TESCO METERING

Introduction to Polyphase Metering

Mid South Electric Metering Association 73rd Meter School

Wednesday May 7, 2025

Group 2: 10:00 AM

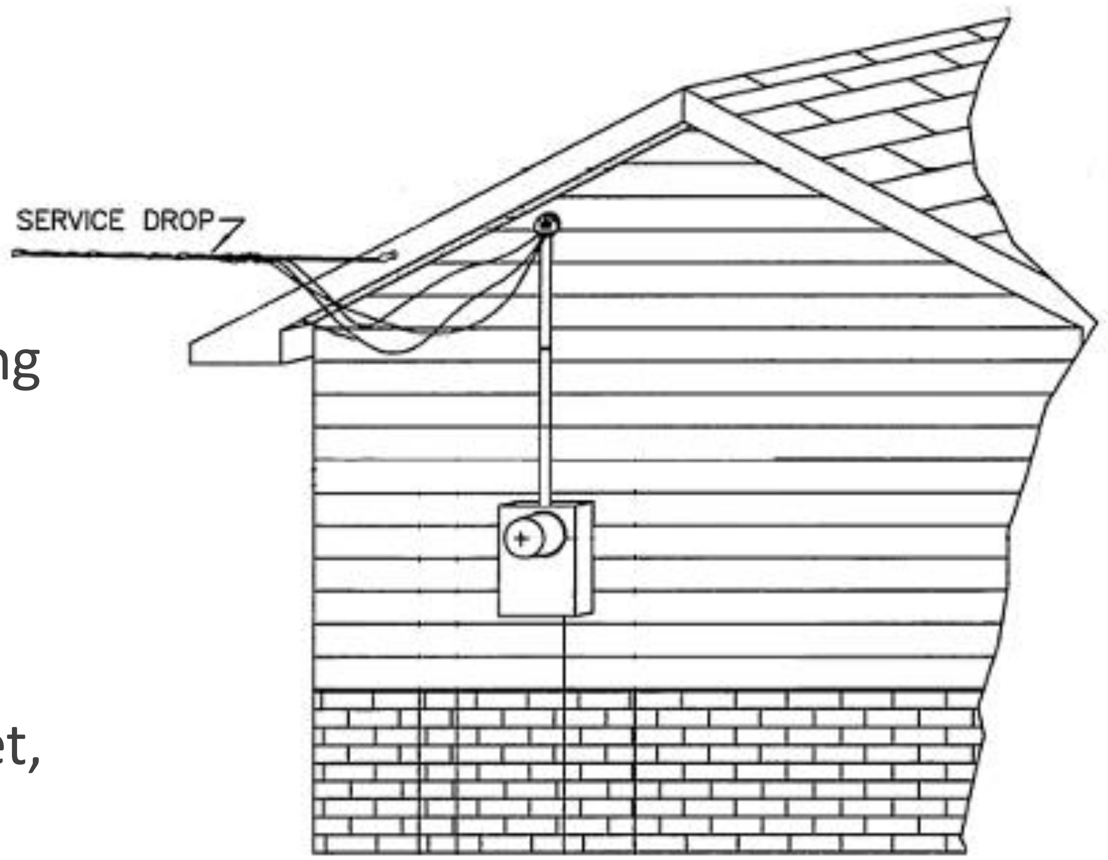
Tom Lawton

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

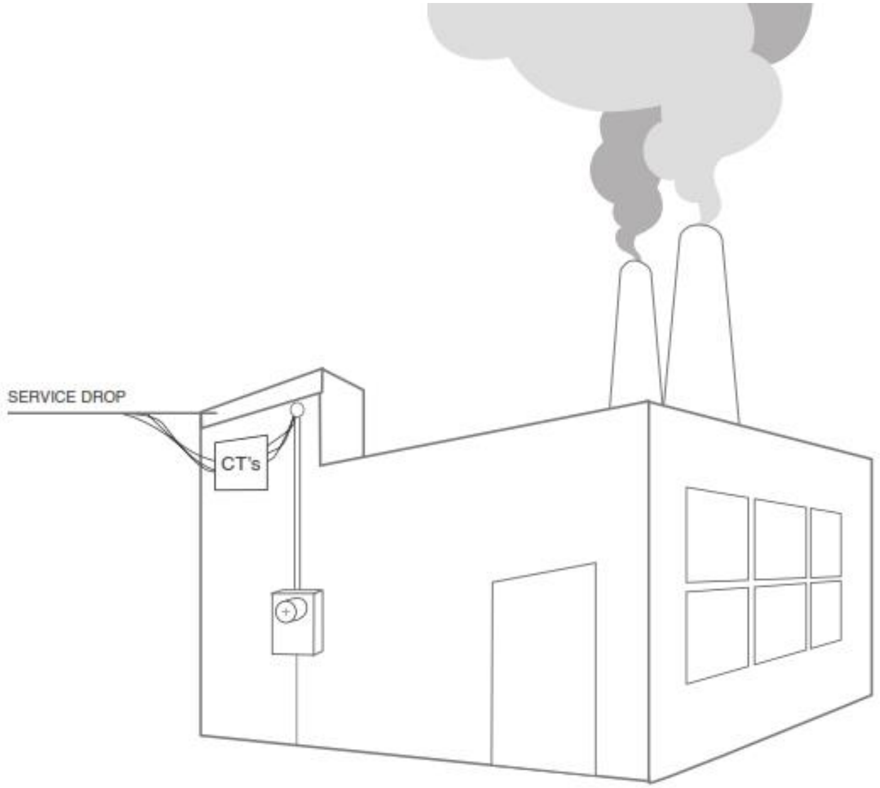
Self Contained Metering

- 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

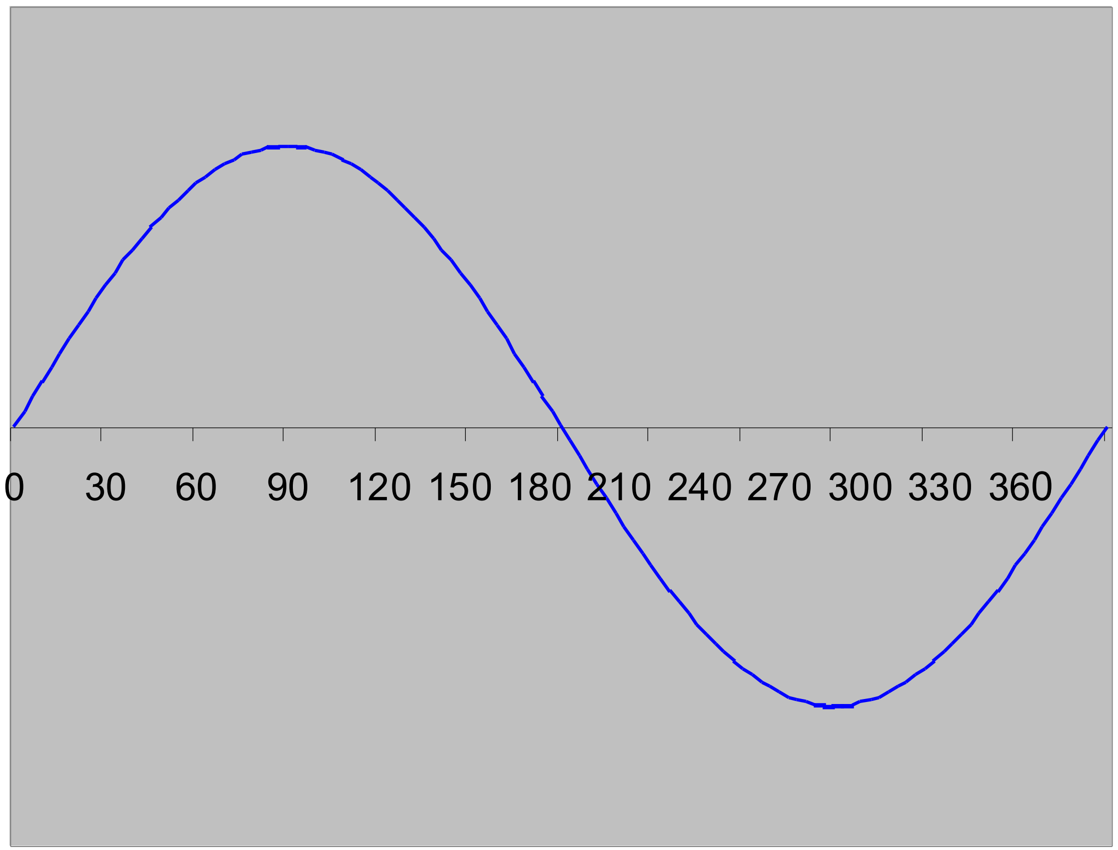


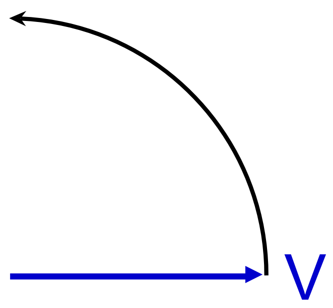
Transformer Rated Metering

- 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.



