Protection Basics

Presented by
John S. Levine, P.E.
Levine Lectronics and Lectric, Inc.
770 565-1556
John@L-3.com
Protection Fundamentals

By 
John Levine
Outline

• Introductions
• Tools
  – Enervista Launchpad
  – On – Line Store
  – Demo Relays at Levine
• ANSI number
• Training CD’s
• Protection Fundamentals
Objective

• We are here to help make your job easier. This is very informal and designed around Applications. Please ask question. We are not here to “preach” to you.

• The knowledge base in the room varies greatly. If you have a question, there is a good chance there are 3 or 4 other people that have the same question. Please ask it.
Tools
Demo Relays at L-3
## Relays at L-3

<table>
<thead>
<tr>
<th>Wan I.P</th>
<th>Firewall Port</th>
<th>Destination IP</th>
<th>Destination Port</th>
<th>Slave Address</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.92.196.201</td>
<td>502</td>
<td>192.168.1.240</td>
<td>502</td>
<td>254</td>
<td>F60</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>503</td>
<td>192.168.1.241</td>
<td>502</td>
<td>1</td>
<td>Multinet</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>503</td>
<td>192.168.1.241</td>
<td>502</td>
<td>3</td>
<td>SPM</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>503</td>
<td>192.168.1.241</td>
<td>502</td>
<td>89</td>
<td>489</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>504</td>
<td>192.168.1.242</td>
<td>502</td>
<td>242</td>
<td>469</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>505</td>
<td>192.168.1.243</td>
<td>502</td>
<td>243</td>
<td>760</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>506</td>
<td>192.168.1.244</td>
<td>502</td>
<td>249</td>
<td>MM300</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>507</td>
<td>192.168.1.245</td>
<td>502</td>
<td>13</td>
<td>T60</td>
</tr>
<tr>
<td>74.92.196.201</td>
<td>508</td>
<td>192.168.1.246</td>
<td>502</td>
<td>2</td>
<td>369</td>
</tr>
</tbody>
</table>
GE Multilin Training CD’s
## ANSI Symbols

### Engineering Data

#### Electrical Power System Device Numbers & Functions

<table>
<thead>
<tr>
<th>Device Number</th>
<th>Definition &amp; Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Master Element is the initiating device, such as a control switch, voltage relay, float switch, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Time-delay starting, or closing relay</td>
</tr>
<tr>
<td>3</td>
<td>When operating in response to the position of one of the other devices.</td>
</tr>
<tr>
<td>4</td>
<td>When contactor is a device, generally controlled by Device #1 or equivalent, and the required protective and protective devices.</td>
</tr>
<tr>
<td>5</td>
<td>Starting device is a control device used to start or stop an equipment and hold it out of operation.</td>
</tr>
<tr>
<td>6</td>
<td>Short circuit breaker is a device whose principal function is to protect a circuit from damage.</td>
</tr>
<tr>
<td>7</td>
<td>Manual circuit breaker is one used in the manual circuits of a power rectifier.</td>
</tr>
<tr>
<td>8</td>
<td>Control power disconnecting device.</td>
</tr>
<tr>
<td>9</td>
<td>Regulating device is used for the purpose of reversing a machine.</td>
</tr>
<tr>
<td>10</td>
<td>Light sequence switch is used to control the sequence.</td>
</tr>
<tr>
<td>11</td>
<td>Reserved.</td>
</tr>
<tr>
<td>12</td>
<td>Over-speed device is usually a direct-connected speed switch which functions on over-speed.</td>
</tr>
<tr>
<td>13</td>
<td>Synchronous speed device, operates at approximately synchronous speed of machine.</td>
</tr>
<tr>
<td>14</td>
<td>Under-speed device functions when the speed of a machine falls below a predetermined value.</td>
</tr>
<tr>
<td>15</td>
<td>Speed or frequency, matching device functions to match and hold the speed of a machine to that of another machine.</td>
</tr>
<tr>
<td>16</td>
<td>Reserved.</td>
</tr>
<tr>
<td>17</td>
<td>Shunting or discharge switch serves to open or close a shunting circuit around any piece of apparatus.</td>
</tr>
<tr>
<td>18</td>
<td>Accelerating or decelerating device is used to increase or decrease the speed of a machine.</td>
</tr>
<tr>
<td>19</td>
<td>Starting-to-running transition contactor causes the automatic transfer of a machine from the starting to the running power connection.</td>
</tr>
<tr>
<td>20</td>
<td>Electrically operated relays are electrically operated, controlled or monitored relays in a fluid line.</td>
</tr>
<tr>
<td>21</td>
<td>Distance relays are devices which functions when the circuit admittance, impedance or resistance increases or decreases beyond predetermined limits.</td>
</tr>
<tr>
<td>22</td>
<td>Equalizer circuit breaker is a breaker which serves to control the current-balancing connections for a machine field.</td>
</tr>
<tr>
<td>23</td>
<td>Temperature control device.</td>
</tr>
<tr>
<td>24</td>
<td>Reserved.</td>
</tr>
<tr>
<td>25</td>
<td>Synchronizing or synchronous-check device operates when two AC circuits are within the desired limits of frequency, phase angle or voltage.</td>
</tr>
</tbody>
</table>

---

Levine Lectronics and Lectric, Inc.

