Introduction to Instrument Transformers

Prepared by Bill Hardy, TESCO

For North Carolina Electric Meter School
Wednesday, June 28, 2017 at 9:00 a.m.

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!

TESCO

Current Transformers (CT's)

Shorting Bar

Accuracy Class

Ratio

Burden Class

Rating Factor

Voltage Rating

Current Transformers (CT's)

Basic Theory

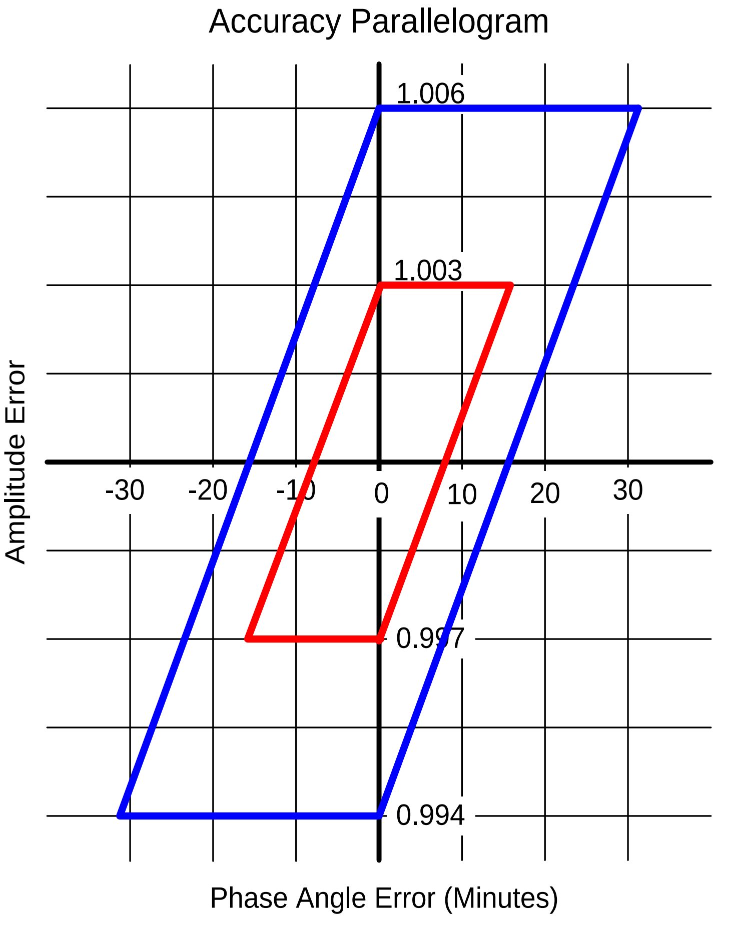
- Basic formula: Is = Ip•(Np/Ns) = Ip/Ns
- Open Circuit Voltage: $V = \sqrt{3.5 \bullet Z_b \bullet I_p / N_s}$
- Where:
  - Zb = Burden Impedance
  - Ip = Primary Current
  - Ns = Number of Secondary Turns (Ratio to 1)

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

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

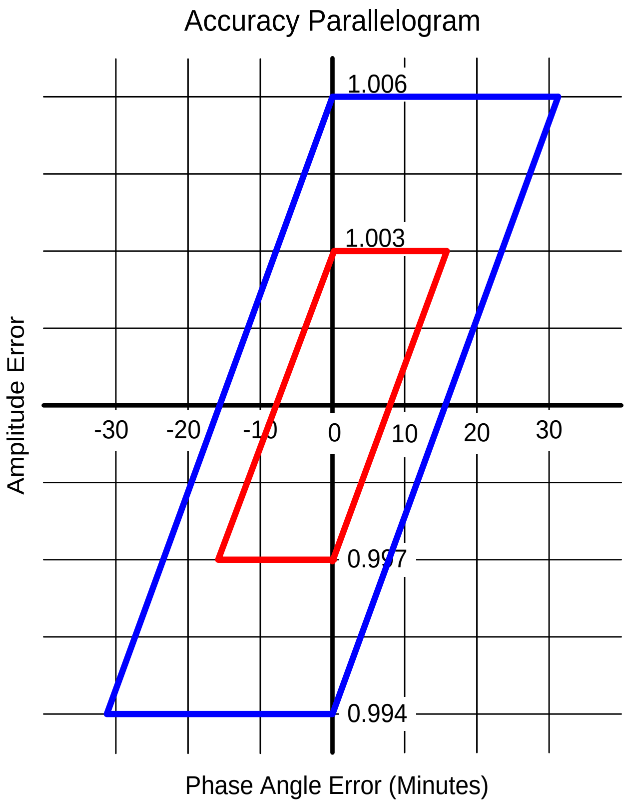
CT – Accuracy Class/Burden

- 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.

