

METERING LEADER SINCE 1904



THE EASTERN SPECIALTY COMPANY

INTRODUCTION TO TRANSFORMER RATED AND POLYPHASE METERING

Prepared by Tom Lawton, TESCO
The Eastern Specialty Company

For Mid-South Meter School

Group 1 and 2

Wednesday, May 3, 2023 at 10:00 AM



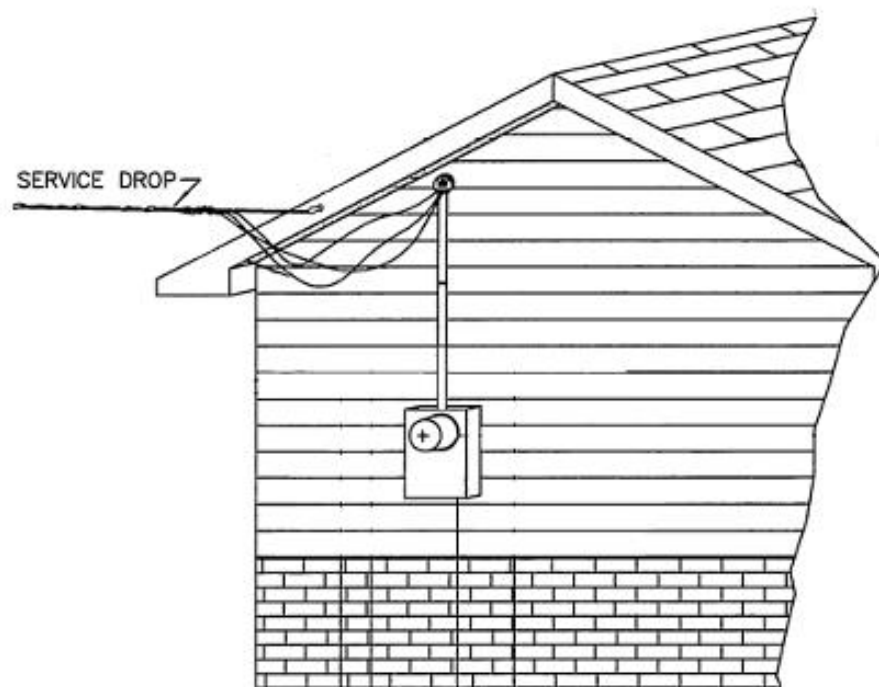
TOPICS WE WILL BE COVERING

- 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



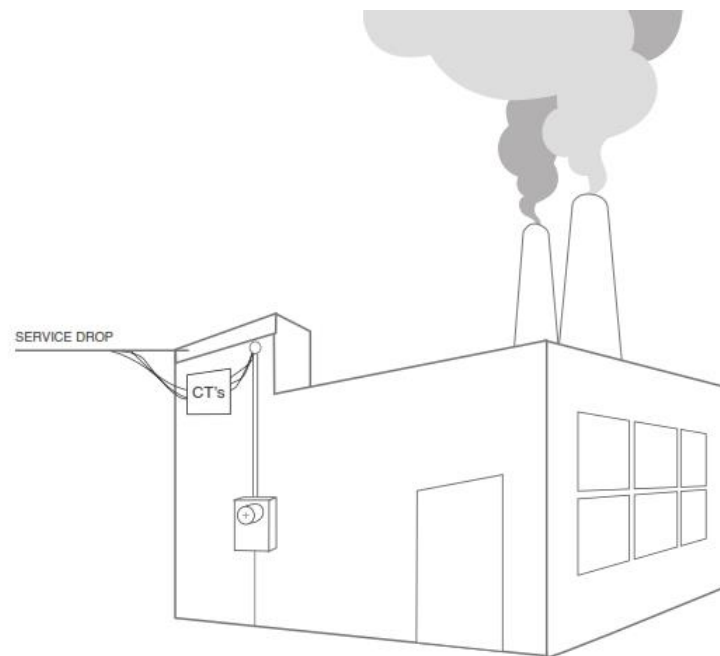
SELF CONTAINED METERING

- 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

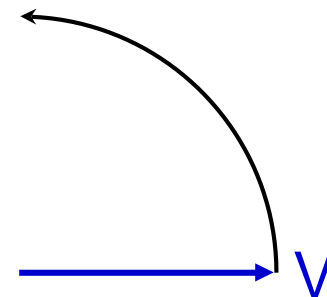
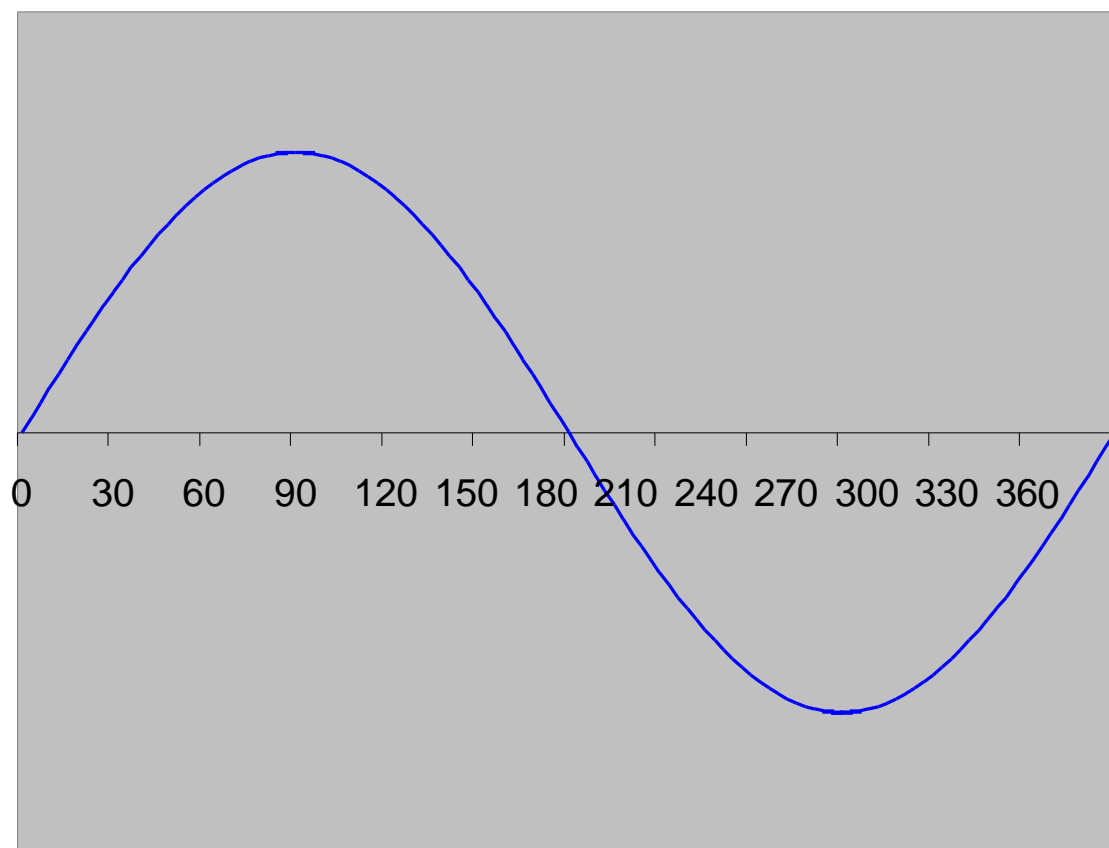


TRANSFORMER RATED METERING

- Meter measures 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.