200 Powers Ferry Road • Marietta, Georgia 30067
Phone (770) 565-1556 • Fax (770) 973-9264

---

Levine Lectronics and Lectric, Inc.

200 Powers Ferry Road • Marietta, Georgia 30067
Phone (770) 565-1556 • Fax (770) 973-9264
Conversion of Electro-Mechanical to Electronic Sheet

Overcurrent Relaying

Conversion of Electromechanical (EM) setting to Digital setting

TOD = Time Overcurrent

TOC = Time Overcurrent

Electromechanical time overcurrent relays are set based on taps. Digital time overcurrent relays are set based on 5% secondary or primary CT setting.

Electromechanical instantaneous overcurrent relays are set based on a dial setting (not time dial). Digital instantaneous overcurrent relays are set based on 5% secondary or primary CT setting.

For example:

<table>
<thead>
<tr>
<th>Setting</th>
<th>EM</th>
<th>Digital (5% CT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOD Picket value</td>
<td>Tap = 5</td>
<td>1 x CT or 1 x PU</td>
</tr>
<tr>
<td>TOC Picket value</td>
<td>Tap = 2</td>
<td>6 x CT or 6 x PU</td>
</tr>
<tr>
<td>Curve Shape</td>
<td>Inverse (IC60)</td>
<td>IAC Inverse</td>
</tr>
<tr>
<td>Curve used within setting</td>
<td>Time Dial</td>
<td>Multiplier</td>
</tr>
<tr>
<td>Reset</td>
<td>Timed</td>
<td>Timed (Linear) or Rel.</td>
</tr>
</tbody>
</table>

For Instantaneous Overcurrent (section 50)

- The instantaneous overcurrent relays operate when the current is greater than the current setting.
- The pickup setting is physically equal to the lower end of the current setting.
- The characteristic curve is known as the "inverse characteristic".
- The instantaneous setting is set on a dial.
- The instantaneous setting is used for overcurrent protection.
- The instantaneous setting is used for overcurrent protection.

Time Overcurrent Protection

During the selection of the curve, the protection device will automatically adjust the "inverse characteristic" to "sloped"

Reset of Time Overcurrent Element

There are (2) different types of resets when time overcurrent protection:

- Delayed - This is the normal trip of an electromechanical relay moving back to the reset position.
- Instantaneous - Once the time overcurrent element operates, it will remain immediately.

Graphic: Instantaneous Overcurrent Protection
PowerPoint presentations at:
http://l-3.com/private/ieee/

<table>
<thead>
<tr>
<th>Name</th>
<th>Last modified</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent Directory</td>
<td>02-Mar-2009 16:13</td>
<td>-</td>
</tr>
<tr>
<td>ANSI Symbols.pdf</td>
<td>12-Oct-2008 21:56</td>
<td>1.6M</td>
</tr>
<tr>
<td>ConversionofElectromechanicalsettingtoDigitalsetting_r3.doc</td>
<td>12-Oct-2008 21:56</td>
<td>331k</td>
</tr>
<tr>
<td>GE Digital Relays 2009.PPT</td>
<td>11-Mar-2009 08:44</td>
<td>11.4M</td>
</tr>
<tr>
<td>IEEE Communications-2008.ppt</td>
<td>14-Oct-2008 09:11</td>
<td>6.7M</td>
</tr>
<tr>
<td>IEEE Generator Protection.ppt</td>
<td>04-Mar-2009 00:14</td>
<td>4.3M</td>
</tr>
<tr>
<td>Motor Protection Principles.pdf</td>
<td>14-Oct-2008 08:50</td>
<td>680k</td>
</tr>
<tr>
<td>Motor Protective Settings.pdf</td>
<td>14-Oct-2008 08:50</td>
<td>384k</td>
</tr>
<tr>
<td>Protection Basics_r3.ppt</td>
<td>17-Mar-2009 15:59</td>
<td>10.0M</td>
</tr>
<tr>
<td>easa_root_cause_0502.pdf</td>
<td>06-Dec-2007 00:30</td>
<td>77.3M</td>
</tr>
<tr>
<td>ieee_21.gif</td>
<td>10-Jun-2008 09:21</td>
<td>1k</td>
</tr>
<tr>
<td>post_glover_resistance_grounding_2008.ppt</td>
<td>16-Dec-2008 17:05</td>
<td>6.5M</td>
</tr>
</tbody>
</table>
Protection Fundamentals
Desirable Protection Attributes

