TESCO METERING

Introduction to Instrument Transformer Rated Metering

Mid South Electric Metering Association 73rd Meter School

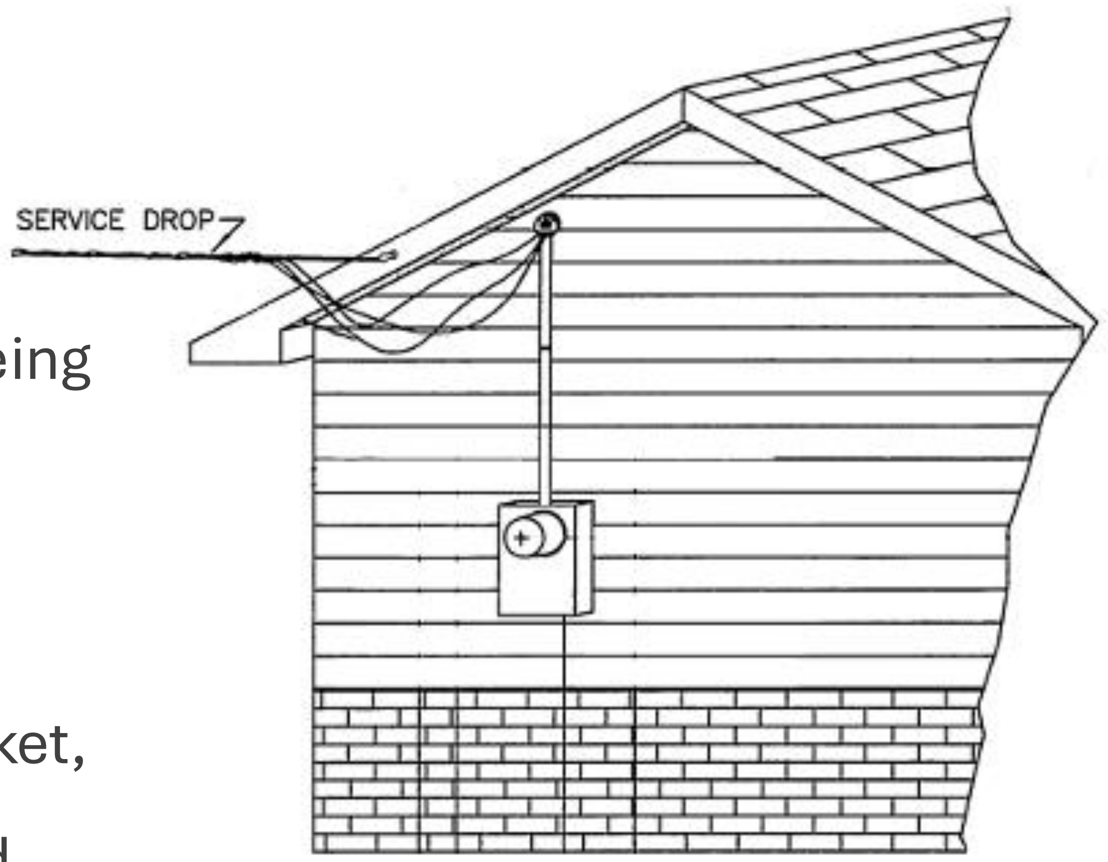
Wednesday May 7, 2025
Group 1: 1:00 PM
Tom Lawton

Topics We will be Covering

- The Basics - Differences Between Self Contained and Transformer or Instrument Rated Meter Sites
- Brief Discussion of polyphase metering for self-contained and transformer rated applications
- Transformer Rated Meter Forms
- Test Switches and CT's
- Blondel's Theorem and why this matters to us in metering
- Meter Accuracy Testing in the Field
- Checking the Health of your CT's and PT's
- Site Verification and not just meter testing

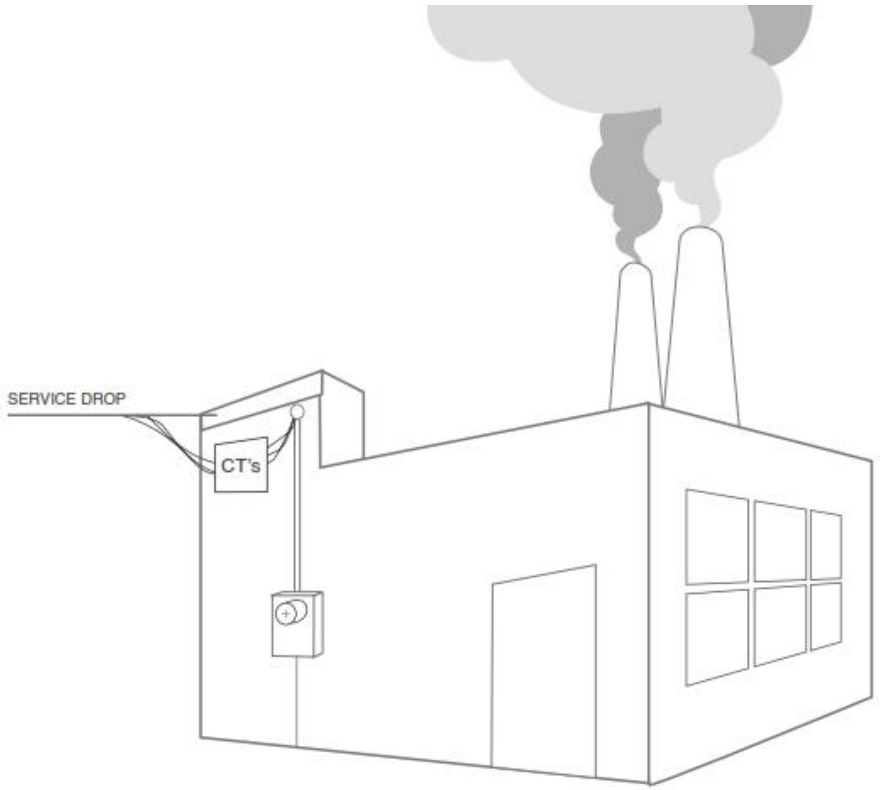
Self Contained Metering

- Typically found in residential metering
- Meters are capable of handling the direct incoming amperage
- Meter is connected directly to the load being measured
- Meter is part of the circuit
- When the meter is removed from the socket, power to the customer is interrupted



Transformer Rated Metering

- Meter measures a scaled down representation of the load.
- Scaling is accomplished by the use of external current transformers (CTs) and sometimes voltage transformers or PTs).
- The meter is NOT part of the circuit
- When the meter is removed from the socket, power to the customer is not affected.



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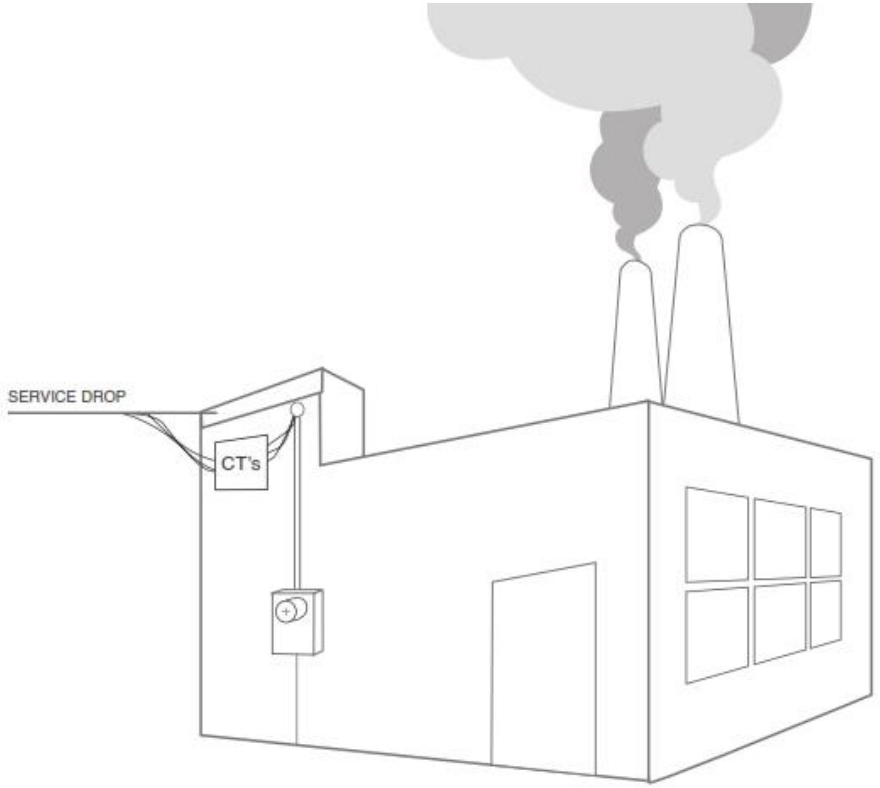
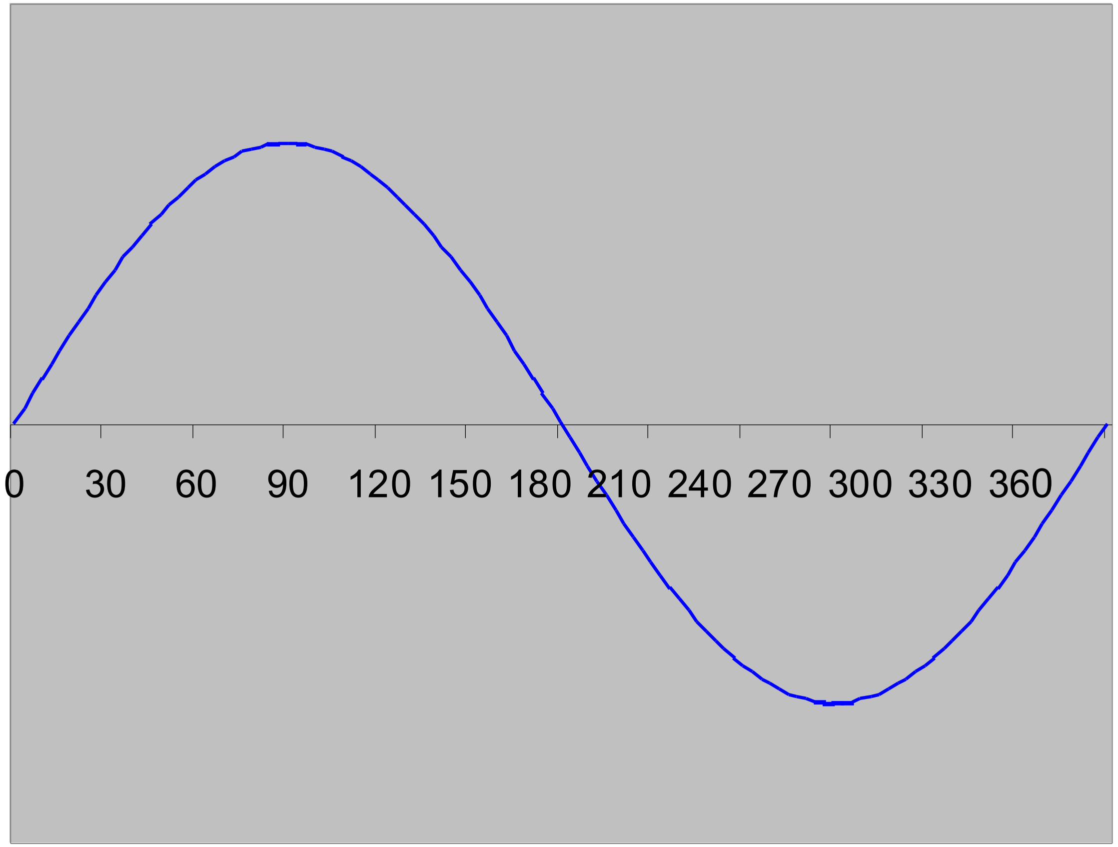
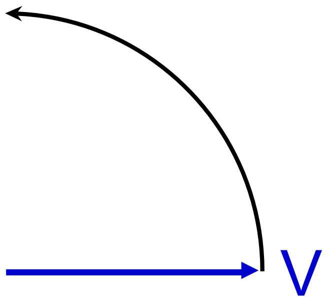


