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POLYPHASE METERING 101

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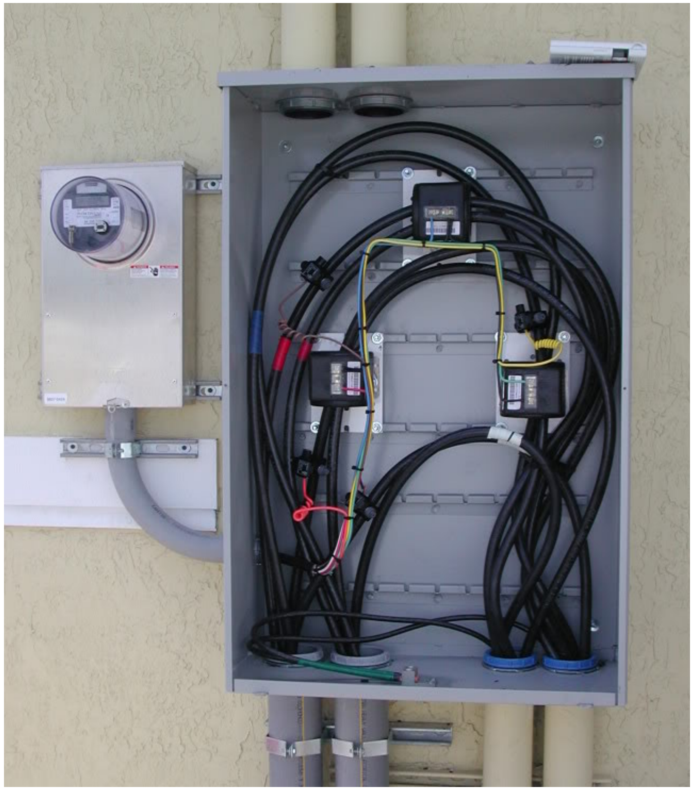
The Eastern Specialty Company

For Mississippi State University 43rd Annual
Electric Power & Meter School
Tuesday, February 20, 2024 ♦ 8:30 AM
Meter II

