Transformer Rated Metering

THE EASTERN SPECIALTY COMPANY

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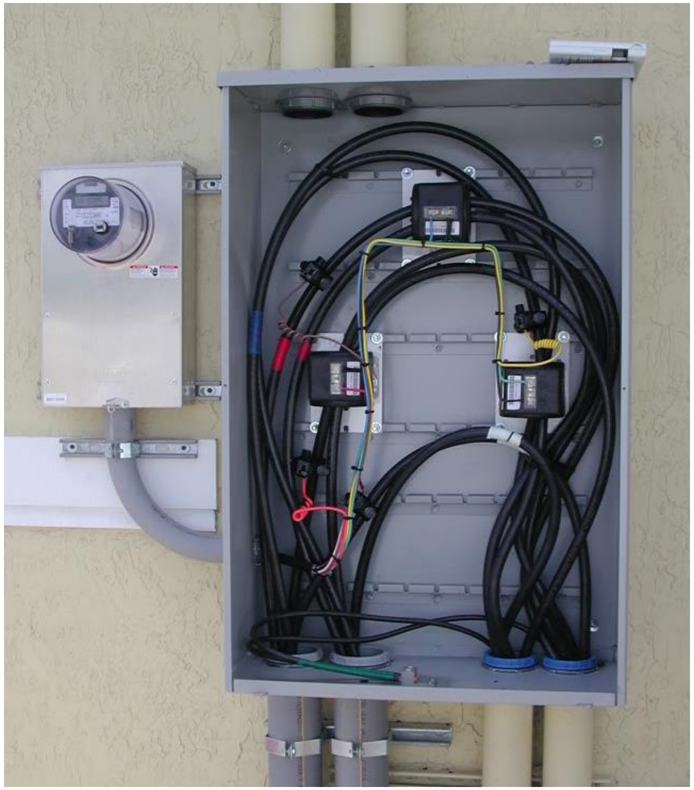
For Mississippi Electric Meter School
Wednesday, October 10, 2018
11:00 a.m. – 11:45 a.m.

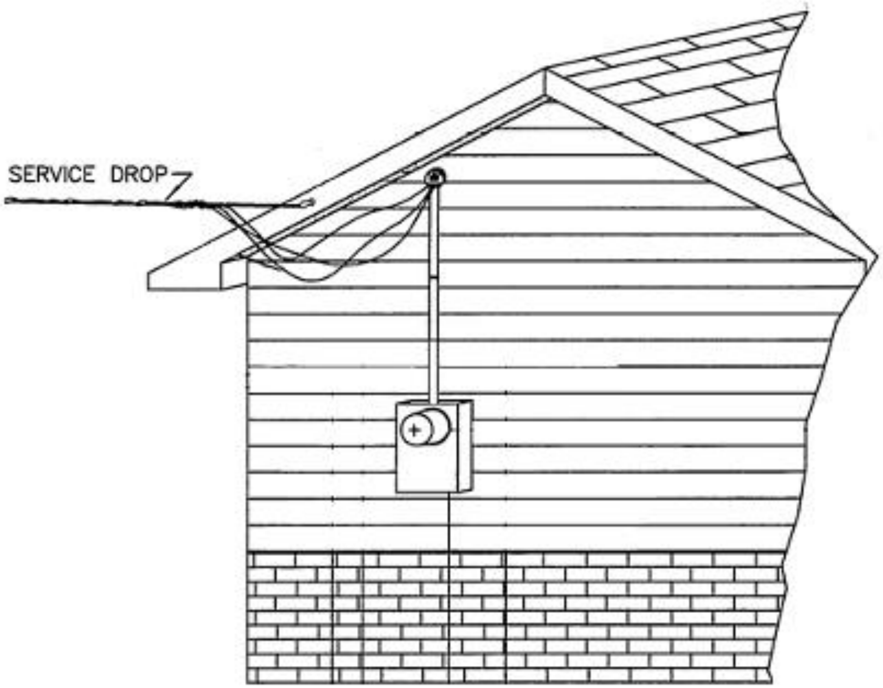
Topics we will be covering

- The Basics- Differences Between Self Contained and Transformer or Instrument Rated Meter Sites
- 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