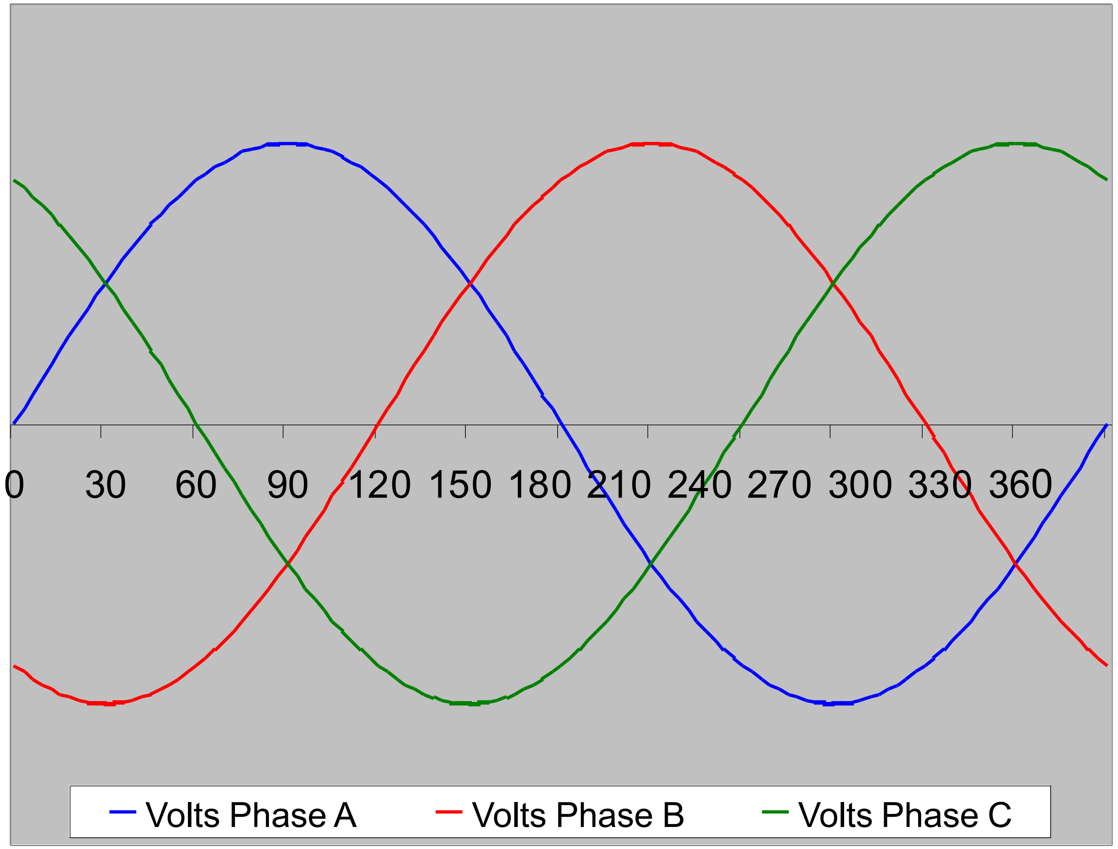
1-Phase and 3-Phase Power

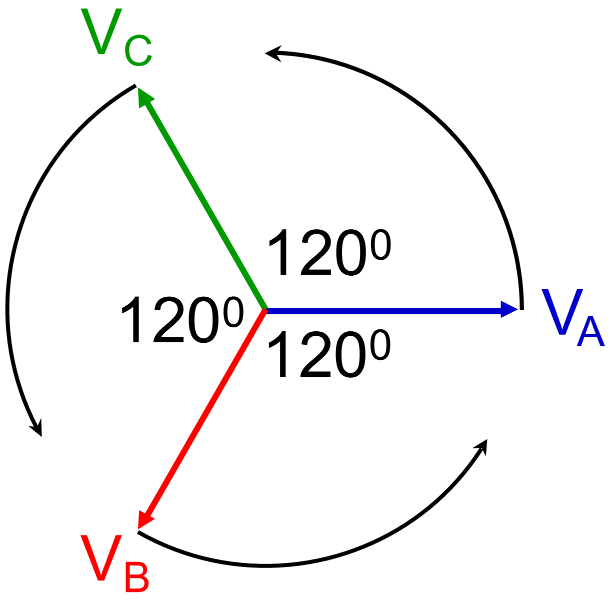




Voltage = V_{max} sine α

1-Phase and 3-Phase Power

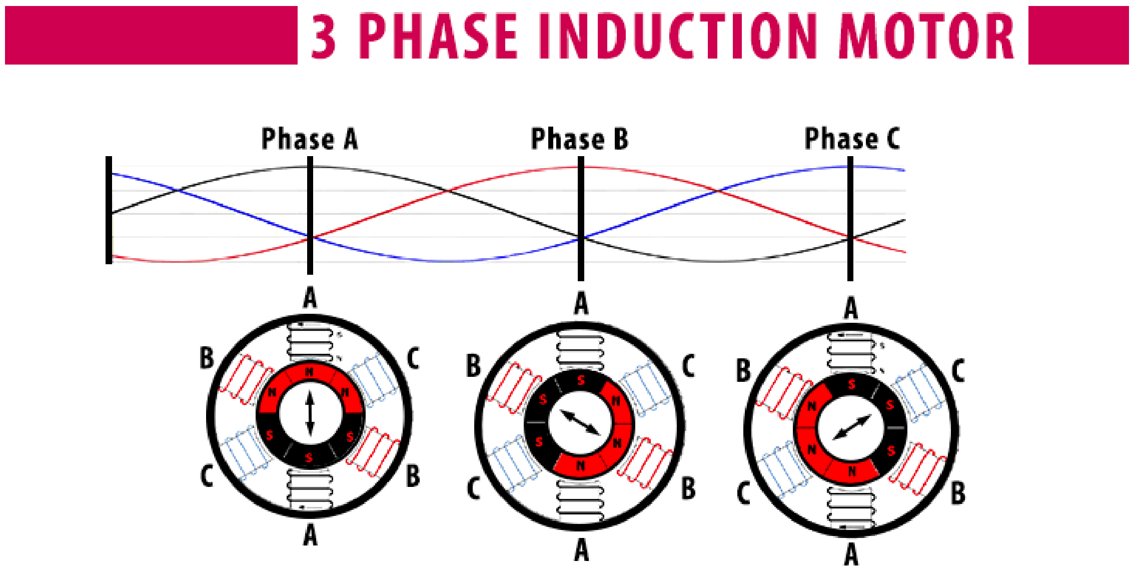




Forward Rotation, ABC

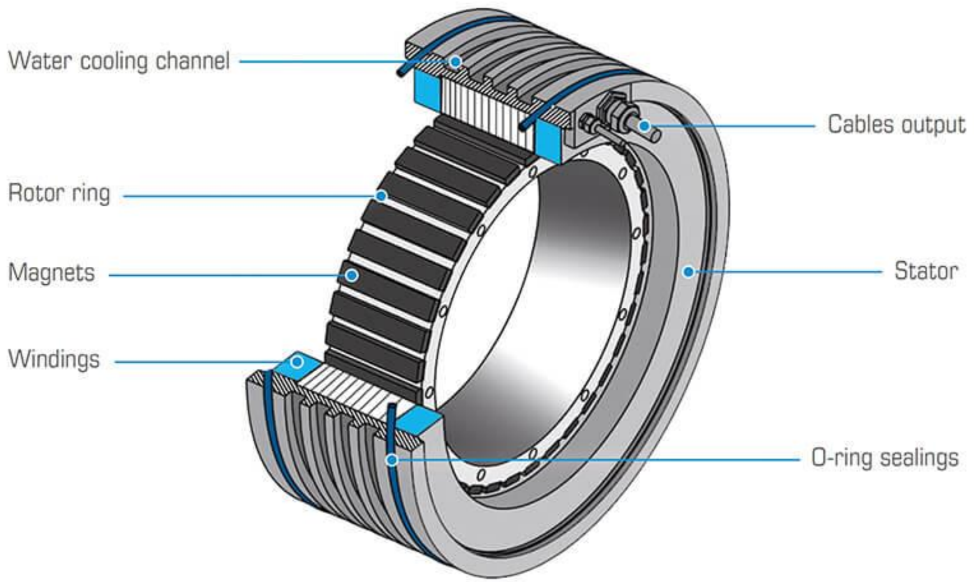
The Need for 3-Phase Power

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.



