



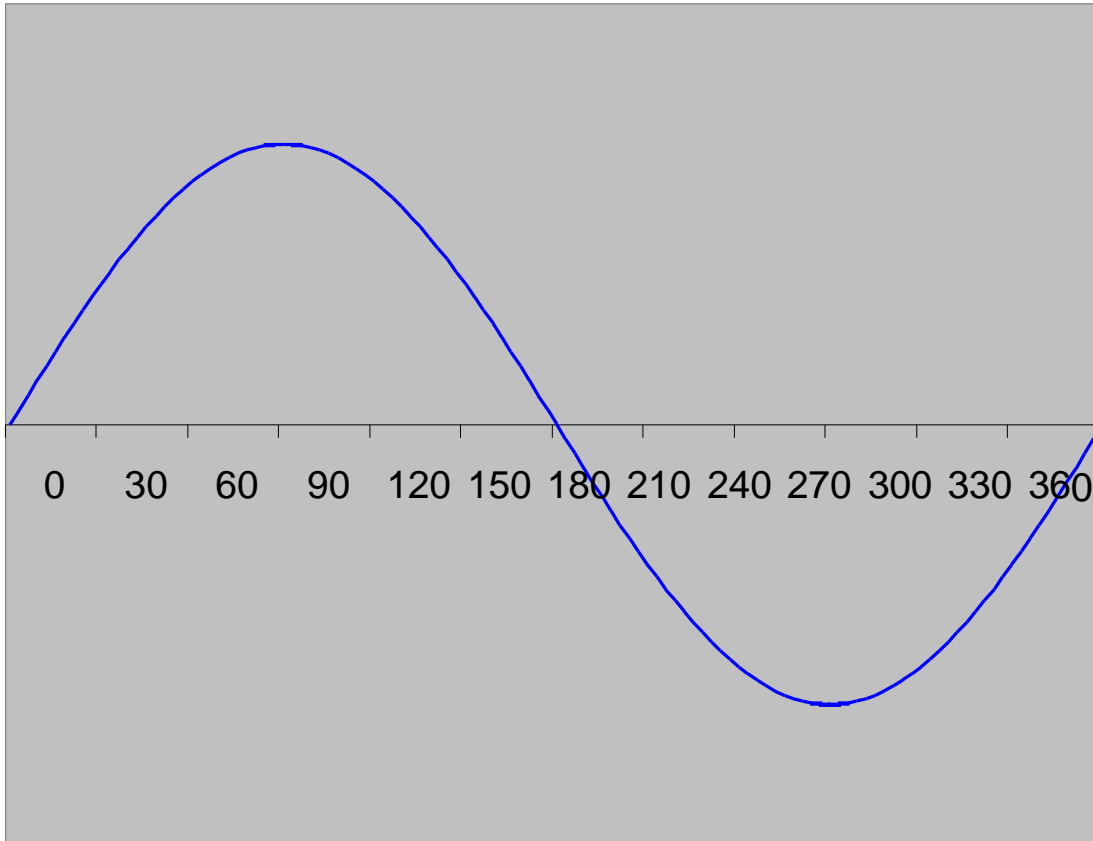
# Introduction to Polyphase Metering



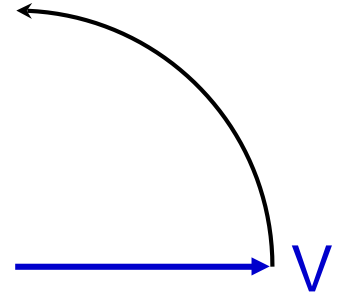
Prepared by Vernon White, TESCO  
The Eastern Specialty Company

*For Mid-South Annual Meter School  
May 5, 2021  
10:00 a.m.  
Group 2*

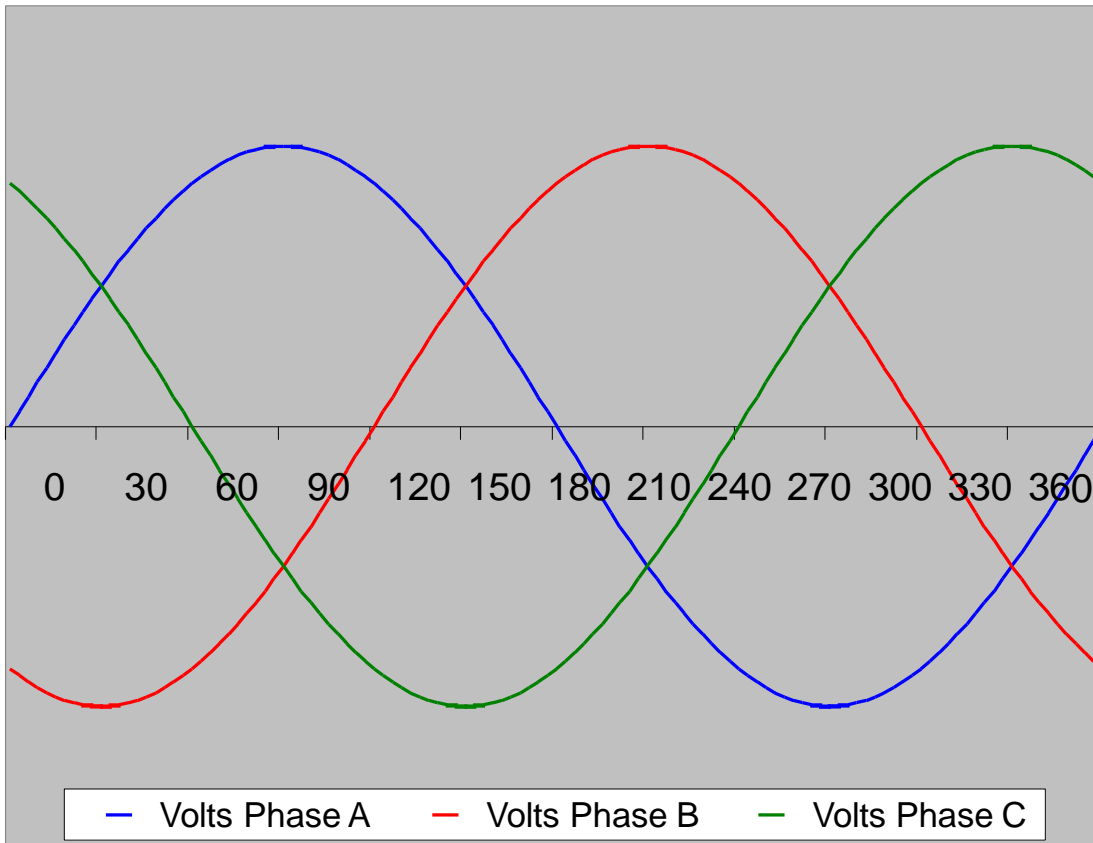
# 1-Phase and 3-Phase Power



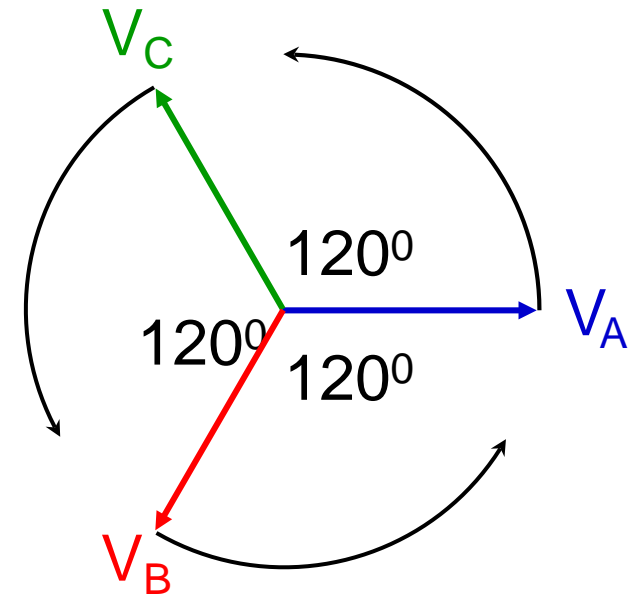
$$\text{Voltage} = V_{\max} \sin \alpha$$



