



TESCO METERING

# INTRODUCTION TO INSTRUMENT TRANSFORMERS

*TESCO's Meter School*

**TESCOOL**

*July 21-24, 2024*

# CURRENT TRANSFORMERS (CT's)

- CT's allow the measurement of high currents at potentially high voltages.
- They come in many shapes and sizes for different applications
- They are potentially extremely dangerous.



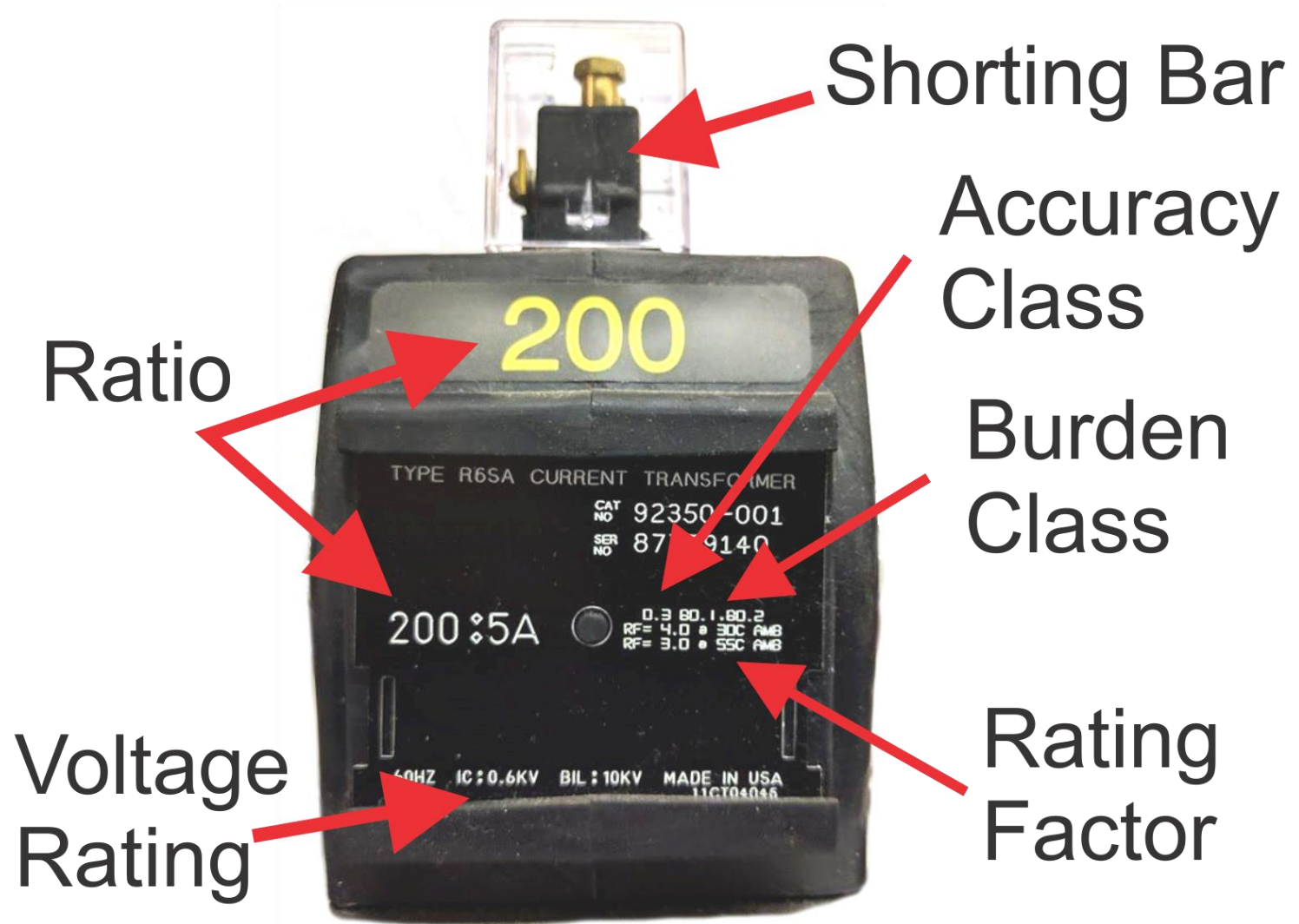
**They can kill you!**





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# CURRENT TRANSFORMERS (CT's)



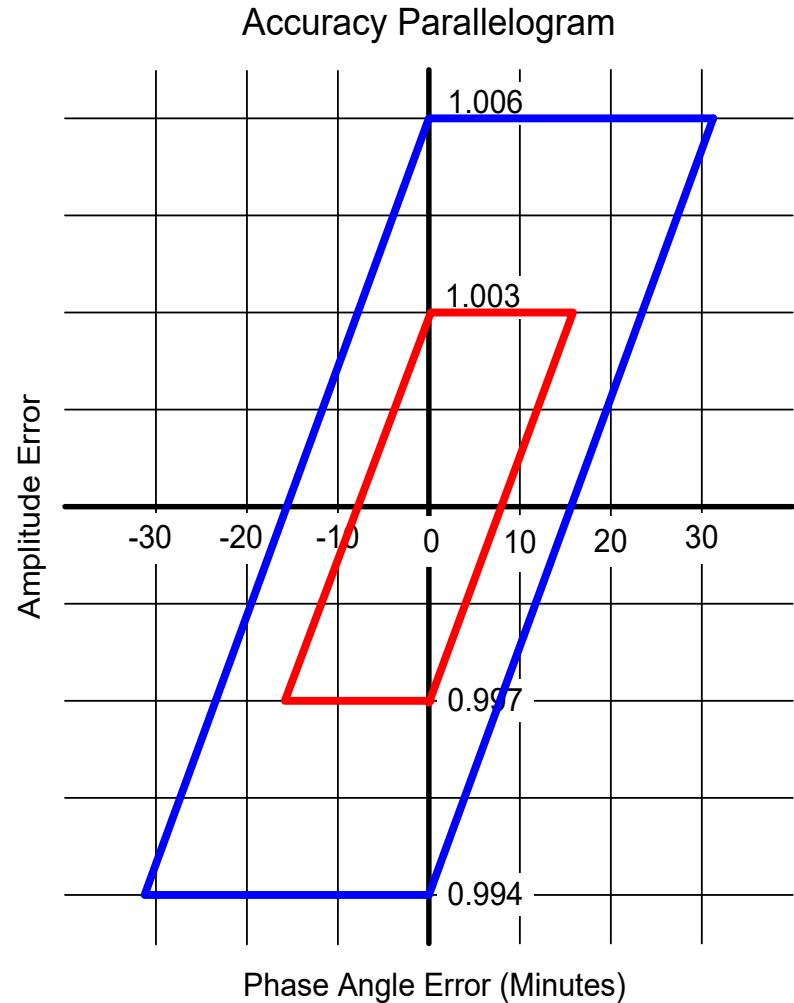
- Basic formula:  $I_s = I_p \cdot (N_p / N_s) = I_p / N_s$
- Open Circuit Voltage:
$$V = \sqrt{3.5 \cdot Z_b \cdot I_p / N_s}$$
- Where:
  - $Z_b$  = Burden Impedance
  - $I_p$  = Primary Current
  - $N_s$  = Number of Secondary Turns (Ratio to 1)

$$V = \sqrt{3.5 \cdot 10^5 \cdot 1000 / 200} = 1320V$$

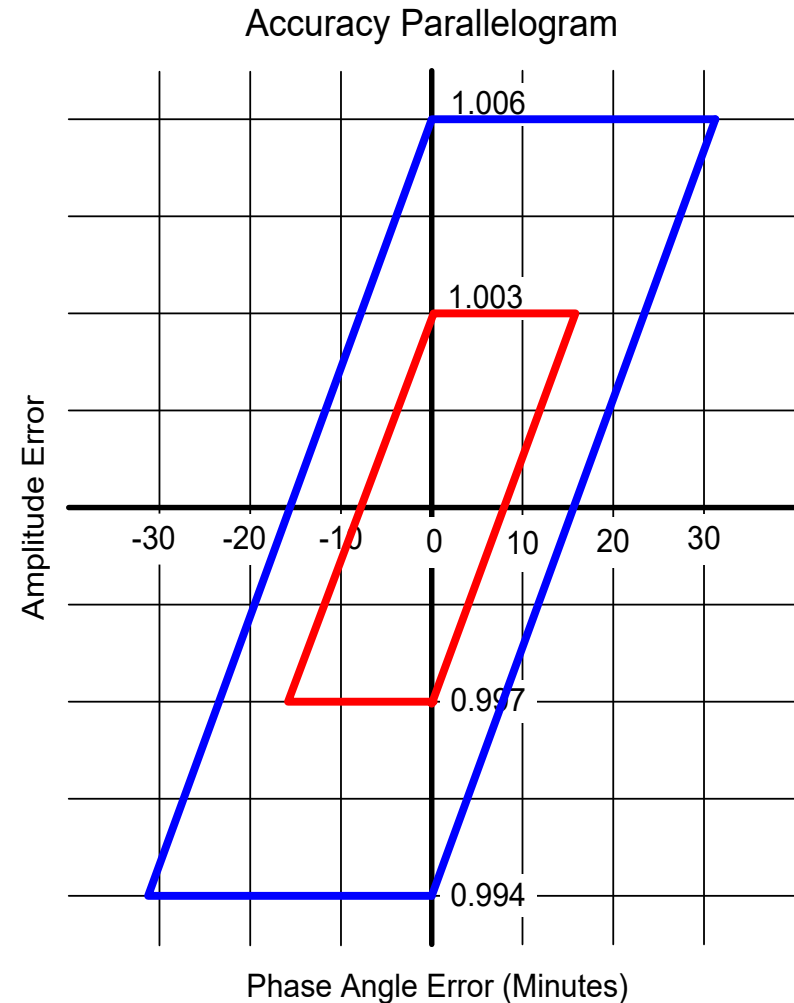
Tests have shown values ranging from 500 to 11,000 volts.

# CT – ACCURACY CLASS/BURDEN

- Most CTs used in North America are 0.3 (0.3 percent) Class devices.
- When an accuracy class is specified the maximum burden for which the device meets the class accuracy is also specified.