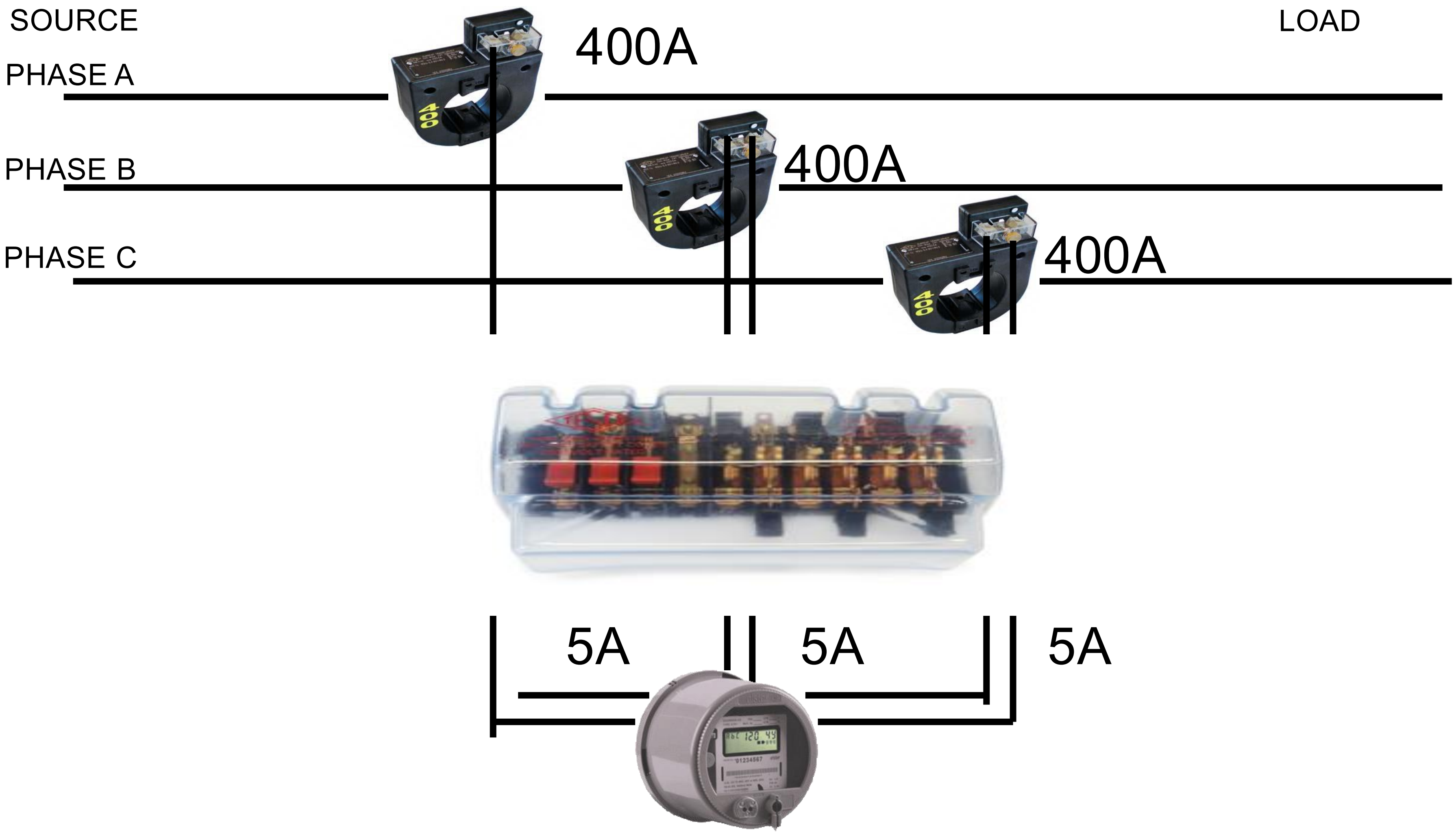
Benefits of 3-Phase Power

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

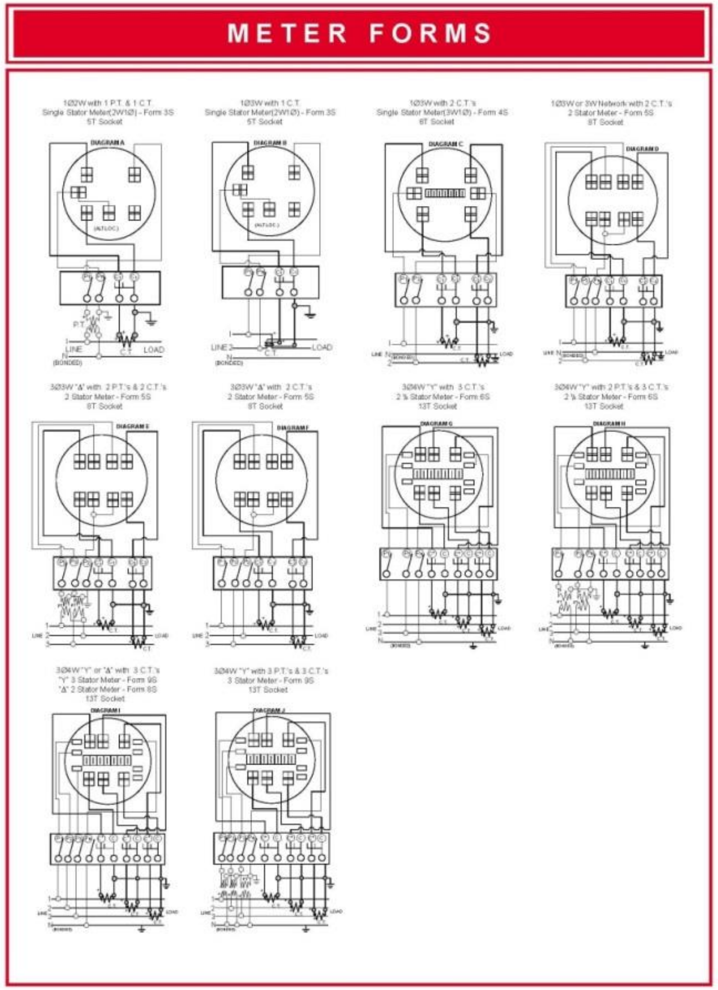


Transformer Rated - The Basic Components

9S Meter Installation with 400:5 CT's



Typical Connections

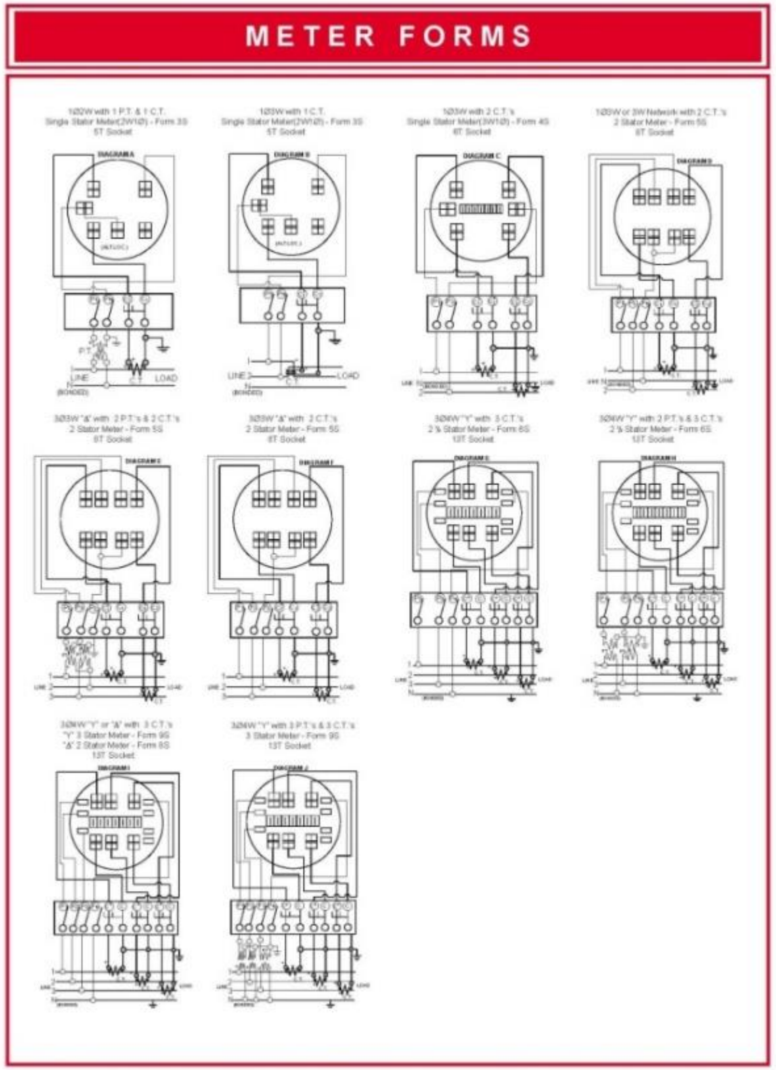


Typical Connections for Common Transformer (Instrument) Rated Meter Forms