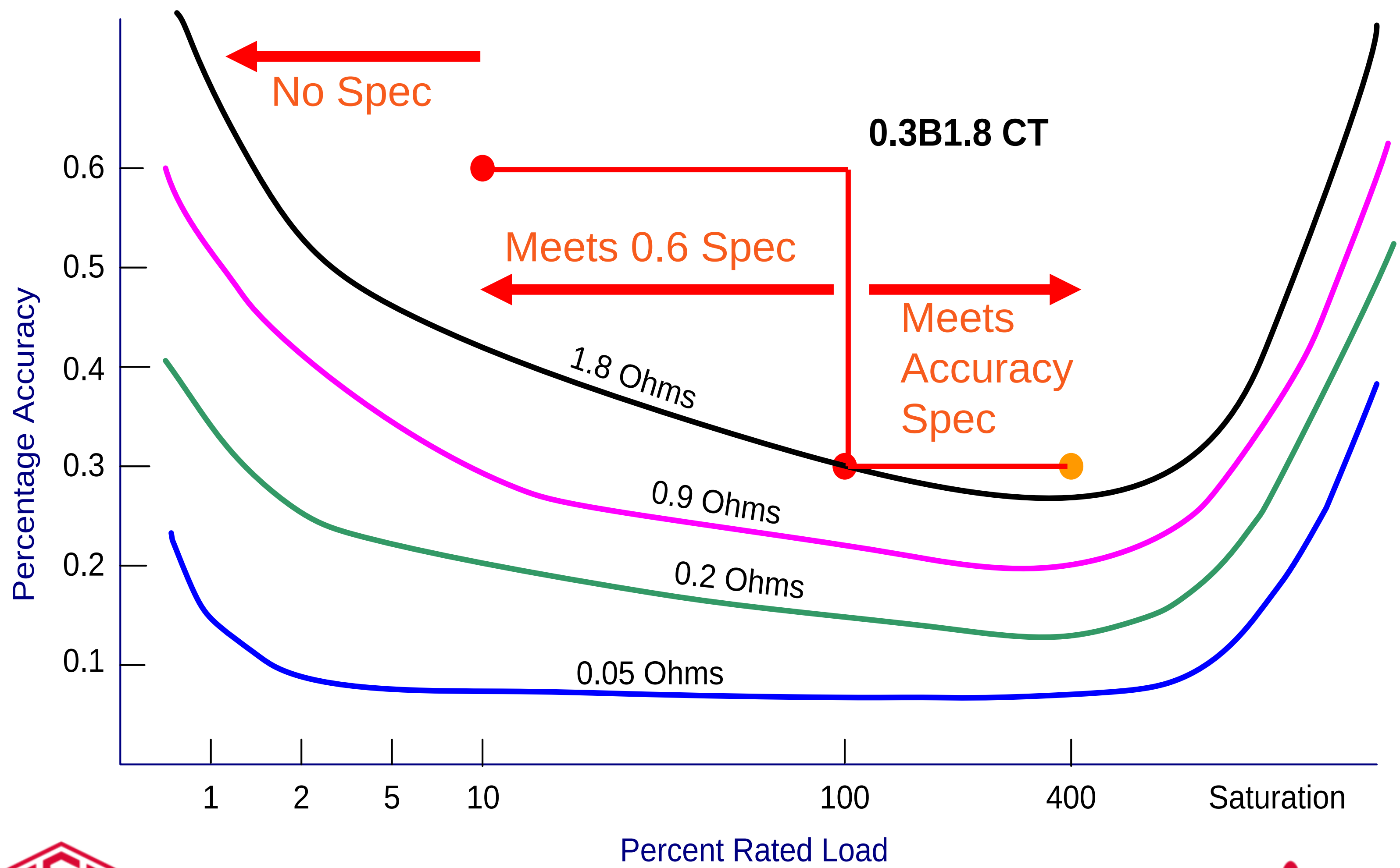


CT – Class 0.3

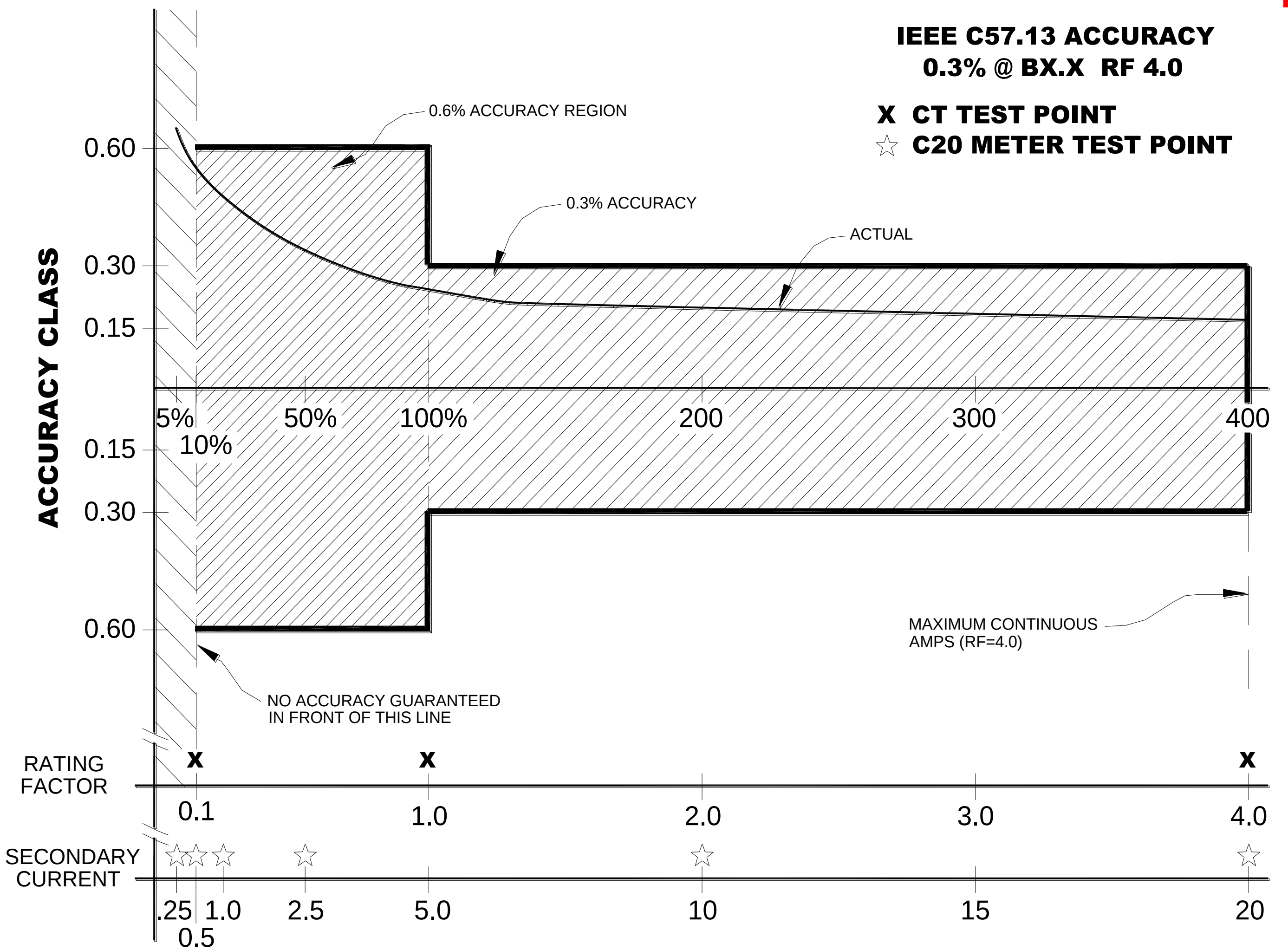
- Metering error shall be less than 0.3% when the CT is used at FULL RATED LOAD and with rated burden.
- Metering error shall be less than 0.6% when the CT is used between 10% and 100% of full rated load.
- Error is a combination of amplitude and phase error.