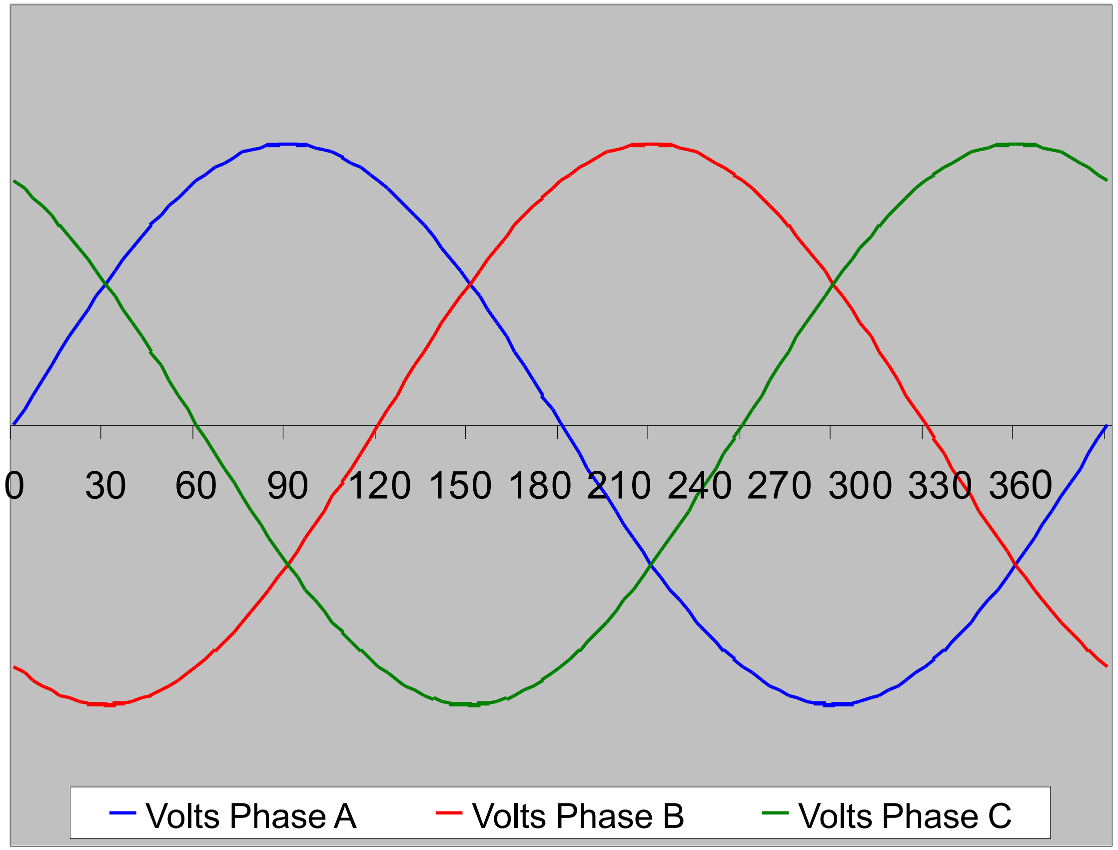
1-Phase and 3-Phase Power

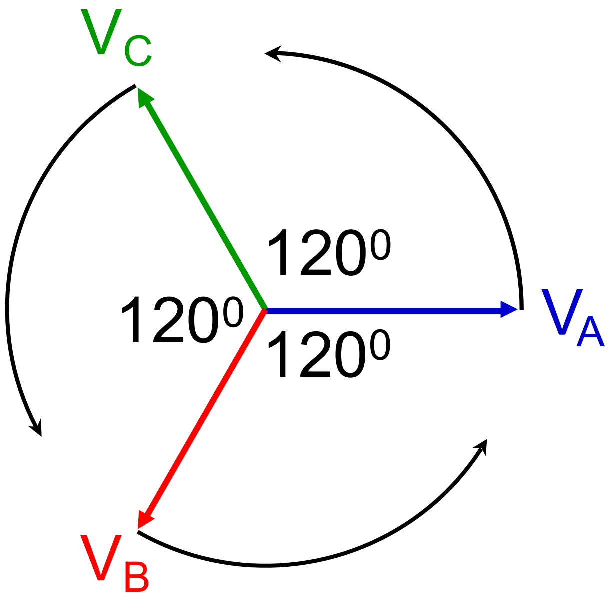




Voltage = V_{max} sine α

1-Phase and 3-Phase Power

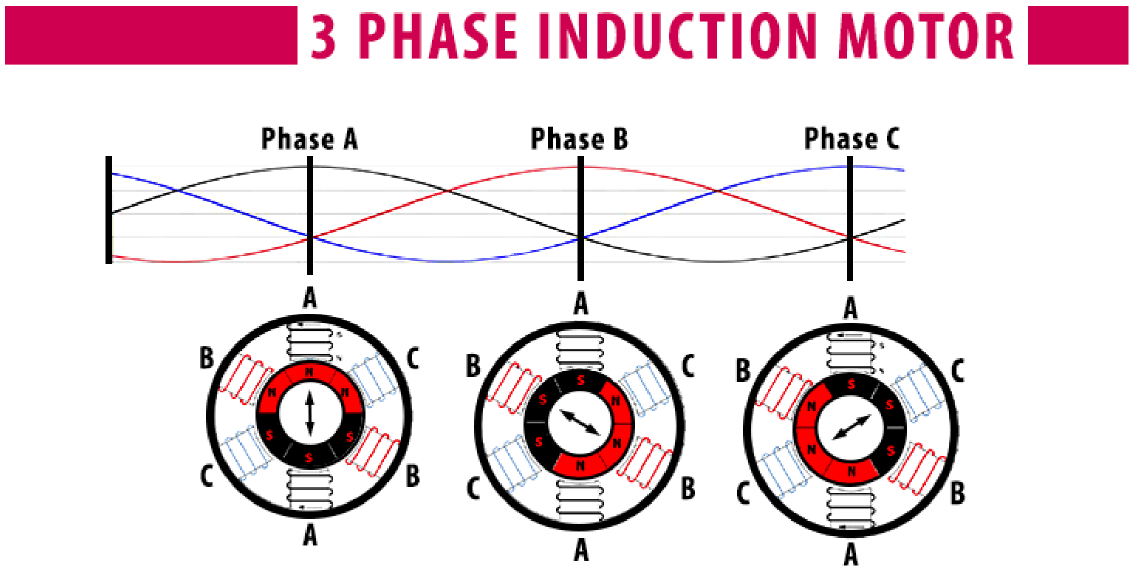




Forward Rotation, ABC

The Need for 3-Phase Power

Single-phase motors provide a pulsating torque to a mechanical load. Loads which require more than 10 horsepower generally also require the steadier torque of a 3-phase motor.