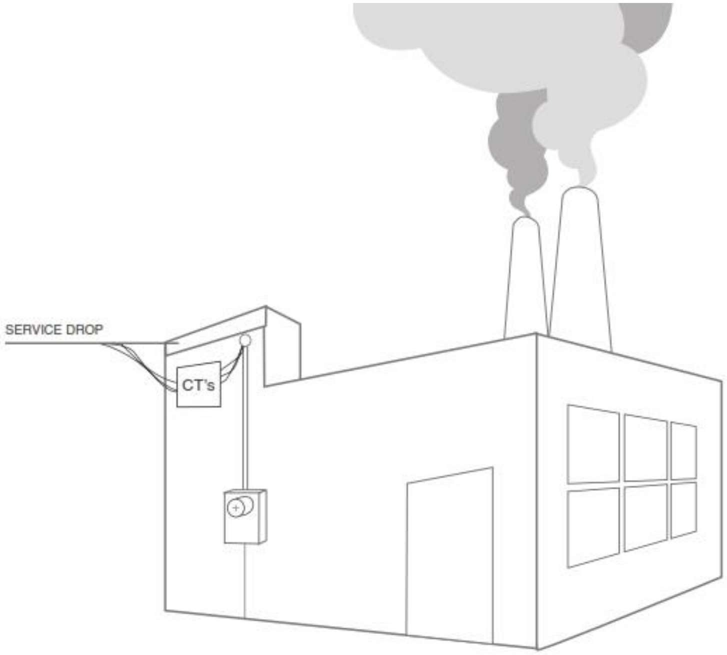
Self Contained Metering

- 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

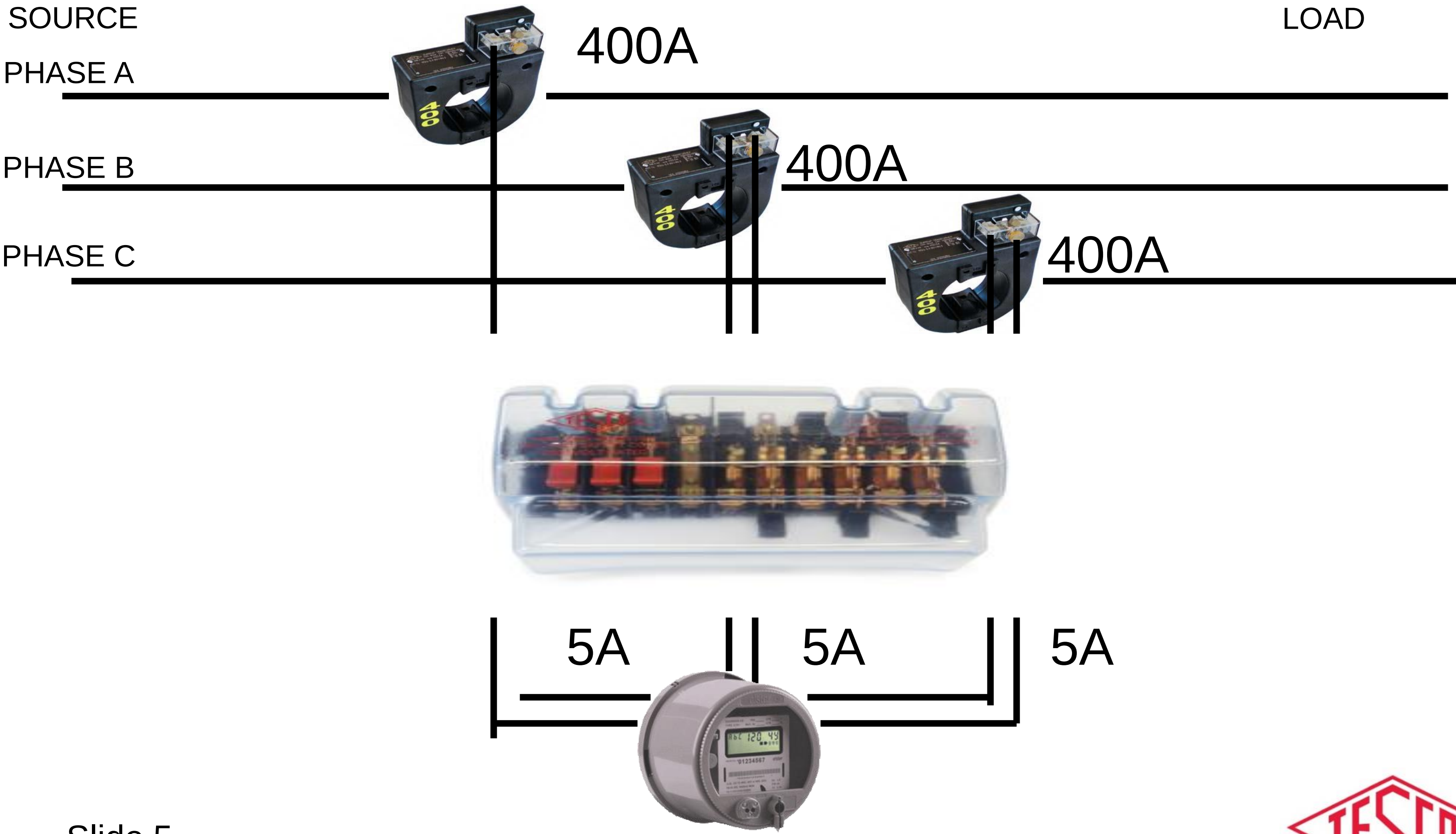


Transformer Rated Metering

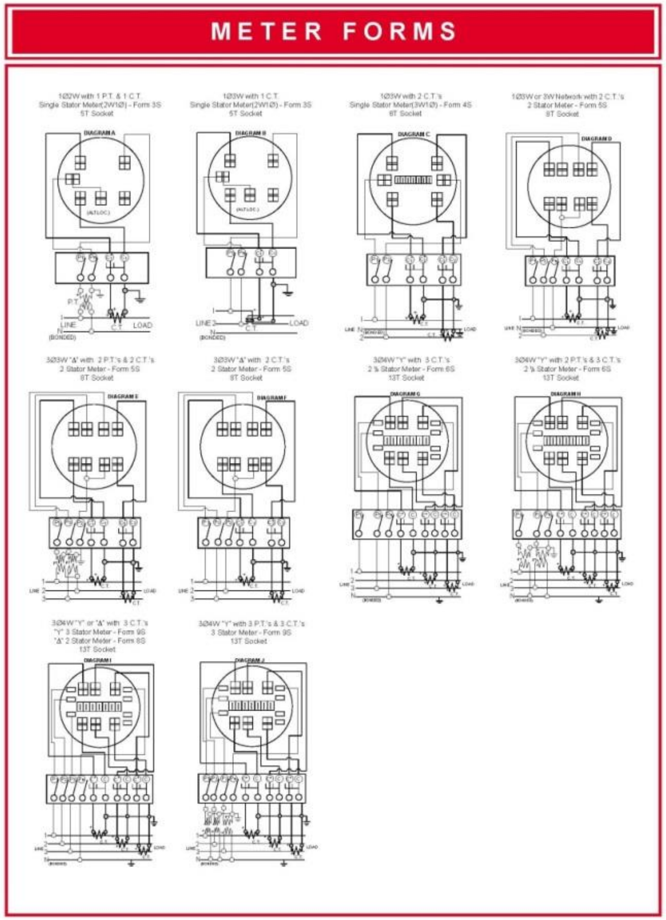
- Meter measures scaled down representation of the load.
- Scaling is accomplished by the use of external current transformers (CTs) and sometimes voltage transformers or PTs).
- The meter is NOT part of the circuit
- When the meter is removed from the socket, power to the customer is not effected.