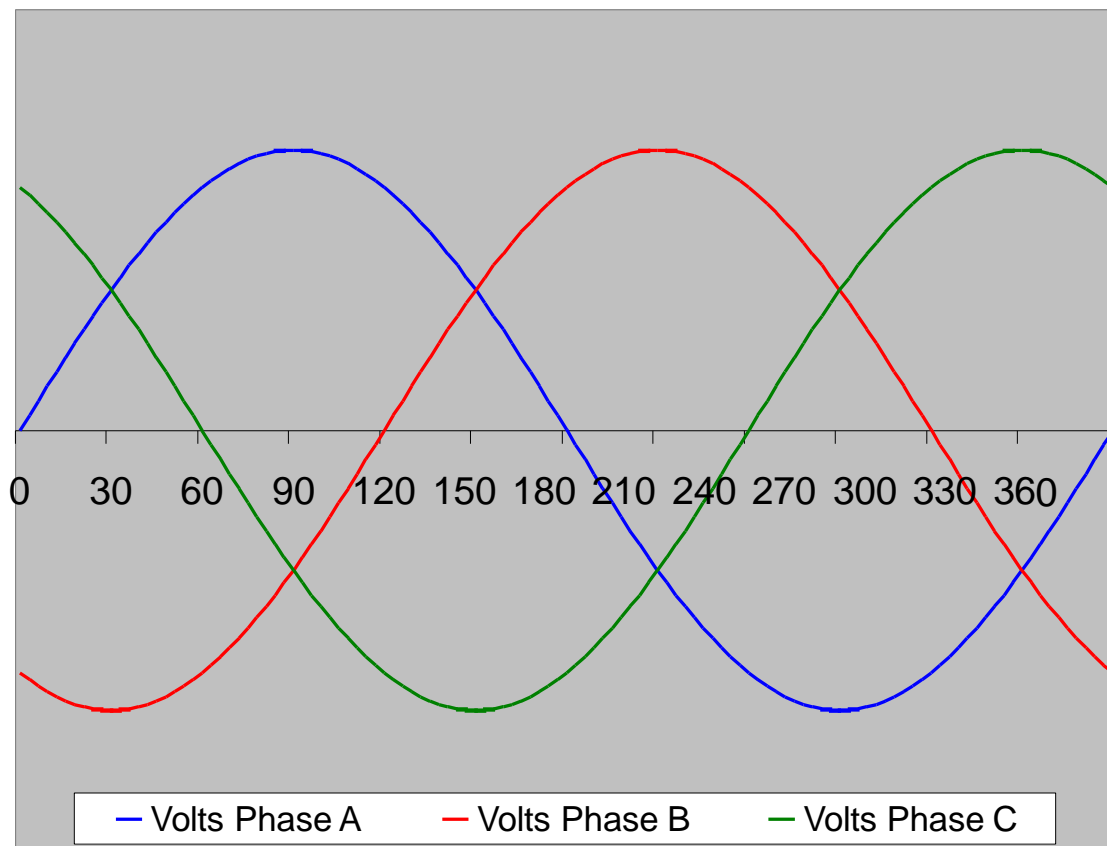


1-PHASE AND 3-PHASE POWER

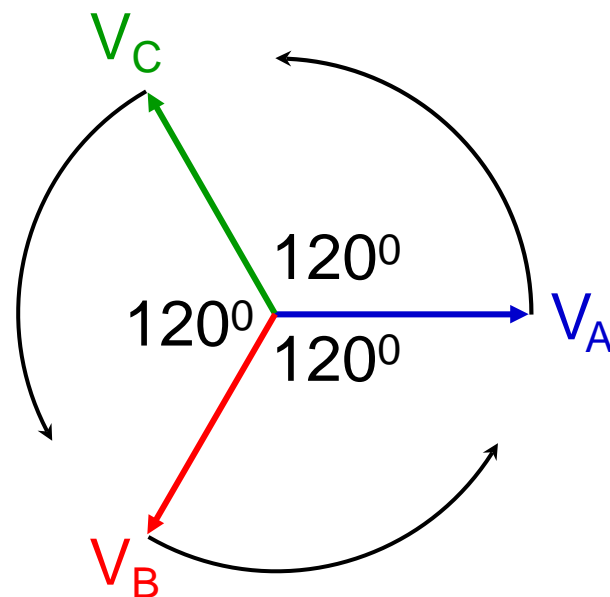


$$\text{Voltage} = V_{\max} \sin \alpha$$

1-PHASE AND 3-PHASE POWER



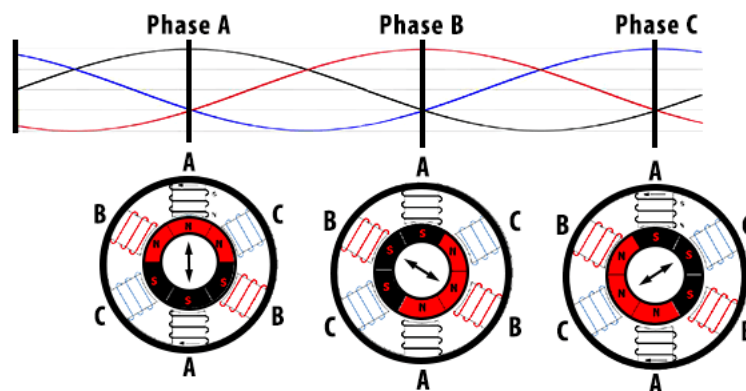
Forward Rotation, ABC



THE NEED FOR 3-PHASE POWER

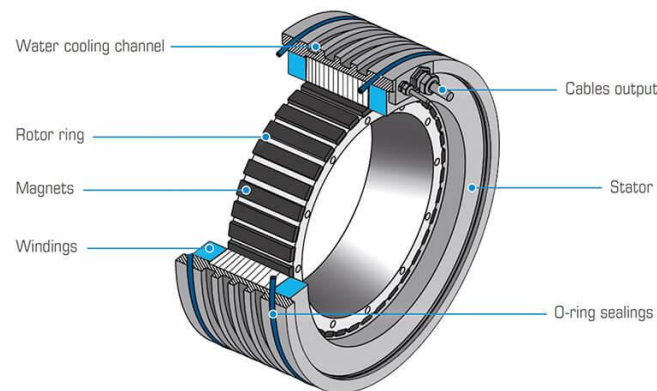
Single-phase motors provide a pulsating torque to a mechanical load. Loads which require more than 10 horsepower generally also require the steadier torque of a 3-phase motor.