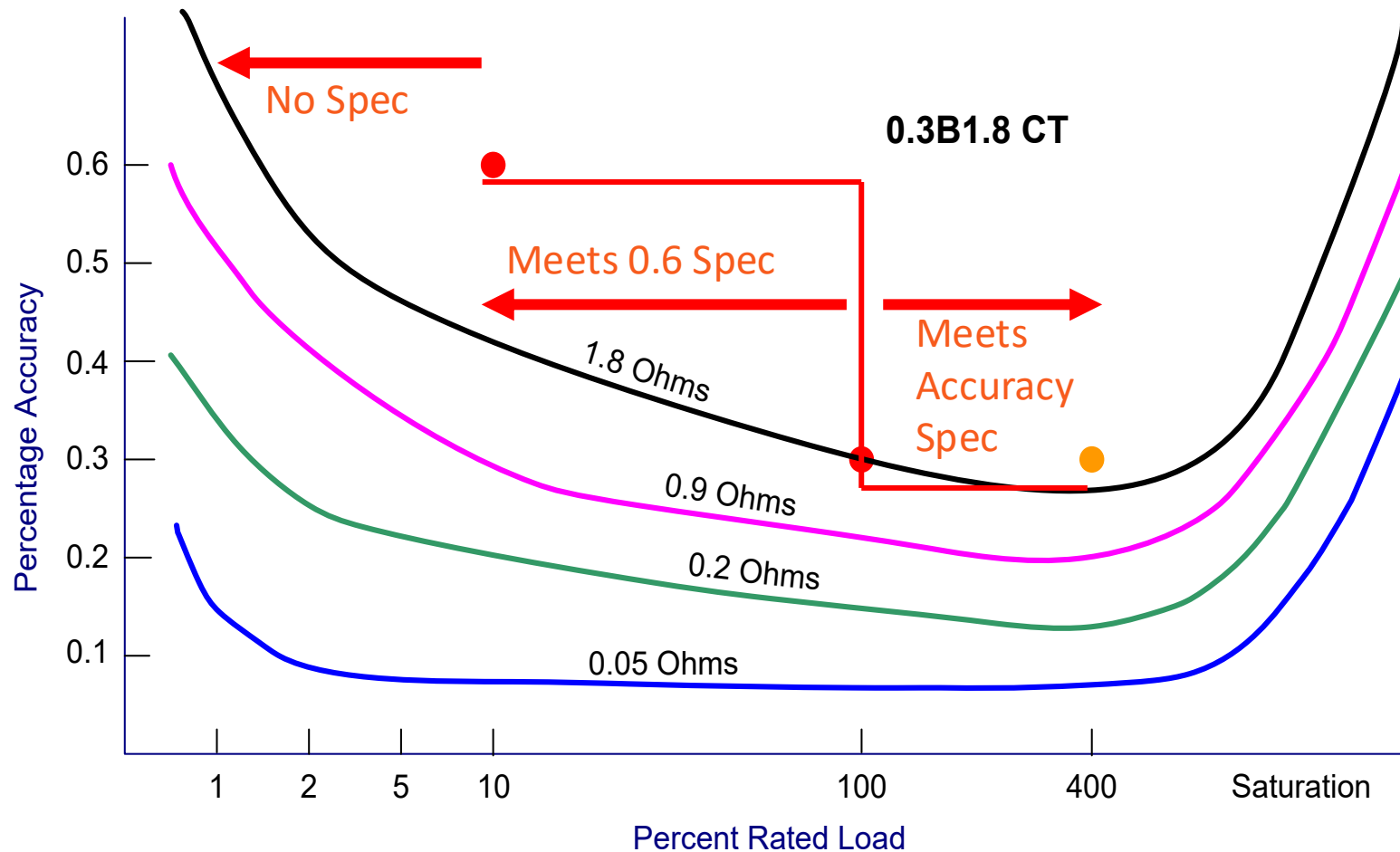
- Metering error shall be less than 0.3% when the CT is used at FULL RATED LOAD and with rated burden.
- Metering error shall be less than 0.6% when the CT is used between 10% and 100% of full rated load.
- Error is a combination of amplitude and phase error.





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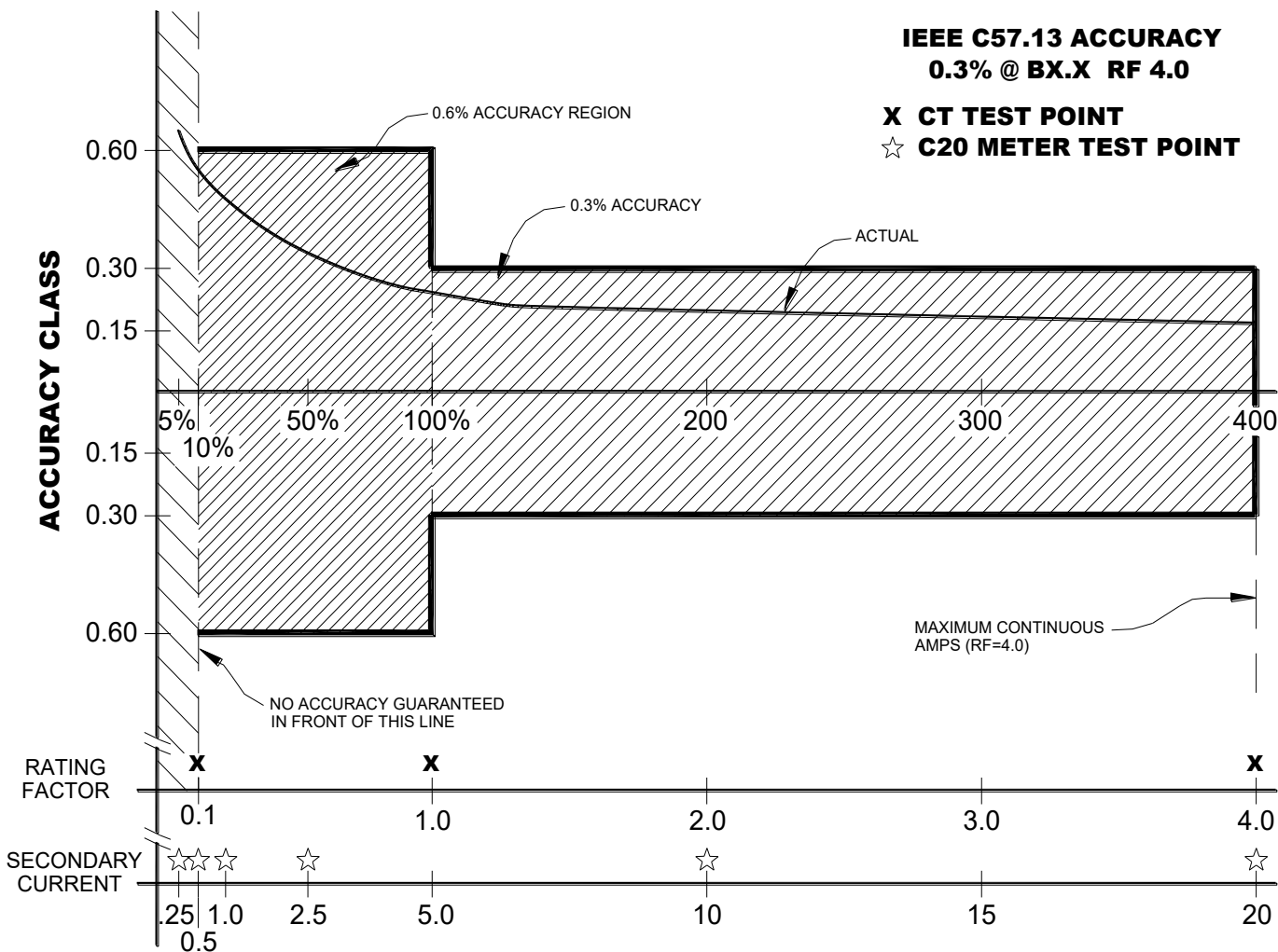
# CT – ACCURACY – BURDEN - LOAD





