Time-Current Curves
Protective Device Coordination Study

Description:

• An organized time-current study of protective devices from the utility to a device.

• A comparison of the time it takes protective devices to operate when certain levels of normal or abnormal current pass through them.
Protective Device Coordination

Objective:

• Determine the characteristics, ratings, and settings of overcurrent protective devices

• Ensure that the minimum, un-faulted load is interrupted when the protective devices isolate a fault or overload anywhere in the system.
Protective Device Coordination

Protective Device Coordination Study-Results:

• Selection of instrument transformers ratios
• Protective relay characteristics and settings
• Fuse ratings
• LV circuit breaker ratings, characteristics, and settings.
Protective Device Coordination

Protective Device Coordination Study - Frequency:

• This study should be revised as new protective devices are added or as existing devices are modified.

• At a minimum, it is recommended that this study be performed every 5 years.
Protective Device Coordination

Protective Device Coordination Study - Frequency:

• This study should be revised as new protective are added or as existing devices are modified.

• At a minimum, it is recommended that this study be performed every 5 years.
(b) Electric power and lighting circuits.

(1) Routine opening and closing of circuits. Load rated switches, circuit breakers, or other devices specifically designed as disconnecting means shall be used for the opening, reversing, or closing of circuits under load conditions. Cable connectors not of the load break type, fuses, terminal lugs, and cable splice connections may not be used for such purposes, except in an emergency.
OSHA 1910.334
Use of Equipment

(b) Electric power and lighting circuits.

(2) Reclosing circuits after protective device operation. After a circuit is de-energized by a circuit protective device, the circuit protective device, the circuit may not be manually reenergized until it has been determined that the equipment and circuit can be safely energized. The repetitive manual reclosing of circuit breakers or reenergizing circuits through replaced fuses is prohibited.

Note: When it can be determined from the design of the circuit and the overcurrent devices involved that the automatic operation of a device was caused by an overload rather than a fault condition, no examination of the circuit or connected equipment is needed before the circuit is reenergized.
OSHA 1910.334
Use of Equipment

(b) Electric power and lighting circuits.

(3) Overcurrent protection modification. Overcurrent protection of circuits and conductors may not be modified, even on a temporary basis, beyond that allowed by 1910.304(e), the installation safety requirements for overcurrent protection.
Time-Current Curves
Transformers
The Time-Current Curves for cables are also known as “Damage” curves.
The Time-Current Curves for motors are also known as “Damage” curves.

The diagram shows different curves for motor operations including:
- O/L Running Curve
- Hot Motor Thermal Damage Curve
- O/L Starting Curve
- Cold Motor Thermal Damage Curve
- Motor Starting
- FLC Motor Running

These curves help in understanding the performance and potential damage of motor operations.
Time-Current Curves
Protective Relays

50 – Instantaneous Overcurrent Relay

51 – AC Time Overcurrent Relay

67 – AC Directional Overcurrent Relay
Time-Current Curves

Fuses
What would cause a fuse to blow?
1. Inappropriate Sizing
2. Inappropriate Type for application
3. Fault
Time-Current Curves
Fuses
Time-Current Curves
Circuit Breakers
Time-Current Curves
Circuit Breakers

No action to left of curve

Trip or clear on and to right of curve

All devices should be considered at same voltage
Time-Current Curves
Circuit Breakers

Long Time (i.e., TOL)

Short Time (i.e., motor starts/stops)

Instantaneous (i.e., Faults)
Time-Current Curves
Circuit Breakers

Cargill Electrical Team Meeting
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Trip Unit</th>
<th>Rating</th>
<th>Fault Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIEMENS RLE, Static Trip III RL-2000</td>
<td>Trip 2000.0 A</td>
<td>Settings Phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTPU (0.5-1.0 x S) 0.5 (1000A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTD (3.5-30 Sec.) 3.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>STPU (2-12 x LTPU) 2 (2000A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>STD (0.08-0.4 Sec.) 0.08 (I^2t Out)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INST (2-15 x S) 2 (4000A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interrupting Rating 100.0 kA</td>
<td></td>
</tr>
</tbody>
</table>
## Available Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTPU</td>
<td>Long Time Pickup</td>
</tr>
<tr>
<td>LTD</td>
<td>Long Time Delay</td>
</tr>
<tr>
<td>STPU</td>
<td>Short Time Pickup</td>
</tr>
<tr>
<td>STD</td>
<td>Short Time Delay</td>
</tr>
<tr>
<td>INST</td>
<td>Instantaneous</td>
</tr>
<tr>
<td>GF</td>
<td>Ground Fault</td>
</tr>
<tr>
<td>GFD</td>
<td>Ground Fault Delay</td>
</tr>
</tbody>
</table>

