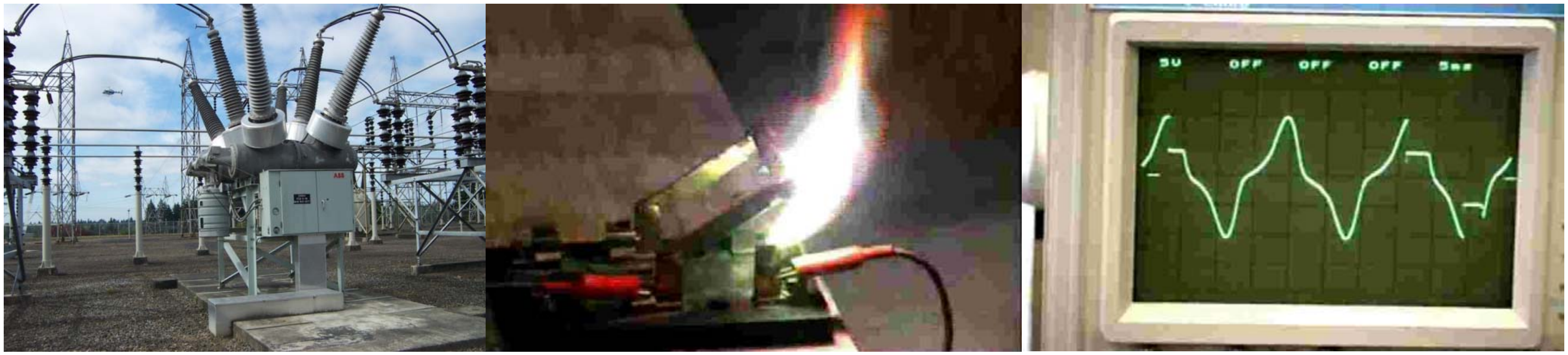
Current Transformers



Steve Laslo

System Protection & Control Specialist

Bonneville Power Administration

For the Hands On Relay School (March 2017)

Revision 1.3

Objectives of the presentation:

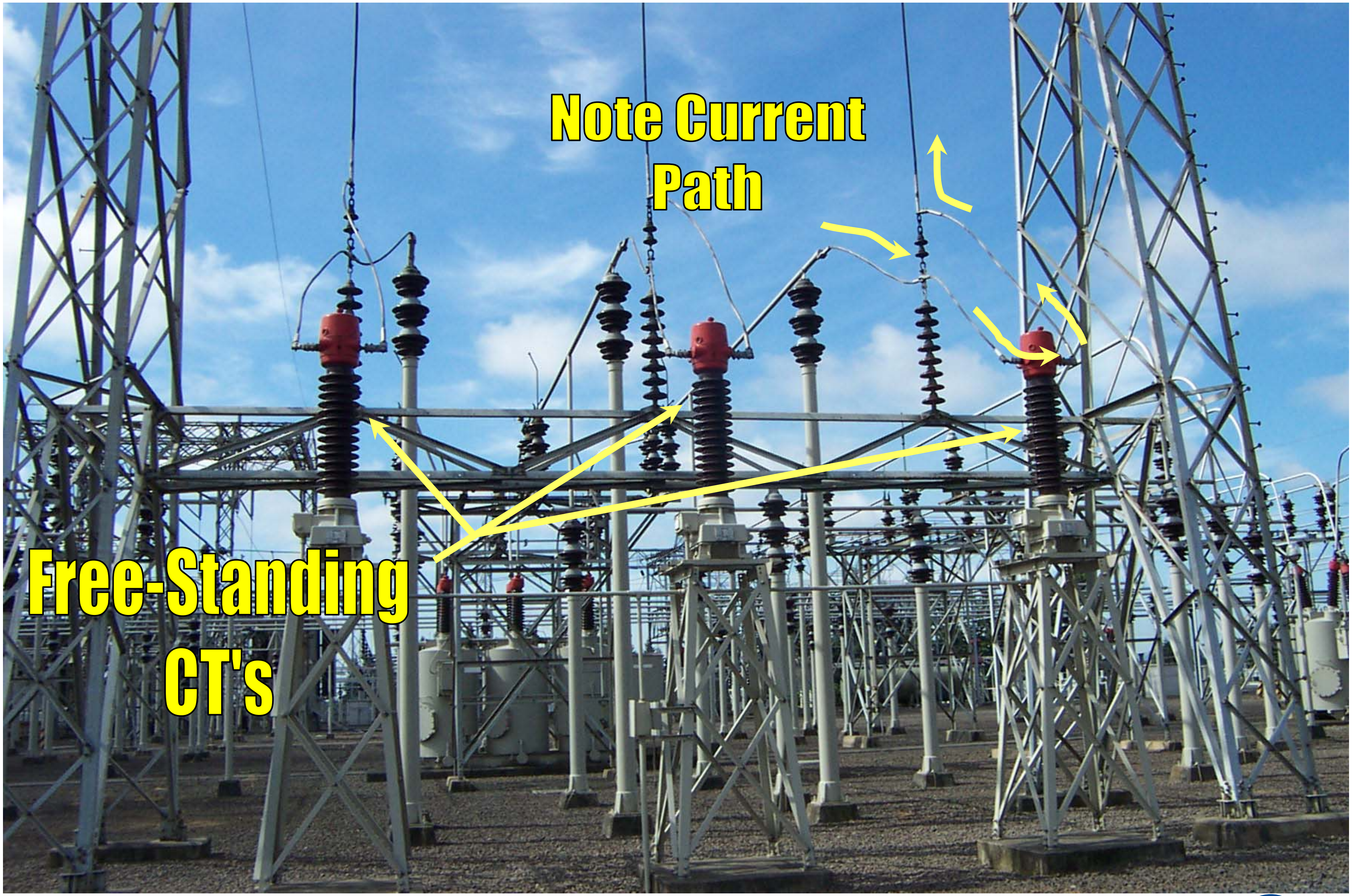
- For learners to increase their knowledge level of Current Transformers in the following areas:
  - Basic Theory
  - Application
  - Terminology
  - Safety Hazards
  - Safe Work Practices

Disclaimers:

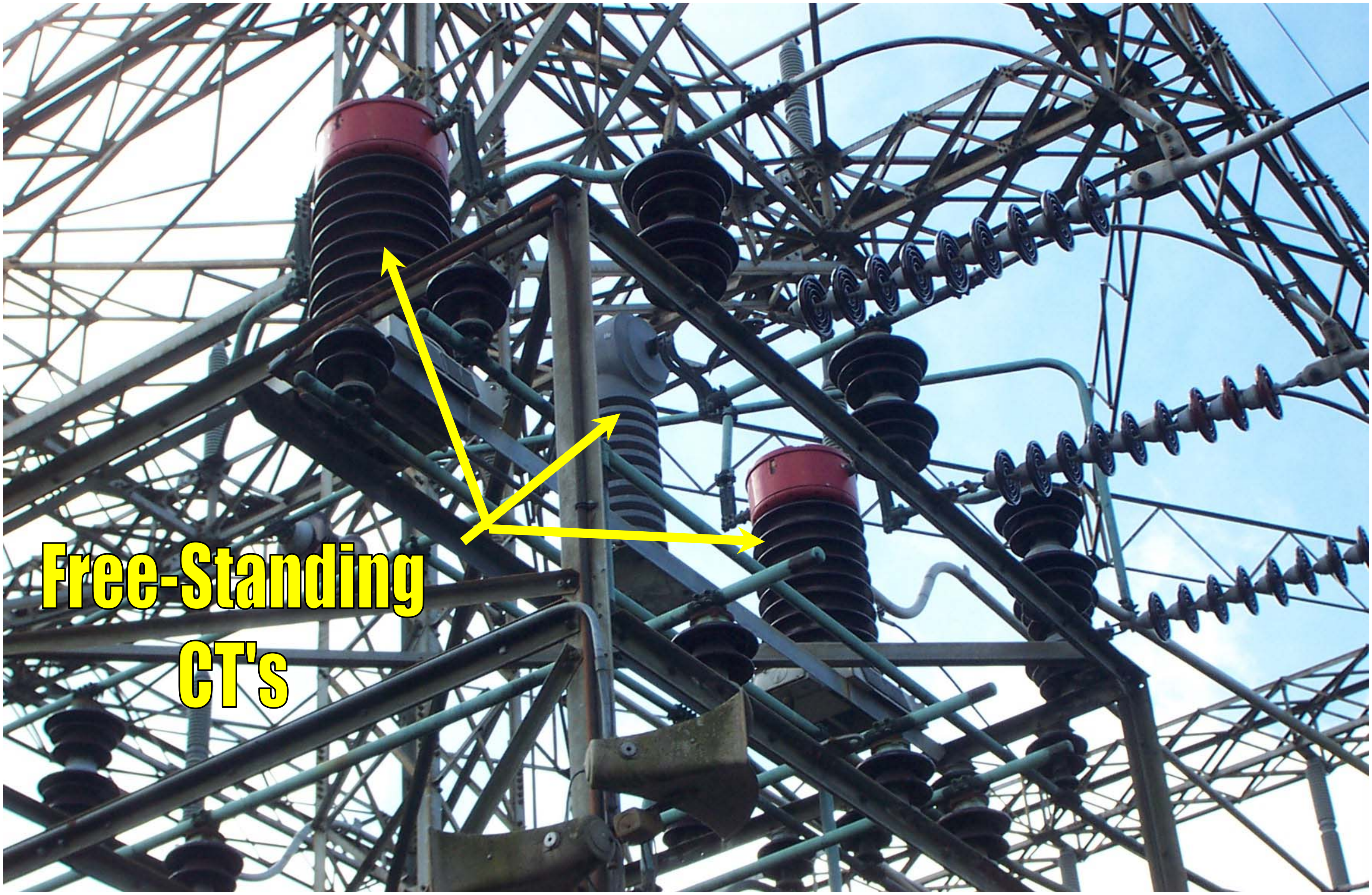
- Though this presentation was created for the Hands-On Relay School, much of the content was originally developed specifically for BPA.
  - Your company's standards and work practices will probably differ from some of those shown in the presentation.

- It should also be noted that the developer of this presentation is a System Protection and Control Craftsman / Relay Tech, not a Protection Engineer.
  - Content for this presentation is basically designed by and for relay technicians and the associated theory is at a corresponding level.

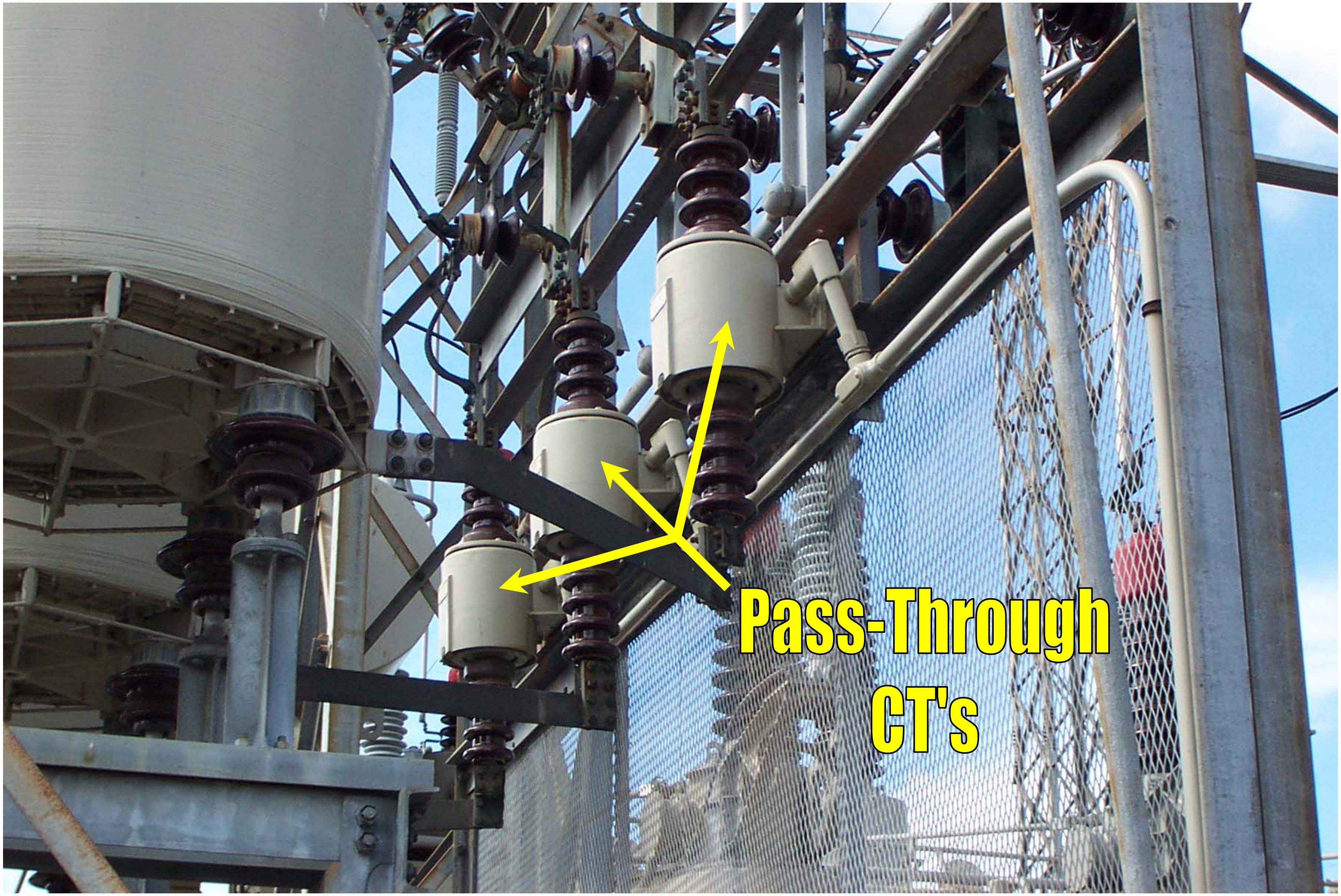
Examples of CT's



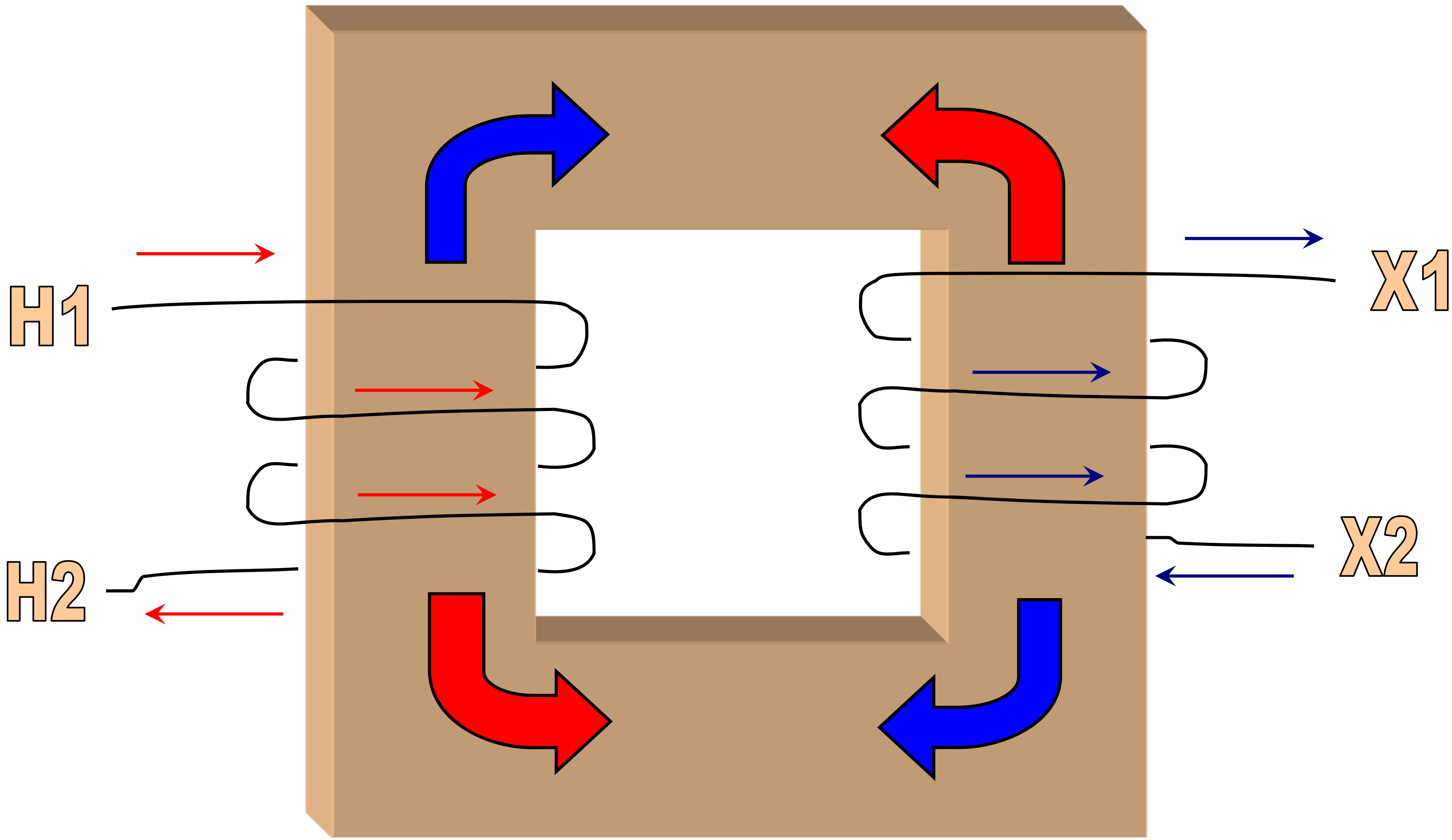
Examples of CT’s



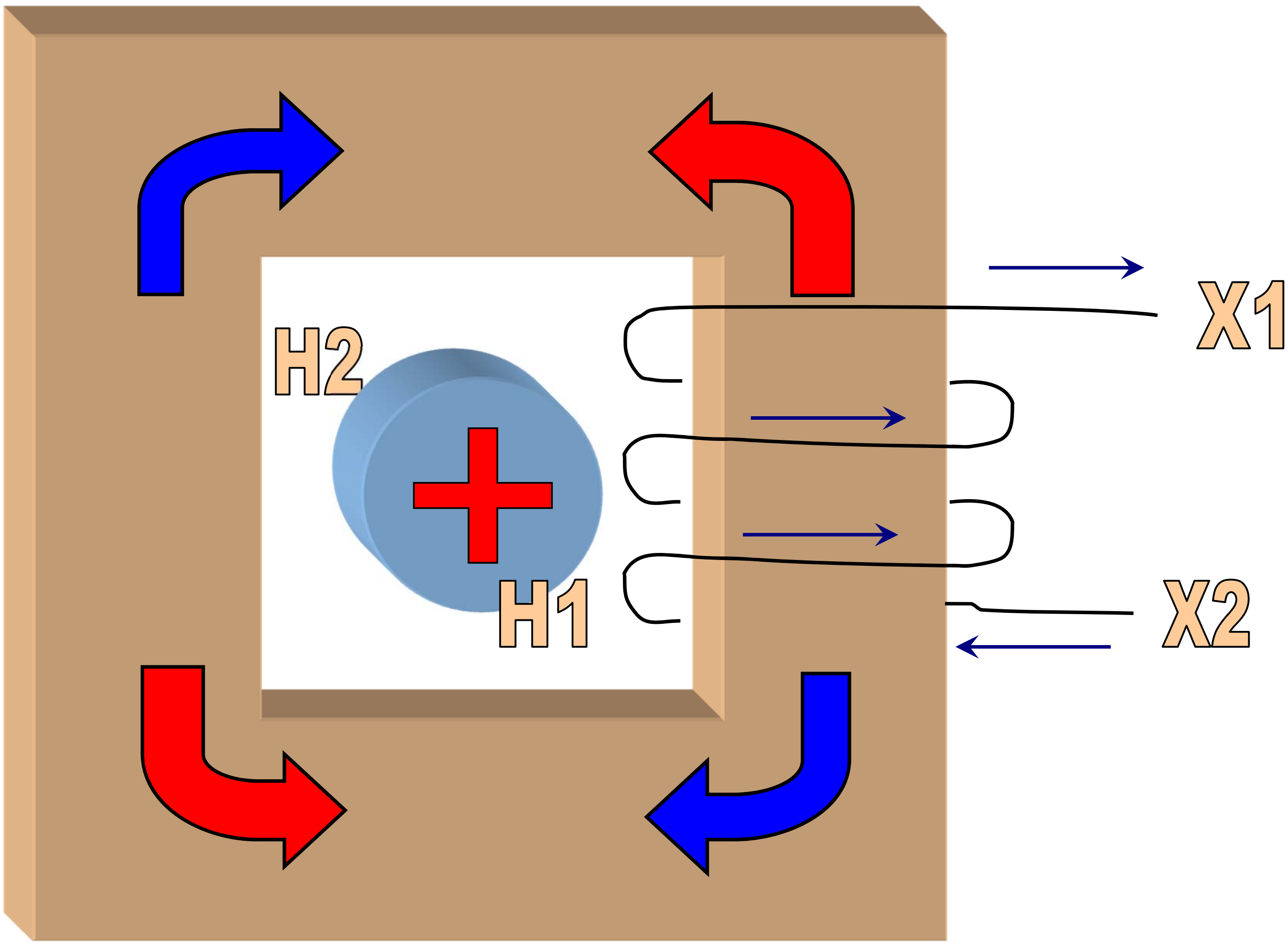
Examples of CT's



Examples of CT’s

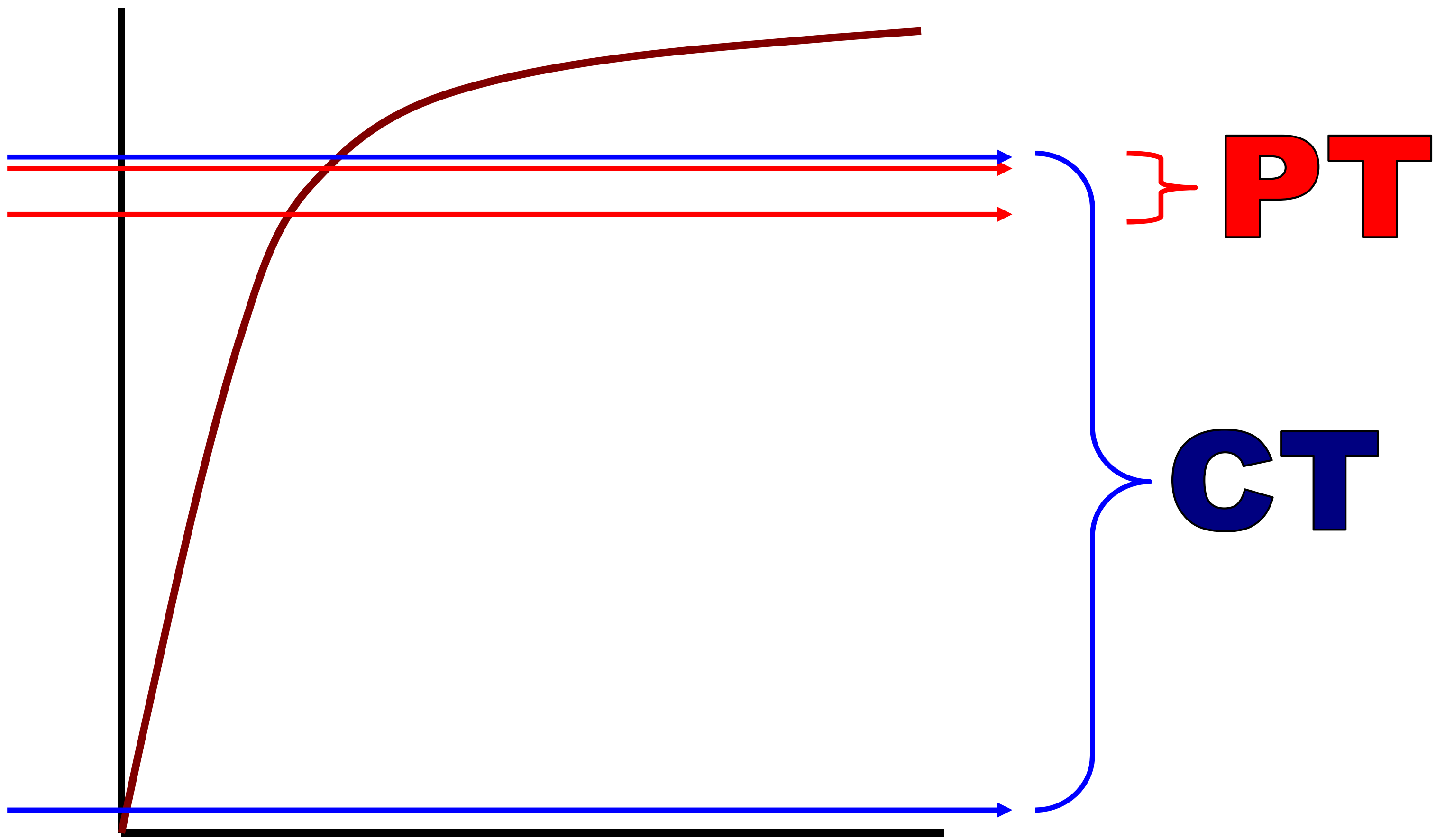


CT as a Voltage Transformer

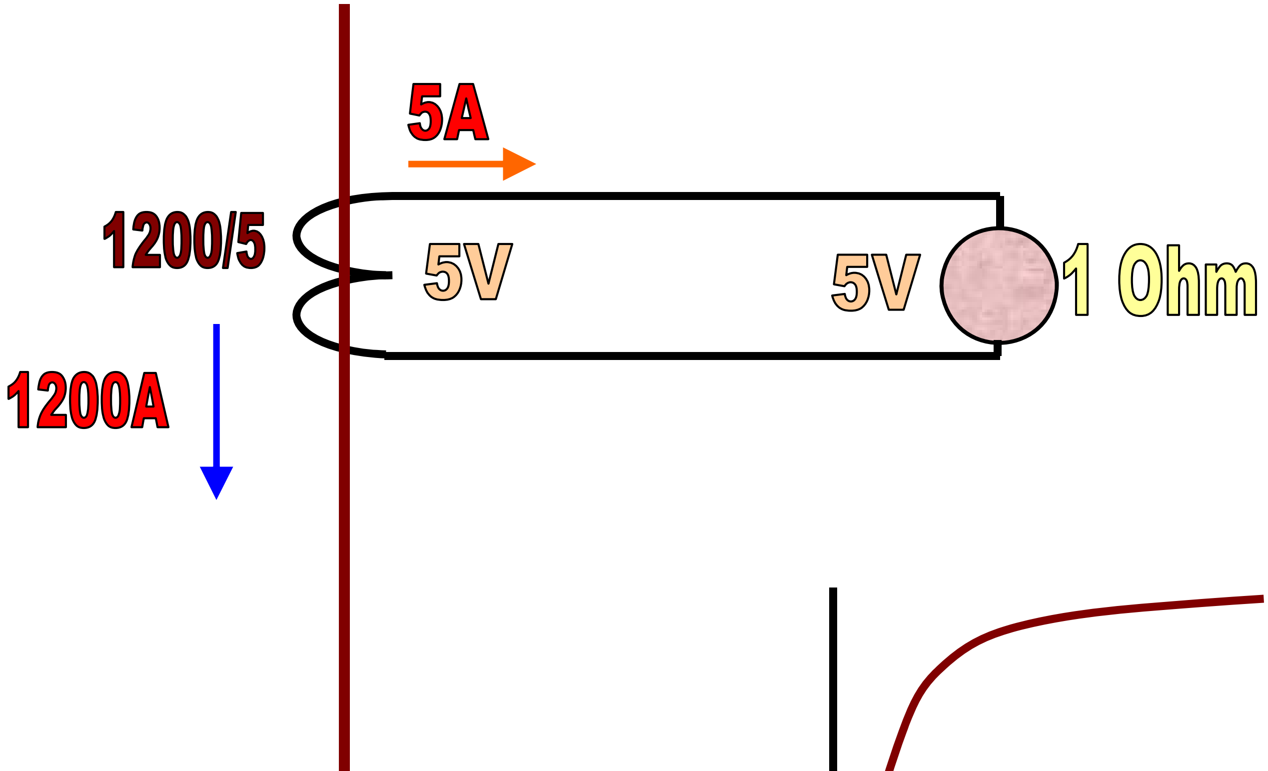


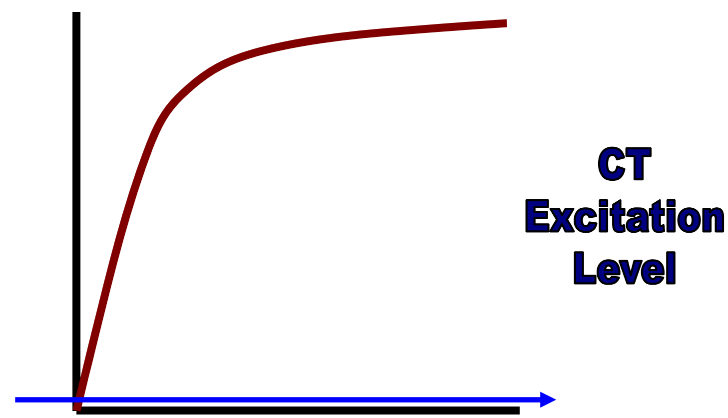
CT as a Voltage Transformer

Working Range of (relative) flux levels on core:

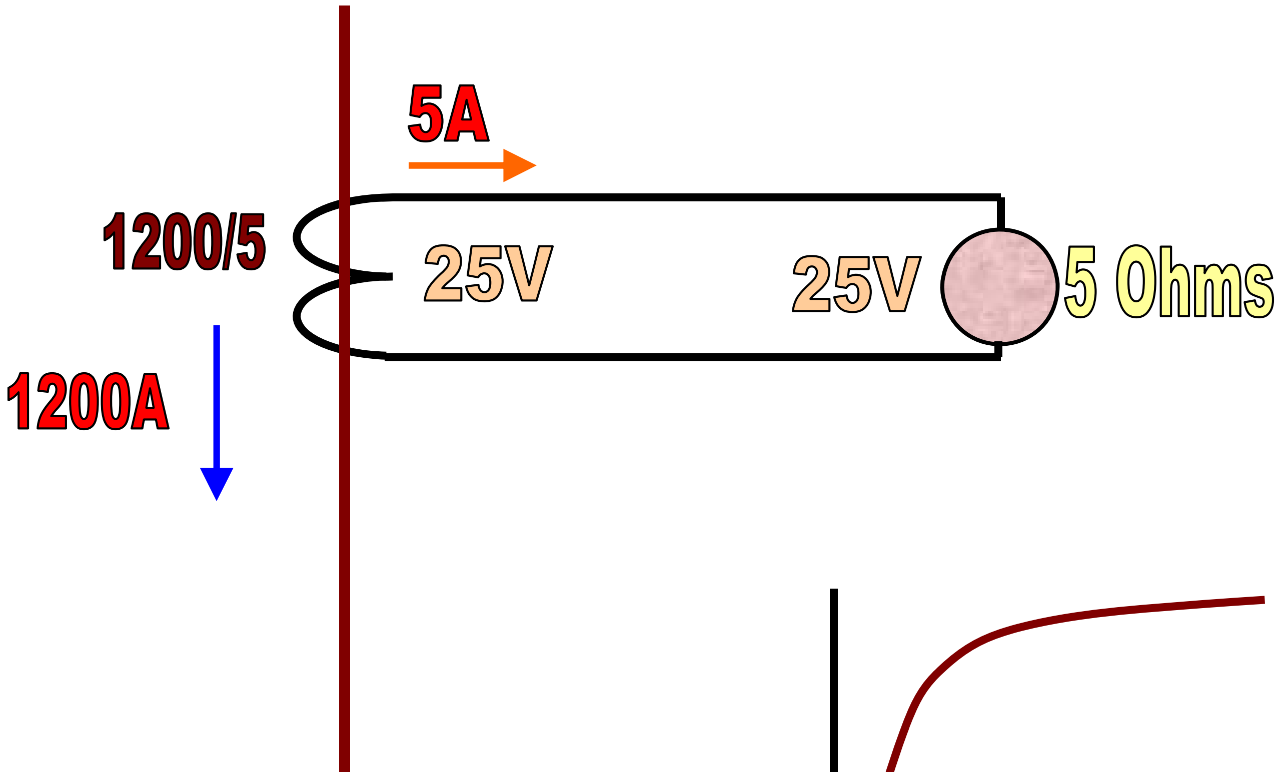


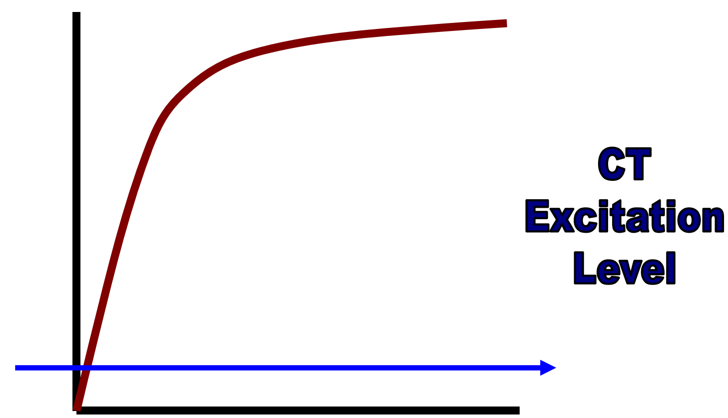
Saturation Curves



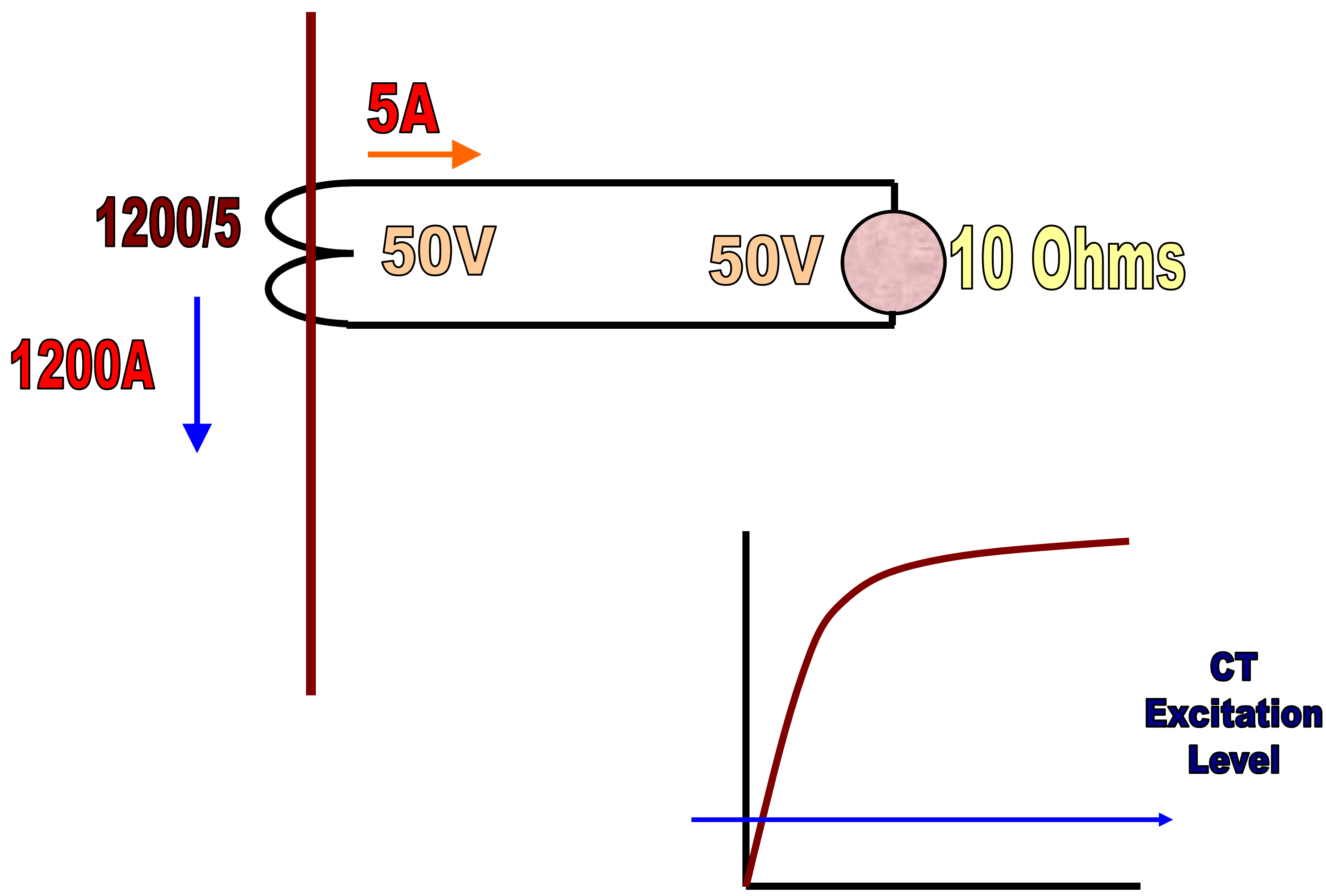


CT with varying burden

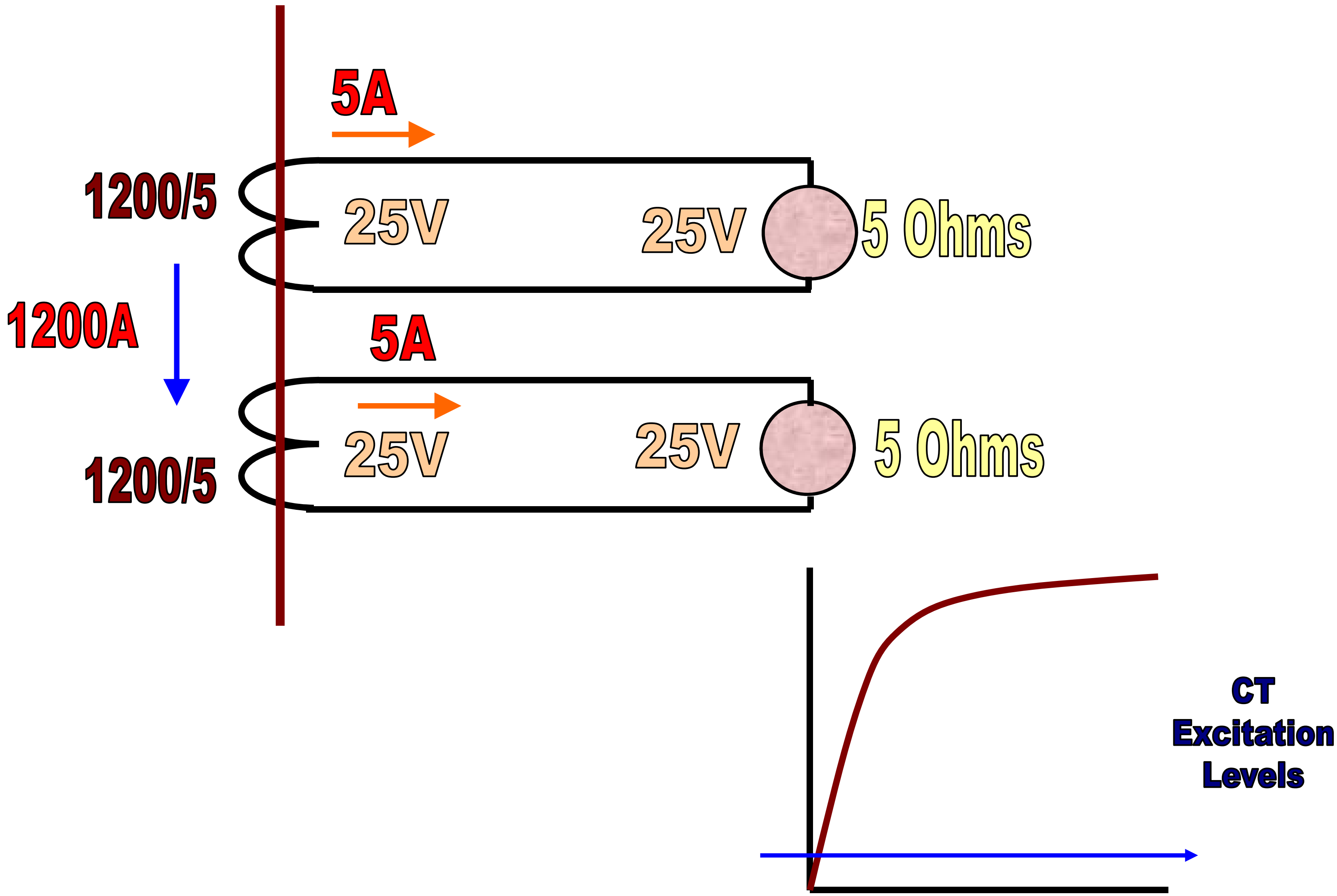




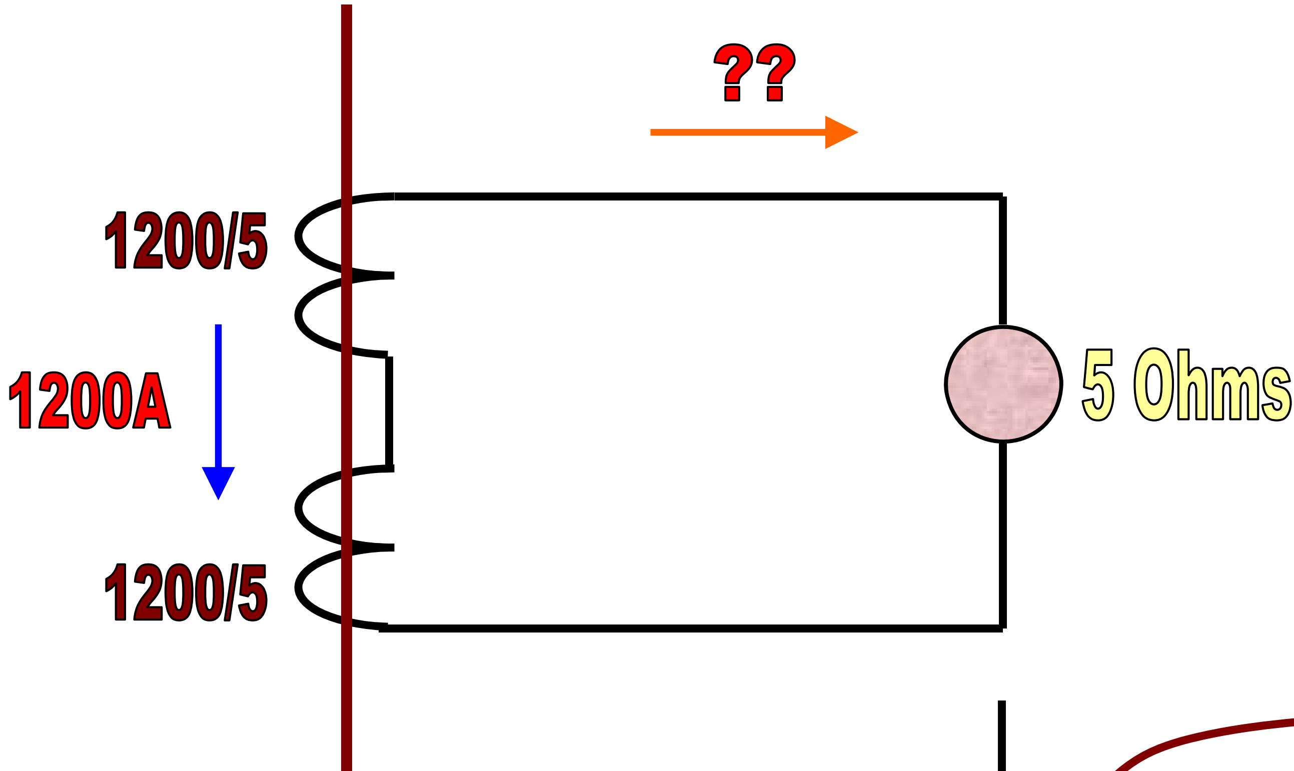
CT with varying burden

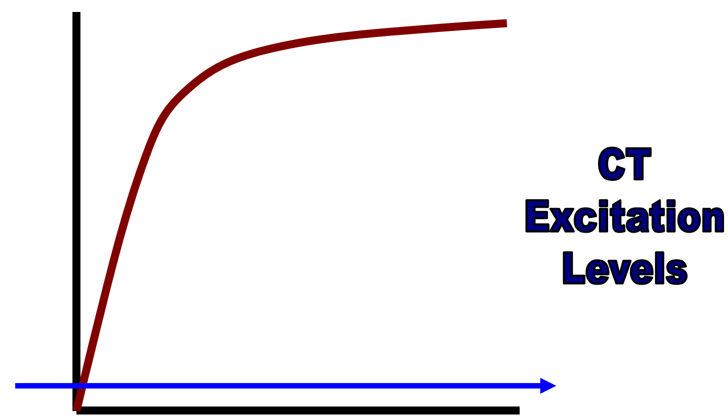


CT with varying burden

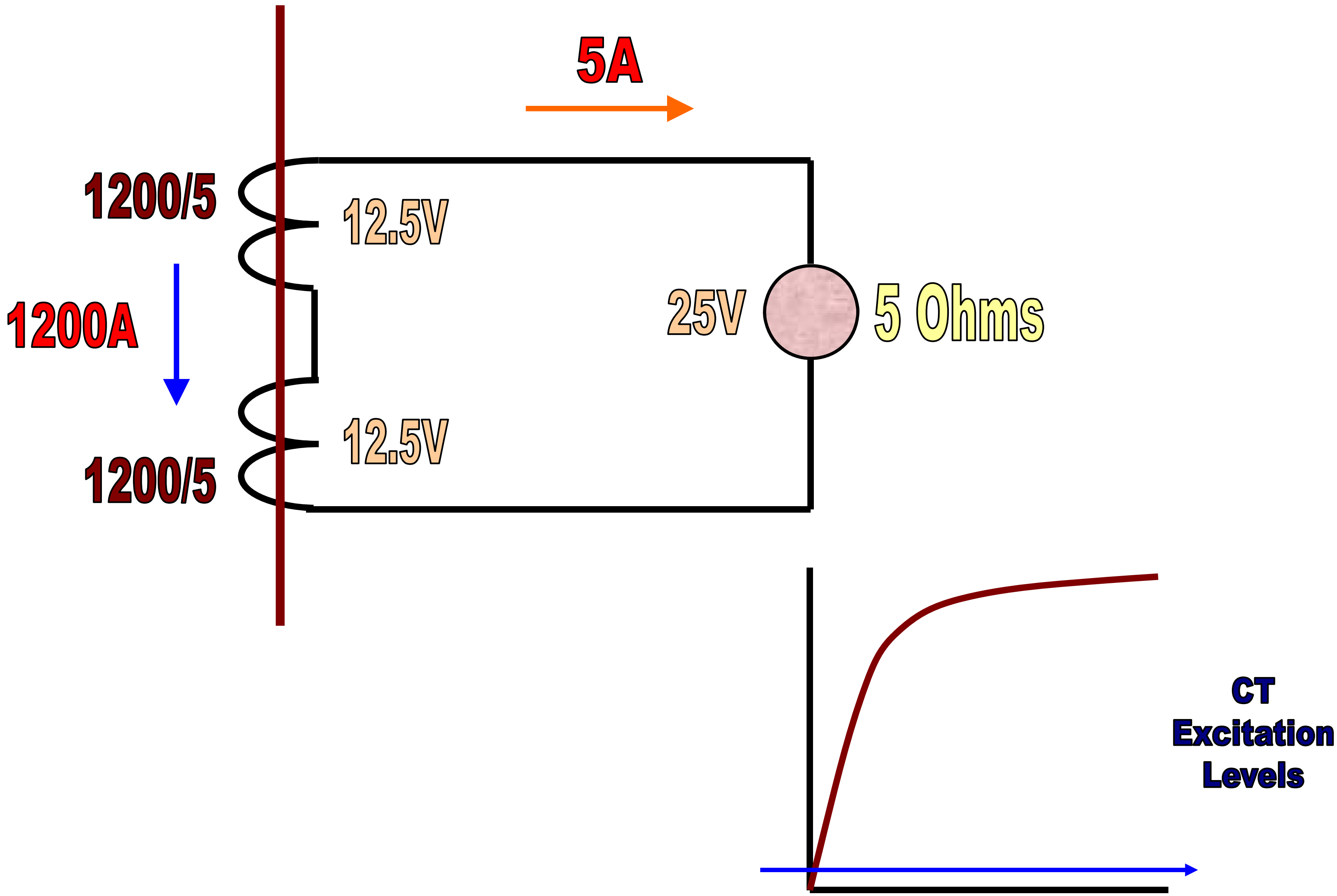

5A
1200/5
25V
25V
5 Ohms
1200A
5A
25V
25V
5 Ohms
1200/5
CT
Excitation
Levels

Single CT's

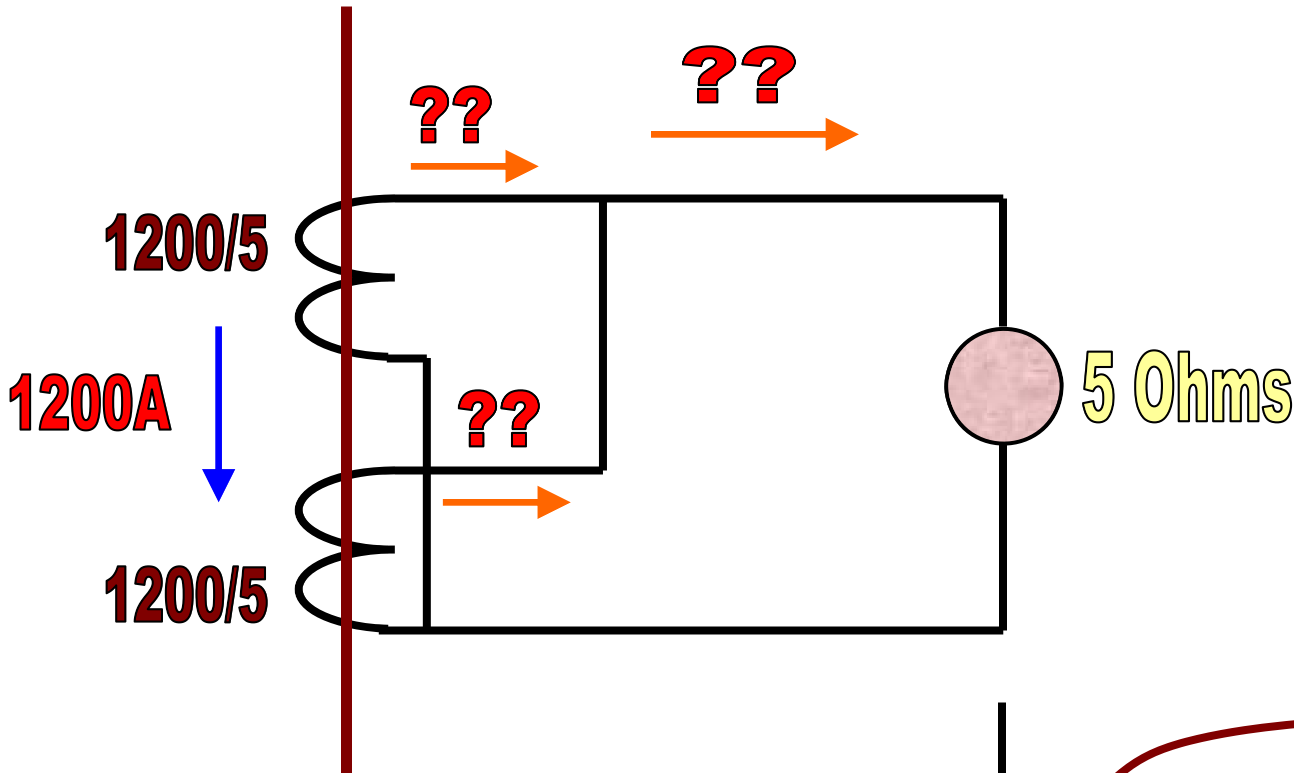


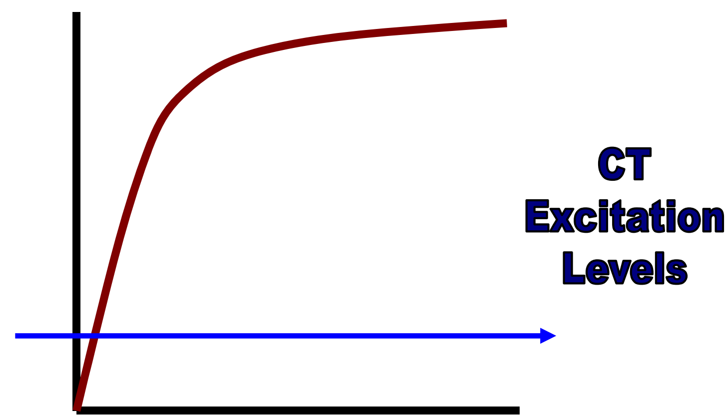


CT’s in Series

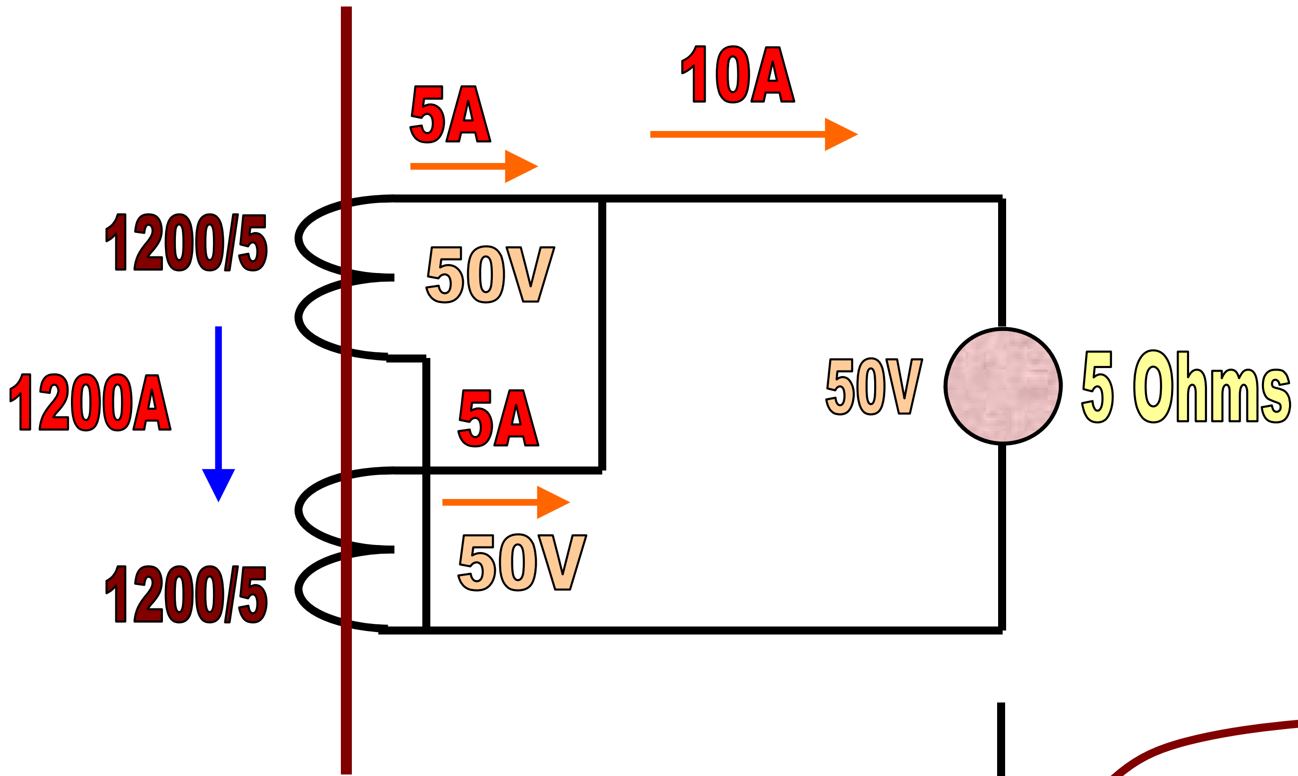


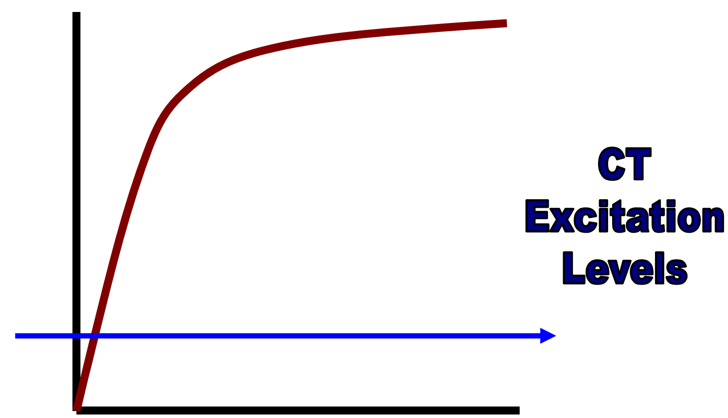
CT's in Series





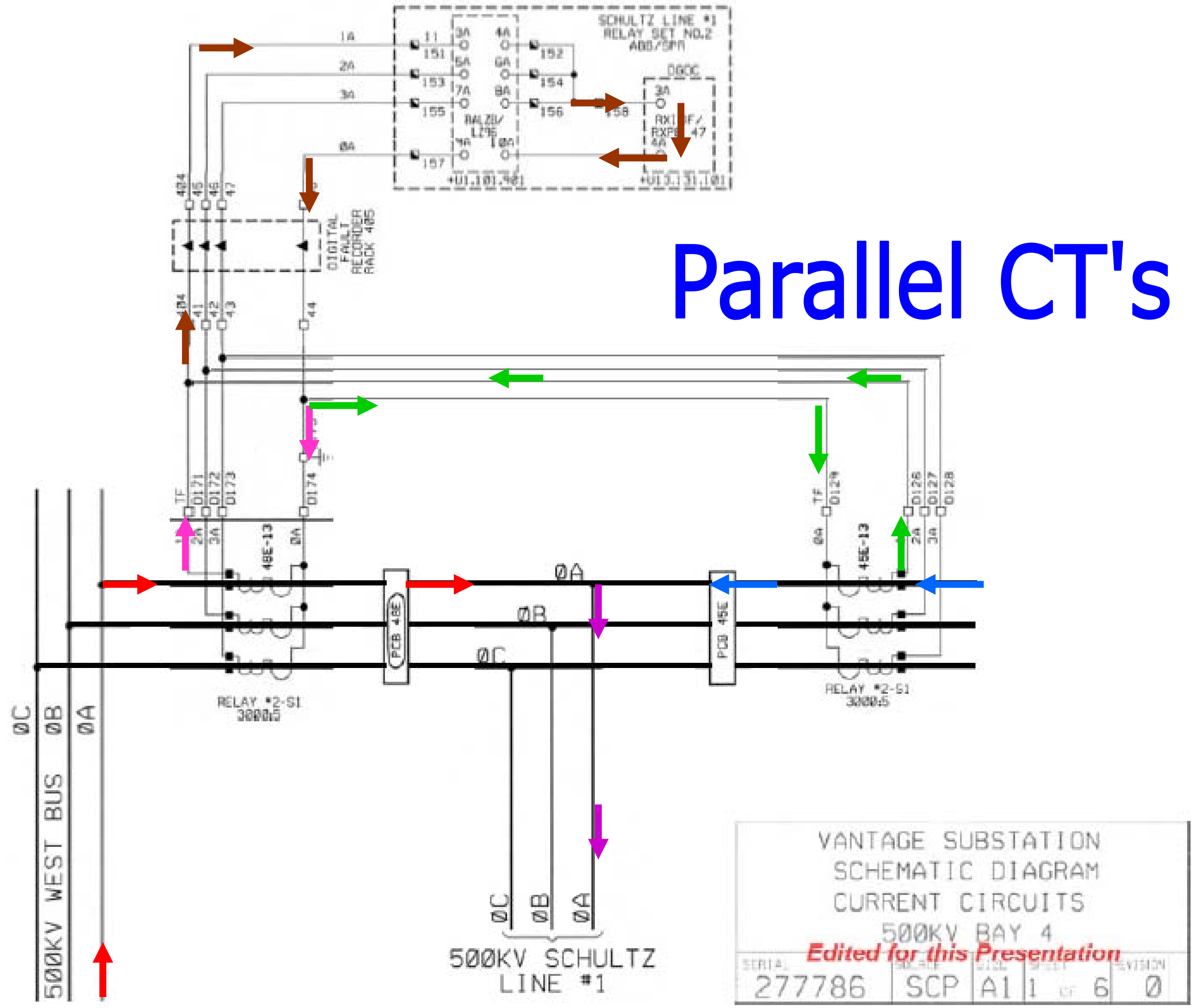
CT’s in Parallel

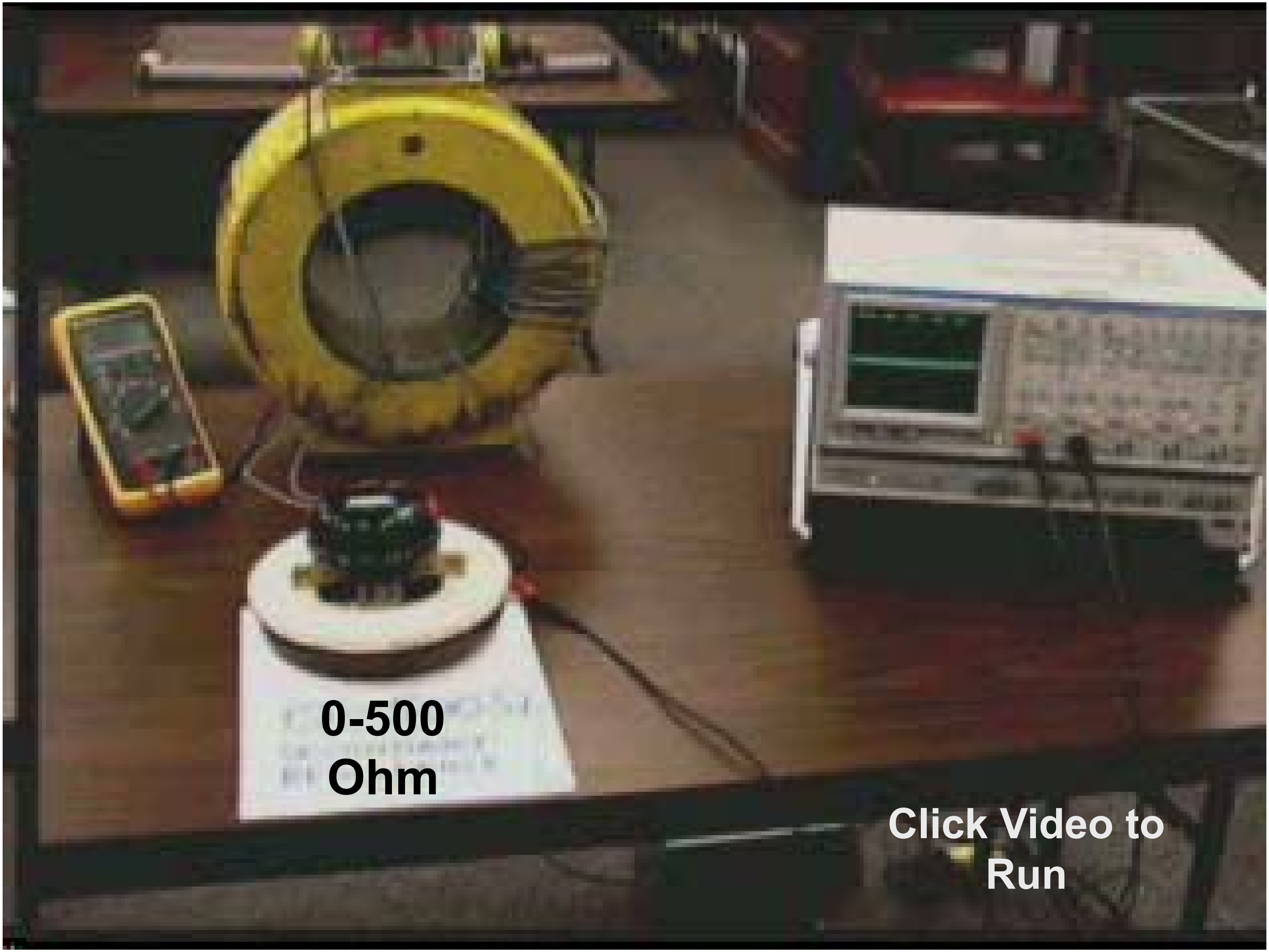


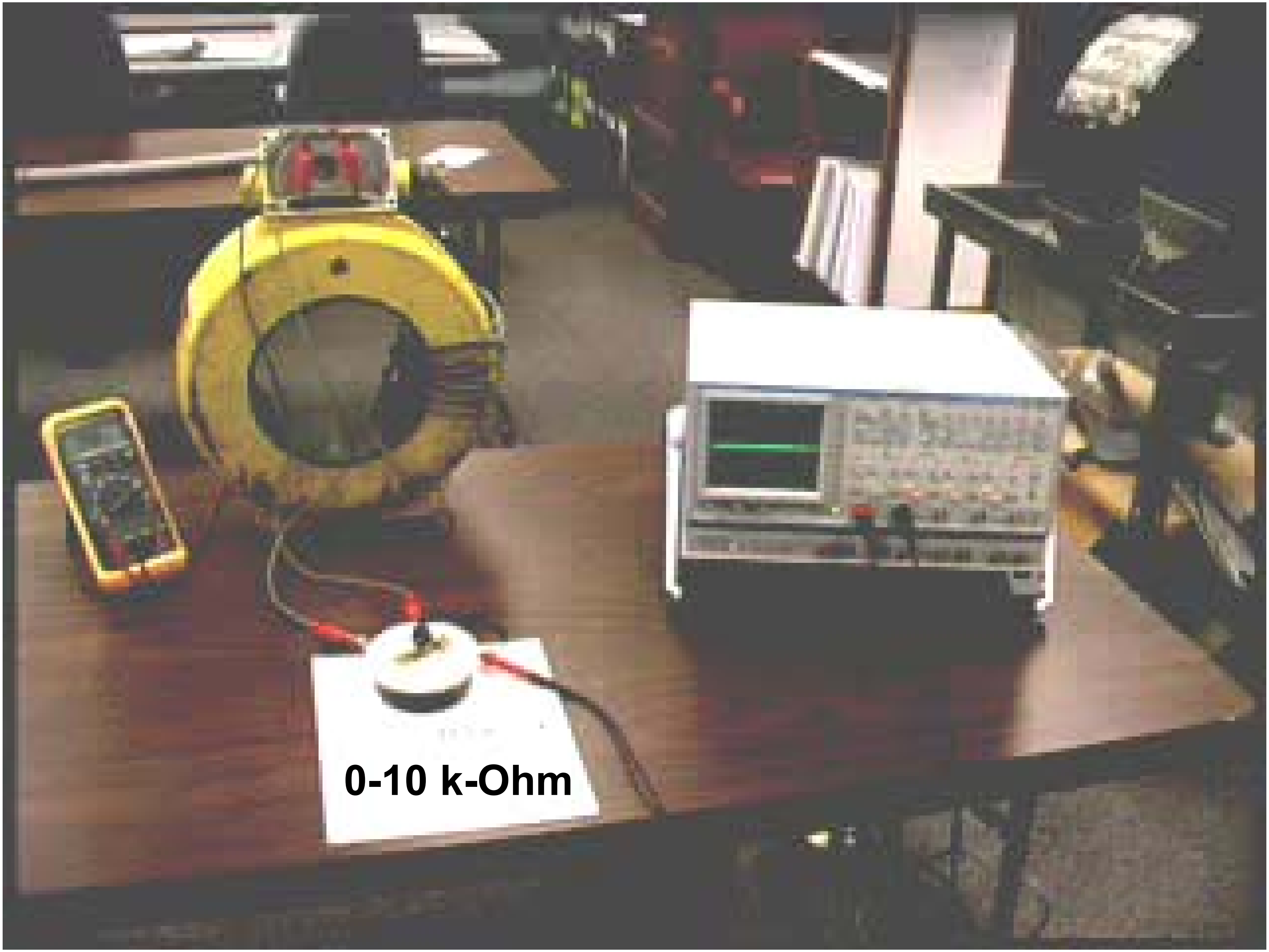


CT's in Parallel

Parallel CT's



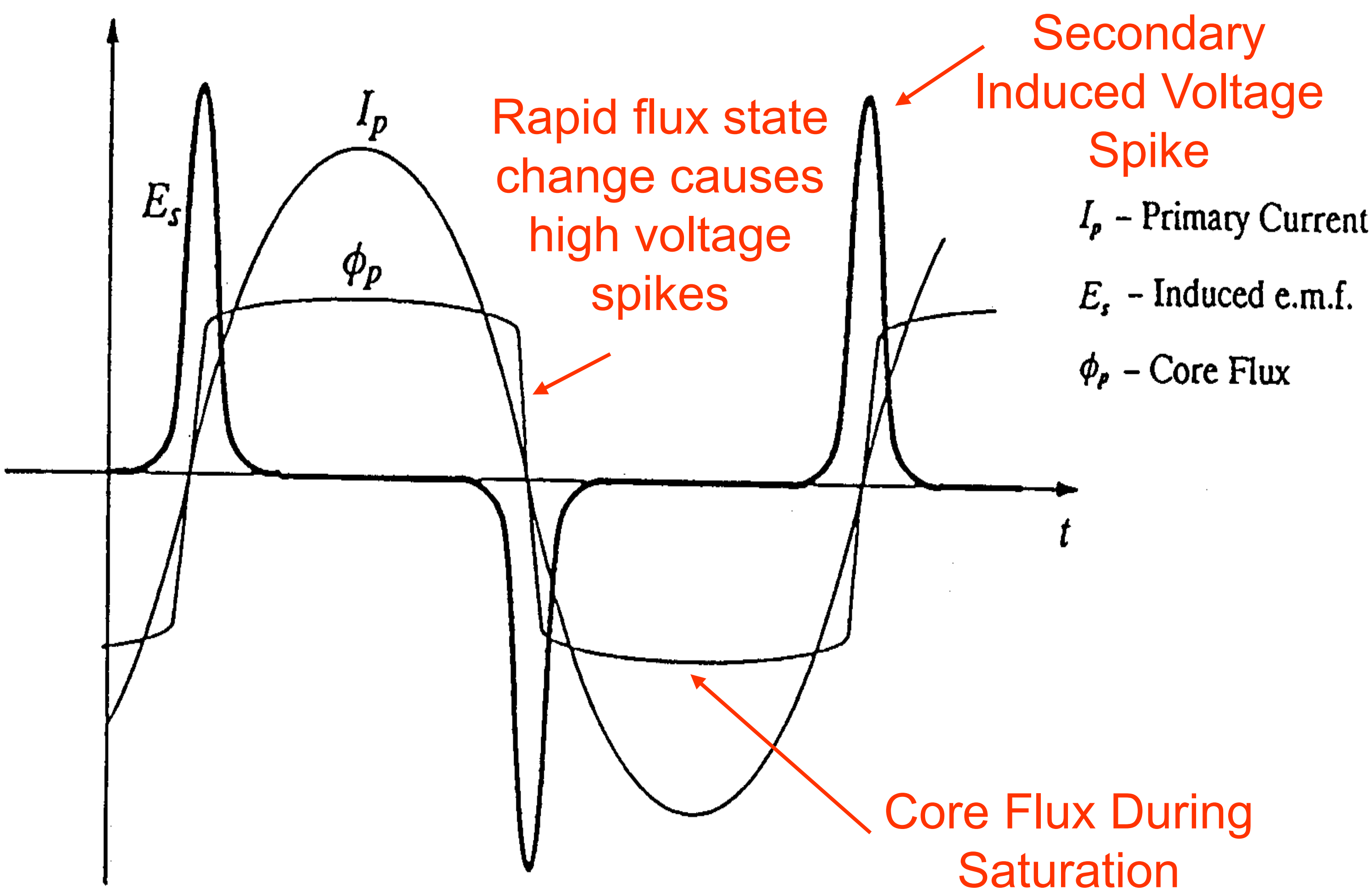

0-500
Ohm
Click Video to
Run


0-10 k-Ohm

- As the secondary burden increases the transformer excitation voltage also increases above the normal level.

- If the secondary burden increases enough, the core will saturate.

Secondary open circuit wave shapes



CT's with large inductance and a high number of turns produce the highest open-circuit secondary voltages.