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# ACCURACY CLASS 0.3

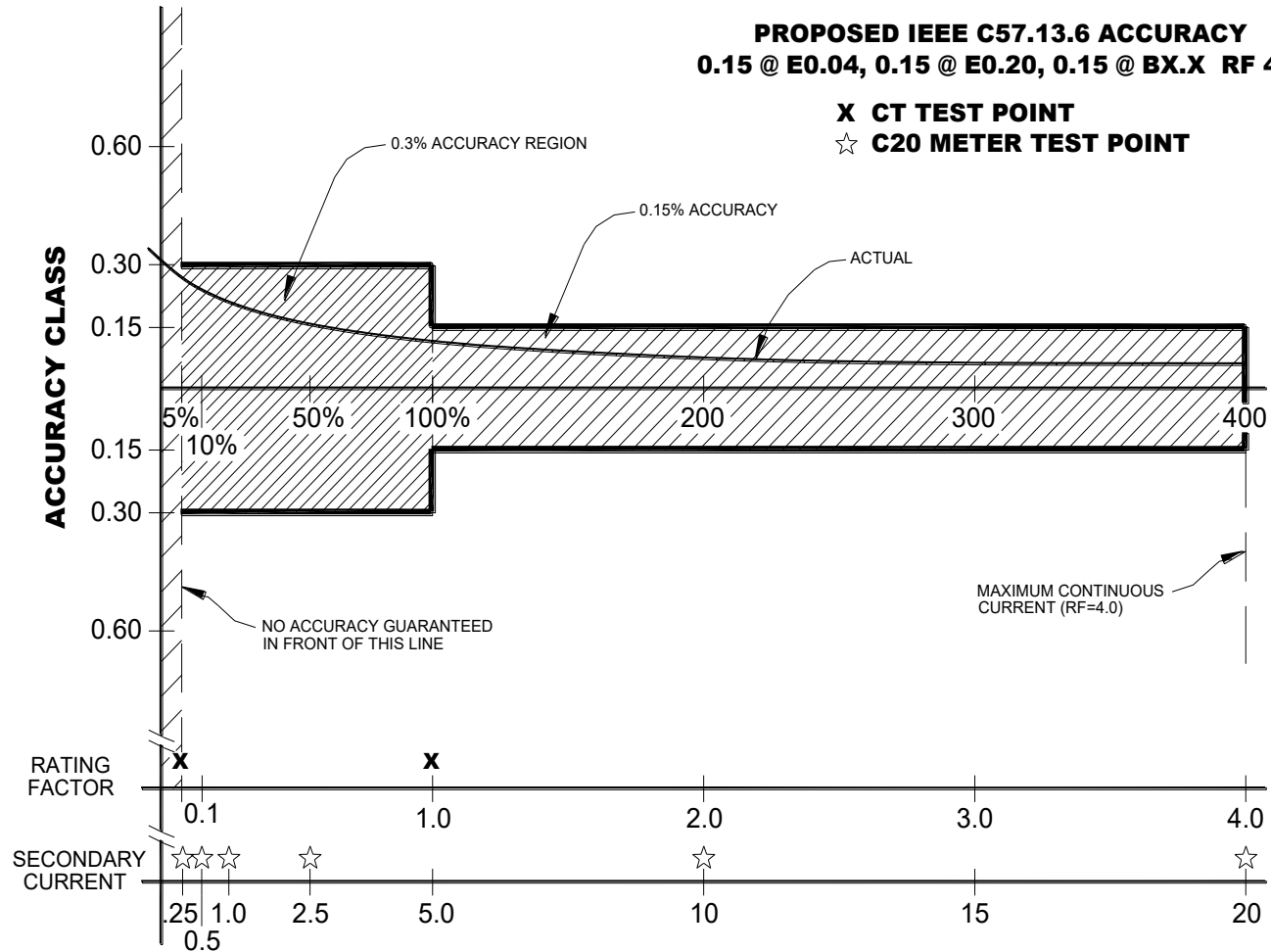


Slide Courtesy Kent Jones, GE



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# ACCURACY CLASS 0.15

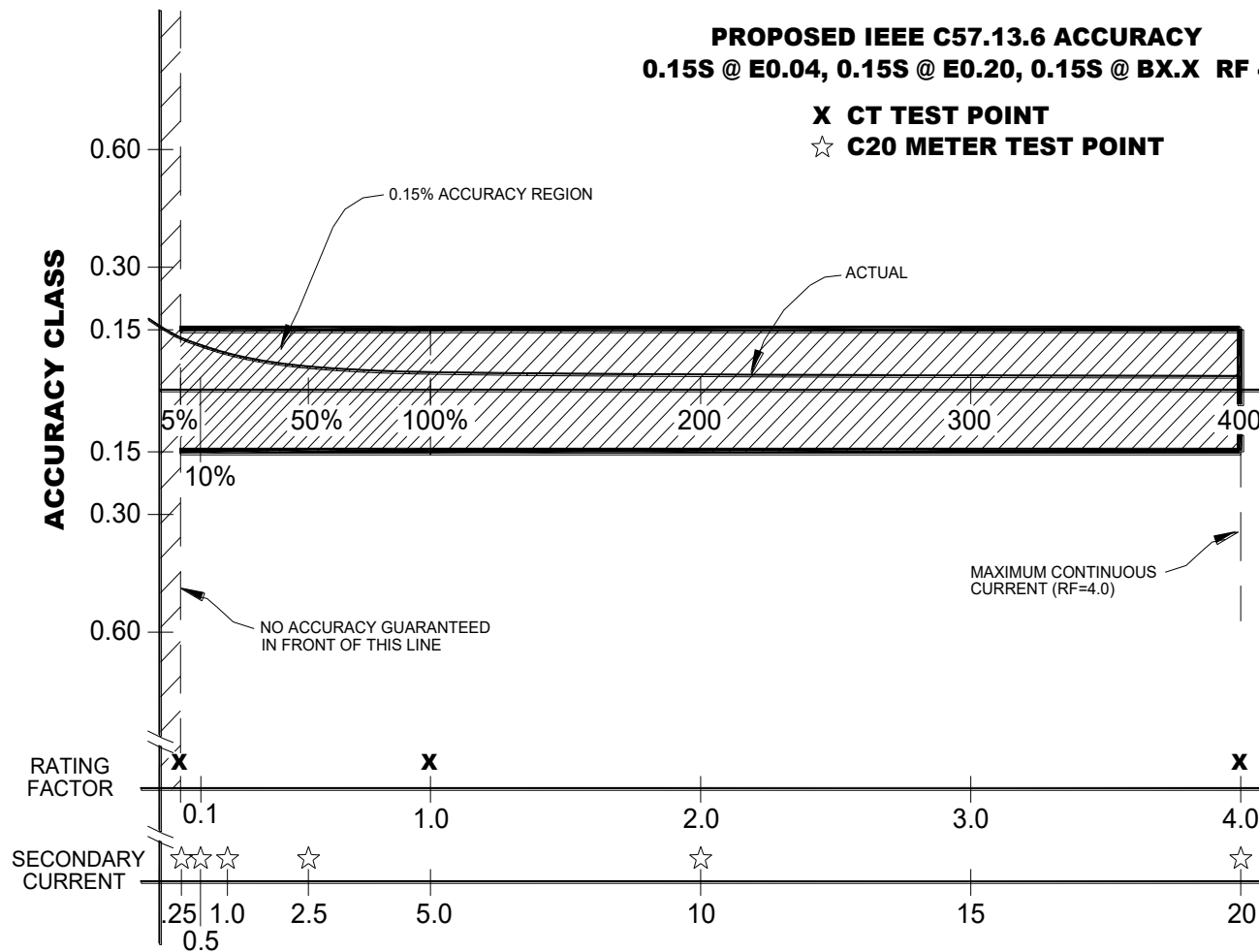


Slide Courtesy Kent Jones, GE



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# ACCURACY CLASS 0.15S



Slide Courtesy Kent Jones, GE

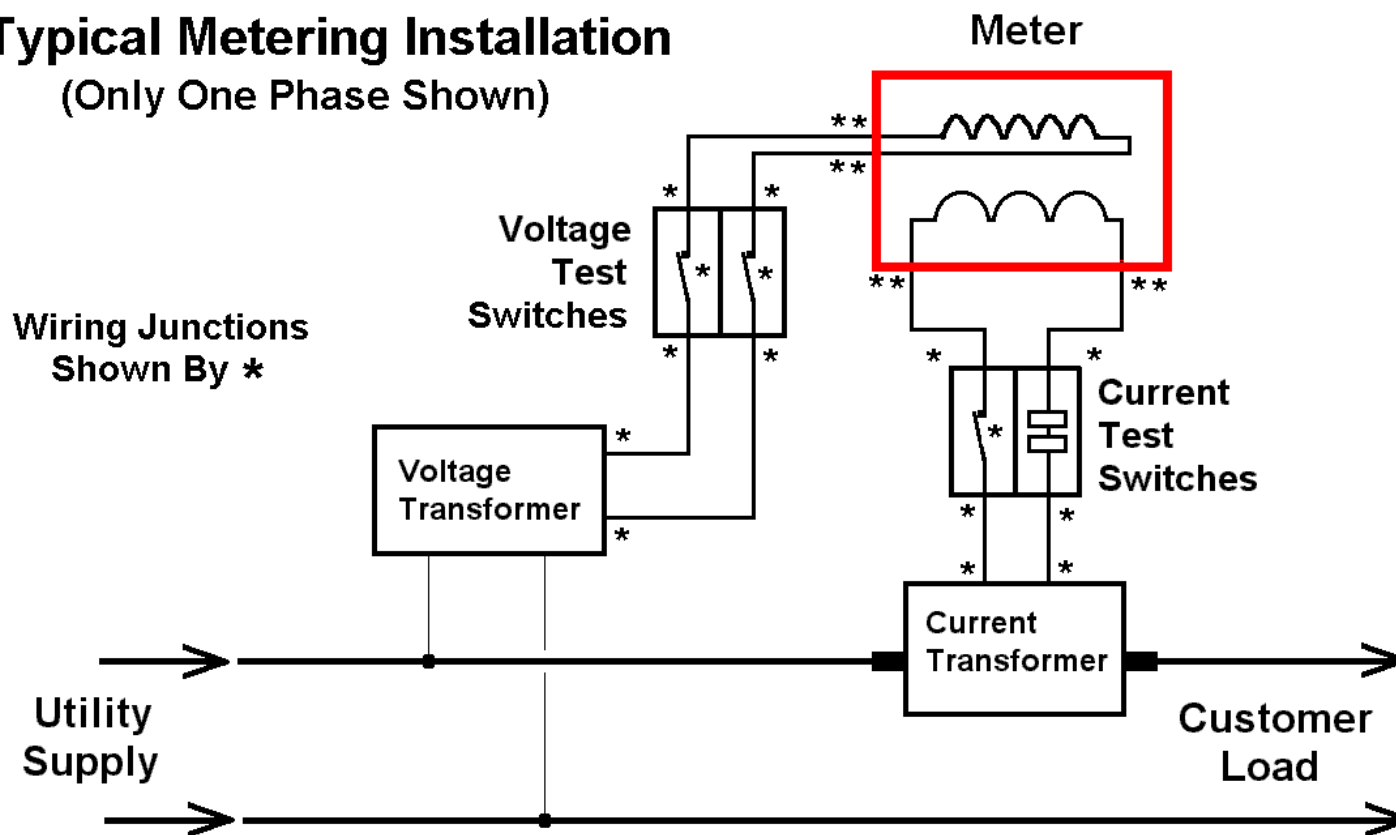
- Do not do “one size fits all.”
- Talked to a guy yesterday whose company chose to use 500:5 CTs everywhere.
- 0.3% accuracy range is 250 to 2000A.
  - These were extended range
  - Normal range would be down to 500A
- Most of the CTs were used well below 250A.

