 Reach = \(28.09 \, \Omega \times \frac{240}{600} = 11.24 \, \Omega \) secondary

Zone 2 Reach = \(42.43 \, \Omega \times \frac{240}{600} = 16.97 \, \Omega \) secondary

Zone 4 Reach = \(28.09 \, \Omega \times \frac{240}{600} = 21.02 \, \Omega \) secondary
Overcurrent Supervision Setting Criteria

1) Find the lowest $\Omega - \Omega$ fault seen by relay 3 for a remote end bus (4, 10, 5, 11).

Zone 1 Phase Fault detector:
Set above (maximum load) and 60% of min fault.

Zone 2 Phase Fault detector:
1) Find the lowest $\Omega - \Omega$ fault seen by relay 3 for a remote end bus (6, 12).

Zone 4 Fault detector same as Zone 2

Repeat same process for Ground Fault detector.
Current Infeed

Apparent Impedance = $\frac{E_L}{I_L}$

Apparent Impedance = $(I_L \times Z_L) + (I_R \times Z_R)$

Apparent Impedance = 4Ω

Actual Impedance from L to the Fault is 3Ω
Thank You