3 PHASE INDUCTION MOTOR

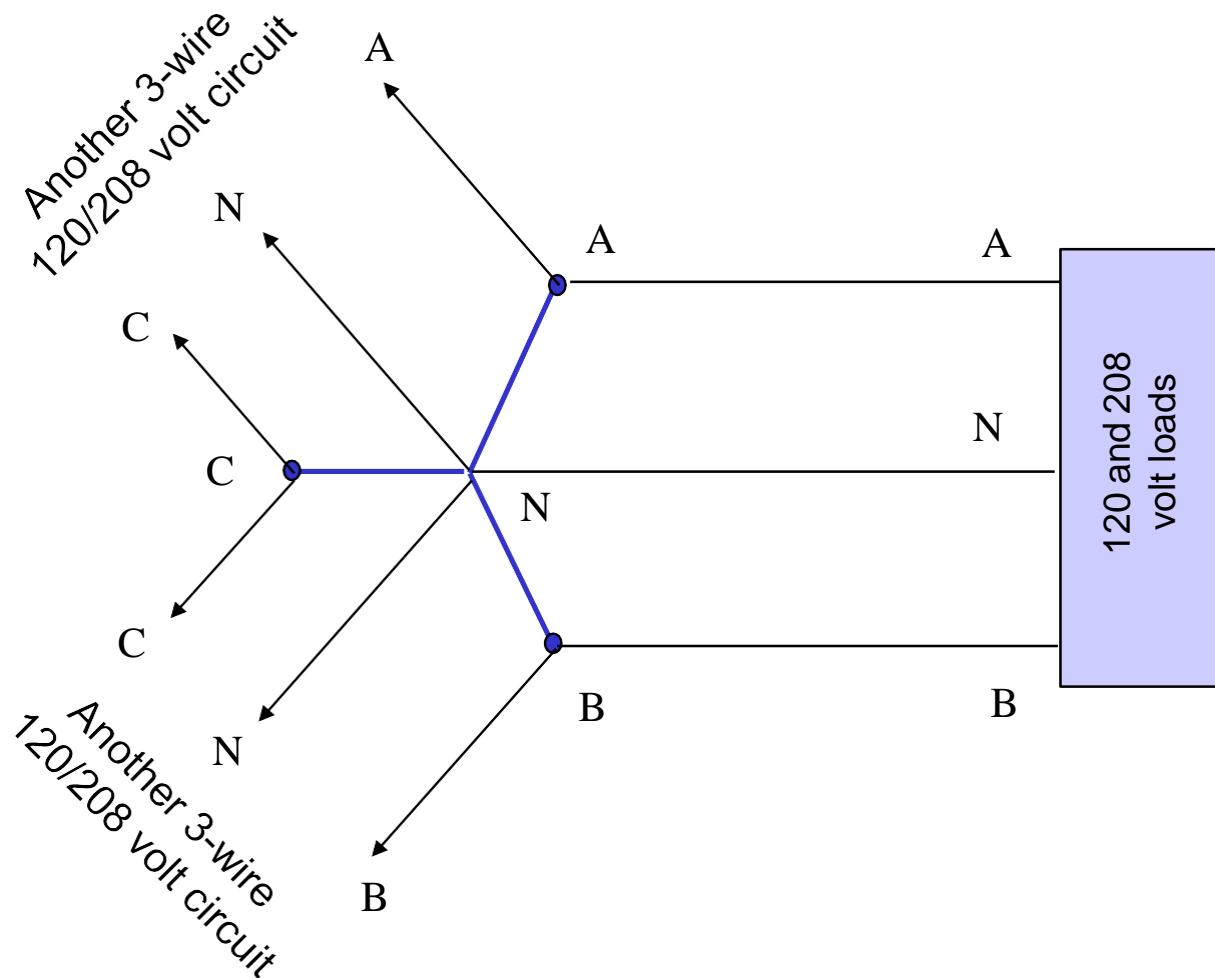


BENEFITS OF 3-PHASE POWER

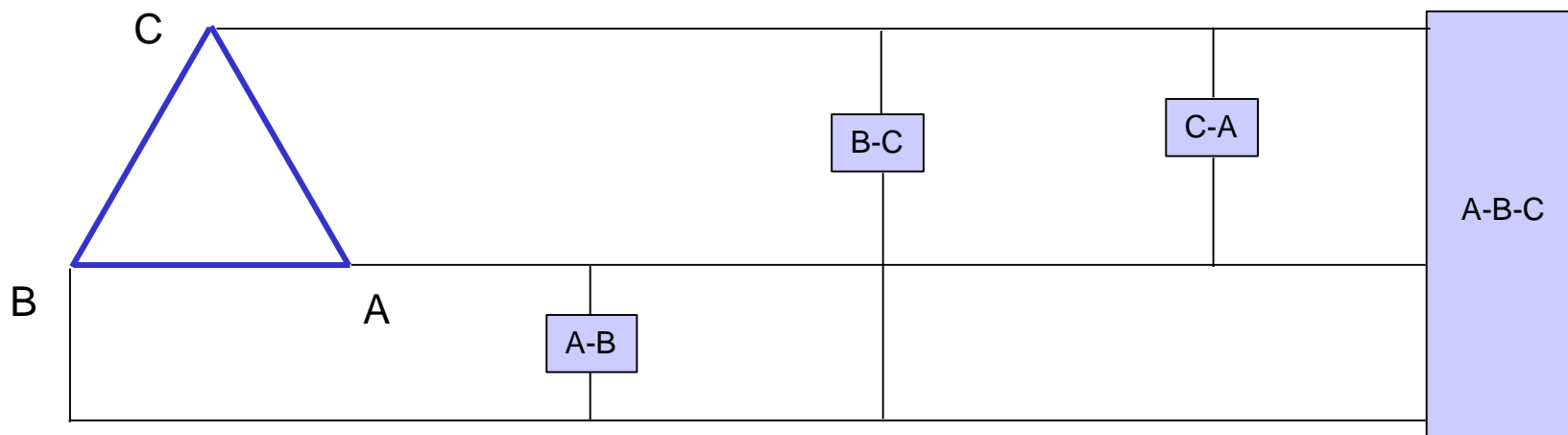
- ✓ Steadier motor torque
- ✓ Less vibration in machinery
- ✓ Greater mechanical efficiency
- ✓ Better voltage regulation
- ✓ Lower heat losses
- ✓ Lighter weight conductors