Benefits of 3-Phase Power

✓Steadier motor torque

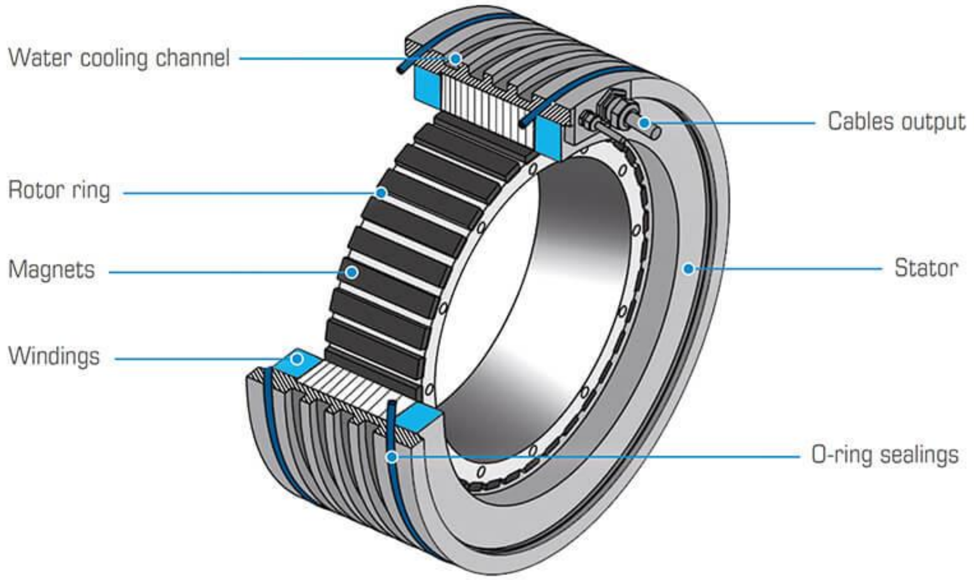
✓Less vibration in machinery

✓Greater mechanical efficiency

✓Better voltage regulation

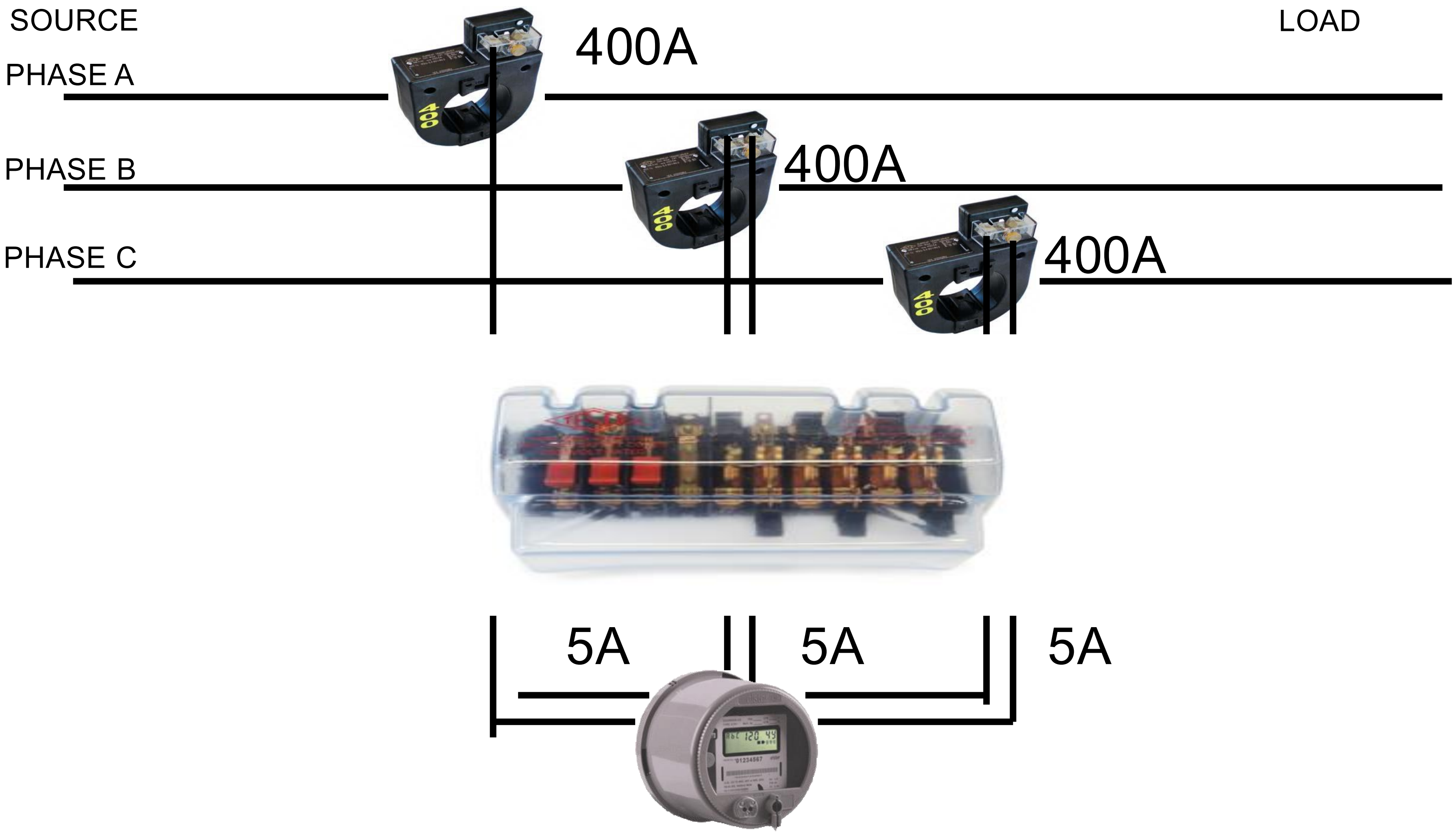
✓Lower heat losses

✓Lighter weight conductors



Transformer Rated - The Basic Components

9S Meter Installation with 400:5 CT's



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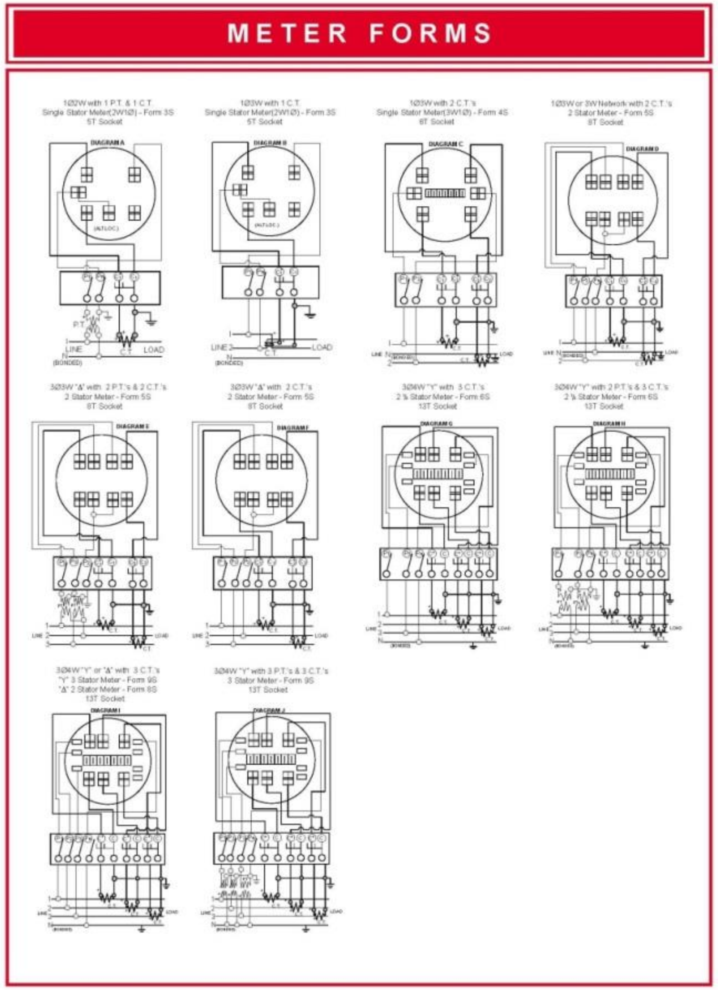
Typical Connections

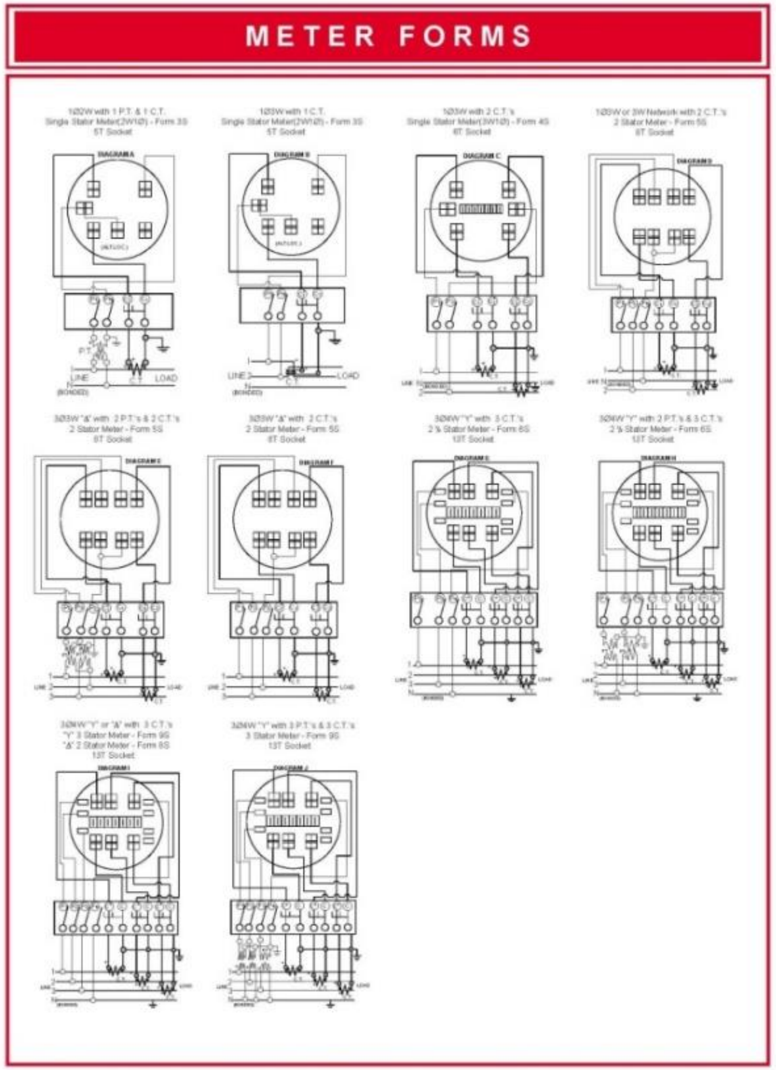


Typical Connections for Common Transformer (Instrument) Rated Meter Forms

Note: See Chapter 4 of the Power Measurement Handbook for more detailed form by form information