MISSISSIPPI STATE UNIVERSITY™
43RD ANNUAL ELECTRIC POWER & METERING SCHOOL

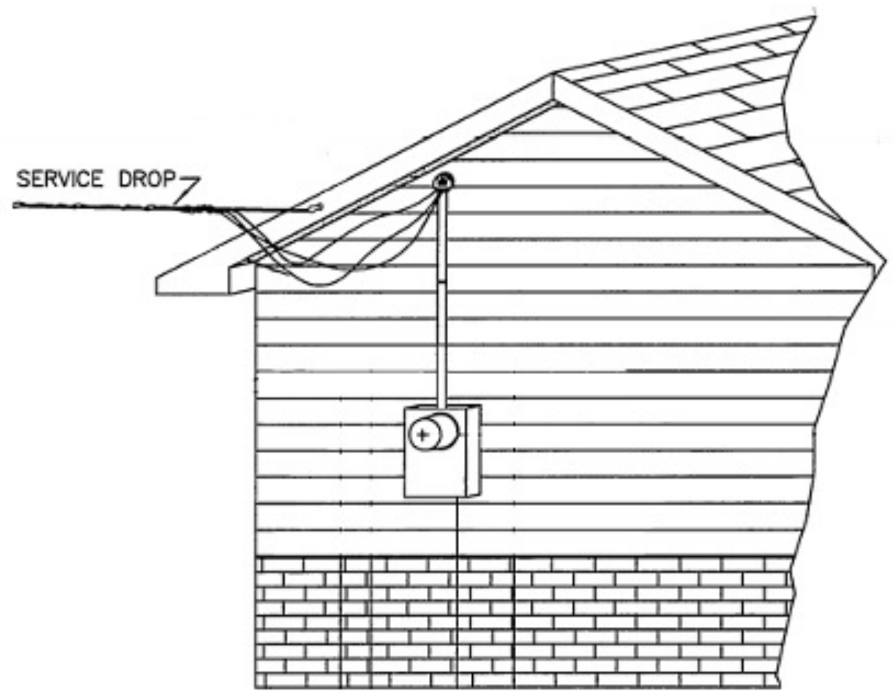
Topics We Will Be Covering

- 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



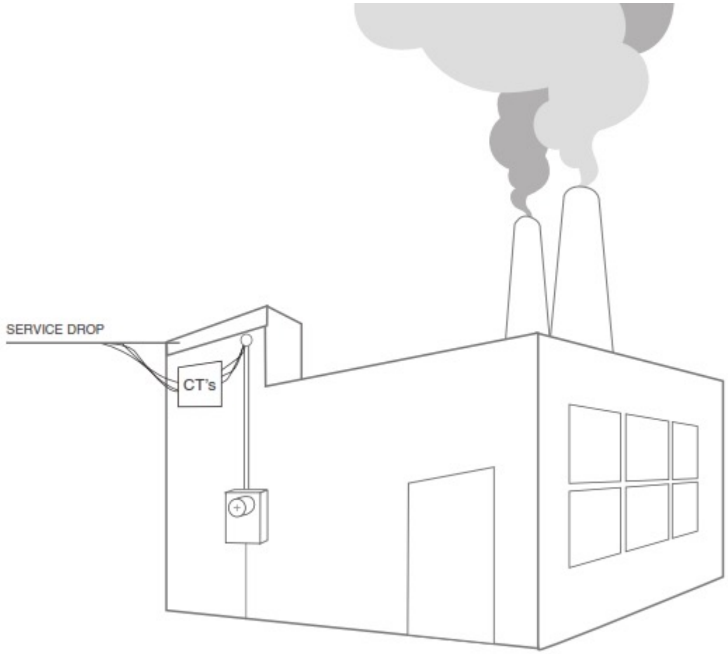
Self Contained Metering

- 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

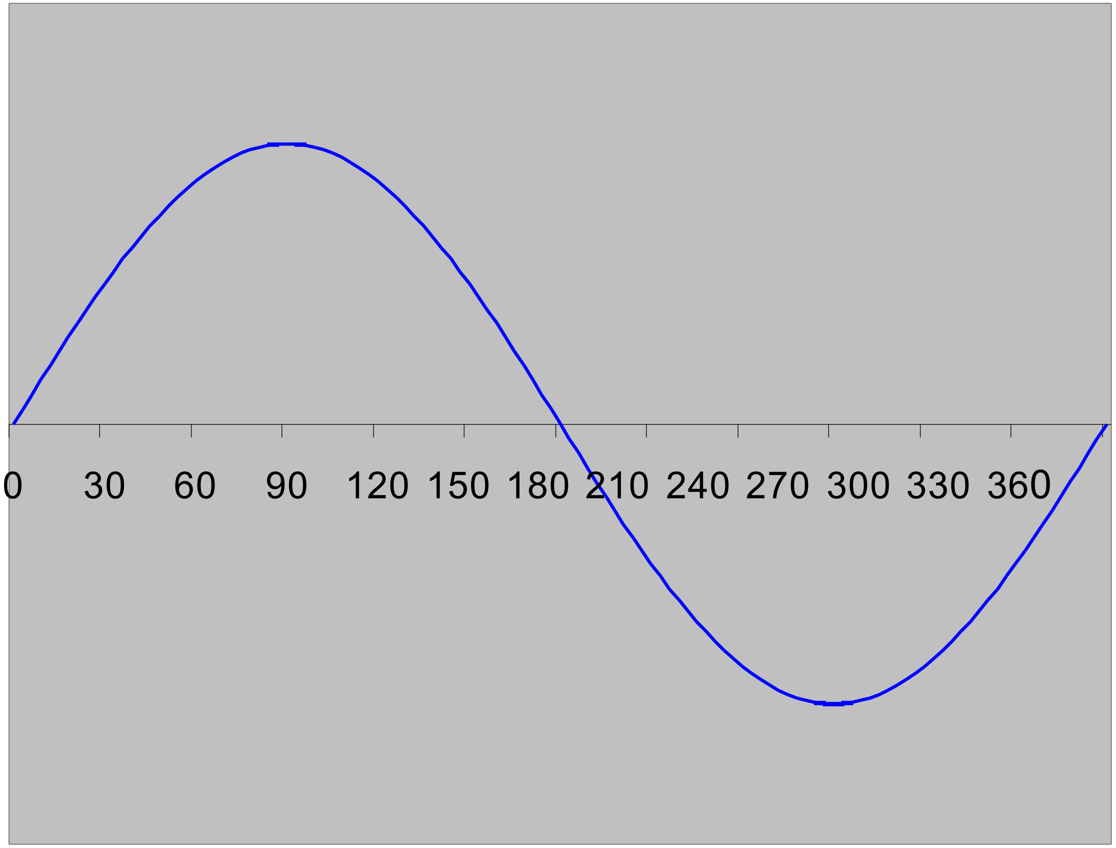


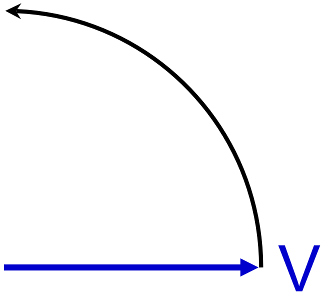
TRANSFORMER RATED METERING

- 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 affected.