NETWORK SERVICE & LOADS

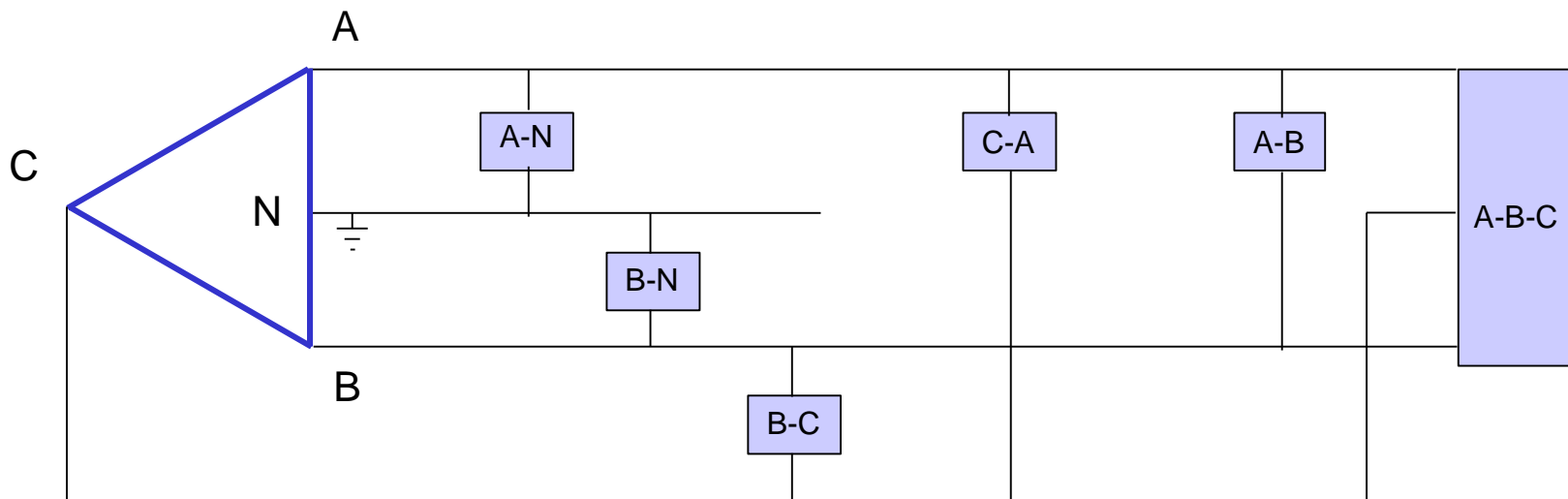


3-WIRE DELTA SERVICE & LOADS



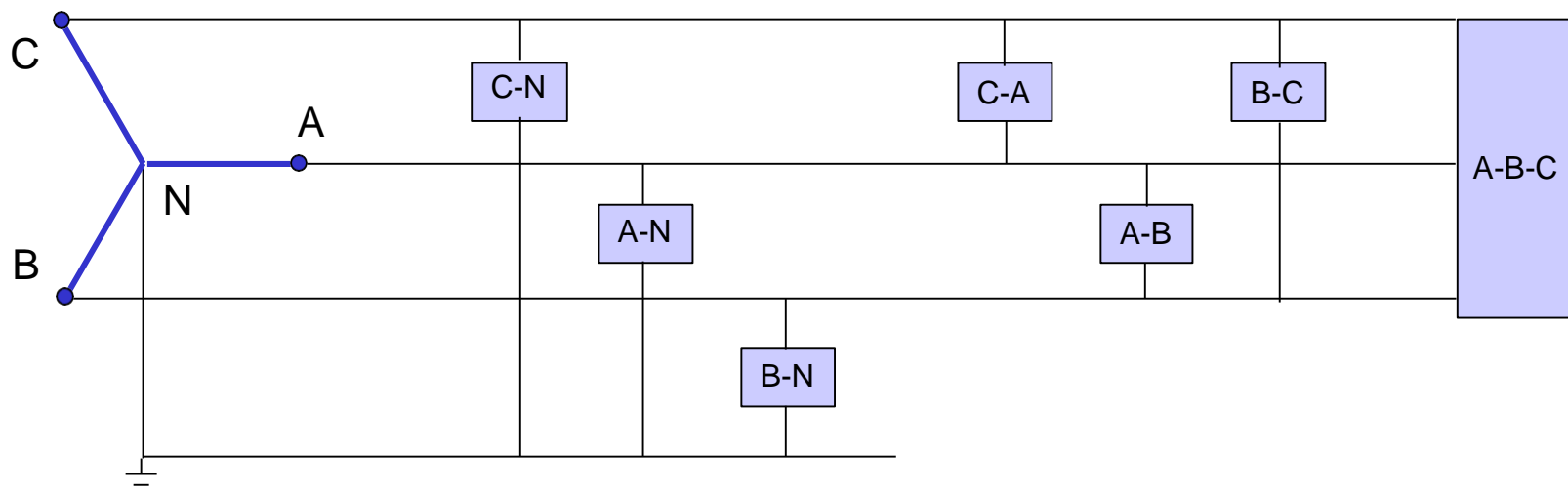
Need to meter single phase line-line loads, as well as three phase loads.

4-WIRE DELTA SERVICE & LOADS



Need to meter single phase line-neutral and line-line loads, as well as three phase loads.