• **Reliability**: System operate properly
  – **Security**: Don’t trip when you shouldn’t
  – **Dependability**: Trip when you should

• **Selectivity**: Trip the minimal amount to clear the fault or abnormal operating condition

• **Speed**: Usually the faster the better in terms of minimizing equipment damage and maintaining system integrity

• **Simplicity**: KISS

• **Economics**: Don’t break the bank
Selection of protective relays requires compromises:

- Maximum and Reliable protection at minimum equipment cost
- High Sensitivity to faults and insensitivity to maximum load currents
- High-speed fault clearance with correct selectivity
- Selectivity in isolating small faulty area
- Ability to operate correctly under all predictable power system conditions
Art & Science of Protection

- Cost of protective relays should be balanced against risks involved if protection is not sufficient and not enough redundancy.

- Primary objectives is to have faulted zone’s primary protection operate first, but if there are protective relays failures, some form of backup protection is provided.

- Backup protection is local (if local primary protection fails to clear fault) and remote (if remote protection fails to operate to clear fault)
Primary Equipment & Components

- **Transformers** - to step up or step down voltage level
- **Breakers** - to energize equipment and interrupt fault current to isolate faulted equipment
- **Insulators** - to insulate equipment from ground and other phases
- **Isolators (switches)** - to create a visible and permanent isolation of primary equipment for maintenance purposes and route power flow over certain buses.
- **Bus** - to allow multiple connections (feeders) to the same source of power (transformer).
Primary Equipment & Components

- **Grounding** - to operate and maintain equipment safely
- **Arrester** - to protect primary equipment of sudden overvoltage (lightning strike).
- **Switchgear** – integrated components to switch, protect, meter and control power flow
- **Reactors** - to limit fault current (series) or compensate for charge current (shunt)
- **VT and CT** - to measure primary current and voltage and supply scaled down values to P&C, metering, SCADA, etc.
- **Regulators** - voltage, current, VAR, phase angle, etc.
Types of Protection

Overcurrent

- Uses current to determine magnitude of fault
  - Simple
  - May employ definite time or inverse time curves
  - May be slow
  - Selectivity at the cost of speed (coordination stacks)
  - Inexpensive
  - May use various polarizing voltages or ground current for directionality
  - Communication aided schemes make more selective
Instantaneous Overcurrent Protection (IOC) & Definite Time Overcurrent

- Relay closest to fault operates first
- Relays closer to source operate slower
- Time between operating for same current is called CTI (Clearing Time Interval)

![Diagram showing the relationships between time (t), current (I), and the clearing time interval (CTI).]

Distribution Substation

Fault
(TOC) Coordination

- Relay closest to fault operates first
- Relays closer to source operate slower
- Time between operating for same current is called CTI
Time Overcurrent Protection (TOC)

- Selection of the curves uses what is termed as a "time multiplier" or "time dial" to effectively shift the curve up or down on the time axis.

- Operate region lies above selected curve, while no-operate region lies below it.

- Inverse curves can approximate fuse curve shapes.
Time Overcurrent Protection (51, 51N, 51G)
Types of Protection

Differential

– current in = current out
– Simple
– Very fast
– Very defined clearing area
– Expensive
– Practical distance limitations
  • Line differential systems overcome this using digital communications
Differential

- Note CT polarity dots
- This is a through-current representation
- Perfect waveforms, no saturation
Differential

- Note CT polarity dots
- This is an internal fault representation
- Perfect waveforms, no saturation
Types of Protection

Voltage

• Uses voltage to infer fault or abnormal condition
• May employ definite time or inverse time curves
• May also be used for undervoltage load shedding
  – Simple
  – May be slow
  – Selectivity at the cost of speed (coordination stacks)
  – Inexpensive
Types of Protection

**Frequency**

- Uses frequency of voltage to detect power balance condition
- May employ definite time or inverse time curves
- Used for load shedding & machinery under/overspeed protection
  - Simple
  - May be slow
  - Selectivity at the cost of speed can be expensive
Types of Protection

Power

- Uses voltage and current to determine power flow magnitude and direction
- Typically definite time
  - Complex
  - May be slow
  - Accuracy important for many applications
  - Can be expensive
Types of Protection

Distance (Impedance)
- Uses voltage and current to determine impedance of fault
- Set on impedance [R-X] plane
- Uses definite time
- Impedance related to distance from relay
- Complicated
- Fast
- Somewhat defined clearing area with reasonable accuracy
- Expensive
- Communication aided schemes make more selective
Impedance

- Relay in Zone 1 operates first
- Time between Zones is called CTI
**Typical Bulk Power System**

- **Generation** - typically at 4-20kV
- **Transmission** - typically at 230-765kV

**Bulk Power Substation**

- Receives power from transmission system and transforms into subtransmission level
- **Subtransmission** - typically at 69-161kV
  - Receives power from subtransmission system and transforms into primary feeder voltage

**Distribution Network** - typically 2.4-69kV

- **Low voltage (service)** - typically 120-600V
Protection Zones

1. Generator or Generator-Transformer Units
2. Transformers
3. Buses
4. Lines (transmission and distribution)
5. Utilization equipment (motors, static loads, etc.)
6. Capacitor or reactor (when separately protected)
1. Overlap is accomplished by the locations of CTs, the key source for protective relays.