9S Meter Installation with 400:5 CT's



Typical Connections



Typical Connections for Common Transformer (Instrument) Rated Meter Forms

Meter Accuracy Testing

Meter Accuracy Testing in a Nutshell

- ✓ Full Load
- ✓ Light Load
- ✓ Power Factor

The Importance of CT Testing in the Field

- One transformer in three 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)

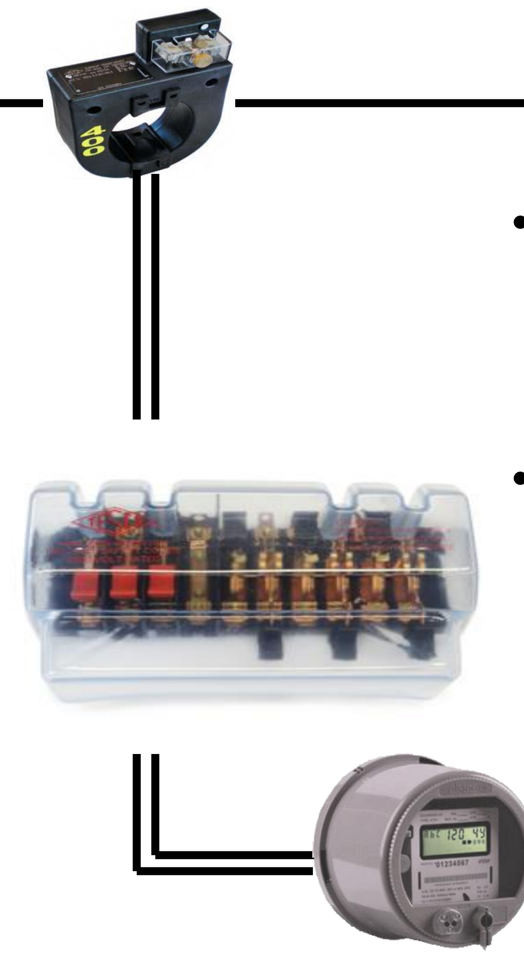
- Cross Phasing (wiring errors)
- Loose or Corroded Connections
- CT Mounted Backwards
- CT's with Shorted Turns
- Wrong Selection of Dual Ratio CT
- Detect Magnetized CT's
- Burden Failure in Secondary Circuit
- Open or Shorted Secondary
- Mislabeled CT's
- Ensures all Shorting Blocks have been Removed

Testing at Transformer Rated Sites

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

Fundamentals of Polyphase Field Meter Testing and Site Verification

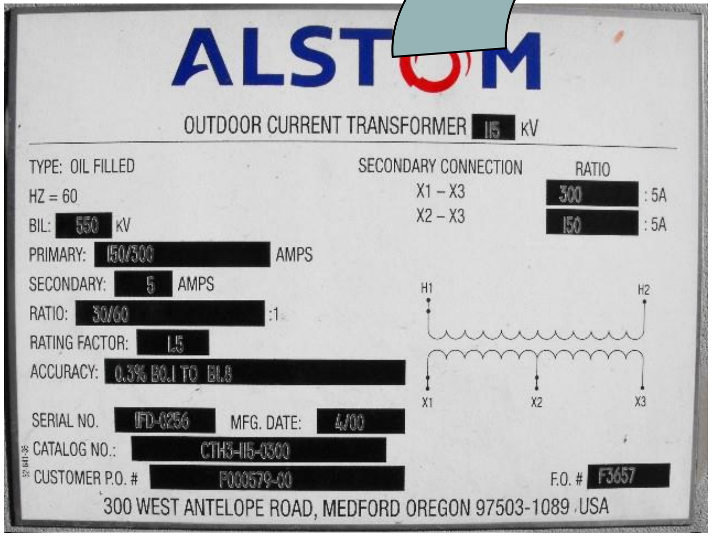
Functionality with Burden Present on the Secondary Loop



- 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.