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



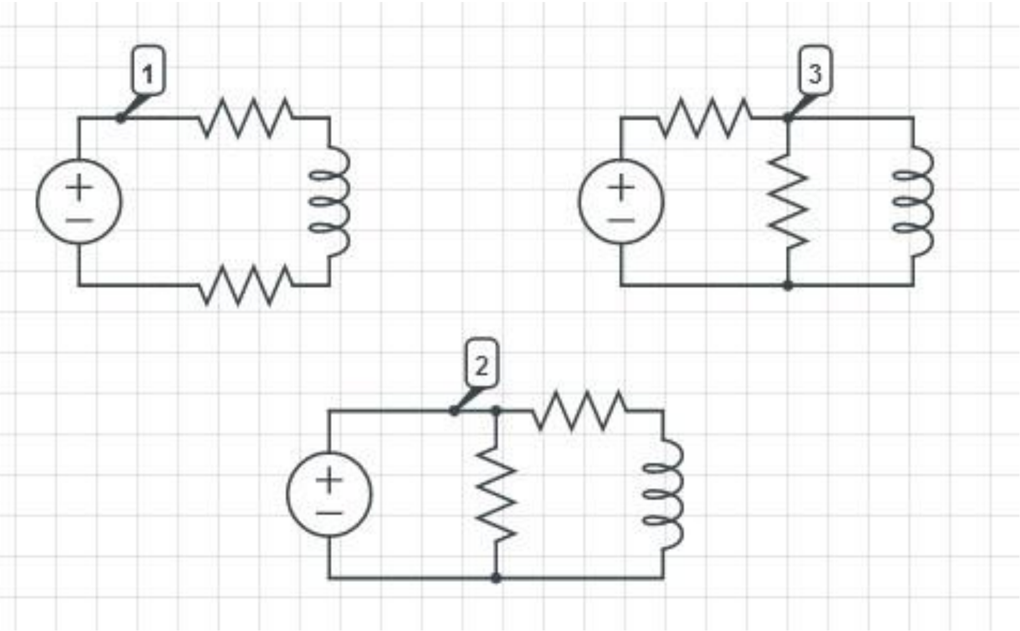
Three Phase Power: Blondel's Theorem

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

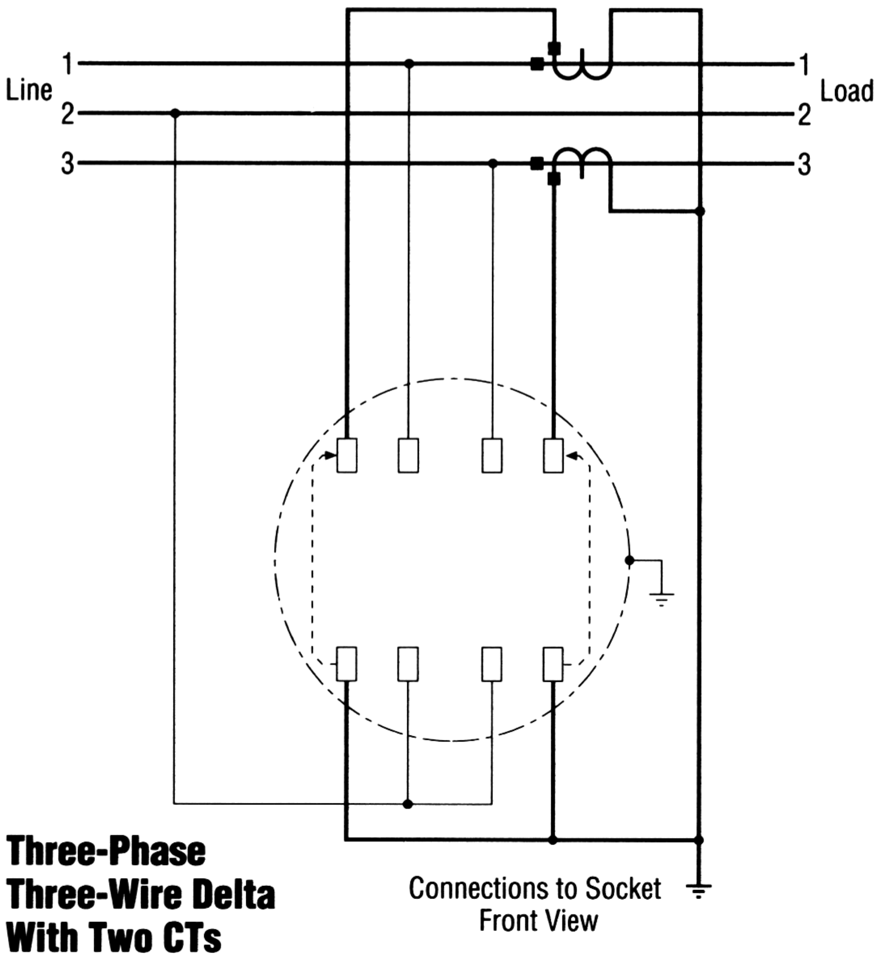
- Simply – We can measure the power in a N wire system by measuring the power in N-1 conductors.
- For example, in a 4-wire, 3-phase system we need to measure the power in 3 circuits.