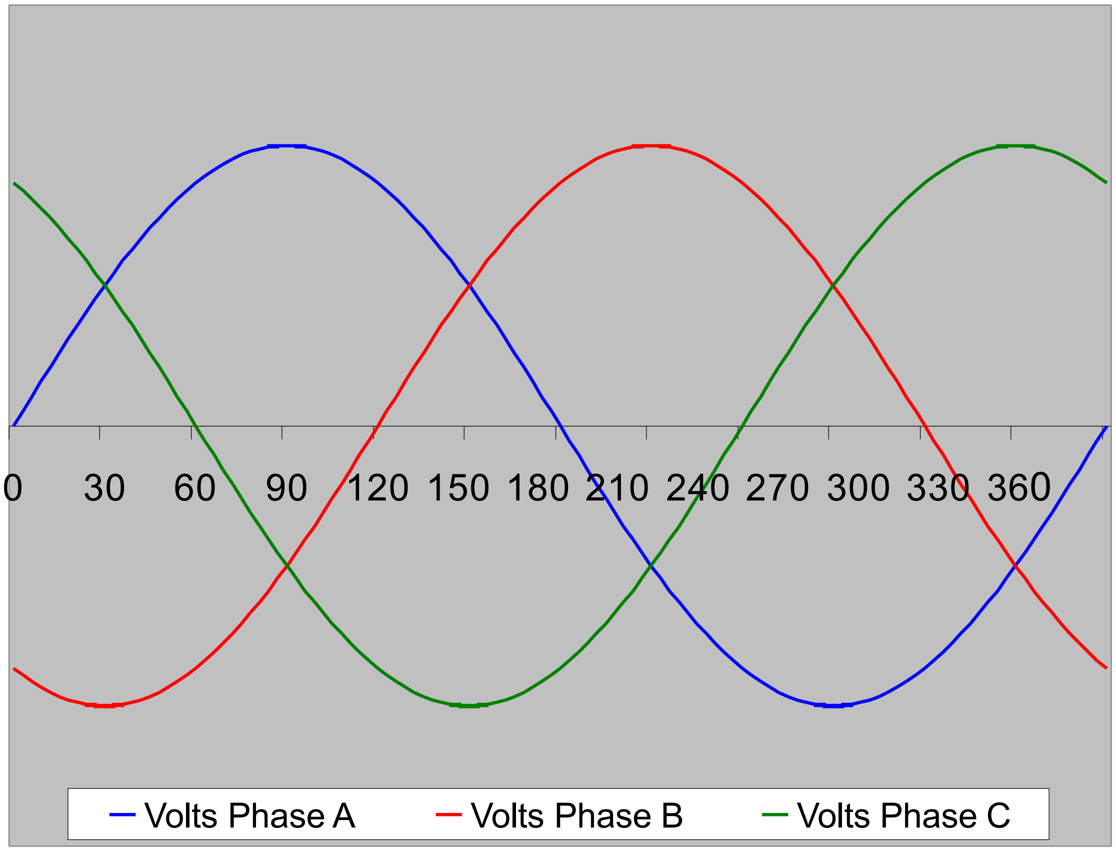
1-Phase and 3-Phase Power

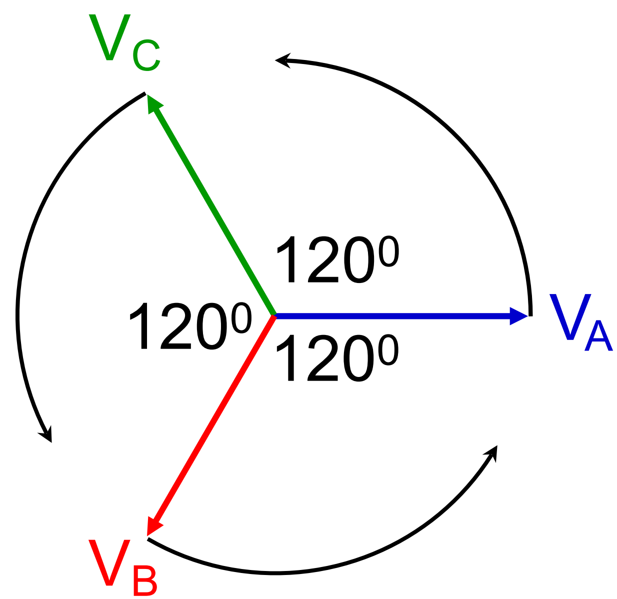




$$\text{Voltage} = V_{max} \text{ sine } \alpha$$

1-Phase and 3-Phase Power

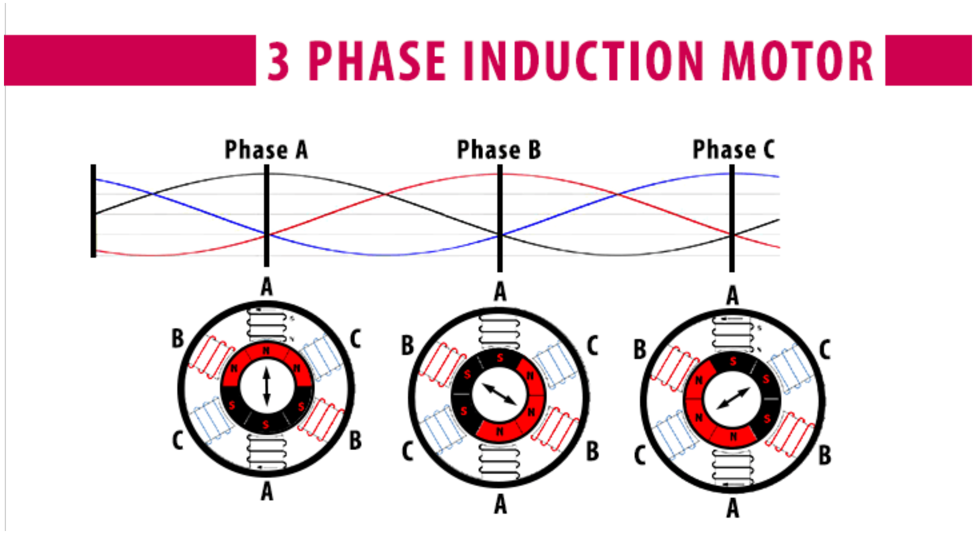




Forward Rotation, ABC

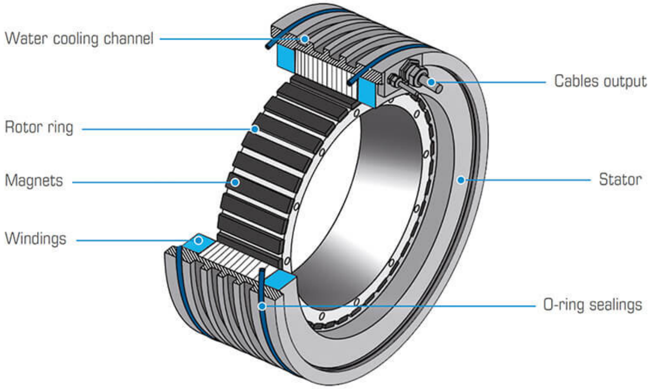
The Need for 3-Phase Power

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.

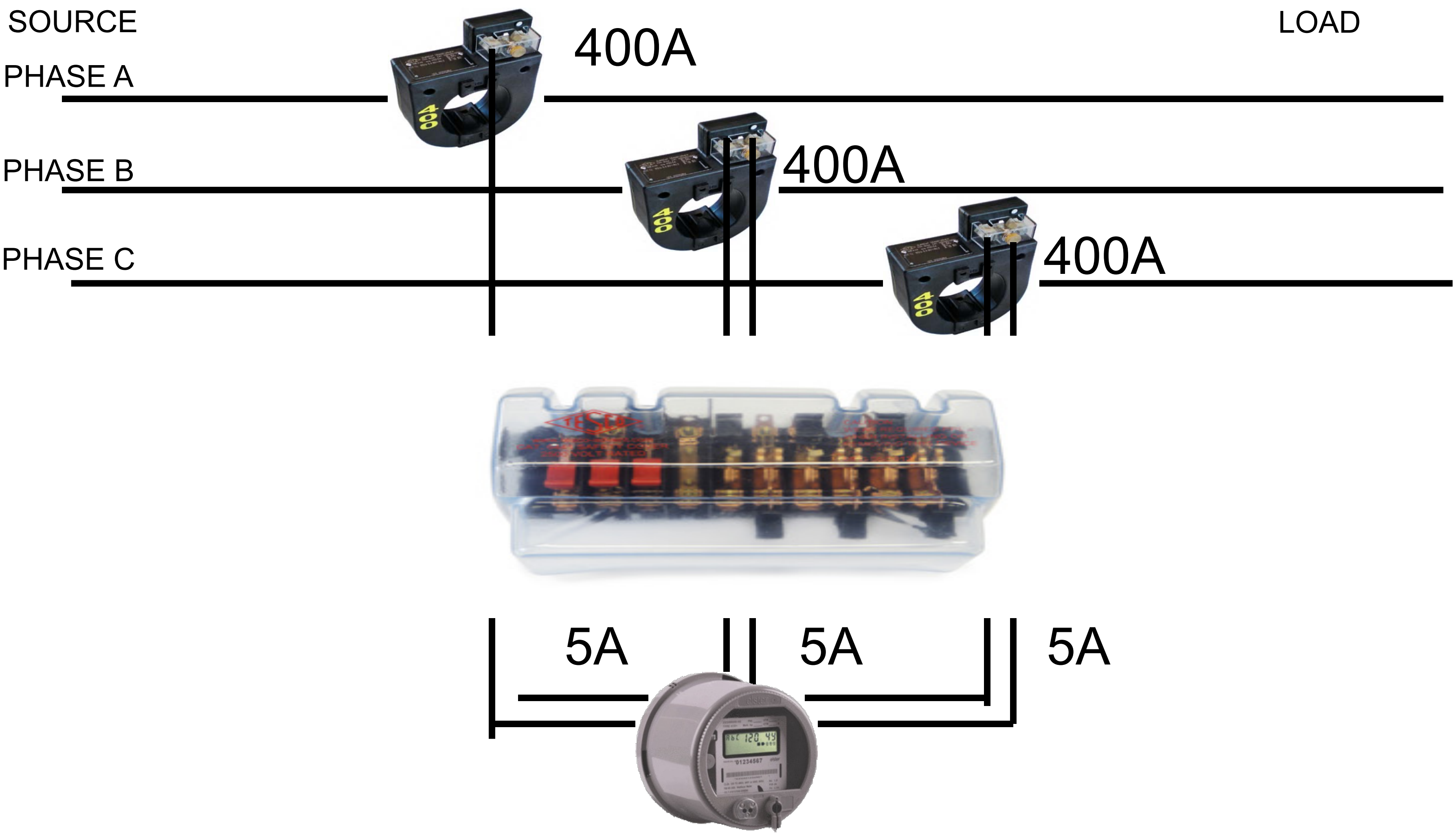


Benefits of 3-Phase Power

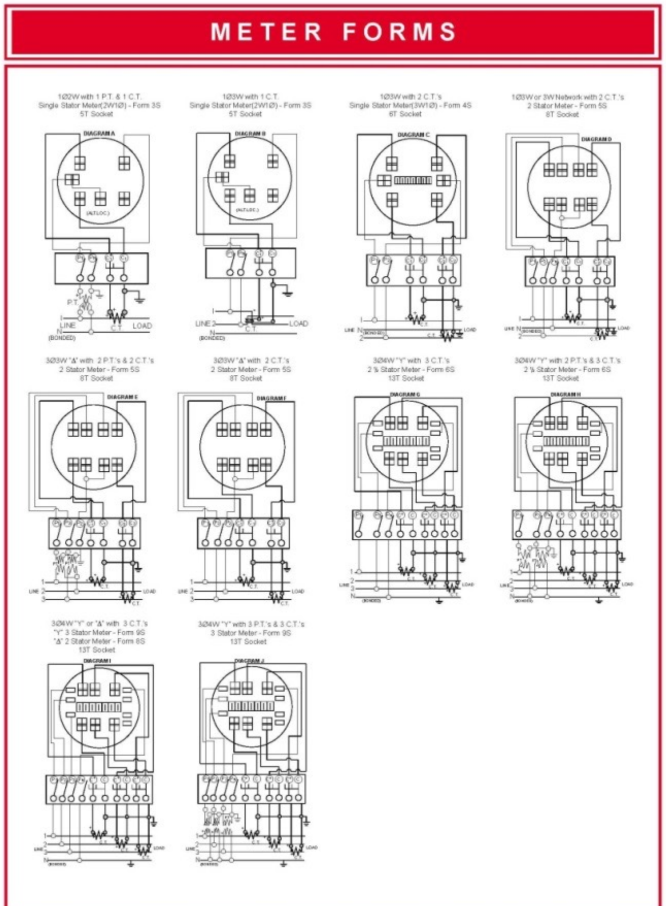
- ✓Steadier motor torque
- ✓Less vibration in machinery
- ✓Greater mechanical efficiency
- ✓Better voltage regulation
- ✓Lower heat losses
- ✓Lighter weight conductors