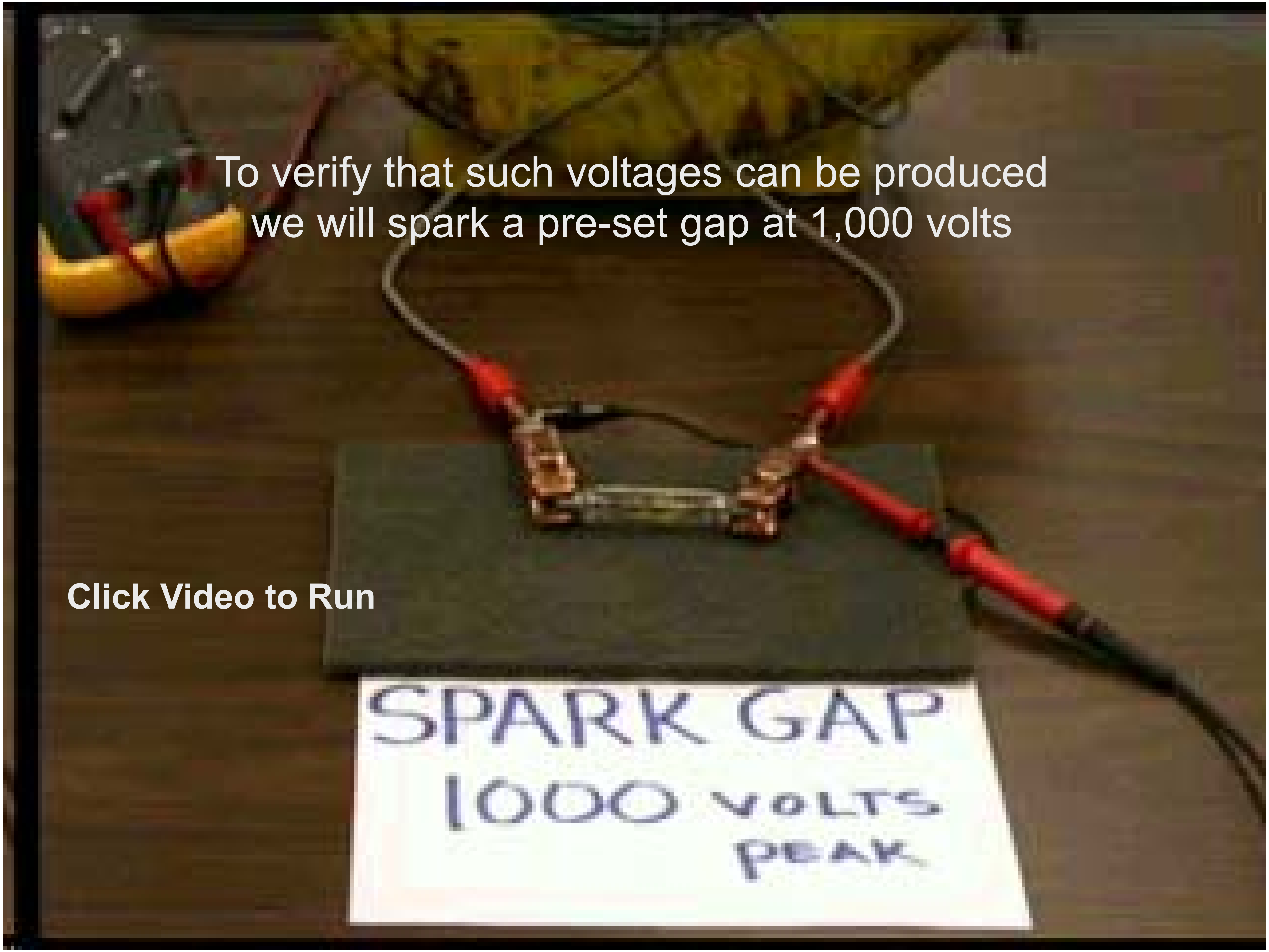
Oil filled 500kV

Bushing CT 345kV

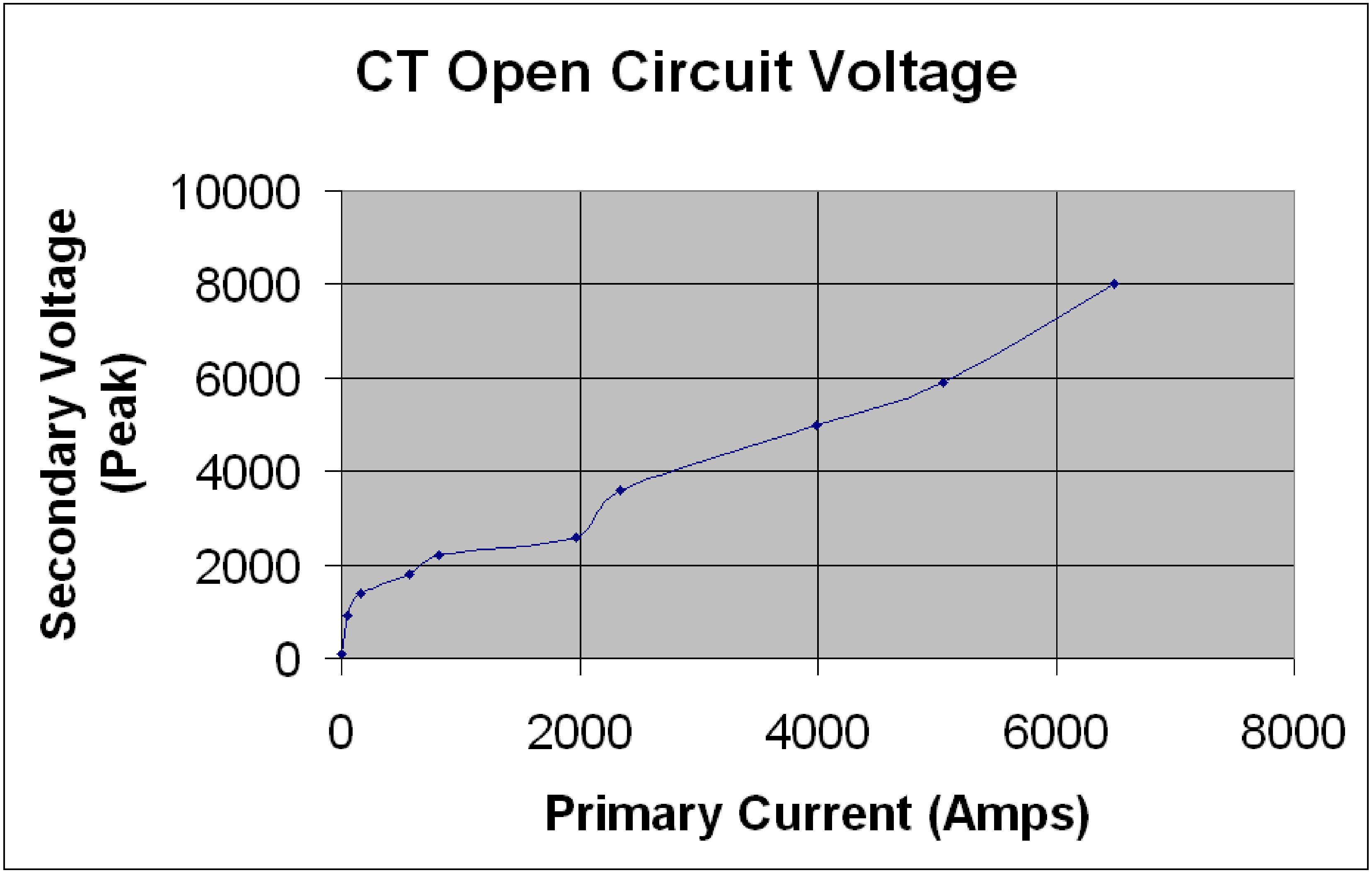
- CT's on a transmission or distribution system can be very large, have very high turns ratios, and can produce very high voltages on the open circuited secondary.

- <u>High voltages can be generated even with low levels of primary current.</u>

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 BPA Mangan Lab - 7/16/02.
Note: Test Data are approximate values combined from two consecutive test runs.
- Added V/A Column 8-02 (SJL); formatting change (6-03).

CT Open Circuit Voltage Test

7-16-02 Ron Denis / Steve Laslo

BPA Lab Data

Primary Current (Amps)	Secondary Output Voltage (V_{PEAK})	V_{PEAK} / Amp	Comments
5	110	22	Sine Wave
49	900	18.37	Slight Distortion
167	1400	8.38	Marked Distortion
567	1800	3.17	
813	2220	2.73	Saturated – CT making significant noise
1967	2600	1.32	
2337	3600	1.54	Fully Saturated – Waveform primarily consisting of Voltage Spikes
3987	5000	1.25	Higher, Narrower Spikes
5047	5900	1.17	
6487	8000	1.23	CT noise level very high Waveform extremely peaked

Safety:

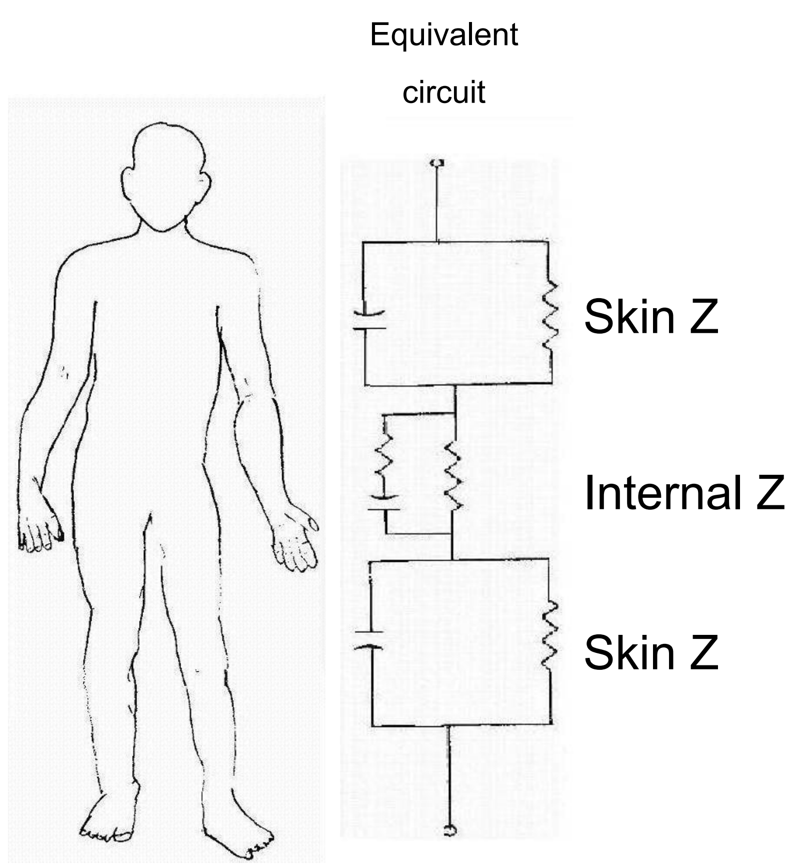
The voltage generated by an open-circuit CT can puncture human skin. If that happens your equivalent body resistance will be approximately 500 ohms or less.

The following slides (26-35) taken and modified with permission from Ron Denis presentation to the Western Energy Institute on '*Power Utility Induced Voltage and Current – Safety Concerns*' (11/06).

What current will a CT drive through your body?

Factors affecting physiological effects of electric shocks

- **The electrical impedance of the human body**
- **The frequency and magnitude of current**
- **The current pathway**
- **The duration of current flow**

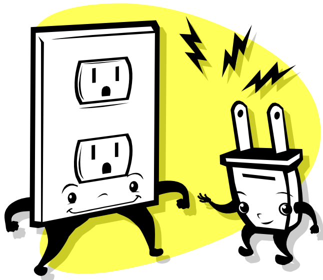


The Terminology of Shocks

As current level increases, people will experience:

- Threshold of perception (feel something)
- Threshold of let go (can't let go)
- ❤ Threshold of ventricular fibrillation (heart fibrillation)

These thresholds vary by individual, mainly dependent on body mass and impedance.



DC, AC, Frequency

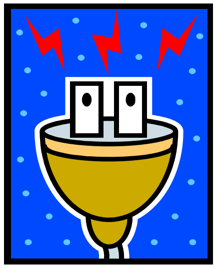
- Generally DC current is less dangerous than low frequency AC current (50-60HZ).
  - Hence, the argument proposed by Thomas Edison against the use of AC by George Westinghouse and Nikola Tesla.
- High frequency currents are also less dangerous because of the pathways of current flow and the apparent impedance of the body.
- Threshold of ventricular fibrillation is about 15 times higher at 1000HZ than at 60HZ. Higher frequencies (>1000HZ) have ever increasing levels of perception, let go, and fibrillation.

This discussion focuses on 60 HZ effects.

Various sources define the approximate levels for 60HZ currents

Source	1	2	3	4	5
Perception	1mA	0.7-1.1mA	1-2mA	0.5mA	1mA
Let go	15mA	10.5 - 16mA	10mA	10mA	9-30mA
Possible fibrillation	80mA	100mA (duration 3sec)	100 - 150mA	<100mA (duration >1sec)	50 - 150mA

1. Merck Manual
2. IEEE Salama and Hackman
3. Salt River Project
4. IEC 479
5. OSHA



The Physiological Effects of Electrical Current

- Muscle pain, seizures
- Respiratory arrest
- Ventricular fibrillation
- Central nervous system injury
- Neurological injury
- Renal injury (Kidneys)
- Burns
- Gastrointestinal injury
- Blunt injury
- Ophthalmic injury (Eyes)
- Infection

Punctured Skin Effects

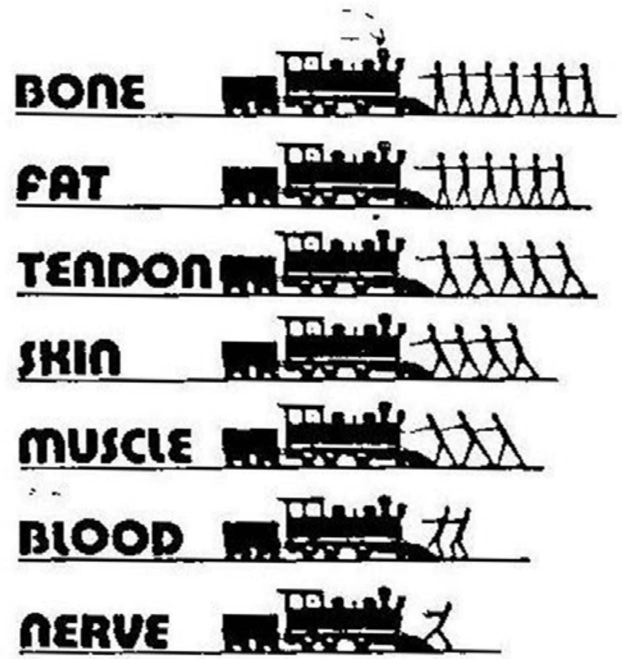
- High voltage shocks are especially dangerous because of a lower "punctured" body impedance. Punctured skin impedance of the body is often assumed to be 500Ω. So the electric chair seemed to be designed to puncture the skin with high voltage, then send current through the 500Ω subject.

- **"Westinghoused" in the electric chair**
  - **1725 volts for 10 seconds 60HZ**
  - **240 volts for 90 seconds 60HZ**

BPA Central Safety and Health Committee

Relative Resistance of Human Body Elements

RELATIVE RESISTANCE TO FLOW OF CURRENT
DECREASING ORDER



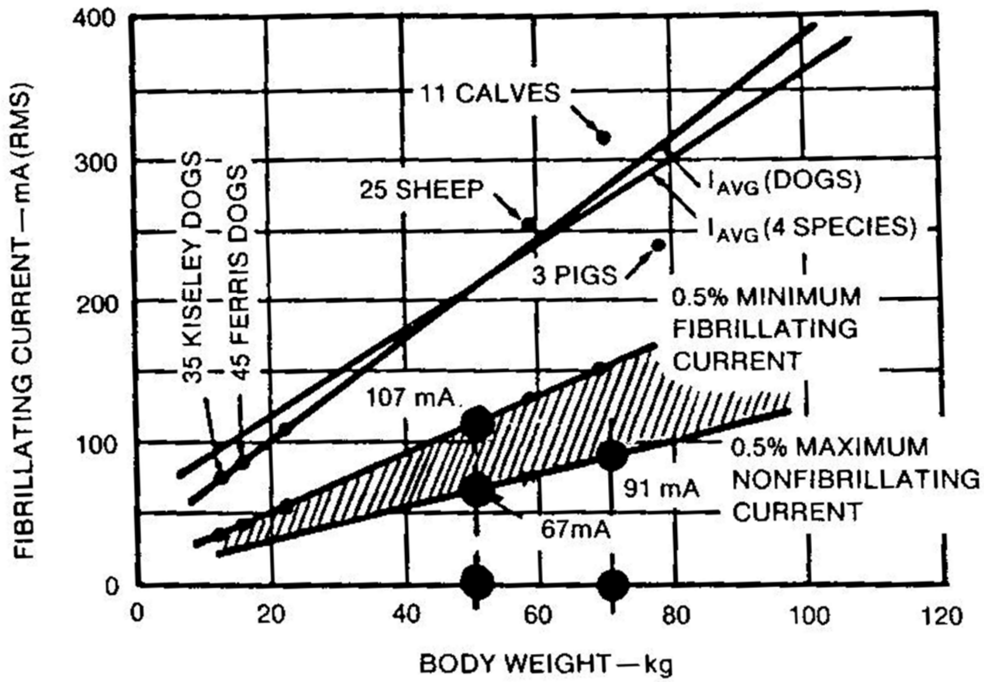
DIFFERENTIAL RESISTANCE

HEAVILY CALLOUSED HAND = 1,000,000 OHMS RESISTANCE

AVERAGE SKIN RESISTANCE = 5000 OHMS RESISTANCE

MOIST SKIN = 1000 OHMS RESISTANCE

Fibrillating Current Versus Body Weight for Various Animals Based on a Three-Second Shock



$I_B = 0.157/\sqrt{t_s}$ for 70 kg body weight

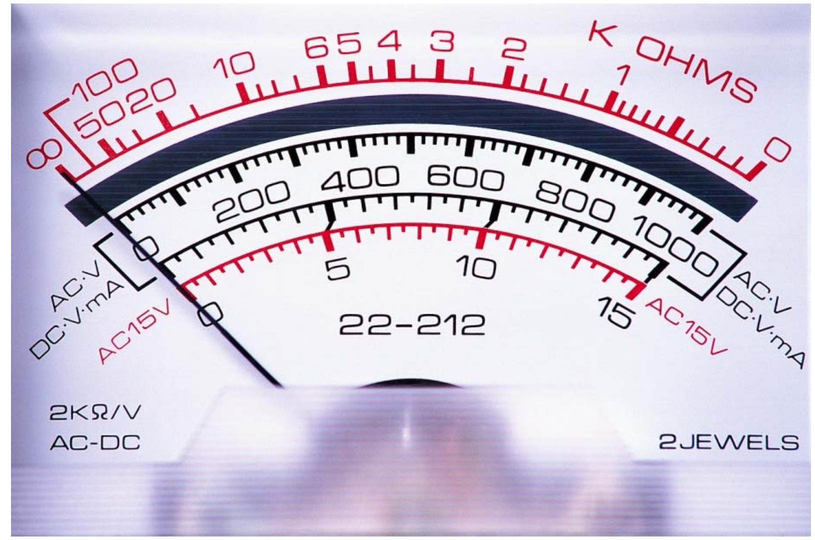
- Statistical Bottom Line: A 154lb body has a 1/44 chance (2.3%) of fibrillation with a 3 second 100mA current.

IEEE 80

Christensen, et. al. 1980.

Effects of Electric Current in the Human Body

Current	Reaction
Below 1 milliampere	Generally not perceptible
1 milliampere	Faint tingle
5 milliamperes	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6–25 milliamperes (women)	Painful shock, loss of muscular control*
9–30 milliamperes (men)	The freezing current or "let-go" range.* Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated.
50–150 milliamperes	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000–4,300 milliamperes	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000 milliamperes	Cardiac arrest, severe burns; death probable

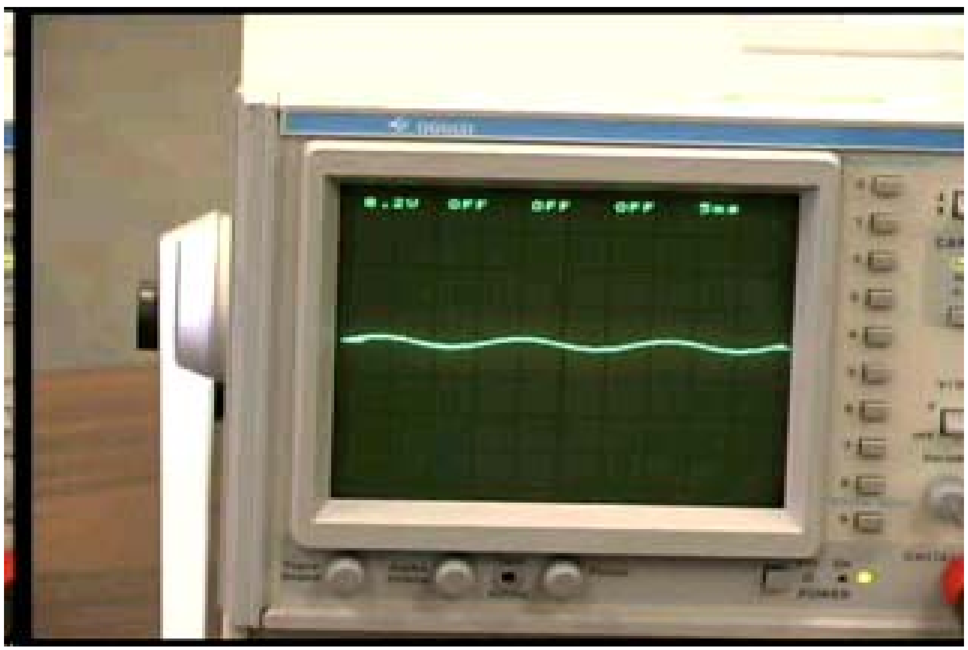


Taken from OSHA website:

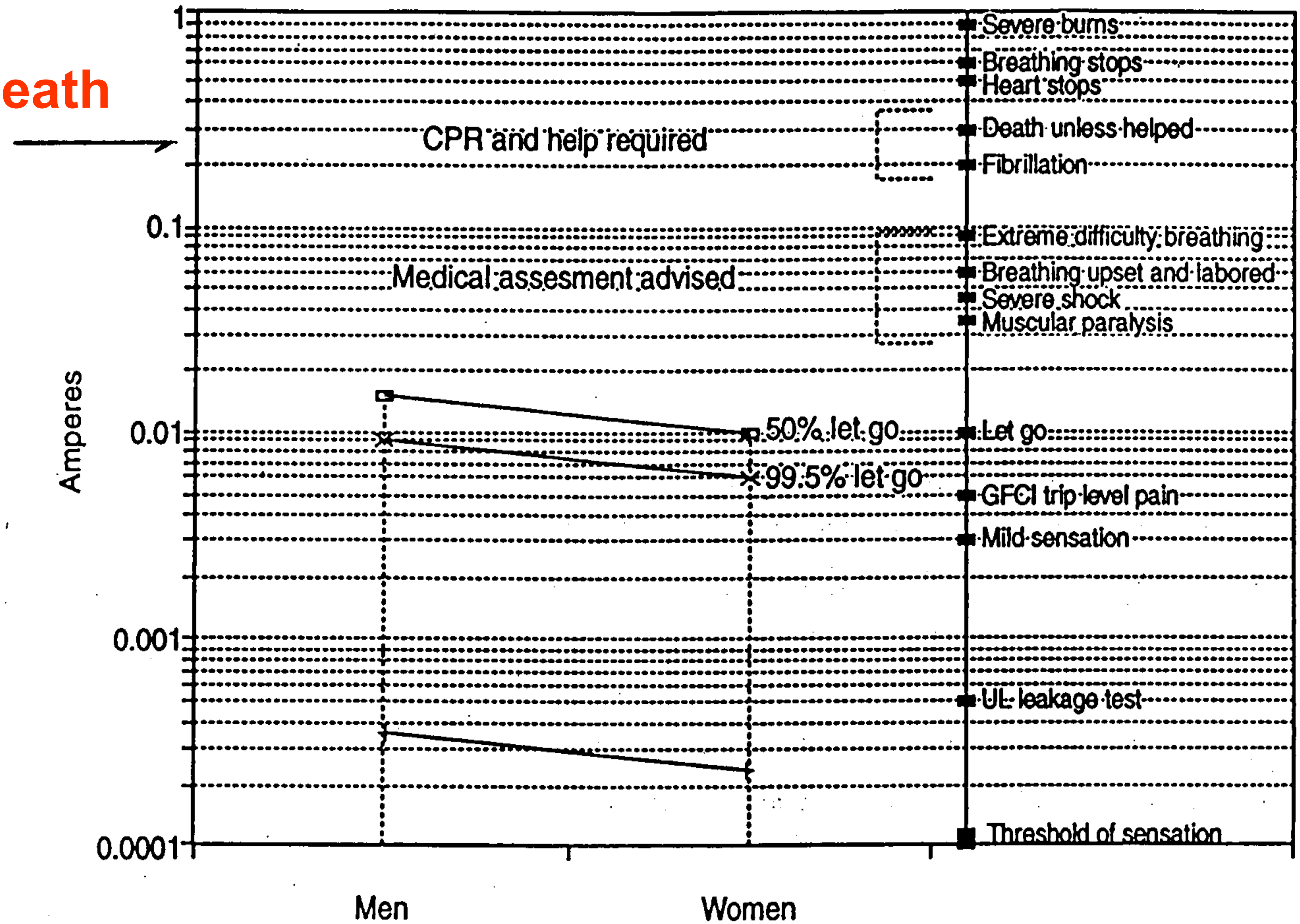
http://www.osha.gov/Publications/osha3075.pdf

What if Your '500 Ohm' Body becomes the CT Burden?

We saw earlier that when using the 500 ohm resistor, the secondary current remained at the same current level that existed before the burden was increased. For a CT rated 2000/5, modest bus current of 500 amps could produce 1.25 amps through a human body - or over 10 times that needed to cause death!



Death



A CT can easily supply currents above lethal levels!

The open circuit situation resolves to high voltages and lethal currents… WATCH THIS!!

CT Accuracy Classifications

ORDERING INFO FOR LG-15-6513				
Ratio	Catalog Number*	Accuracy/Burden		Rating Factor
		Metering	Relay	
200:5	D040200S1	0.3 B0.2	C50	2.0
300:5	D040300S1	0.3 B0.5	C100	2.0
400:5	D040400S1	0.3 B0.5	C100	2.0
600:5	D040600S1	0.3 B0.5	C150	2.0
800:5	D040800S1	0.3 B0.9	C200	2.0
1000:5	D041000S1	0.3 B1.8	C250	2.0
1200:5	D041200S1	0.3 B1.8	C300	2.0
1500:5	D041500S1	0.3 B1.8	C300	2.0
2000:5	**D042000S1**	0.3 B1.8	C400	2.0
2500:5	D042500S1	0.3 B1.8	C600	2.0
3000:5	**D043000S1**	0.3 B1.8	C800	2.0
4000:5	D044000S1	0.3 B1.8	C800	1.5
5000:5	D045000S1	0.3 B1.8	C800	1.5
6000:5	**D046000S1**	0.3 B1.8	C800	1.0
8000:5	D048000S1	0.3 B1.8	C800	1.0
10000:5	D0410000S1	0.3 B1.8	C800	1.0
200/400:5	D040200D1	0.3 B0.5/B0.9	C100/C200	2.0/2.0
300/600:5	D040300D1	0.3 B0.5/B1.8	C200/C400	2.0/2.0
400/800:5	D040400D1	0.3 B0.9/B1.8	C300/C600	2.0/2.0
600/1200:5	D040600D1	0.3 B0.9/B1.8	C150/C300	2.0/2.0
1000/2000:5	D041000D1	0.3 B1.8/B1.8	C200/C400	2.0/2.0
1500/3000:5	D041500D1	0.3 B1.8/B1.8	C400/C800	2.0/2.0
2000/4000:5	**D042000D1**	0.3 B1.8/B1.8	C400/C800	2.0/1.5
3000/6000:5	**D043000D1**	0.3 B1.8/B1.8	C400/C800	1.5/1.0

HIGH ACCURACY LGX-15-6513			
Catalog Number	0.15/0.3 @ Burden	0.15/0.3 Acc Range	Rating Factor
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D040400X1	B0.5	400/4 to 1200A	3.0
D040600X1	B0.9	600/6 to 2400A	4.0
D040800X1	B0.9	800/8 to 3200A	4.0
D041000X1	B0.9	100/10 to 3000A	3.0
D041200X1	B0.9	120/12 to 3600A	3.0
D041500X1	B0.9	150/15 to 3000A	2.0
D042000X1	B0.9	200/20 to 4000A	2.0
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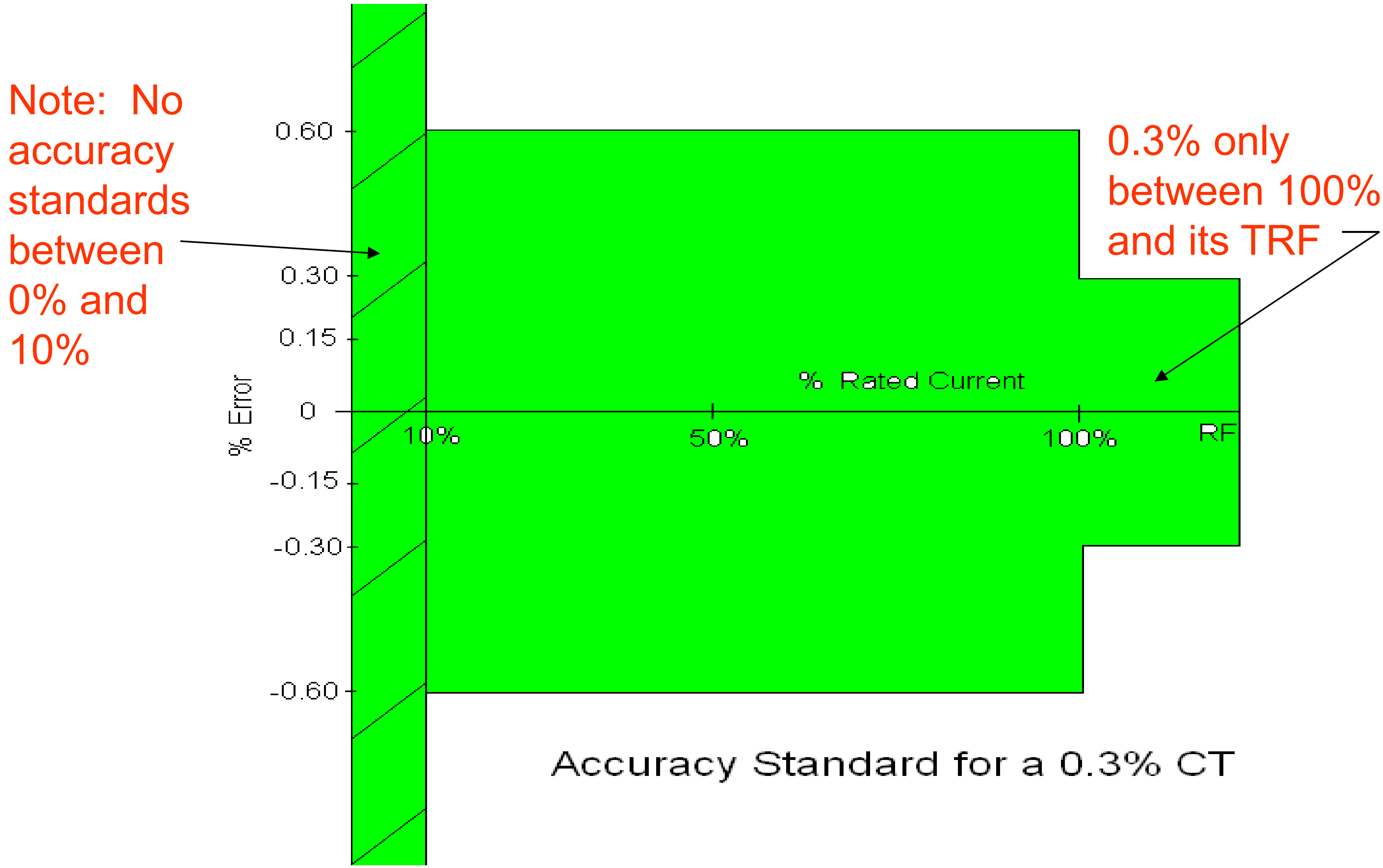
- Available in multi-ratio designs (full tap ratings same as single ratio above).
- 1 Second Thermal/Mechanical Rating: 80x full winding I_{nom} / Unlimited mechanical.

* **IC Approval (AE-1104) is noted by bold catalog number.**

From ABB/Kuhlman 15kV Instrumentation Brochure

Current Ratio	Catalog #	Meter Accuracy	Relay Accuracy	Rating Factor
1200:5	D041200S1	0.3 B1.8	C300	2.0

- 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.

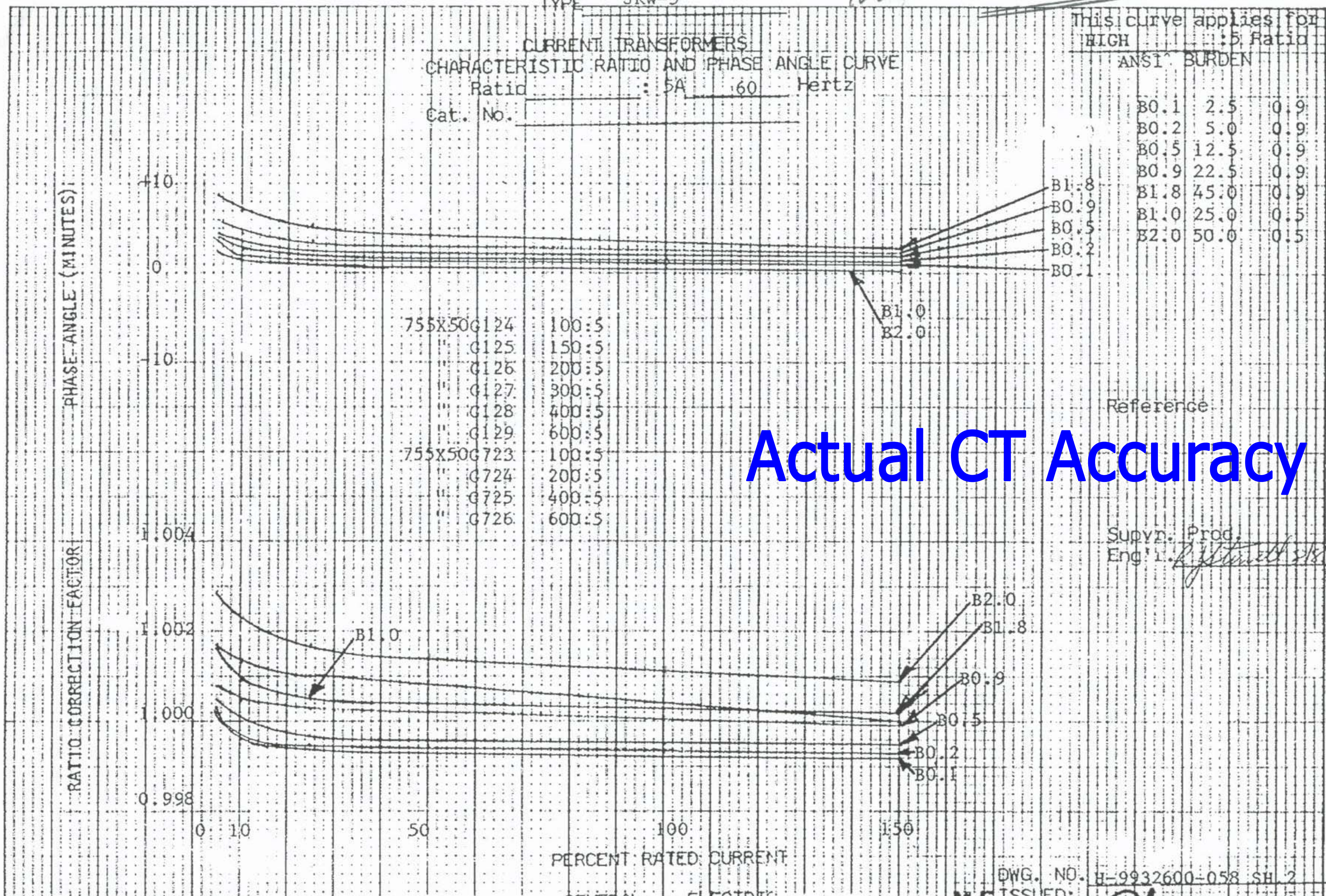


By the IEEE Standard, does a 0.3% CT mean its 0.3% accurate?