# 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.

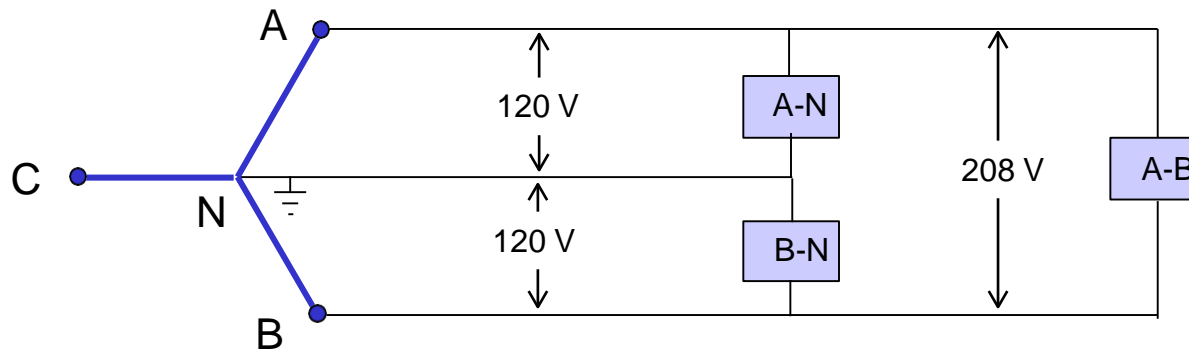


# Benefits of 3-Phase Power

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

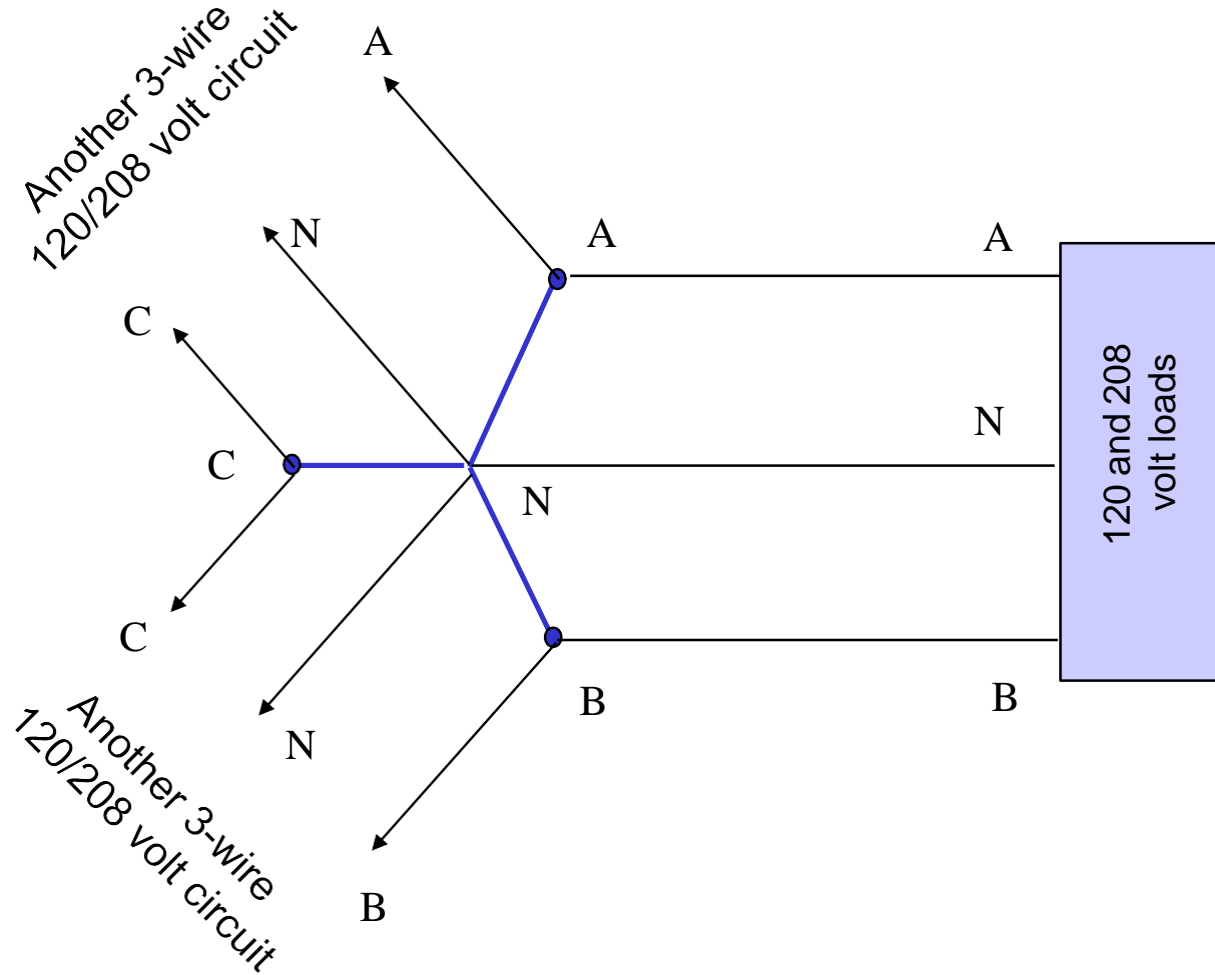


# Network Service & Loads

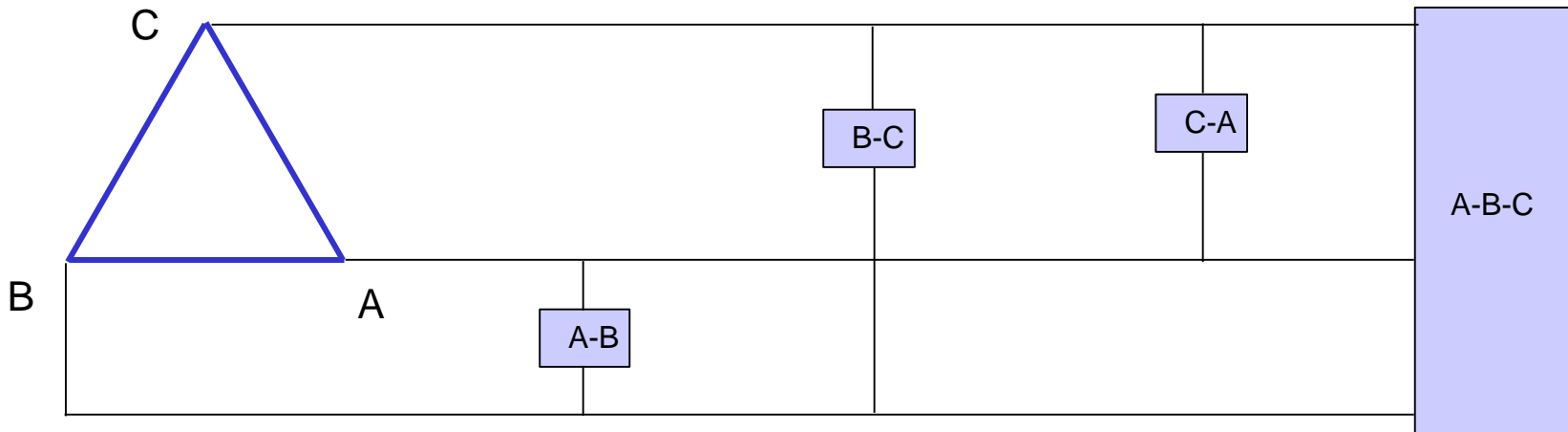


Need to meter line-neutral and line-line loads.

# Network Service & Loads



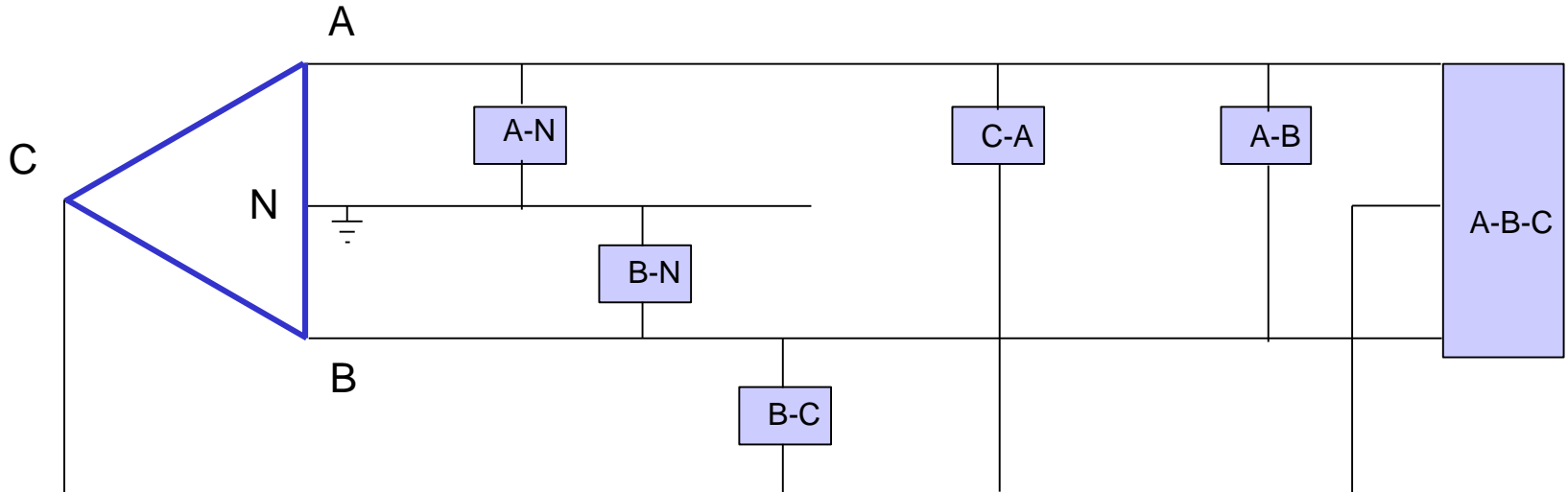
# 3-Wire Delta Service & Loads



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

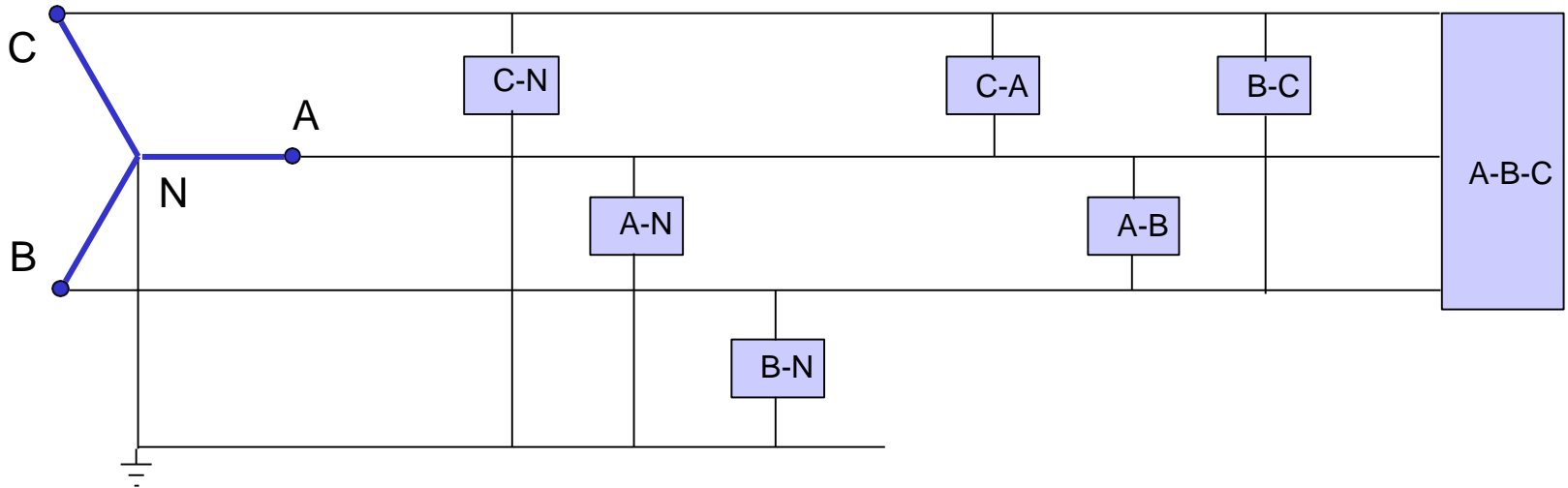


# 4-Wire Delta Service & Loads



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.

# Blondel's Theorem

*Blondel says:*

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 readings of  $N$  wattmeters, so arranged that each of the  $N$  wires contains one current coil, the corresponding potential 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.

Andre E. Blondel, 1893

- We would use “watthour meters” in place of “watt meters” and “energy” in place of “power”.
- We would also consider “ground” as a possible current carrying conductor when counting “ $N$ ”.



# Blondel's Theorem

- In a system of  $N$  conductors,  $N-1$  meter elements, properly connected, will measure the power or energy taken. The connection must be such that all voltage coils have a common tie to the conductor in which there is no current coil.<sup>1</sup>

<sup>1</sup> From the Handbook For Electricity Metering, 9th edition.



# What is a Meter Form Number?

- A Form designation tells us:
  - The number and arrangement of meter terminals, and
  - The number and **internal connection** of meter elements (stators).
- The Form designation describes the meter, not the service.
  - With modern meters, some meter Forms may be used to correctly meter more than one service configuration.
  - More than one meter Form could be used with a particular service depending on the connection of the Instrument Transformers.
- The same Form designation is usually applicable to equivalent meters of all manufacturers.



# Will's Meter Forms Cheat Sheet

SERVICE	SELF-CONT FORM	XFMR-RATD FORM	NUMBER OF ELEMENTS
1-Phase, 2-Wire	1S	3S	1
1-Phase, 3-Wire	2S	4S	1.5
Network, 3-Wire	12S	5S / 45S	2
3-Phase, 3-Wire, Delta			
3-Phase, 4-Wire, Delta	15S	8S	2.5
3-Phase, 4-Wire, Wye	14S	6S / 36S	
	16S	9S	3