2. In some cases a fault might involve a CT or a circuit breaker itself, which means it can not be cleared until adjacent breakers (local or remote) are opened.
What Info is Required to Apply Protection

1. One-line diagram of the system or area involved
2. Impedances and connections of power equipment, system frequency, voltage level and phase sequence
3. Existing schemes
4. Operating procedures and practices affecting protection
5. Importance of protection required and maximum allowed clearance times
6. System fault studies
7. Maximum load and system swing limits
8. CTs and VTs locations, connections and ratios
9. Future expansion expectancy
10. Any special considerations for application.
<table>
<thead>
<tr>
<th>No.</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Time-delay</td>
</tr>
<tr>
<td>21</td>
<td>Distance</td>
</tr>
<tr>
<td>25</td>
<td>Synchronism-check</td>
</tr>
<tr>
<td>27</td>
<td>Undervoltage</td>
</tr>
<tr>
<td>30</td>
<td>Annunciator</td>
</tr>
<tr>
<td>32</td>
<td>Directional power</td>
</tr>
<tr>
<td>37</td>
<td>Undercurrent or underpower</td>
</tr>
<tr>
<td>38</td>
<td>Bearing</td>
</tr>
<tr>
<td>40</td>
<td>Field</td>
</tr>
<tr>
<td>46</td>
<td>Reverse-phase</td>
</tr>
<tr>
<td>47</td>
<td>Phase-sequence voltage</td>
</tr>
<tr>
<td>49</td>
<td>Thermal</td>
</tr>
<tr>
<td>50</td>
<td>Instantaneous overcurrent</td>
</tr>
<tr>
<td>51</td>
<td>AC time overcurrent</td>
</tr>
<tr>
<td>59</td>
<td>Overvoltage</td>
</tr>
<tr>
<td>60</td>
<td>Voltage balance</td>
</tr>
<tr>
<td>63</td>
<td>Pressure</td>
</tr>
<tr>
<td>64</td>
<td>Apparatus ground</td>
</tr>
<tr>
<td>67</td>
<td>AC directional overcurrent</td>
</tr>
<tr>
<td>68</td>
<td>Blocking</td>
</tr>
<tr>
<td>69</td>
<td>Permissive</td>
</tr>
<tr>
<td>74</td>
<td>Alarm</td>
</tr>
<tr>
<td>76</td>
<td>DC overcurrent</td>
</tr>
<tr>
<td>78</td>
<td>Out-of-step</td>
</tr>
<tr>
<td>79</td>
<td>AC reclosing</td>
</tr>
<tr>
<td>81</td>
<td>Frequency</td>
</tr>
<tr>
<td>85</td>
<td>Carrier or pilot-wire</td>
</tr>
<tr>
<td>86</td>
<td>Lock out</td>
</tr>
<tr>
<td>87</td>
<td>Differential</td>
</tr>
<tr>
<td>94</td>
<td>Tripping</td>
</tr>
</tbody>
</table>
One Line Diagram

- Non-dimensioned diagram showing how pieces of electrical equipment are connected
- Simplification of actual system
- Equipment is shown as boxes, circles and other simple graphic symbols
- Symbols should follow ANSI or IEC conventions
## 1-Line Symbols [1]

<table>
<thead>
<tr>
<th>Item</th>
<th>ANSI</th>
<th>Alternate</th>
<th>IEC</th>
<th>Alternate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td><img src="image1" alt="Symbol" /></td>
<td><img src="image2" alt="Alternate" /></td>
<td><img src="image3" alt="Symbol" /></td>
<td><img src="image4" alt="Alternate" /></td>
</tr>
<tr>
<td>Motor</td>
<td><img src="image5" alt="Symbol" /></td>
<td><img src="image6" alt="Alternate" /></td>
<td><img src="image7" alt="Symbol" /></td>
<td><img src="image8" alt="Alternate" /></td>
</tr>
<tr>
<td>Two Winding Transformer</td>
<td><img src="image9" alt="Symbol" /></td>
<td><img src="image10" alt="Alternate" /></td>
<td><img src="image11" alt="Symbol" /></td>
<td><img src="image12" alt="Alternate" /></td>
</tr>
</tbody>
</table>

- **ANC**
- **MOT**
- **S**
- **LTC**
- **GEN**
- **G**
- **G**
- **Synchronous**
- **Induction**
## 1-Line Symbols [2]