IEEE Standard

Not "high accuracy"
Normal 0.3 accuracy

H-9932600-58 SH.2

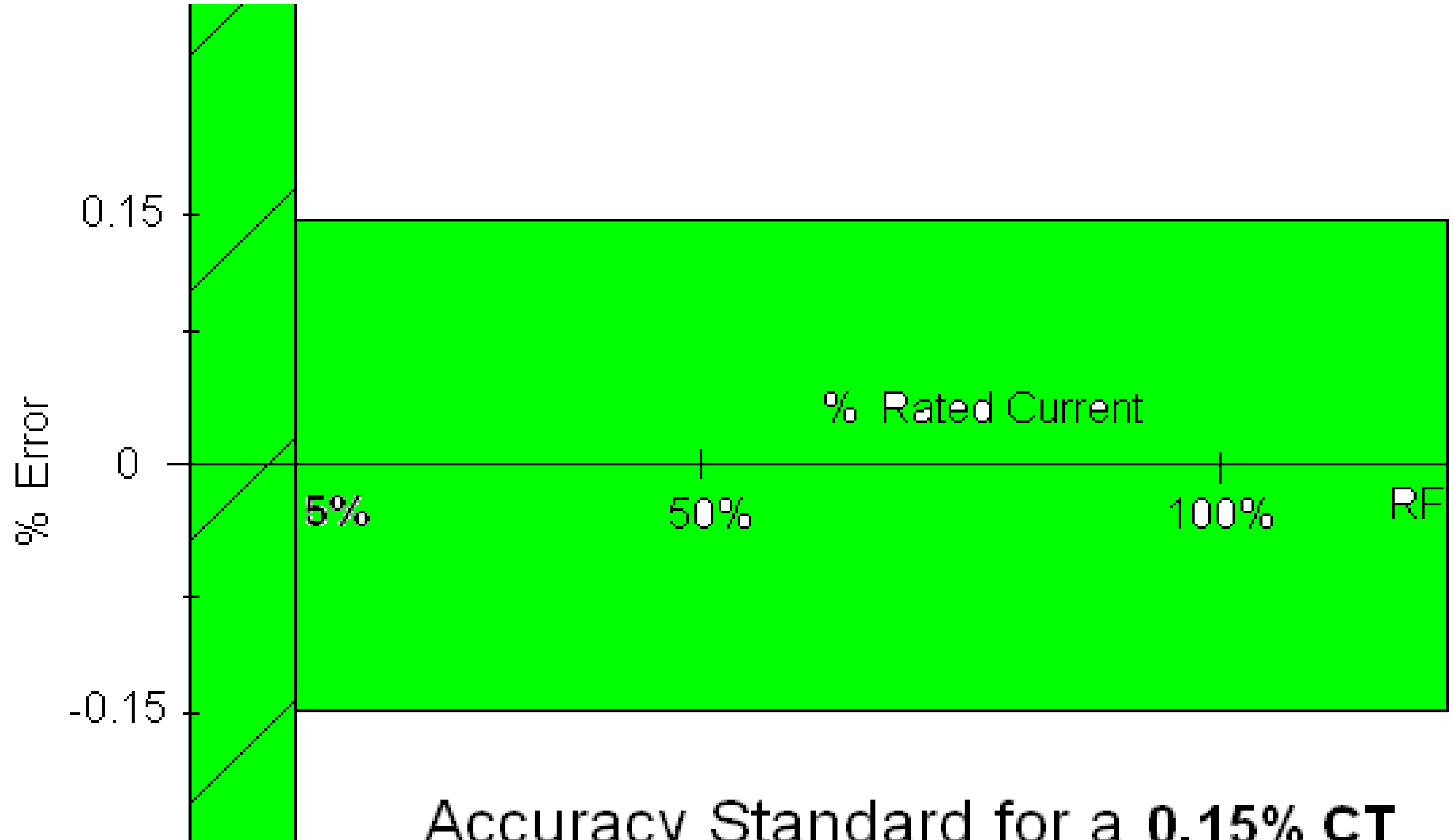


MF AUG 16 1985

(2) EC 4549 NF OCT 15, 1985

GENERAL ELECTRIC
METER DEPARTMENT
SOMERSWORTH, NEW HAMPSHIRE

HT



Accuracy Standard for a **0.15% CT**

- 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

Cφ C-7998

KUHLMAN ELECTRIC ORDER 116048-00

CURRENT TRANSFORMER

TYPE CXM-1050 N° 0640844006

NOM. VOLTAGE 230 kV NORM IEEE C57.13

RATIO 1200:5 RATING FACTOR 2.0 IN

BIL 1050 kV

THERMAL CURRENT 144 KA

MECHANICAL CURRENT 360 KA

SEC. T. X1-X2 BURDEN (VA) B0.1-B1.8

CLASS 0.15 0.15 from 0.5% to 200%
0.3 from 0.25% to 0.5%

CREEP. DISTANCE 266 in. 60 Hz

WEIGHT 1300 lbs OIL 44 US gal 0.3 g

OPERATION ALT. 3300 ft YEAR 2006

-30°C to +40°C

"OIL CONTAINS LESS THAN 1 ppm PCB"

W O W !!!!

Beyond new IEEE Standard: 0.15% accurate at 0.5% current rating (not just 5%)

And further, 0.3% accurate down to 0.25% current rating

Keep in mind, old standard didn't have accuracy rating below 10% current rating; and above was 0.6% accuracy

- What is happening when we 'burden' a CT?
  - Resistance/Impedance is added to the CT Secondary Circuit.
  - The CT is 'pushed' higher up on the excitation curve.
  - Secondary output voltage rises.
  - If the CT is healthy and/or excessive burden is avoided, measurements indicate close approximations of the current and voltage present before the burden was inserted.

- Note that circuit loading has a large impact on the results of any burden test.
  - If the CT is already operating near it's 'knee' voltage, more deviation will occur and is expected.

- Line loading should be taken into consideration whenever any type of 'burden effect' is examined.

- Significant deviations in current magnitude and/or phase angle indicate two possible problems:
  - 1) CT Secondary burden is so high, and coupled with the load current the CT is working close to the 'knee' of it's excitation curve under 'normal' in-service conditions.
  - Relaying CT's should never be working near the 'knee' of their excitation curves under normal load conditions, as this indicates they will saturate under fault conditions and currents of improper magnitudes will be supplied to connected devices.

- Significant deviations in current magnitude and/or phase angle indicate two possible problems:
  - 2) The CT may have turns shorted due to a myriad of reasons, such as a manufacturing defect, water/corrosion entry, or overvoltage damage.

Model BA-185
Current Transformer Burden Ammeter

APPLICATIONS

Within the accuracy limits of the CT, a good current transformer should not have a noticeable change in ratio when a secondary burden is added. This is because the primary effect of additional burden on a good CT is a rise in the secondary voltage.

However, if one or more turns of a CT are shorted, a substantial amount of the total available ampere-turns is diverted into the shunt path created by the short. Thus, the current to the circuit connected to the CT is less than the CT's total secondary current.

Therefore, when the proper burden within the ammeter is added in series with the circuit connected to a good CT, the current indicated by the ammeter should only decrease a few percent.

Radian Research, Inc.

585 UTEC Burden Tester

Time Controlled Thermally Protected to Prevent Element Burnout

Rated 20 Amps

Available Burdern from 0.1 to 15.8 ohms

Easy to Read Current Values

Displays Before & After Current Readings when Burden is Applied, and Displays Percent Change

Controlled Dwell Time to Prevent Element Burnout

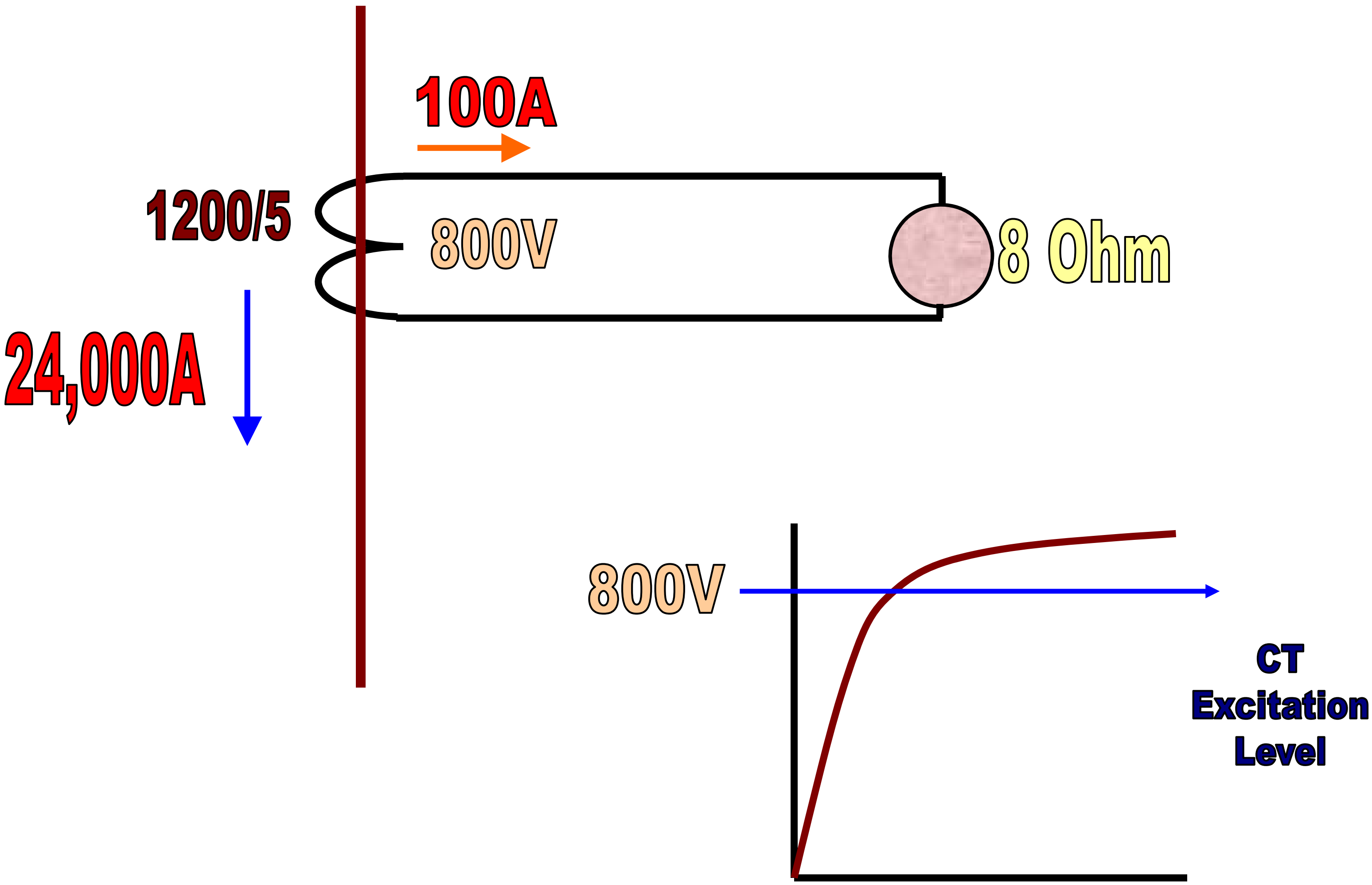
Automatic System Continuity Check enhances safety by ensuring the instruments current path is continuous

Durable/Compact design

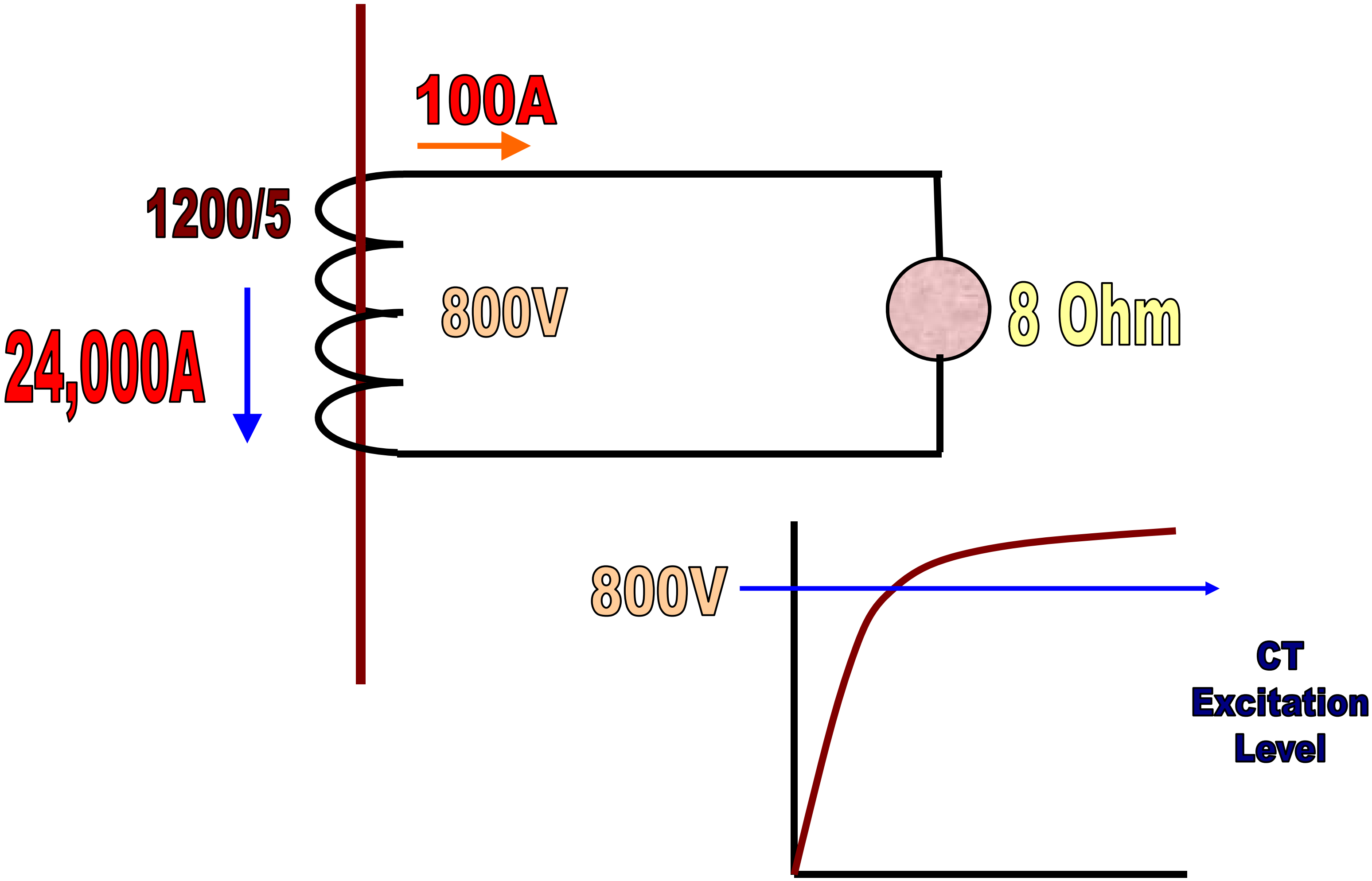
Powered by AA Alkaline Batteries

Light Weight - 5 lbs.

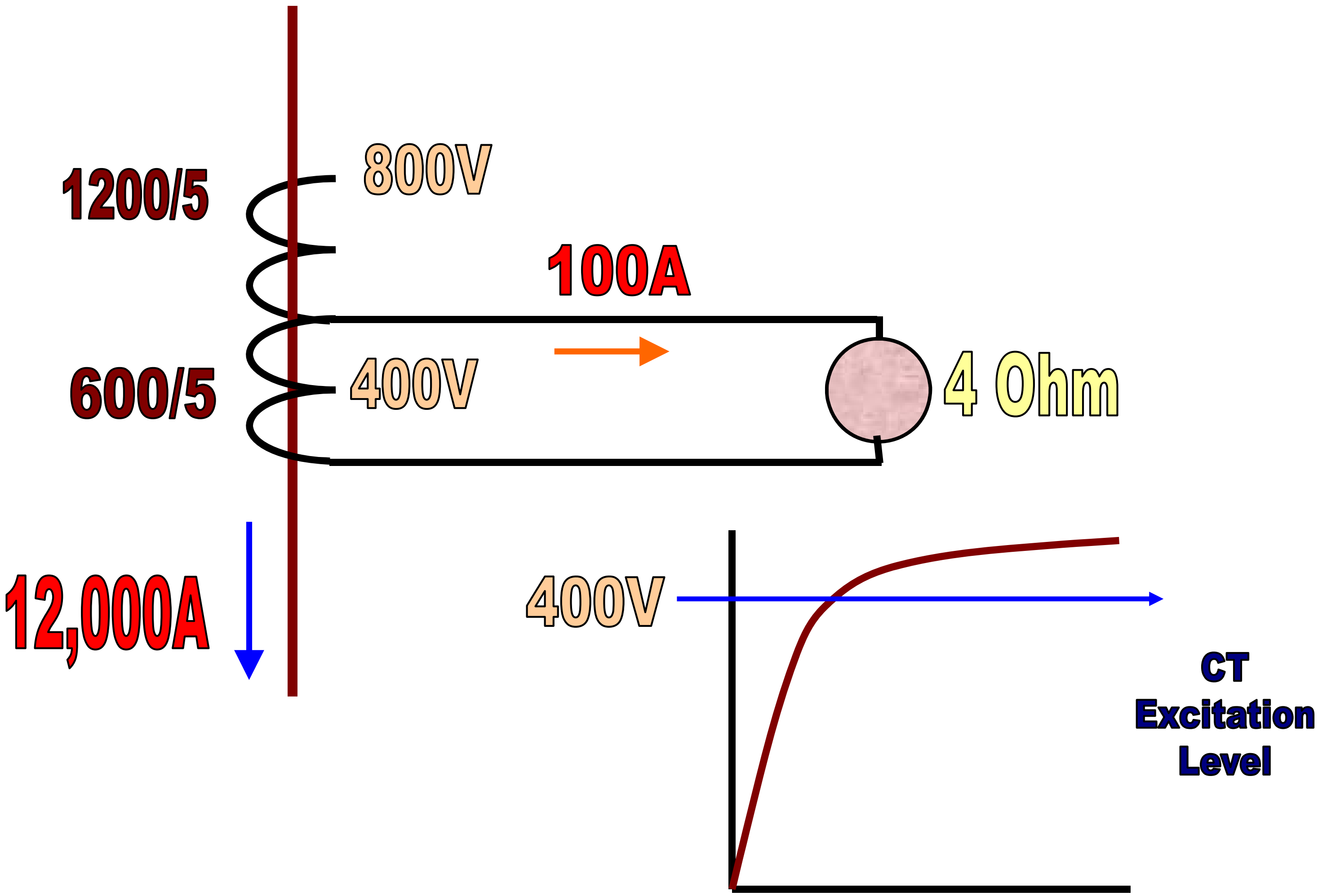
C800 CT Working Limits



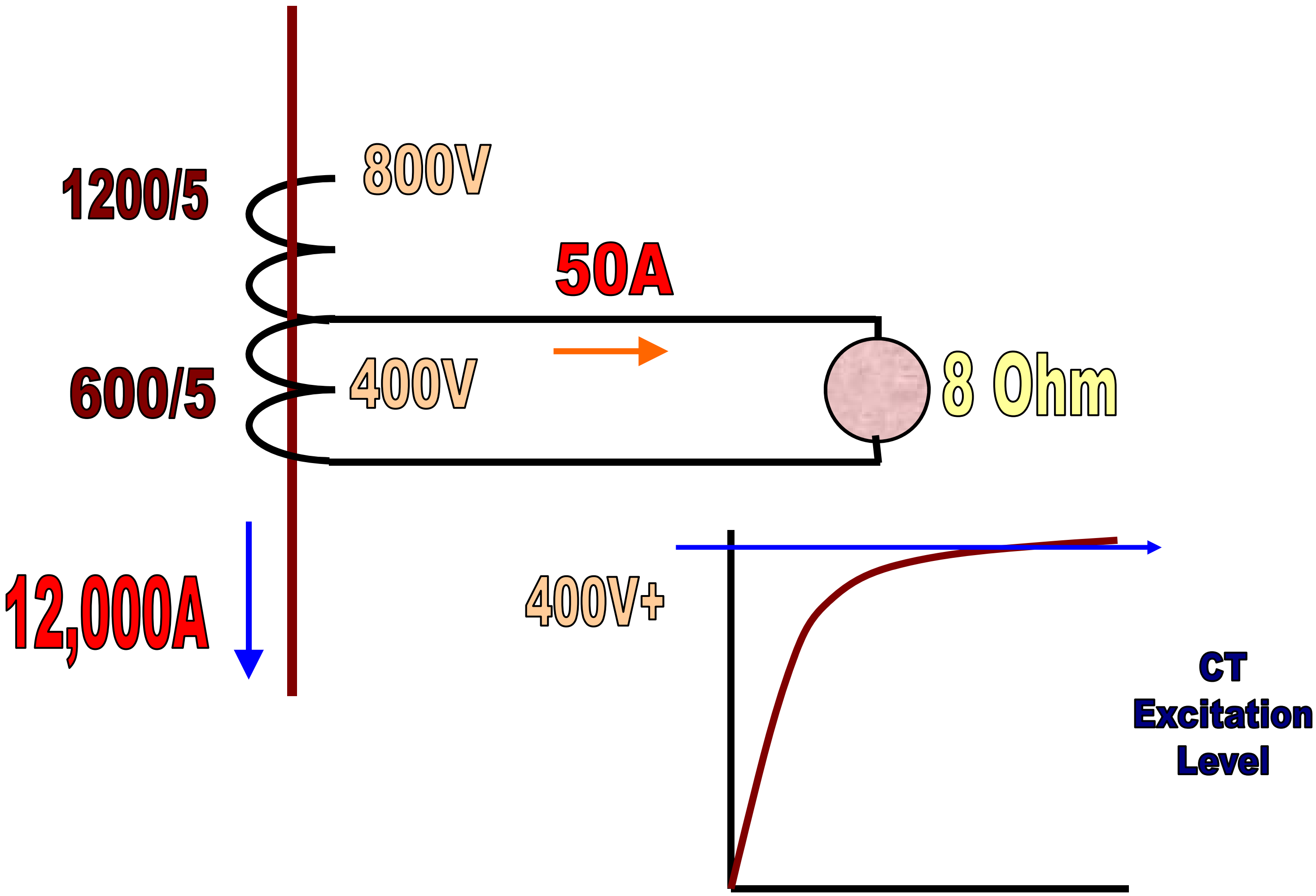
Multi-ratio issues



Multi-ratio issues



Multi-ratio issues



ORDERING INFO FOR LG-15-6513				
Ratio	Catalog Number*	Accuracy/Burden		Rating Factor
		Metering	Relay	
200:5	D040200S1	0.3 B0.2	C50	2.0
300:5	D040300S1	0.3 B0.5	C100	2.0
400:5	D040400S1	0.3 B0.5	C100	2.0
600:5	D040600S1	0.3 B0.5	C150	2.0
800:5	D040800S1	0.3 B0.9	C200	2.0
1000:5	D041000S1	0.3 B1.8	C250	2.0
1200:5	D041200S1	0.3 B1.8	C300	2.0
1500:5	D041500S1	0.3 B1.8	C300	2.0
2000:5	**D042000S1**	0.3 B1.8	C400	2.0
2500:5	D042500S1	0.3 B1.8	C600	2.0
3000:5	**D043000S1**	0.3 B1.8	C800	2.0
4000:5	D044000S1	0.3 B1.8	C800	1.5
5000:5	D045000S1	0.3 B1.8	C800	1.5
6000:5	**D046000S1**	0.3 B1.8	C800	1.0
8000:5	D048000S1	0.3 B1.8	C800	1.0
10000:5	D0410000S1	0.3 B1.8	C800	1.0
200/400:5	D040200D1	0.3 B0.5/B0.9	C100/C200	2.0/2.0
300/600:5	D040300D1	0.3 B0.5/B1.8	C200/C400	2.0/2.0
400/800:5	D040400D1	0.3 B0.9/B1.8	C300/C600	2.0/2.0
600/1200:5	D040600D1	0.3 B0.9/B1.8	C150/C300	2.0/2.0
1000/2000:5	D041000D1	0.3 B1.8/B1.8	C200/C400	2.0/2.0
1500/3000:5	D041500D1	0.3 B1.8/B1.8	C400/C800	2.0/2.0
2000/4000:5	**D042000D1**	0.3 B1.8/B1.8	C400/C800	2.0/1.5
3000/6000:5	**D043000D1**	0.3 B1.8/B1.8	C400/C800	1.5/1.0

HIGH ACCURACY LGX-15-6513			
Catalog Number	0.15/0.3 @ Burden	0.15/0.3 Acc Range	Rating Factor
--	--	--	--
--	--	--	--
D040400X1	B0.5	400/4 to 1200A	3.0
D040600X1	B0.9	600/6 to 2400A	4.0
D040800X1	B0.9	800/8 to 3200A	4.0
D041000X1	B0.9	100/10 to 3000A	3.0
D041200X1	B0.9	120/12 to 3600A	3.0
D041500X1	B0.9	150/15 to 3000A	2.0
D042000X1	B0.9	200/20 to 4000A	2.0
--	--	--	--
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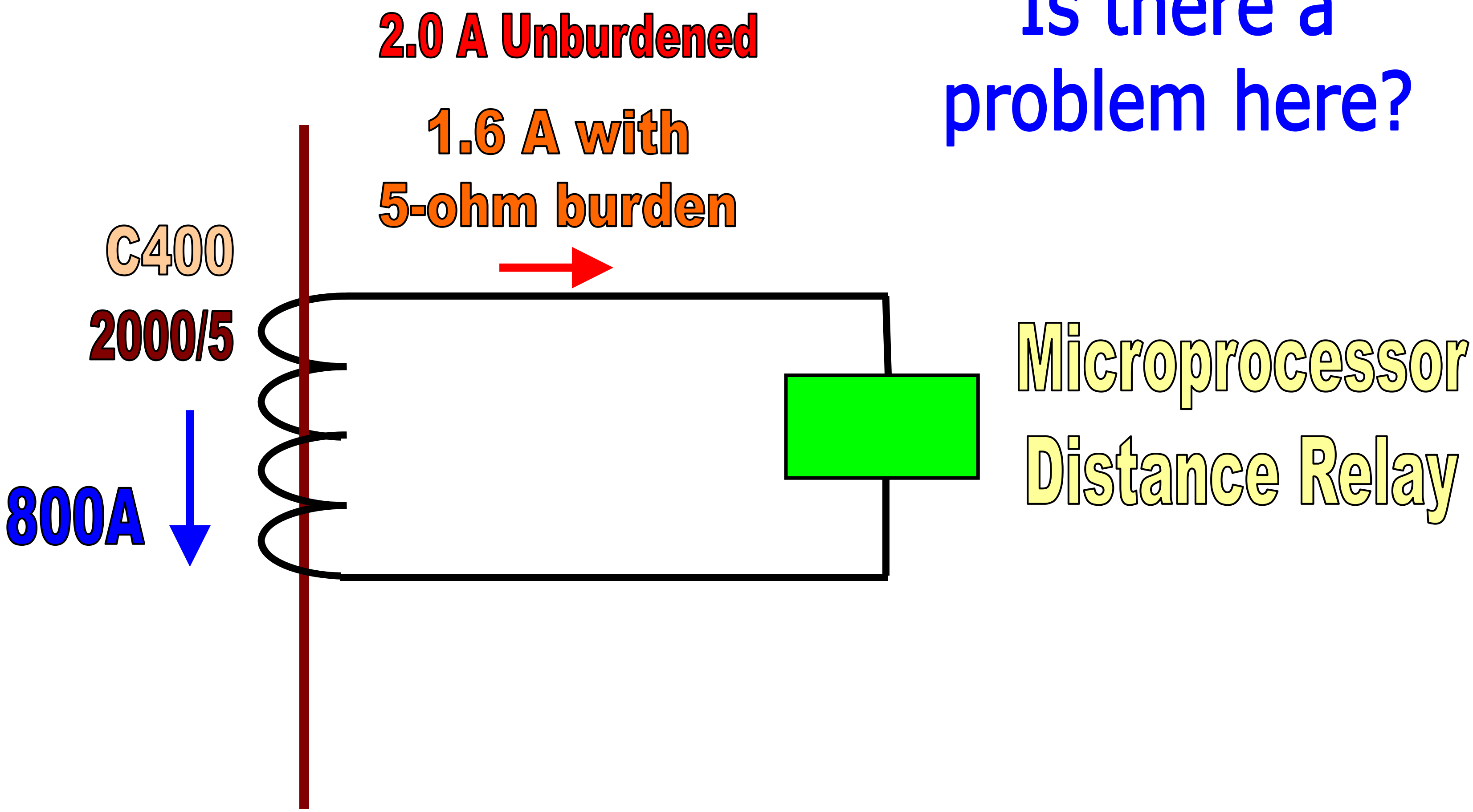
- Available in multi-ratio designs (full tap ratings same as single ratio above).
- 1 Second Thermal/Mechanical Rating: 80x full winding I_{nom} / Unlimited mechanical.

* **IC Approval (AE-1104) is noted by bold catalog number.**

Based on previous discussion, with two C800 CT's, one 1200:5 and another 2000:5, which would have a larger core, all else being equal?

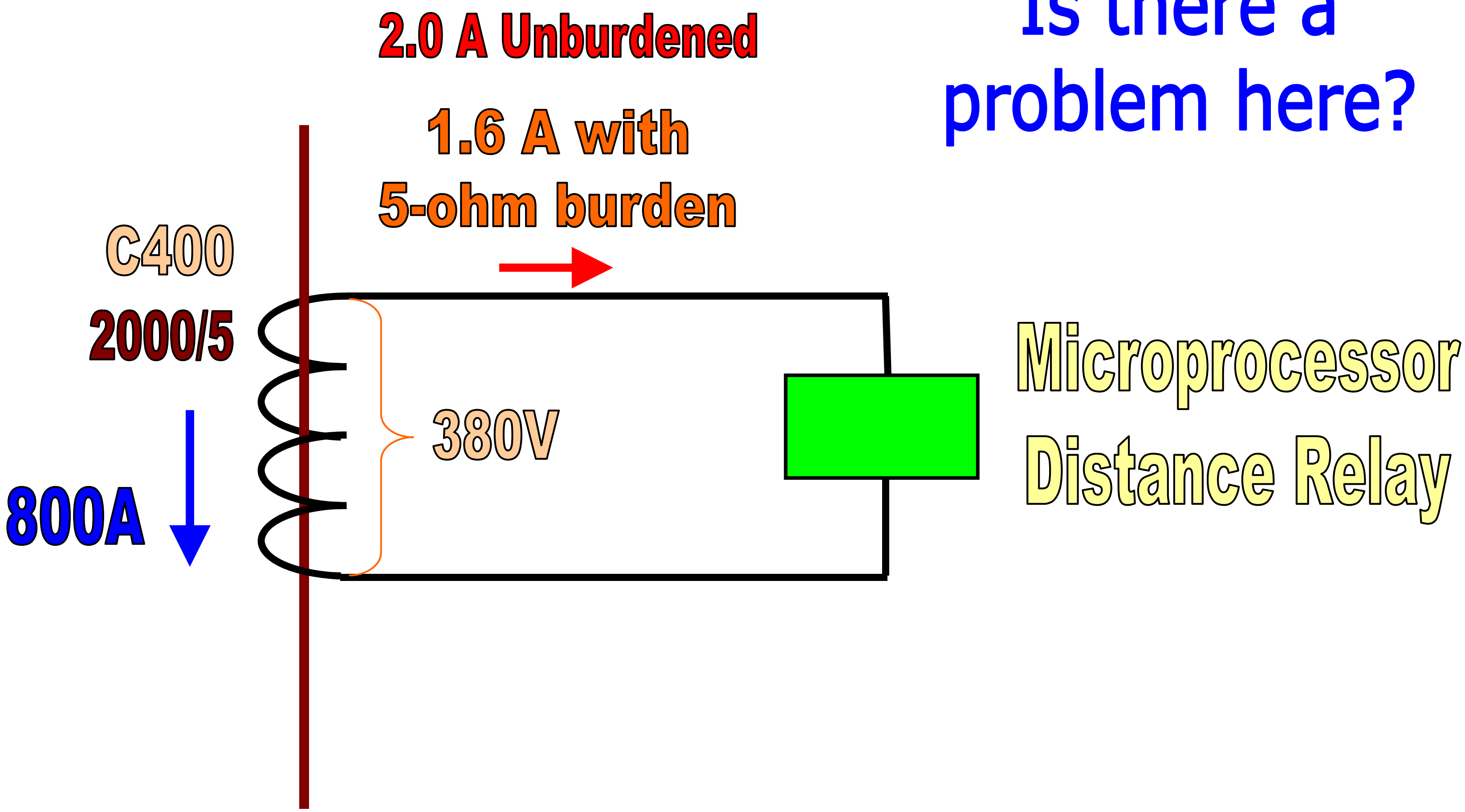
From ABB/Kuhlman 15kV Instrumentation Brochure

Is there a problem here?



Burden Test Deviations

Is there a problem here?