Selecting the right meter form

- Select the meter form based on the source, not the load.
  - The "service type" is not always obvious.
  - Loads other than the "known" load can be connected and may be unmetered.
- Meter form numbers describe certain meter characteristics not the service or application
- Consider that *ground* can be a current carrying conductor when applying Blondel's Theorem.
- Understand the operation of present day, polyphase solid state meters and how they may be used to advantage



Three Phase Power: Blondel’s Theorem

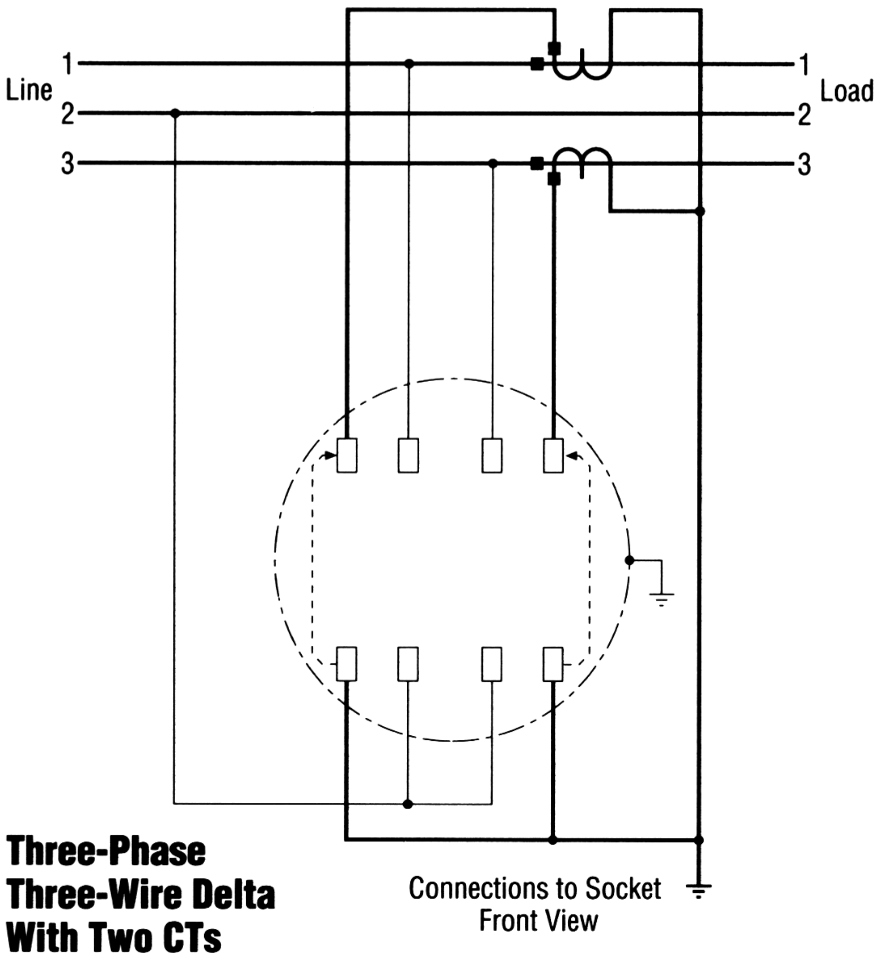
The theory of polyphase watthour metering was first set forth on a scientific basis in 1893 by Andre E. Blondel, engineer and mathematician. His theorem applies to the measurement of real power in a polyphase system of any number of wires. The theorem is as follows:

- *If energy is supplied to any system of conductors through N wires, the total power in the system is given by the algebraic sum of the readings of N wattmeters, so arranged that each of the N wires contains one current coil, the corresponding voltage coil being connected between that wire and some common point. If this common point is on one of the N wires, the measurement may be made by the use of N-1 wattmeters.*

Three Phase Power: Blondel’s Theorem

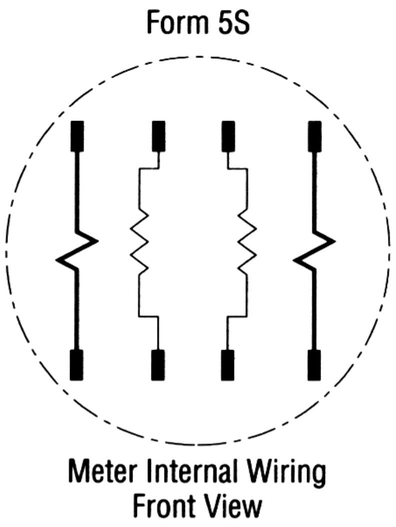
- If a meter installation meets Blondel’s Theorem then we will get accurate power measurements under all circumstances.
- If a metering system does not meet Blondel’s Theorem then we will only get accurate measurements if certain assumptions are met.

Blondel's Theorem

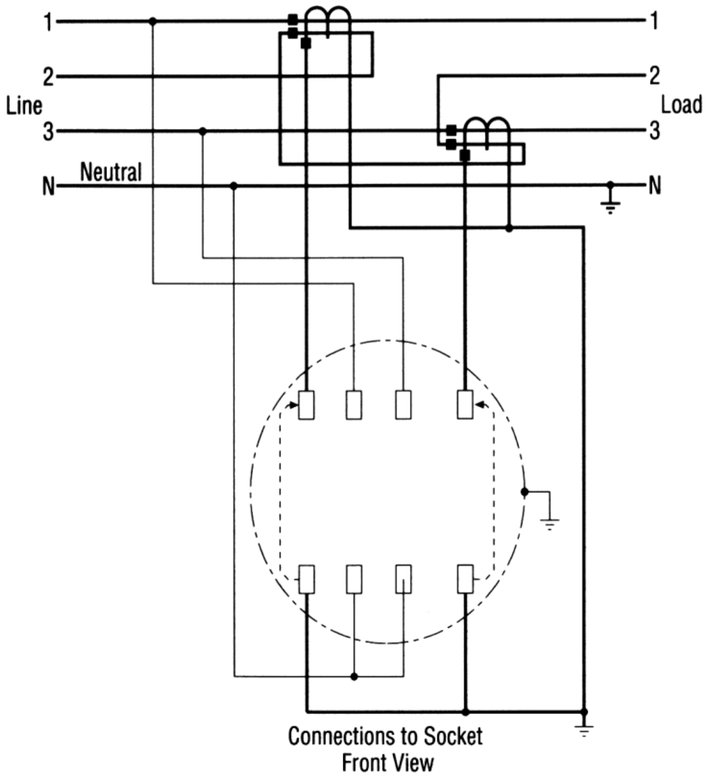


- Three wires
- Two voltage measurements with one side common to Line 2
- Current measurements on lines 1 & 3.

This satisfies Blondel's



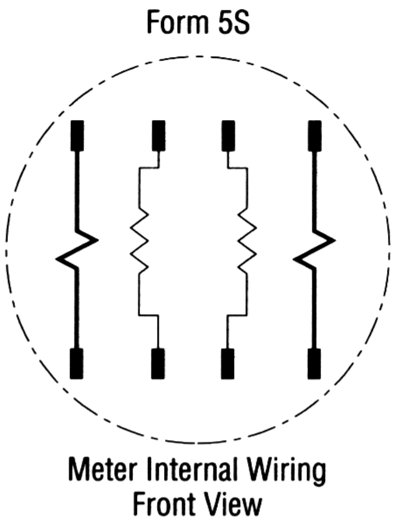
Blondel’s Theorem



Three-Phase
Four-Wire Wye
With Two Equal-Ratio CTs

- Four wires
- Two voltage measurements to neutral
- Current measurements on lines 1 & 3. How about line 2?

This DOES NOT satisfy Blondel’s



Blondel's Theorem

- In the previous example:
  - What are the "ASSUMPTIONS"?
  - When do we get errors?
- What would the "Right Answer" be?

$$P_{sys} = V_a I_a \cos(\theta_a) + V_b I_b \cos(\theta_b) + V_c I_c \cos(\theta_c)$$

- What did we measure?

$$P_{sys} = V_a [I_a \cos(\theta_a) - I_b \cos(\theta_b)] + V_c [I_c \cos(\theta_c) - I_b \cos(\theta_b)]$$

Blondel's Theorem

- Phase B power would be:
  - $P = V_b I_b \cos\theta$
- But we aren't measuring Vb
- What we are measuring is:
  - $I_b V_a \cos(60 - \theta) + I_b V_c \cos(60 + \theta)$
- $\cos(\alpha + \beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta)$
- $\cos(\alpha - \beta) = \cos(\alpha)\cos(\beta) + \sin(\alpha)\sin(\beta)$
- So

Blondel's Theorem

- $Pb = Ib\ Va \cos(60 - \theta) + Ib\ Vc \cos(60 + \theta)$
- Applying the trig identity
  - $IbVa(\cos(60)\cos(\theta) + \sin(60)\sin(\theta))$

    $IbVc(\cos(60)\cos(\theta) - \sin(60)\sin(\theta))$
  - $Ib(Va+Vc)0.5\cos(\theta) + Ib(Vc-Va)\ 0.866\sin(\theta)$
- Assuming
  - Assume Vb = Va = Vc
  - And, they are exactly 120° apart
- $Pb = Ib(2Vb)(0.5\cos\theta) = IbVb\cos\theta$