<table>
<thead>
<tr>
<th>Item</th>
<th>ANSI Symbol</th>
<th>ANSI Alternate</th>
<th>ANSI Alternate</th>
<th>IEC Symbol</th>
<th>IEC Alternate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Winding</td>
<td><img src="symbols/three-winding.png" alt="Symbol" /></td>
<td><img src="symbols/three-winding-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/three-winding-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/three-winding-iec.png" alt="Symbol" /></td>
<td><img src="symbols/three-winding-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Transformer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor</td>
<td><img src="symbols/resistor.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Resistor Iron Core</td>
<td><img src="symbols/resistor-iron-core.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-iron-core-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-iron-core-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Resistor Tapped</td>
<td><img src="symbols/resistor-tapped.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-tapped-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-tapped-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/resistor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/resistor-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Capacitor</td>
<td><img src="symbols/capacitor.png" alt="Symbol" /></td>
<td><img src="symbols/capacitor-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/capacitor-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/capacitor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/capacitor-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Reactor Iron Core</td>
<td><img src="symbols/reactor-iron-core.png" alt="Symbol" /></td>
<td><img src="symbols/reactor-iron-core-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/reactor-iron-core-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/reactor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/reactor-iec.png" alt="Alternate" /></td>
</tr>
<tr>
<td>Reactor Tapped</td>
<td><img src="symbols/reactor-tapped.png" alt="Symbol" /></td>
<td><img src="symbols/reactor-tapped-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/reactor-tapped-alternate.png" alt="Alternate" /></td>
<td><img src="symbols/reactor-iec.png" alt="Symbol" /></td>
<td><img src="symbols/reactor-iec.png" alt="Alternate" /></td>
</tr>
</tbody>
</table>
## 1-Line Symbols [3]

<table>
<thead>
<tr>
<th>Item</th>
<th>ANSI</th>
<th>IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Symbol</td>
<td>Alternate</td>
</tr>
<tr>
<td>High Voltage Breaker</td>
<td>Drawout</td>
<td>Fixed</td>
</tr>
<tr>
<td>Low Voltage Breaker</td>
<td>Drawout</td>
<td>Network Protector</td>
</tr>
<tr>
<td></td>
<td>Series Trip</td>
<td>Thermal Overload</td>
</tr>
</tbody>
</table>
## 1-Line Symbols [4]

<table>
<thead>
<tr>
<th>Item</th>
<th>ANSI Symbol</th>
<th>ANSI Alternate</th>
<th>IEC Symbol</th>
<th>IEC Alternate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch</td>
<td><img src="image1" alt="Switch Symbol" /></td>
<td><img src="image2" alt="Switch Alternate" /></td>
<td><img src="image3" alt="Switch Symbol" /></td>
<td><img src="image4" alt="Switch Alternate" /></td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>NC</td>
<td></td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>Double Throw</td>
<td></td>
<td></td>
<td>Double Throw</td>
</tr>
<tr>
<td></td>
<td>Fused Switch</td>
<td></td>
<td></td>
<td>Fused Switch</td>
</tr>
<tr>
<td>Contactor</td>
<td><img src="image5" alt="Contactor Symbol" /></td>
<td><img src="image6" alt="Contactor Alternate" /></td>
<td><img src="image7" alt="Contactor Symbol" /></td>
<td><img src="image8" alt="Contactor Alternate" /></td>
</tr>
<tr>
<td></td>
<td>Fused</td>
<td>Thermal Overload</td>
<td></td>
<td>Fused</td>
</tr>
<tr>
<td></td>
<td>Thermal Overload</td>
<td></td>
<td></td>
<td>Thermal Overload</td>
</tr>
<tr>
<td>Fuse</td>
<td><img src="image9" alt="Fuse Symbol" /></td>
<td><img src="image10" alt="Fuse Alternate" /></td>
<td><img src="image11" alt="Fuse Symbol" /></td>
<td><img src="image12" alt="Fuse Alternate" /></td>
</tr>
<tr>
<td></td>
<td>Drawout</td>
<td></td>
<td></td>
<td>Drawout</td>
</tr>
</tbody>
</table>
1-Line [1]
CB Trip Circuit (Simplified)
Lock Out Relay

Shown in RESET position
CB Coil Circuit Monitoring:
T with CB Closed; C with CB Opened

Trip/Close Contact

Coil Monitor Input

Relay

52/a or 52/b

T/C Coil

Breaker

52/a for trip circuit
52/b for close circuit
CB Coil Circuit Monitoring: Both T&C Regardless of CB state

**Drawing A:** Connection where access to breaker coil is available (‘breaker state bypass’ setpoint should be enabled for this type of connection.)

**Drawing B:** Alternate path with one breaker auxiliary contact.
Current Transformers

- Current transformers are used to step primary system currents to values usable by relays, meters, SCADA, transducers, etc.
- CT ratios are expressed as primary to secondary; 2000:5, 1200:5, 600:5, 300:5
- A 2000:5 CT has a “CTR” of 400
Standard IEEE CT Relay Accuracy

• IEEE relay class is defined in terms of the voltage a CT can deliver at 20 times the nominal current rating without exceeding a 10% composite ratio error.