Consolidated  
by kV2c  
Form 16S



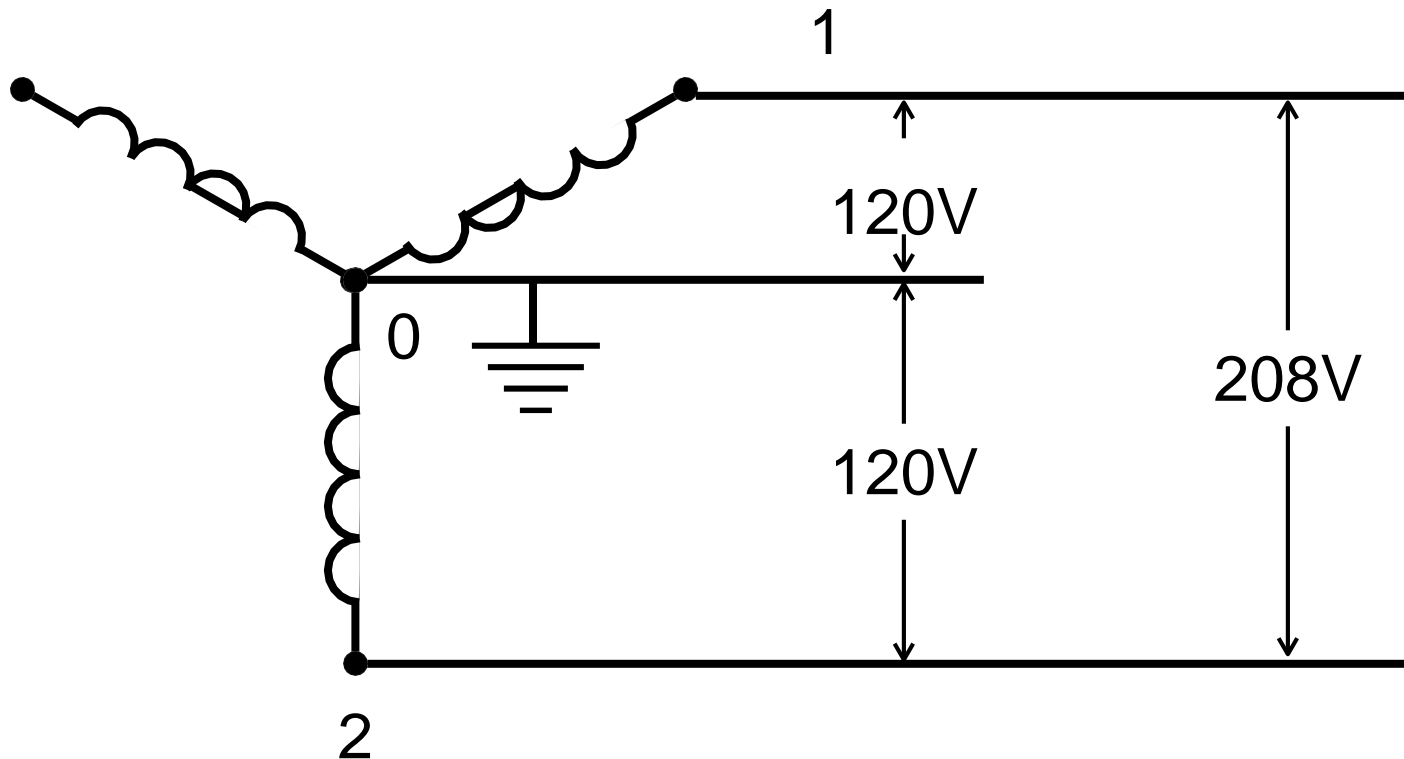
Consolidated  
by kV2c  
Form 9S



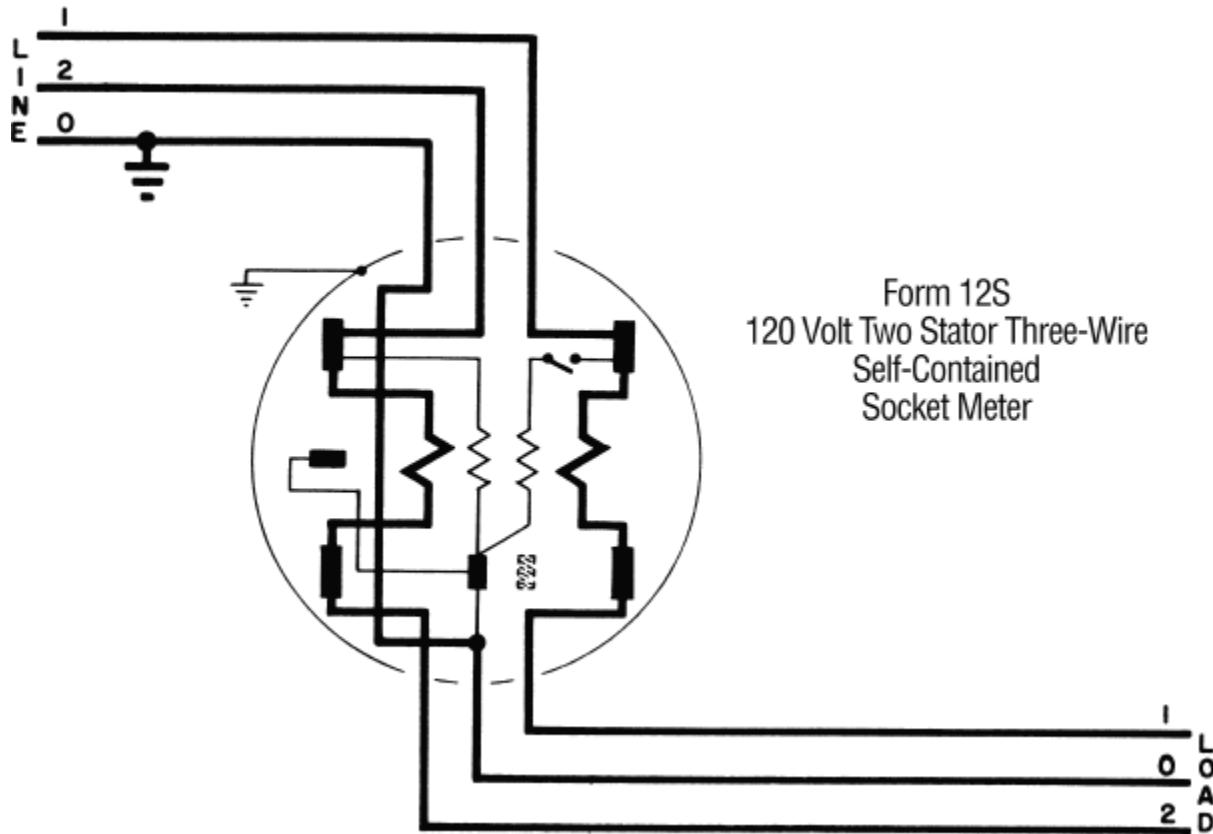
Blondel  
Solution



# Network, 3-Wire

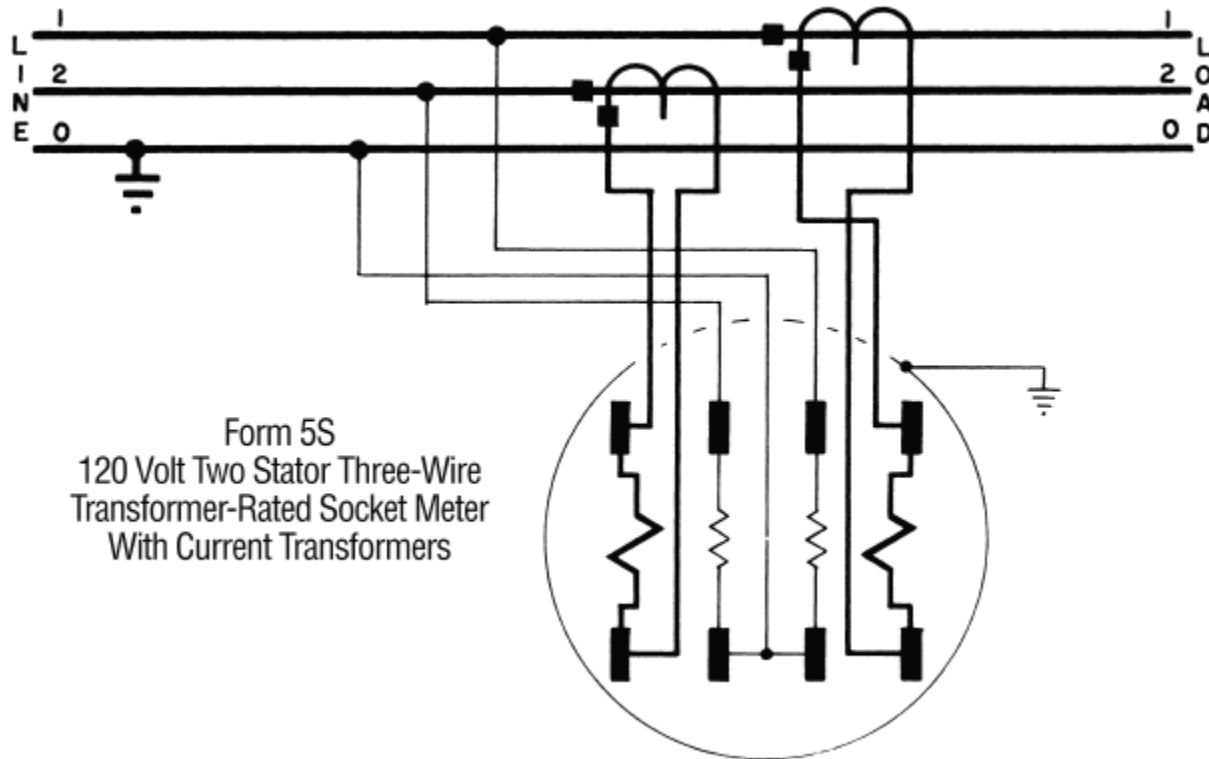


# Network, 3-Wire



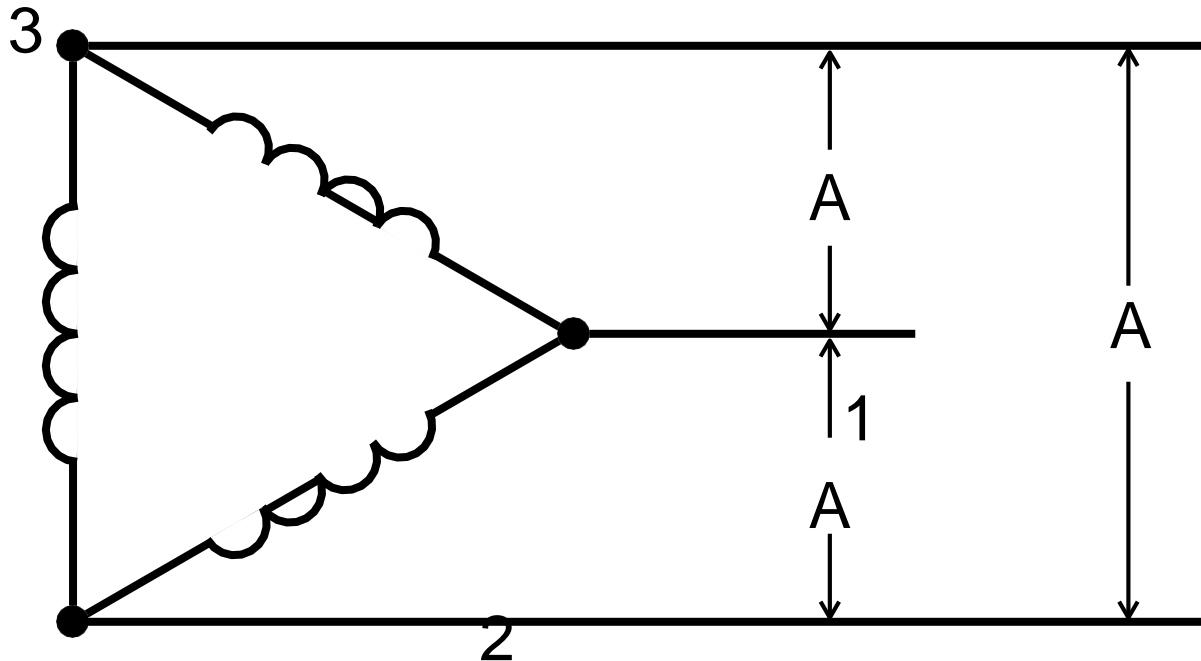


# Network, 3-Wire



Form 5S  
120 Volt Two Stator Three-Wire  
Transformer-Rated Socket Meter  
With Current Transformers