Slide Courtesy Kent Jones, GE

# ERRORS WITH CURRENT TRANSFORMERS

## Typical Metering Installation

(Only One Phase Shown)



- CTs require a lot of care to insure accurate metering.
  - Burden – Over burden reduces CT accuracy.
  - Wiring – Faulty or improper wiring reduces accuracy by increasing burden.
  - Shunt – Failure to remove the safety shunt will not keep the CT from operating but it will reduce the readings by 50-80%

# ERRORS WITH CURRENT TRANSFORMERS

- When you see a CT spec sheet it will give you the burden at which the CT meets a specific accuracy Class

| CURRENT<br>RATING<br>PRI:SEC<br>AMPERES | IEEE METER ACCURACY CLASS, 60 HZ |       |       |
|-----------------------------------------|----------------------------------|-------|-------|
|                                         | B 0.1                            | B 0.2 | B 0.5 |
| 100:5                                   | 0.3                              | -     | -     |
| 200:5                                   | 0.3                              | 0.3   | -     |
| 300:5                                   | 0.3                              | 0.3   | 0.6   |
| 400:5                                   | 0.3                              | 0.3   | 0.6   |
| 600:5                                   | 0.3                              | 0.3   | 0.6   |
| 800:5                                   | 0.3                              | 0.3   | 0.3   |

# ERRORS WITH CURRENT TRANSFORMERS

| Primary<br>Amps | Style<br>Number | IEEE Meter Accuracy |      |      |
|-----------------|-----------------|---------------------|------|------|
|                 |                 | B0.1                | B0.2 | B0.5 |
|                 |                 |                     |      |      |
| 200             | 7524A85G01      | 0.3                 | 0.3  |      |
| 300             | 7524A85G02      | 0.3                 | 0.3  |      |
| 400             | 7524A83G02      | 0.3                 | 0.3  |      |
| 600             | 7524A83G03      | 0.3                 | 0.3  |      |
|                 |                 |                     |      |      |
| 200             | 7524A85G03      | 0.3                 | 0.3  |      |
| 300             | 7524A85G04      | 0.3                 | 0.3  |      |
| 400             | 7524A83G05      | 0.3                 | 0.3  |      |
| 600             | 7524A83G06      | 0.3                 | 0.3  |      |

- Many CTs are only rated at B0.1 and B0.2
- #16 wire is 4.5 mΩ/ft
- #14 wire is 2.8 mΩ/ft
- #12 wire is 1.8 mΩ/ft
- #10 wire is 1.1 mΩ/ft
- #8 wire is 0.7 mΩ/ft
- 50 ft of #12 wire is nearly 100 mΩ

- Leaving the shunt in the wrong position produces wrong readings not no readings.



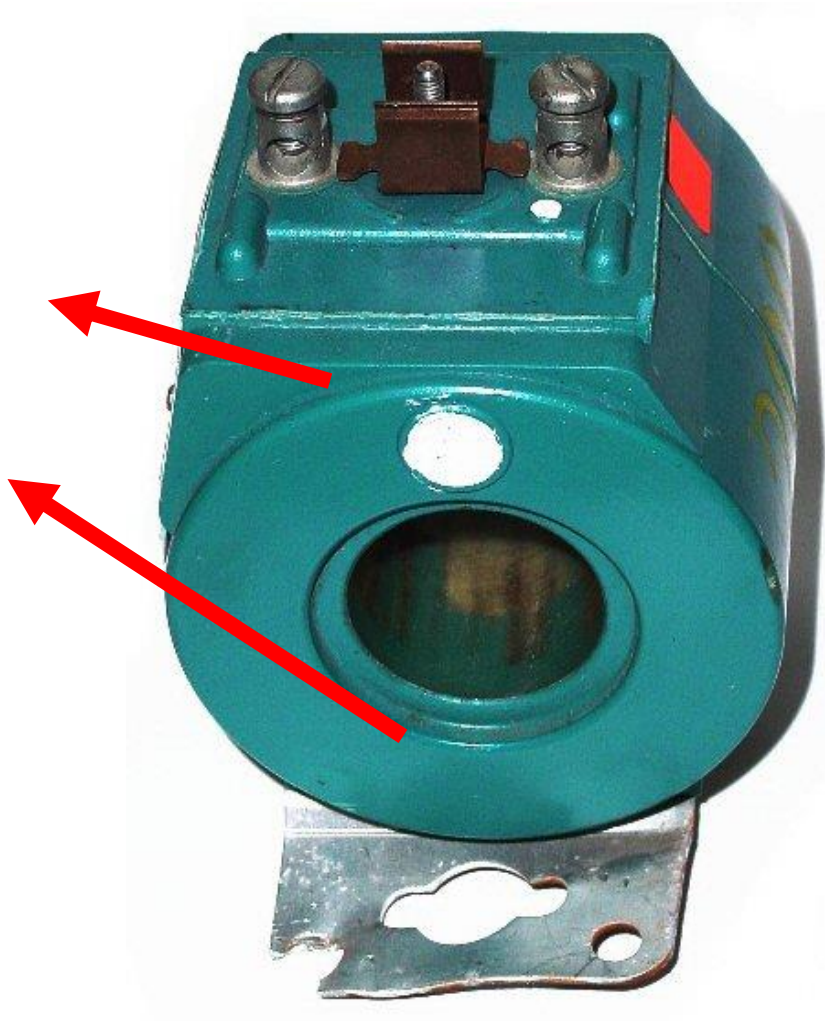
SHUNT CLOSED



SHUNT OPEN

# ERRORS WITH INSTRUMENT TRANSFORMERS

## CT - POLARITY



- Polarity of the connection matters.
- Wrong polarity means totally wrong metering.
- When  $PF \neq 0$ , reversed polarities may not be obvious.

- Rating Factor has absolutely nothing to do with burden.
- If a CT has a rating factor of 4 it means that at **30°C** it can be used up to 4X its label current and maintain its accuracy Class.
- A CT with a label RF=4 only has an RF = 3 at **55°C**

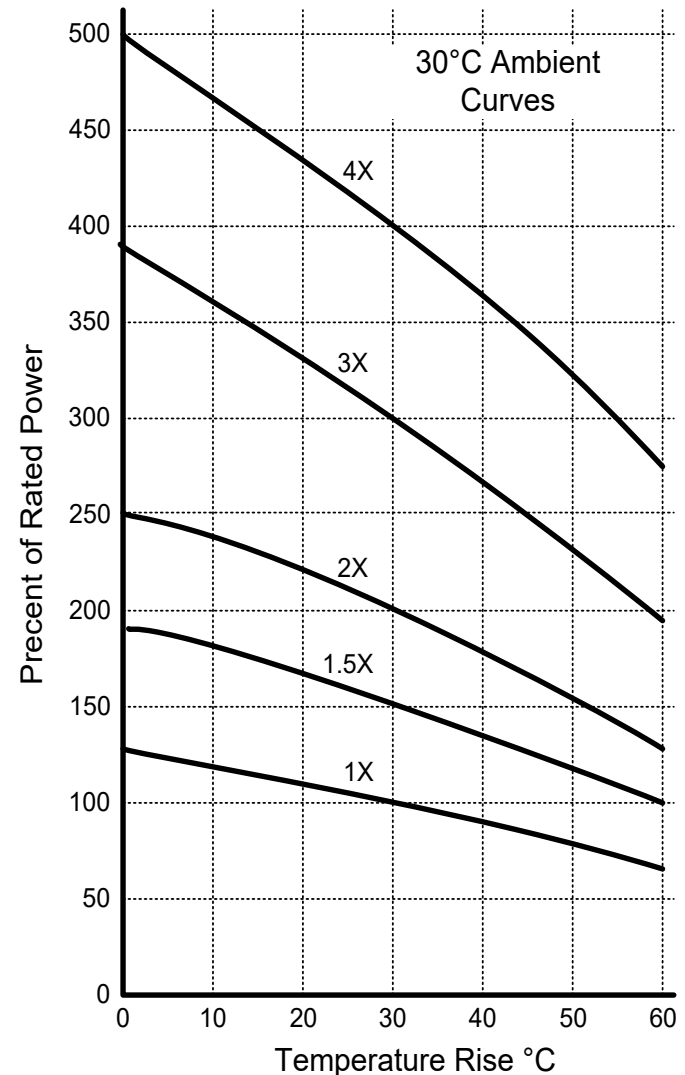


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# CT RATING FACTOR

- Rating Factor is a strong function of temperature.
- If a CT has a rating factor of 4 it means that at 30°C it can be used up to 4X its label current and maintain its accuracy Class.
- Operating temperature affects Rating Factor significantly.
  - A CT with RF=4 at 30°C is only RF=3 at 55°C

|    |    |    |     |     |
|----|----|----|-----|-----|
| °C | 0  | 30 | 55  | 70  |
| °F | 32 | 86 | 131 | 158 |



- Three Approaches in use today
  - Direct RATIO measurement with applied burden
    - ◆ Most accurate approach tells us exactly what we want to know
    - ◆ Measures directly the quantities we care about CT Ratio and Phase Error
    - ◆ Is more complicated to perform.

- Alternate Approaches

- Burden only

- A compromise: tells us if circuit is stable under excess burden
    - Can't give us the ratio which is what we really care about.

- Admittance Testing

- Allows us to look for changes from previous measurements.
    - Doesn't directly give ratio
    - Accuracy typically  $\pm 5\%$

- Other Tests

- Direct Burden Measurement

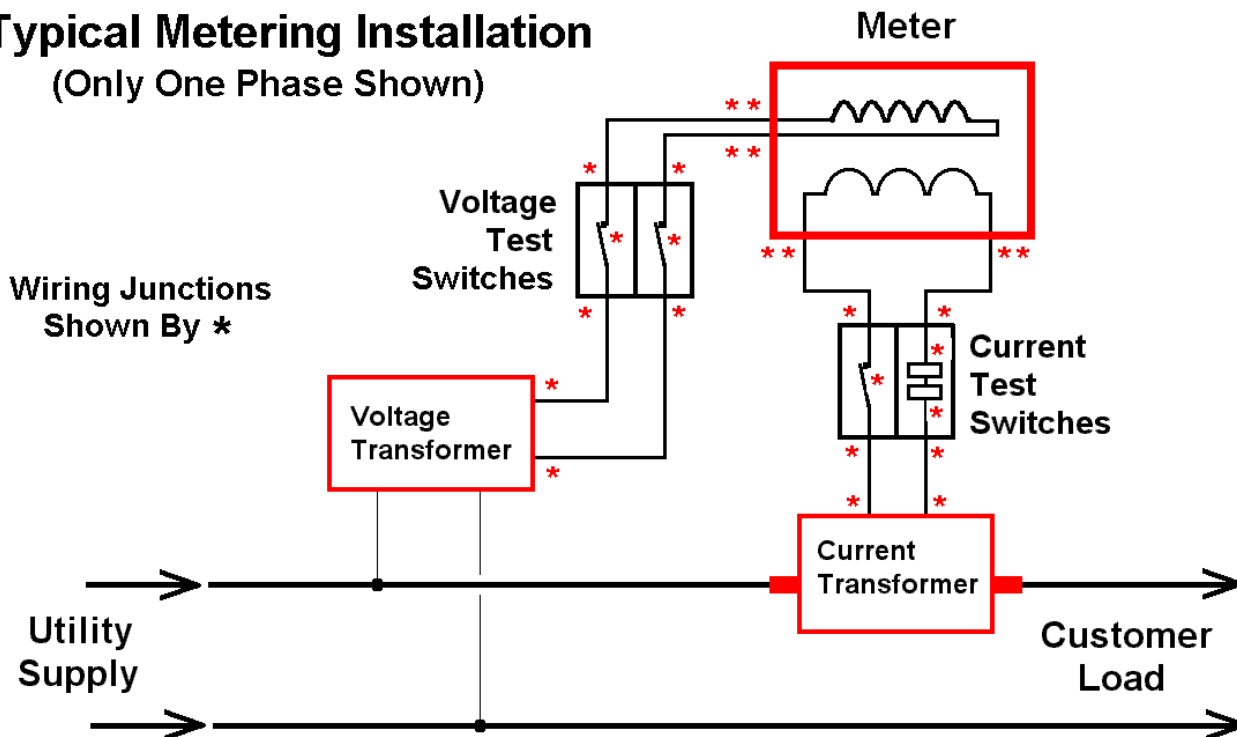
- If you measure the voltage across the CT terminals
    - AND
    - The current output of the CT
    - Using Ohms Law you can compute the actual burden seen by the CT