For example, a relay class of C100 on a 1200:5 CT means that the CT can develop 100 volts at 24,000 primary amps (1200*20) without exceeding a 10% ratio error. Maximum burden = 1 ohm.

\[
\begin{align*}
100 \text{ V} &= 20 \times 5 \times (1 \text{ ohm}) \\
200 \text{ V} &= 20 \times 5 \times (2 \text{ ohms}) \\
400 \text{ V} &= 20 \times 5 \times (4 \text{ ohms}) \\
800 \text{ V} &= 20 \times 5 \times (8 \text{ ohms})
\end{align*}
\]
# Standard IEEE CT Burdens (5 Amp)
(Per IEEE Std. C57.13-1993)

<table>
<thead>
<tr>
<th>Application</th>
<th>Burden Designation</th>
<th>Impedance (Ohms)</th>
<th>VA @ 5 amps</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metering</td>
<td>B0.1</td>
<td>0.1</td>
<td>2.5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>B0.2</td>
<td>0.2</td>
<td>5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>B0.5</td>
<td>0.5</td>
<td>12.5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>B0.9</td>
<td>0.9</td>
<td>22.5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>B1.8</td>
<td>1.8</td>
<td>45</td>
<td>0.9</td>
</tr>
<tr>
<td>Relaying</td>
<td>B1</td>
<td>1</td>
<td>25</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>2</td>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>4</td>
<td>100</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>B8</td>
<td>8</td>
<td>200</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Voltage Transformers

- Voltage (potential) transformers are used to isolate and step down and accurately reproduce the scaled voltage for the protective device or relay.

- VT ratios are typically expressed as primary to secondary; 14400:120, 7200:120

- A 4160:120 VT has a “VTR” of 34.66
Typical CT/VT Circuits

Courtesy of Blackburn, Protective Relay: Principles and Applications
CT/VT Circuit vs. Casing Ground

- Case ground made at IT location
- Secondary circuit ground made at first point of use
Equipment Grounding

– Prevents shock exposure of personnel
– Provides current carrying capability for the ground-fault current
– Grounding includes design and construction of substation ground mat and CT and VT safety grounding
System Grounding

- Limits overvoltages
- Limits difference in electric potential through local area conducting objects
- Several methods
  - Ungrounded
  - Reactance Coil Grounded
  - High Z Grounded
  - Low Z Grounded
  - Solidly Grounded
1. Ungrounded: There is no intentional ground applied to the system—however it’s grounded through natural capacitance. Found in 2.4-15kV systems.

2. Reactance Grounded: Total system capacitance is cancelled by equal inductance. This decreases the current at the fault and limits voltage across the arc at the fault to decrease damage.

\[ X_0 \leq 10 \times X_1 \]
3. High Resistance Grounded: Limits ground fault current to 10A-20A. Used to limit transient overvoltages due to arcing ground faults.

\[ R_0 \leq \frac{X_{0c}}{3}, \quad X_{0c} \text{ is capacitive zero sequence reactance} \]

4. Low Resistance Grounded: To limit current to 25-400A

\[ R_0 \geq 2X_0 \]
System Grounding

5. Solidly Grounded: There is a connection of transformer or generator neutral directly to station ground.

Effectively Grounded: $R_0 \leq X_1$, $X_0 \leq 3X_1$, where $R$ is the system fault resistance
Basic Current Connections: How System is Grounded Determines How Ground Fault is Detected

Medium/High Resistance Ground

Low/No Resistance Ground
Substation Types

- Single Supply
- Multiple Supply
- Mobile Substations for emergencies
- Types are defined by number of transformers, buses, breakers to provide adequate service for application
Industrial Substation Arrangements
(Typical)

RADIAL
(SINGLE-ENDED SUBSTATION)

PRIMARY SELECTIVE

FEEDERS
MAIN

FEEDERS
MAIN
Industrial Substation Arrangements (Typical)

SECONDARY SELECTIVE (DOUBLE-ENDED SUBSTATION)

NETWORKS

MAIN

TIE

N.O.

FEEDERS

NETWORK PROTECTORS
Utility Substation Arrangements

(Typical)

Single Bus, 1 Tx, Dual supply

Single Bus, 2 Tx, Dual Supply

2-sections Bus with HS Tie-Breaker, 2 Tx, Dual Supply
**Utility Substation Arrangements**

*(Typical)*

**Breaker-and-a-half** – allows reduction of equipment cost by using 3 breakers for each 2 circuits. For load transfer and operation is simple, but relaying is complex as middle breaker is responsible to both circuits.