CT – Accuracy – Burden - Load

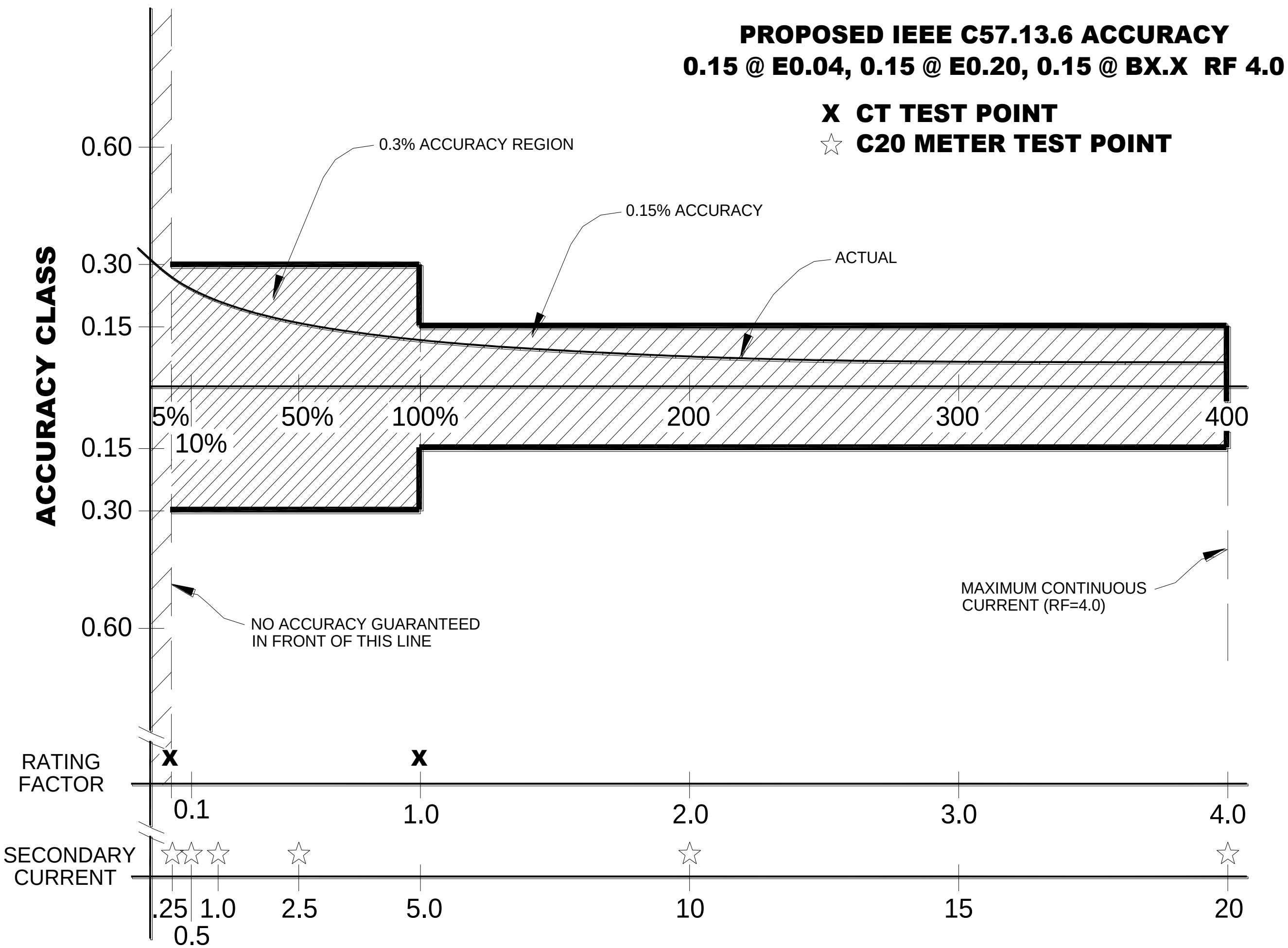


Accuracy Class 0.3



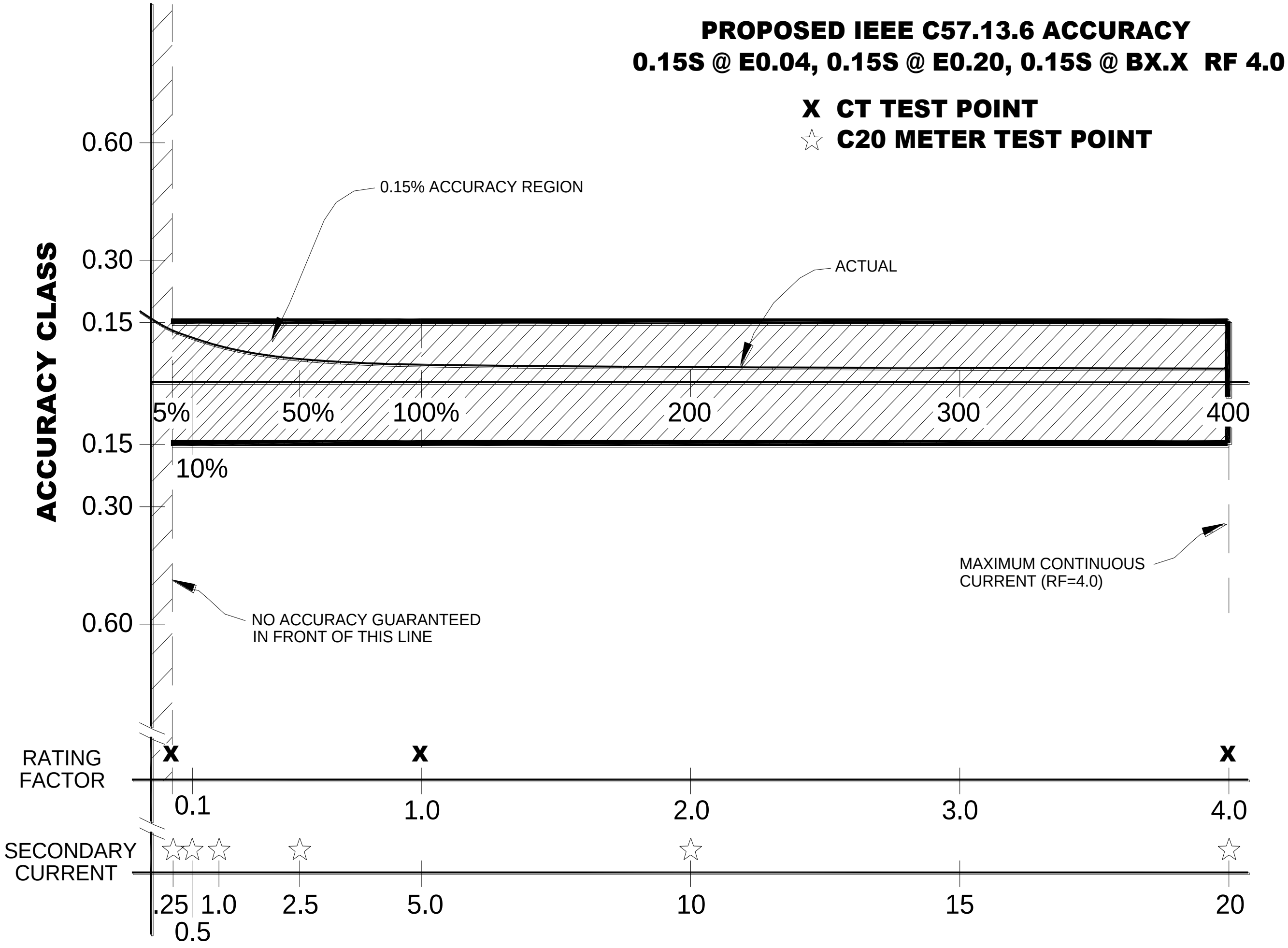
Slide Courtesy Kent Jones, GE

Accuracy Class 0.15



Slide Courtesy Kent Jones, GE

Accuracy Class 0.15S



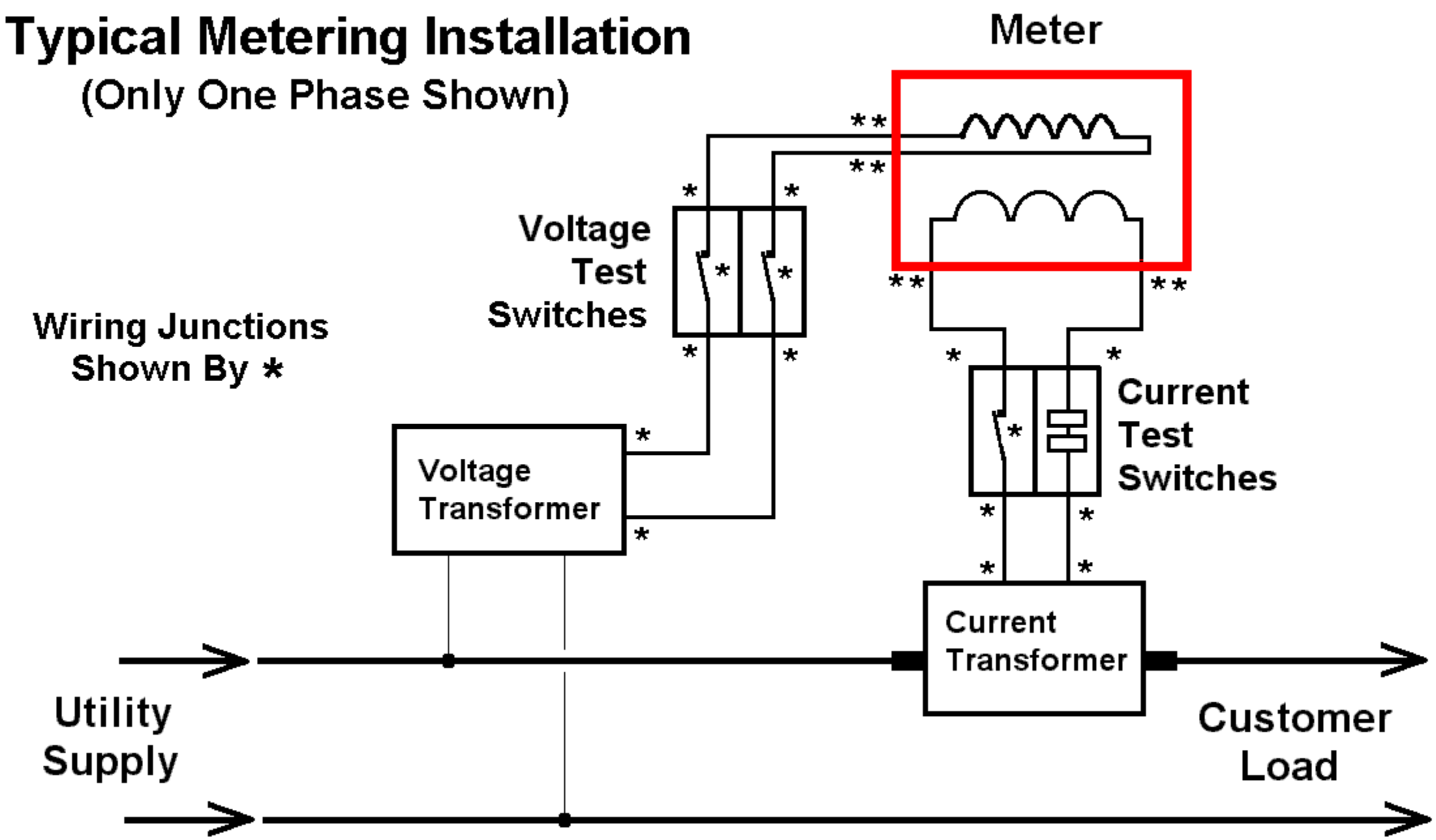
Slide Courtesy Kent Jones, GE

What NOT to do!