9S Meter Installation with 400:5 CT's



Typical Connections

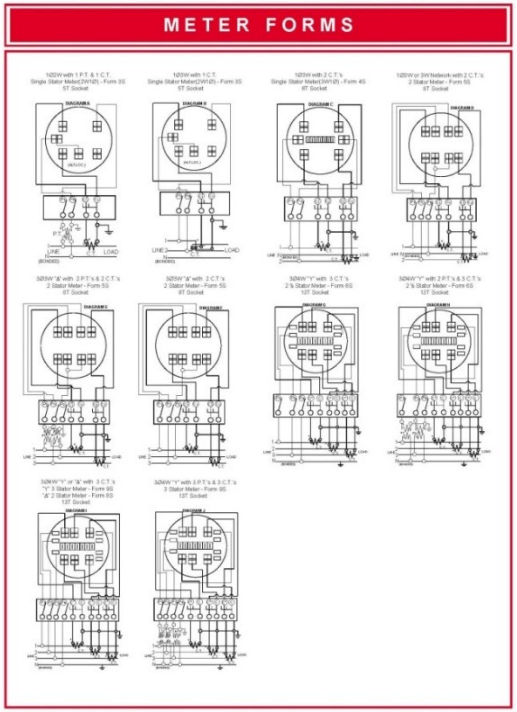


Typical Connections for Common Transformer (Instrument) Rated Meter Forms

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



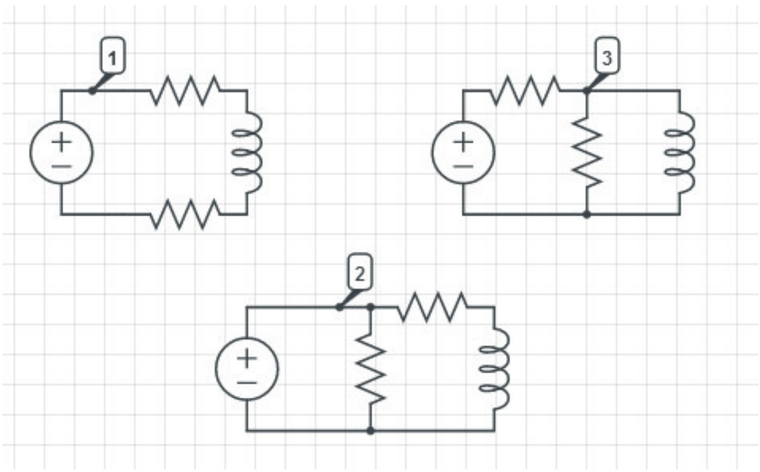
Three Phase Power: Blondel's Theorem

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

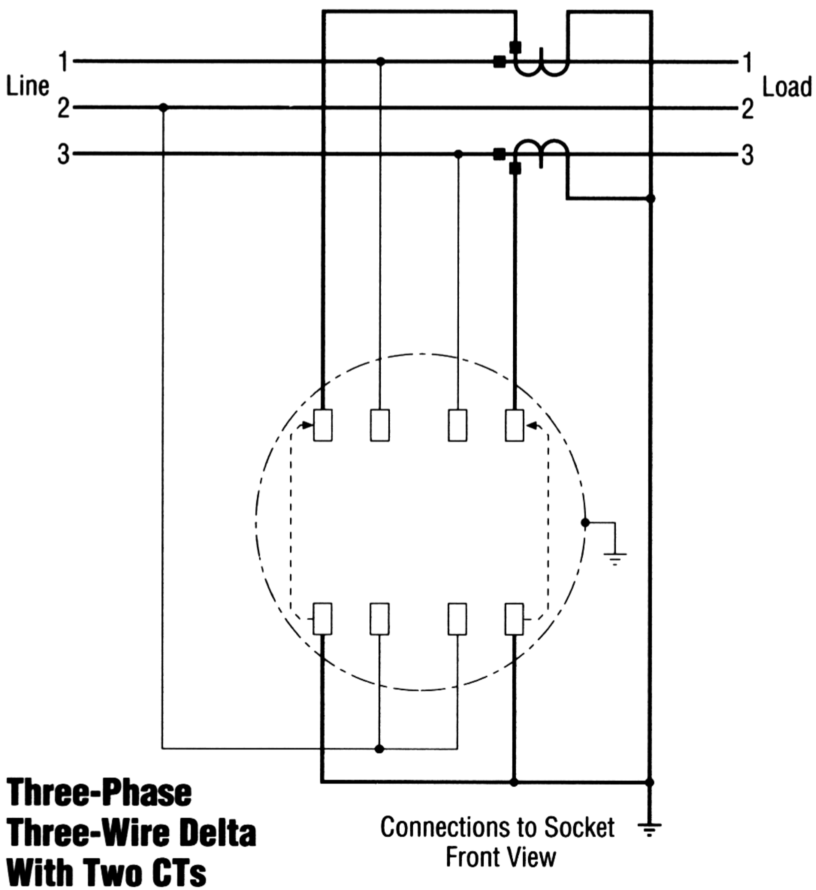
- Simply – We can measure the power in a N wire system by measuring the power in N-1 conductors.
- For example, in a 4-wire, 3-phase system we need to measure the power in 3 circuits.

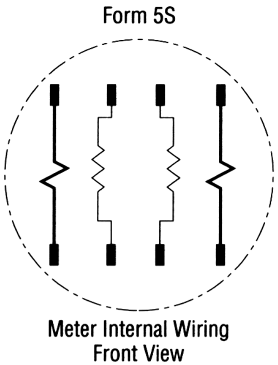


Three Phase Power: Blondel's Theorem

- 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

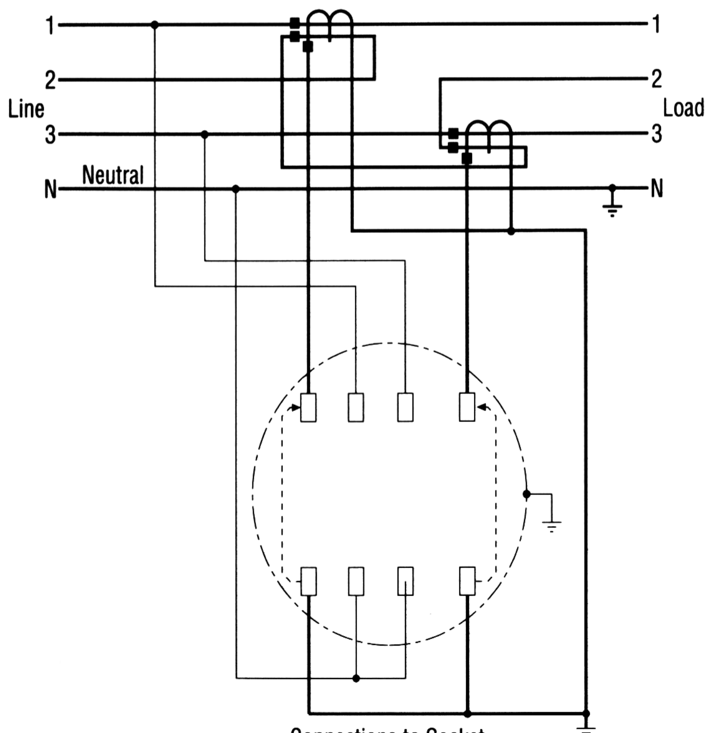




- Three wires
- Two voltage measurements with one side common to Line 2
- Current measurements on lines 1 & 3.