**Ring bus** – advantage that one breaker per circuit. Also each outgoing circuit (Tx) has 2 sources of supply. Any breaker can be taken from service without disrupting others.
**Utility Substation Arrangements (Typical)**

**Double Bus:** Upper Main and Transfer, bottom Double Main bus

**Main-Reserved and Transfer Bus:** Allows maintenance of any bus and any breaker
Switchgear Defined

• Assemblies containing electrical switching, protection, metering and management devices
• Used in three-phase, high-power industrial, commercial and utility applications
• Covers a variety of actual uses, including motor control, distribution panels and outdoor switchyards
• The term "switchgear" is plural, even when referring to a single switchgear assembly (never say, "switchgears")
• May be a described in terms of use:
  – "the generator switchgear"
  – "the stamping line switchgear"
Switchgear Examples

Air insulated, 2- high drawout Vacuum Switchgear

Air insulated, fused load-interrupter Switchgear

Air insulated, load-interrupter Padmounted Switchgear

SF6 insulated, vacuum interrupter Switchgear
A Good Day in System Protection……

– CTs and VTs bring electrical info to relays
– Relays sense current and voltage and declare fault
– Relays send signals through control circuits to circuit breakers
– Circuit breaker(s) correctly trip

What Could Go Wrong Here????
A Bad Day in System Protection……

- CTs or VTs are shorted, opened, or their wiring is
- Relays do not declare fault due to setting errors, faulty relay, CT saturation
- Control wires cut or batteries dead so no signal is sent from relay to circuit breaker
- Circuit breakers do not have power, burnt trip coil or otherwise fail to trip

Protection Systems Typically are Designed for N-1
Protection Performance Statistics

- Correct and desired: 92.2%
- Correct but undesired: 5.3%
- Incorrect: 2.1%
- Fail to trip: 0.4%
Contribution to Faults

1. Short-circuit current from generator
2. Short-circuit current from syn. motor
3. Short-circuit current from induction motor
4. Short-circuit current from electric utility system

Total short-circuit current from all four sources.
Fault Types (Shunt)

THREE PHASE

LINE-TO LINE

LINE-TO GROUND

TWO LINES TO GROUND
AC & DC Current Components of Fault Current

When DC becomes zero, then AC will be balanced around zero axis
# Useful Conversions

<table>
<thead>
<tr>
<th>To Find</th>
<th>Single Phase</th>
<th>Three Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPERES when</td>
<td><strong>KVA \times 1000</strong></td>
<td><strong>KVA \times 1000</strong></td>
</tr>
<tr>
<td>KVA is known</td>
<td><strong>\frac{E}{KVA}</strong></td>
<td><strong>\frac{E \times 1.73}{KVA}</strong></td>
</tr>
<tr>
<td>AMPERES when</td>
<td><strong>HP \times 746</strong></td>
<td><strong>HP \times 746</strong></td>
</tr>
<tr>
<td>horsepower is</td>
<td><strong>\frac{E \times % \text{Eff.} \times PF}{HP}</strong></td>
<td><strong>\frac{E \times 1.73 \times % \text{Eff.} \times PF}{HP}</strong></td>
</tr>
<tr>
<td>known</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMPERES when</td>
<td><strong>KW \times 1000</strong></td>
<td><strong>KW \times 1000</strong></td>
</tr>
<tr>
<td>kilowatts are</td>
<td><strong>\frac{E \times PF}{KW}</strong></td>
<td><strong>\frac{E \times 1.73 \times PF}{KW}</strong></td>
</tr>
<tr>
<td>known</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KILOWATTS</td>
<td><strong>\frac{I \times E \times PF}{1000}</strong></td>
<td><strong>\frac{I \times E \times 1.73 \times PF}{1000}</strong></td>
</tr>
<tr>
<td>KILOVOLT/AMPERES</td>
<td><strong>\frac{I \times E}{1000}</strong></td>
<td><strong>\frac{I \times E \times 1.73}{1000}</strong></td>
</tr>
<tr>
<td>HORSEPOWER</td>
<td><strong>\frac{I \times E \times % \text{Eff.} \times PF}{746}</strong></td>
<td><strong>\frac{I \times E \times 1.73 \times % \text{Eff.} \times PF}{746}</strong></td>
</tr>
</tbody>
</table>
Per Unit System

Establish two base quantities:

- Standard practice is to define
  - Base power – 3 phase
  - Base voltage – line to line
- Other quantities derived with basic power equations
Per Unit Basics

PER-UNIT SYSTEM | BASE VALUES

- SELECT BASE kVA AND BASE VOLTS
- CALCULATE BASE AMPS AND BASE OHMS

\[
\text{BASE AMPS} = \frac{\text{BASE kVA} \times 1000}{\text{BASE VOLTS} \times \sqrt{3}}
\]

\[
\text{BASE OHMS} = \frac{\text{BASE VOLTS}}{\text{BASE AMPS} \times \sqrt{3}}
\]