Fundamentals of Polyphase Field Meter Testing and Site Verification

Functionality with Burden Present on the Secondary Loop



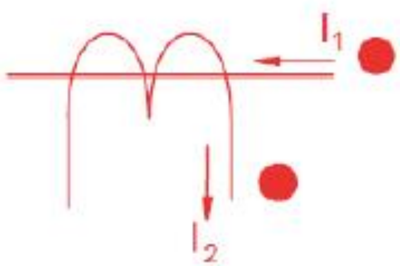
Example Burden Spec:

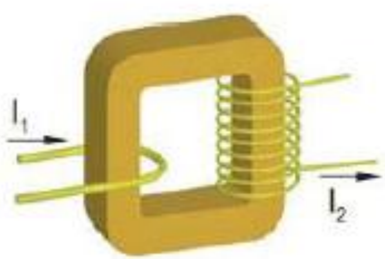
0.3% @ B0.1, B0.2, B0.5

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

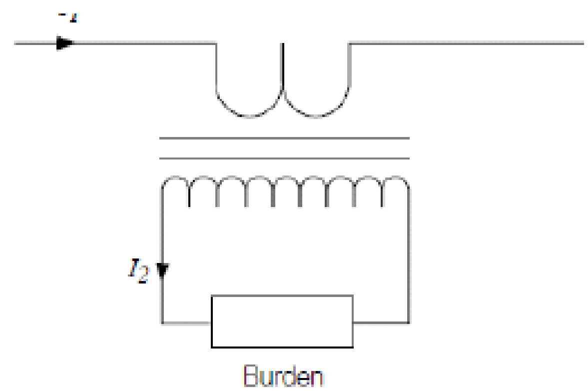
Current Transformers Conceptual Representation



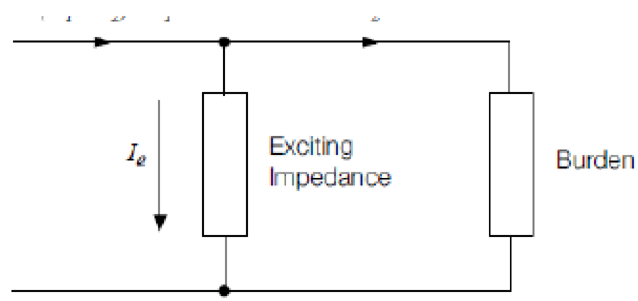


$$I_1 \times N_1 = I_2 \times N_2$$

Ideal. No losses



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



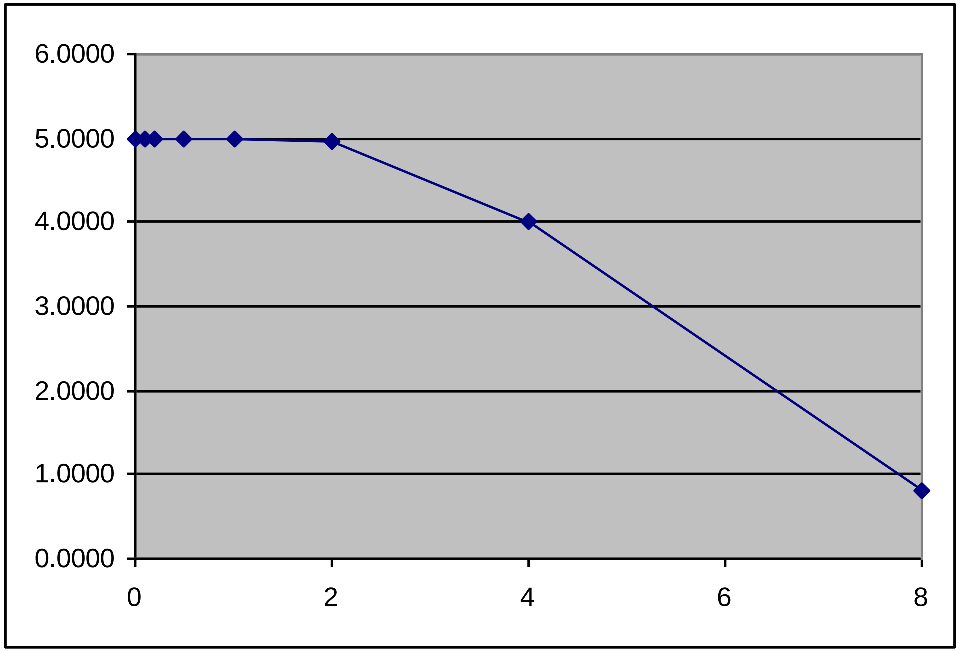
$$I_2 = \frac{N_1}{N_2} \times I_1 - I_e$$