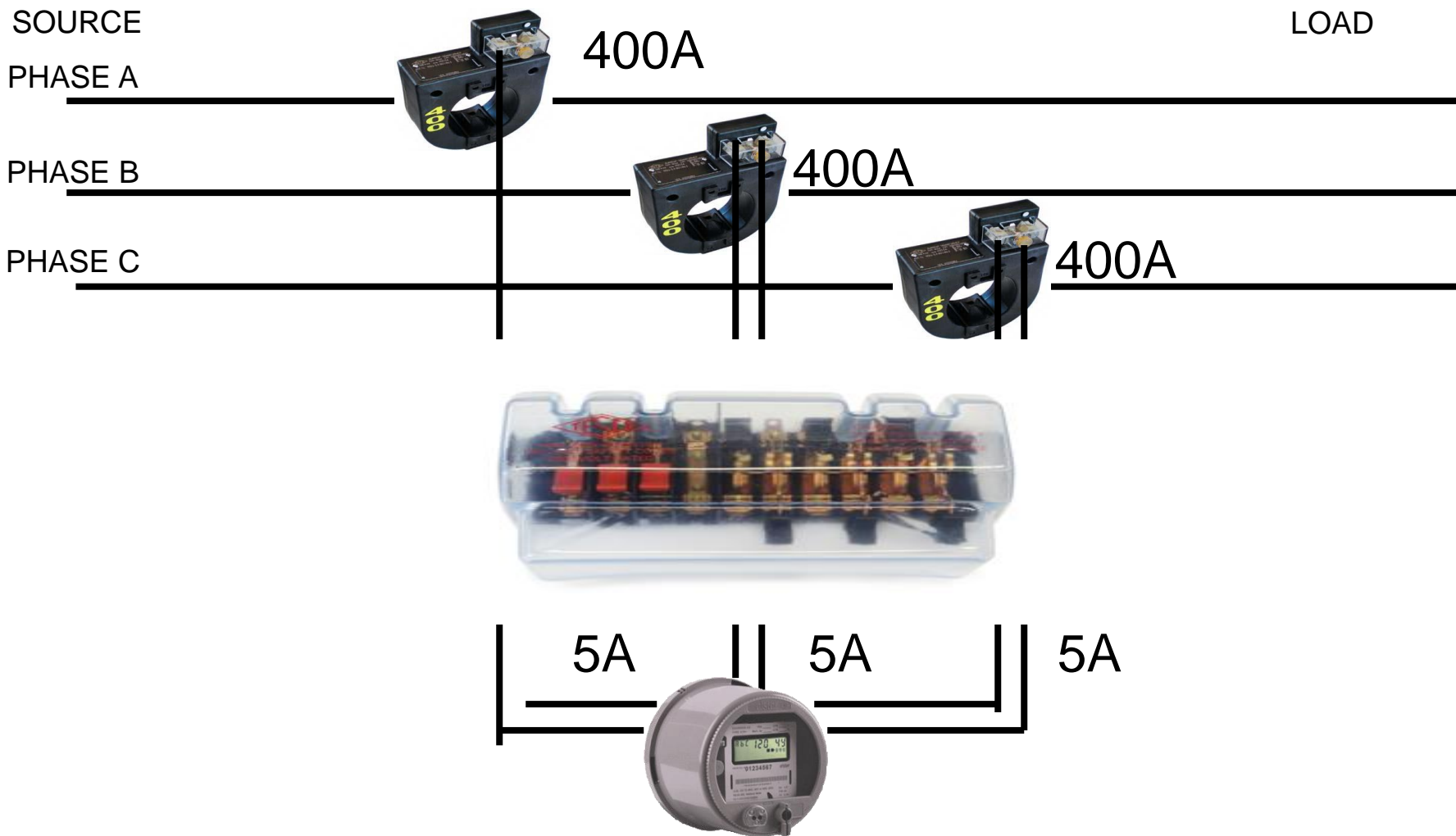
4-WIRE WYE SERVICE & LOADS



Need to meter single phase line-neutral and line-line loads, as well as three phase loads.

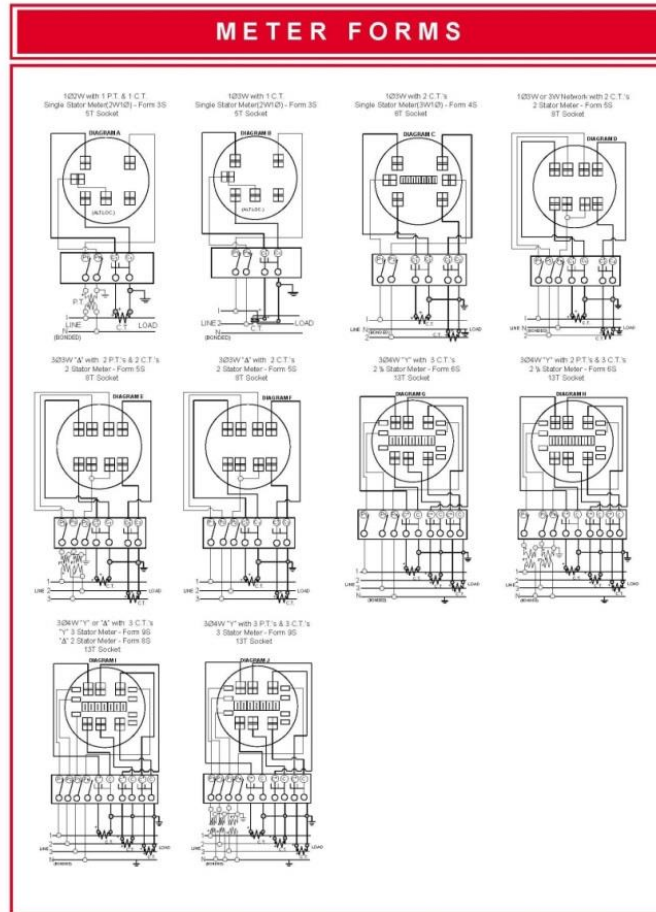
TRANSFORMER RATED - THE BASIC COMPONENTS

9S Meter Installation with 400:5 CT's





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

METER ACCURACY TESTING

Meter Accuracy Testing in a Nutshell



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



THE IMPORTANCE OF CT TESTING IN THE FIELD

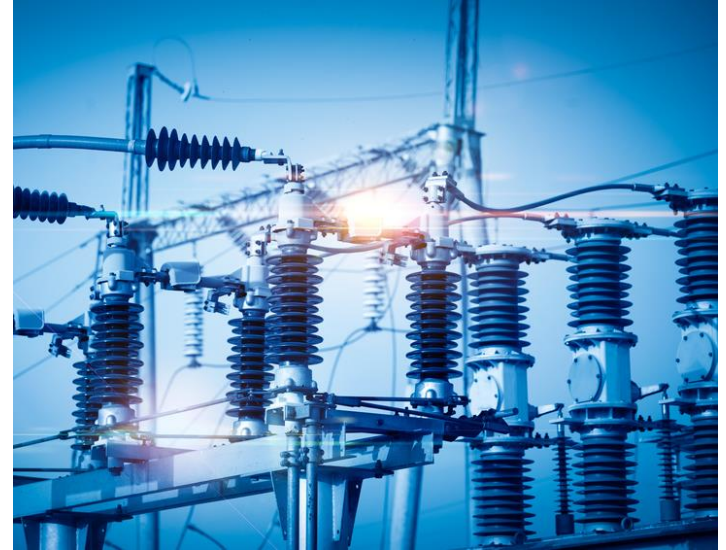
- One transformer in three wired backwards will give the customer a bill of 1/3rd the actual bill.
- One broken wire to a single transformer will give the customer a bill of 2/3rd the actual bill
- One dual ratio transformer inappropriately marked in the billing system as 400:5 instead of 800:5 provides a bill that is 1/2 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

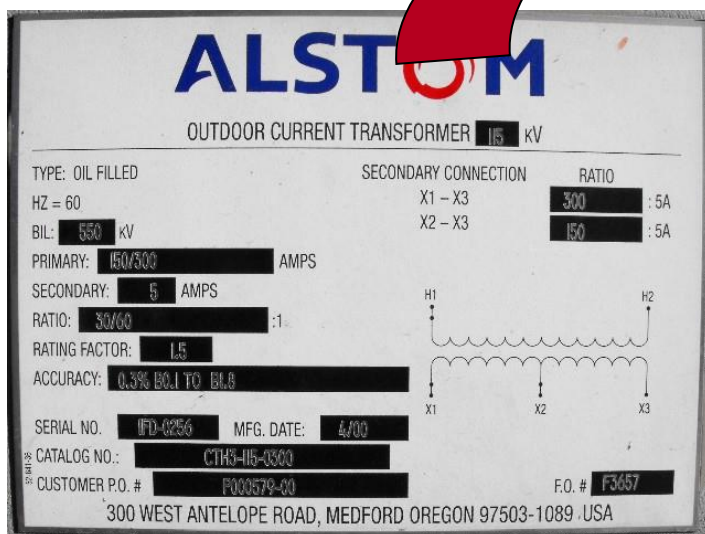
PHASE A



- 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

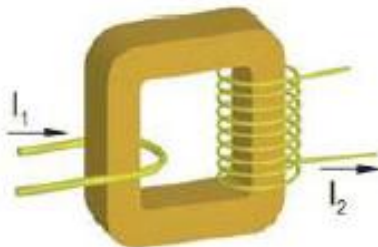
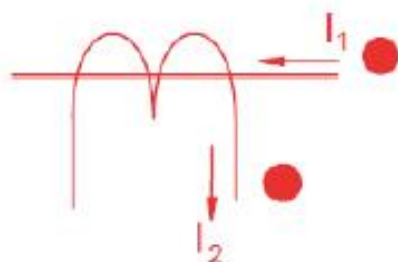
Functionality with Burden Present on the Secondary Loop