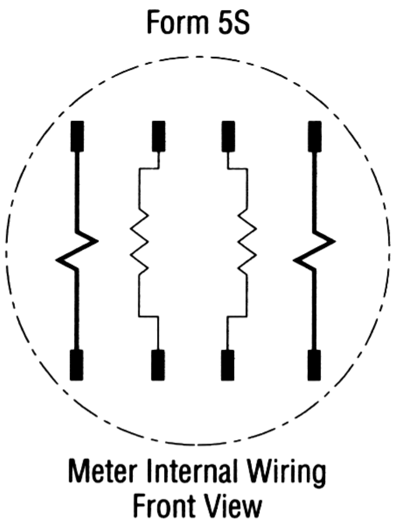
Three Phase Power: Blondel's Theorem

- 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



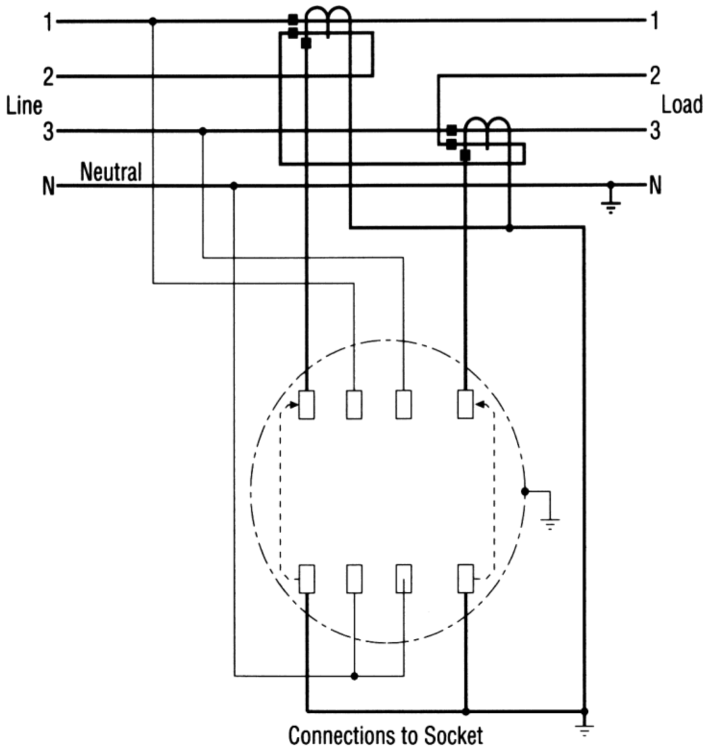
Three-Phase
Three-Wire Delta
With Two CTs



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

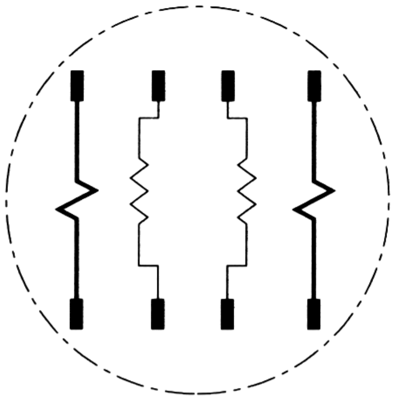
This satisfies Blondel's Theorem.

Blondel's Theorem



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

Form 5S



Meter Internal Wiring
Front View

- 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 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

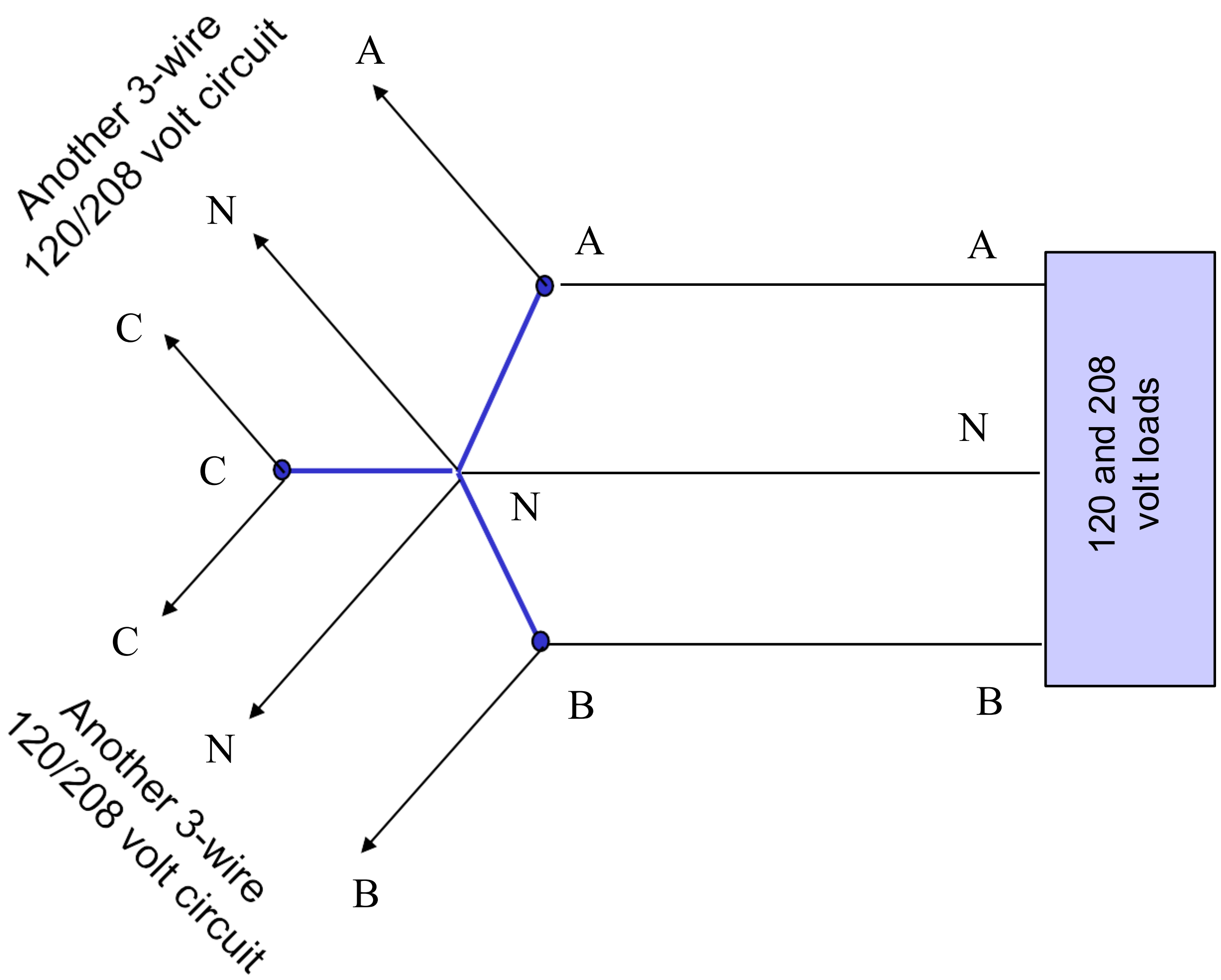
  Va=117, Vb=120, Vc=119, PF=1 then E=-1.67%