- 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



Errors with Current Transformers

- 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 RATING PRI:SEC 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

- 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

Primary Amps	Style 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	

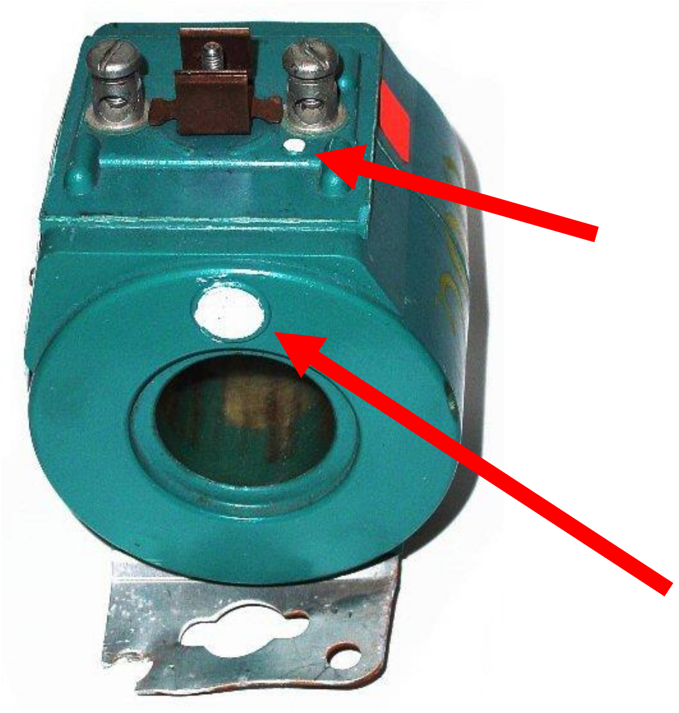
Errors with Instrument Transformers
CT - Shunt

- 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≠0, reversed polarities may not be obvious.

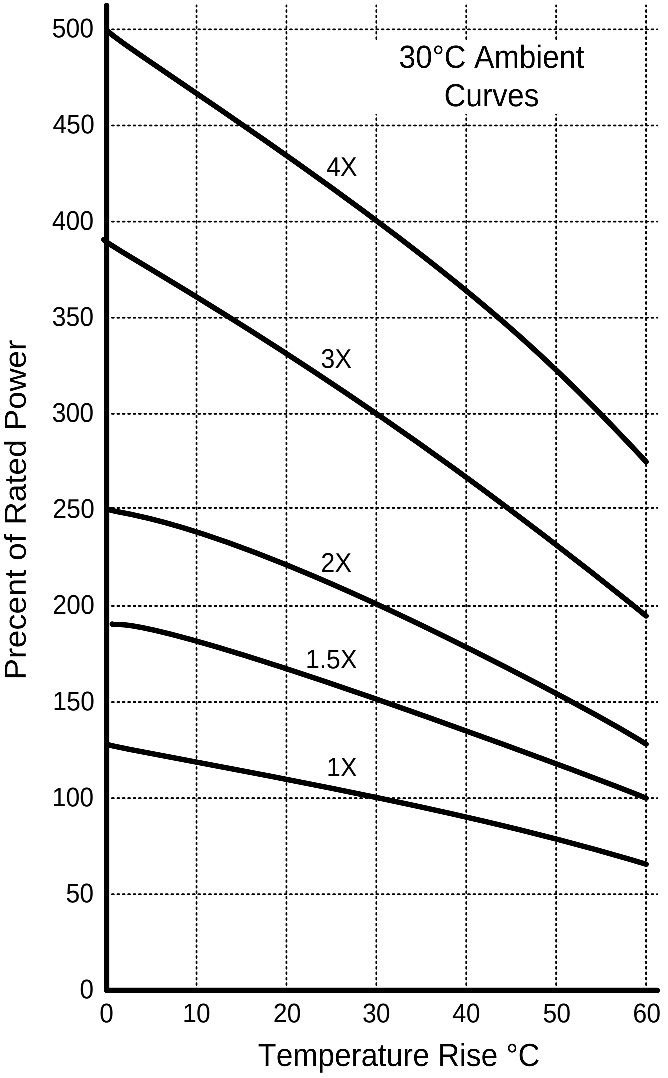
CT Rating Factor

The MOST Misunderstood Spec

- 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

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

CT Testing

- 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.

CT Testing

- 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 ±5%

CT Testing

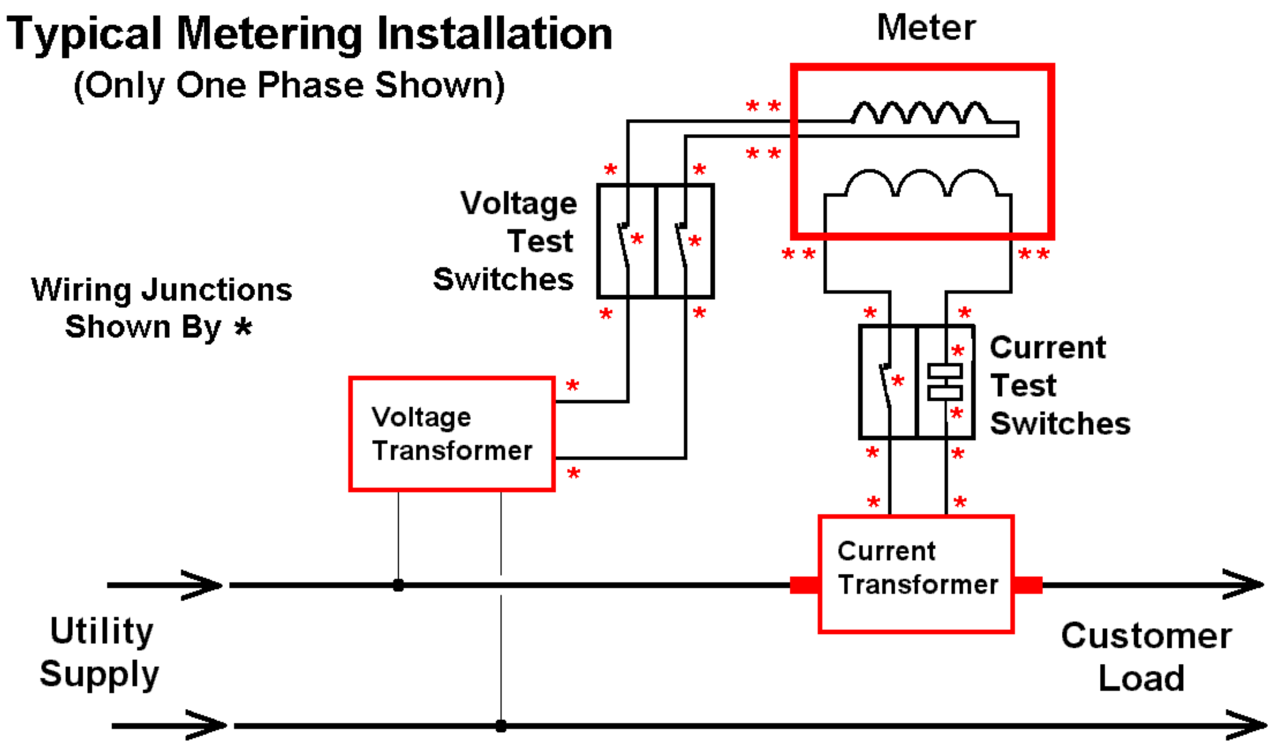
- Other Tests
  - Direct Burden Measurement
    - If you measure the voltage across the CT terminals
    - AND
    - The current output of the CT
    - Using Ohms Law you can compute the actual burden seen by the CT