SIMPLY:  $\text{Burden} = \text{Voltage} / \text{Current}$

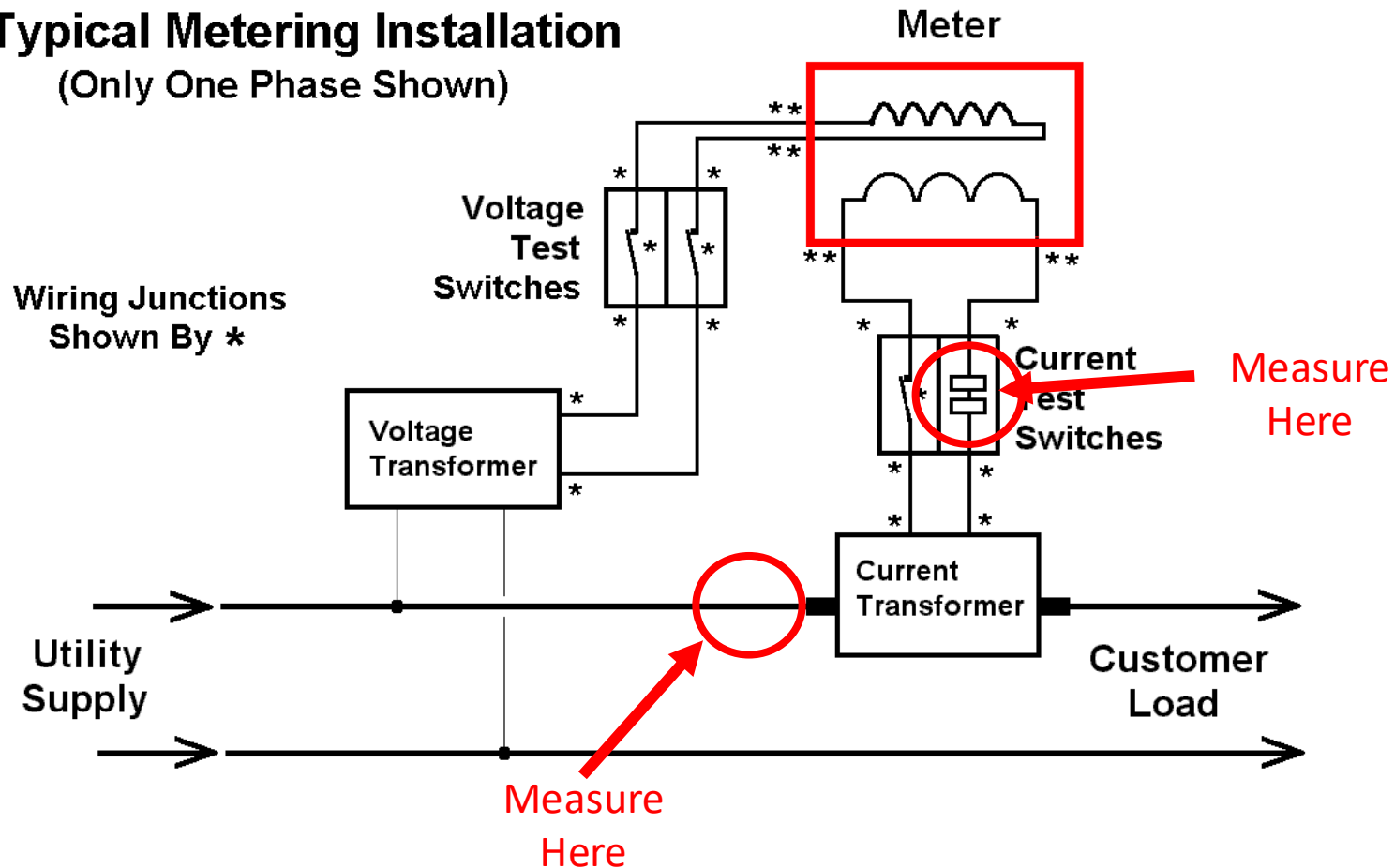
- A very simple and direct way to see if a CT is overburdened, but not to test its accuracy

- The meter measures ONLY the voltage and current reaching the meter terminals.
- To verify that the CT is working at the site we have to test the entire circuit.

## Typical Metering Installation (Only One Phase Shown)



### Typical Metering Installation (Only One Phase Shown)



# CT RATIO WITH BURDEN TESTING



- Ratio Testing is the preferred approach when we can gain access to the CT primary.
- Various types of probes can be used for primary side.
  - Flex
  - HV

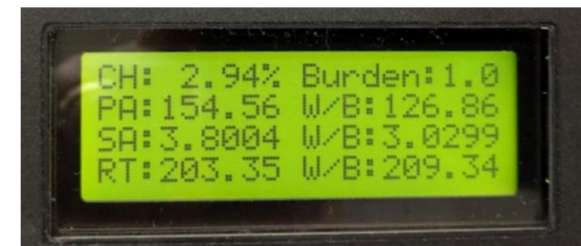


- Direct Ratio vs Burden Only

|                    | Un-burdened Value | Burdened Value |
|--------------------|-------------------|----------------|
| Primary Amps       | 154.58            | 151.63         |
| Secondary Amps     | 3.8135            | 3.7337         |
| Ratio              | 202.67            | 203.06         |
| % Ratio Change     |                   | -0.19%         |
| % Secondary Change |                   | 2.14%          |

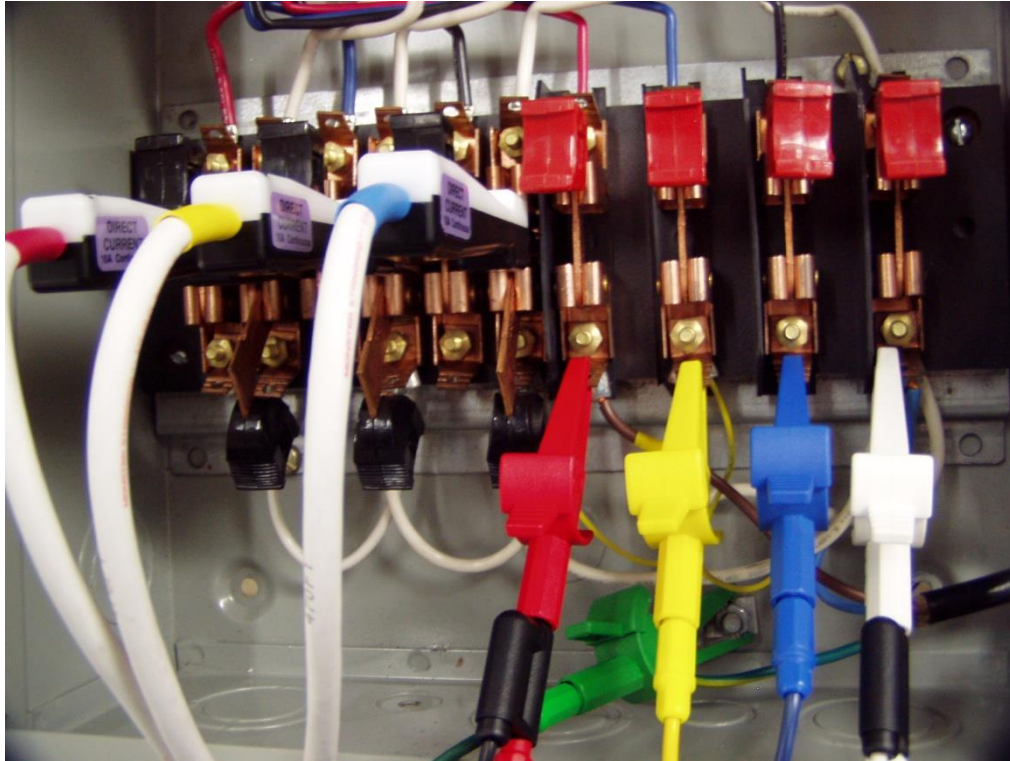


By simultaneously measuring primary and secondary currents we get an accurate picture of performance under load. Only measuring secondary current change can give a false picture.



# CT RATIO WITH BURDEN TESTING

- Secondary connection is made through the test switch
- Same connection that is used for the rest of the site testing.



**Disadvantage:**  
Requires access to the  
primary side if the CT to  
measure current.

**Ratio Testing with applied burden is the most accurate and complete approach for testing at CT in service.**

- CT testing can be done with very high accuracy

|                               |                               |          |
|-------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 399.88</b> | <b>PASS</b>                   | <b>A</b> |
| Nameplate Ratio: 400 : 5      | Primary Amps: 34.31           |          |
| Ratio Error (%): -0.03%       | Secondary Amps: 0.429         |          |
| Phase Error (degrees): 0.095° | Phase Error (minutes): 5' 43" |          |

|                               |                               |          |
|-------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 400.09</b> | <b>PASS</b>                   | <b>B</b> |
| Nameplate Ratio: 400 : 5      | Primary Amps: 27.18           |          |
| Ratio Error (%): 0.02%        | Secondary Amps: 0.340         |          |
| Phase Error (degrees): 0.079° | Phase Error (minutes): 4' 43" |          |

|                               |                               |          |
|-------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 400.05</b> | <b>PASS</b>                   | <b>C</b> |
| Nameplate Ratio: 400 : 5      | Primary Amps: 40.10           |          |
| Ratio Error (%): 0.01%        | Secondary Amps: 0.501         |          |
| Phase Error (degrees): 0.125° | Phase Error (minutes): 7' 30" |          |

Reference CT measured using PowerMaster with 752 clamp-on probes. Essentially NO ratio error, phase shift, or change in secondary current versus applied burden.