  Va=117, Vb=116, Vc=119, PF=.866 then E=-1.67%

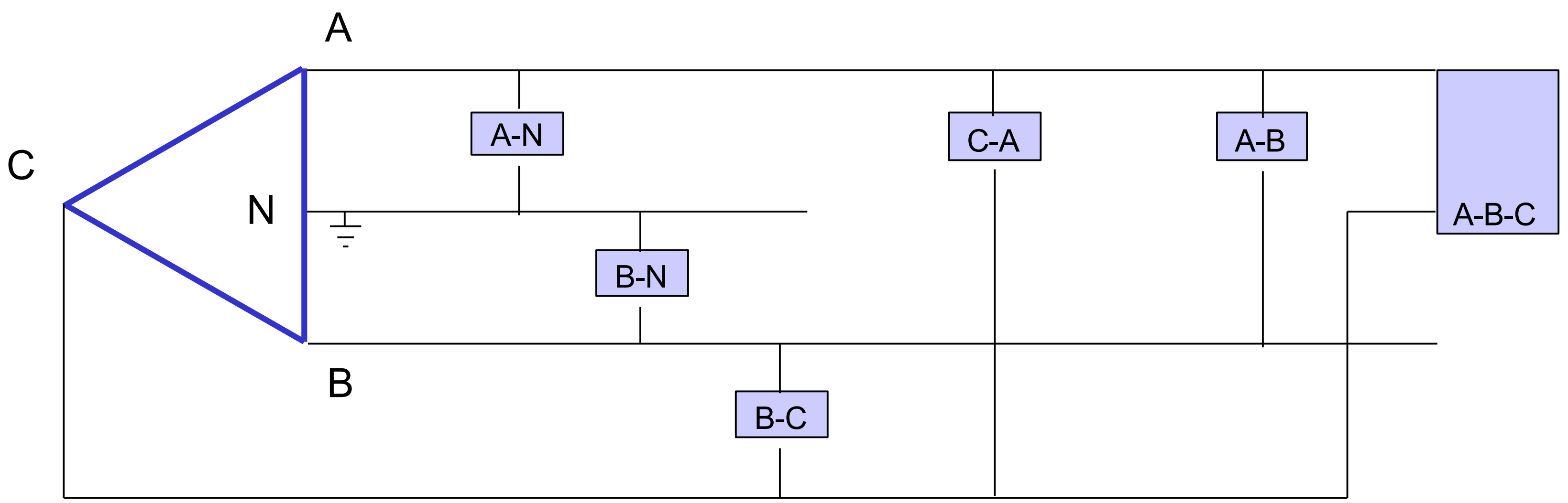
Power Measurements Handbook

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%

Network Service & Loads

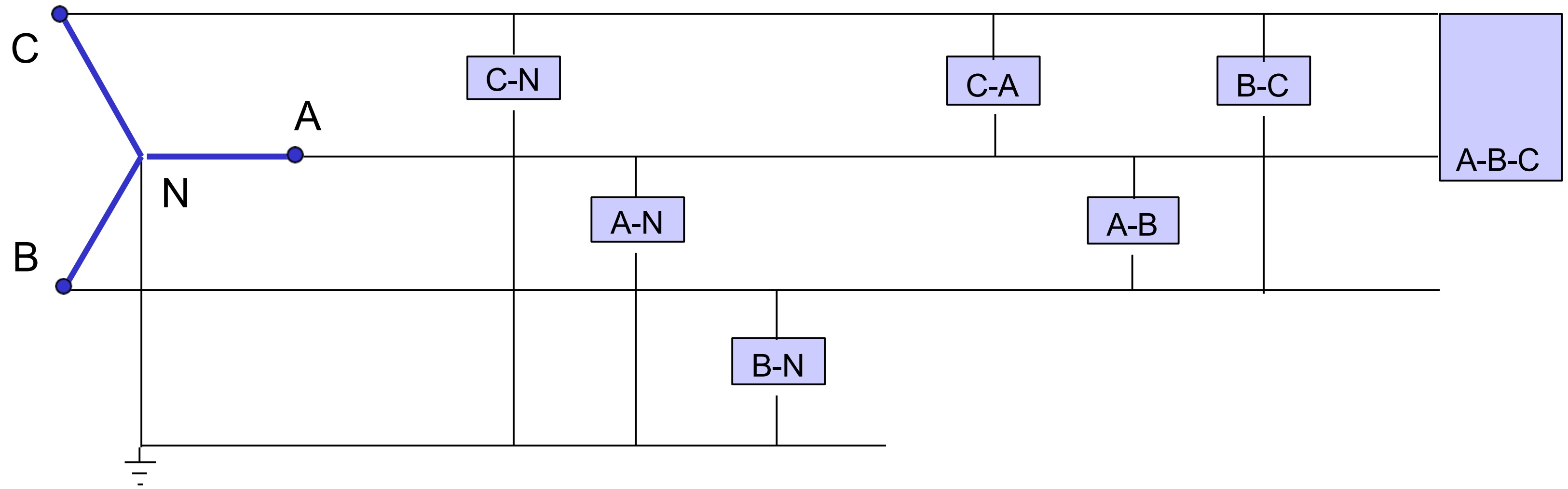


4-Wire Delta Service & Loads



Need to meter single phase line-neutral and line-line loads, as well as three phase loads. For self contained a Form 16 network meter and Transformer rated a 9S meter. We need to be Blondel Compliant and use a three-element meter. Note: For electro-mechanicals common practice was a Form 15S which was not Blondel compliant. Similarly, a 5S is not Blondel compliant for these services.

4-Wire Wye Service & Loads



Need to meter single phase line-neutral and line-line loads, as well as three phase loads. Use a Form 16 Network meter and a Form 9S Current Meter.

Meter Accuracy

Testing in a Nutshell

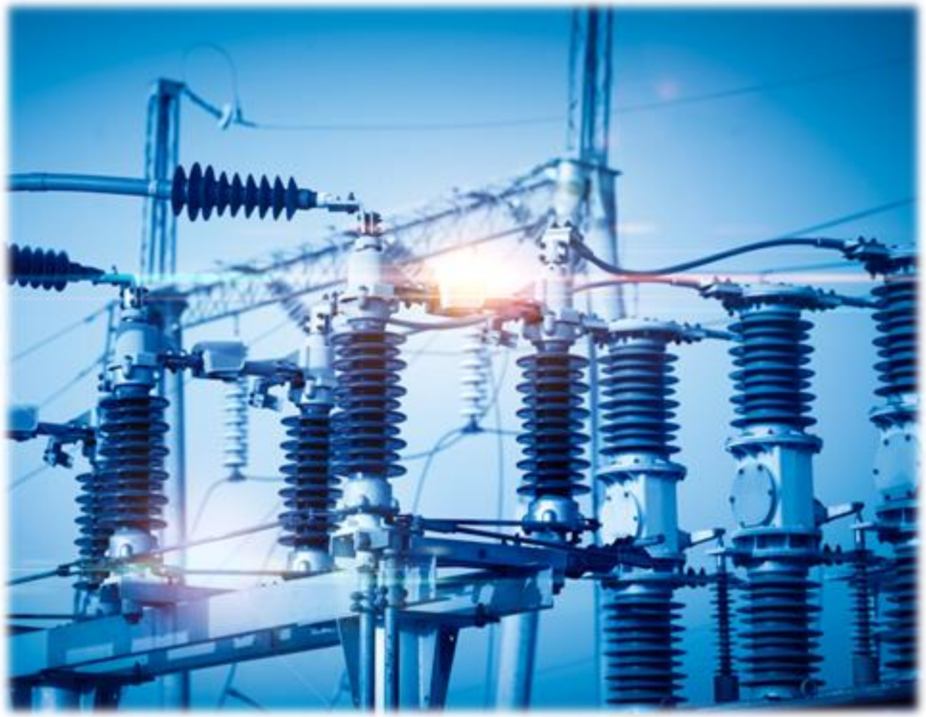
- ✓Full Load
- ✓Light Load
- ✓Power Factor

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)