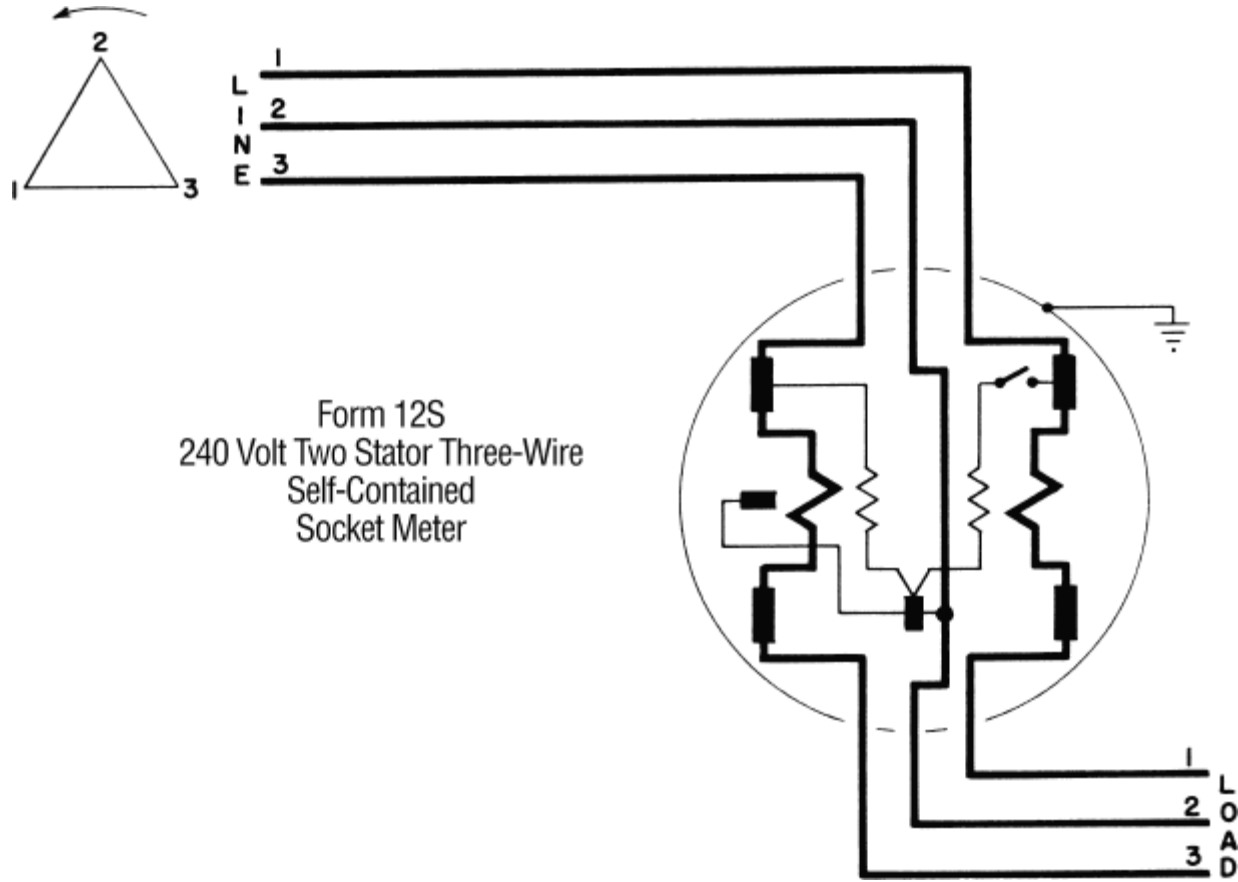
# 3-Phase, 3-Wire, Delta



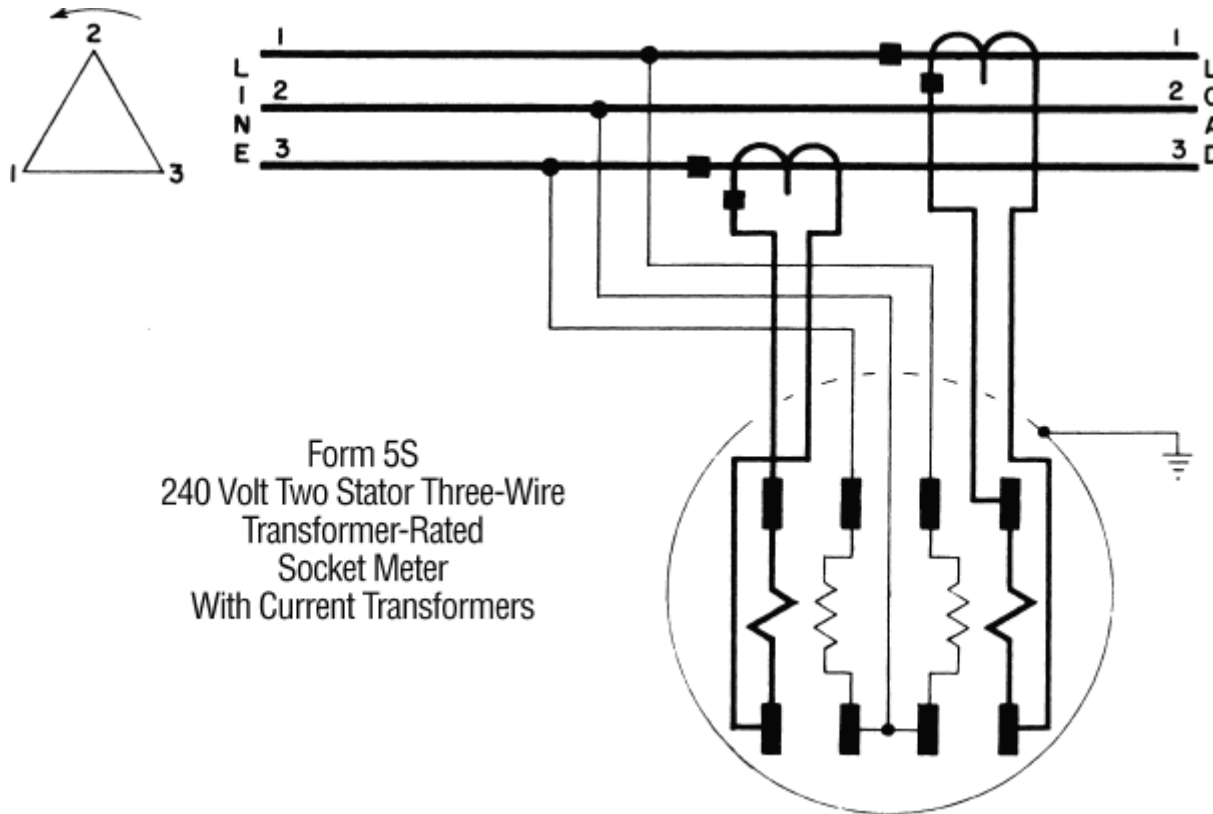
$A = 120V, 240V, \text{ or } 480V$



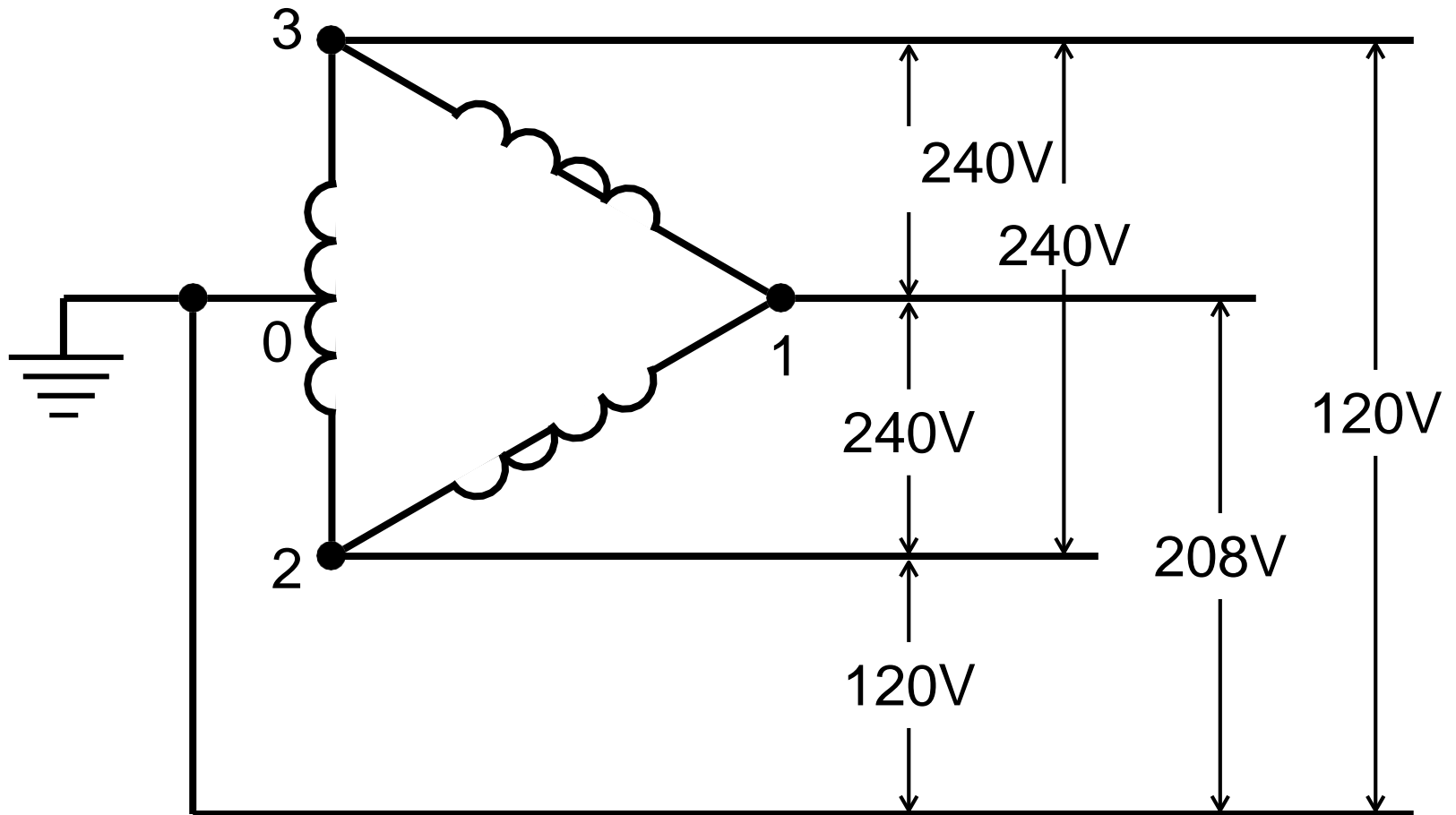
# 3-Phase, 3-Wire, Delta



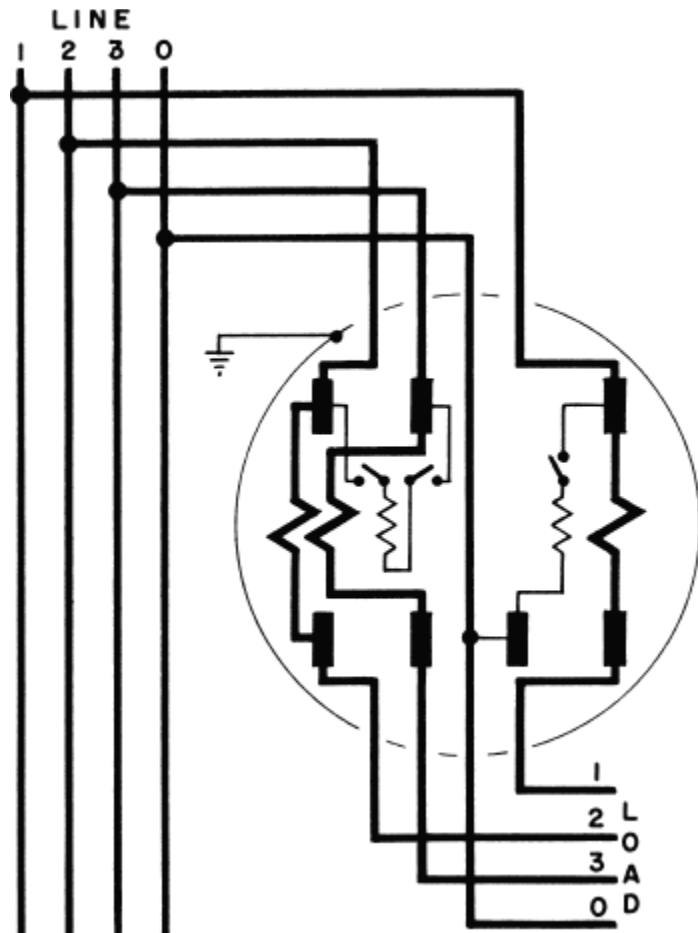
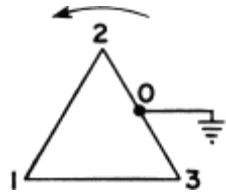
# 3-Phase, 3-Wire, Delta



# 3-Phase, 4-Wire, Delta



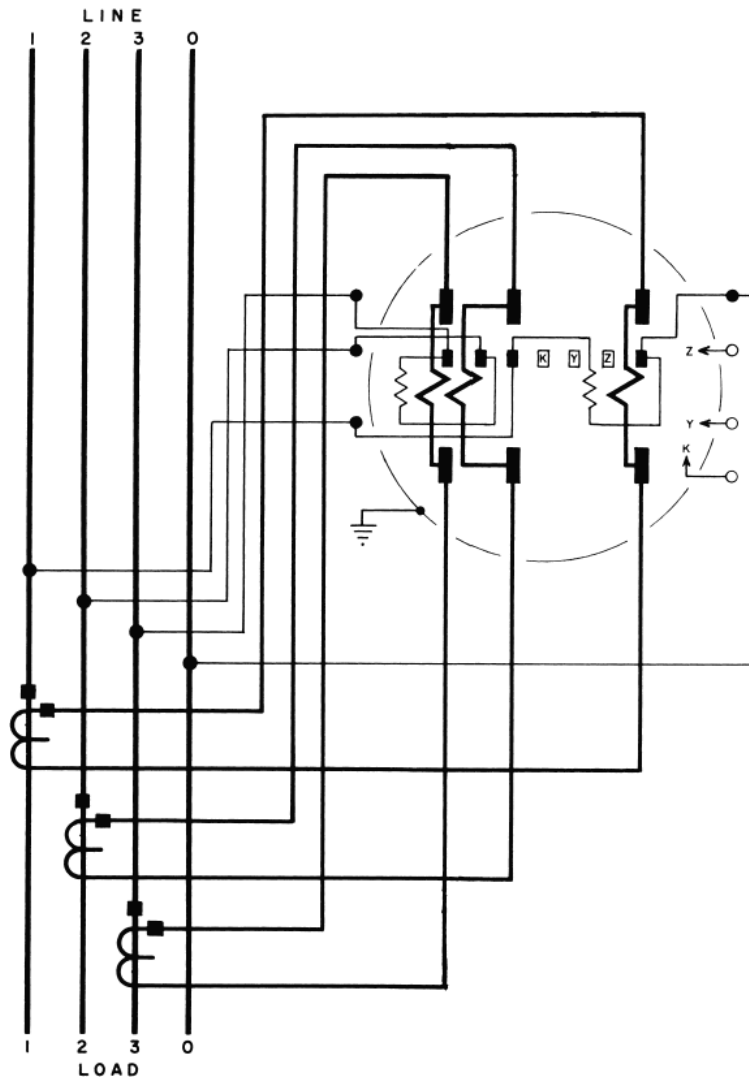
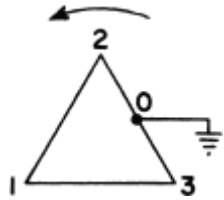
# 3-Phase, 4-Wire, Delta