- CT testing can be done with very high accuracy

|                               |                               |             |          |
|-------------------------------|-------------------------------|-------------|----------|
| <b>Measured Ratio: 399.88</b> |                               | <b>PASS</b> | <b>A</b> |
| Nameplate Ratio: 400 : 5      | Primary Amps: 34.31           |             |          |
| Ratio Error (%): -0.03%       | Secondary Amps: 0.429         |             |          |
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|                               |                               |             |          |
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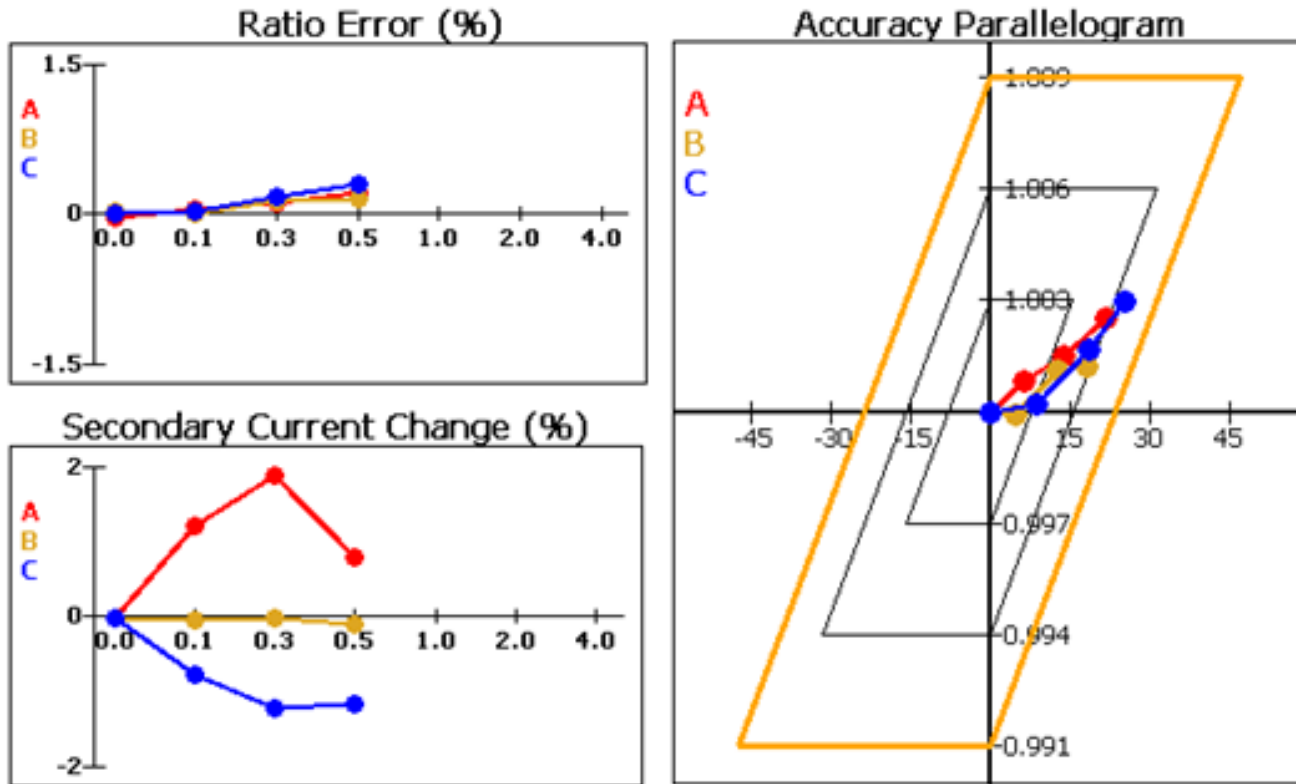
  

|                               |                               |             |          |
|-------------------------------|-------------------------------|-------------|----------|
| <b>Measured Ratio: 400.05</b> |                               | <b>PASS</b> | <b>C</b> |
| Nameplate Ratio: 400 : 5      | Primary Amps: 40.10           |             |          |
| Ratio Error (%): 0.01%        | Secondary Amps: 0.501         |             |          |
| Phase Error (degrees): 0.125° | Phase Error (minutes): 7' 30" |             |          |

Field measurement using PowerMaster with 752 clamp-on probes. Essentially NO ratio error or phase shift.

# TESTING CURRENT TRANSFORMERS

## RATIO VS APPLIED BURDEN



Note: As additional burden is applied both ratio and phase errors increase. The direction of change is in the customer's favor.

# TESTING CURRENT TRANSFORMERS

## RATIO VS APPLIED BURDEN

|                               |                                |          |
|-------------------------------|--------------------------------|----------|
| <b>Measured Ratio: 4.98</b>   | <b>PASS</b>                    | <b>A</b> |
| Nameplate Ratio: 5 : 5        | Primary Amps: 3.27             |          |
| Ratio Error (%): -0.36%       | Secondary Amps: 3.281          |          |
| Phase Error (degrees): 0.489° | Phase Error (minutes): 29' 20" |          |

|                                |                                 |          |
|--------------------------------|---------------------------------|----------|
| <b>Measured Ratio: 5.08</b>    | <b>FAIL</b>                     | <b>B</b> |
| Nameplate Ratio: 5 : 5         | Primary Amps: 2.33              |          |
| Ratio Error (%): <b>1.56%</b>  | Secondary Amps: 2.295           |          |
| Phase Error (degrees): -0.230° | Phase Error (minutes): -13' 48" |          |

|                                       |                                           |          |
|---------------------------------------|-------------------------------------------|----------|
| <b>Measured Ratio: 5.17</b>           | <b>FAIL</b>                               | <b>C</b> |
| Nameplate Ratio: 5 : 5                | Primary Amps: 1.29                        |          |
| Ratio Error (%): <b>3.31%</b>         | Secondary Amps: 1.252                     |          |
| Phase Error (degrees): <b>-1.305°</b> | Phase Error (minutes): <b>-1° 18' 16"</b> |          |

Burden Class 0.1 CTs various issues: too small gauge wire, bad connections, high harmonic content.

In the phase B test we measured 35.86 amps on the primary and 1.799 secondary amps.

$$\text{Ratio} = 5.0 * (\text{Primary} / \text{Secondary}) = 99.68$$

If the ratio had been 100:5 and the primary was 35.86 amps we should have measured 1.793 amps on the secondary.

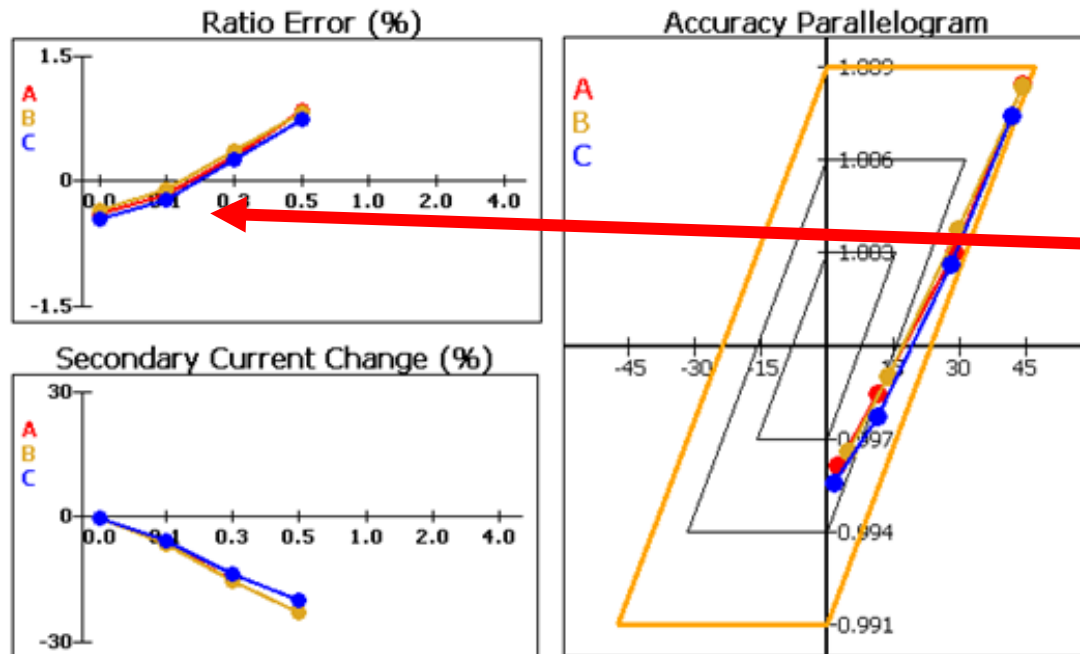
We measured 1.799 – **MORE** than we should have.

Therefore a tested ratio of 99.68 means that we are measuring more current than we should. **This error is in our favor.**

# TESTING CURRENT TRANSFORMERS

## RATIO ERROR – IN WHOSE FAVOR?

Suppose we add burden to the metering circuit.