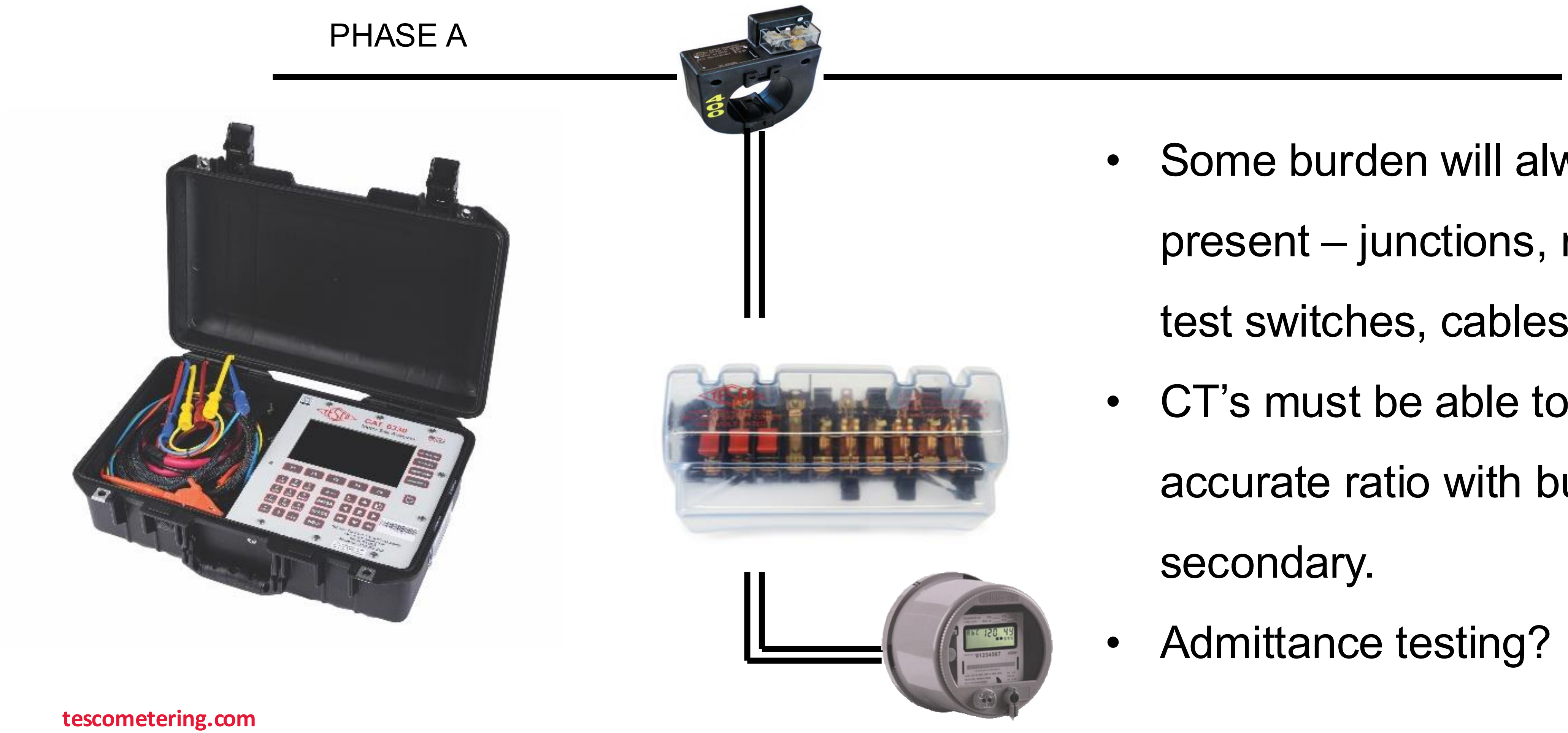
- Cross Phasing (wiring errors)
- Loose or Corroded Connections
- CT Mounted Backwards
- CT's with Shorted Turns
- Wrong Selection of Dual Ratio CT
- Detect Magnetized CT's
- Burden Failure in Secondary Circuit
- Open or Shorted Secondary
- Mislabeled CT's
- Ensures all Shorting Blocks have been Removed



Testing at Transformer Rated Sites

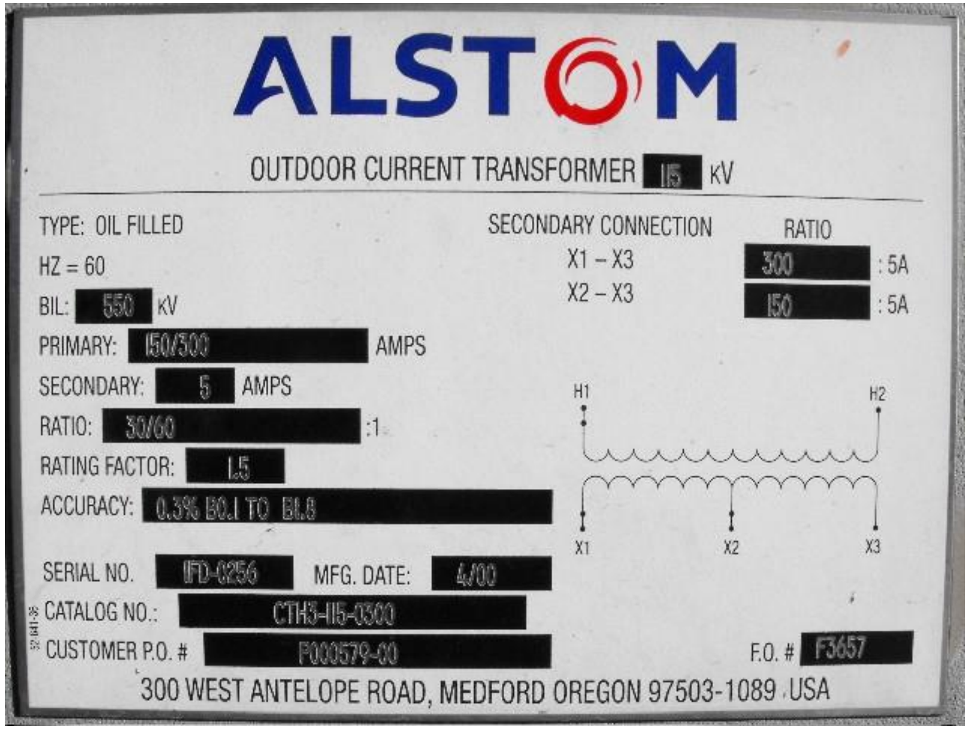
- ✓Meter Accuracy
- ✓Full Load
- ✓Light Load
- ✓Power Factor
- ✓CT Health
- ✓Burden Testing
- ✓Ratio Testing
- ✓Admittance Testing
- ✓Site Verification

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.
- Admittance testing?

Functionality with Burden Present on the Secondary Loop



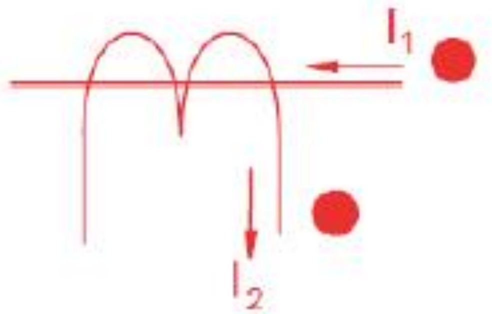
Example Burden Spec:
0.3% @ B0.1, B0.2, B0.5

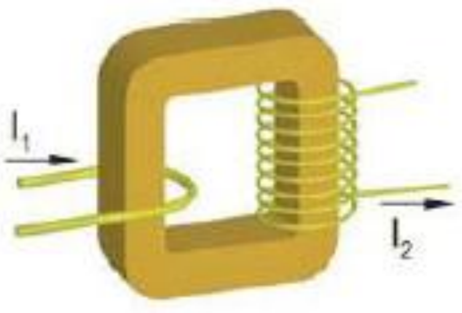
or

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

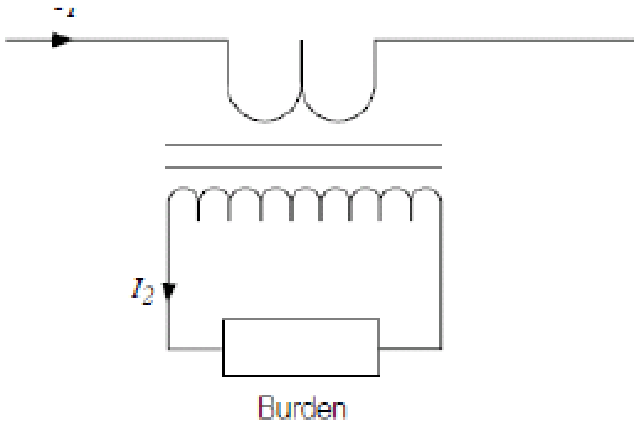
Fundamentals of Polyphase Field Meter Testing and Site Verification (Cont)