Form 15S  
240 Volt Two Stator Four-Wire  
Self-Contained  
Socket Meter



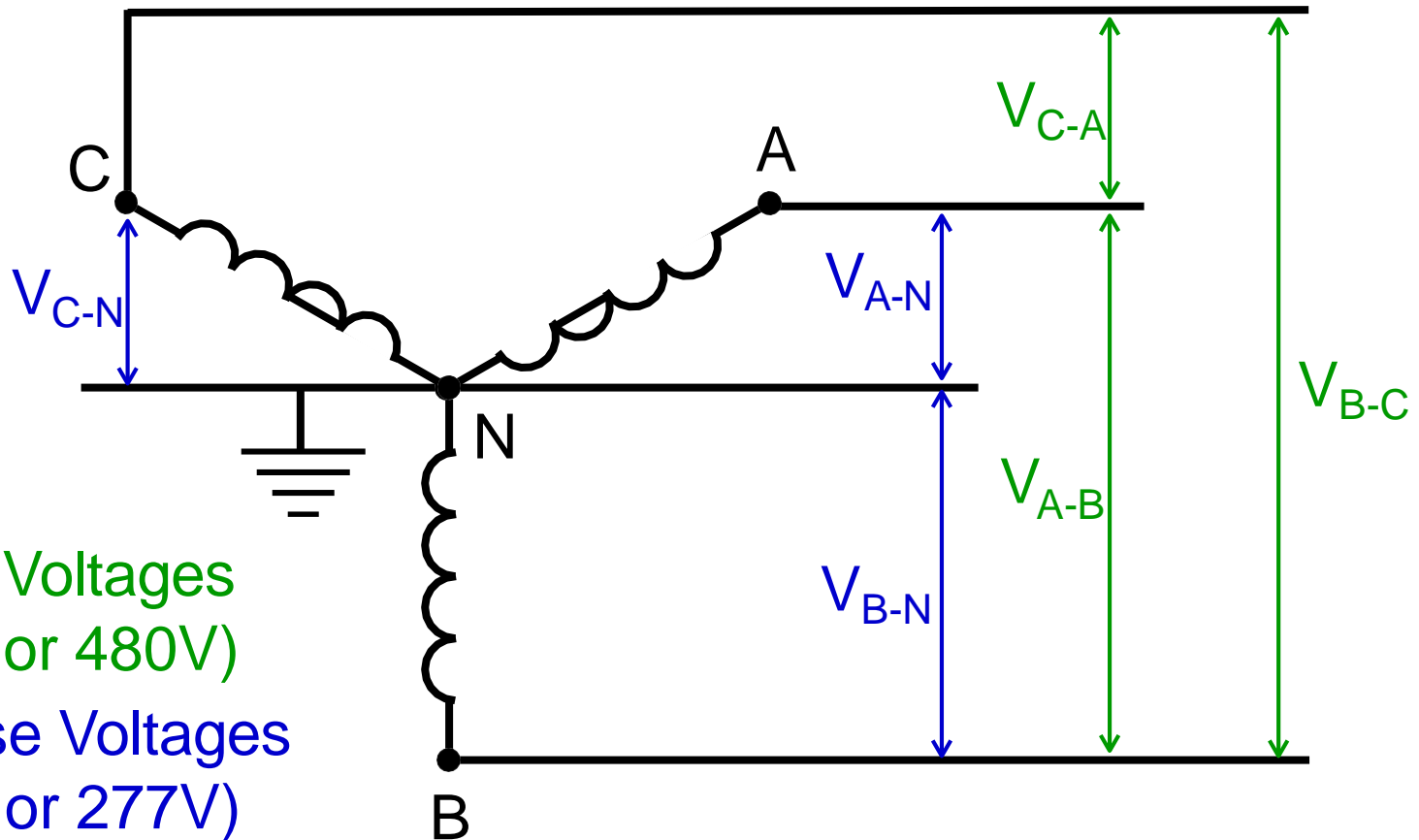
# 3-Phase, 4-Wire, Delta



Form 8S  
240 Volt Two Stator Four-Wire  
Transformer-Rated  
Socket Meter  
With Current Transformers



# 3-Phase, 4-Wire, Wye



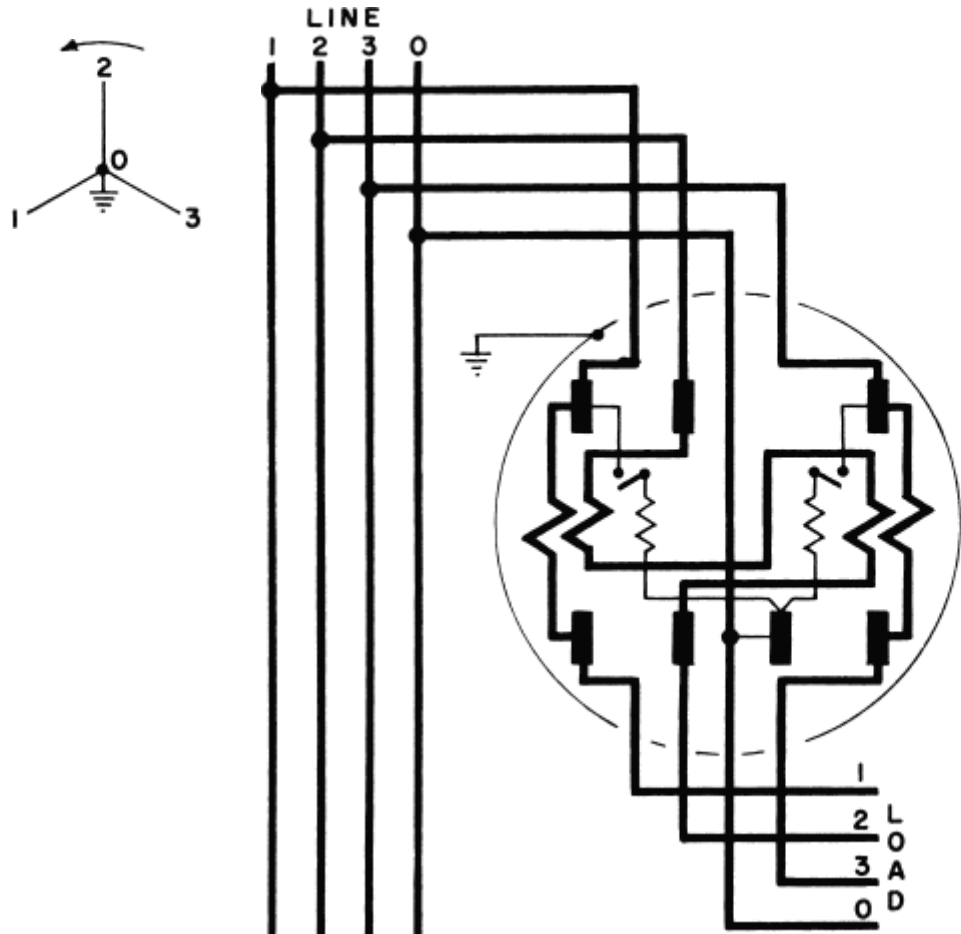
Line Voltages  
(208 or 480V)

Phase Voltages  
(120 or 277V)





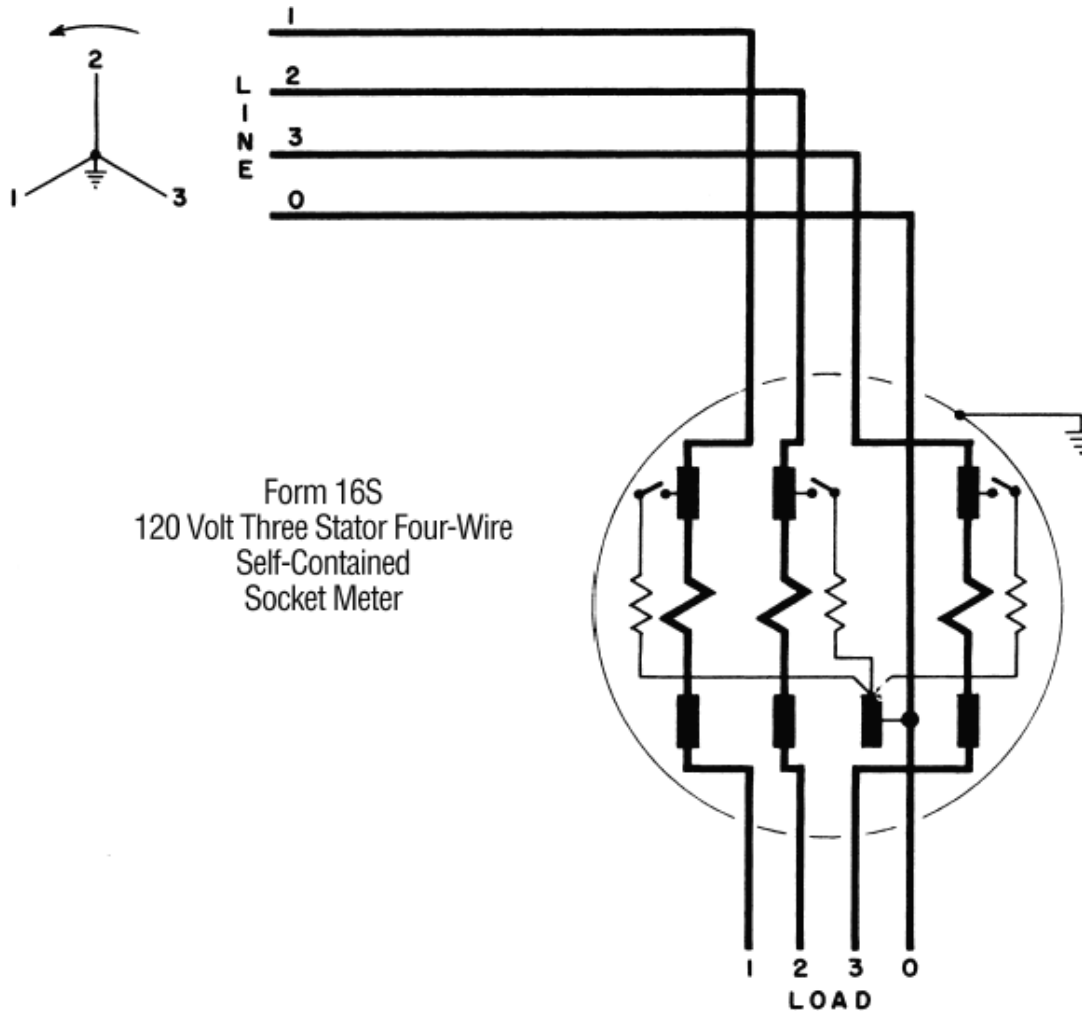
# 3-Phase, 4-Wire, Wye



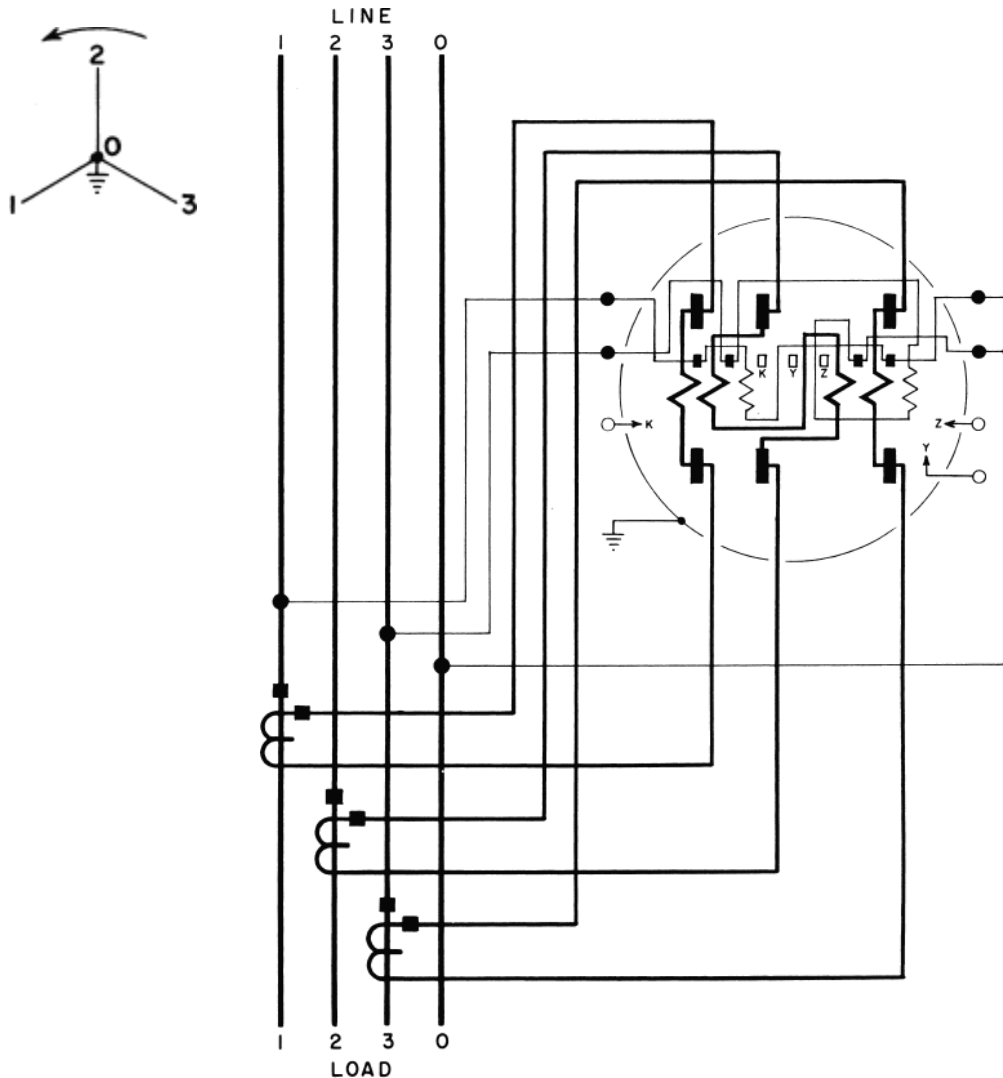
Form 14S  
120 Volt Two Stator Four-Wire  
Self-Contained  
Socket Meter