KVA IS THREE-PHASE
VOLTS IS LINE-TO-LINE
OHMS IS LINE-TO-NEUTRAL
Short Circuit Calculations
Per Unit System

Per Unit Value = \frac{\text{Actual Quantity}}{\text{Base Quantity}}

V_{pu} = \frac{V_{\text{actual}}}{V_{\text{base}}}

I_{pu} = \frac{I_{\text{actual}}}{I_{\text{base}}}

Z_{pu} = \frac{Z_{\text{actual}}}{Z_{\text{base}}}

Short Circuit Calculations
Per Unit System

\[
I_{\text{base}} = \frac{\text{MVA}_{\text{base}} \times 1000}{\sqrt{3} \times kV_{L-L \text{ base}}}
\]

\[
Z_{\text{base}} = \frac{kV^2_{L-L \text{ base}}}{\text{MVA}_{\text{base}}}
\]
Short Circuit Calculations
Per Unit System – Base Conversion

\[ Z_{pu} = \frac{Z_{\text{actual}}}{Z_{\text{base}}} \]

\[ Z_{\text{base}} = \frac{kV^2_{\text{base}}}{MVA_{\text{base}}} \]

\[ Z_{\text{pu1}} = \frac{\text{MVA}_{\text{base1}}}{kV^2_{\text{base1}}} \times Z_{\text{actual}} \]

\[ Z_{\text{pu2}} = \frac{\text{MVA}_{\text{base2}}}{kV^2_{\text{base2}}} \times Z_{\text{actual}} \]

\[ \Rightarrow Z_{\text{pu2}} = Z_{\text{pu1}} \times \frac{kV^2_{\text{base1}} \times \text{MVA}_{\text{base2}}}{kV^2_{\text{base2}} \times \text{MVA}_{\text{base1}}} \]
A Study of a Fault

Total Clearing Time

Relaying (2 Cycles)  Mech Time (1 Cycle)  Arcing Time (2 Cycles)

ARC Extinguished in Five Cycles

SHORT CIRCUIT OCCURS HERE
Arc Flash Hazard
Protective Relaying Methods of Reducing Arc Flash Hazard

- Bus differential protection (this reduces the arc flash energy by reducing the clearing time)
- Zone interlock schemes where bus relay selectively is allowed to trip or block depending on location of faults as identified from feeder relays
- Temporary setting changes to reduce clearing time during maintenance
  - **Sacrifices coordination**
- FlexCurve for improved coordination opportunities
- Employ 51VC/VR on feeders fed from small generation to improve sensitivity and coordination
- Employ UV light detectors with current disturbance detectors for selective gear tripping
# Arc Flash Hazards

<table>
<thead>
<tr>
<th>Skin Temperature</th>
<th>Time of Skin Temp.</th>
<th>Damage Caused</th>
</tr>
</thead>
<tbody>
<tr>
<td>110 °F</td>
<td>6 Hours</td>
<td>Cell breakdown starts</td>
</tr>
<tr>
<td>158 °F</td>
<td>1 sec.</td>
<td>Total cell destruction</td>
</tr>
<tr>
<td>176 °F</td>
<td>0.1 sec</td>
<td>Curable burn</td>
</tr>
<tr>
<td>200 °F</td>
<td>0.1 sec</td>
<td>Incurable burn</td>
</tr>
</tbody>
</table>

## NFPA-70E 2004 Equipment Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Energy Level</th>
<th>Typical Personal Protective Equipment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.2 cal/cm²</td>
<td>Non-melting flammable materials</td>
</tr>
<tr>
<td>1</td>
<td>5 cal/cm²</td>
<td>Fire Resistant (FR) shirt and FR pants</td>
</tr>
<tr>
<td>2</td>
<td>8 cal/cm²</td>
<td>FR shirt, FR pants, cotton underwear</td>
</tr>
<tr>
<td>3</td>
<td>25 cal/cm²</td>
<td>Two layers FR clothing, cotton underwear</td>
</tr>
<tr>
<td>4</td>
<td>40 cal/cm²</td>
<td>FR shirt, FR pants, multilayer flash suit, cotton underwear</td>
</tr>
</tbody>
</table>

Other:
- Face Protection  Face Shield and/or safety glasses
- Hand Protection  Leather over rubber for arc flash protection
- Leather work boots above 5 cal/cm²
Arc Pressure Wave

\[ P = 11.65 \times \left( \frac{kA}{R^{0.9}} \right) \]

Where:
- \( P \) = Pressure developed by arc in \( \text{lbs/ft}^2 \)
- \( kA \) = Short circuit current \( \text{rms} \) in kiloamps
- \( R \) = Distance in feet from arc center to area of interest

Available Short Circuit Current (Amps - RMS) 1KA 2.5KA 5KA 10KA 25KA 50KA 100KA
Copy of this presentation are at:
www.L-3.com\private\IEEE
Protection Fundamentals

QUESTIONS?