SIMPLY: Burden = Voltage/Current

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

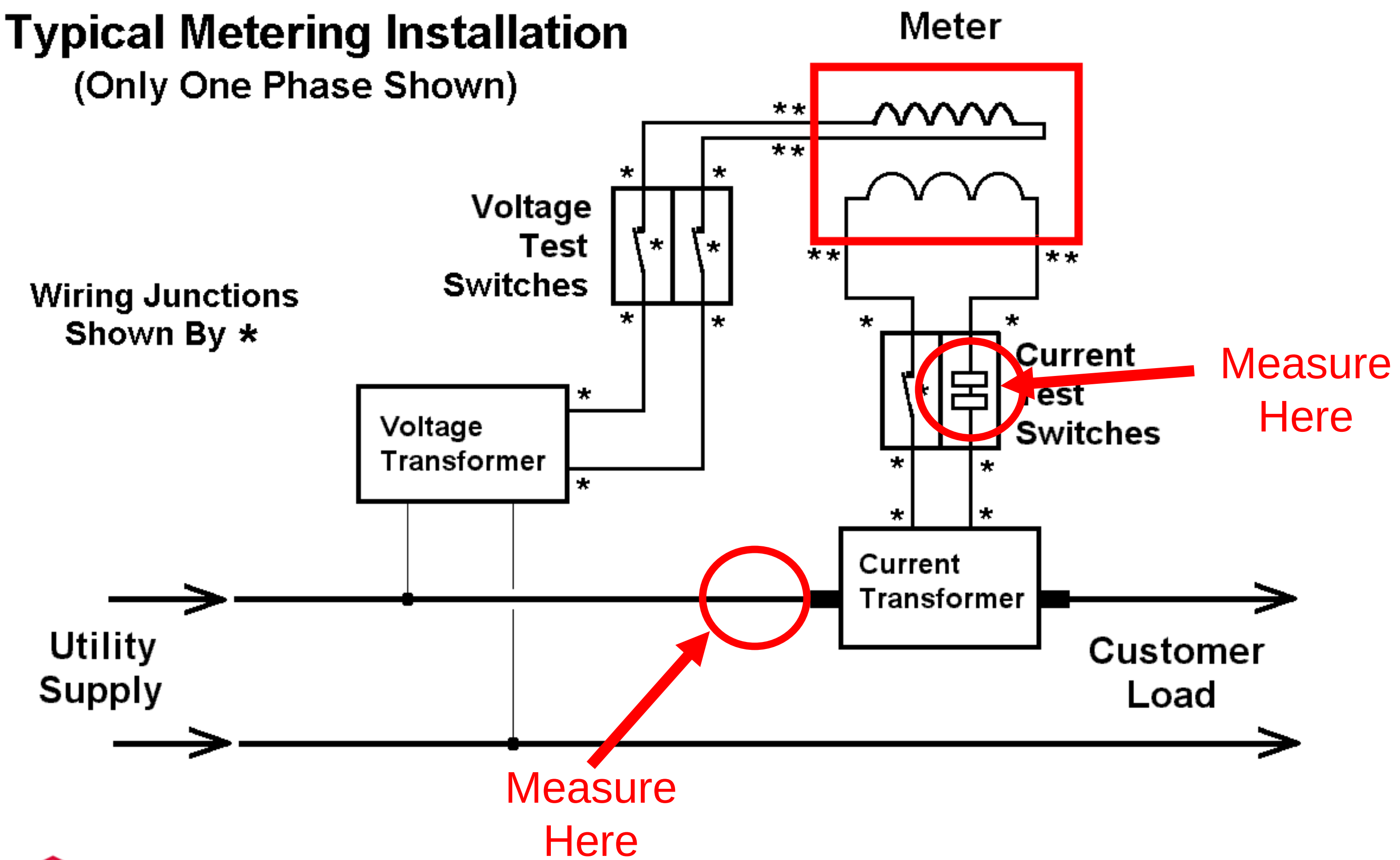
On Site CT Testing

- 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.



CT Transformers

Field Verification – Full Ratio Measurement



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

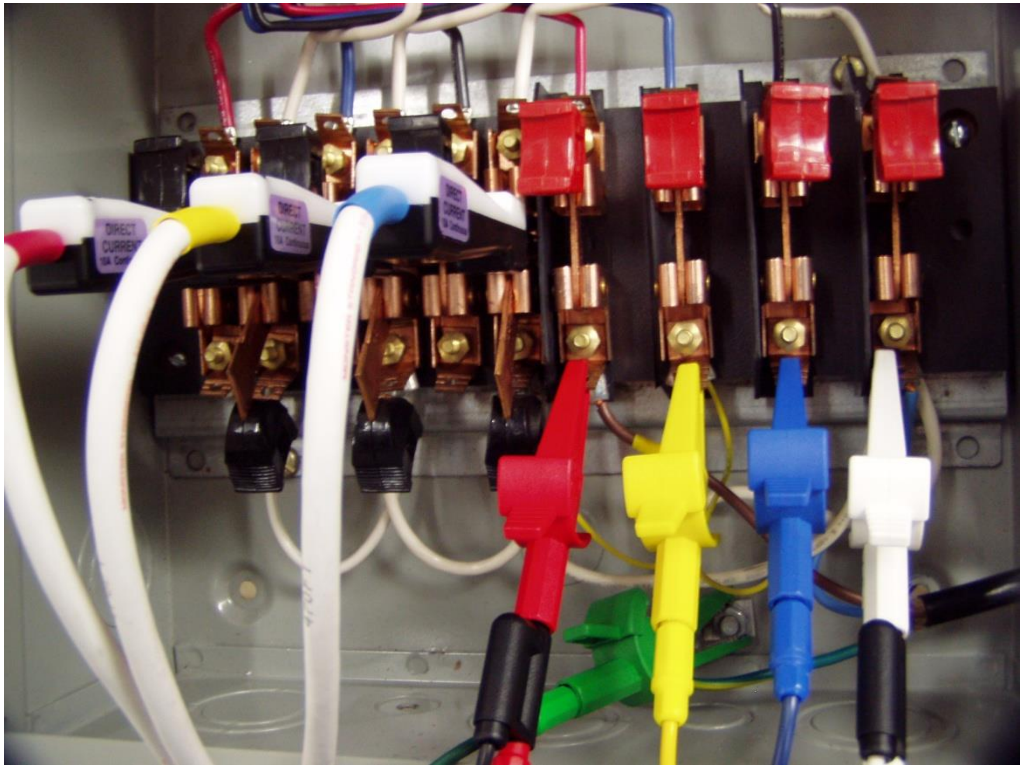
CT Testing

- 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.

Testing Current Transformers
Ratio vs Applied Burden

- CT testing can be done with very high accuracy

Measured Ratio: 399.88 PASS A

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"

Measured Ratio: 400.09 PASS 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"

Measured Ratio: 400.05 PASS C

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.