# 3-Phase, 4-Wire, Wye



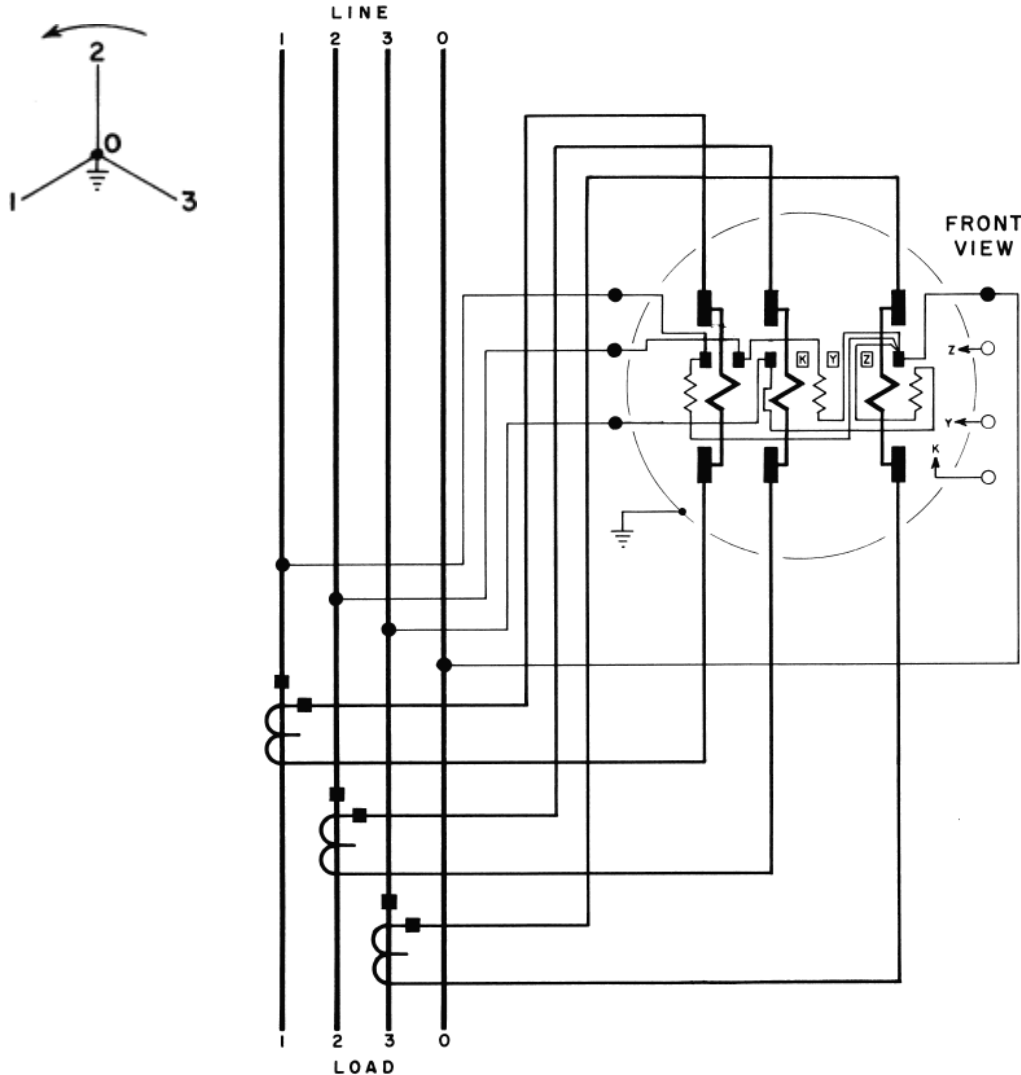
# 3-Phase, 4-Wire, Wye



Form 6S  
120 Volt Two Stator Four-Wire  
Transformer-Rated  
Socket Meter  
With Current Transformers



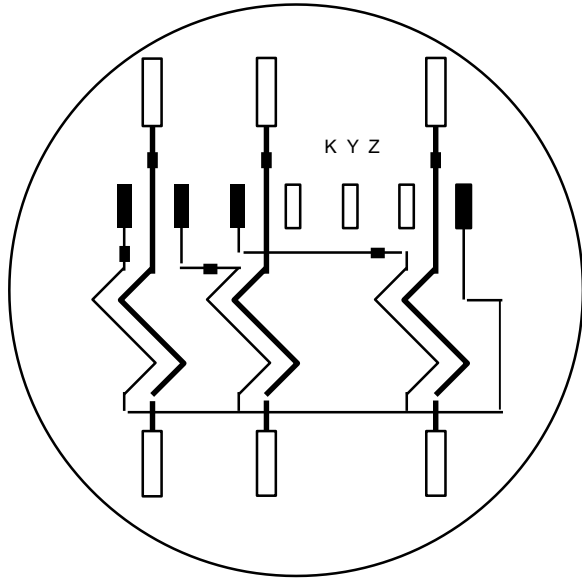
# 3-Phase, 4-Wire, Wye



Form 9S  
120 Volt Three Stator Four-Wire  
Transformer-Rated  
Socket Meter  
With Current Transformers