Ideal. No losses

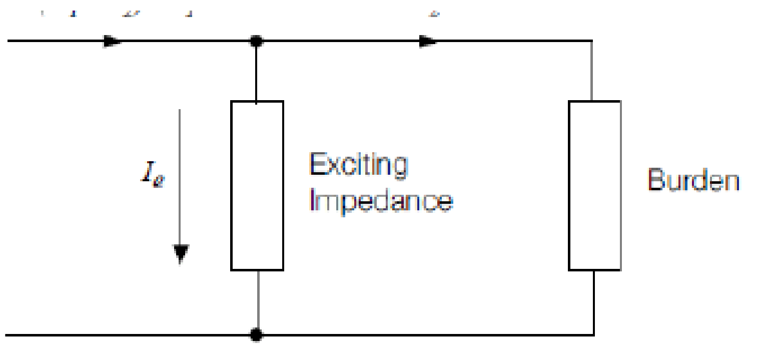




$$I_1 \times N_1 = I_2 \times N_2$$



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

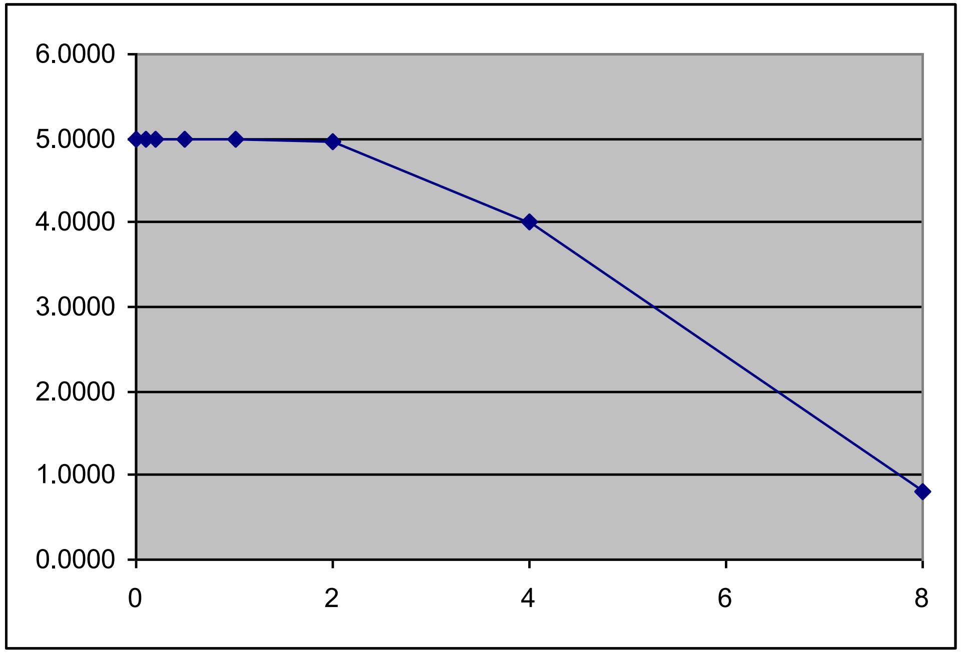


$$I_2 = \frac{N_1}{N_2} \times I_1 - I_e$$

Real, with core losses

Functionality with Burden Present on the Secondary Loop

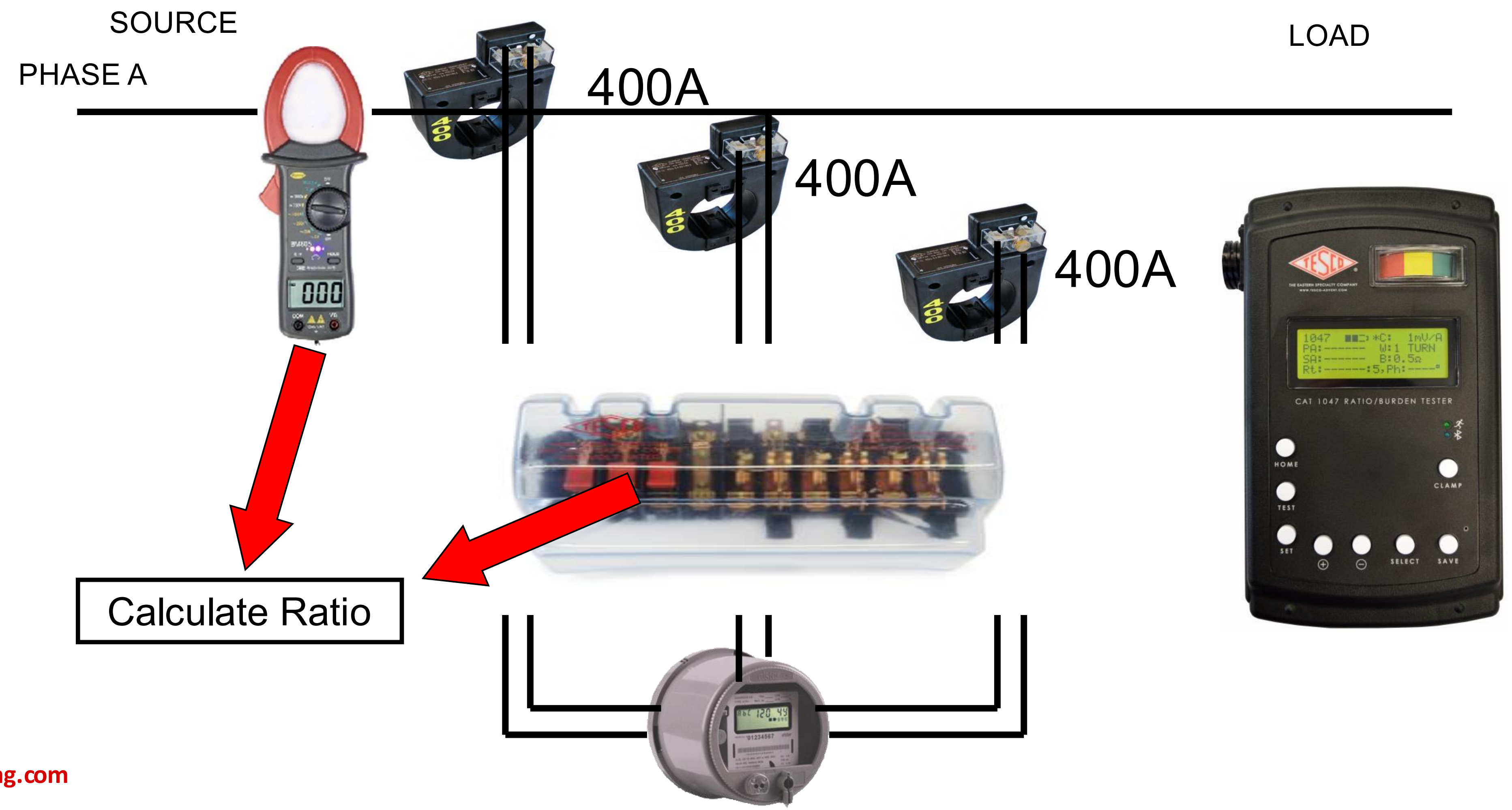
0.3% @ B0.1, B0.2, B0.5



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

Ratio of Primary Current to Secondary Current



Questions and Discussion

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