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

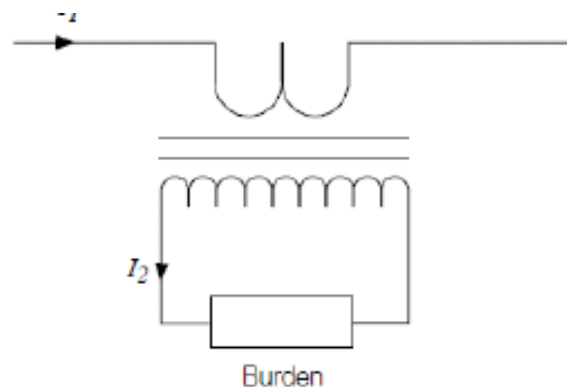
There should be less than the 0.3% change in secondary current from initial ("0" burden) reading, when up to 0.5 Ohms of burden is applied

FUNDAMENTALS OF POLYPHASE FIELD METER TESTING AND SITE VERIFICATION

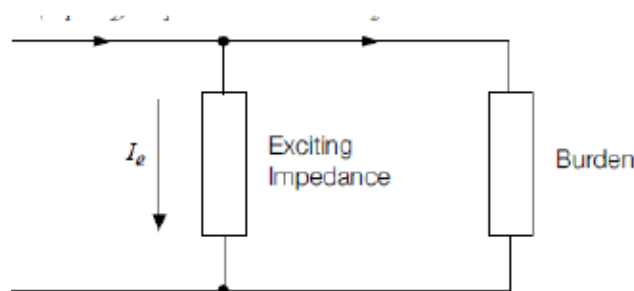


$$I_1 \times N_1 = I_2 \times N_2$$

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

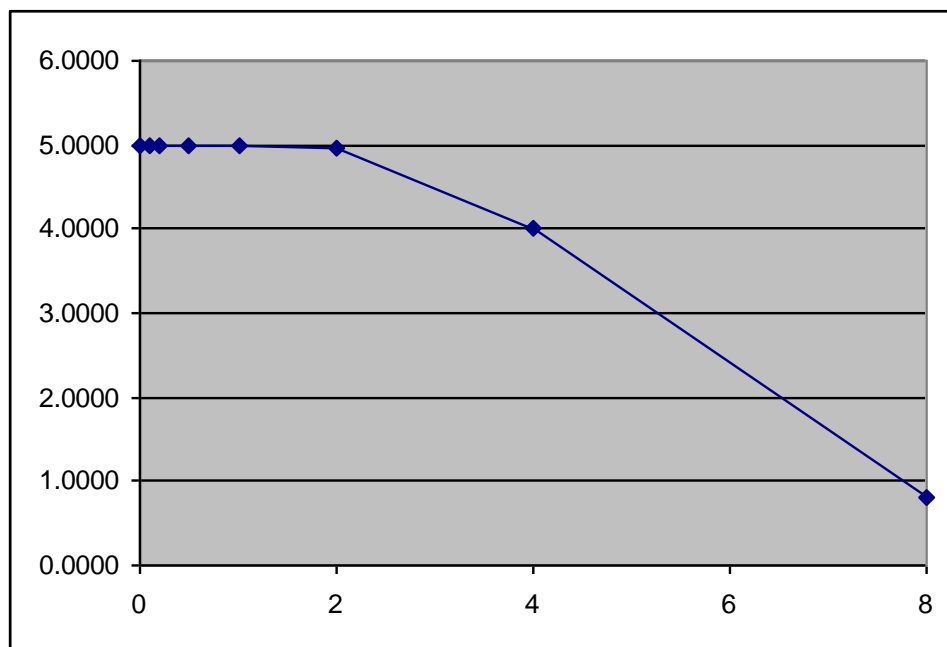
Functionality with Burden Present on the Secondary Loop