This satisfies Blondel's Theorem.

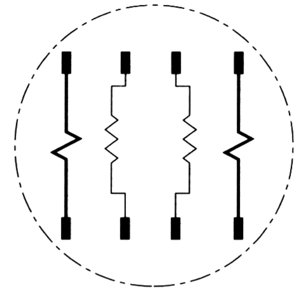
Blondel's Theorem



Connections to Socket
Front View

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

Form 5S

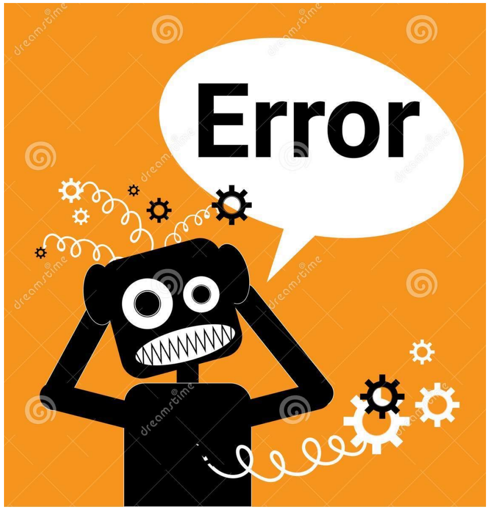


Meter Internal Wiring
Front View

- 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:
  - $P = Vb\ Ib \cos\theta$
- 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

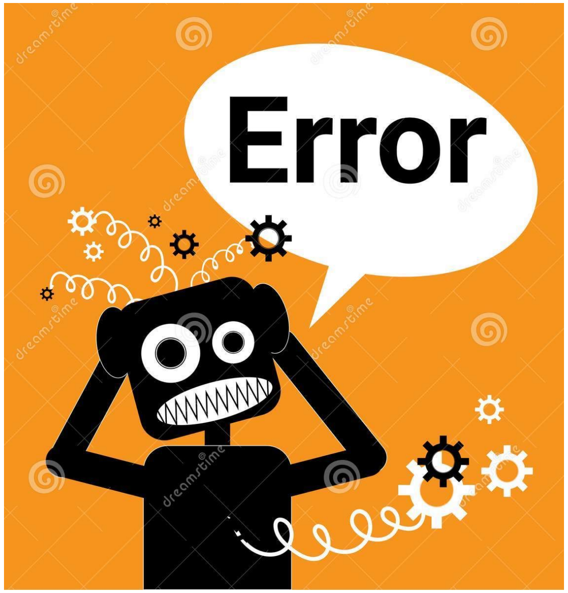
BLONDEL'S THEOREM

- $Pb = Ib\ Va \cos(60 - \theta) + Ib\ Vc \cos(60 + \theta)$
- 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%

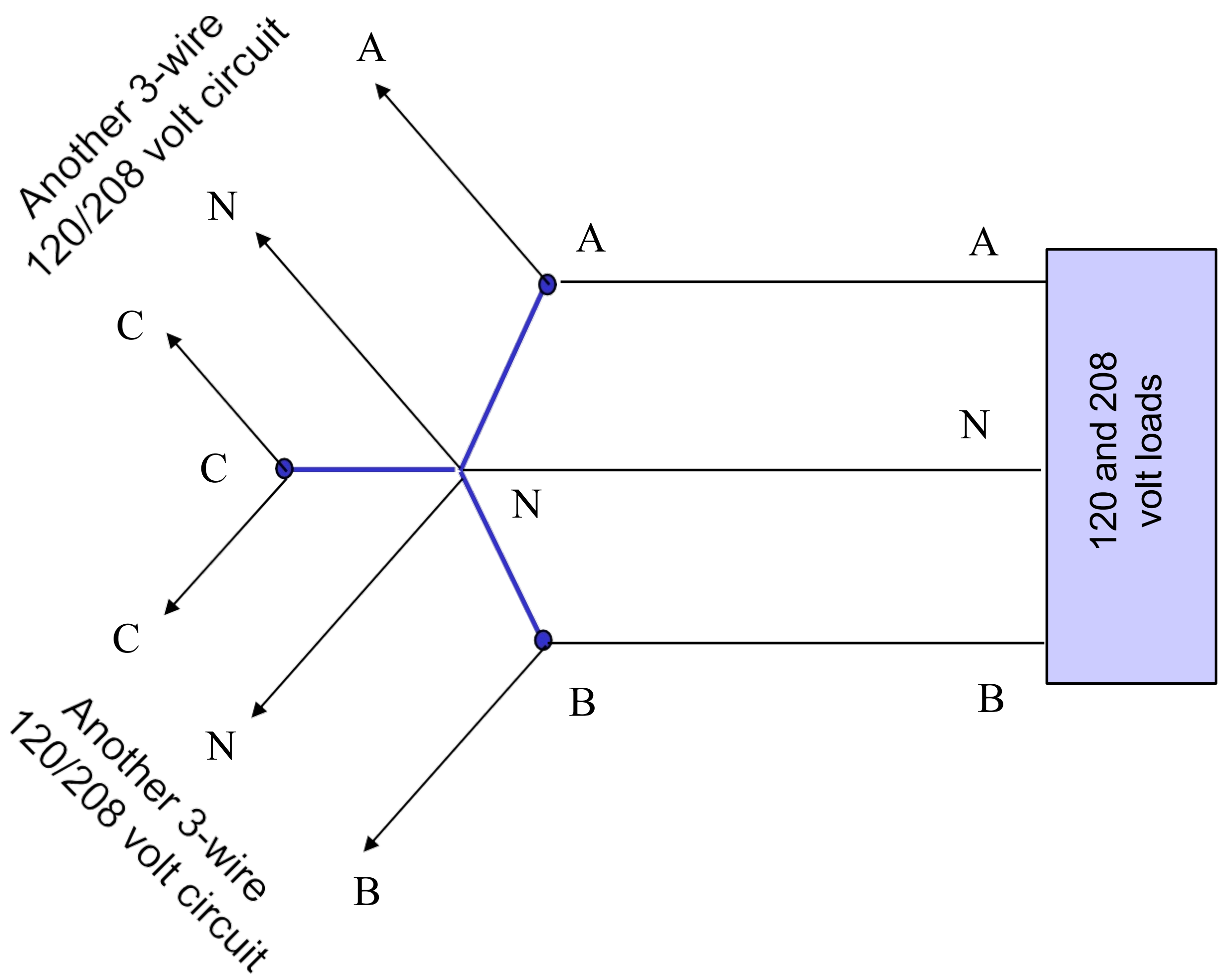
Va=117, Vb=116, Vc=119, PF=.866 then E=-1.67%

