Current Transformers

- Bonneville Power Administration
  - Steve Laslo
    - For the Hands On Relay School (3-12)
      - Revision 1.1 (Basic)
Objective of the presentation:

- For learners to increase their knowledge level of Current Transformers in the following areas:
  - Basic Theory
  - Application
  - Terminology
  - Safety Hazards
  - Safe Work Practices
Examples of CT’s

Bushing CT’s
Examples of CT’s

Free-Standing CT’s

Note Current Path
Examples of CT’s
Basic Theory:

CT as a Voltage Transformer
CT as a Voltage Transformer
Working Range of (relative) flux levels on core:

Saturation Curves
CT with varying burden
CT with varying burden
CT with varying burden
<table>
<thead>
<tr>
<th>Ratio</th>
<th>Catalog Number</th>
<th>Accuracy/Burden</th>
<th>Rating Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>200:5</td>
<td>D040200S1</td>
<td>0.3 B0.2</td>
<td>2.0</td>
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<td>300:5</td>
<td>D040300S1</td>
<td>0.3 B0.5</td>
<td>2.0</td>
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<td>2.0</td>
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<td>0.3 B0.9</td>
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<td>0.3 B1.8</td>
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<td>0.3 B1.8</td>
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<td>0.3 B1.8</td>
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<td>0.3 B0.5/B0.9</td>
<td>2.0/2.0</td>
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<td>300/600:5</td>
<td>D040300D1</td>
<td>0.3 B0.5/B1.8</td>
<td>2.0/2.0</td>
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<td>2.0/2.0</td>
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<td>2.0/2.0</td>
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<td>2.0/2.0</td>
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<td>0.3 B1.8/B1.8</td>
<td>2.0/1.5</td>
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<td>D043000D1</td>
<td>0.3 B1.8/B1.8</td>
<td>1.5/1.0</td>
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</table>

- Available in multi-ratio designs (full tap ratings same as single ratio above).
- 1 Second Thermal/Mechanical Rating: 80x full winding I_{nom} / Unlimited mechanical.
* IC Approval (AE-1104) is noted by bold catalog number.

CT Accuracy Classifications

From ABB/Kuhlman 15kV Instrumentation Brochure
• **Meter Accuracy:**
  - Secondary Current will be within 0.3% accuracy at rated current and Burden levels of 1.8 ohms or less.

• **Relay Accuracy:**
  - Secondary Current will be within 10% accuracy at 1-20 x rated current with burden levels of 3 ohms or less.
  - Full winding output of the CT is essentially 300V, which can drive 100A secondary current through a 3 ohm burden (or less).
  - ‘C’ indicates accuracy can be calculated based on design of this CT. ‘C’ ratings are the most common.
  - Less common letter classes: K, T, H, L

• **Rating Factor:**
  - Up to 2 x rated current can be applied continuously with the CT staying within it’s accuracy and thermal ratings.

### Ratings of CT’s

<table>
<thead>
<tr>
<th>Current Ratio</th>
<th>Catalog #</th>
<th>Meter Accuracy</th>
<th>Relay Accuracy</th>
<th>Rating Factor</th>
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<td>D041200S1</td>
<td>0.3 B1.8</td>
<td>C300</td>
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</table>
By the IEEE Standard, does a 0.3% CT mean its 0.3% accurate?

IEEE Standard
New supplement to IEEE Standard
  ◦ C57.13.6-2005
  ◦ Creates a new 0.15% accuracy class
    • With an extended, consistent range between 5% and TRF

New Extended Accuracy Range CT’s
C800 CT Working Limits
Multi-ratio issues
Multi-ratio issues
Multi-ratio issues
Commonly performed field tests:

- Insulation Resistance
  - Winding to Winding and Winding to Ground insulation check
- CT Resistance
  - ‘Bridge’ or Low-resistance ohmmeter check of CT Secondary Winding.
- Ratio Test
  - Check of CT to confirm proper Ratio
- Polarity
  - Confirmation of CT polarity
- Excitation
  - Confirmation of CT rating, verifies no shorted turns
- Burden
  - Check of CT’s ability to deliver current
- **Ratio Test**
  - Two commonly used out-of-service methods to test:
    - Voltage Method
      - CT is essentially tested as a voltage transformer by applying voltage to the CT Secondary and measuring the primary voltage.
      - The turns ratio is approximately equal to the voltage ratio.
**Ratio Test**