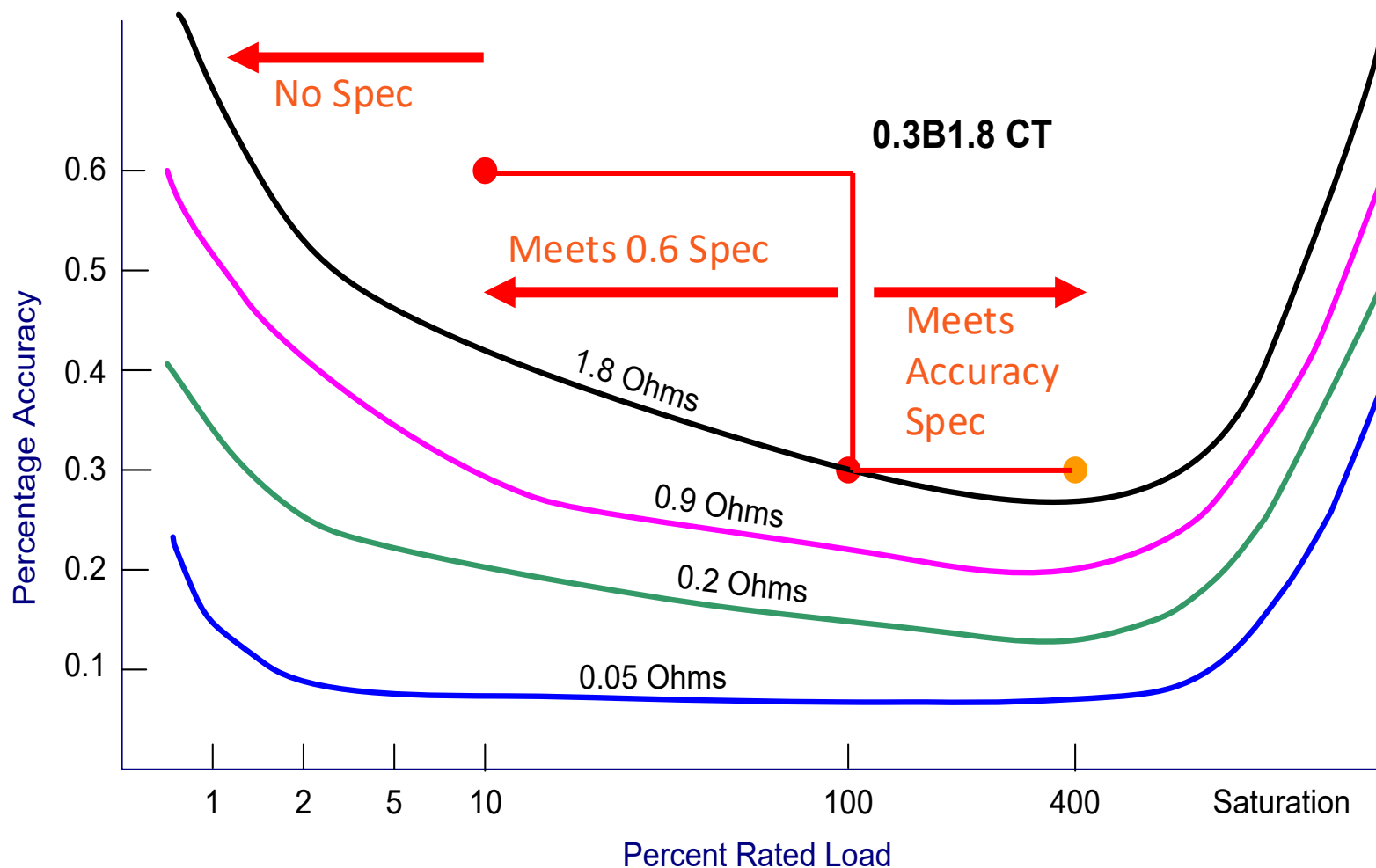


Notice that the ratio increases as we apply burden. Just above 0.1 additional burden the ratio switches from less than 100:5 to greater than 100:5. This is the point where things swing to being in favor of the customer.



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# CT – ACCURACY – BURDEN - LOAD



# TESTING CURRENT TRANSFORMERS

## WHAT'S WRONG? → POWER THEFT



## Power thefts surge in bad times

It's dangerous, and other consumers pick up the tab

By Paul Davidson  
USA TODAY

As the dismal economy spawns desperate measures, some Americans are resorting to a hazardous practice: stealing electricity.

Many utilities say energy theft has risen sharply during the economic downturn. Culprits include

vice was turned off in early 2008, 30% were illegally using electricity late last year, utility PECO says.

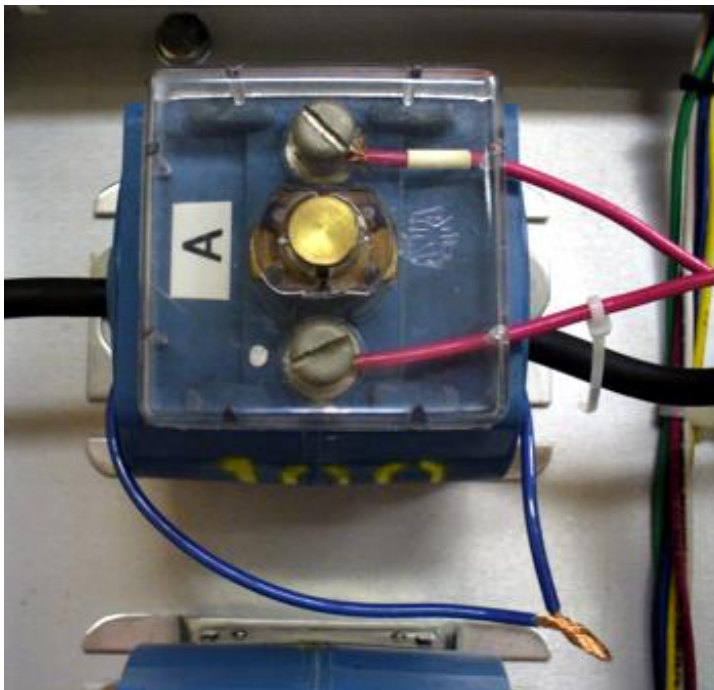
Customers have stolen power for decades, costing utilities 1% to 3% of revenue — or about \$6 billion industrywide — each year, according to *Electric Light & Power* magazine. Losses are borne by other customers. Many thieves operate home-based marijuana farms that use lots of lights.

But the problem is mushrooming. In Pennsylvania, utility PPL says thefts rose 16% last year, with fewer drug-related incidents and more tied to serving businesses.

# TESTING CURRENT TRANSFORMERS

## WHAT'S WRONG? → POWER THEFT

A simple piece of wire wrapped around the CT.

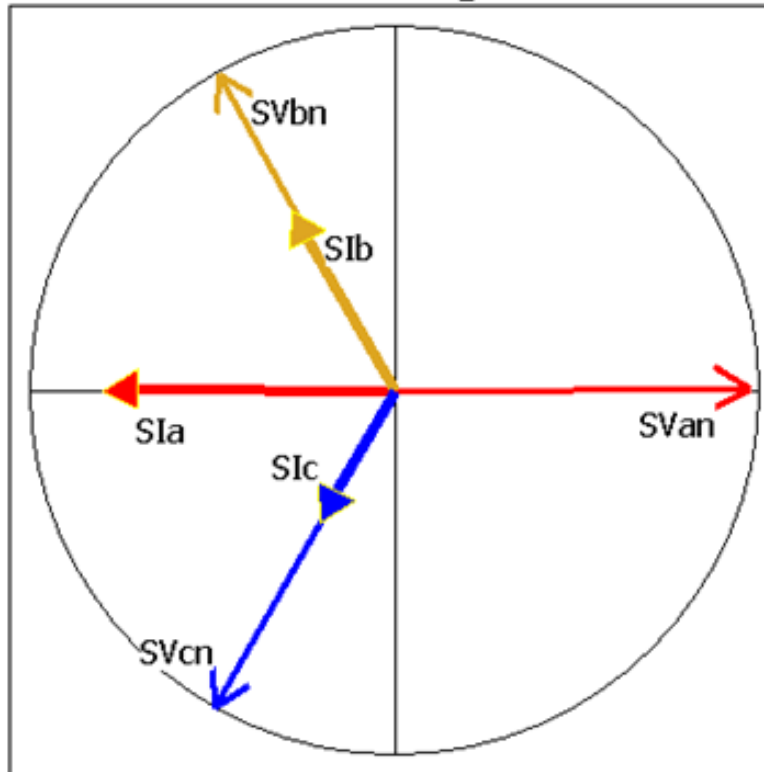


Would you spot it?

# TESTING CURRENT TRANSFORMERS

## WHAT'S WRONG?

Vector Diagram



$\Phi$ SVanSIa

|      |         |         |
|------|---------|---------|
| SVan | 117.914 | 0.00°   |
| SIa  | 3.243   | 179.78° |
| PF = | 1.000   | 179.78° |
| Lag  |         |         |

$\Phi$ SVbnSIb

|      |         |         |
|------|---------|---------|
| SVbn | 119.674 | 240.87° |
| SIb  | 2.288   | 240.42° |
| PF = | 1.000   | -0.45°  |
| Lead |         |         |

$\Phi$ SVcnSIc

|      |         |         |
|------|---------|---------|
| SVcn | 121.251 | 119.46° |
| SIc  | 1.679   | 119.21° |
| PF = | 1.000   | -0.25°  |
| Lead |         |         |

SYS

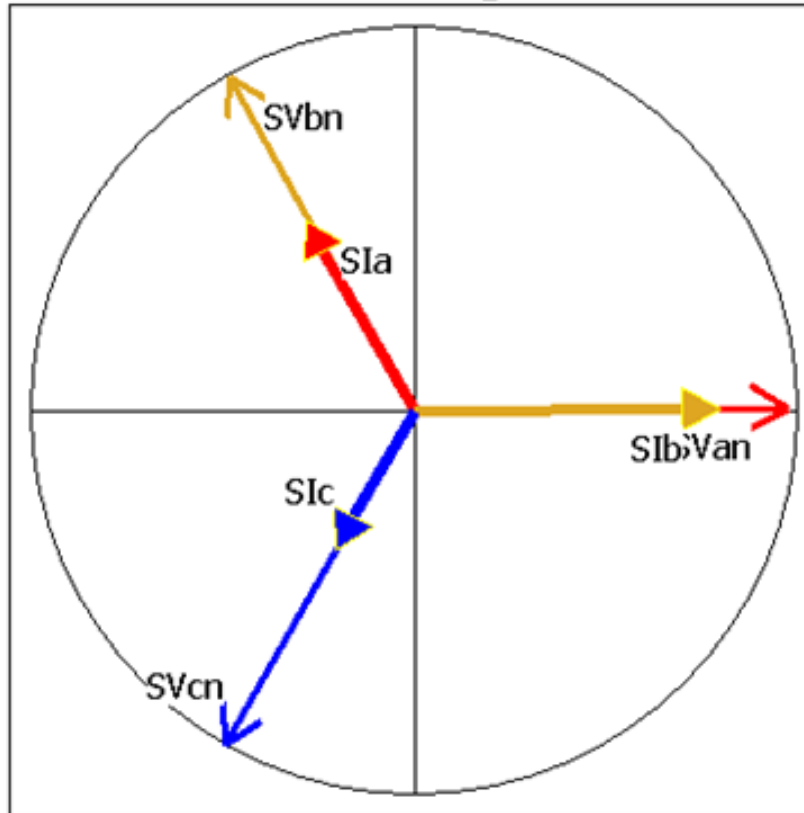
|        |         |
|--------|---------|
| Vsys = | 119.613 |
| Isys = | 2.403   |
| PF =   | 1.000   |
| ROT =  | CBA     |

Phase A CT reversed.