Testing Current Transformers
Ratio vs Applied Burden

- CT testing can be done with very high accuracy

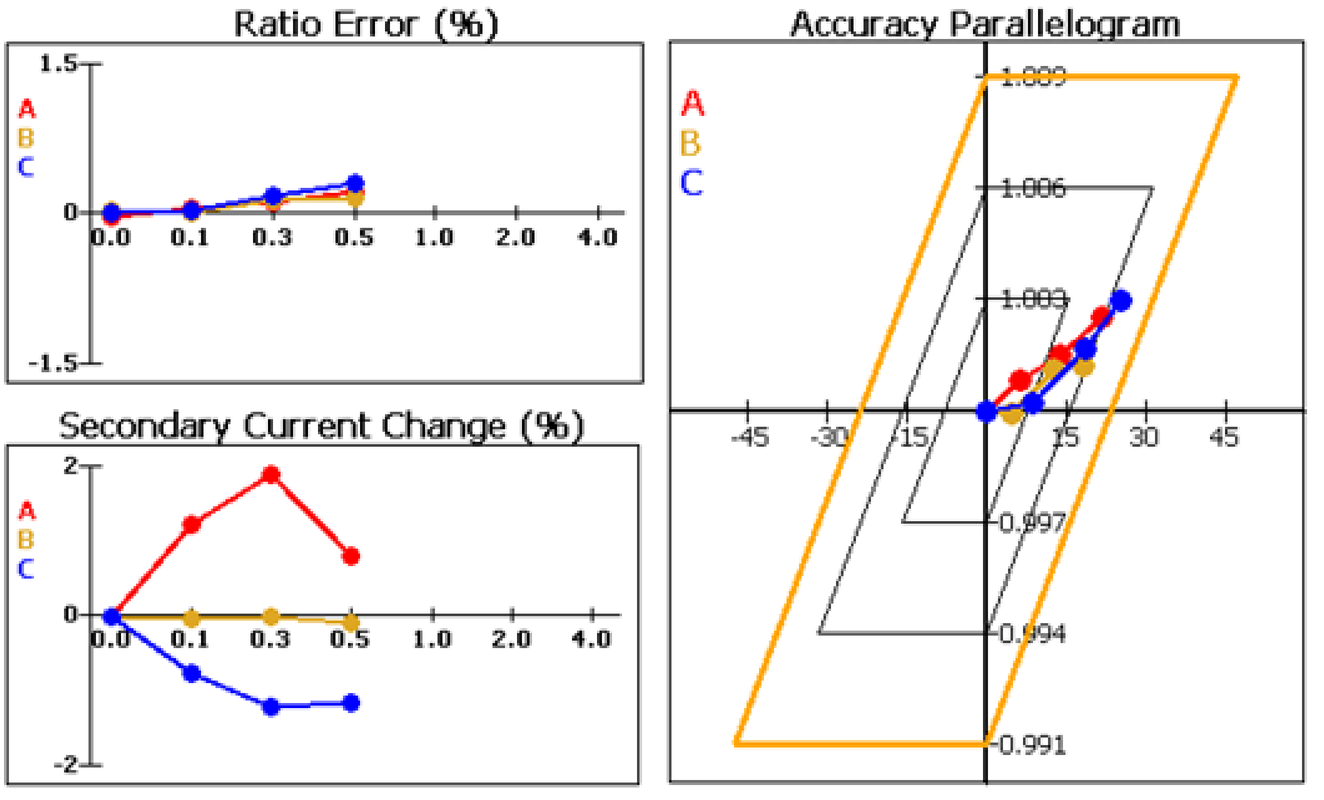
Measured Ratio:	399.88	PASS	A
Nameplate Ratio:	400 : 5	Primary Amps:	34.31
Ratio Error (%):	-0.03%	Secondary Amps:	0.429
Phase Error (degrees):	0.095°	Phase Error (minutes):	5' 43"

Measured Ratio:	400.09	PASS	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"

Measured Ratio:	400.05	PASS	C
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

Measured Ratio: 4.98 PASS A

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"

Measured Ratio: 5.08 FAIL B

Nameplate Ratio:	5 : 5	Primary Amps:	2.33
Ratio Error (%):	1.56%	Secondary Amps:	2.295
Phase Error (degrees):	-0.230°	Phase Error (minutes):	-13' 48"

Measured Ratio: 5.17 FAIL C

Nameplate Ratio:	5 : 5	Primary Amps:	1.29
Ratio Error (%):	3.31%	Secondary Amps:	1.252
Phase Error (degrees):	-1.305°	Phase Error (minutes):	-1° 18' 16"

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

Testing Current Transformers
Ratio Error – In Whose Favor?

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

Ratio = 5.0 * (Primary / Secondary) = 99.68

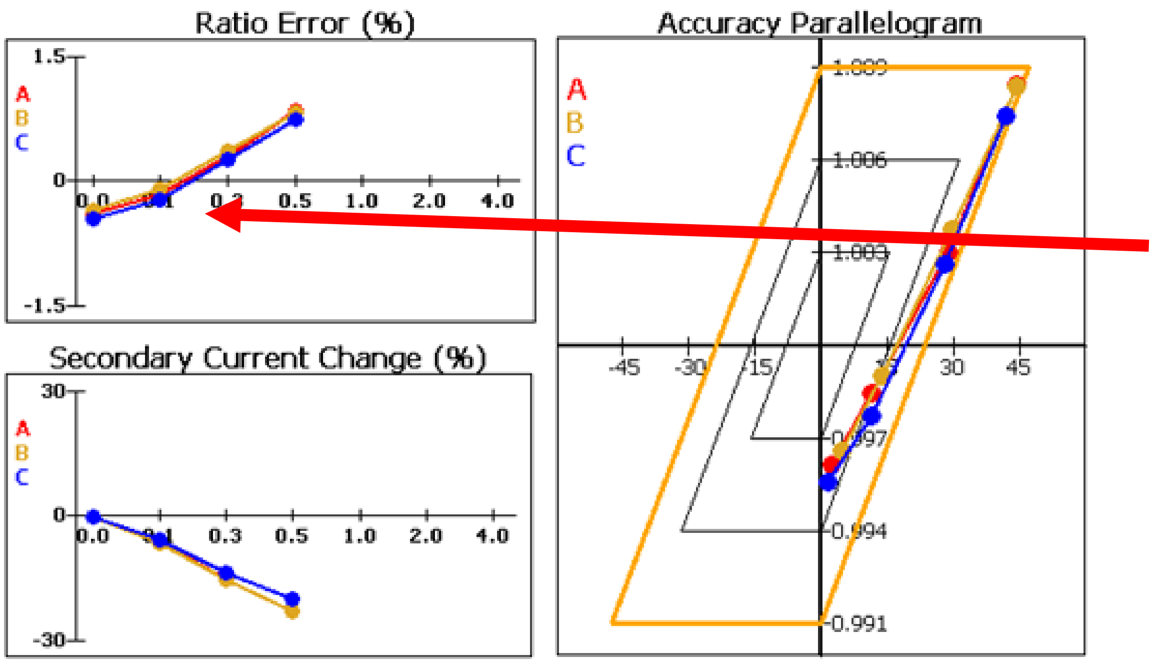
If the ratio had been 100:5 and the primary was 35.86 amps we should have measured 1.793 amps on the secondary.

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.

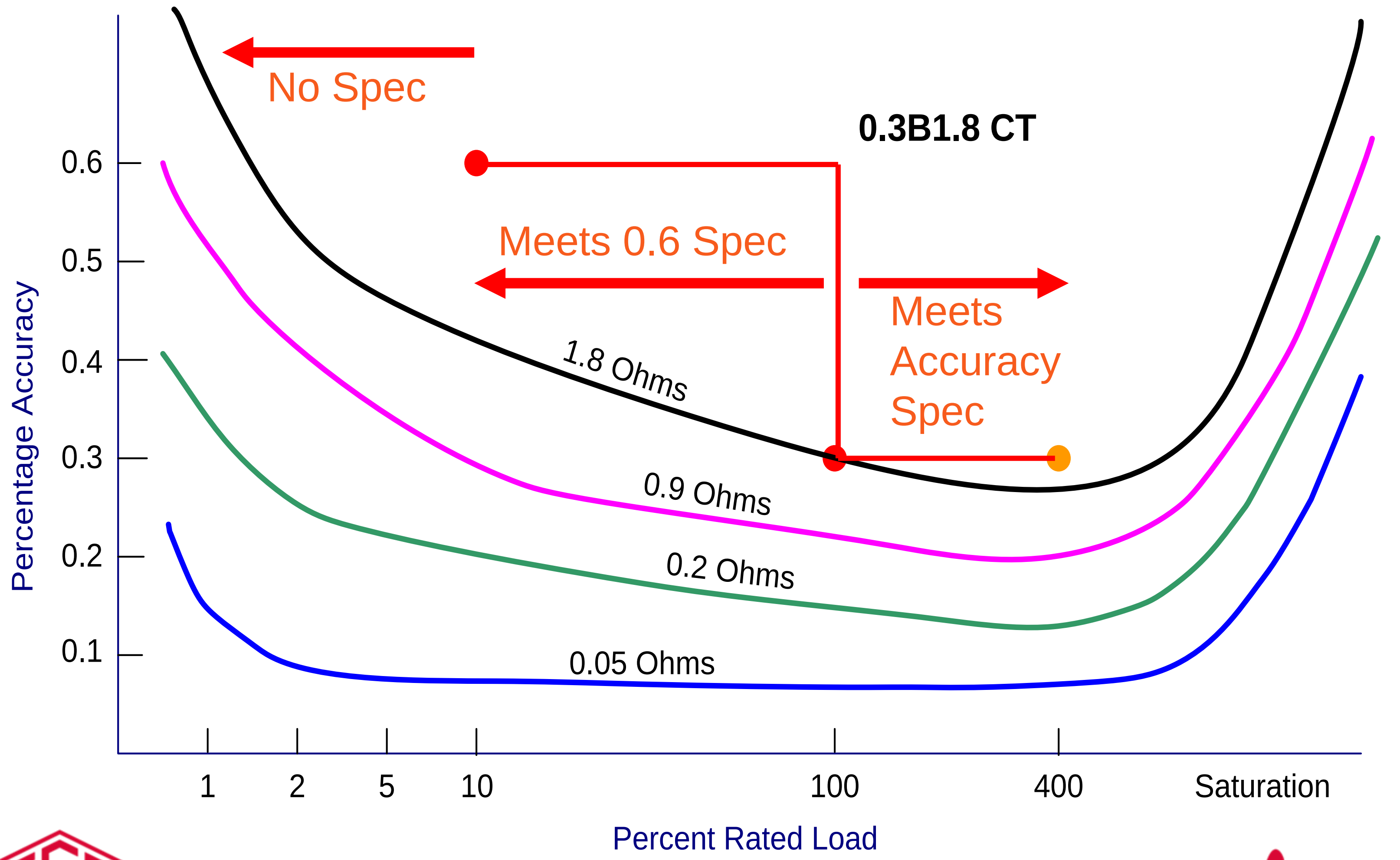
Testing Current Transformers
Ratio Error – In Whose Favor?