Blondel's Theorem

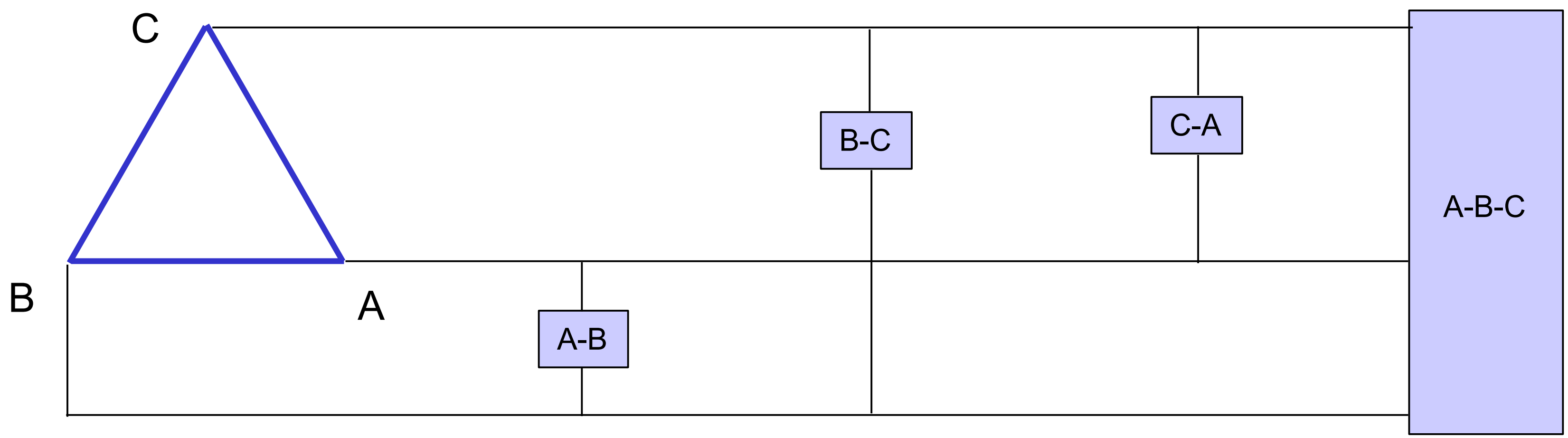
Power Measurements Handbook

Condition	% V Imb	% I Imb	Phase A V	Phase A φvan	Phase A I	Phase A φian	Phase B V	Phase B φvbn	Phase B I	Phase B φibn	non-Blondel % 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

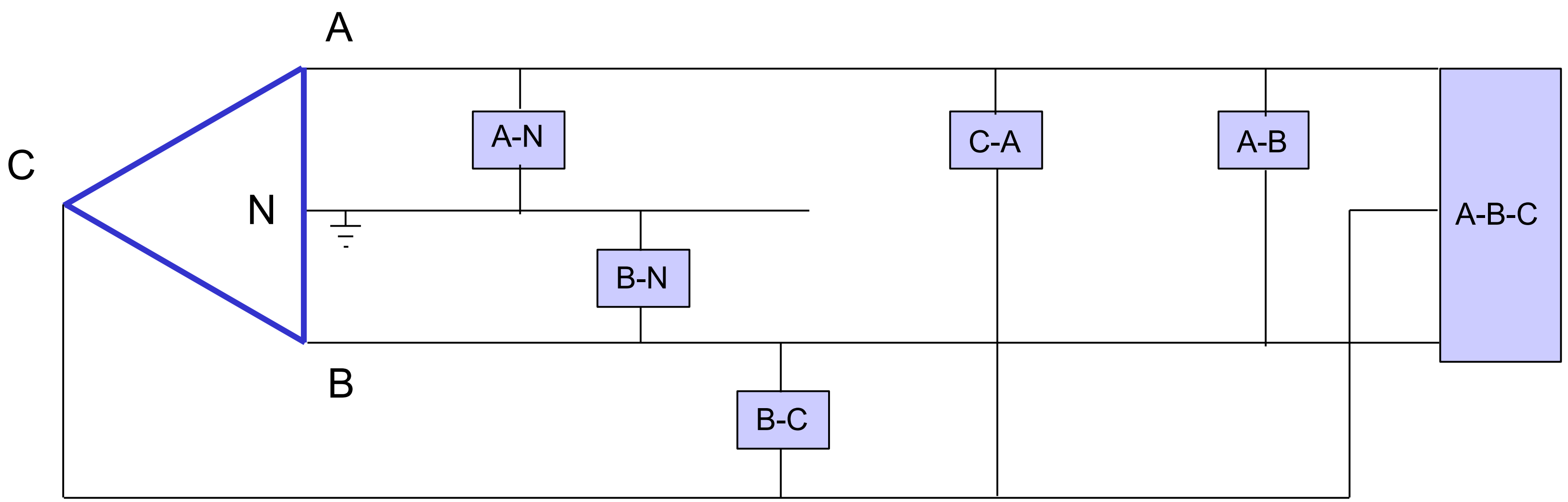


3-Wire Delta Service & Loads



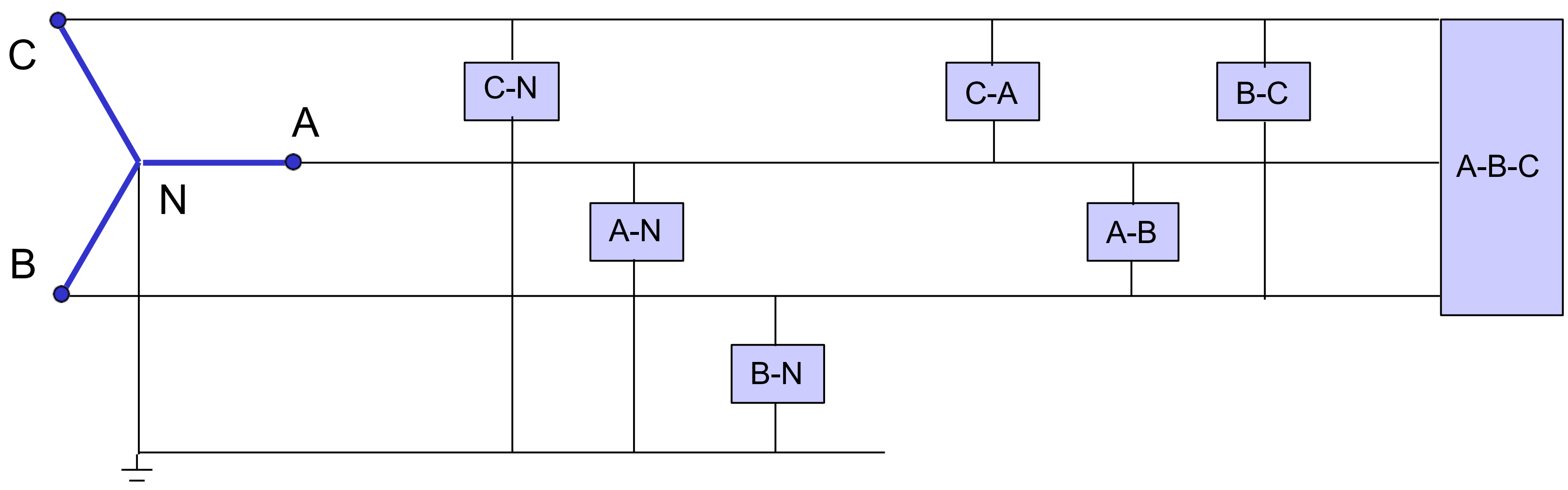
Need to meter single phase line-line loads, as well as three phase loads. Form 12 for Self Contained and Form for Transformer Rated. You need a two element meter only. Network metering is less expensive than Transformer rated. If you need to be transformer rated you save by using a single bushing VT and one less PT since you are only two element (typically do not meter B element).