# TESTING CURRENT TRANSFORMERS

## WHAT'S WRONG?

Vector Diagram



$\Phi$ SVanSIa

|      |         |          |
|------|---------|----------|
| SVan | 118.017 | 0.00°    |
| SIa  | 2.289   | 240.46°  |
| PF = | 0.493   | -119.54° |
| Lead |         |          |

$\Phi$ SVbnSIb

|      |         |         |
|------|---------|---------|
| SVbn | 119.774 | 240.91° |
| SIb  | 3.245   | 359.77° |
| PF = | 0.482   | 118.86° |
| Lag  |         |         |

$\Phi$ SVcnSIc

|      |         |         |
|------|---------|---------|
| SVcn | 121.387 | 119.50° |
| SIc  | 1.680   | 119.24° |
| PF = | 1.000   | -0.26°  |
| Lead |         |         |

SYS

|        |         |
|--------|---------|
| Vsys = | 119.726 |
| Isys = | 2.405   |
| PF =   | 0.658   |
| ROT =  | CBA     |

Phase A & B CTs swapped.

- **Another potentially low accuracy item in chain**
  - 0.3 percent basic accuracy
- **Accuracy decreases rapidly with burden**
- **Power supplies in meters may cause measurement errors.**

# TESTING POTENTIAL TRANSFORMERS

## RATIO TEST

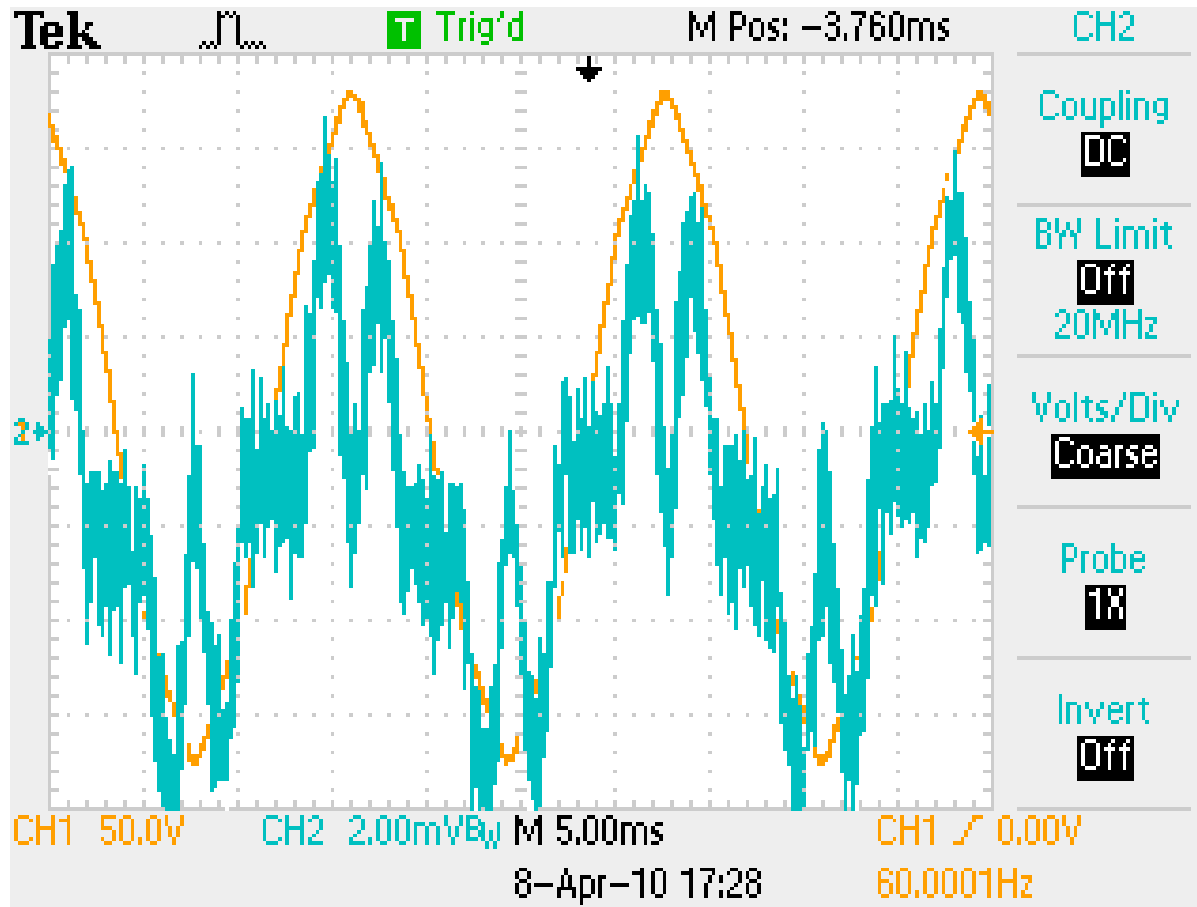
|                                |                               |          |
|--------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 3.99</b>    | <b>PASS</b>                   | <b>A</b> |
| Nameplate Ratio: 4 : 1         | Primary Volts: 454.96         |          |
| Ratio Error (%): -0.27%        | Secondary Volts: 114.051      |          |
| Phase Error (degrees): -0.018° | Phase Error (minutes): -1' 3" |          |

|                                |                               |          |
|--------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 3.99</b>    | <b>PASS</b>                   | <b>B</b> |
| Nameplate Ratio: 4 : 1         | Primary Volts: 454.89         |          |
| Ratio Error (%): -0.30%        | Secondary Volts: 114.061      |          |
| Phase Error (degrees): -0.050° | Phase Error (minutes): -3' 1" |          |

|                               |                               |          |
|-------------------------------|-------------------------------|----------|
| <b>Measured Ratio: 3.99</b>   | <b>PASS</b>                   | <b>C</b> |
| Nameplate Ratio: 4 : 1        | Primary Volts: 455.07         |          |
| Ratio Error (%): -0.26%       | Secondary Volts: 114.062      |          |
| Phase Error (degrees): 0.064° | Phase Error (minutes): 3' 50" |          |

PT's can be tested easily in the field. Primary and secondary values can be accurately measured.

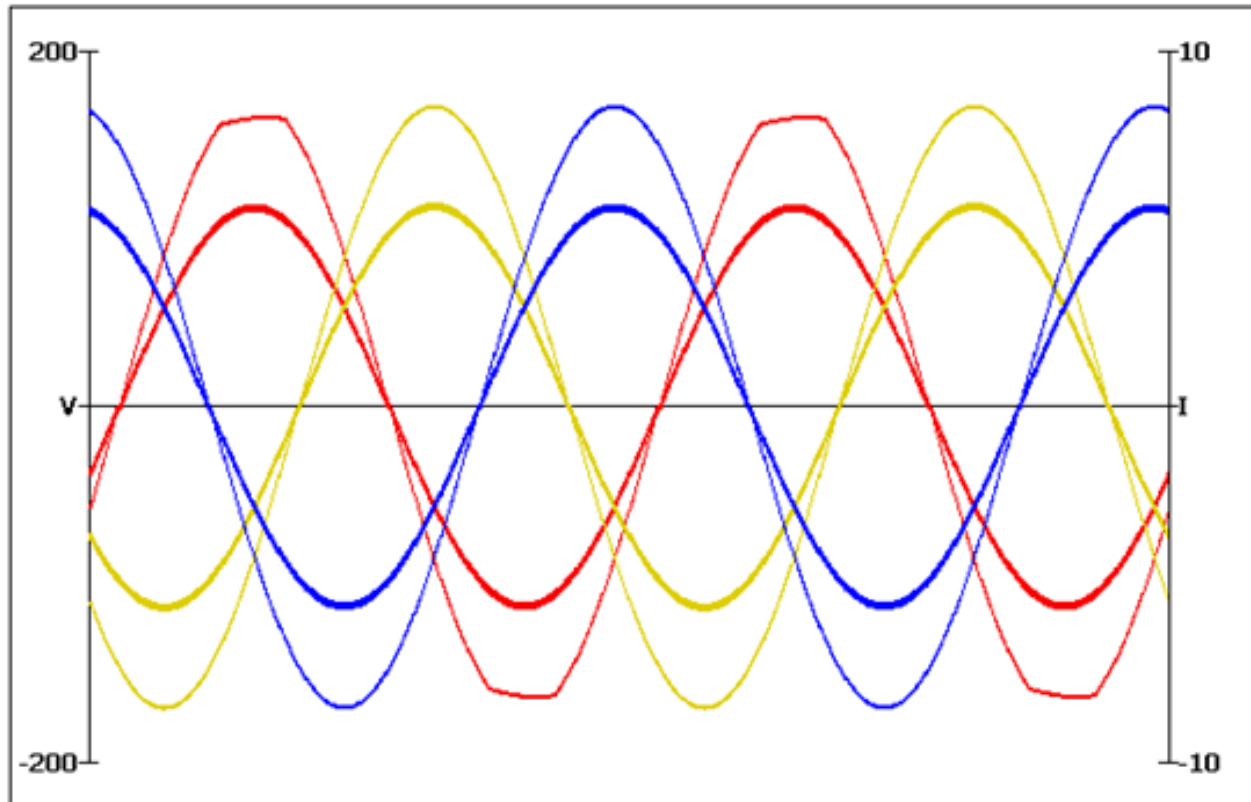
- Under sized PT can lead to overburden situation and waveform distortion. Especially with high end meters.



Yellow — PT output

Blue — Current being drawn by meter from this phase

- Under sized PT can lead to overburden situation and waveform distortion. Especially with high end meters.



Primary waveform is undistorted yet secondary waveform shows clipped voltage on phase powering meter.

# QUESTIONS AND DISCUSSION

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Dan Falcone  
ConnectDER



This presentation can also be found under Meter Conferences and Schools on the TESCO website: [www.tesco-advent.com](http://www.tesco-advent.com)