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.

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

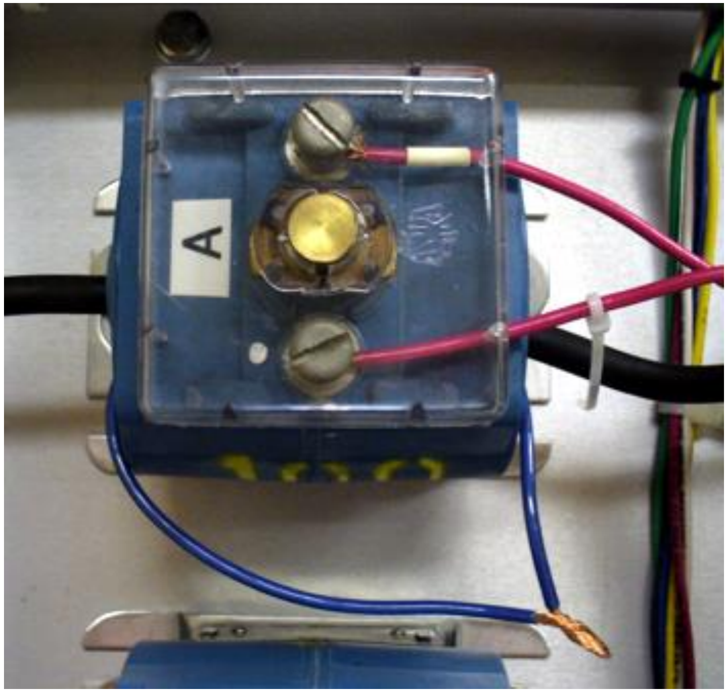
vice was turned off in early 2008, 30% were illegally using electricity late last year, utility PECO says.

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 ser-

Testing Current Transformers
What's Wrong? → Power Theft

A simple piece of wire wrapped around the CT.

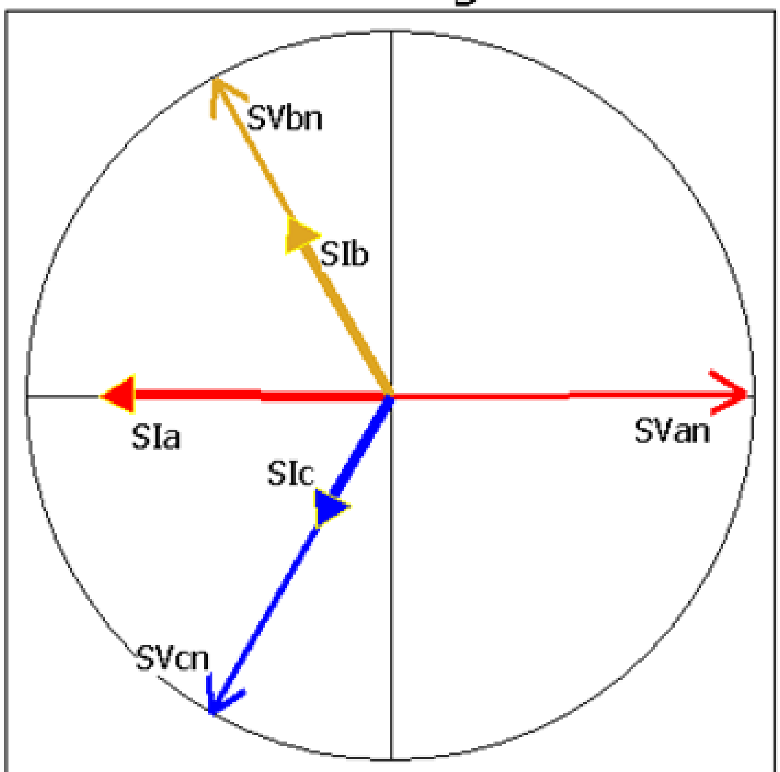


Would you spot it?

Testing Current Transformers

What's Wrong?

Vector Diagram



ΦSVanSIa

SVan	117.914	0.00º
SIa	3.243	179.78º
PF =	1.000	179.78º
Lag		

ΦSVbnSIb

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

ΦSVcnSIc

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

SYS

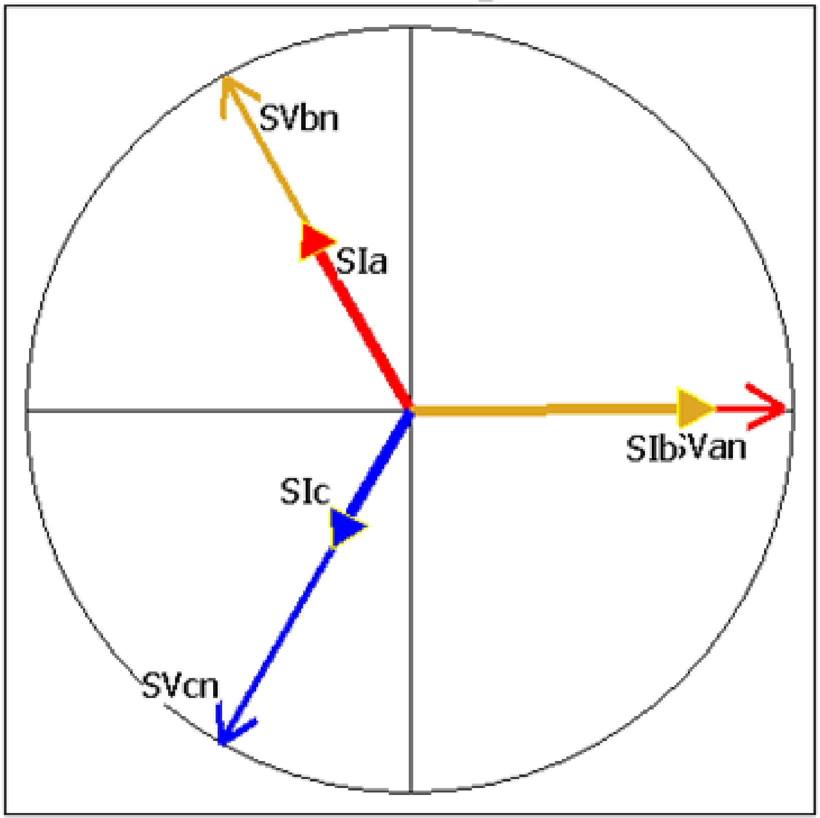
Vsys =	119.613
Isys =	2.403
PF =	1.000
ROT = CBA	

Phase A CT reversed.