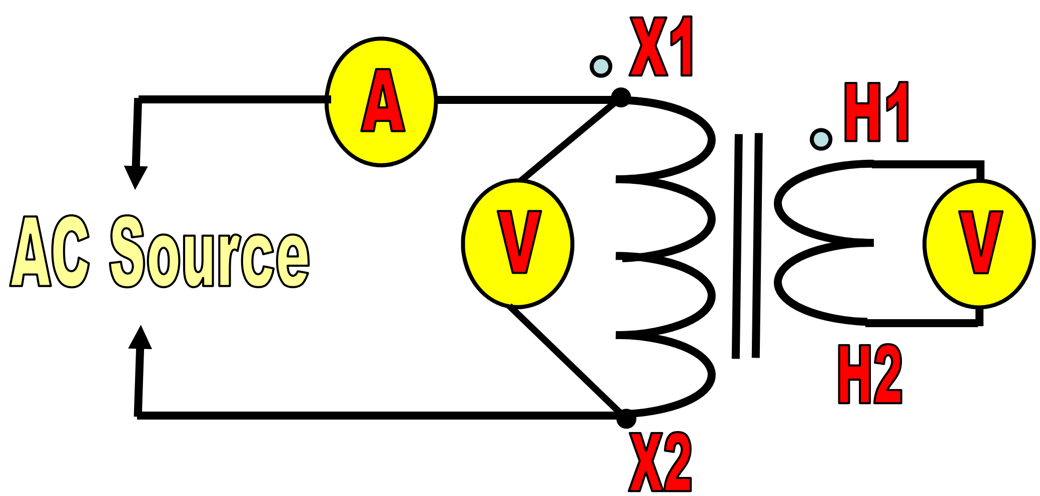
Burden Test Deviations

- Commonly performed Field tests:
  - Insulation Resistance
  - CT Resistance
  - Ratio Test
  - Polarity
  - Excitation
  - Burden
  - Sometimes performed: Admittance
  - Associated Tests:
    - Overall Loading
    - Ground check(s)
    - Nameplate data verification

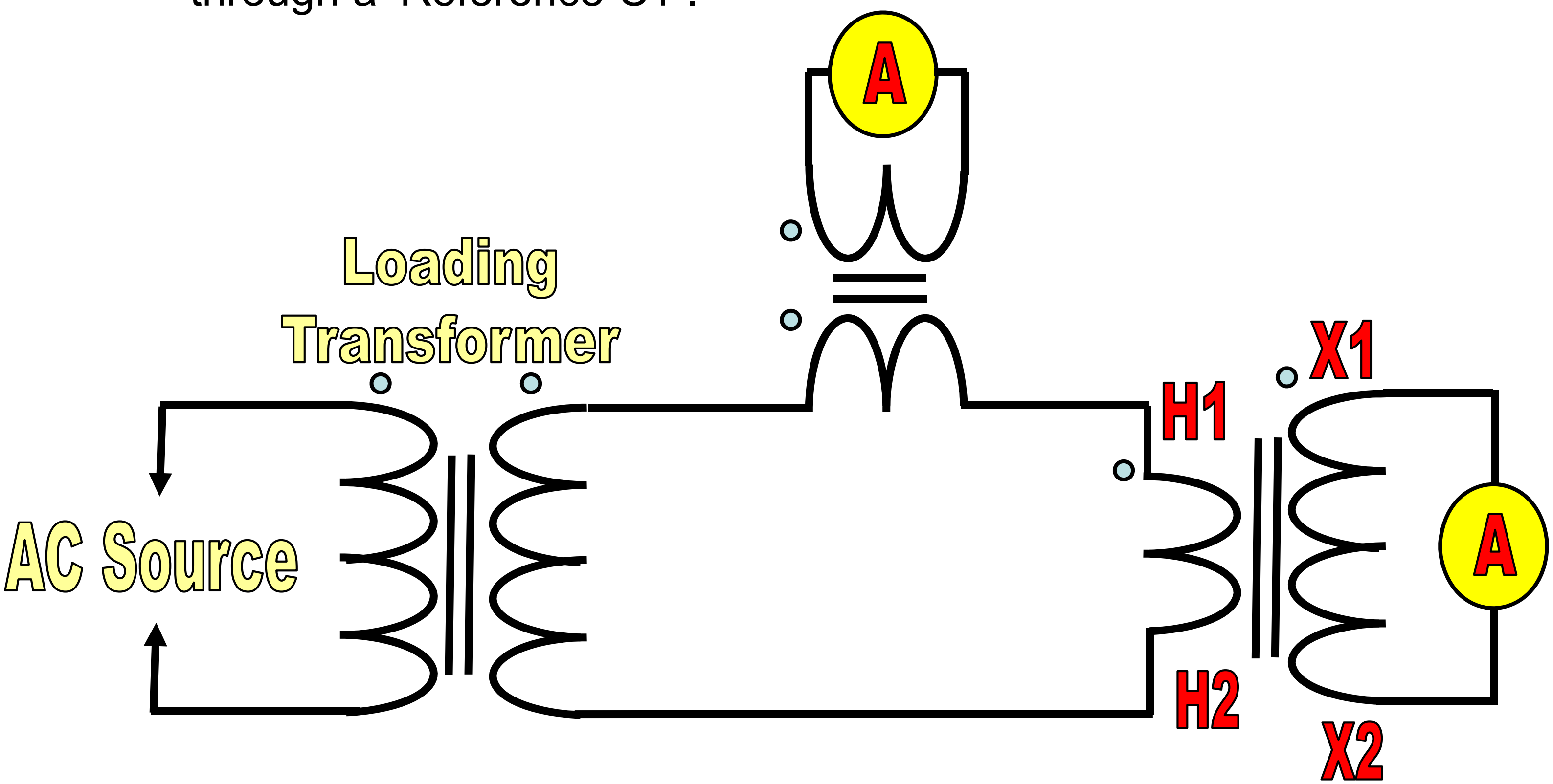
- Commonly performed field tests:
  - Insulation Resistance
    - Winding to Winding and Winding to Ground insulation check
  - CT Resistance
    - ‘Bridge’ or Low-resistance ohmmeter check of CT Secondary Winding.
  - Ratio Test
    - Check of CT to confirm proper Ratio
  - Polarity
    - Confirmation of CT polarity
  - Excitation
    - Confirmation of CT rating, verifies no shorted turns
  - Burden
    - Check of CT’s ability to deliver current

▪ Ratio Test

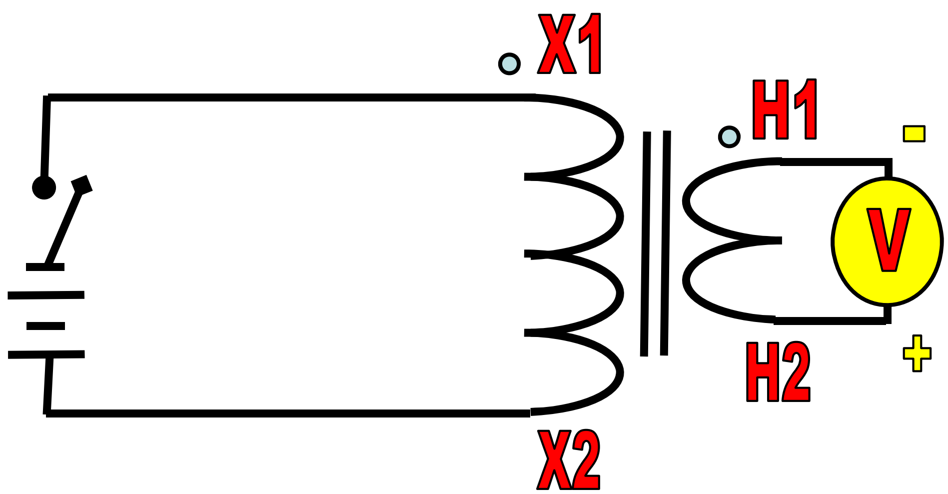
- Two commonly used out-of-service methods to test:
  - Voltage Method
    - CT is essentially tested as a voltage transformer by applying voltage to the CT Secondary and measuring the primary voltage.
    - The turns ratio is approximately equal to the voltage ratio.



- 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’.

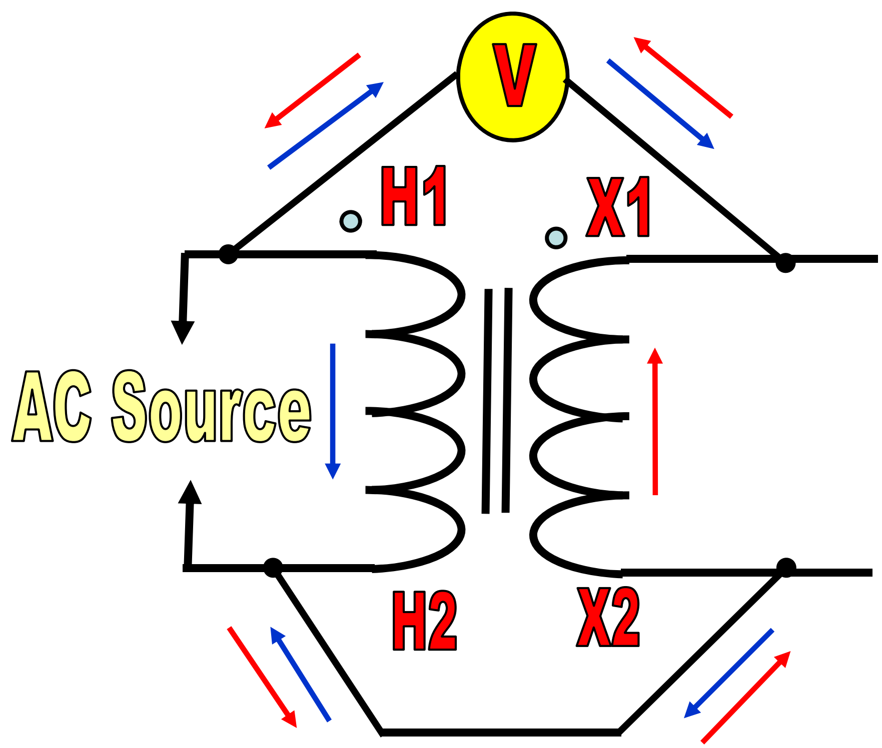


- Polarity Test
  - Four commonly used out-of-service methods to test:
    - DC Flash Method
      - A lantern battery or equivalent DC source is momentarily connected to the CT Secondary and the primary voltage is monitored with a voltmeter.

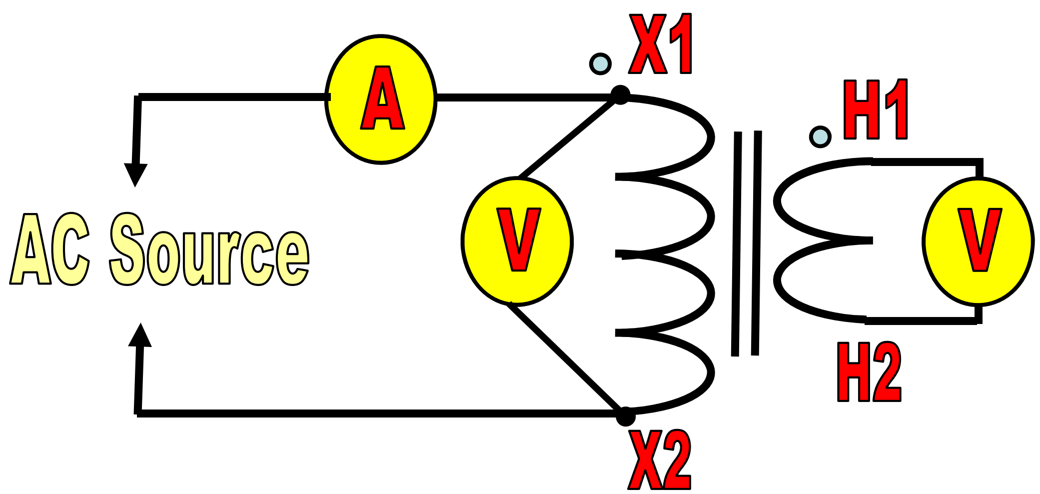


Classical Polarity Test

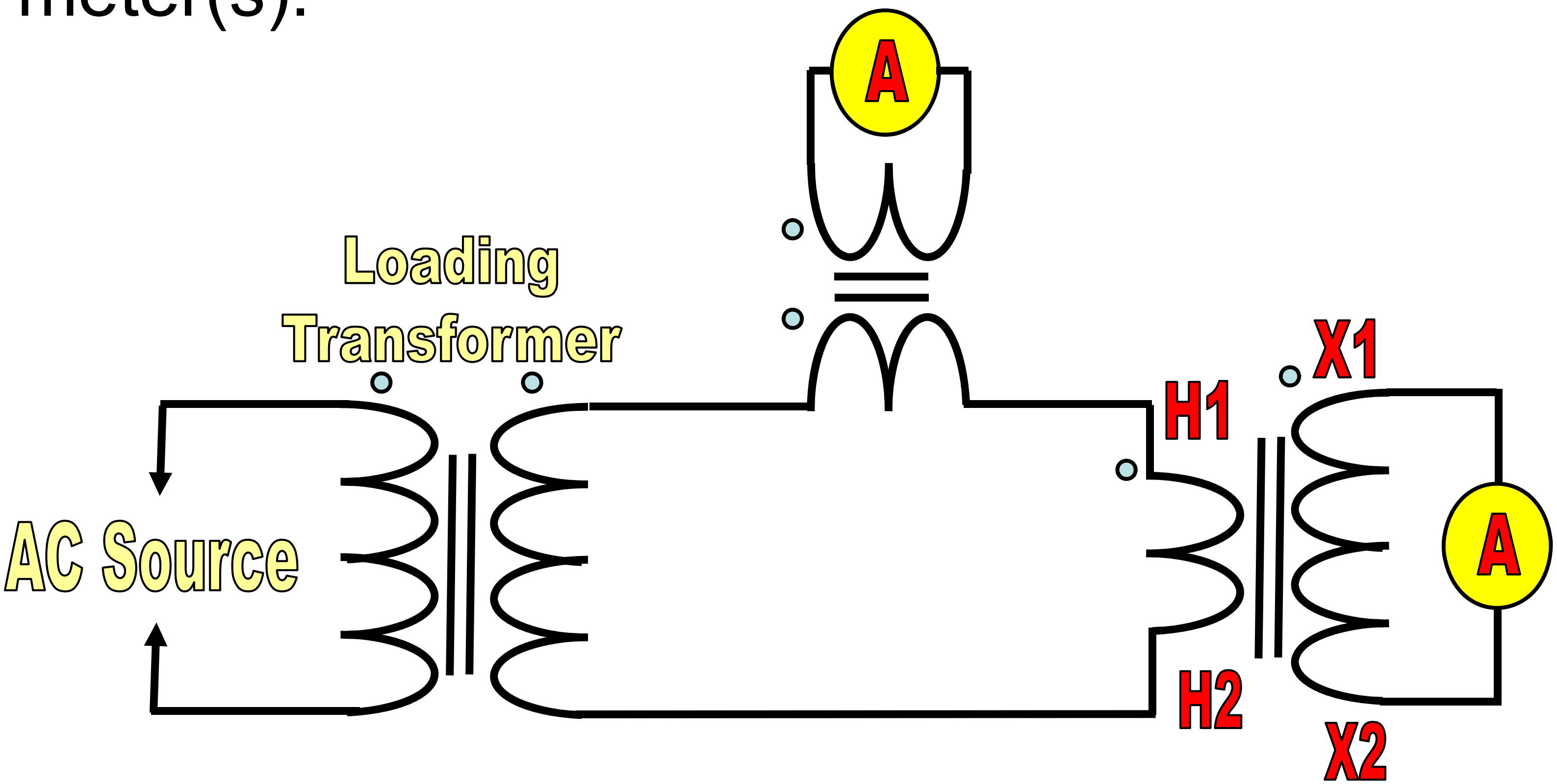
- Voltage Method
  - This test is performed in the same manner as a voltage transformer polarity test.



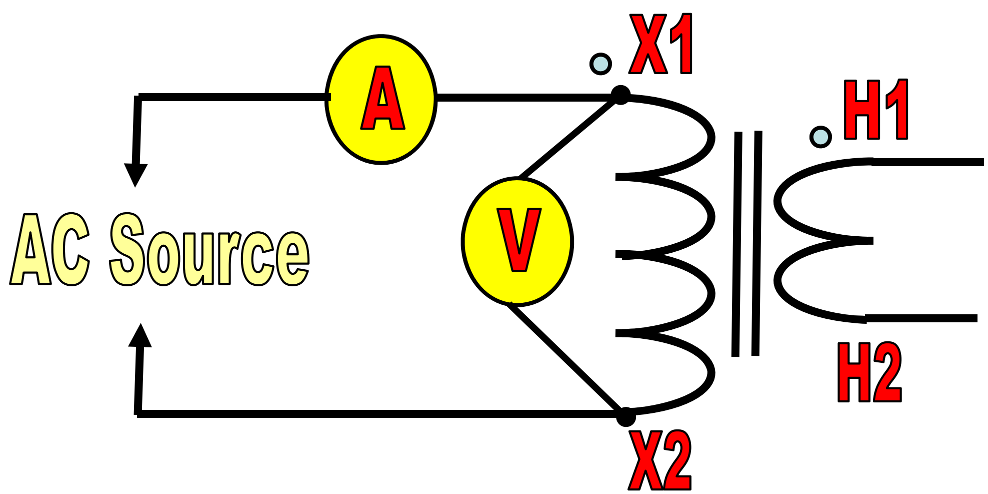
- Ratio/Polarity Test using voltage method:
  - While performing ratio check, phase angle of both voltages is compared using phase angle meter(s).



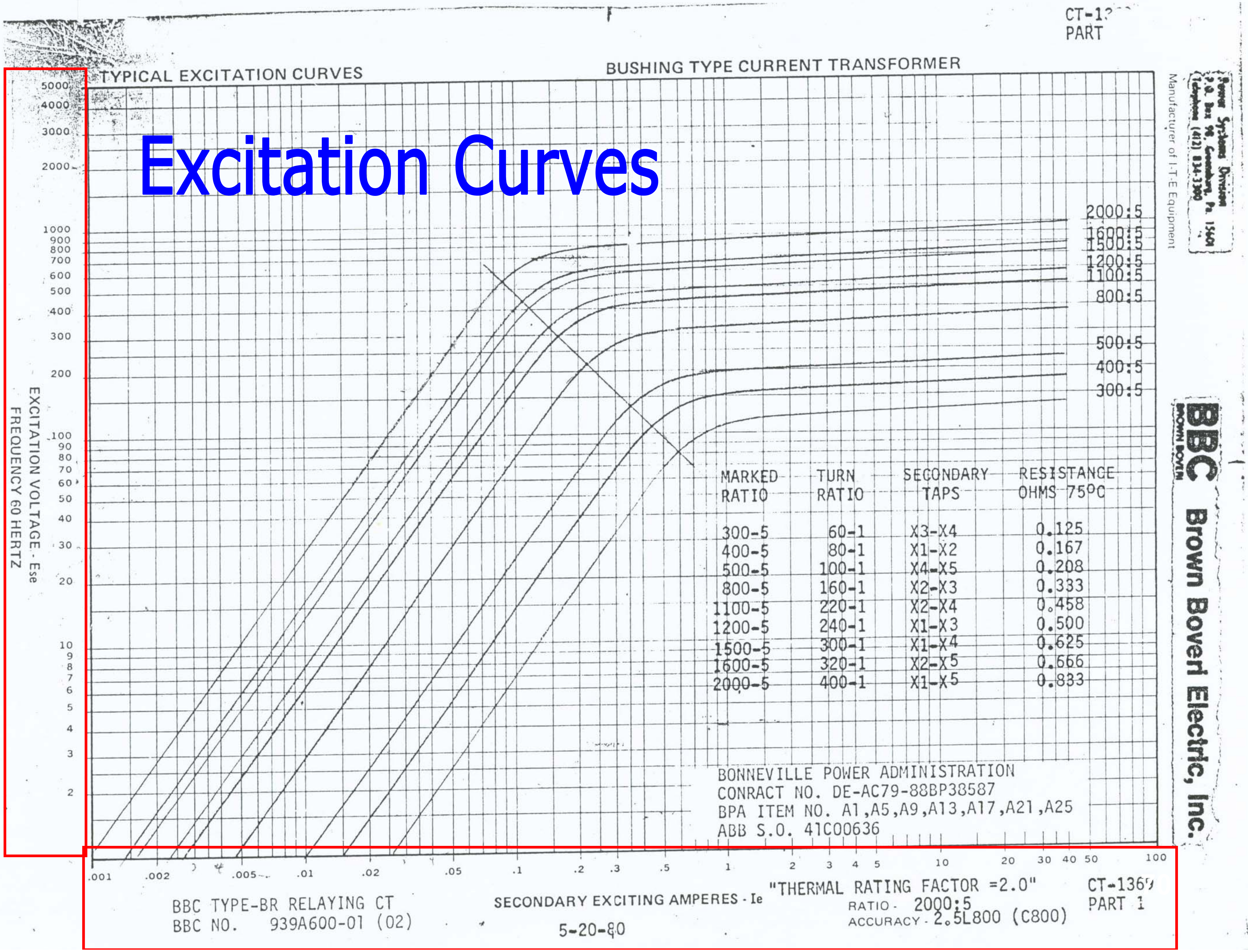
- Ratio/Polarity Test using Current Method
  - While performing ratio check, phase angle of both voltages is compared using phase angle meter(s).



- Excitation Test
  - Secondary Excitation Method
    - Secondary voltage is applied and exciting current is measured
    - Voltage / Current are plotted and compared to manufacturer’s information

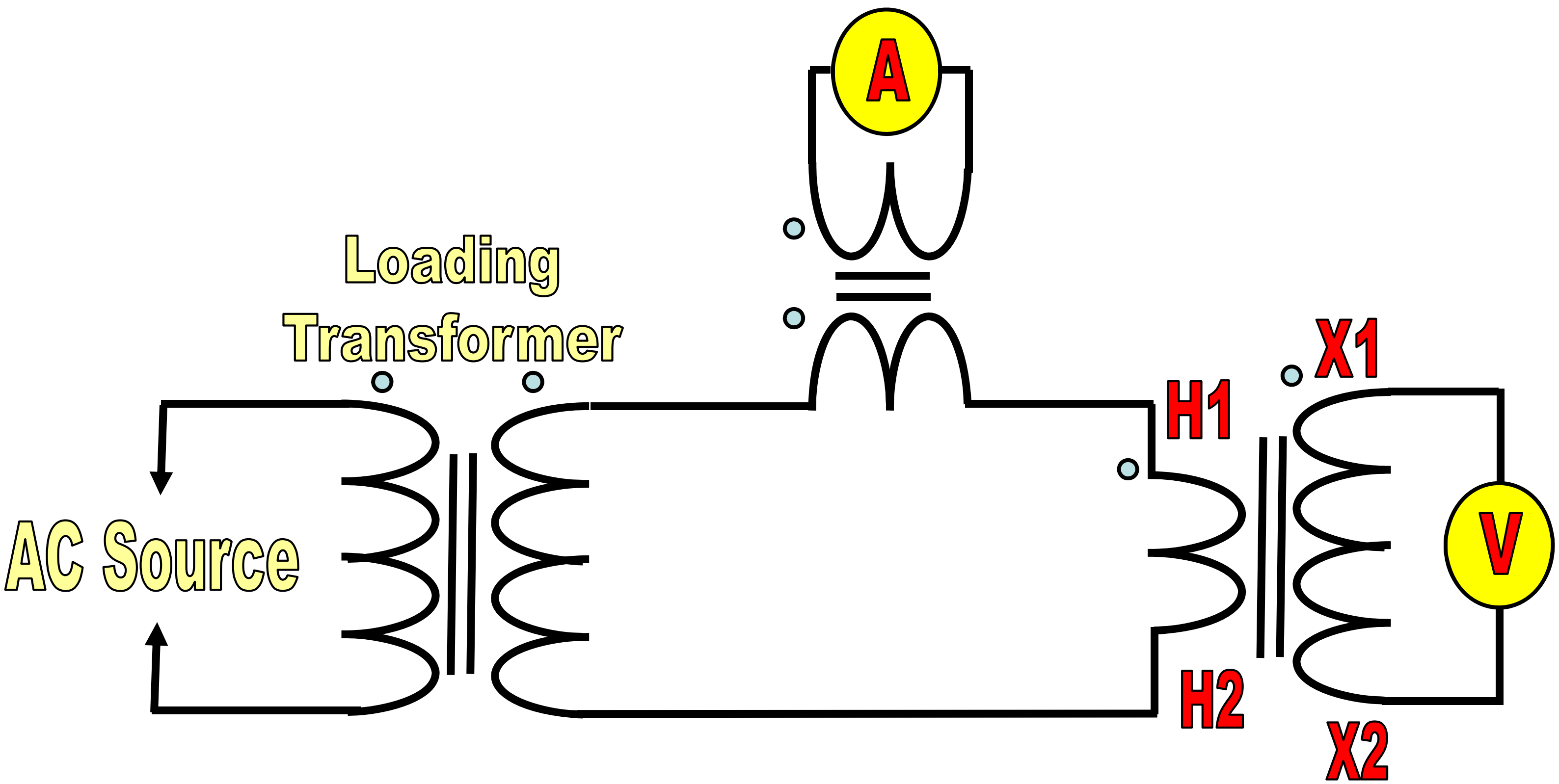


Excitation Curves



Excitation Test using Primary Current Injection

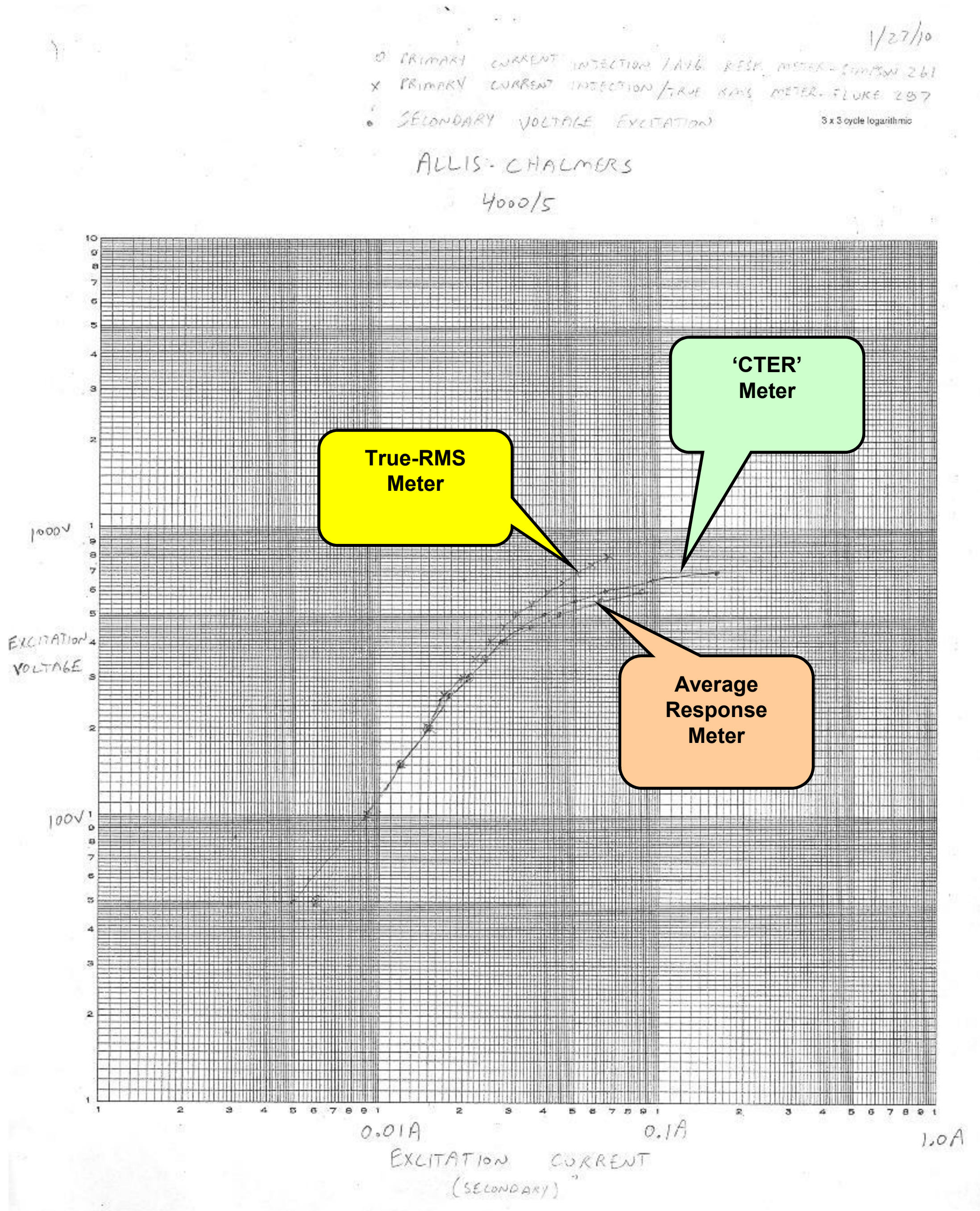
- Primary Current is measured along with secondary voltage
- Primary exciting current is divided by the CT ratio to determine equivalent secondary exciting current to compare to manufacturer's diagrams.



- When CT's saturate, they produce non-sinusoidal waveforms.
  - True RMS Meters will not give the same results as an Averaging Meter.

- Manufacturer's published excitation data is typically recorded with average-responding meters.
  - Above the knee of the excitation curves, True RMS meters will read 'high' if they are used for Field Excitation tests.

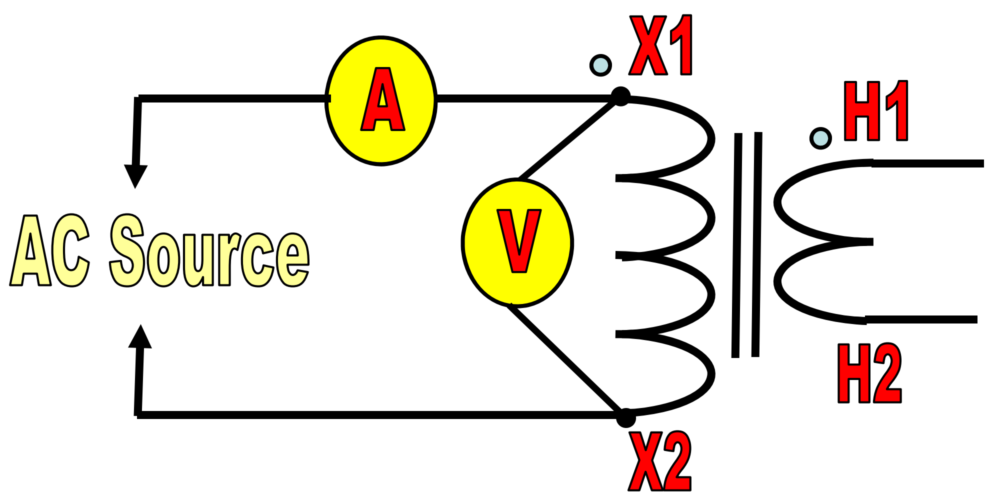
Excitation Test Considerations


1/27/10
X PRIMARY CURRENT INJECTION / TRUE RMS METER - FLUKE 287
• SECONDARY VOLTAGE EXCITATION
3 x 3 cycle logarithmic
ALLIS-CHALMERS
4000/5
'CTER' Meter
True-RMS Meter
Average Response Meter
1000V
EXCITATION VOLTAGE
100V
0.01A
0.1A
1.0A
EXCITATION CURRENT
(SECONDARY)

- Certain conditions can magnetize the core of a CT.
  - During high-current faults with significant DC offset
  - During Millivolt-drop testing with DC sources

- Some utilities routinely demagnetize CT's, others consider the effects to be minimal/short-duration and do not.

- The easiest way to demagnetize a CT is to apply test current at a level that approaches it's excitation 'knee', then slowly decrease the input current to zero.
  - This can be done with secondary excitation or primary current injection.



Sample Test Record

BPA F 6560.38
(01-90)
(Previously BPA 85)

U.S. DEPARTMENT OF ENERGY – BONNEVILLE POWER ADMINISTRATION

CURRENT TRANSFORMER TEST RECORD

Thyrite Protector

MAKE ______ TYPE ______ RATING ______

INSULATION AΦ ______ BΦ ______ CΦ ______

Name Plate Data

MAKE ______ TYPE ______ AMPS RATIO ______ RATIO ______

VOLT CLASS ______ ACC CLASS ______

BPA NO. & PHASE	C– PHASE–	C– PHASE–	C– PHASE–
SER NO. & POSITION	NORTH-EAST	MIDDLE	SOUTH-WEST

RATIO & POLARITY

STD CT RATIO — LOADING POLARITY ON H — MB SIDE / LINE SIDE — AS LEFT RATIO

CONNECTION

EXPECTED RATIO

I STD

I SEC WOB *

I SEC WB *

POLARITY*

MEAS RATIO

OPEN CIRCUIT

SEC V TO

I STD

DC RES IN OHMS

CONNECTION

CT TO GRP BLOCK

CT LOOP — DESIG– — DESIG– — DESIG–

INSULATION RESISTANCE IN MEGOHMS

WEATHER — TEMP

CONN	TEST V	1 MIN	MIN	1 MIN	MIN	1 MIN	MIN

OIL TESTS

Oil Dielectric Strength in KV — Samples 1, 2, 3

CONDITION — COLOR — TEST OIL TEMP — COLOR — TEST OIL TEMP — COLOR — TEST OIL TEMP

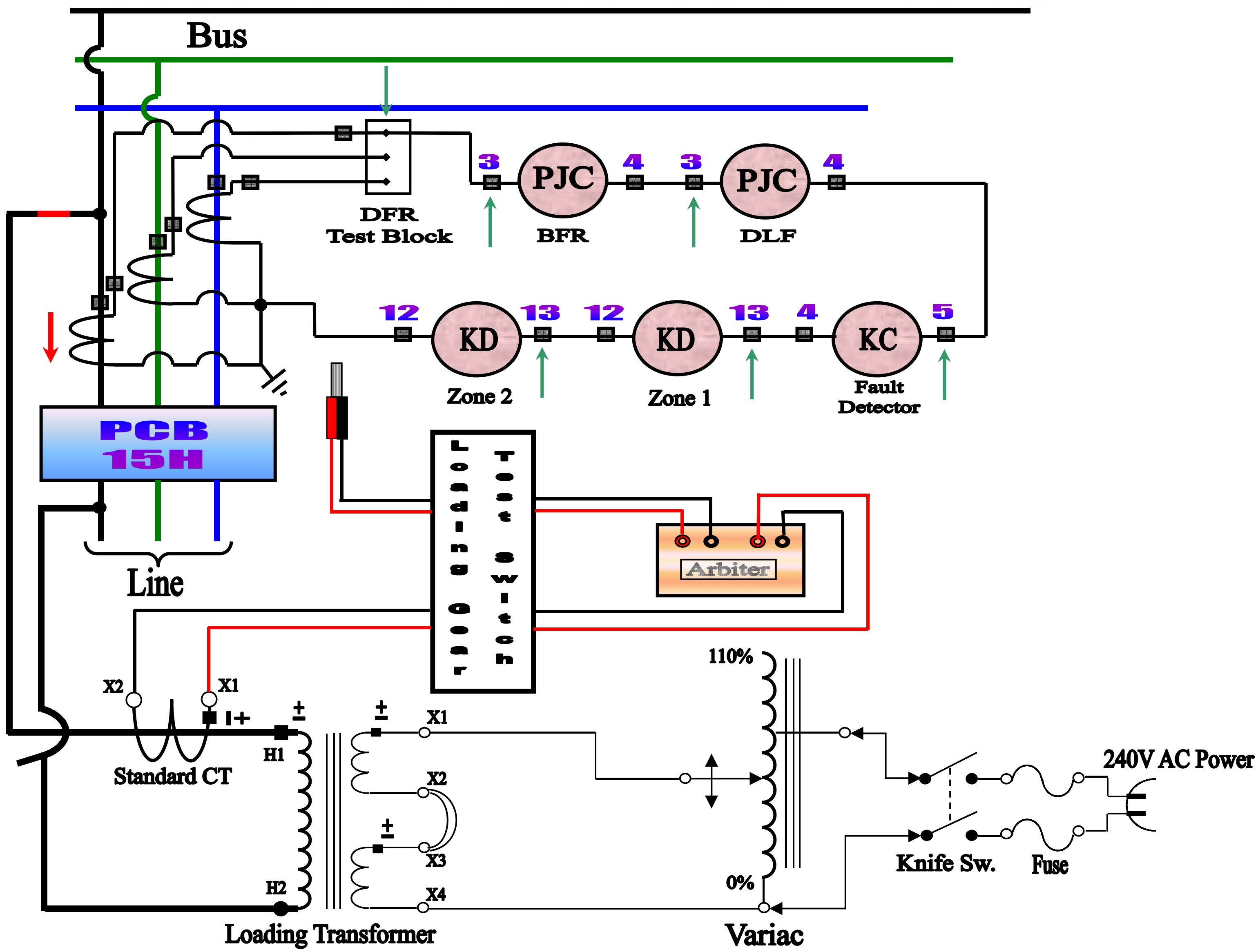
OIL ACIDITY

* NOTE: "N" = NORMAL; TEST CT CURRENT AND STANDARD CT CURRENT ADD "WOB" = WITHOUT 25 WATT BURDEN
"R" = REVERSE; TEST CT CURRENT AND STANDARD CT CURRENT SUBTRACT "WB" = WITH 25 WATT BURDEN

REMARKS ______

SUBSTATION ______ CIRCUIT ______

______ DATE ______ BY ______ SHEET ______ OF ______



Overall Loading

- 'Isolated' CT Circuits are typically single-point grounded.
  - Since most CT connections are 'Wye', this ground is typically placed at the neutral connection.
  - The ground keeps the whole CT winding at a reasonably low potential to ground
  - This is especially important in high-voltage environments where capacitive voltage dividers can be formed which can elevate the entire CT winding to an unsafe level.
  - Multiple grounds are generally to be avoided to prevent current loops through the ground connections.
    - These loops allow current to flow around the intended devices.
    - One of the ground-checks that can be performed is to remove the single-ground and verify that no other ground connections exist.

Ground Checks

- ‘Common’ CT Circuits, such as exist with Differential circuits or Ring-Bus and Breaker and a Half schemes are typically grounded at a point common to both CT circuits.
- Where Transformer differential circuits exist with Delta-Wye CT circuits, grounding at the relay effectively grounds both CT circuits at the same time.

From Kuhlman/ABB Brochure

A ground shield should be used on the unit as it is normally mounted in an area of high lightning incidence, the strike-over zone of the bushing or close to the bottom of the porcelain. The ground shield lead should be routed on the same side of the CT where the mounting hardware is located (see Figures 1, 2 & 3).