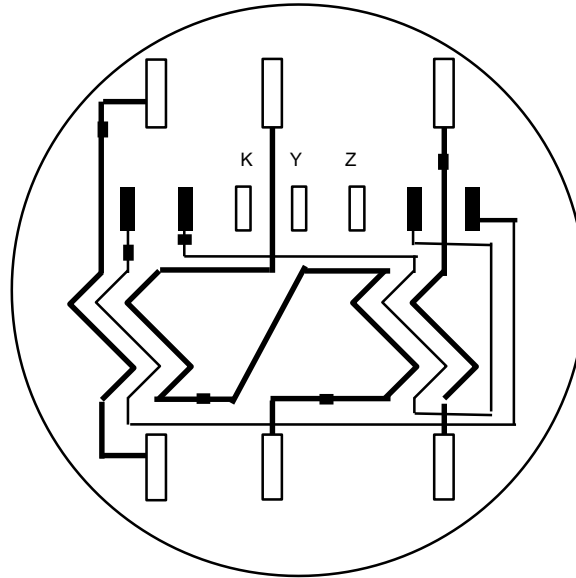


# 4-Wire Wye Metering



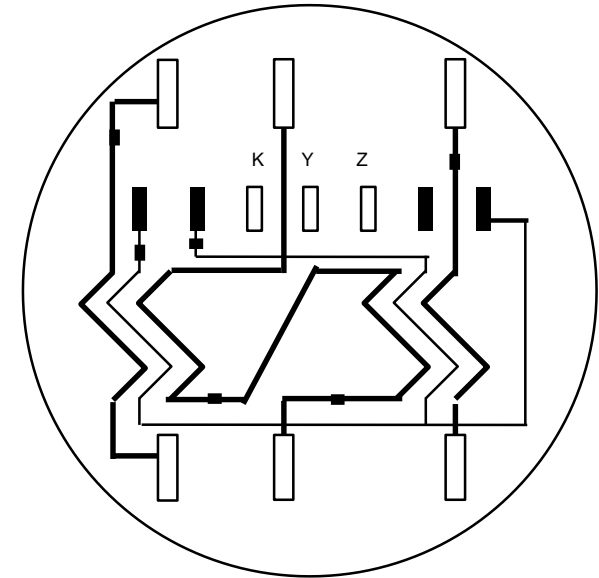
**Form 9**

**3 Element,  
4 wire, wye**



**Form 6**

**2½ Element,  
4 wire, wye**



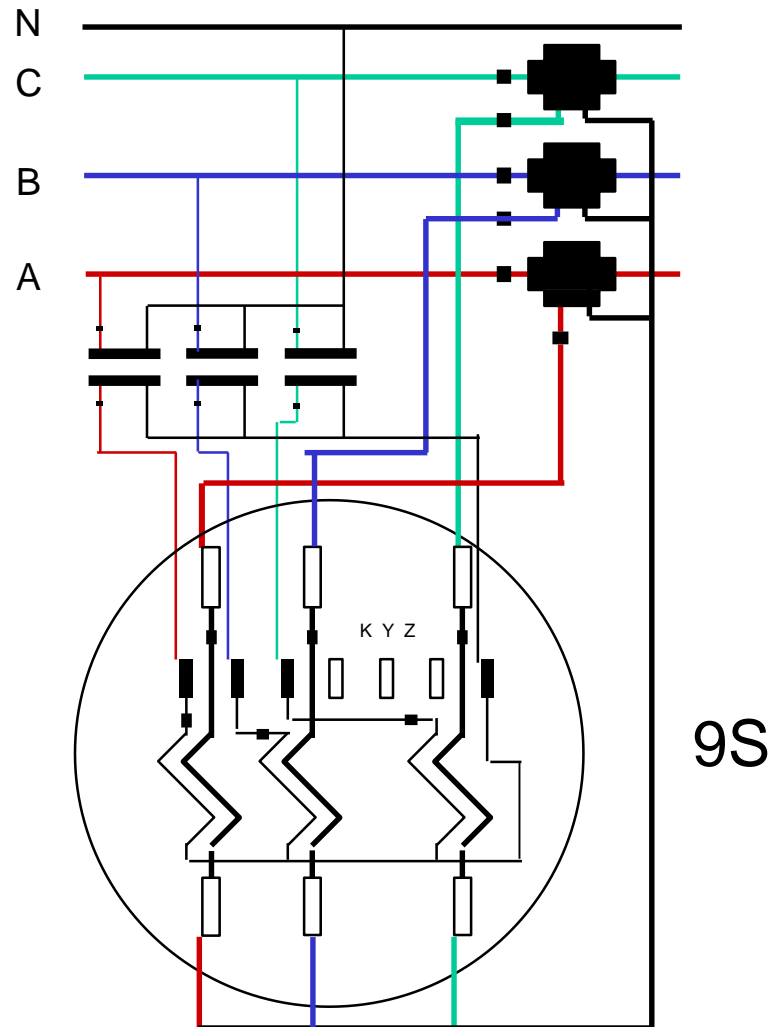
**Form 36**

**2½ Element,  
4 wire, wye**

Transformer-rated



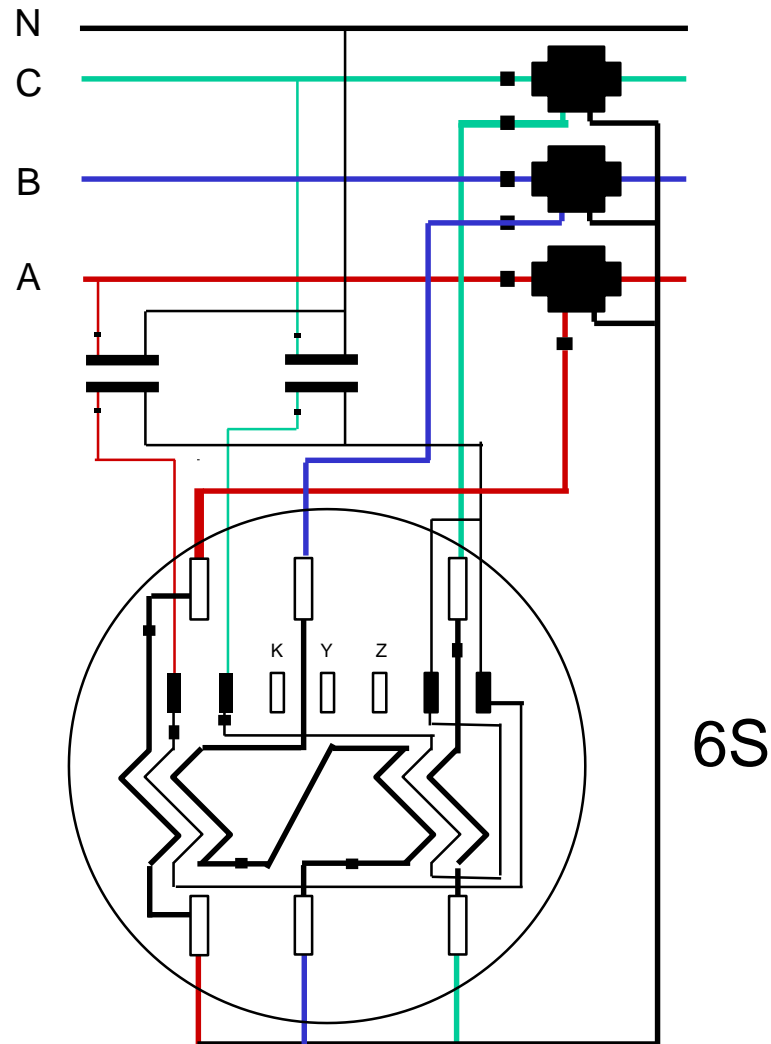
# 4-Wire, Wye Metering



Transformer-rated



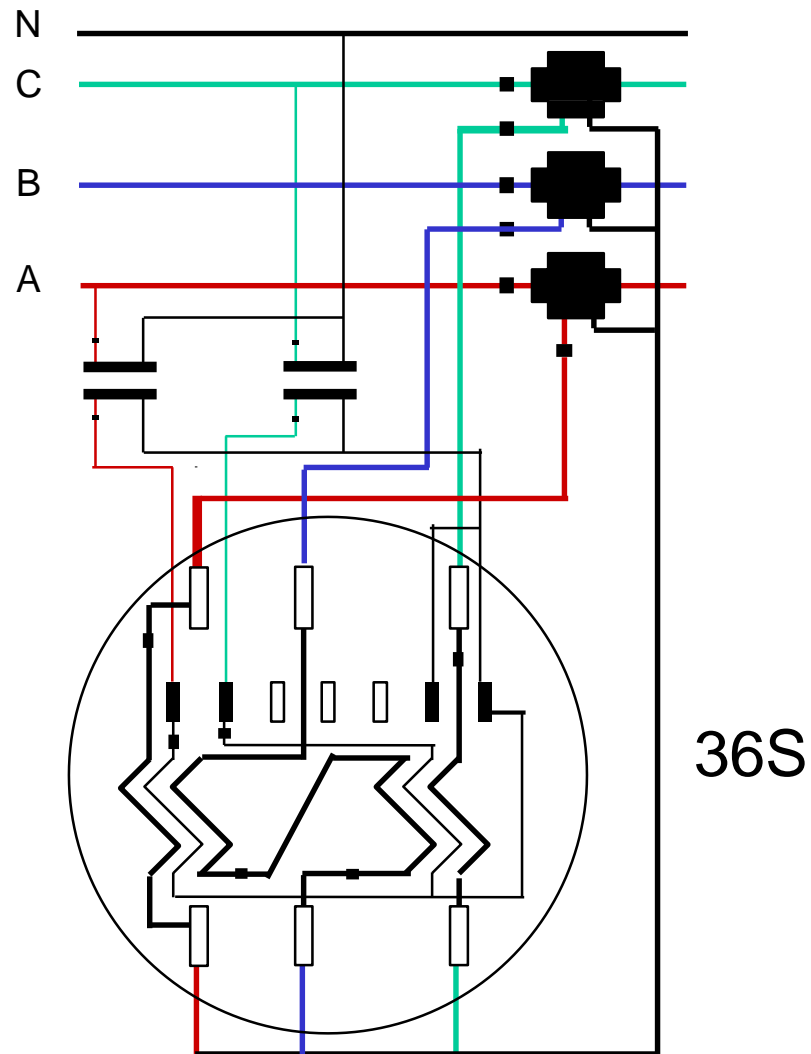
# 4-Wire, Wye Metering



Transformer-rated



# 4-Wire, Wye Metering

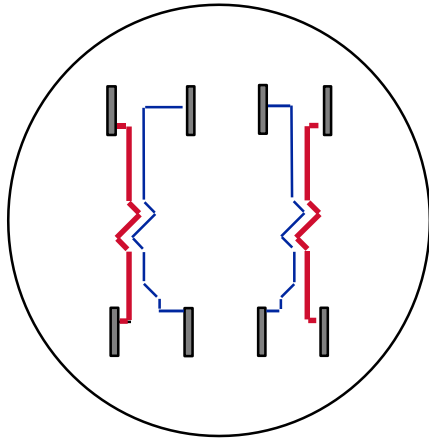


Transformer-rated

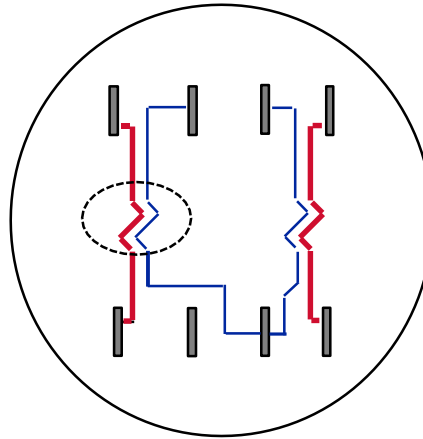




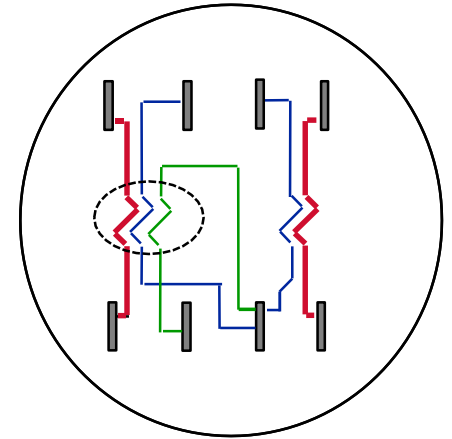
# 2 Element Meters



**Form 5**



**Form 35**



**Form 45**

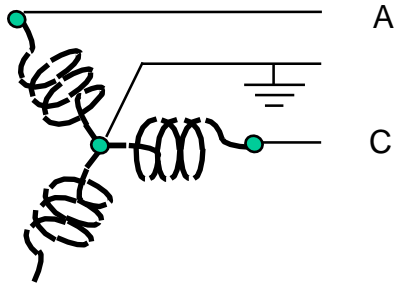
**Typically used for 3 wire Network or 3 wire, 3 phase Delta applications**

**Occasionally used for other service types including 2 wire single phase, 4 wire Wye and 4 wire Delta (except Fm 35 not for 4W Delta)**

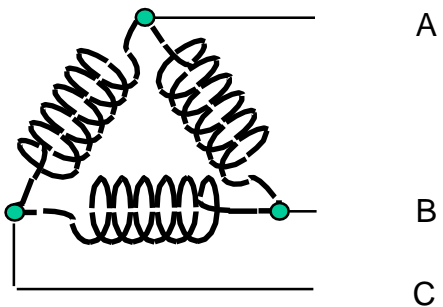
Transformer-rated



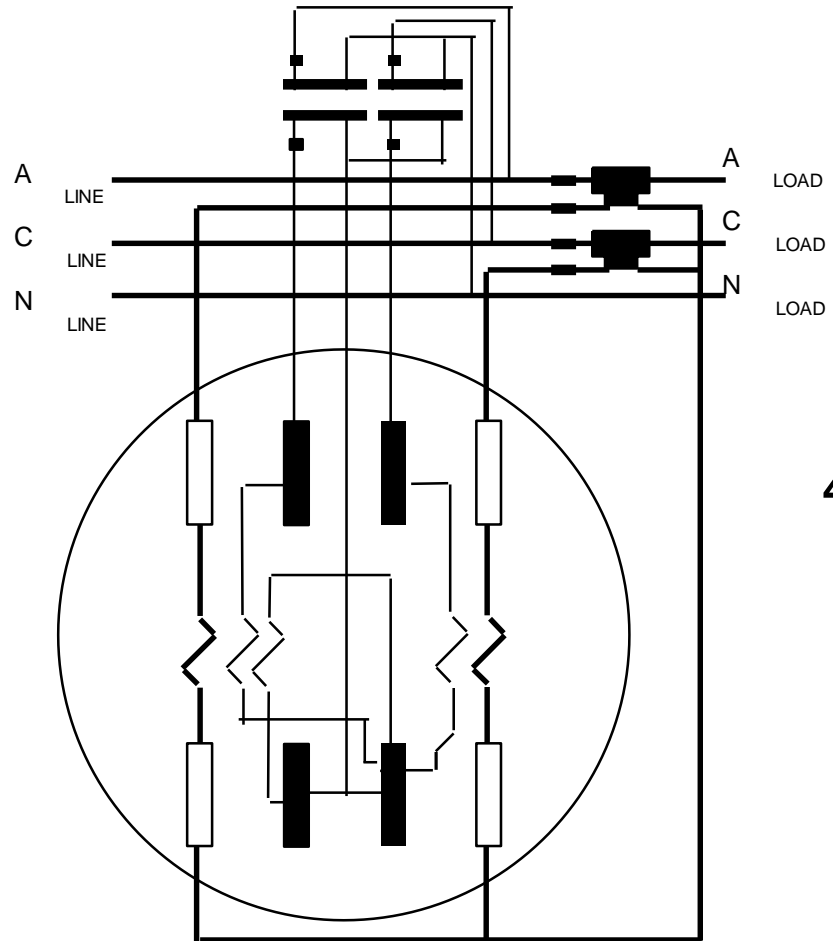
# 2 Element Meters



3 wire, network



3 wire, delta



45S



# Polyphase Meters

## Other Considerations

- Meter Multipliers
  - Self Contained: The meter multiplier is 1
  - Transformer Rated: The multiplier is (typically) the product of the CT and VT ratio
- Service Types
  - Some polyphase meters may be used in multiple service types
- Selection
  - Proper wiring and form selection is critical