Blondel's Theorem

- If Va ≠ Vb ≠ Vc then the error is
- %Error =

  -Ib{(Va+Vc)/(2Vb) - (Va-Vc)

  0.866sin(θ)/(Vbcos(θ))
- How big is this in reality? If

  Va=117, Vb=120, Vc=119, PF=1 then E=-1.67%

  Va=117, Vb=116, Vc=119, PF=.866 then E=-

  1.67%

Blondel's Theorem

Power Measurements Handbook

Condition	% V	% I	Phase A				Phase B				non-Blondel
	Imb	Imb	V	ϕvan	I	ϕian	V	ϕvbn	I	ϕibn	% Err
All balanced	0	0	120	0	100	0	120	180	100	180	0.00%
Unbalanced voltages PF=1	18%	0%	108	0	100	0	132	180	100	180	0.00%
Unbalanced current PF=1	0%	18%	120	0	90	0	120	180	110	180	0.00%
Unbalanced V&I PF=1	5%	18%	117	0	90	0	123	180	110	180	-0.25%
Unbalanced V&I PF=1	8%	18%	110	0	90	0	120	180	110	180	-0.43%
Unbalanced V&I PF=1	8%	50%	110	0	50	0	120	180	100	180	-1.43%
Unbalanced V&I PF=1	18%	40%	108	0	75	0	132	180	125	180	-2.44%
Unbalanced voltages PF≠1 PFa = PFb	18%	0%	108	0	100	30	132	180	100	210	0.00%
Unbalanced current PF≠1 PFa = PFb	0%	18%	120	0	90	30	120	180	110	210	0.00%
Unbalanced V&I PF≠1 PFa = PFb	18%	18%	108	0	90	30	132	180	110	210	-0.99%
Unbalanced V&I PF≠1 PFa = PFb	18%	40%	108	0	75	30	132	180	125	210	-2.44%
Unbalanced voltages PF≠1 PFa ≠ PFb	18%	0%	108	0	100	60	132	180	100	210	-2.61%
Unbalanced current PF≠1 PFa ≠ PFb	0%	18%	120	0	90	60	120	180	110	210	0.00%
Unbalanced V&I PF≠1 PFa ≠ PFb	18%	18%	108	0	90	60	132	180	110	210	-3.46%
Unbalanced V&I PF≠1 PFa ≠ PFb	18%	40%	108	0	75	60	132	180	125	210	-4.63%

Why Do We Test?

Why?

Because the Transformer-Rated Services are where the money is!

The Importance of CT Testing in the Field

- One transformer in 3 wired backwards will give the customer a bill of 1/3rd the actual bill.
- One broken wire to a single transformer will give the customer a bill of 2/3rd the actual bill
- One dual ratio transformer inappropriately marked in the billing system as 400:5 instead of 800:5 provides a bill that is ½ of the actual bill. And the inverse will give a bill double of what should have been sent. Both are lose-lose situations for the utility.

The Importance of CT Testing in the Field (cont)

- Cross Phasing (wiring errors)
- Loose or Corroded Connections
- CT Mounted Backwards
- CT's with Shorted Turns
- Wrong Selection of Dual Ratio CT
- Detect Magnetized CT's
- Burden Failure in Secondary Circuit
- Open or Shorted Secondary
- Mislabeled CT's
- Ensures all Shorting Blocks have been Removed

Testing at Transformer Rated Sites

- ✓Meter Accuracy
- ✓Full Load
- ✓Light Load
- ✓Power Factor
- ✓CT Health
- ✓Burden Testing
- ✓Ratio Testing
- ✓Admittance Testing
- ✓Site Verification

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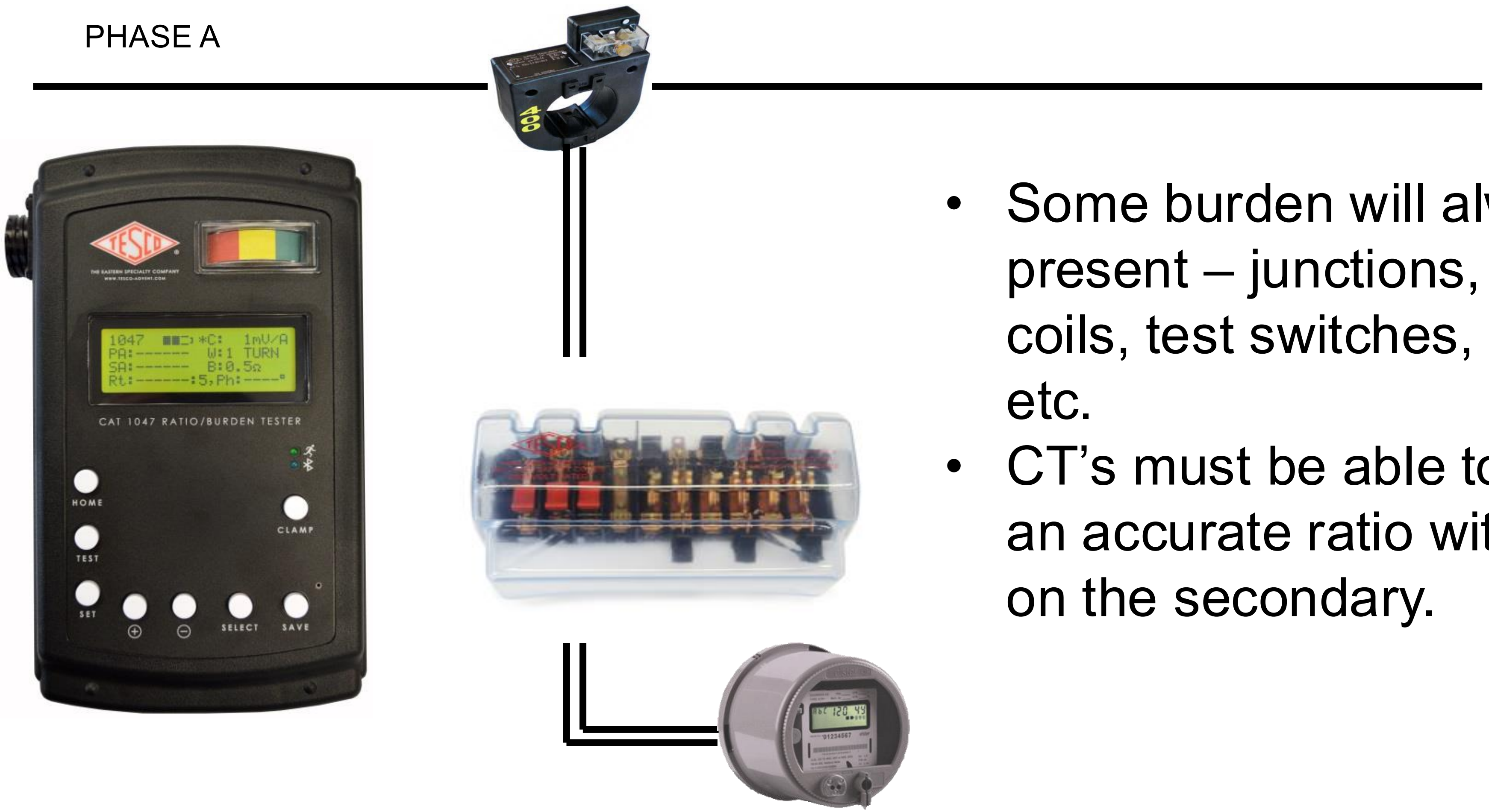
Properly Sizing Conventional and Extended Range CT's

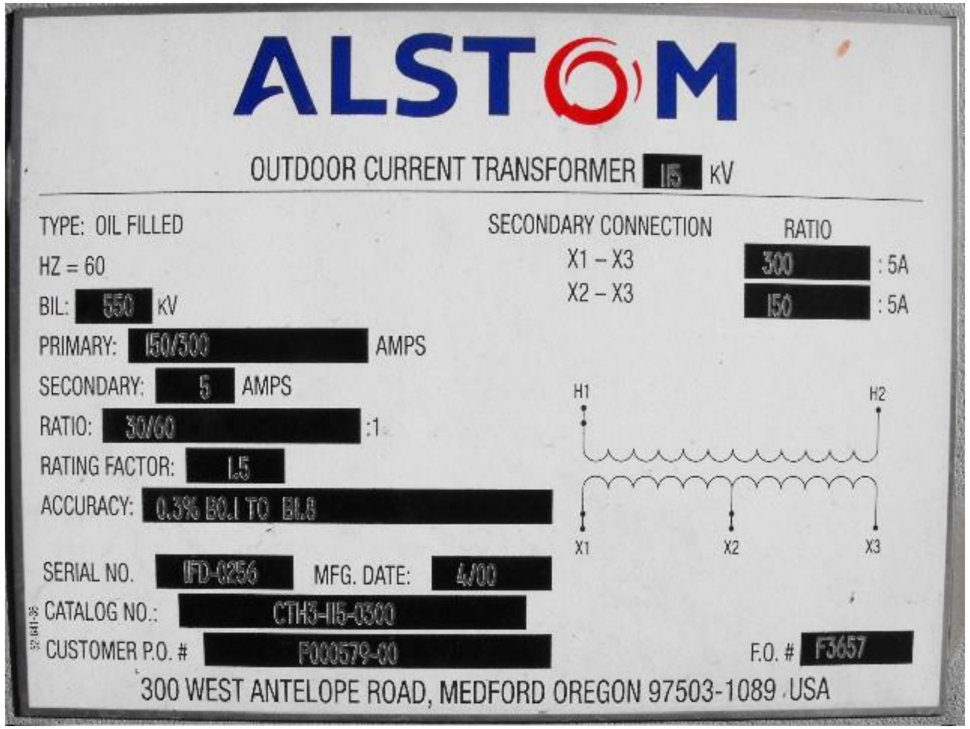
- CT Ratings/Parameters
- Standard Accuracy Classes
- Extended-Range Ratings/Types
- Applying ERCTs
- Advantages of ERCT
- The historic revenue metering class is 0.3, with 0.15 being used with increasing frequency.
- 0.15 "high accuracy" classes were introduced under IEEE C57.13.6.