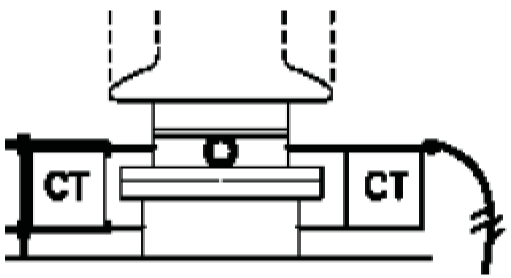


Figure 1

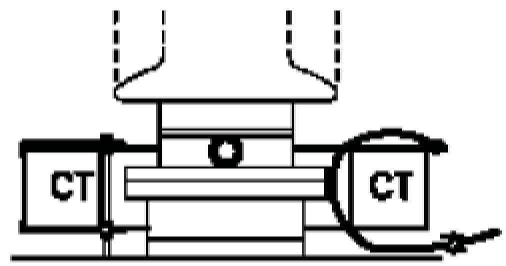


Figure 2

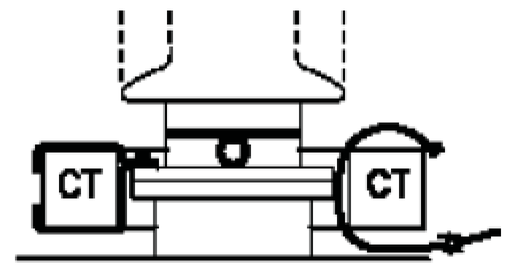


Figure 3

- If shield wires are improperly run, induced ground current can flow through the CT causing ratio errors.

Possible Ground Loop Traps

From Kuhlman/ABB Brochure

A ground shield should be used on the unit as it is normally mounted in an area of high lightning incidence, the strike-over zone of the bushing or close to the bottom of the porcelain. The ground shield lead should be routed on the same side of the CT where the mounting hardware is located (see Figures 1, 2 & 3).

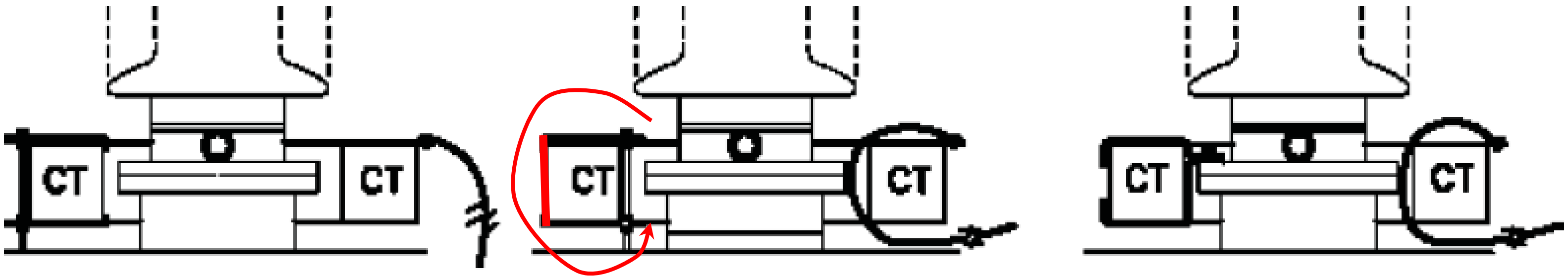
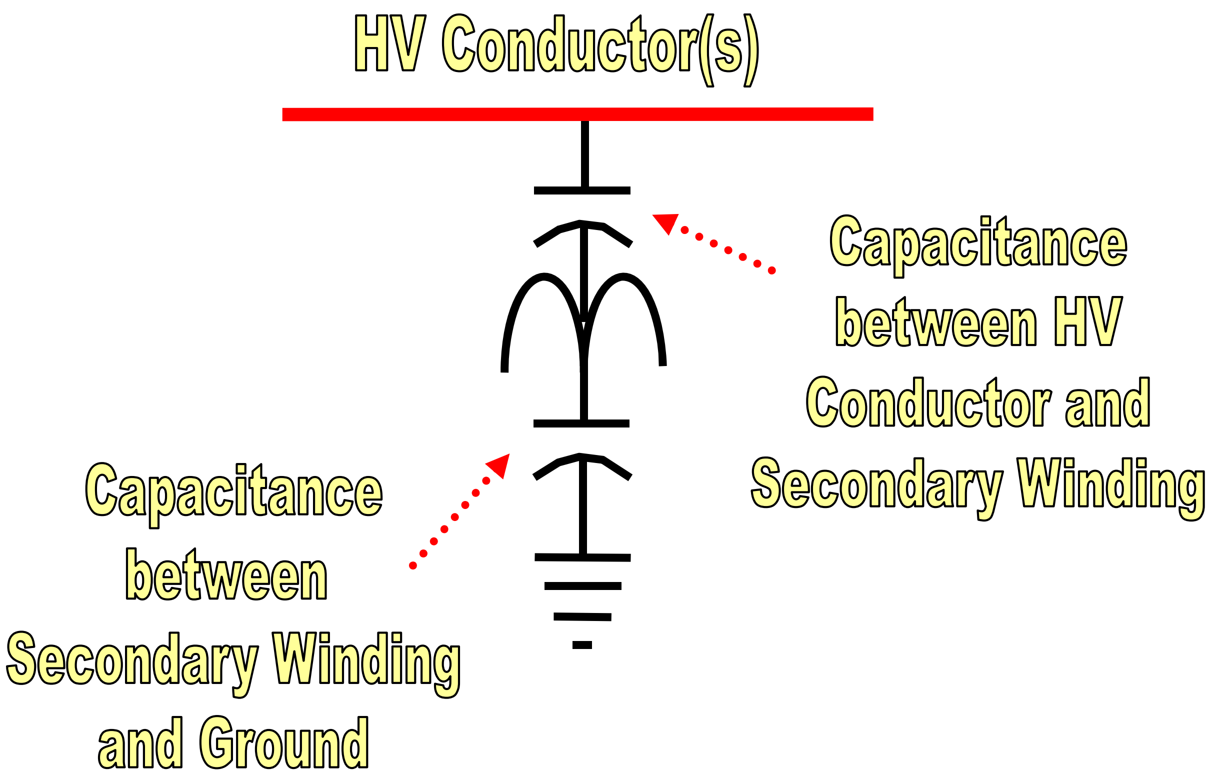


Figure 1 Figure 2 Figure 3

- If shield systems are improperly mounted, induced current will flow through the CT, causing ratio errors.

Possible Ground Loop Traps

Floating Secondary Issues



- 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

- 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.

Circuit Identification

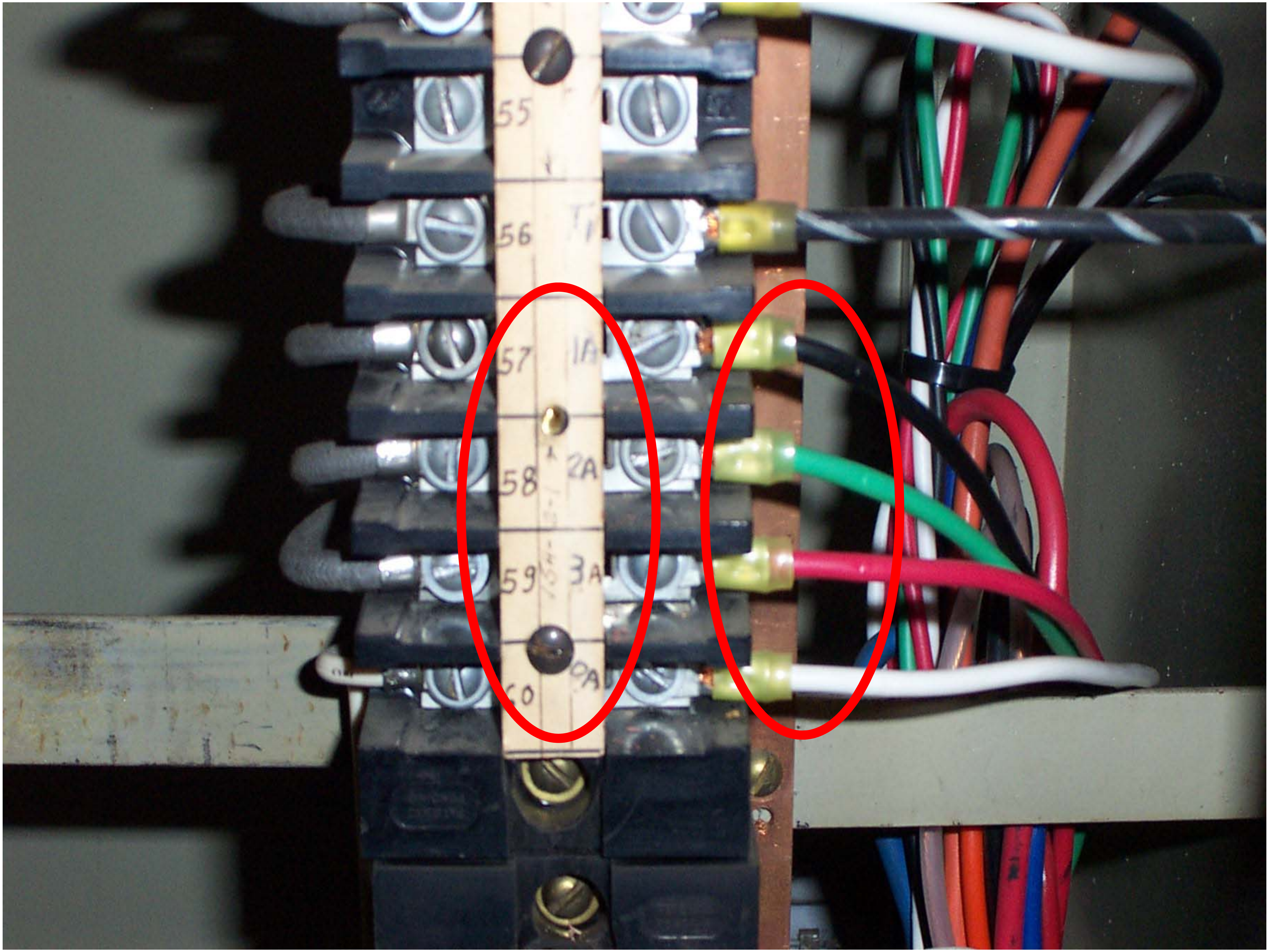
- Equipment, Terminal Blocks, and Cables should be labeled.
  - As Unidentified Circuits are encountered during normal Maintenance or replacement activities these Circuits should be identified and labeled.
- When working with electrical circuits of any kind, it is a good idea to review the wiring diagram and the physical layout of panel(s) with other Electrical Workers before beginning work.

Circuit Identification

- 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.

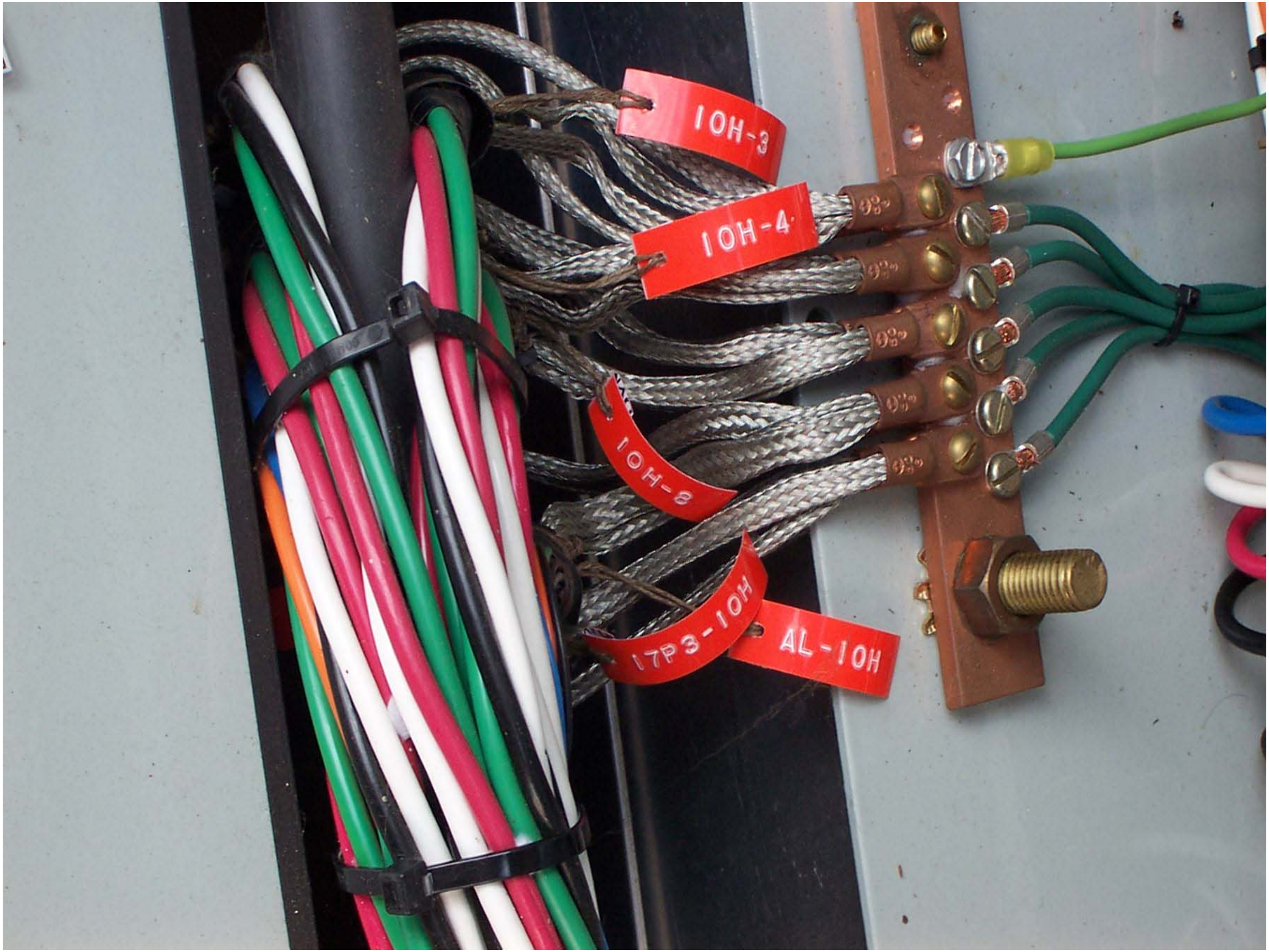
- Example BPA standard for CT's:
  - Normally Color Coded on BPA run cabling:
    - **Black (1A) – A-Phase**
    - **Green (2A) – B-Phase**
    - **Red (3A) – C-Phase**
    - **White (0A) – CT Common / Neutral**
  - Normally designated 1A, 2A, 3A, and 0A (if Wye-connected)

Circuit Identification


55
56
57
1A
58
2A
59
3A
60

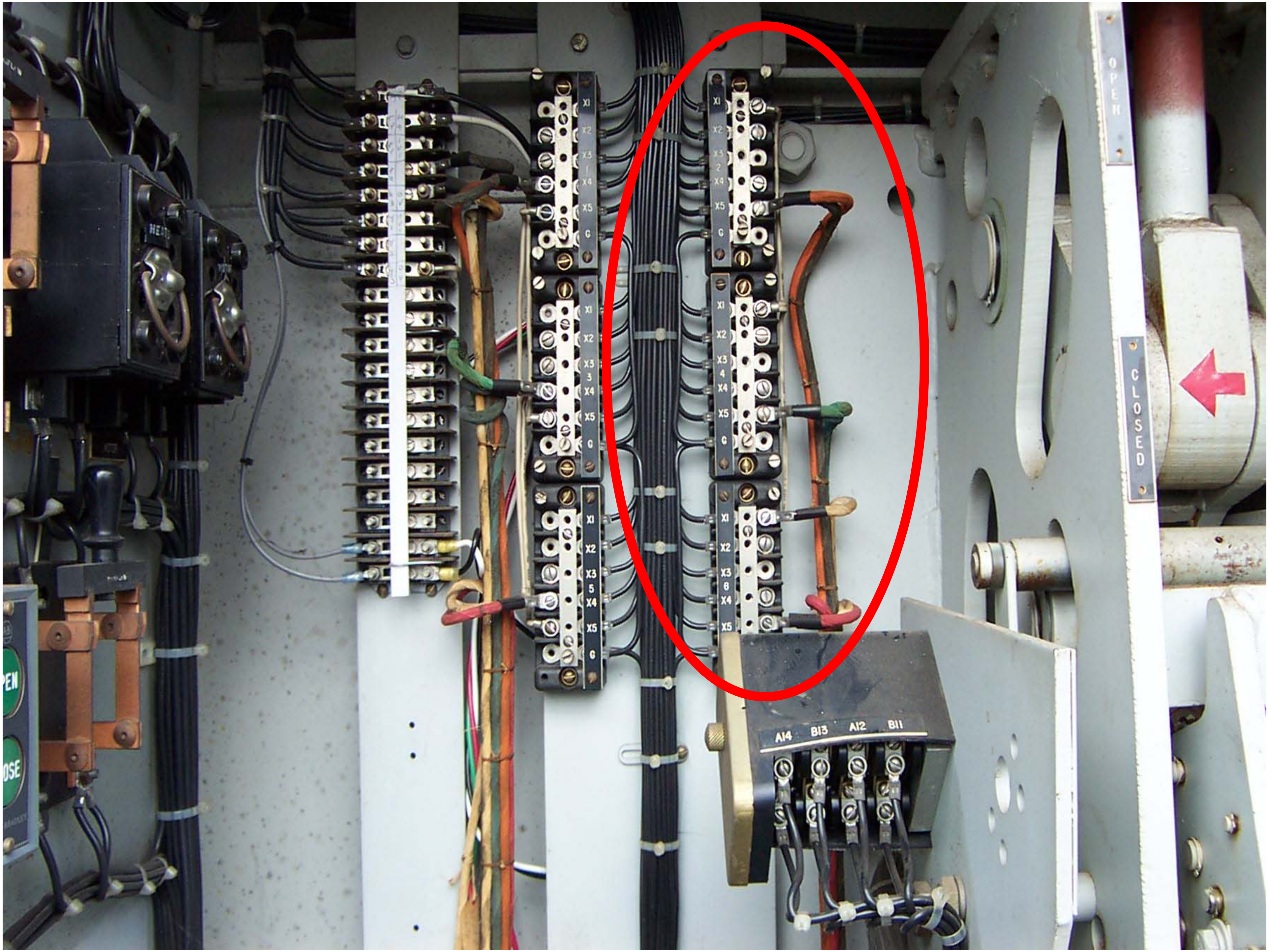
- Example BPA Standards for CT's:
  - Identification of CT Circuits for PCB's
    - Cable Designations (generally) follow the form:
      - **1H-2 = CT circuits to Instrumentation**
      - **1H-3 = CT circuits to Protective Relays**
      - **1H-4 = CT circuits to Bus Differential Relays**
      - **1H-5 = CT circuits to Revenue Metering**
    - The first number is the Construction Bay # - for our example it is Bay #1
    - The letter designates the Voltage Level of the Equipment – for our example: H = 230kV
    - The last number designates the type of Current Circuit
      - 2 = Instruments, 5 = Revenue Metering, etc.

Circuit Identification


1OH-3
1OH-4
1OH-8
17P3-1OH
AL-1OH

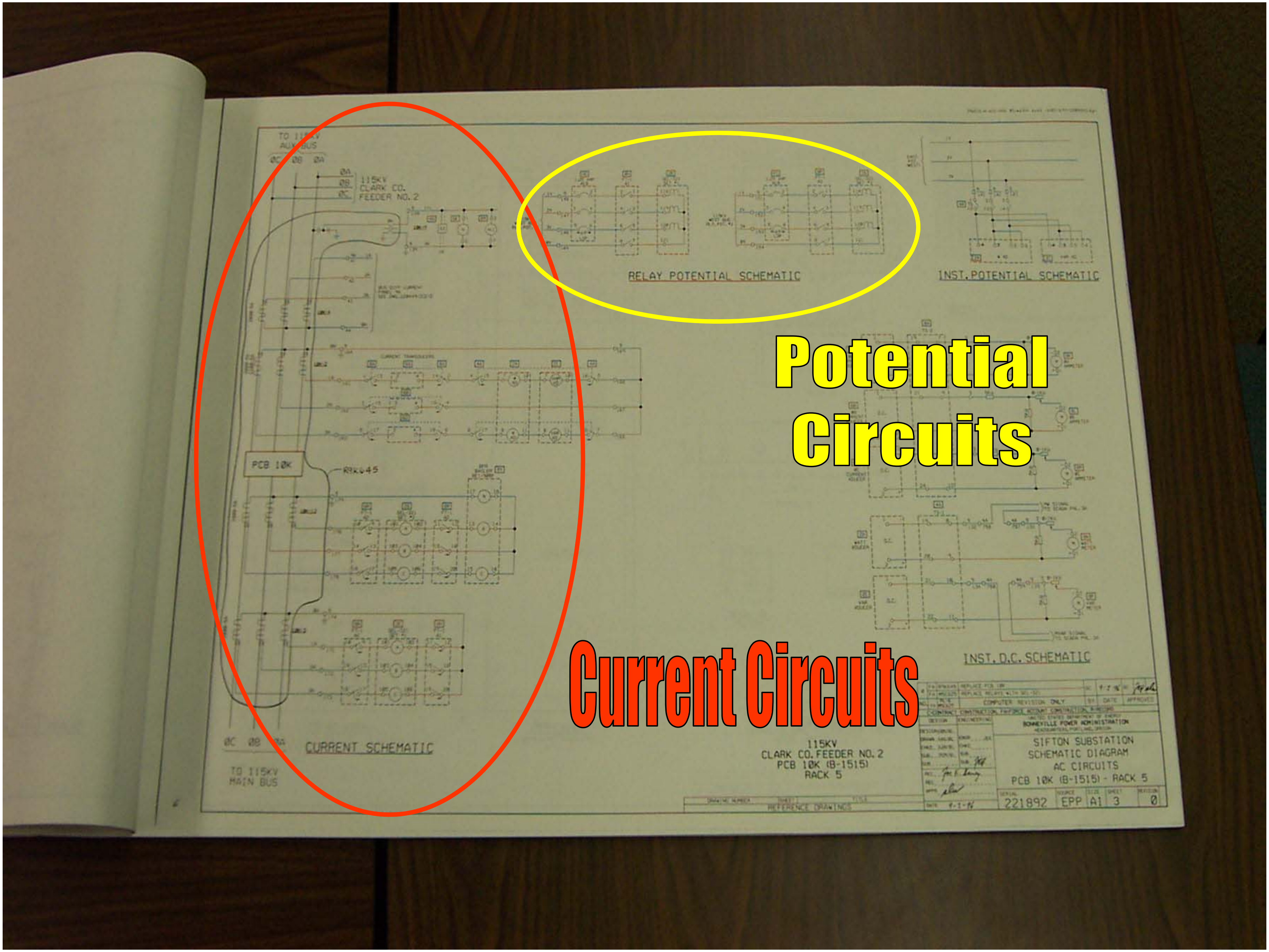
- CT Circuit considerations:
  - **Long CT Circuits may have multiple conductors in parallel for reduced CT Burden.**
  - **Multiple-conductor cables may use a different color-code for CT Circuits.**
  - **Inter-panel or internal equipment wiring from CT's to equipment terminal blocks may not have color-codes at all.**
  - **CT Wiring is generally connected with Ring-Lugs – no Spade-Lugs, etc. but exceptions do exist.**
  - **CT Circuits usually use #12 or larger wire.**
  - **Terminal Blocks may have Shorting Capability, but CT Circuits can pass through regular, non-shorting terminal blocks.**
  - **Unused CT circuits must be shorted.**
  - **CT Secondary Circuits are typically grounded, and at only one point.**

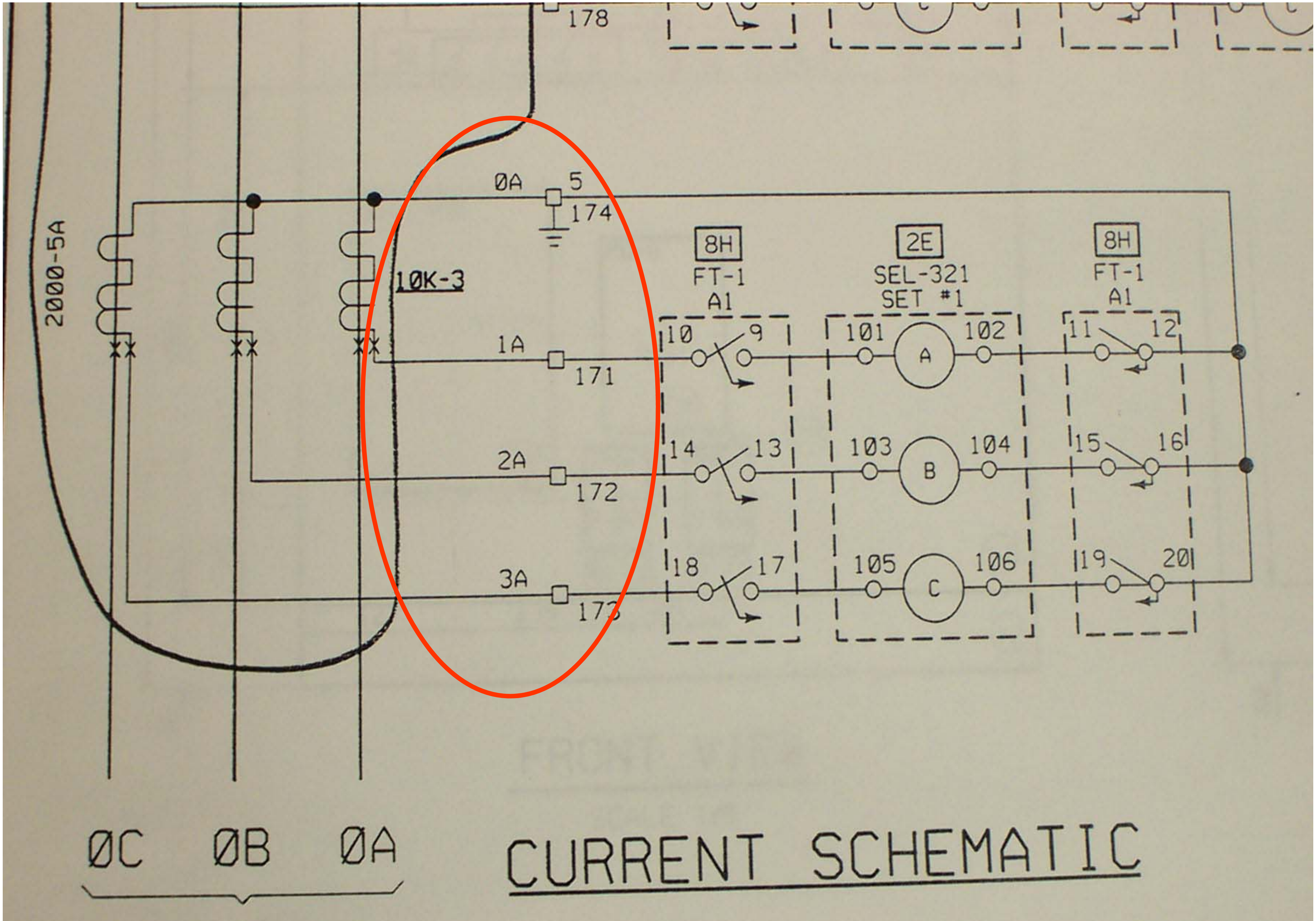
Circuit Identification


OPEN
CLOSED
X1
X2
X3
X4
X5
G
A14
B13
A12
B11

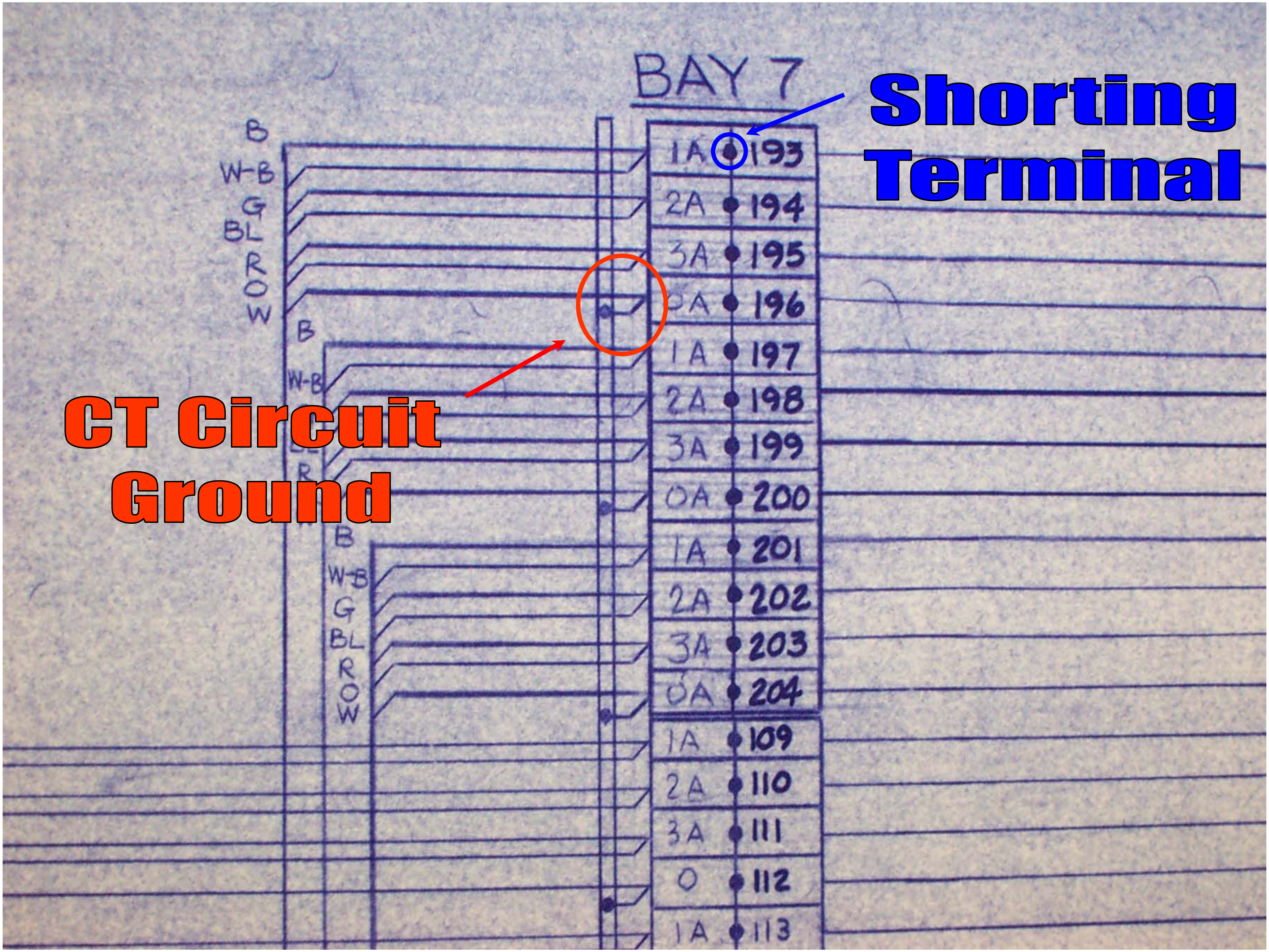
- Wiring Diagrams and/or Layout Prints should show actual placement of Terminal Blocks seen on Schematic Diagrams.
- Schematic Diagrams show Circuit Functionality and may have some Wiring Diagram information shown on them.
- Schematics and Wiring Diagrams should agree with each other.
- Your company may have standards for typical CT configurations that may aid in the identification process.

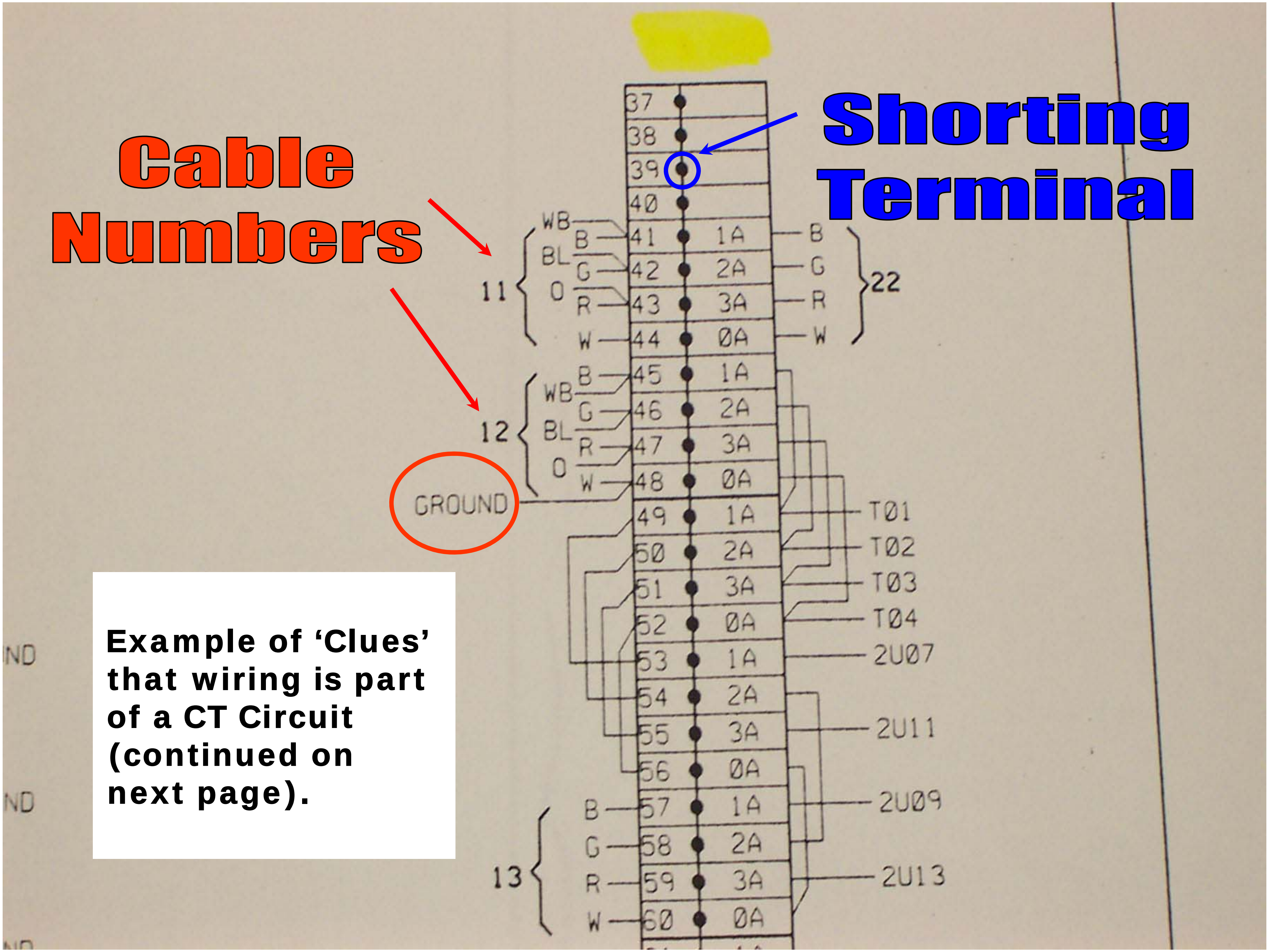
Circuit Identification


Potential Circuits
Current Circuits
TO 115KV AUX BUS
115KV CLARK CO. FEEDER NO. 2
RELAY POTENTIAL SCHEMATIC
INST. POTENTIAL SCHEMATIC
PCB 10K
INST. D.C. SCHEMATIC
CURRENT SCHEMATIC
TO 115KV MAIN BUS
115KV
CLARK CO. FEEDER NO. 2
PCB 10K (B-1515)
RACK 5
SIFTON SUBSTATION
SCHEMATIC DIAGRAM
AC CIRCUITS
PCB 10K (B-1515) - RACK 5
221892
EPP
A1
3
0
REFERENCE DRAWINGS



CURRENT SCHEMATIC


BAY 7
Shorting Terminal
CT Circuit Ground
B
W-B
G
BL
R
O
W
1A 193
2A 194
3A 195
0A 196
1A 197
2A 198
3A 199
0A 200
1A 201
2A 202
3A 203
0A 204
1A 109
2A 110
3A 111
0 112
1A 113



Example of 'Clues' that wiring is part of a CT Circuit (continued on next page).