- Current Method
  - Some form of ‘loading gear’ is used to push current through the CT primary. Secondary current is compared to primary current, usually through a ‘Reference CT’.
• Polarity Test
  ◦ Four commonly used out-of-service methods to test:
    • DC Flash Method
      ◦ A lantern battery or equivalent DC source is momentarily connected to the CT Secondary and the primary voltage is monitored with a voltmeter.
• Classical Polarity Test
  ◦ Voltage Method
    • This test is performed in the same manner as a voltage transformer polarity test.
• **Excitation Test**
  ◦ **Secondary Excitation Method**
    • Secondary voltage is applied and exciting current is measured
    • Voltage / Current are plotted and compared to manufacturer’s information
**Excitation Test using Primary Current Injection**

- Primary Current is measured along with secondary voltage.
- Primary exciting current is divided by the CT ratio to determine equivalent secondary exciting current to compare to manufacturer’s diagrams.
Floating Secondary Issues

- Capacitance between HV Conductor and Secondary Winding
- Capacitance between Secondary Winding and Ground
Secondary open circuit wave shapes

Rapid flux state change causes high voltage spikes

Secondary Induced Voltage Spike

$I_p$ - Primary Current

$E_s$ - Induced e.m.f.

$\phi_p$ - Core Flux

Core Flux During Saturation
Demonstration of high voltages

To verify that such voltages can be produced we will spark a pre-set gap at 1,000 volts

Click Video to Run
CT used was from a retired 500kV ITE SF6 PCB - BCT 3000/5 (Full Winding).
Test Equipment: TEK 20kV probe, ITE/Gould Digital Scope, Transrex high current supply.
Test Performed in EPA Mangan Lab - 7/16/02.
Note: Test Data are approximate values combined from two consecutive test runs.
- Added V/A Column 8-02 (SIL); formatting change (6-03).
A CT can easily supply currents above lethal levels!
The open circuit situation resolves to high voltages and lethal currents… WATCH THIS!!
Working around CT Circuits:
  ◦ Circuit Identification
    • Wiring Diagram / AC Schematic Information.
  ◦ Testing for Energized Circuits
    • Secondary Current measurement.
    • Audible/Visual arcing check.
  ◦ Safe work practices
    • Use of Safety Gloves, Blankets, and Insulated Tools.
  ◦ Job Briefings
  ◦ Methods of shorting at CT Shorting Blocks

Practical / Safety Considerations
Circuit Identification was a primary factor in a CT accident at BPA.

- CT leads were lifted on the wrong terminal block. Instead of being a circuit that was 'shorted' and isolated, the circuit had live current flowing.

- If you aren’t 100% sure of the identity and function of the circuit you are about to work on, don’t work on it – research and get assistance if necessary until you are... Circuit Identification is an important part of safe CT work.
Most utilities have standards for wiring specific circuits like those associated with CT’s and/or PT’s.

- Use your knowledge of your company’s standards to help identify CT circuits so that you can treat them appropriately. When in doubt – research until you are sure.

Example BPA standard for CT’s:

- Normally Color Coded on BPA run cabling:
  - **Black (1A)** – A-Phase
  - **Green (2A)** – B-Phase
  - **Red (3A)** – C-Phase
  - **White (0A)** – CT Common / Neutral
- Normally designated 1A, 2A, 3A, and 0A (if Wye-connected)
Circuit Identification Example
Wiring Diagrams and/or Layout Prints should show actual placement of Terminal Blocks seen on Schematic Diagrams.

Schematic Diagrams show Circuit Functionality and may have some Wiring Diagram information shown on them.

Schematics and Wiring Diagrams should agree with each other.