Functionality with Burden Present on the Secondary Loop



- Some burden will always be present – junctions, meter coils, test switches, cables, etc.
- CT's must be able to maintain an accurate ratio with burden on the secondary.

Functionality with Burden Present on the Secondary Loop



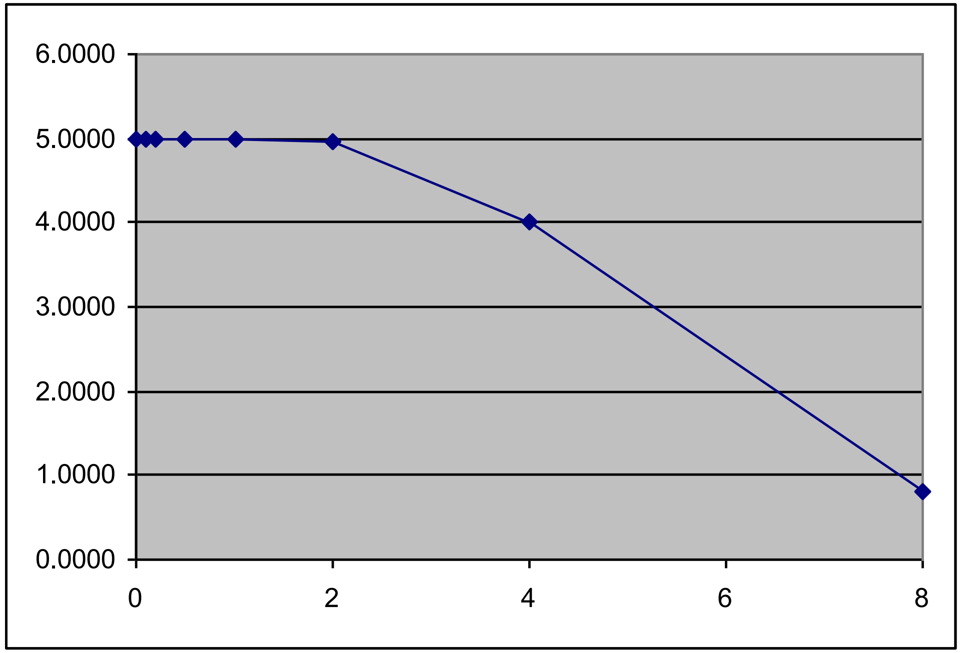
Example Burden Spec:
0.3% @ B0.1, B0.2, B0.5

or

There should be less than the 0.3% change in secondary current from initial ("0" burden) reading, when up to 0.5 Ohms of burden is applied

Functionality with Burden Present on the Secondary Loop

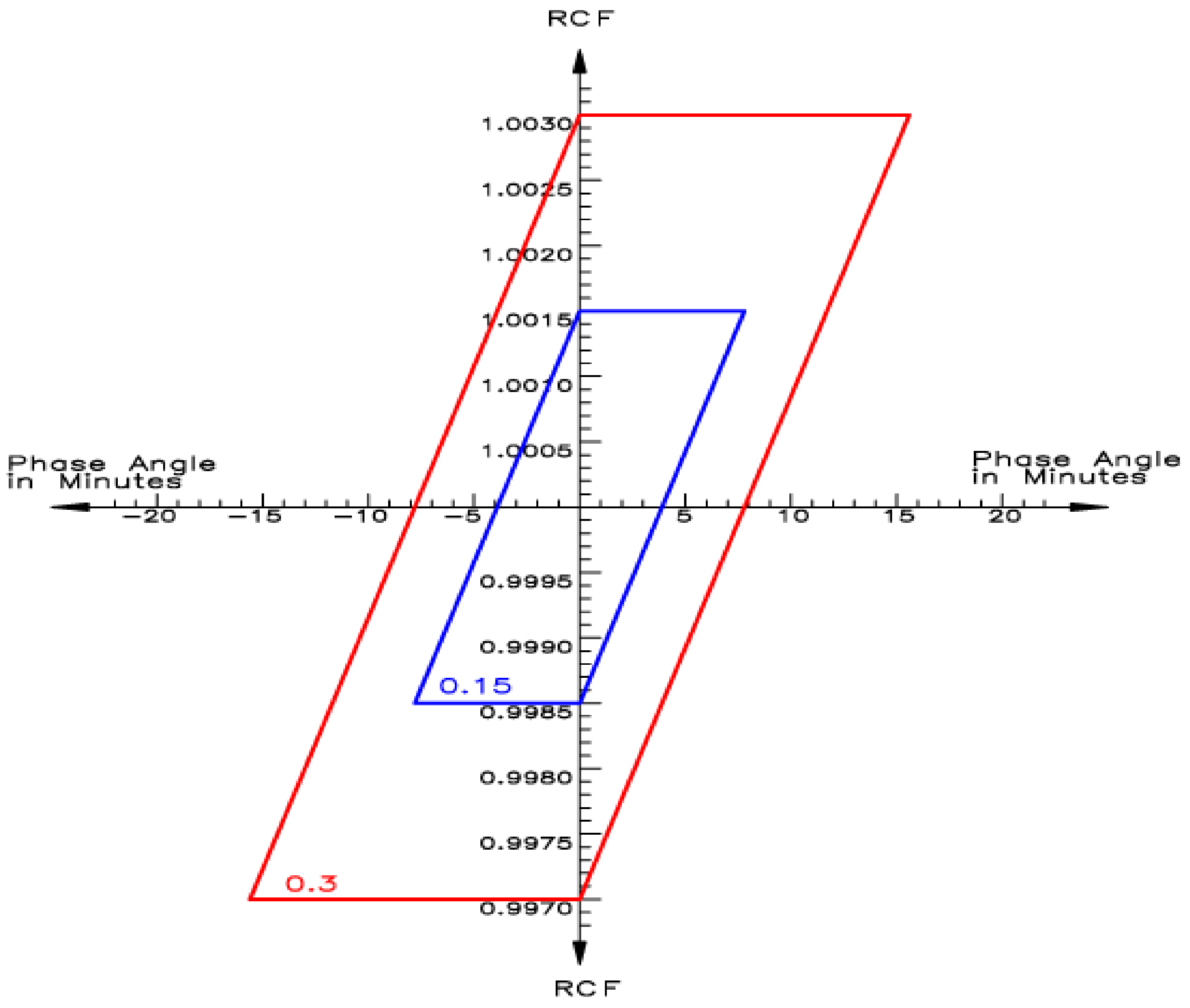
0.3% @ B0.1, B0.2, B0.5



Initial Reading = 5Amps
0.3% x 5A = 0.015A
5A – 0.015 = 4.985A

Burden	Reading
0	5.0000
0.1	4.9999
0.2	4.9950
0.5	4.9900
1	4.9800
2	4.9500
4	4.0000
8	0.8000

Current Transformer Accuracy Classes

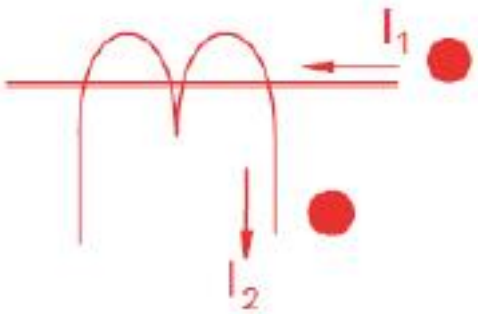


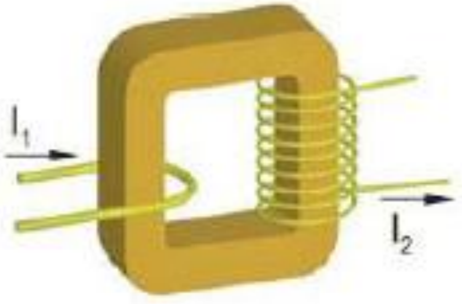
CT Error

CT error is always negative…meaning less current in the secondary than there “should” be by the defined ratio.

CT error becomes increasingly negative as the primary current level decreases.