Real, with core losses

Fundamentals of Polyphase Field Meter Testing and Site Verification

Functionality with Burden Present on the Secondary Loop

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

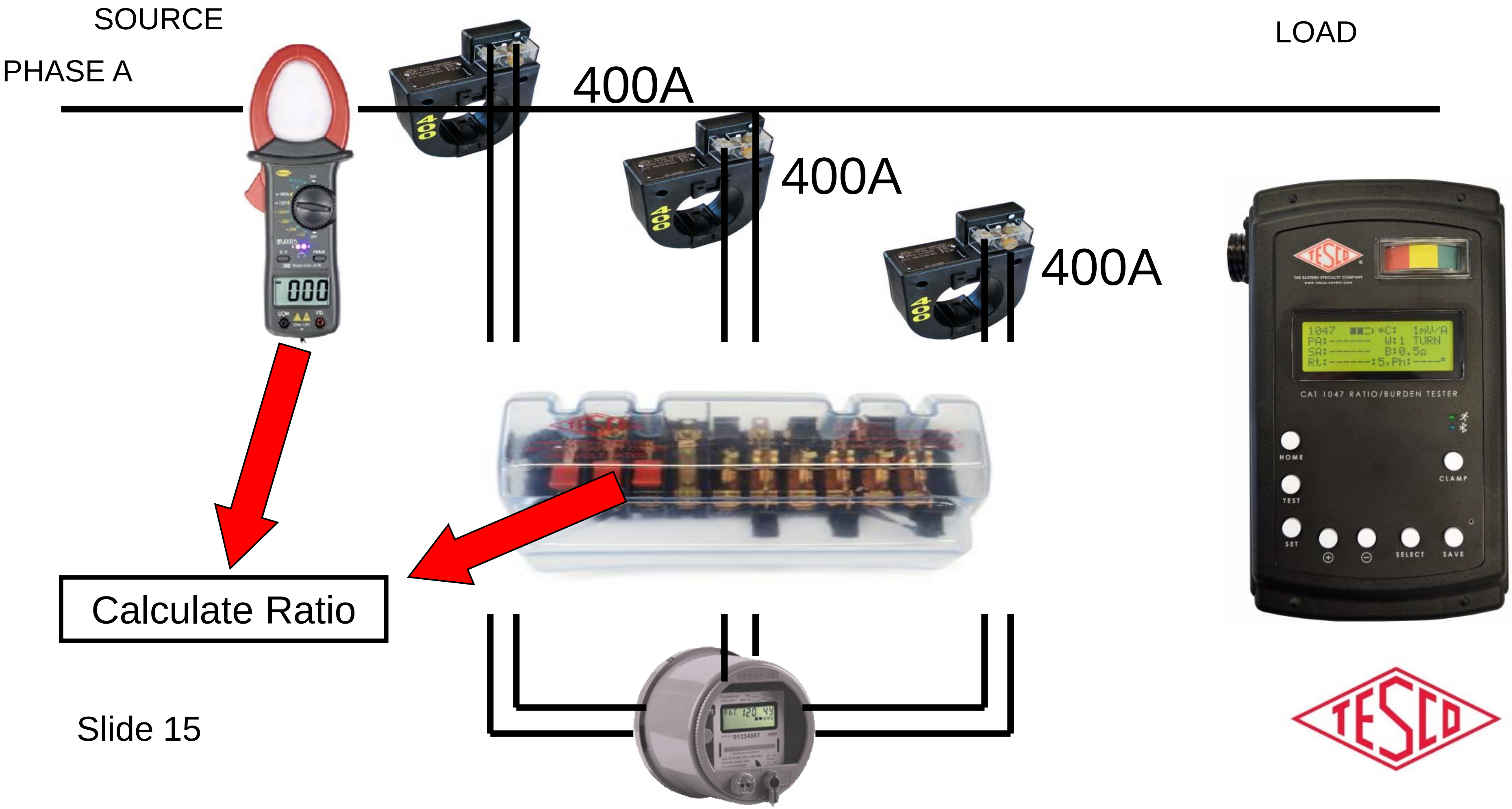


Initial Reading = 5Amps
0.3% x 5A = 0.015A
5A – 0.015 = 4.985A

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

Fundamentals of Polyphase Field Meter Testing and Site Verification