Testing Current Transformers

What's Wrong?

Vector Diagram



ΦSVanSIa

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

ΦSVbnSIb

SVbn	119.774	240.91º
SIb	3.245	359.77º
PF =	0.482	118.86º
Lag		

ΦSVcnSIc

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

SYS

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

Phase A & B CTs swapped.

Potential Transformers

- **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

Measured Ratio: 3.99		PASS	A
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"

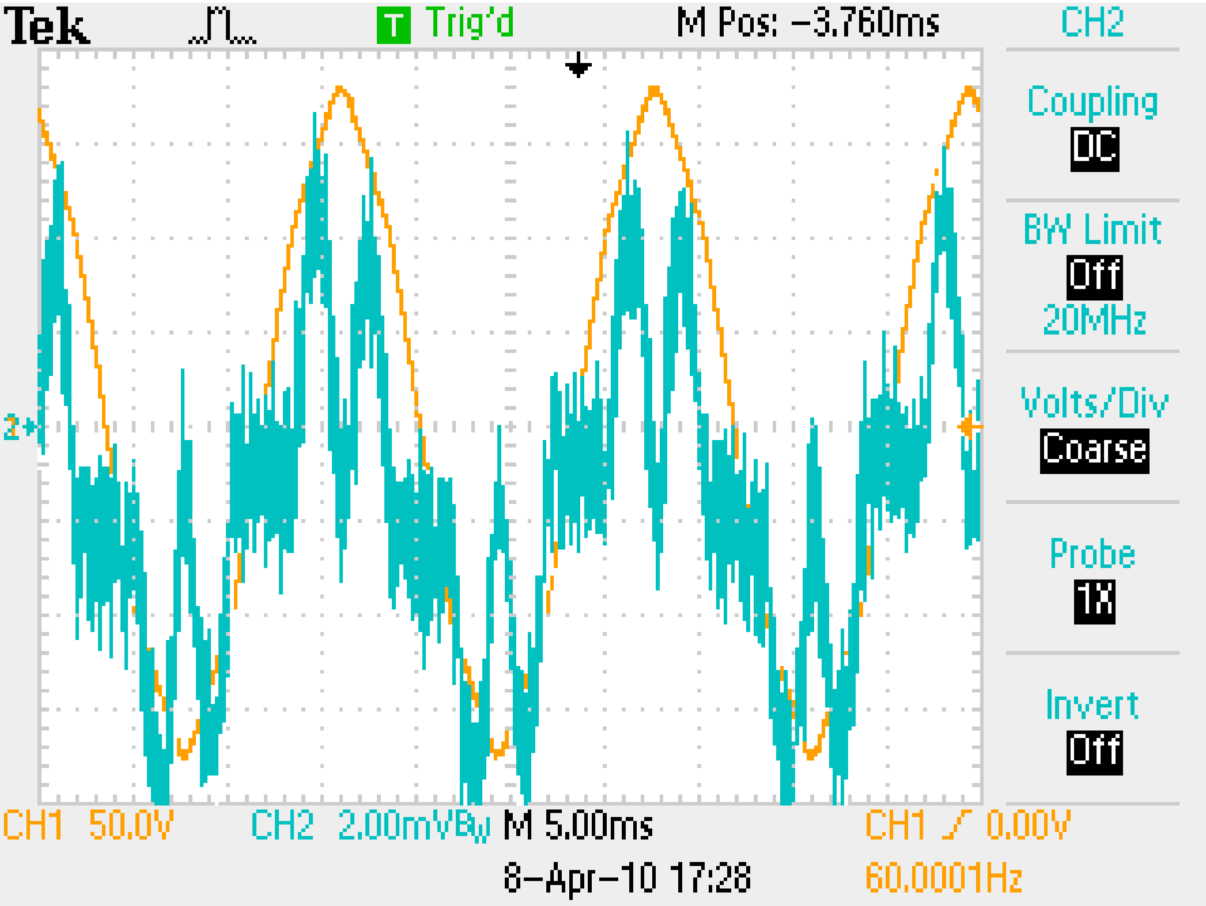
Measured Ratio: 3.99		PASS	B
Nameplate Ratio:	4 : 1	Primary Volts:	454.89
Ratio Error (%):	-0.30%	Secondary Volts:	114.061
Phase Error (degrees):	-0.050°	Phase Error (minutes):	-3' 1"

Measured Ratio: 3.99		PASS	C
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.

Overloaded PT

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

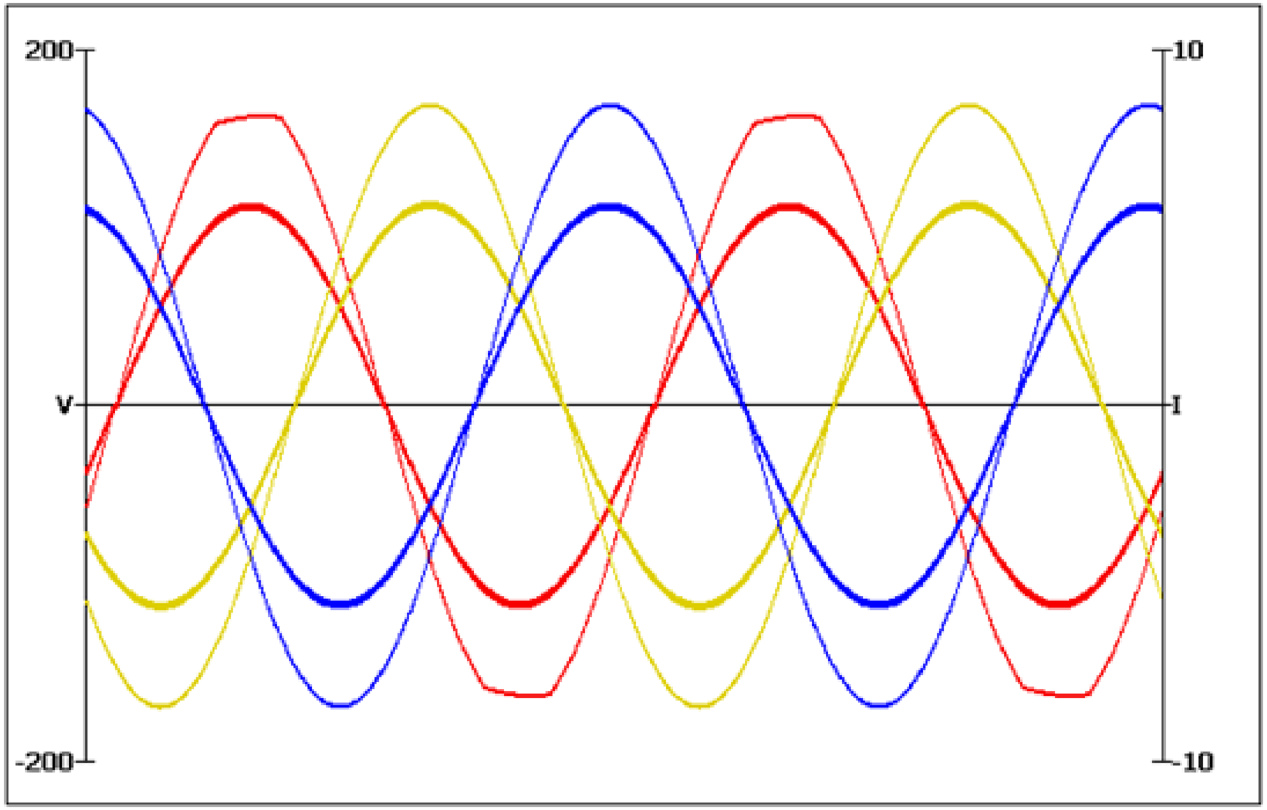


Yellow — PT output

Blue – Current being drawn by meter from this phase

Overloaded PT

- **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

Bill Hardy

TESCO – The Eastern Specialty Company

Bristol, PA

215-688-0298 (cell)

215-785-2338

This presentation can also be found under Meter Conferences and Schools on the TESCO website: www.tesco-advent.com