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

Meter Accuracy Testing in a Nutshell

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

The Importance of CT Testing in the Field

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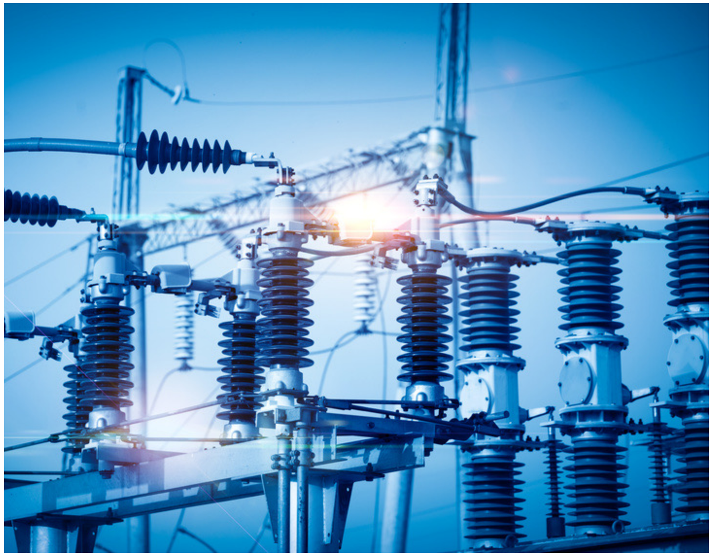
- One transformer in three wired backwards will give the customer a bill of 1/3rd the actual bill.
- One broken wire to a single transformer will give the customer a bill of 2/3rd the actual bill
- One dual ratio transformer inappropriately marked in the billing system as 400:5 instead of 800:5 provides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

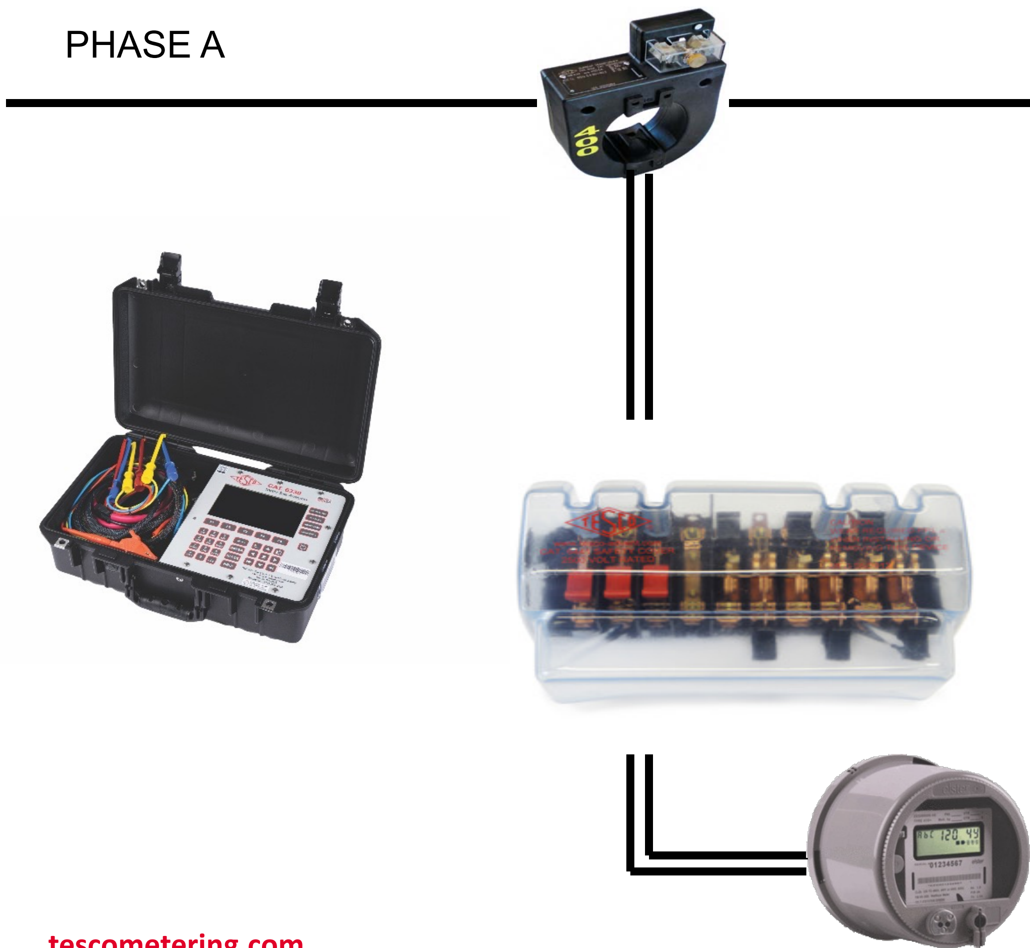


- Cross Phasing (wiring errors)
- Loose or Corroded Connections
- CT Mounted Backwards
- CT's with Shorted Turns
- Wrong Selection of Dual Ratio CT
- Detect Magnetized CT's
- Burden Failure in Secondary Circuit
- Open or Shorted Secondary
- Mislabeled CT's
- Ensures all Shorting Blocks have been Removed

Testing at Transformer Rated Sites

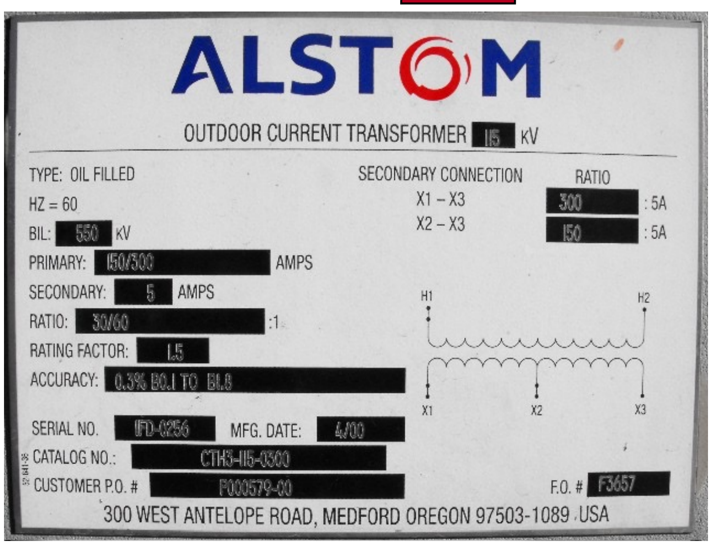
- ✓Meter Accuracy
- ✓Full Load
- ✓Light Load
- ✓Power Factor
- ✓CT Health
- ✓Burden Testing
- ✓Ratio Testing
- ✓Admittance Testing
- ✓Site Verification

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



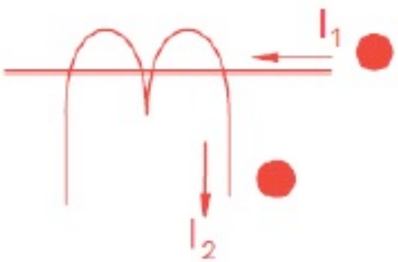
Example Burden Spec:

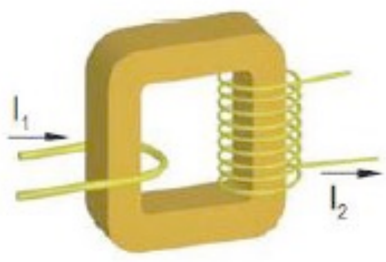
0.3% @ B0.1, B0.2, B0.5

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

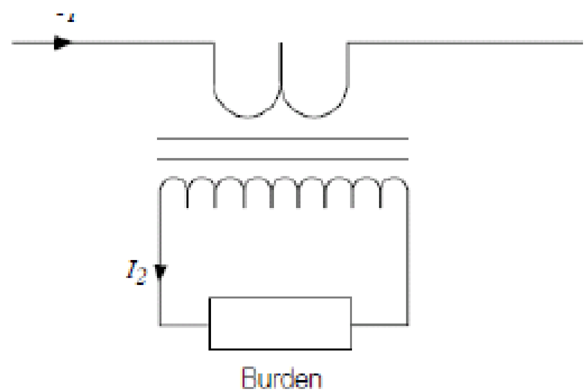
FUNDAMENTALS OF POLYPHASE FIELD METER TESTING AND SITE VERIFICATION (CONT)