Ratio of Primary Current to Secondary Current



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.*

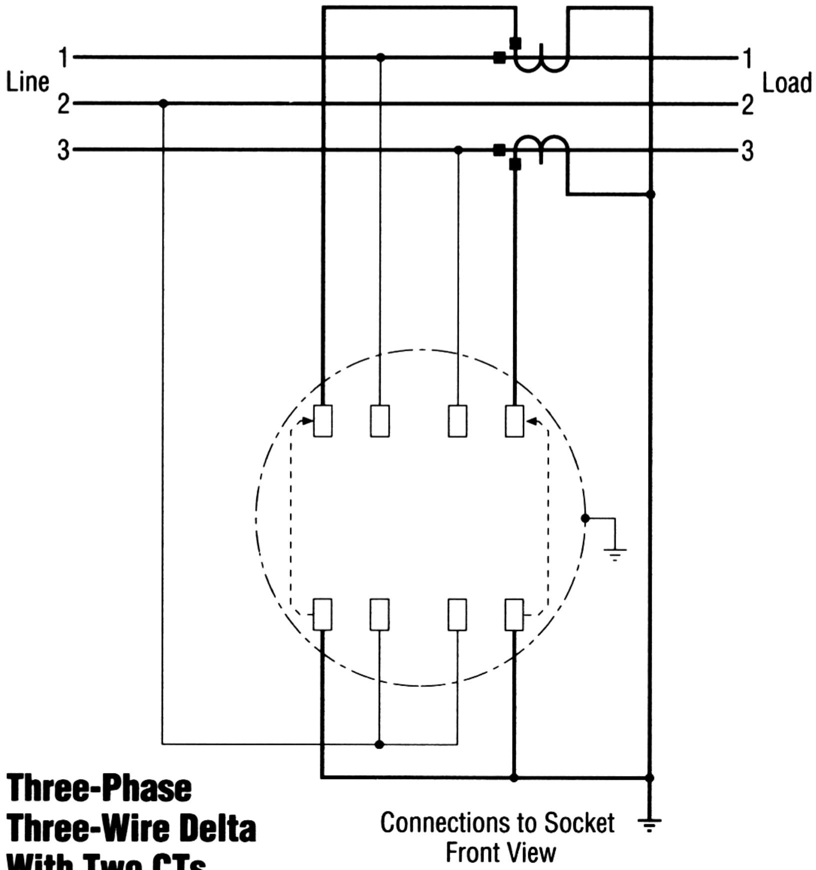
Three Phase Power
Blondel's Theorem

- Simply – We can measure the power in a N wire system by measuring the power in N-1 conductors.
- For example, in a 4-wire, 3-phase system we need to measure the power in 3 circuits.