### Circuit Breaker Settings

- **SIEMENS RLE, Static Trip III RL-2000**
- **Trip 2000.0 A**
- **Settings Phase**
  - LTPU (0.5-1.0 x S) 0.5 (1000A)
  - LTD (3.5-30 Sec.) 3.5
  - STPU (2-12 x LTPU) 2 (2000A)
  - STD (0.08-0.4 Sec.) 0.08 (I^2t Out)
  - INST (2-15 x S) 2 (4000A)
- **Interrupting Rating**: 100.0 kA
Time-Current Curves
Circuit Breakers

SIEMENS
RLE, Static Trip III
RL-2000
Trip 2000.0 A
Settings Phase
LTPU (0.5-1.0 x S) 0.5 (1000A)
LTD (3.5-30 Sec.) 3.5
STPU (2-12 x LTPU) 2 (2000A)
STD (0.08-0.4 Sec.) 0.08 (I^2t Out)
INST (2-15 x S) 2 (4000A)
InterruptingRating 100.0 kA
SIEMENS
RLE, Static Trip III
RL-2000
Trip 2000.0 A
Settings Phase
LTPU (0.5-1.0 x S) 0.5 (1000A)
LTD (3.5-30 Sec.) 3.5
STPU (2-12 x LTPU) 2 (2000A)
STD (0.08-0.4 Sec.) 0.08 (I^2t Out)
INST (2-15 x S) 2 (4000A)
Interrupting Rating 100.0 kA

Time-Current Curves
Circuit Breakers

Cargill Electrical Team Meeting
Time-Current Curves
Circuit Breakers

SIEMENS
RLE, Static Trip III
RL-2000
Trip 2000.0 A
Settings Phase
LTPU (0.5-1.0 x I) 0.5 (1000A)
LTD (3.5-30 Sec.) 3.5
STPU (2-12 x LTPU) 2 (2000A)
STD (0.08-0.4 Sec.) 0.08 (I^2t Out)
INST (2-15 x S) 2 (4000A)
Interrupting Rating 100.0 kA
Time-Current Curves
Circuit Breakers

SIEMENS
RLE, Static Trip III
RL-2000
Trip 2000.0 A
Settings Phase
  LTPU (0.5-1.0 x S) 0.5 (1000A)
  LTD (3.5-30 Sec.) 3.5
  STPU (2-12 x LTPU) 2 (2000A)
  STD (0.08-0.4 Sec.) 0.08 (I^2t Out)
  INST (2-15 x S) 2 (4000A)
Interruping Rating 100.0 kA

INST Setting
Time-Current Curves
Circuit Breakers
Time-Current Curves
Thermal-Mag Breakers

Thermal portion
(usually fixed)

“Mag” portion
(usually adjustable)

“Mag” Setting –
Equates to INST
Time-Current Curves
Transformers

<table>
<thead>
<tr>
<th>Protection Point</th>
<th>&lt; 2500 kVA</th>
<th>&gt; 2500 kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI</td>
<td>17.6 x I_{fl} x 58%</td>
<td>16.6 x I_{fl} x 58%</td>
</tr>
<tr>
<td>Inrush (for 0.1 sec)</td>
<td>8 x I_{fl}</td>
<td>12 x I_{fl}</td>
</tr>
<tr>
<td>NEC Rule (6 x I_{fl})</td>
<td>6 x I_{fl}</td>
<td>6 x I_{fl}</td>
</tr>
</tbody>
</table>
Transformer Inrush must be left of curve
Time Current Curves
Motor Protection

Refer to NEC Article 430.52, “Rating or Setting for Individual Motor Circuit” and manufacturer recommendations for determining appropriate motor protection.

<table>
<thead>
<tr>
<th>Type of Motor</th>
<th>Percentage of Full-Load Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nontime Delay Fuse $^{1}$</td>
</tr>
<tr>
<td>Single-phase motors</td>
<td>300</td>
</tr>
<tr>
<td>AC polyphase motors other than wound-rotor</td>
<td>300</td>
</tr>
<tr>
<td>Squirrel cage — other than Design B energy-efficient</td>
<td>300</td>
</tr>
<tr>
<td>Design B energy-efficient</td>
<td>300</td>
</tr>
<tr>
<td>Synchronous $^{3}$</td>
<td>300</td>
</tr>
<tr>
<td>Wound rotor</td>
<td>150</td>
</tr>
<tr>
<td>Direct current (constant voltage)</td>
<td>150</td>
</tr>
</tbody>
</table>

Note: For certain exceptions to the values specified, see 430.54.