08	C08E-3	7CC #19/22	TO PCB C08E	RELAY CURRENT NO 1
09	C08E-23	7CC #19/22	TO PCB C08E	RELAY CURRENT NO 2
10			TO PCB C08E	RELAY CURRENT-BFR
11	C08E-14	7CC #19/22	TO PCB C08E	WEST BUS DIFF CURRENT
12	C08E-2	7CC #19/22	TO PCB C08E	INSTR CURRENT
13	C0508E-2	4CC #12	TO PANEL 1	INSTR CURRENT
14	C05E-3-1	4CC #12	TO RACK 58	RELAY CURRENT NO 2
15				
16	C08E-13-1	4CC #12	TO RACK 203	RELAY CURRENT NO 1
17	C05E-13-1	4CC #12	TO RACK 203	RELAY CURRENT NO 1
18	C05E-23-1	4CC #12	TO RACK 56	RELAY CURRENT-BFR
19	C05E-14-1	4CC #12	TO RACK 59A	WEST BUS DIFF CURRENT
20	C08E-3-1	4CC #12	TO RACK 58	RELAY CURRENT NO 2
21	C08E-23-1	4CC #12	TO RACK 56	RELAY CURRENT-BFR
22	C08E-14-1	4CC #12	TO RACK 59A	WEST BUS DIFF CURRENT
23				
24				
25	CAP1-SA	4CC #19/22	TO CAP GRP 1	CAP GRP 1 SUBGRP A RLY POT.
26	CAP1-SB	4CC #19/22	TO CAP GRP 1	CAP GRP 1 SUBGRP B RLY POT.
27	CAP1-SA-1	4CC #12	TO RACK 57	CAP GRP 1 SUBGRP A RLY POT.
28	CAP1-SA-2	4CC #12	TO RACK 203	CAP GRP 1 SUBGRP A RLY POT.
29	CAP1-SB-1	4CC #12	TO RACK 57	CAP GRP 1 SUBGRP B RLY POT.
30	CAP1-SB-2	4CC #12	TO RACK 203	CAP GRP 1 SUBGRP B RLY POT.
31	CAP2-SA	4CC #19/22	TO CAP GRP 2	CAP GRP 2 SUBGRP A RLY POT.
32	CAP2-SB	4CC #19/22	TO CAP GRP 2	CAP GRP 2 SUBGRP B RLY POT.
33	CAP2-SA-1	4CC #12	TO RACK 59	CAP GRP 2 SUBGRP A RLY POT.
34	CAP2-SA-2	4CC #12	TO RACK 203	CAP GRP 2 SUBGRP A RLY POT.
35	CAP2-SB-1	4CC #12	TO RACK 59	CAP GRP 2 SUBGRP B RLY POT.
36	CAP2-SB-2	4CC #12	TO RACK 203	CAP GRP 2 SUBGRP B RLY POT.
				WEST BUS INSTR POT #2

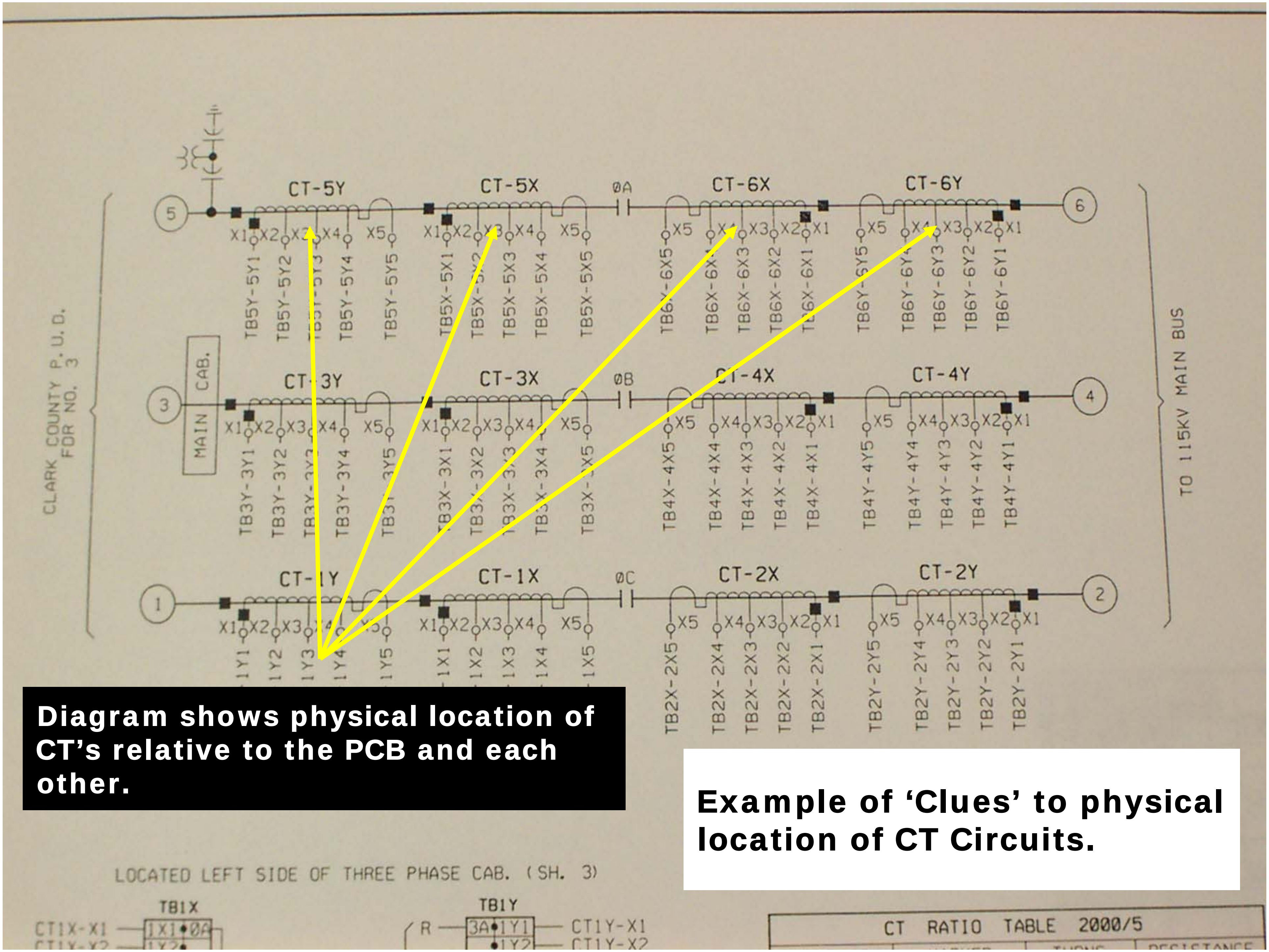
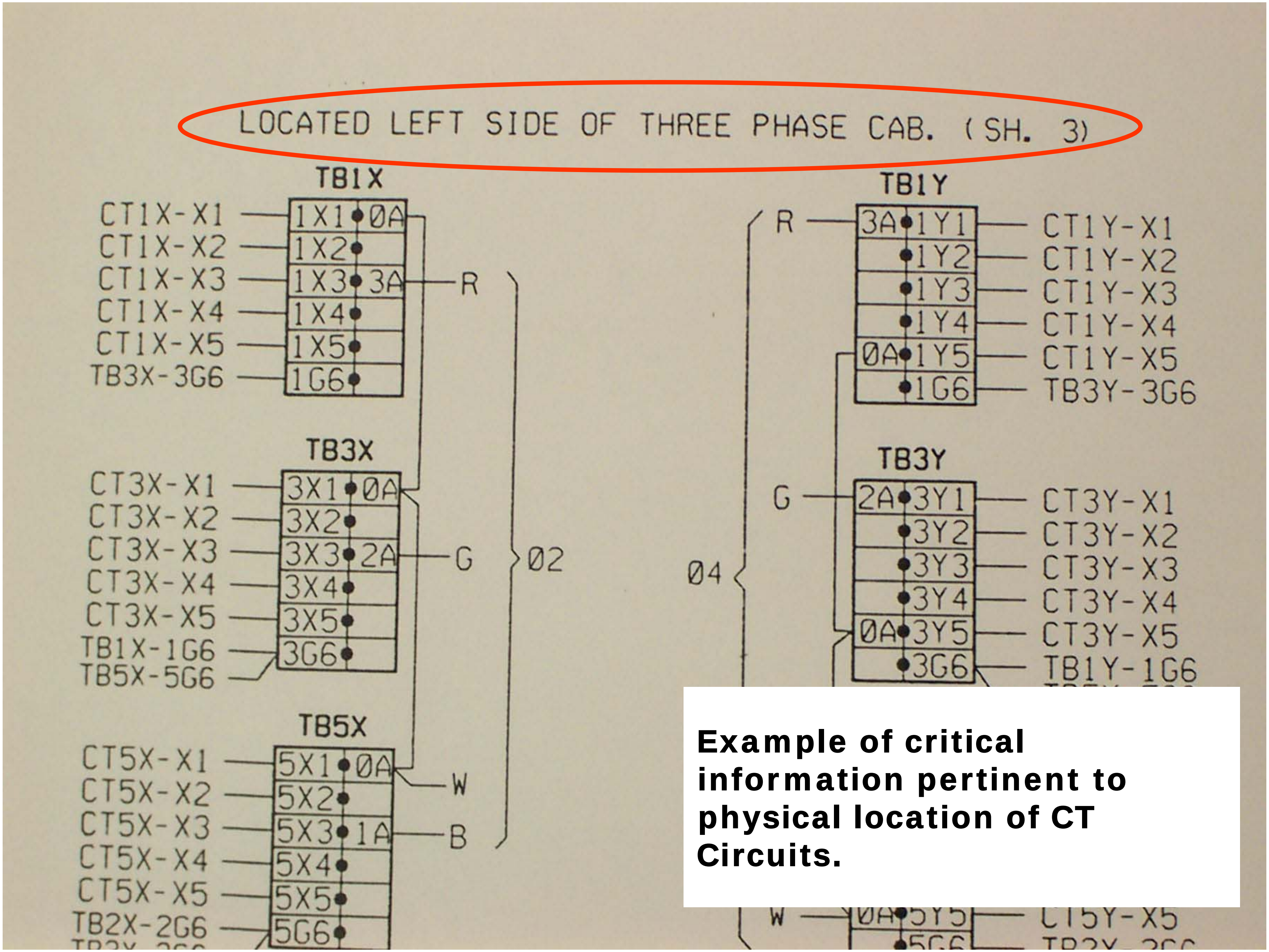


Diagram shows physical location of CT's relative to the PCB and each other.

Example of 'Clues' to physical location of CT Circuits.



Example of critical information pertinent to physical location of CT Circuits.

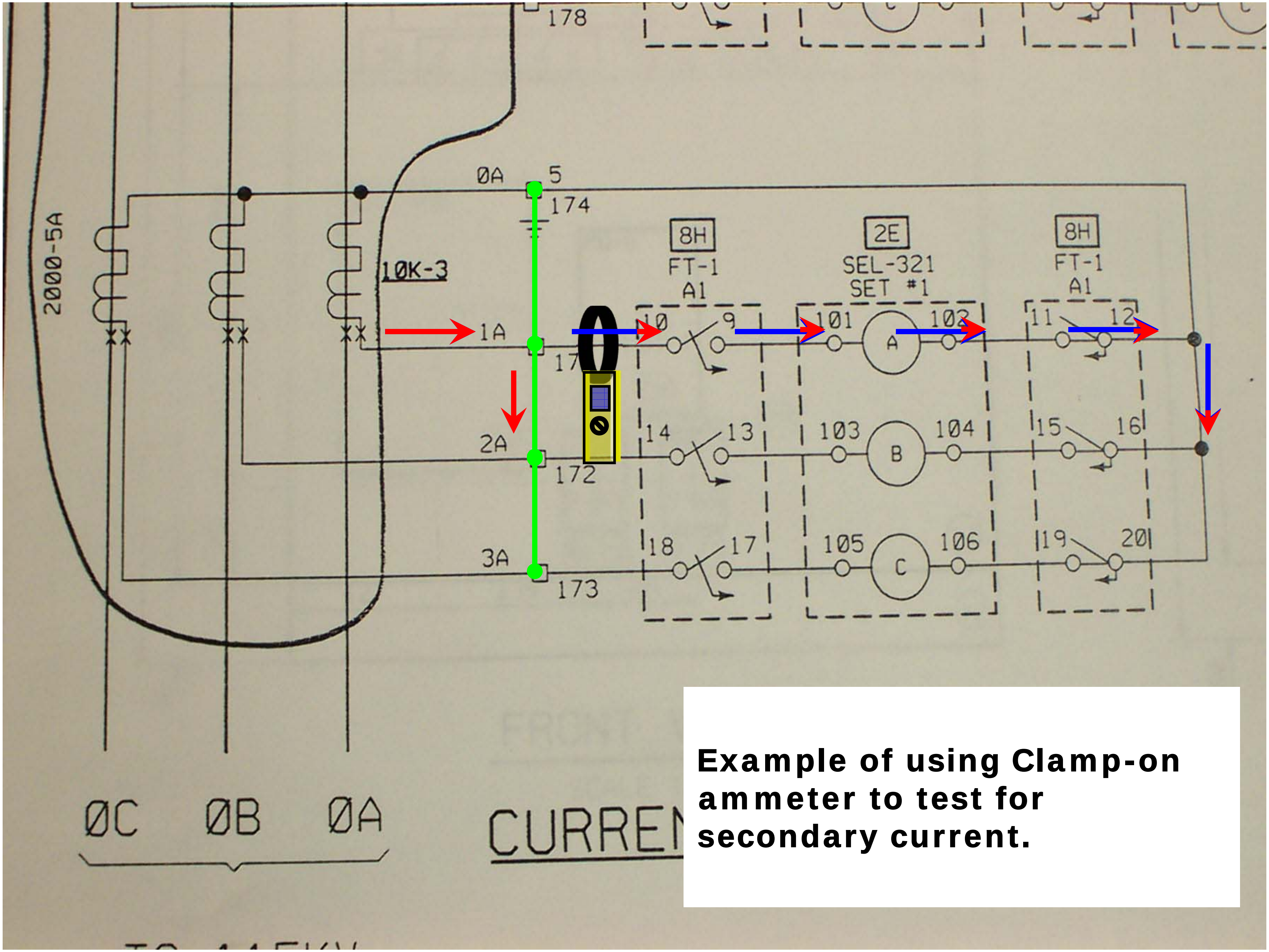
- At some companies, testing CT's for secondary current before lifting wires is normal operating procedure. At others it is optional.
- This presentation recommends always testing for secondary current.
- Although it is not a definitive test, it is still a good aid in determining the condition of a CT Secondary.
- Almost every CT accident the author has heard of that caused physical injury did not involve this test, and most would likely have been prevented had it been done.

- After a CT Circuit is identified, testing before work begins helps verify that the CT Secondary will not be opened with current in the primary.
- Ideally, CT secondary work will be performed with no primary current flowing in the CT, and thus no secondary current.
  - If you test the circuit and find it unloaded as you thought it should be, the testing helps reaffirm your identification procedure – although it doesn't confirm it 100% because of the possibility that the CT Circuit was unloaded but In-Service at the time of testing…
- Testing is not 'foolproof' – <u>you can still be on the wrong circuit</u>.

Testing for Energized Circuits

- One good method for testing is to put a clamp-on ammeter on the circuit to be modified before installing CT shorting screws. Upon installation of the CT shorting screws, any current in the CT secondary circuit should decrease to low values. This provides indication that the correct circuit was shorted as well as indication that any residual circuit current will divert through the CT shorting device when CT secondary wiring is lifted.

Testing for Energized Circuits



Example of using Clamp-on ammeter to test for secondary current.

- When CT secondary work is performed with the expectation that the CT has no primary current at all – such as when equipment is out-of-service – any ‘measurable’ CT secondary current is indication that the circuit identification needs to be reviewed.

- **Note that in cases where multiple CT’s are connected into one circuit, current testing will probably be inconclusive.**
  - This will typically occur with Differential Relay circuits as well as Breaker and ½ or Ring Bus configurations.

Testing for Energized Circuits

- Q: Why do we test for Secondary current if it may indicate current on a ‘safe’ circuit and it may indicate no current on a potentially ‘unsafe’ circuit?
- **A: Because it can indicate that a circuit is unsafe when it is unsafe.**

- It is therefore another ‘tool’ in the safe work process. Like most evaluation methods, it is not foolproof – thought must be given to what the ‘tool’ tells us.

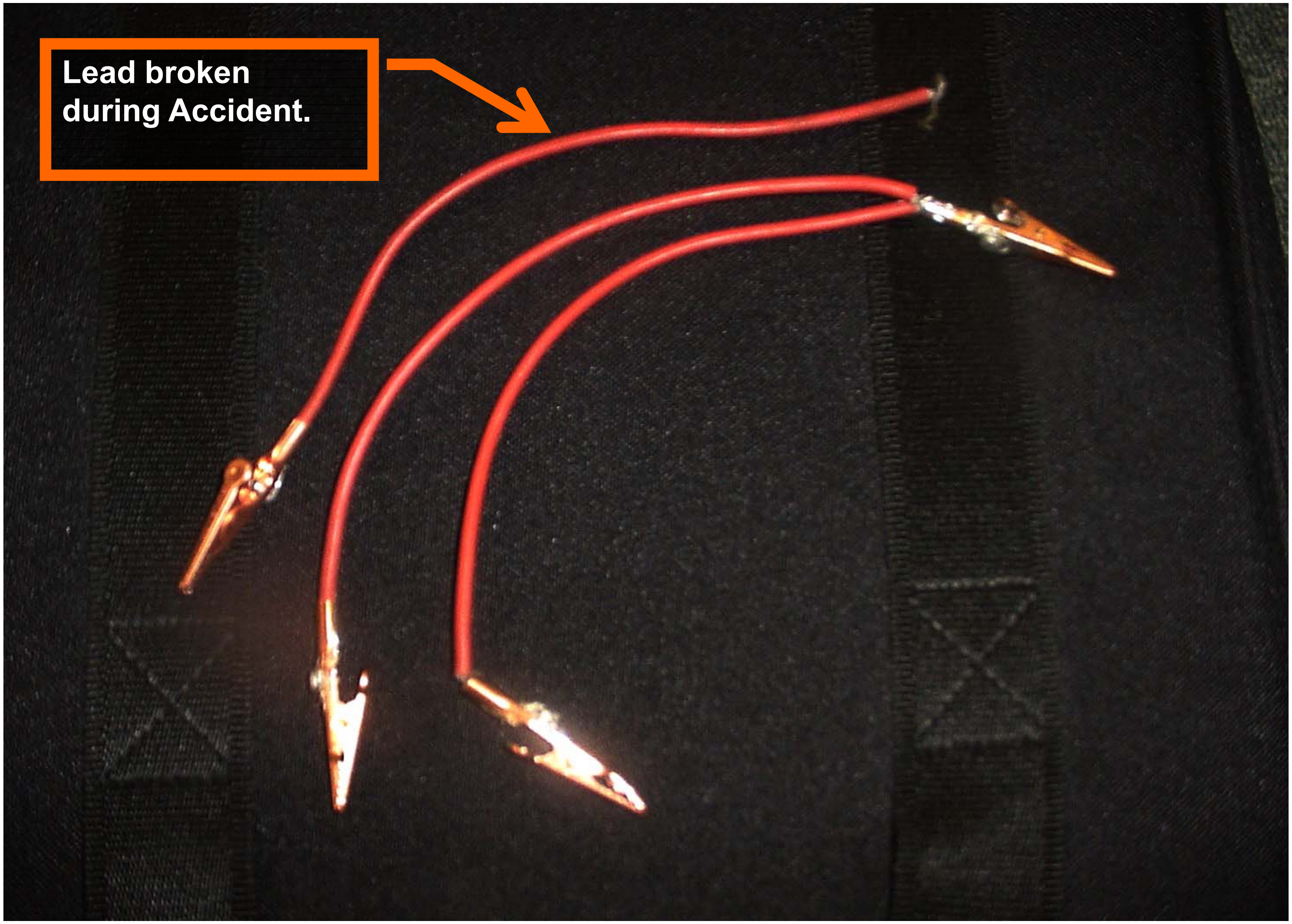
❤ Note that two accidents mentioned in this presentation could have potentially been avoided if testing for current had been performed prior to lifting of CT secondary wiring.

- 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.

Visual / Audible Arcing Check

- When the visible/audible arcing check cannot be performed at a terminal block, extra caution should be used to properly perform this test if possible.
  - For example, if a current ‘short’ was made with alligator clips on wires hanging in open-air (waiting to be terminated), this test would be much harder to perform than as is normally done with a holding screwdriver at a terminal block.

Leads in-use at time of 2nd Accident



- With a primary load current that would normally produce a CT secondary current as low as 500 milliamps (0.5A), an open-circuit condition can produce over 1500V on power system CT secondaries.
- 500 milliamps is high enough to possibly stop the heart as well as breathing and is enough to kill*.
- Note that 0.5A secondary can be produced from a primary load current as low as:
  - 300A on a 3000:5 CT
  - 400A on a 4000:5 CT
  - 120A on a 1200:5 CT

Visual / Audible Arcing Check

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.**

- Some known Field Practices for lifting CT Wiring are:
  1) Break screw loose with regular screwdriver then lift slowly with Holding Screwdriver so that screw can be re-tightened quickly in the event the CT does become open-circuited under-load.
  2) Break screw loose with regular screwdriver and back almost all the way out with screwdriver, then use pliers to gently pull screw out.

3) Break screw loose and completely remove with screwdriver while holding on to cabling with hand. Not the best method as it's the hardest to restore if necessary and also provides more opportunity for the hand holding the wiring to become part of the CT Current Circuit in the event the CT does become open-circuited under-load.

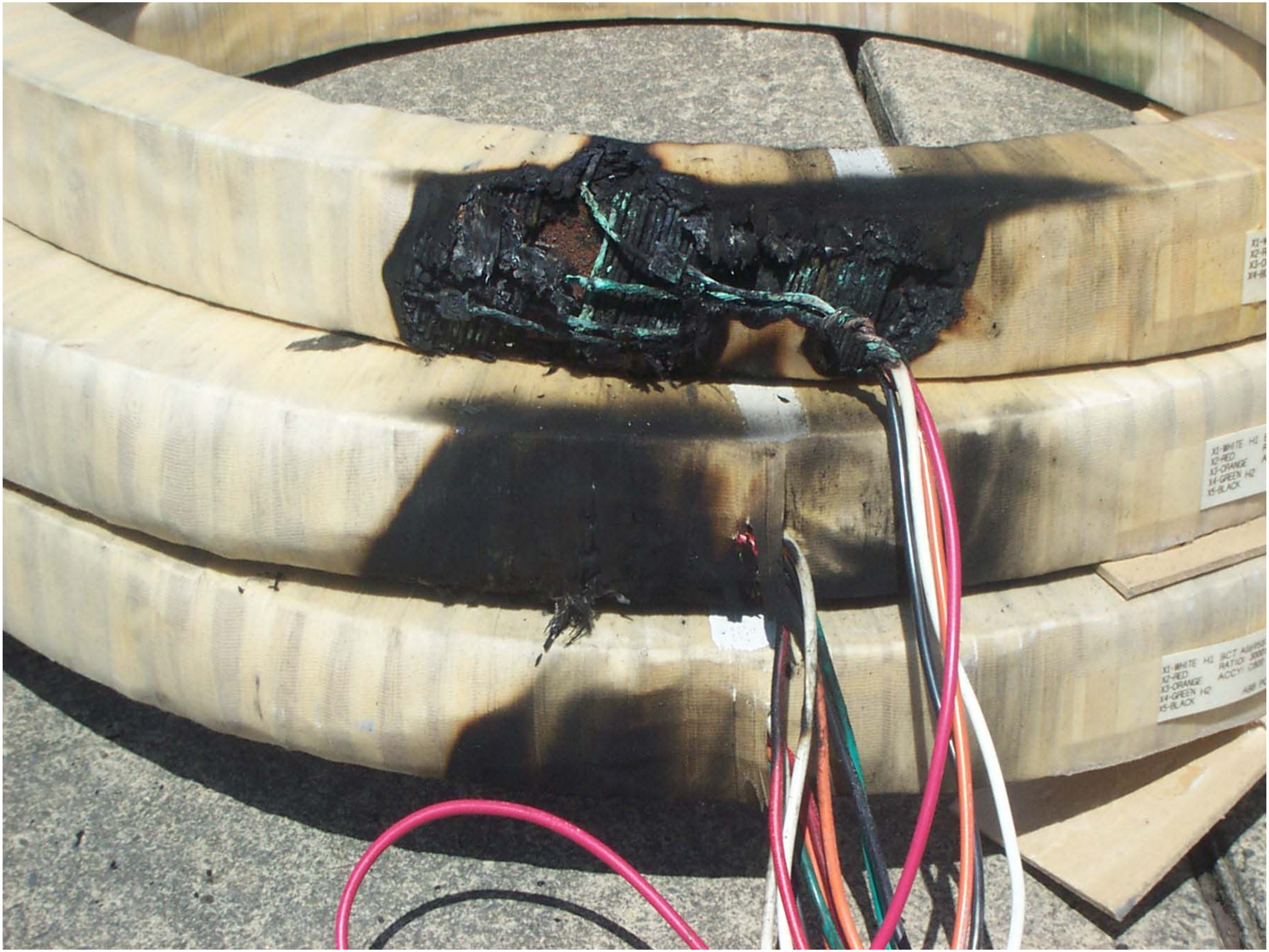
- #1 is the Best Method of those described, although even better is the additional use of Insulated Tools.

- 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…

- CT Secondary wires can be shorted after removal or before being ‘laid down’ during installation as a safety precaution.
- Any time CT circuits are shorted they should be tested and handled as if they were energized before open-circuiting them.
  - These circuits should be treated just like any other CT circuits because of the possibility of them carrying current.

- One additional point:
  - Open-Circuiting a CT could potentially cause internal failure of the CT itself. Internal Failure of the CT could cause failure of the equipment that the CT is installed on.

If a High-Voltage Breaker or Transformer fails there is added potential for Human Injury in addition to Equipment Loss…


X1-WHITE H1
X2-RED
X3-ORANGE
X4-GREEN H2
X5-BLACK
X1-WHITE H1
X2-RED
X3-ORANGE
X4-GREEN H2
X5-BLACK

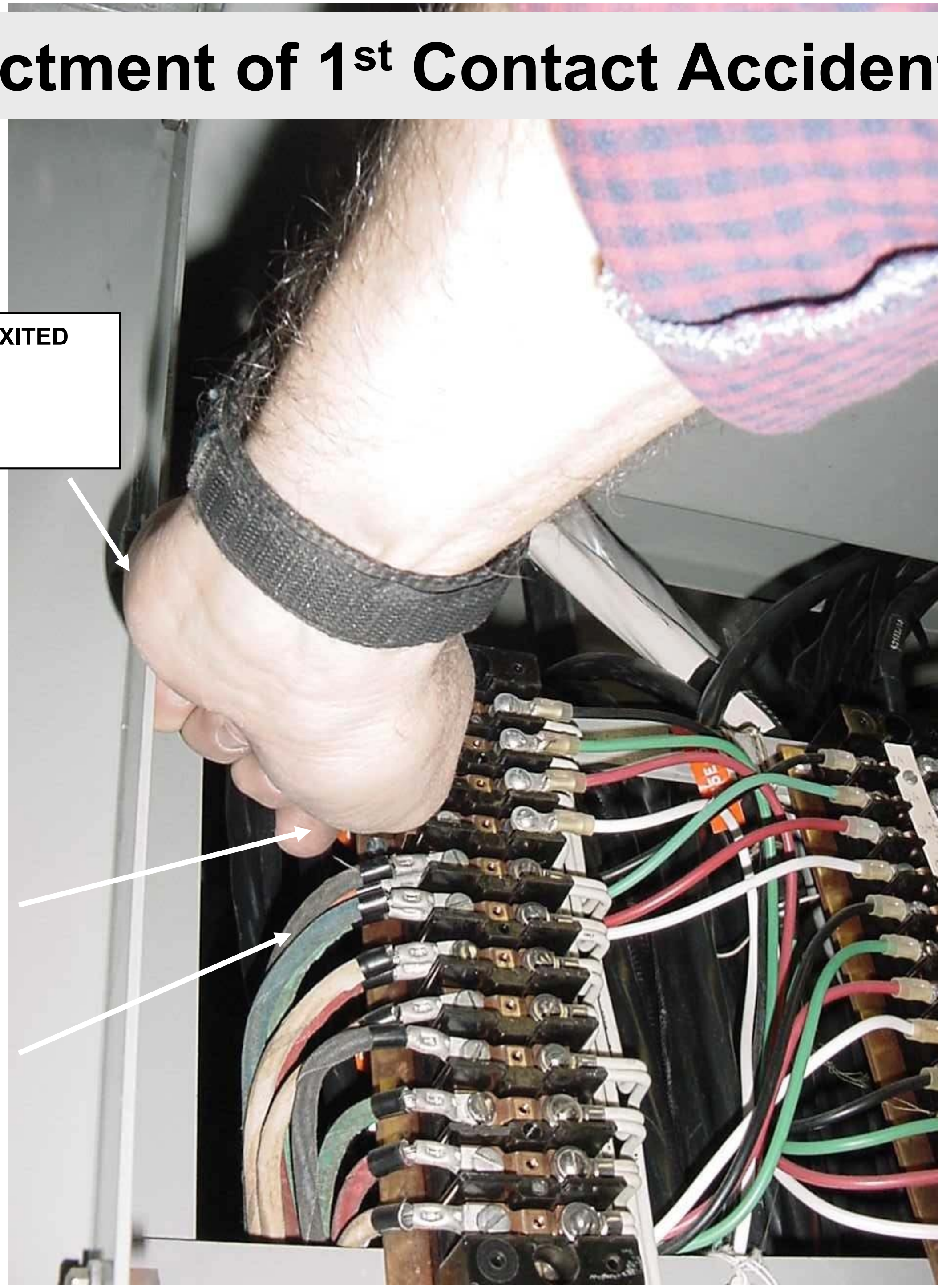
- Care should be taken to keep yourself from becoming a possible current path for the CT Circuit should it become open-circuited.

  - 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.

- It is good practice to work with no part of your body touching a grounded object if there is a chance that you may contact the CT conductor during a CT open-circuit condition.
  - You can help insulate yourself through the use of Insulated Tools and/or Safety Gloves and Blankets.
    - Note that there is no known standard for what level of Safety equipment to use – but since CT's can produce 10kV+ peak voltages, you must make sure to use a blanket or glove with a high enough classification level that will adequately protect you. If you determine that you need extra protection, contact your Safety Office for assistance.
- Basically – treat the conductor as being energized with high-voltage. Insulate yourself from it and avoid becoming part of it's possible electrical path.
- It should also be noted that most insulated tools are rated for 1kV AC. Therefore they should not be relied upon for personal safety. Their use is an added safety measure, but not a guarantee of safety.
  - Some utilities issue high-voltage gloves and workers wear them whenever they are dealing with CT circuits…

Safe Work Practices

Re-enactment of 1st Contact Accident



Quote from the Accident Report:

"The Electrician said he could smell his flesh burning"

- It is the author's opinion that if a CT Circuit does become open-circuited to the point where it has arced to a person or a relay rack it is safer to immediately open the Power System Circuits necessary to remove the Primary CT Current rather than trying to handle the CT Lead with High Voltage on it to restore the CT Secondary.
- Handling a violently arcing CT Secondary can cause injury to the person trying to restore the circuit…

- Note that high-voltage is still present at shorting blocks as well as all points that are still part of the CT secondary circuit.

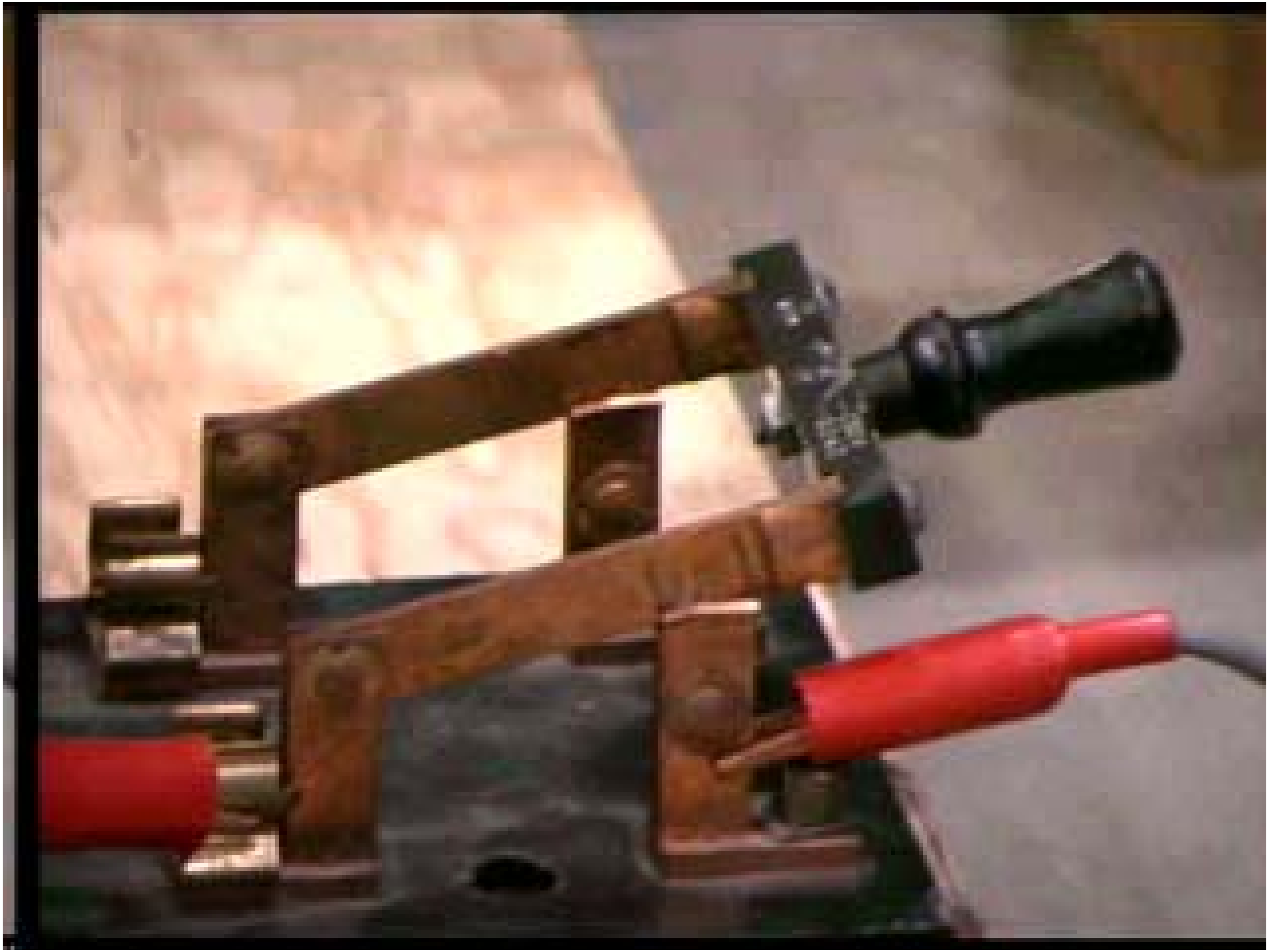
- CT Circuits can be restored safely with no Primary Current if necessary. It is not worth getting someone hurt or killed to save an Outage…

- If the CT Secondary leads are lifted slowly and arcing is heard it should be easy to restore without having to open PCB’s. In this case it would be safer to put the screw back in than to completely open-circuit the CT Secondary by dropping the screwdriver/starter.

- Note that if **Job Briefings** are held and **Energy Source Controls** are discussed, the consequences of an open-circuited CT secondary can be discussed **before** they happen and appropriate actions can be discussed **before** they are needed.

- If time is taken beforehand to discuss these things, it may be possible in an emergency to avoid further injury to people **as well as** avoid an outage.

- Sample items that can be covered at a Job Briefing or ‘Tailgate’:
  - **<u>Hazards associated with the Job.</u>**
  - **<u>Work Procedures.</u>**
  - **<u>Special Precautions.</u>**
  - **<u>Energy Source Controls</u>**
  - **<u>Personal Protective Equipment.</u>**
  - **<u>Clearances, Work Permits, Hold Orders</u>**



- 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.