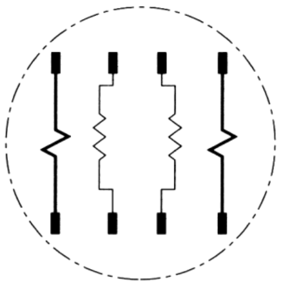
Three Phase Power
Blondel's Theorem

- 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



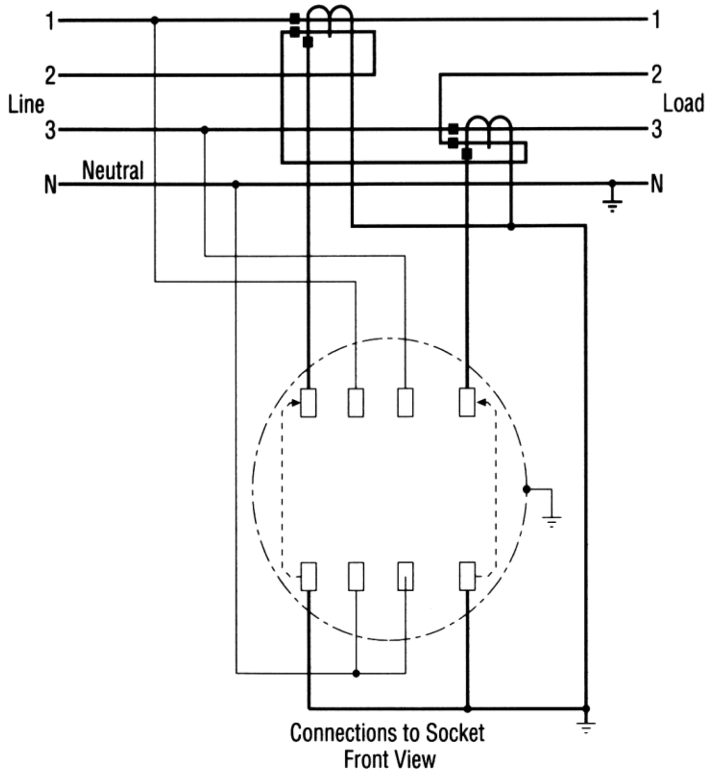
Three-Phase
Three-Wire Delta
With Two CTs



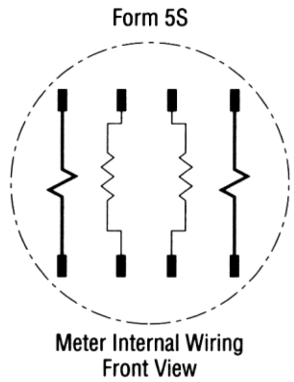
- Three wires
- Two voltage measurements with one side common to Line 2
- Current measurements on lines 1 & 3.

This satisfies Blondel's Theorem.

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 Theorem.

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:
  - $P = Vb\ Ib\ \cos\theta$
- But we aren't measuring Vb
- What we are measuring is:
  - $IbVa\cos(60-\theta) + IbVc\cos(60+\theta)$
- $\cos(\alpha + \beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta)$
- $\cos(\alpha - \beta) = \cos(\alpha)\cos(\beta) + \sin(\alpha)\sin(\beta)$
- 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%

Site Verification: Why should we invest our limited meter service resources here

- These customers represent a disproportionately large amount of the overall revenue for every utility in North America.

- For some utilities the ten percent of their customers who have transformer rated metering services can represent over 70% of their overall revenue.

- While these numbers will vary from utility to utility the basic premise should be the same for all utilities regarding where Meter Services should focus their efforts

- This is perhaps one of the larger benefits that AMI can provide for our Utilities – more time to spend on C&I metering and less on residential

Easy Answer: Money.

Potential list of tasks to be completed during a Site Verification of a Transformer Rated Metering Site

- 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.
- 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.

Site Verification Checklist (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.
- Confirm we have a Blondel compliant metering set up
- 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).
- 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.

Site Verification Checklist (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. If present test/inspect isolation relays/pulse splitters for things like blown fuses to ensure they are operating properly.

- Verify meter information including meter multiplier, 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.

- Look for signs of excessive heat on the meter base e.g. melted plastic or discoloration related to heat

Periodic Site Inspections…..

<u>….Can Discover or Prevent:</u>

- 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

Questions and Discussion

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