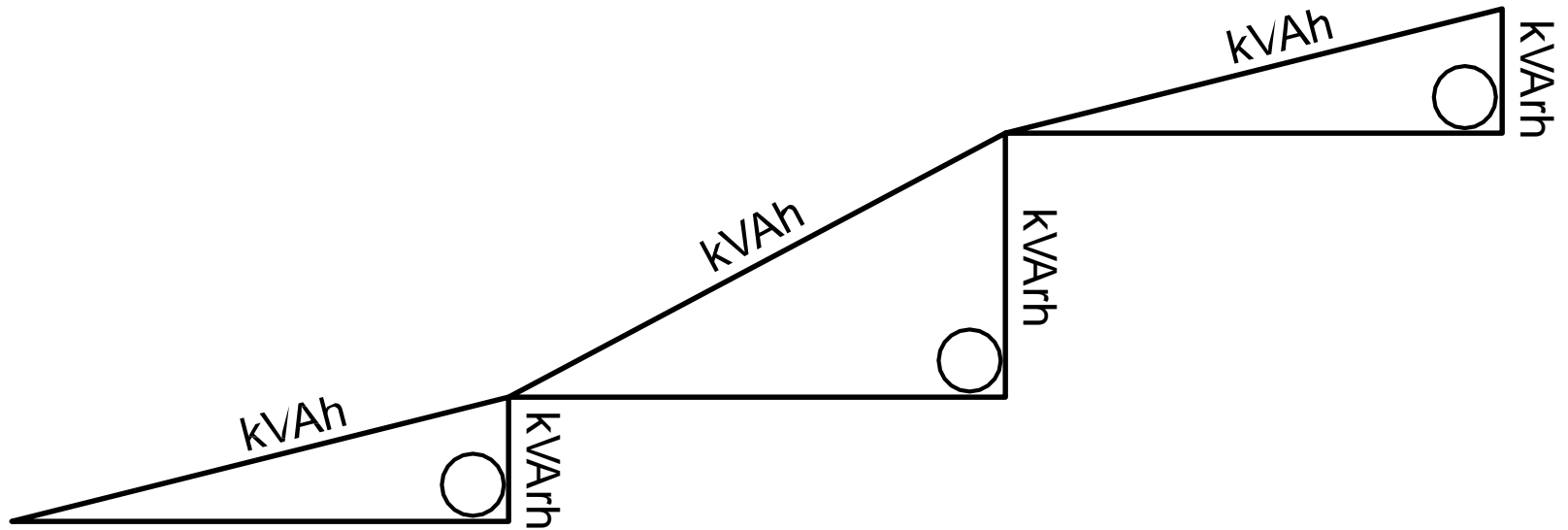


# Polyphase Meters

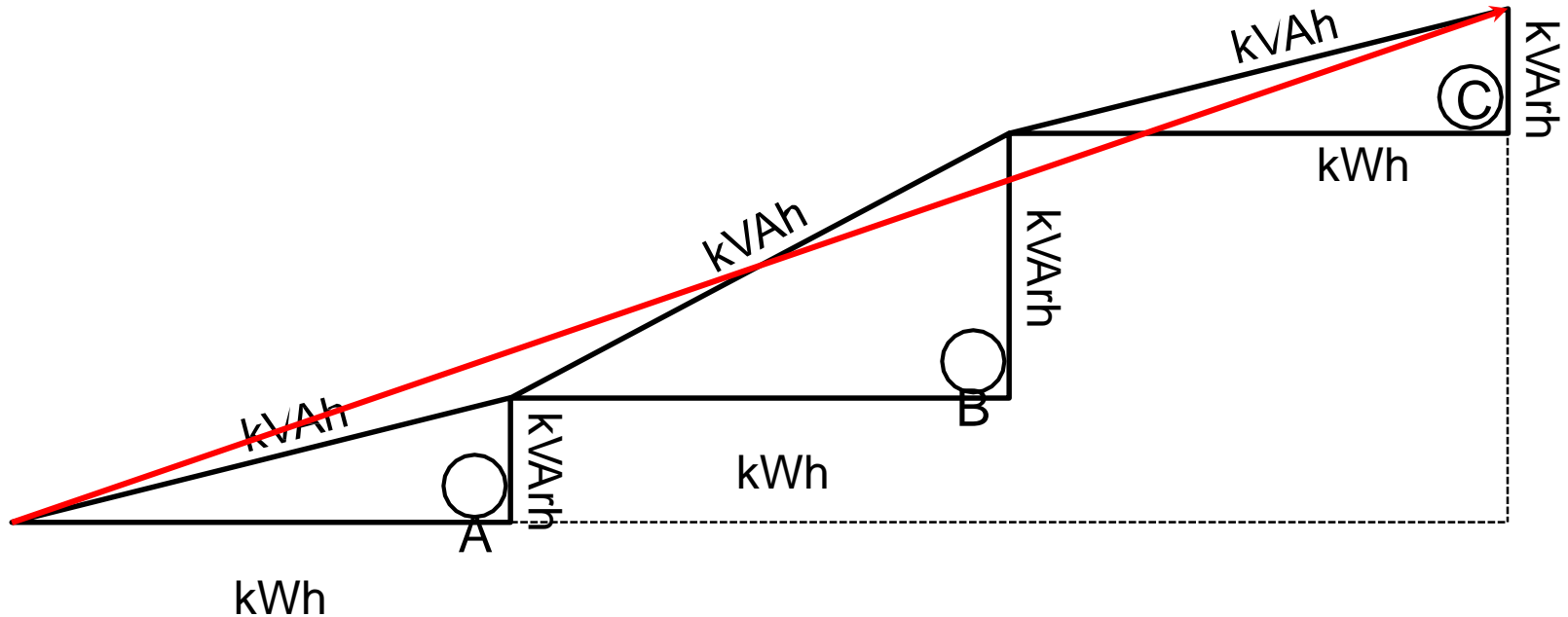
- Select the meter based on the source, not the load.
  - The “service type” is not always obvious.
  - Loads other than the “known” load can be connected and may be unmetered.
- Meter form numbers describe certain meter characteristics not the service or application
- Consider that *ground* can be a 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



# Combining Polyphase kVAh



# Combining Polyphase kVAh

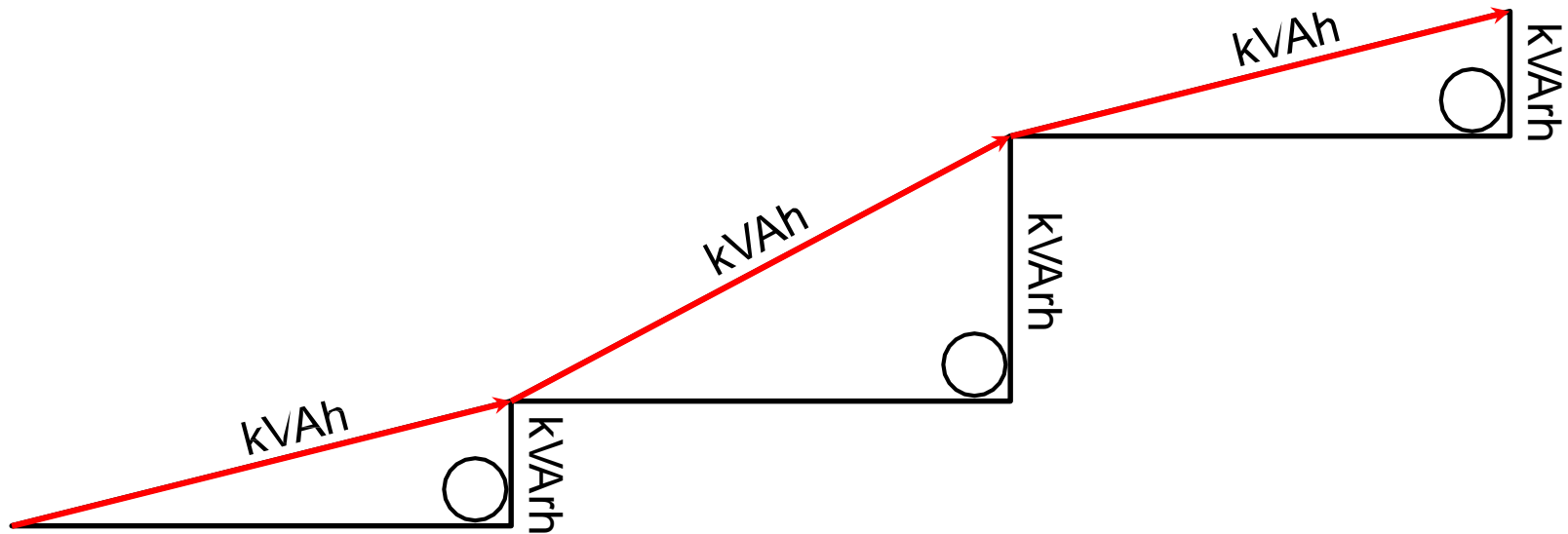


Vectoral Method (as the crow flies):

$$\sqrt{(\text{kWh}_A + \text{kWh}_B + \text{kWh}_C)^2 + (\text{kVArh}_A + \text{kVArh}_B + \text{kVArh}_C)^2}$$



# Combining Polyphase kVAh

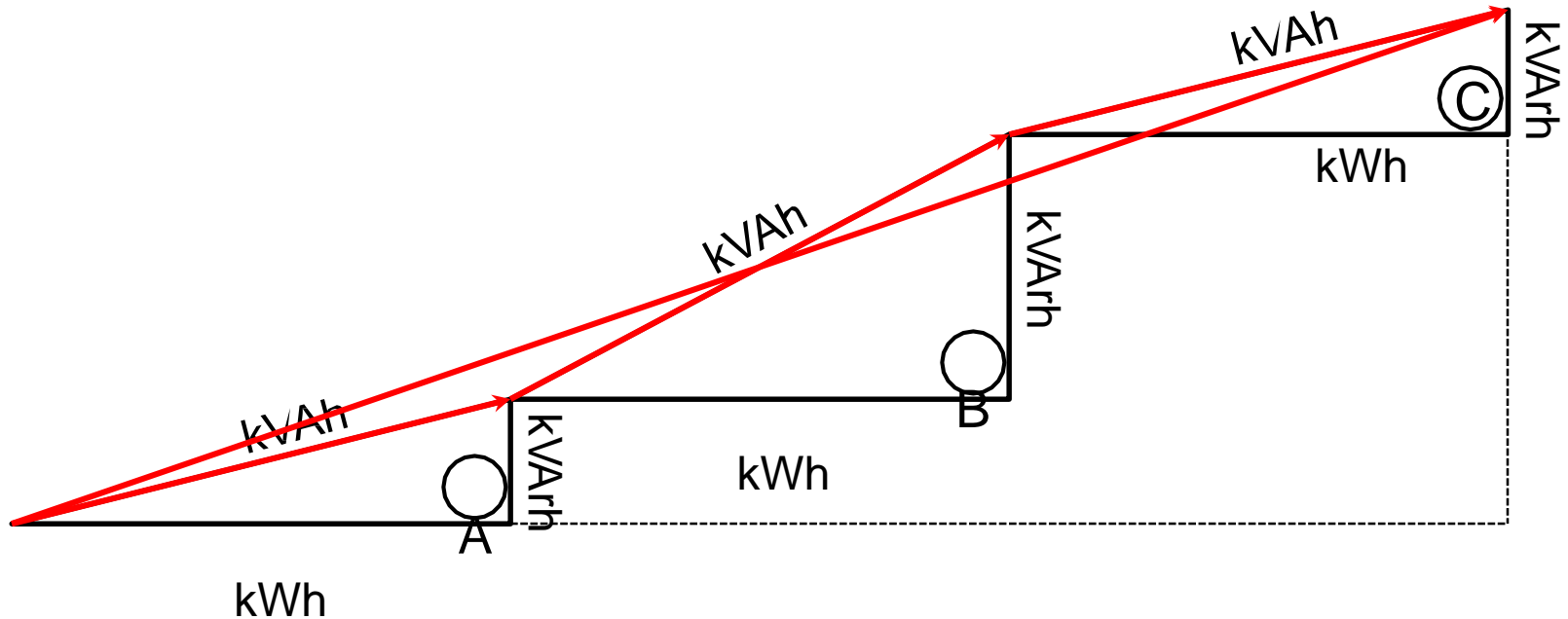


Arithmetic Method:

$$\sqrt{kWh_A^2 + kVArh_A^2} + \sqrt{kWh_B^2 + kVArh_B^2} + \sqrt{kWh_C^2 + kVArh_C^2}$$



# Combining Polyphase kVAh



Arithmetically combined kVAh  $\geq$  Vectorally combined kVAh

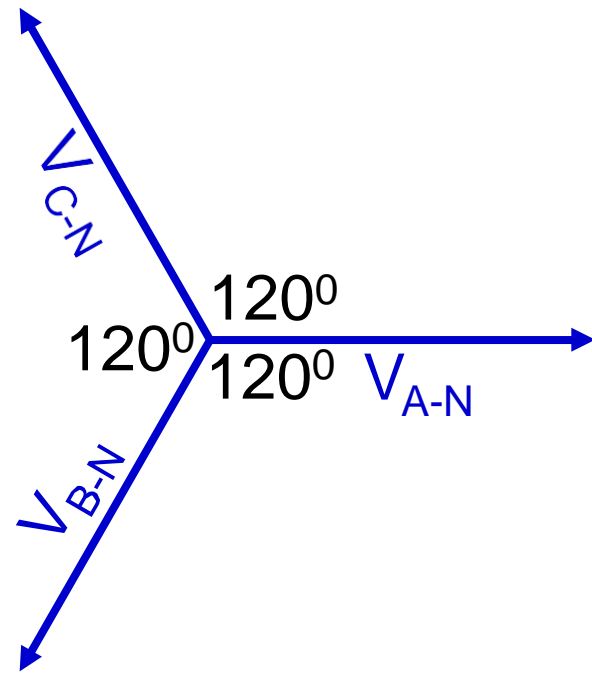
They are equal only if all phases have equal phase angles.



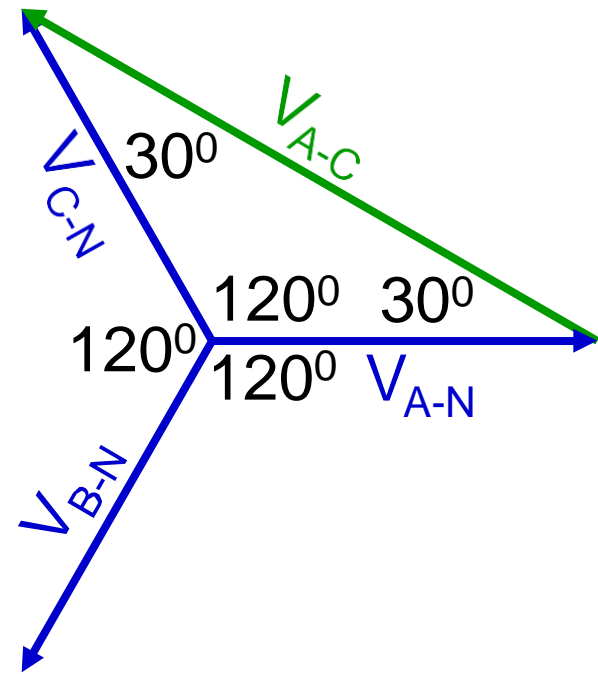
# Voltages in a Wye-Connection

$$V_{L-L} = \sqrt{3} V_{L-N}$$

We can prove this by constructing the Line-voltage (L-L) phasors based on the Phase-voltage (L-N) phasors.



# Voltages in a Wye-Connection



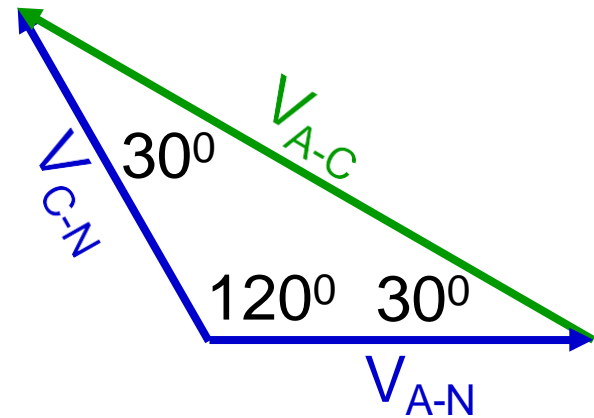
# Voltages in a Wye-Connection

Using the Law of Sines:

$$\frac{V_{A-C}}{\sin 120^\circ} = \frac{V_{A-N}}{\sin 30^\circ}$$

$$V_{A-C} = V_{A-N} \sin 120^\circ / \sin 30^\circ$$

$$\overline{V_{A-C}} = \sqrt{3} V_{A-N}$$



# Questions and Discussion



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