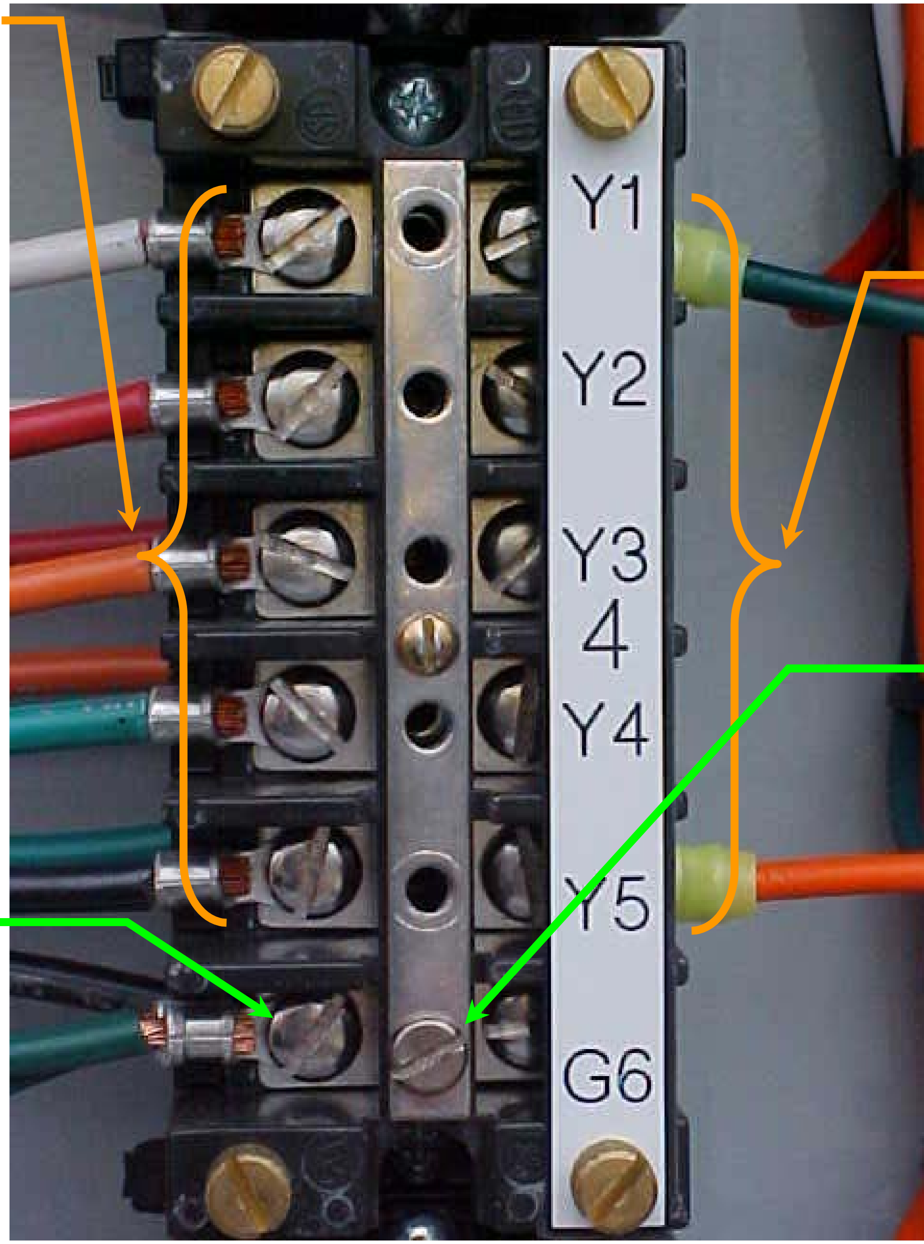
CT Shorting Blocks

'Single-Phase' Type CT Shorting Block

CT ratio tap wiring from one individual CT

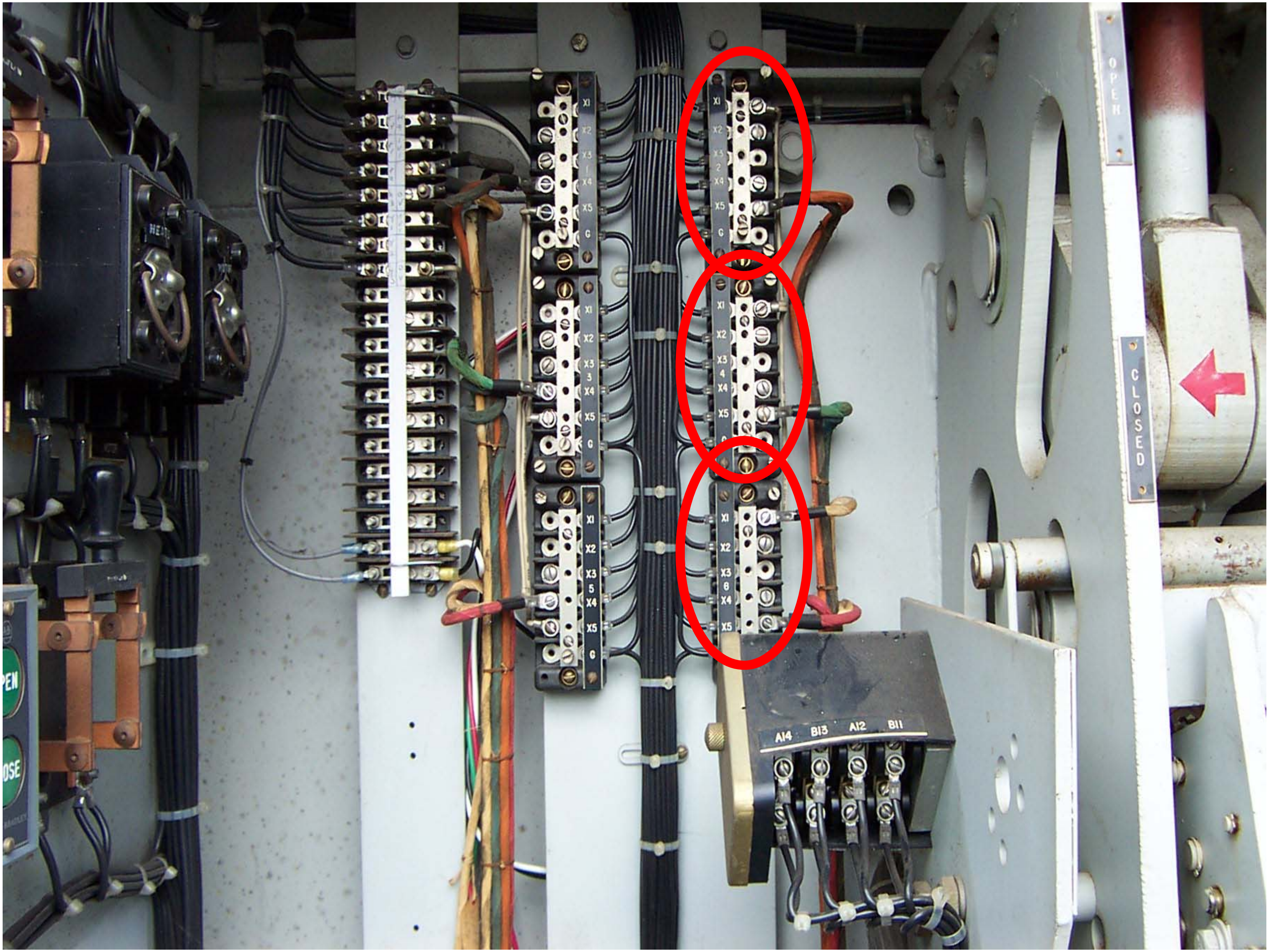
Note that a **minimum** of **two** screws are needed to short this 1 CT – if the full winding is shorted (Y1-Y5 in this case).

Shorting Block Ground



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

Ground screw connection normally left in-place.

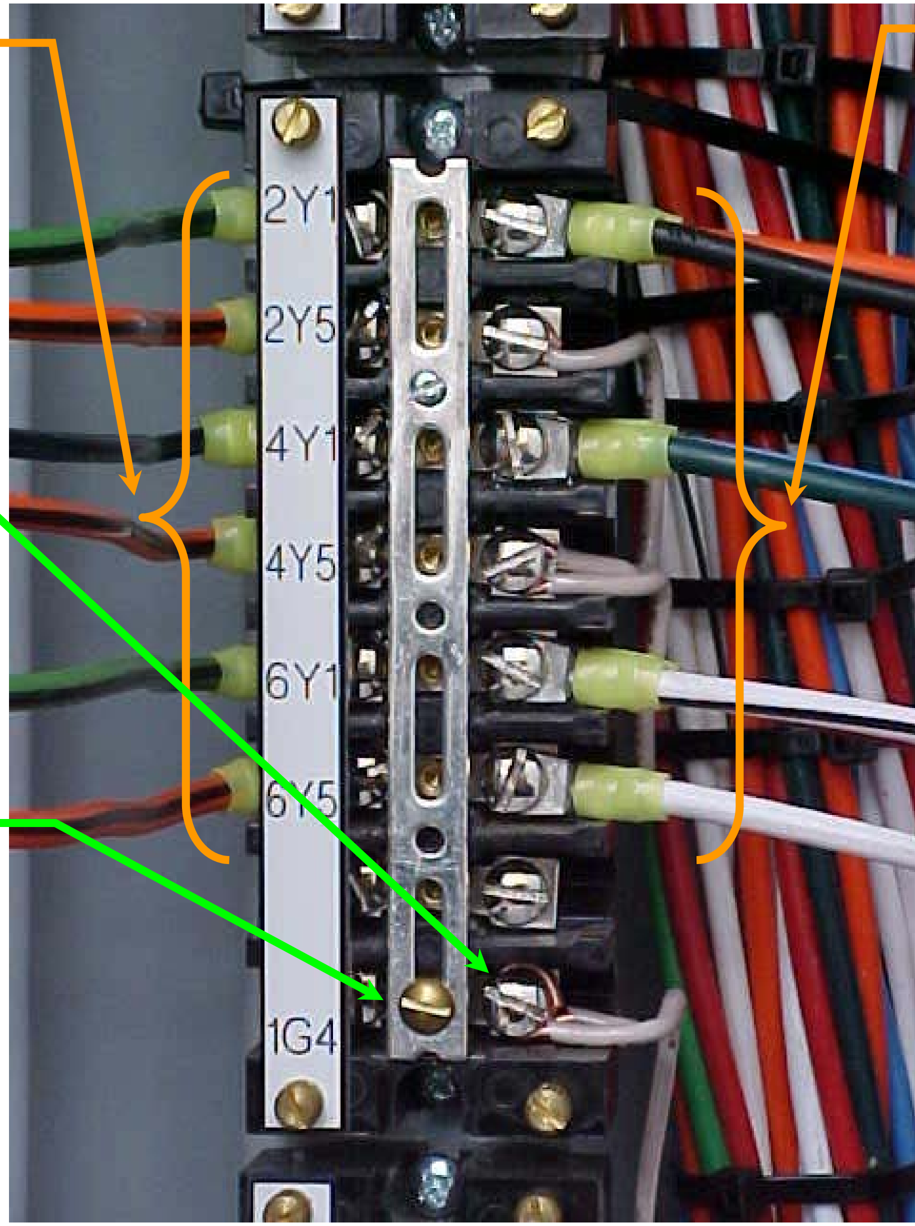

X1
X2
X3
X4
X5
G
OPEN
CLOSED
A14
B13
A12
B11

‘Three-Phase’ Type CT Shorting Block

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

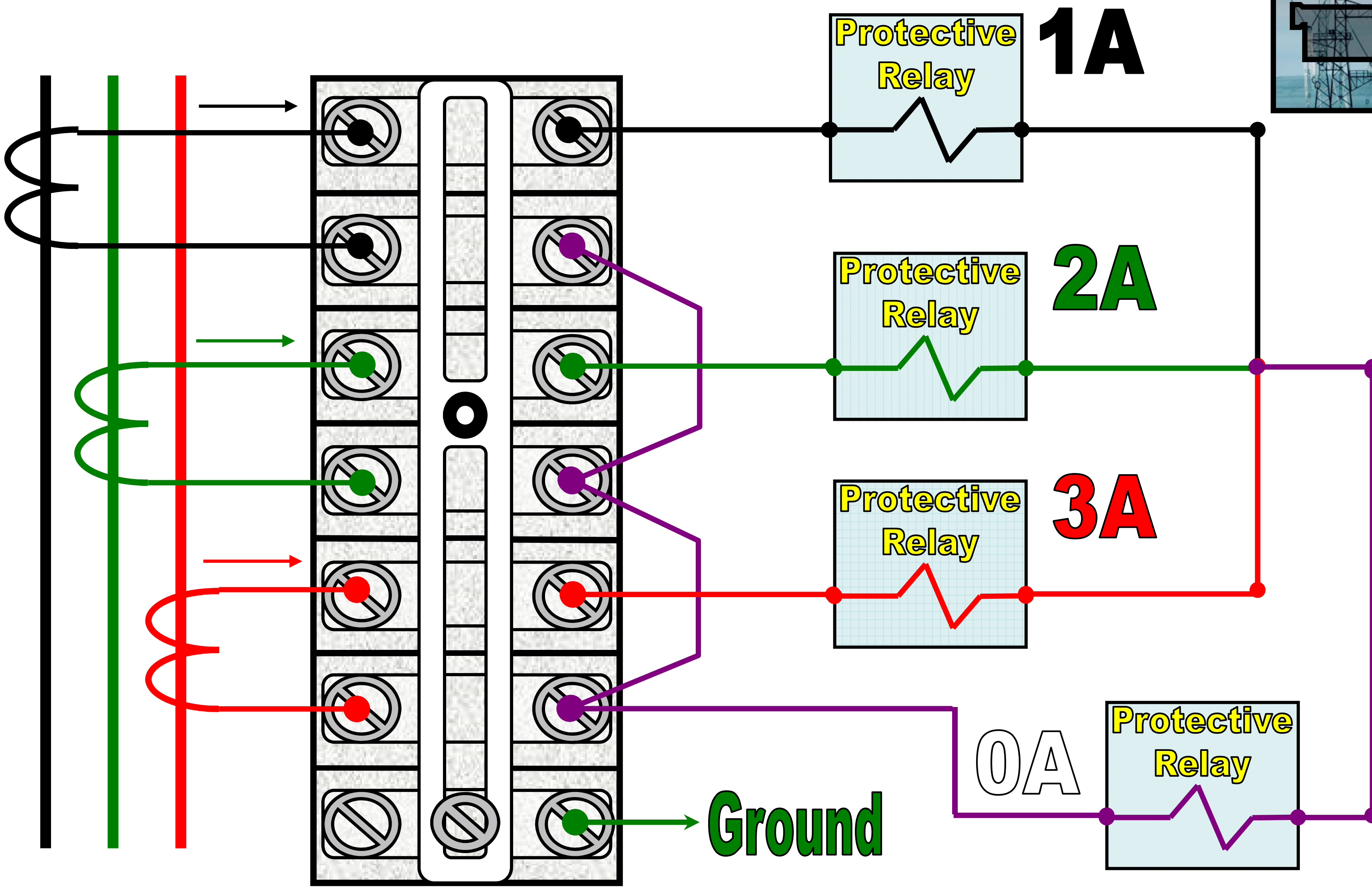
Shorting Block Ground

Ground screw connection normally left in-place.

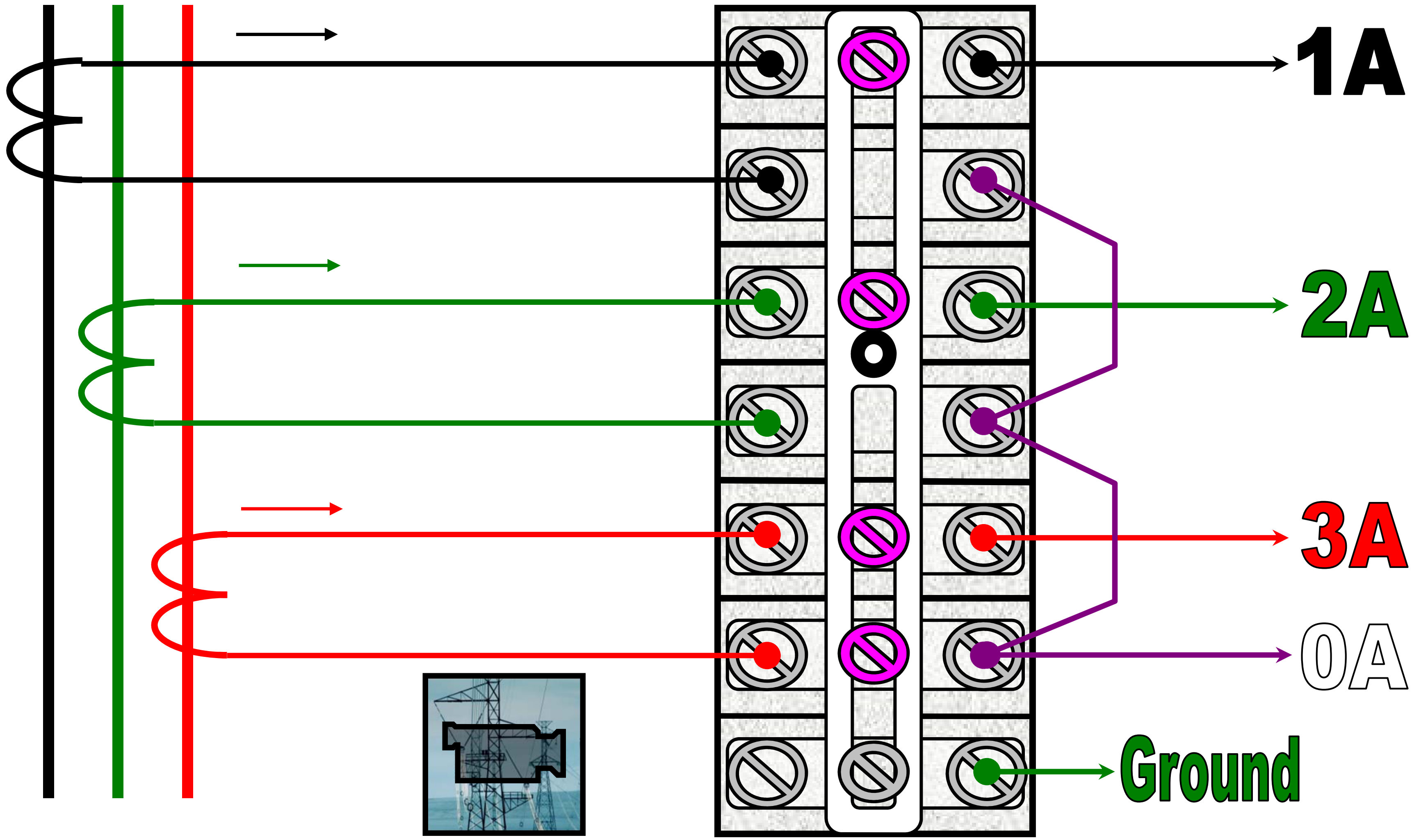


Three-Phase wiring to relays, instruments, etc.

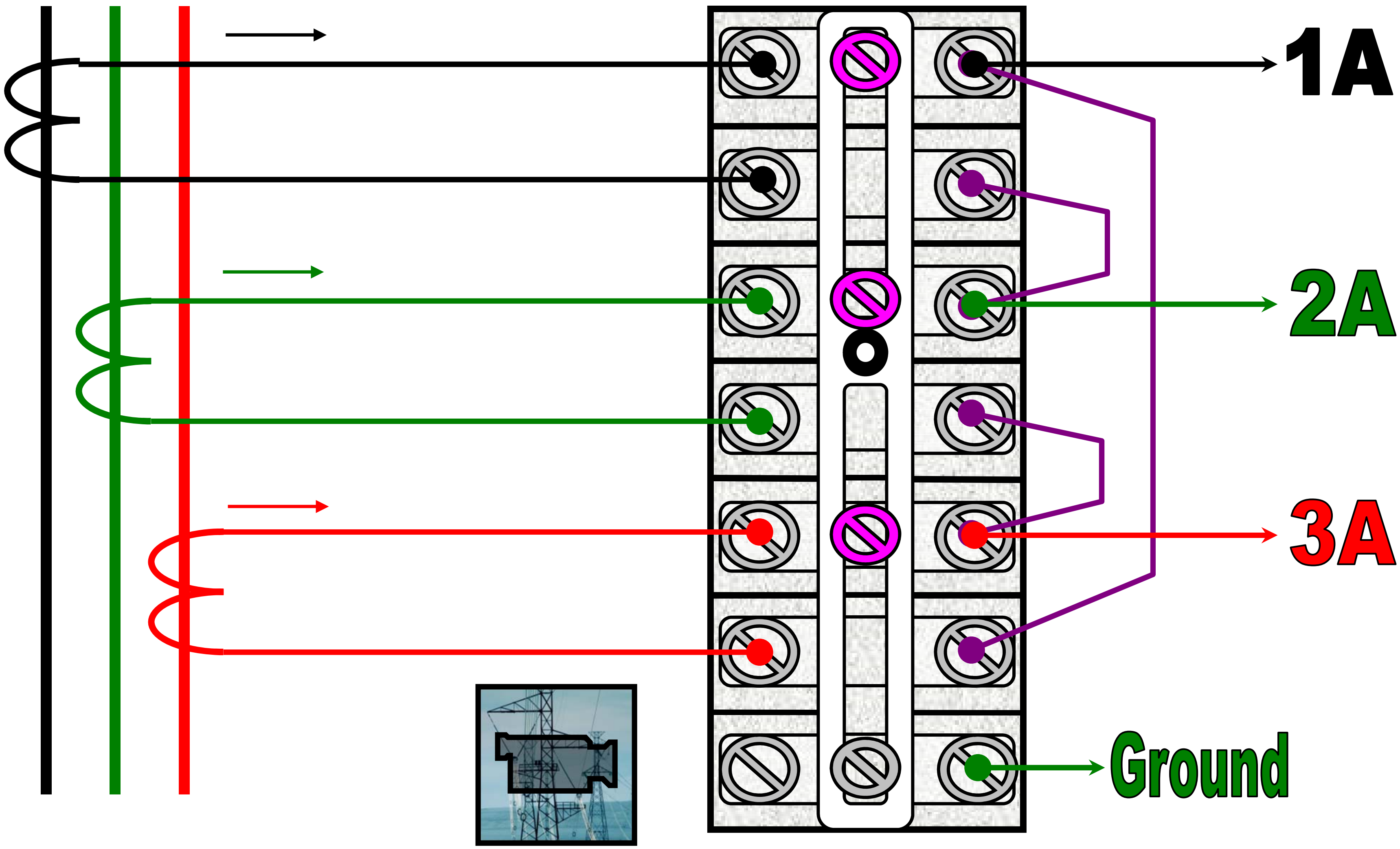
Note that it takes a **minimum** of **four** screws to short this set of 3 CT’s – (**2Y1**, **4Y1**, **6Y1**, and **one** of 2Y5, 4Y5, and 6Y5 in this case) – as long as the Wye connection is intact – white wiring here.



Three-Phase Block Analysis



Three-Phase Block Analysis



Three-Phase Block Analysis

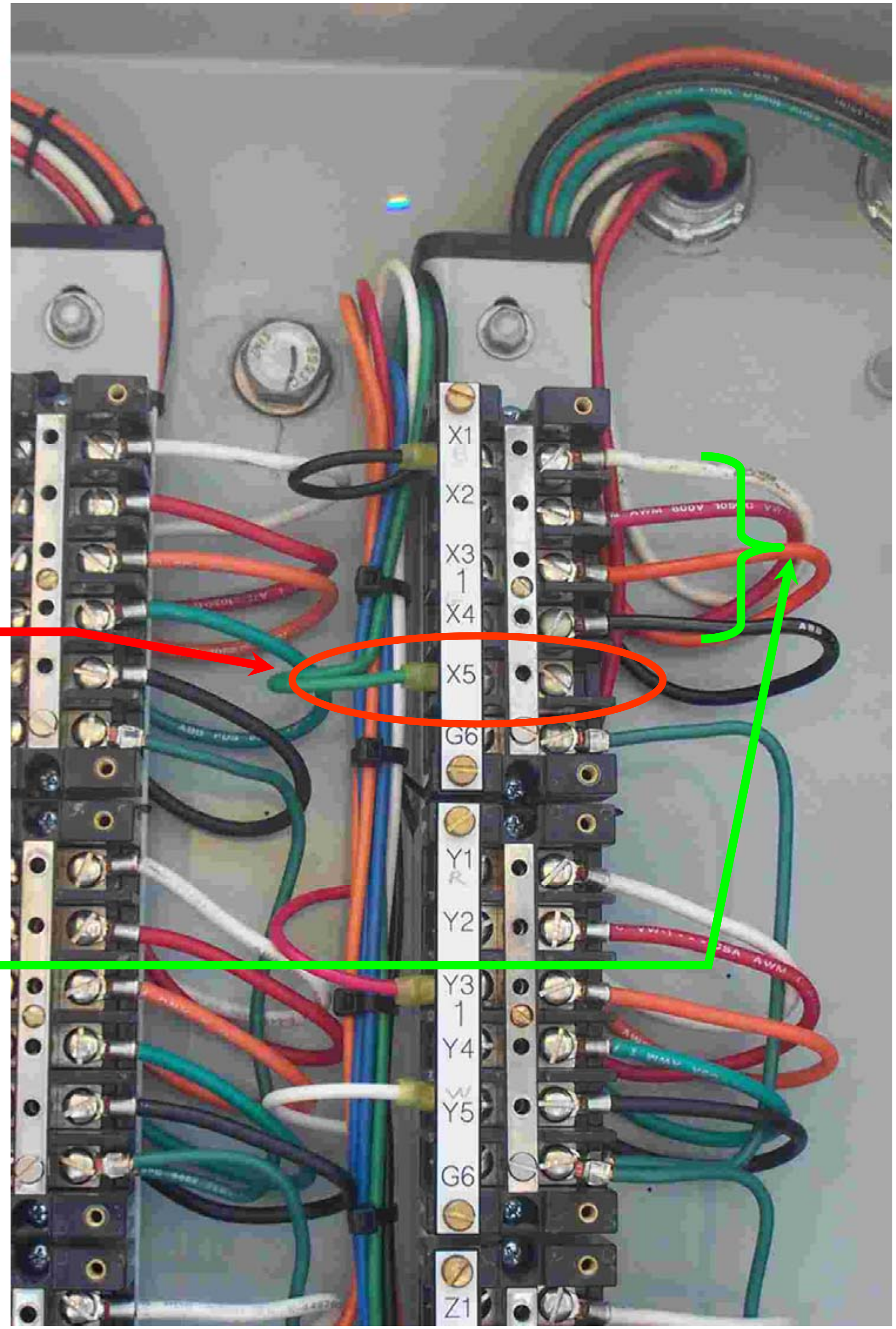
- Make sure shorting block screws are proper for the block being shorted.
  - Screws that are improper for the block in question may ‘bottom out’ and not make good contact with the shorting bar.
- If there are enough shorting screws available, consider completely shorting the whole block.
- Some blocks have the labels held in place by the shorting screws. If necessary, use an alternate method to hold labels in place to avoid mixing up the labels.

CT Shorting Block Cautions

- Make sure necessary wiring is in place to effectively short ‘Three-Phase’ type blocks.
- **Whenever using less than 6 shorting screws for a 3-phase circuit, the ‘Wye’ or ‘Delta’ connections MUST be intact or some CT’s may not be properly shorted.**
- When shorting ‘Single-Phase’ CT’s, general practice is to short the full winding.
  - CT’s have varying numbers of wires/ratios available. Don’t just assume ‘5’ wires brought out to the shorting block.

CT Shorting Block Cautions

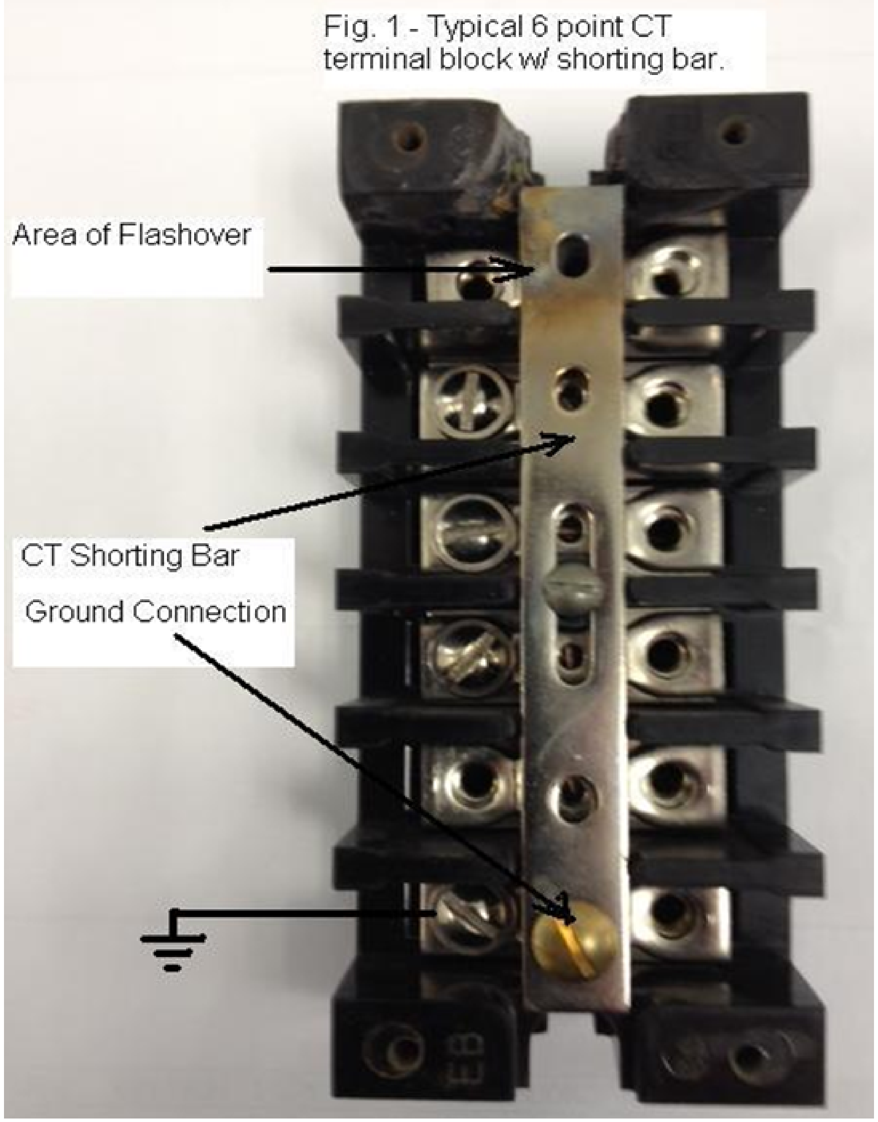
Ostrander Open-Circuit CT Incident



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

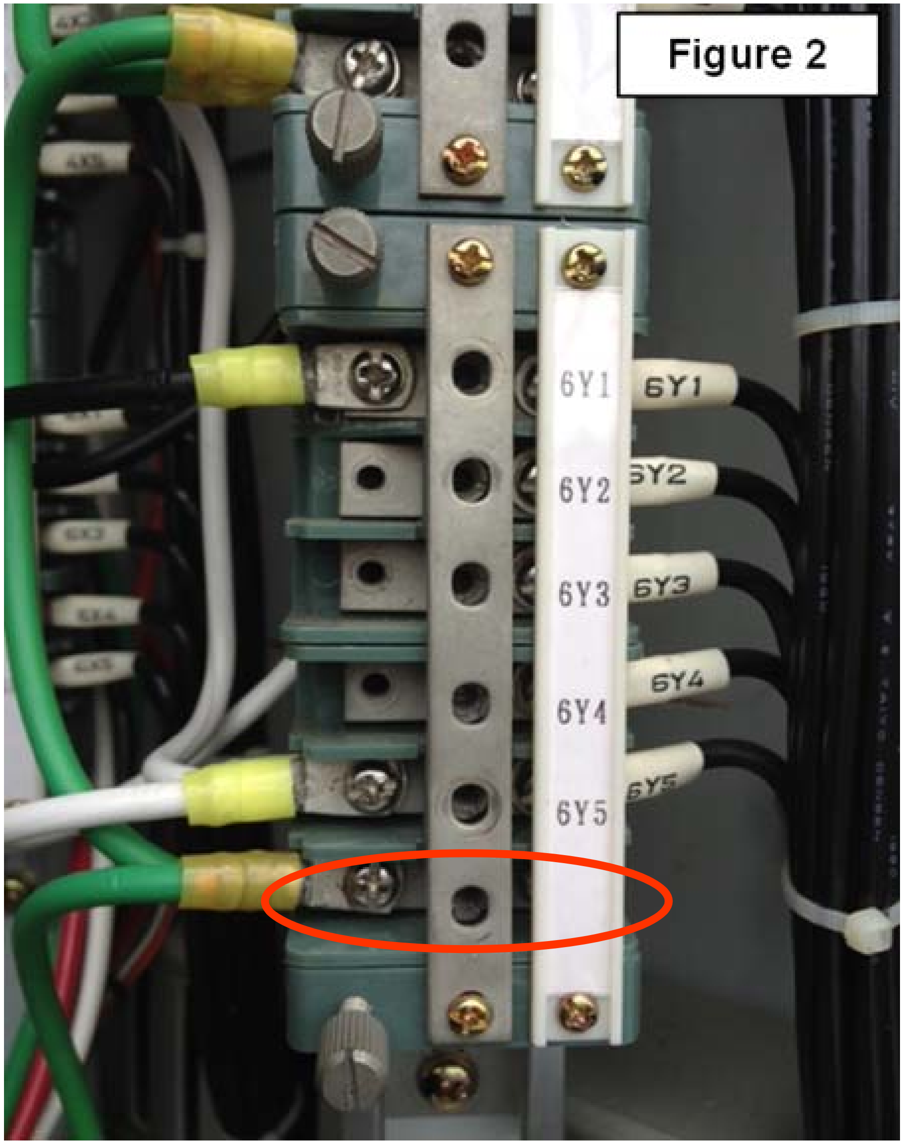
Note only 4 wires from CT pocket.

- A grounded shorting bar can provide some voltage-limiting protection in the event a CT is open-circuited.
- In this example, routine work (not near the shorting block) dislodged a CT conductor from it's lug due to a bad crimp.
- The CT flashed over at the shorting block.



Shorting Block Ground

- In this example, a CT shorting block was found with the ground-screw left off.
- If a CT is open-circuited in a control house, the entire circuit will rise to a high-voltage and the weakest insulation point will flash over.
- Control house fires have been known to start from Open-circuited CT's.



Shorting Block Ground

- Application of Lockout/Tagout (LOTO) to CT secondary circuits.
- Use as much caution and attention to detail on the second and later wires as you did on the first.
- Consider whether work can be done at the shorting blocks.
- Consider whether it is safer to work at ‘Single-Phase’ shorting blocks instead of the ‘Three-Phase’ blocks if you have both.

CT Circuit Considerations

- When dealing with CT shorting blocks, it should be noted that it is also very important to make sure that shorting screws are not inadvertently left in-place after work is completed.

- Shorting screws left in-place may defeat protective relaying and render relay circuits inoperable, thus jeopardizing System stability as well as reducing the positive effects of proper relaying related to personnel safety.

- CT Circuits can easily provide enough voltage and associated current to inflict lethal wounds if open-circuited while primary current is flowing.
- Before working on CT Circuitry a Job Briefing should be held, and the Circuits positively Identified and Tested.
- Good work practices can help avoid injury in the event a current circuit does become open-circuited.
- Take whatever time is necessary to perform the job properly and safely.

Safety Summary

Credits

- Thanks to the following people for assistance with this presentation:
  - **Mick Johnson – Ross Labs Mechanical Engineer**
  - **Jim Donald – Ross Labs Craftsman (retired)**
  - **Janet Geddie – Training Center Staff**
  - **Randy Gorman – Electrician Instructor**
  - **Kurt Dobin – SPC/Electrician Instructor (retired)**
  - **Ross Complex Electricians**
  - **Rodney Krause – Operations Specialist**
  - **Bob Beck – SPC District Engineer (retired)**
  - **Richard Becker – BPA Manager and former SPC District Engineer**
  - **Paul Johnson – Trade Theory Instructor**
  - **Marty O’Rourke and Gavin Bepple – SPC District Engineers**
  - **Greg Butler – BPA Test & Energization Engineer**