$^{1}$The values in the Nontime Delay Fuse column apply to Time-Delay Class CC fuses.

$^{2}$The values given in the last column also cover the ratings of nonadjustable inverse time types of circuit breakers that may be modified as in 430.52(C)(1), Exception No. 1 and No. 2.

$^{3}$Synchronous motors of the low-torque, low-speed type (usually 450 rpm or lower), such as are used to drive reciprocating compressors, pumps, and so forth, that start unloaded, do not require a fuse rating or circuit-breaker setting in excess of 200 percent of full-load current.
Time Current Curves
Motor Protection
Time Current Curves
Motor Protection
Motor protection relays are typically programmed to operate approximately halfway between Load Current Curve and the Motor Damage Curve.
Time Current Curves
Motor Protection
Time-Current Curves

Questions or Comments?
Troubleshooting
Troubleshooting Tools:

• Design Information:
  — One-Line Diagrams
  — Time-Current Curves
  — Manufacturer Literature
  — Operating History

• Maintenance Information:
  — Visual Inspection
  — IR Surveys
  — Oil Sample Reports
  — UE/PD Surveys
  — Testing Data Sheets
  — Protective Relays
  — Power Monitors
- Scheduled PM Overdue (Needed Cleaning)
- High Humidity compounded problem
- Expulsion Type Fuse failed to operate correctly
Transformer Inrush must be left of curve
Control Power Transformer (CPT)
Breaker Trip:
Cause - Rodent
Troubleshooting

High Resistance Fuse
Extenuating Circumstances:

• Inadequate spare parts
• Production pressure

Note: First indication provided through IR Survey.
HV Bushing Repair Required

- Jumpers undersized
- Heating resulted in gasket failure
- Oil contamination resulted in flashover at bushing.

Note: First indication provided through IR Survey.
## Troubleshooting

### TABLE 100.18

<table>
<thead>
<tr>
<th>Temperature difference (ΔT) based on comparisons between similar components under similar loading.</th>
<th>Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures.</th>
<th>Recommended Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1° C – 3° C</td>
<td>1° C – 10° C</td>
<td>Possible deficiency; warrants investigation</td>
</tr>
<tr>
<td>4° C – 15° C</td>
<td>11° C – 20° C</td>
<td>Indicates probable deficiency; repair as time permits</td>
</tr>
<tr>
<td>21° C – 40° C</td>
<td>&gt;40° C</td>
<td>Monitor until corrective measures can be accomplished</td>
</tr>
</tbody>
</table>

Temperature specifications vary depending on the exact type of equipment. Even in the same class of equipment (i.e., cables) there are various temperature ratings. Heating is generally related to the square of the current; therefore, the load current will have a major impact on ΔT. In the absence of consensus standards for ΔT, the values in this table will provide reasonable guidelines.


It is a necessary and valid requirement that the person performing the electrical inspection be thoroughly trained and experienced concerning the apparatus and systems being evaluated as well as knowledgeable of thermographic methodology.
HV Insulated Bus

Insulation Tracking
(Carbon Treeing)
Troubleshooting

HV Jumper Cable

Insulation Tracking
(Corona Damage Due to Improper Installation)
Troubleshooting

Tap Changer

Eminent Connection Failure

Note: First indication provided through Oil Sampling.
Event: Fault (~8,000A) resulted in switchgear lineup burning without fuses clearing.

Cause: Only one of nine 4/0 ground cables was connected.

Cable burned through, effectively “protecting” fuse.
December 2011
Event: Fuse (HS0202A) and Utility relay (50/51) cleared, shutting plant down.

Cause: TBD.
Troubleshooting

Indicative of Fault
Troubleshooting

Indicative of Fault
HS0202A feeds the following:
TH0202B thru HS0202B (65A)
TH0202C thru HS0202C (100A)
TH0202D thru HS0202D (100A)
TH0202E thru HS0202E (200A)

Apparent fault on B and/or C phase below HS0202A
(b) Electric power and lighting circuits.

(2) Reclosing circuits after protective device operation. After a circuit is de-energized by a circuit protective device, the circuit protective device, the circuit may not be manually reenergized until it has been determined that the equipment and circuit can be safely energized. The repetitive manual reclosing of circuit breakers or reenergizing circuits through replaced fuses is prohibited.

Note: When it can be determined from the design of the circuit and the overcurrent devices involved that the automatic operation of a device was caused by an overload rather than a fault condition, no examination of the circuit or connected equipment is needed before the circuit is reenergized.
Questions or Comments?