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

Initial Reading = 5Amps

$$0.3\% \times 5A = 0.015A$$

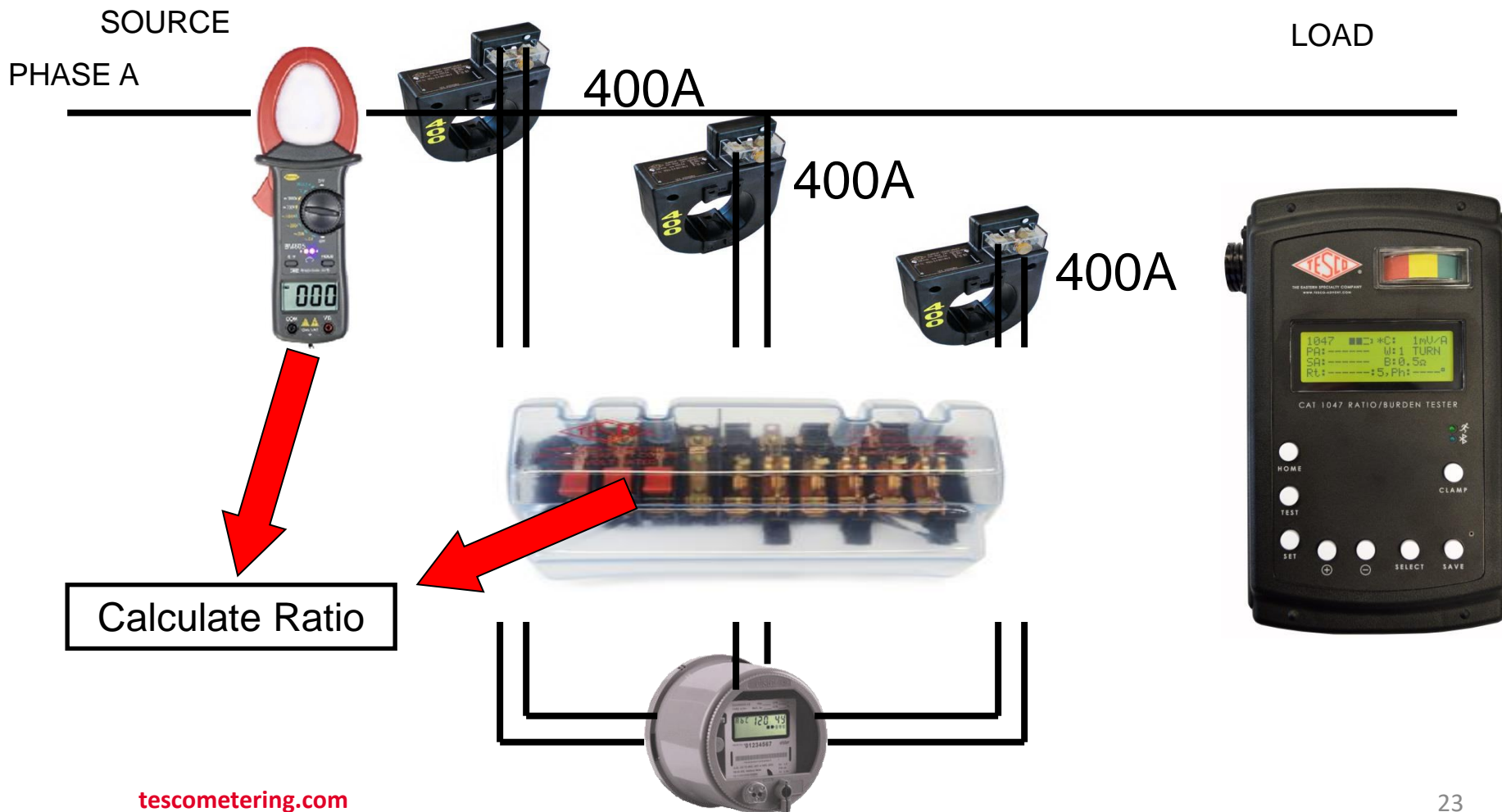
$$5A - 0.015 = 4.985A$$



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

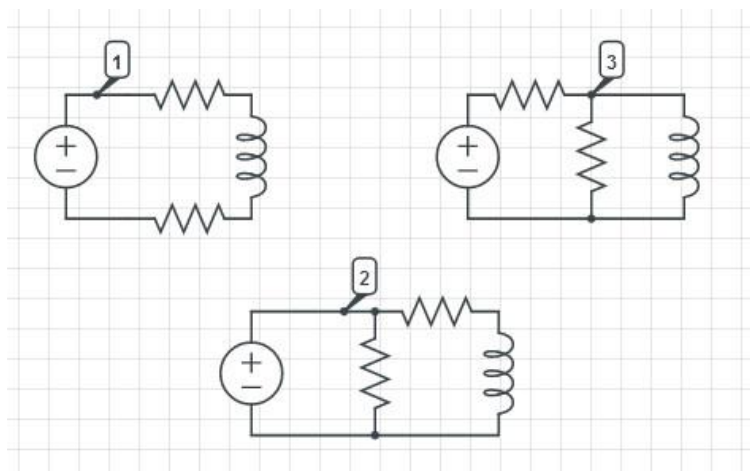
The theory of polyphase watt-hour metering was first set forth on a scientific basis in 1893 by Andre E. Blondel, engineer and mathematician. His theorem applies to the measurement of real power in a polyphase system of any number of wires. The theorem is as follows:

- 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.





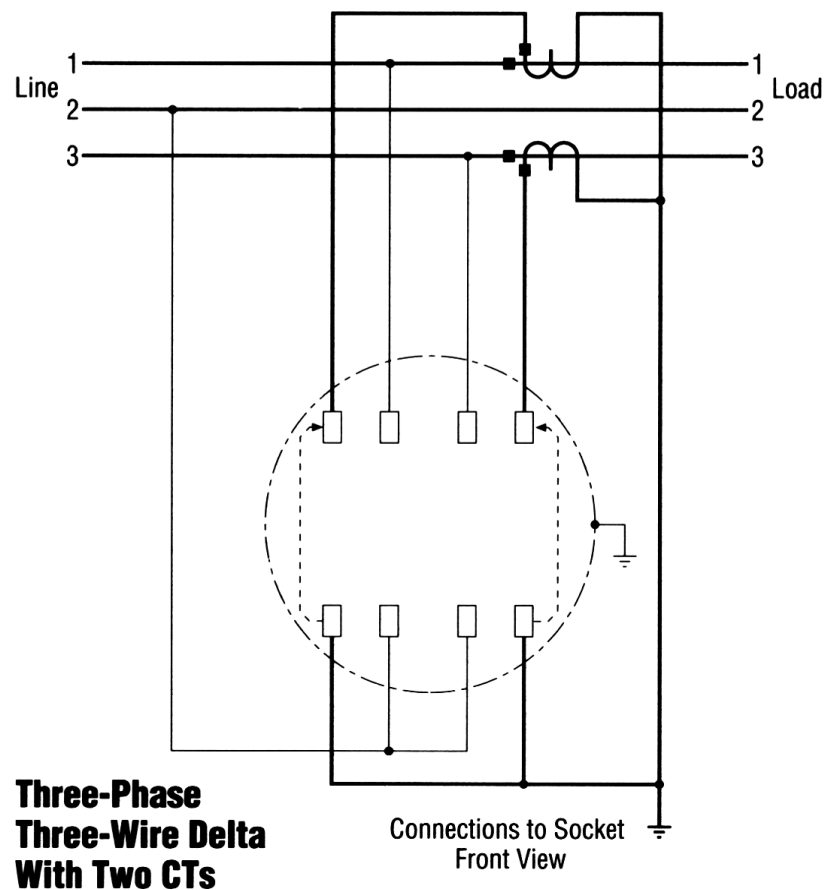
THREE PHASE POWER: BLONDEL'S THEOREM

- 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.

YOU ALWAYS JUST
ASSUME THAT
EVERYONE WANTS
WHATEVER YOU
WANT.



BLONDEL'S THEOREM

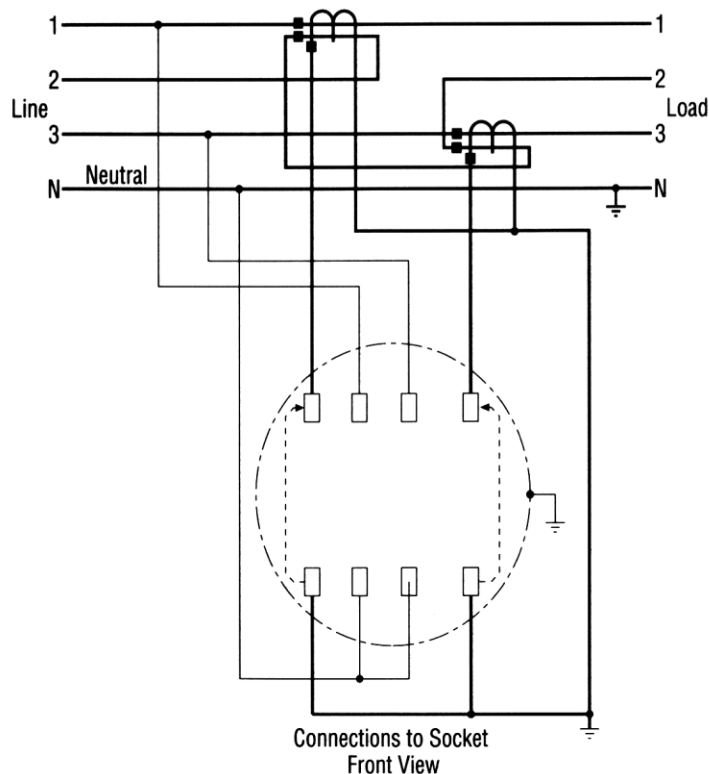


- Three wires
- Two voltage measurements with one side common to Line 2
- Current measurements on lines 1 & 3.

This satisfies Blondel's Theorem.

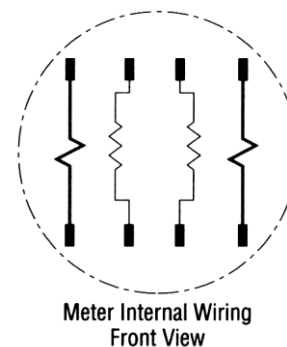


BLONDEL'S THEOREM



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

Form 5S



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

This DOES NOT satisfy Blondel's Theorem.