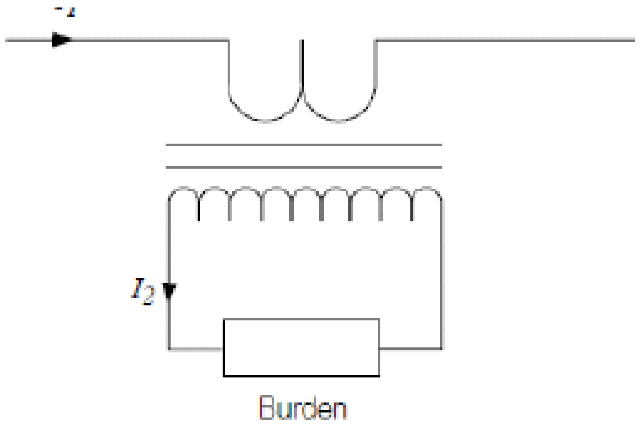
Negative Error = Lost Revenue



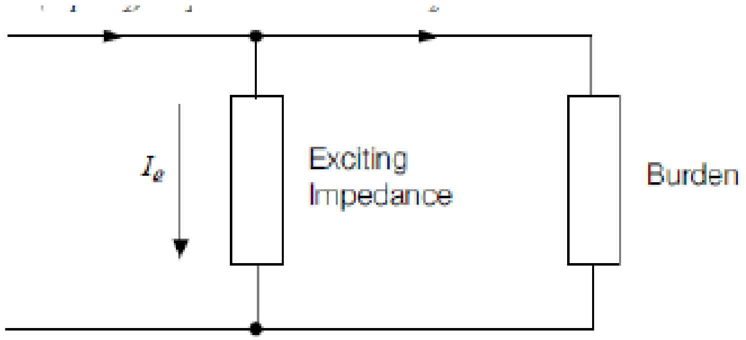


$$I_1 \times N_1 = I_2 \times N_2$$

Ideal. No losses



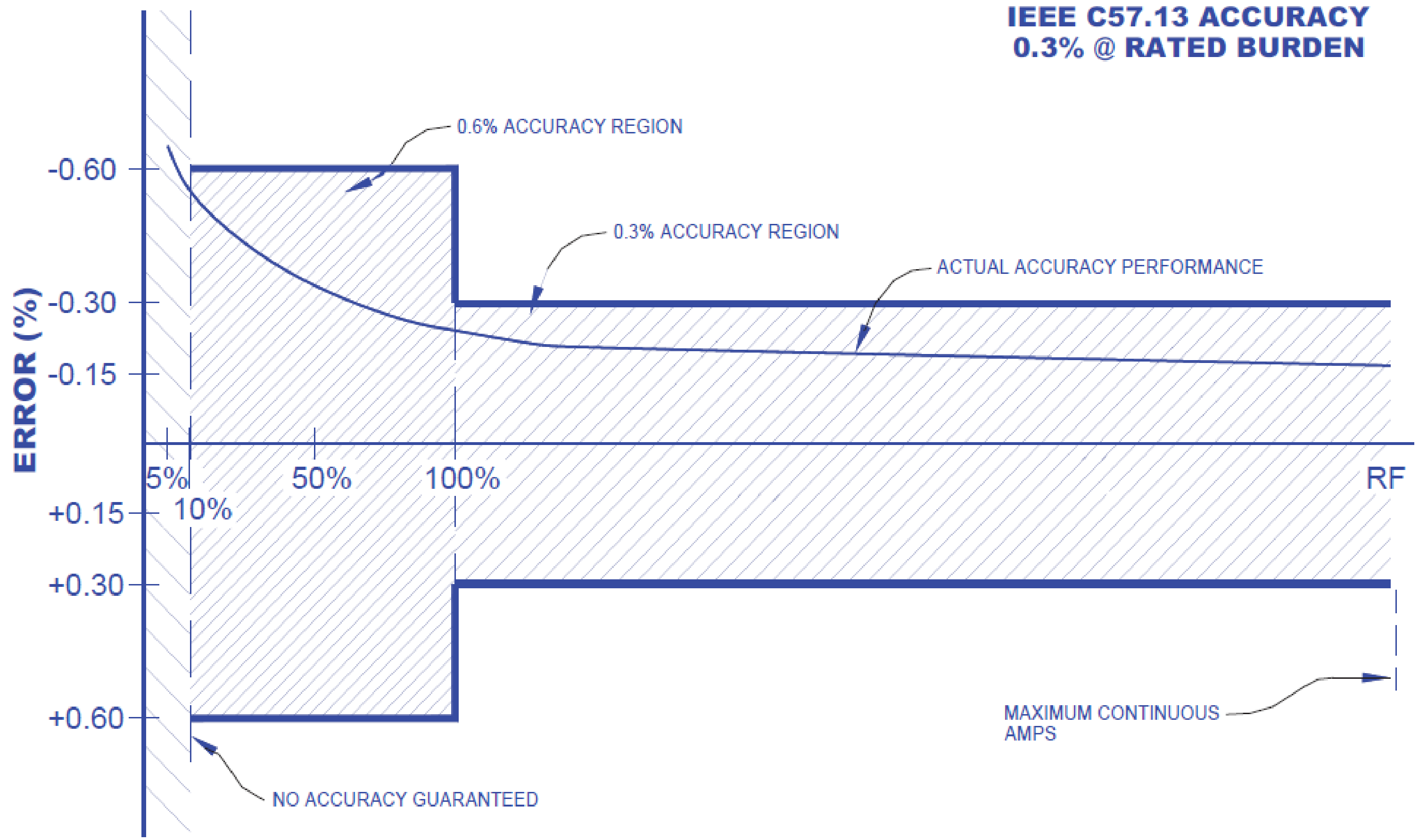
$$I_2 = \frac{N_1}{N_2} \times I_1$$



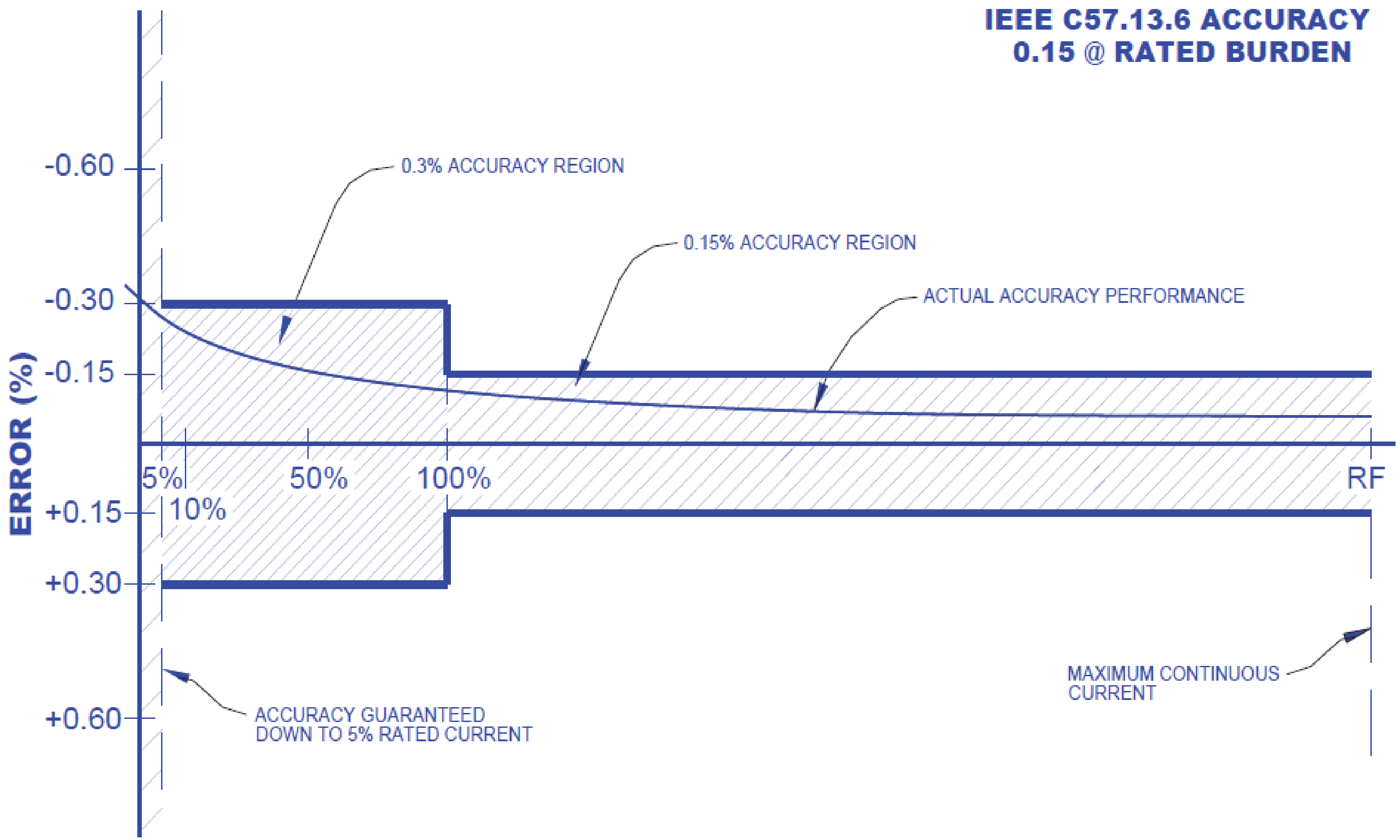
$$I_2 = \frac{N_1}{N_2} \times I_1 - I_e$$

Real, with core losses

CT 0.3 Accuracy Class



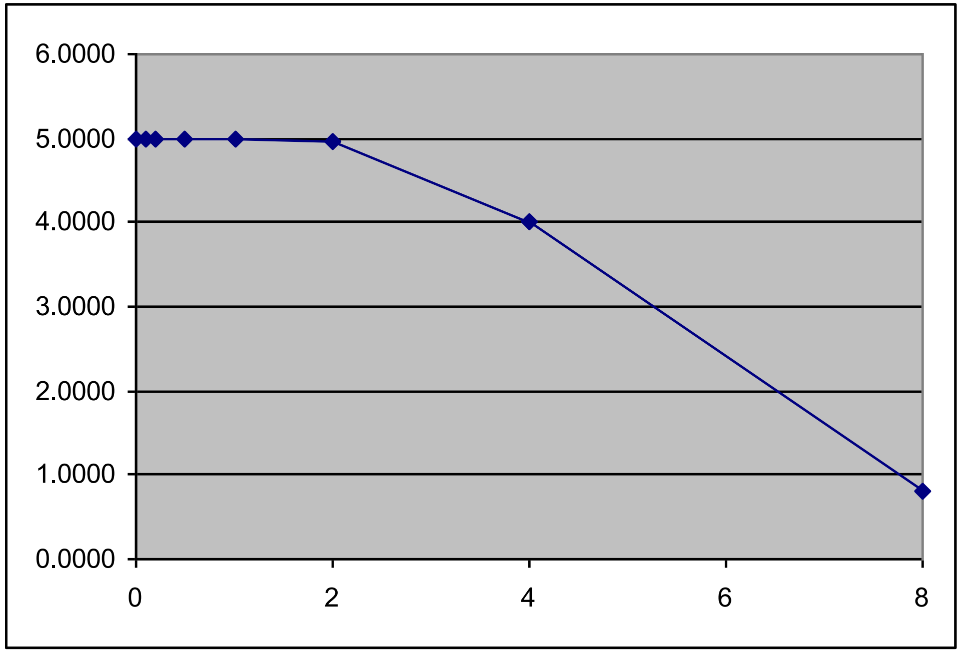
CT 0.15 Accuracy Class



Burden Test – the Quick Indicator

Functionality with Burden Present on the Secondary Loop

0.3% @ B0.1, B0.2, B0.5



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Burden	Reading
0	5.0000
0.1	4.9999
0.2	4.9950
0.5	4.9900
1	4.9800
2	4.9500
4	4.0000
8	0.8000

Site Verification: Potential Site Check List

- Double check the meter number, the location the test result and the meter record.
- Perform a visual safety inspection of the site. This includes utility and customer equipment. Things to look for include intact down ground on pole, properly attached enclosure, unwanted voltage on enclosure, proper trimming and site tidiness (absence of discarded seals, etc.).
- Visually inspect for energy diversions (intentional and not). This includes broken or missing wires, jumpers, open test switch, unconnected wires and foreign objects on meters or other metering equipment. Broken or missing wires can seriously cause the under measurement of energy. A simple broken wire on a CT or VT can cause the loss of 1/3 to 1/2 of the registration on either 3 element or 2 element metering, respectively.