Your company may have standards for typical CT configurations that may aid in the identification process.
Example of wiring information on AC Circuit Schematic
Example of ‘Clues’ that wiring is part of a CT Circuit (continued on next page).
<table>
<thead>
<tr>
<th>No.</th>
<th>Connecting Part</th>
<th>Description</th>
<th>Notes</th>
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<td>C08E-3</td>
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<tr>
<td>09</td>
<td>C08E-23</td>
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<tr>
<td>11</td>
<td>C08E-14</td>
<td>7CC #19/22</td>
<td>TO PCB C08E</td>
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<td>17</td>
<td>C05E-13-1</td>
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<td>18</td>
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<td>CAP GRP 2 SUBGRP A RLY POT.</td>
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</table>
Diagram shows physical location of CT’s relative to the PCB and each other.

Example of ‘Clues’ to physical location of CT Circuits.
Example of critical information pertinent to physical location of CT Circuits.

LOCATED LEFT SIDE OF THREE PHASE CAB. (SH. 3)
Example of using Clamp-on ammeter to test for secondary current.
CT Secondary Wires should be lifted slowly while listening for arcing as a final verification check.

- The visual/audible Arcing Check is also not 100% reliable as a test for an open-circuit CT condition.
  - In brightly lit and/or noisy areas, it may be difficult to detect the arcing condition.
  - With low values of CT secondary current, there may be little-to-no arcing when wiring is lifted.
Using Test Instruments

Fluke Current Measuring Devices
• Make sure to check the Current Test Instrument on a known circuit first, then
the unidentified circuit, then the known circuit again, just like voltage test
devices…

  ○ Verify test instrument operation before relying on it’s results.
Another item to consider when using normal hand-tools or placing your fingers on secondary wiring insulation is whether the insulation between you and the secondary conductor is truly adequate to protect you from the possible voltages a CT can produce on the secondary wiring.

- If that insulation is normally rated at 600VAC or 1000VAC, are you protected from voltages that can have peaks well over 4kV?
- Can that screwdriver protect you from that same voltage? It's going to be directly connected to the conductor as you remove that screw on the termination block...

Safe Work Practices
Ostrander Open-Circuit CT Incident

Note there is no wire on the CT side of the block.

Note only 4 wires from CT pocket.
Damaged CT's from 500kV PCB
Damaged CT’s from 500kV PCB
Care should be taken to keep yourself from becoming a possible current path for the CT Circuit should it become open-circuited.

- Since CT Circuits are very often grounded (Wye), if you are touching Termination Frames or Relay Racks you may become part of the current path if you contact the CT conductor during an open-circuit incident.
Re-enactment of 1st Contact Accident

Quote from the Accident Report:

“The Electrician said he could smell his flesh burning”
• Sample items that can be covered at a Job Briefing or ‘Tailgate’:
  ◦ **Hazards associated with the Job.**
  ◦ **Work Procedures.**
  ◦ **Special Precautions.**
  ◦ **Energy Source Controls**
  ◦ **Personal Protective Equipment.**
  ◦ **Clearances, Work Permits, Hold Orders**
CT Open-Circuit Secondary Arcing

Click Video to Run
When shorting CT secondaries at CT Shorting Blocks, care must be taken to properly short the CT Circuit.

- Depending on the connection made at the block it may take anywhere from 2 to 6 shorting screws to fully short the CT secondaries.
‘Single-Phase’ Type CT Shorting Block

CT ratio tap wiring from one individual CT

Note that a minimum of two screws are needed to short this 1 CT – if the full winding is shorted (Y1-Y5 in this case).

Shorting Block Ground

Single-Phase wiring from individual CT to relays, instruments, etc.

Ground screw connection normally left in-place.
Three-Phase Type CT Shorting Block

CT wiring from three single-phase individual CT’s (three pairs)

Shorting Block Ground

Ground screw connection normally left in-place.

Three-Phase wiring to relays, instruments, etc.

Note that it takes a minimum of four screws to short this set of 3 CT’s – (2Y1, 4Y1, 6Y1, and one of 2Y5, 4Y5, and 6Y5 in this case) – as long as the Wye connection is intact – white wiring here.
Three-Phase Block Analysis
Questions?