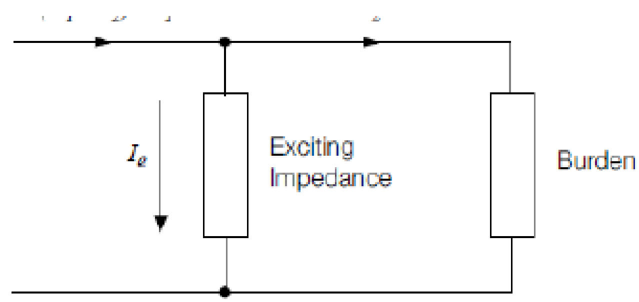


$$I_1 \times N_1 = I_2 \times N_2$$

Ideal. No losses



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



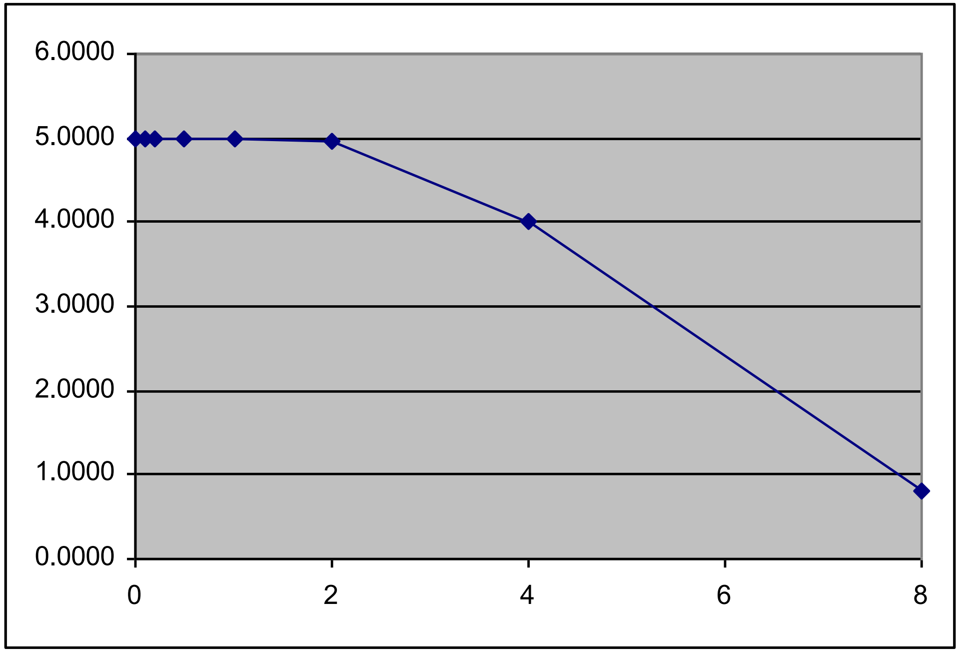
$$I_2 = \frac{N_1}{N_2} \times I_1 - I_e$$

Real, with core losses

Functionality with Burden Present on the Secondary Loop

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

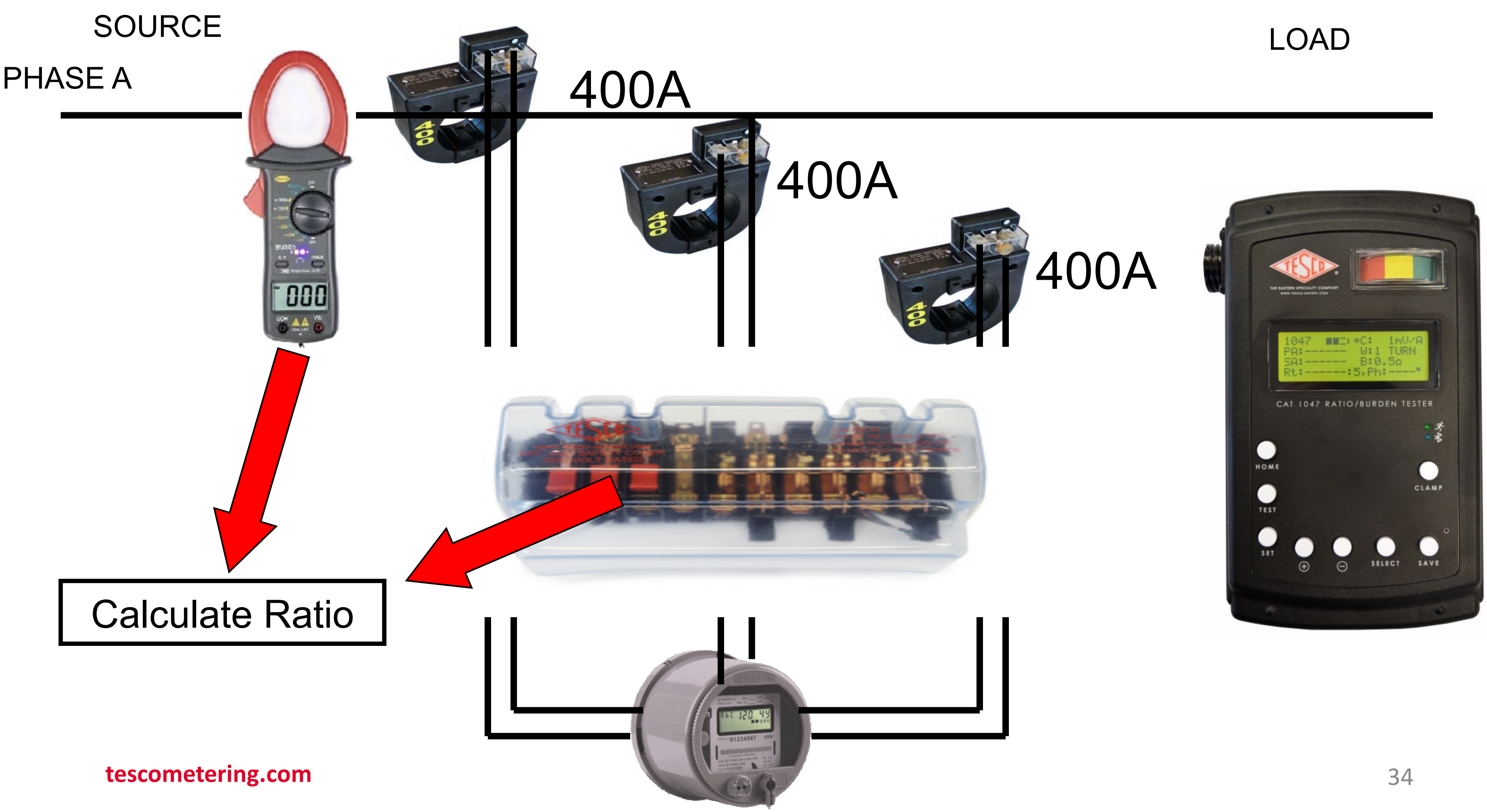
Initial Reading = 5Amps
0.3% x 5A = 0.015A
5A – 0.015 = 4.985A



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 (Cont)

Ratio of Primary Current to Secondary Current



QUESTIONS AND DISCUSSION

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