Potential Site Check List (cont)

- Visually check lightning arrestors and transformers for damage or leaks.

- Check for proper grounding and bonding of metering equipment. Poor grounding and bonding practices may result in inaccurate measurements that go undetected for long periods of time. Implementing a single point ground policy and practice can reduce or eliminate this type of issue.

- Burden test CTs and voltage check PTs.

Potential Site Check List (cont)

- Verify service voltage. Stuck regulator or seasonal capacitor can impact service voltage.
- Verify condition of metering control wire. This includes looking for cracks in insulation, broken wires, loose connections, etc.
- Compare the test switch wiring with the wiring at the CTs and VTs. Verify CTs and VTs not cross wired. Be sure CTs are grounded in one location (test switch) only.
- Check for bad test switch by examining voltage at the top and bottom of the switch. Also verify amps using amp probe on both sides of the test switch. Verify neutral connection to cabinet (voltage).

Potential Site Check List (cont)

- Check rotation by closing in one phase at a time at the test switch and observing the phase meter for forward rotation. If forward rotation is not observed measurements may be significantly impacted as the phases are most likely cancelling each other out.
- Test meter for accuracy. Verify demand if applicable with observed load. If meter is performing compensation (line and/or transformer losses) the compensation should be verified either through direct testing at the site or by examining recorded pulse data.
- Loss compensation is generally a very small percentage of the overall measurement and would not be caught under utilities normal high/low checks. However, the small percentages when applied to large loads or generation can really add up overtime. Billing adjustments can easily be in the $million range if not caught early.

Potential Site Check List (cont)

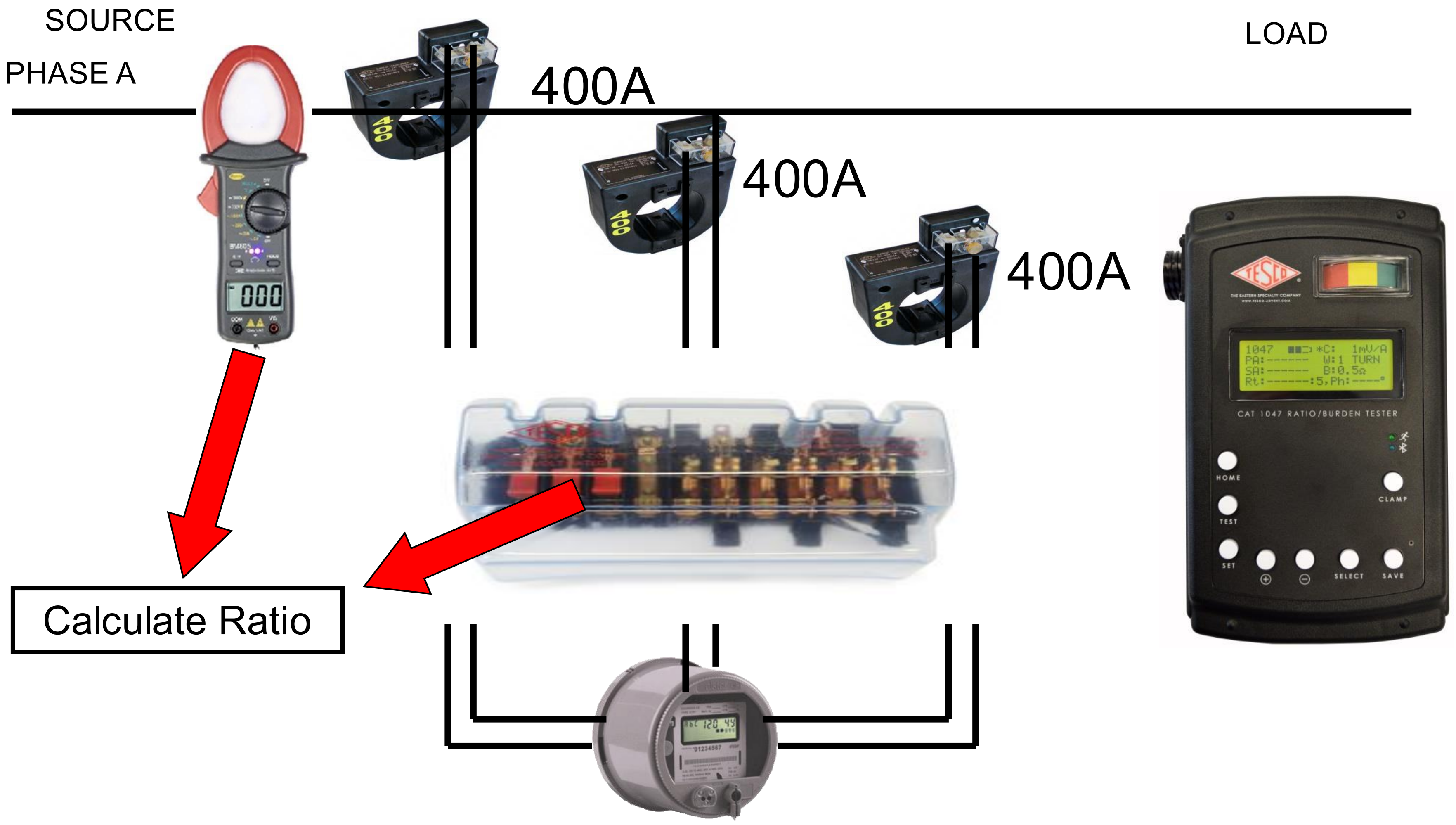
- Verify metering vectors. Traditionally this has been done using instruments such as a circuit analyzer. Many solid-state meters today can provide vector diagrams along with volt/amp/pf and values using meter manufacturer software or meter displays. Many of these desired values are programmed into the meters Alternate/Utility display. Examining these values can provide much information about the metering integrity. It may also assist in determining if unbalanced loads are present and if CTs are sized properly. The vendor software generally has the ability to capture both diagnostic and vector information electronically. These electronic records should be kept in the meter shop for future comparisons.

- If metering is providing pulses/EOI pulse to customers, SCADA systems or other meters for totalization they also should be verified vs. the known load on the meter.

- Verify meter information including meter multiplier (rework it), serial number, dials/decimals, Mp, Ke, Primary Kh, Kr and Rate. Errors in this type of information can also cause a adverse impact on measured/reported values.

- Verify CT shunts are all opened.

Ratio of Primary Current to Secondary Current



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Periodic Site Inspections…

….Can Discover or Prevent:

- Billing Errors
- Bad Metering set-up
- Detect Current Diversion
- Identify Potential Safety Issues
- Metering Issues (issues not related to meter accuracy)
- AMR/AMI Communications Issues
- The need for Unscheduled Truck Rolls due to Undetected Field Related Issues
- Discrepancies between what is believed to be at a given site versus the actual setup and equipment at the site

Shop Testing

- Accuracy Testing
- Meter Communications Performance
- Software & Firmware Verification
- Setting Verification
- Functional Testing
- Disconnect/Reconnect Functionality and as left setting
- Ratio and accuracy testing
- Polarity checking
- Accuracy class determination

Shop Testing Programs

100% of all Transformers

- If not possible then sample testing of all and 100% of all those over a certain size for CT's and all VT's (generally not a large volume)

Transformer testing should include

- Ratio and accuracy testing
- Polarity checking
- Accuracy class determination

100% of all transformer rated meters

- If not possible then sample testing of all transformer rated meters and 100% of all those going into a certain size service and over

Meter testing should include:

- Software & Firmware Verification
- Setting Verification
- Functional Testing
- Disconnect/Reconnect Functionality and as left setting

Use AMI to Target Sites to Visit

- **Use** your AMI analytics to determine where there are misses:
  - No draw on one leg
  - Intermittent draw on one leg
  - Performing outside the rated range for the installed transformers
  - Reversed polarity

Summary

- **Reduce** the resources spent on self-contained metering by leveraging your AMI data as much as possible and creating new systems and procedures to replace older processes that did not have the availability of this type of data.
- **Perform** a shop test of every meter going into a transformer rated service. This includes a functional test as well as an accuracy test.

Summary (cont)

- **Perform** a shop test of every CT and VT going into a transformer rated service – or do a full site verification on every new site within 30 days of installation
- **Perform** a base line site verification of every transformer rated service in your service territory.
- **Use** your AMI analytics to determine where there are misses.
- **Start** checking for field issues all over again.

Questions and Discussion

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This presentation can also be found under Meter Conferences and Schools on the TESCO website: tescometering.com

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ISO 17025:2017 Accredited Laboratory