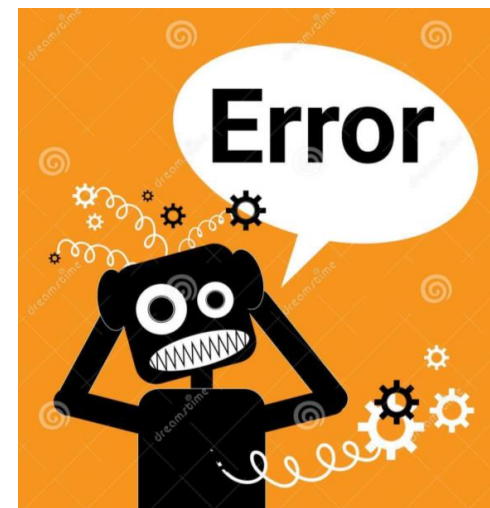
BLONDEL'S THEOREM

- 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?

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



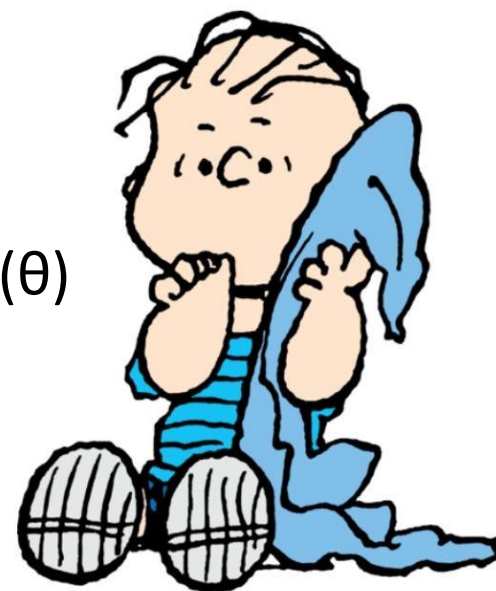
BLONDEL'S THEOREM

- Phase B power would be:
 - $P = V_b I_b \cos\theta$
- But we aren't measuring V_b
- 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

- $P_b = I_b V_a \cos(60^\circ - \theta) + I_b V_c \cos(60^\circ + \theta)$
- Applying the trig identity
 - $I_b V_a (\cos(60^\circ)\cos(\theta) + \sin(60^\circ)\sin(\theta))$
 $I_b V_c (\cos(60^\circ)\cos(\theta) - \sin(60^\circ)\sin(\theta))$
 - $I_b (V_a + V_c) 0.5 \cos(\theta) + I_b (V_c - V_a) 0.866 \sin(\theta)$
- Assuming
 - Assume $V_b = V_a = V_c$
 - And, they are exactly 120° apart
- $P_b = I_b (2V_b) (0.5 \cos \theta) = I_b V_b \cos \theta$



**HAPPINESS IS
ASSUMING THE
WORLD IS LINEAR**

BLONDEL'S THEOREM

- If $V_a \neq V_b \neq V_c$ then the error is
- %Error =
$$-I_b \{ (V_a + V_c) / (2V_b) - (V_a - V_c) / 0.866 \sin(\theta) / (V_b \cos(\theta)) \}$$

How big is this in reality? If

$V_a=117$, $V_b=120$, $V_c=119$, $PF=1$ then $E=-1.67\%$

$V_a=117$, $V_b=116$, $V_c=119$, $PF=.866$ then $E=-1.67\%$



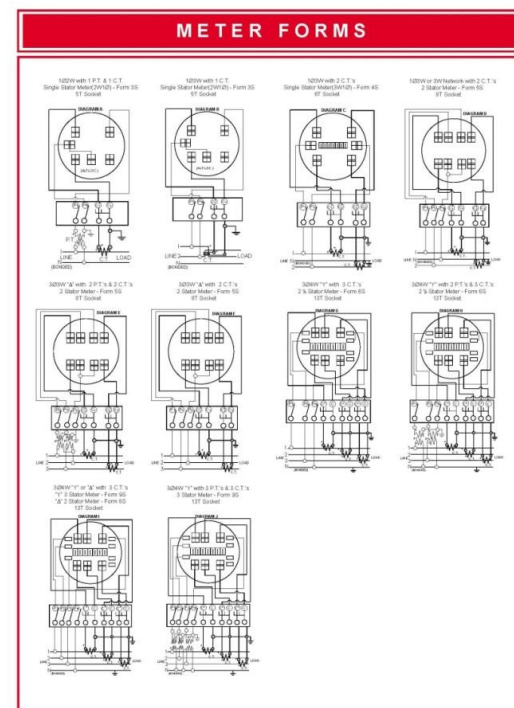
BLONDEL'S THEOREM

Power Measurements Handbook

Condition	% V	% I	Phase A				Phase B				non-Blondel
	Imb	Imb	V	ϕ_{van}	I	ϕ_{ian}	V	ϕ_{vbn}	I	ϕ_{ibn}	% 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%

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



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.***



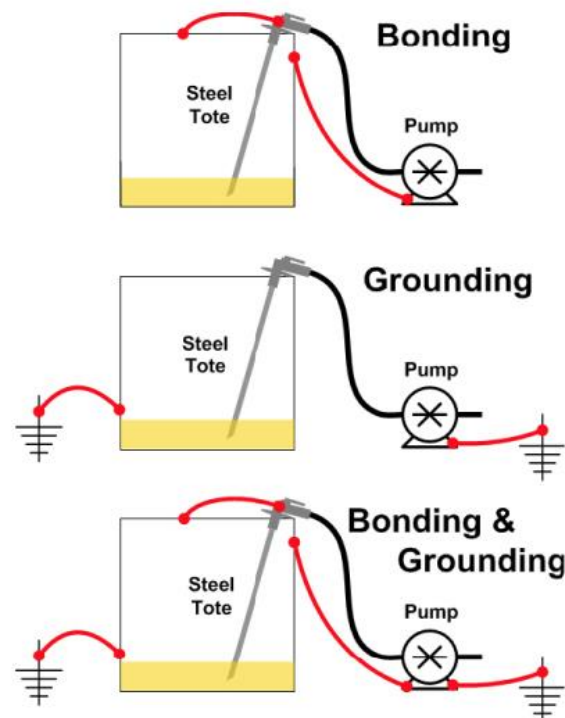
POTENTIAL LIST OF TASKS TO BE COMPLETED DURING A SITE VERIFICATION OF A TRANSFORMER RATED METERING SITE

- 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 $\frac{1}{3}$ to $\frac{1}{2}$ of the registration on either 3 element or 2 element metering, respectively.



SITE VERIFICATION CHECKLIST (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 issue.
- Burden test CTs and voltage check PTs.
- 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.



SITE VERIFICATION CHECKLIST (CONT)

- 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.



SITE VERIFICATION CHECKLIST (CONT)

- 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.....

....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



QUESTIONS AND DISCUSSION



Tom Lawton

TESCO – The Eastern Specialty Company

Bristol, PA

Tom.Lawton@tescometering.com

215-228-0500

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