



TESCO METERING

Advanced Polyphase Metering

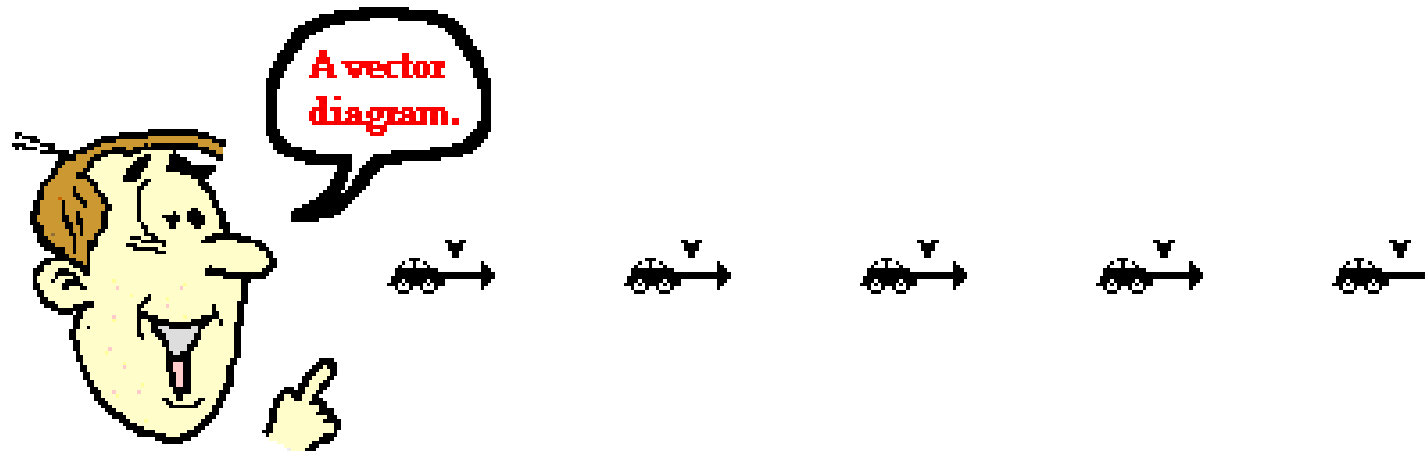
An Introduction to Vectors and Phasors

Tom Lawton
TESCO Metering



*North Carolina Meter School
Advanced
Tuesday, June 9, 2026
10:15 AM*

- Electrical Quantities are Difficult to Visualize.
- Written or Spoken work is inadequate.
 - Usually hard to explain in a universally understood way.
 - Would take a relatively long time to explain.
- Employ Vector Diagram to Represent Electrical Quantities.
 - Saves time
 - Vastly more effective, once it is understood



The most basic statement of metering:

$$\text{Watts} = \text{Voltage} \times \text{Current} \times$$

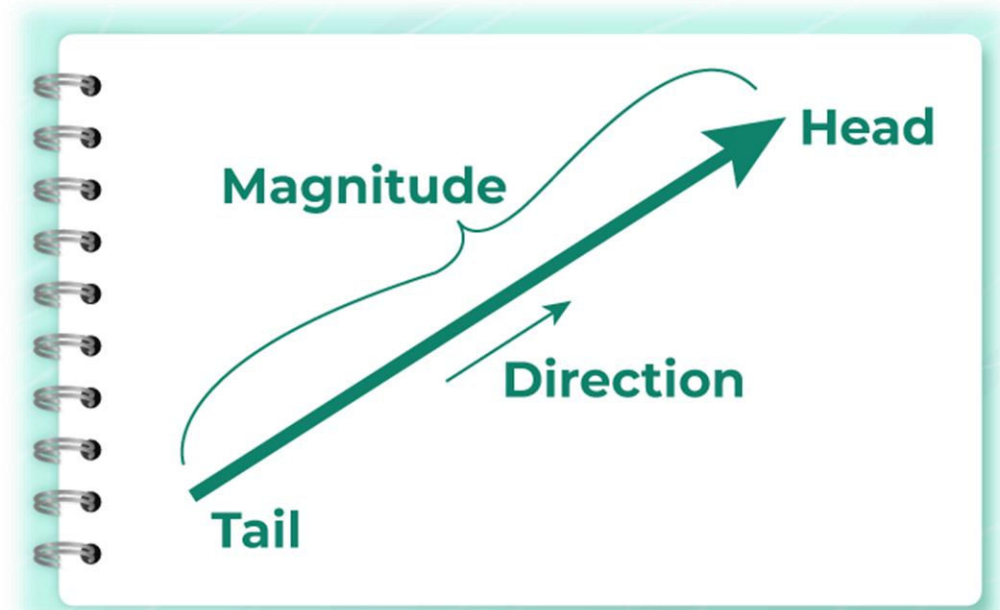
Power Factor Mathematically:

$$\text{Watts} = V \times I \times \cos\theta$$

What is a Vector?

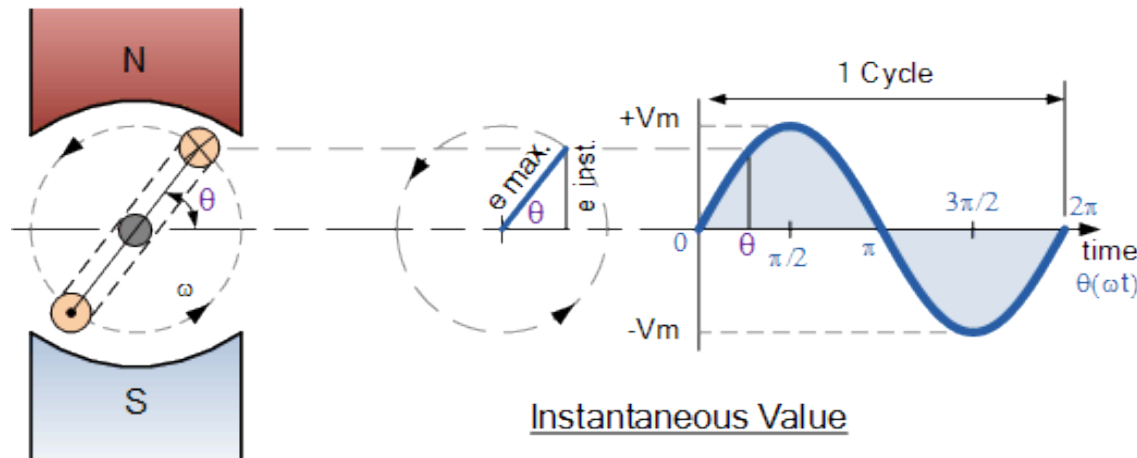
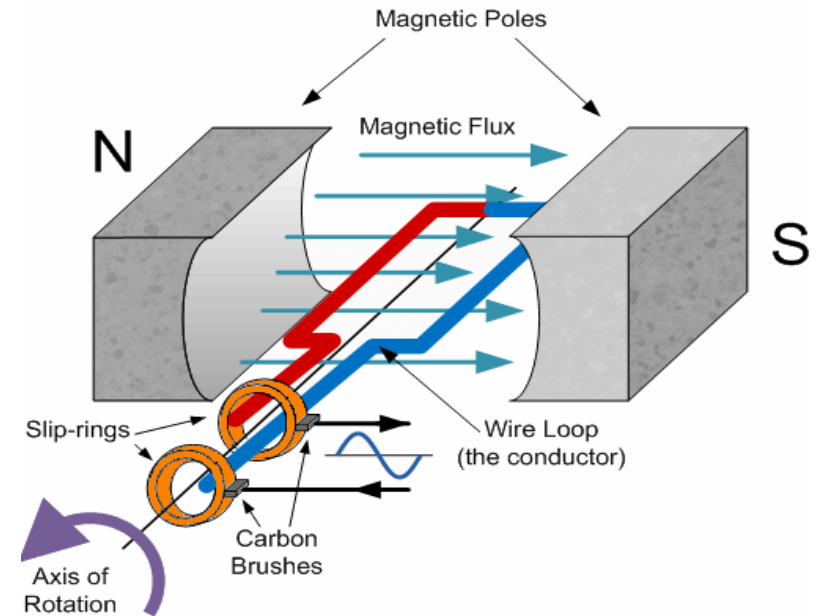
A measurement that takes two numbers to represent.

BOTH a magnitude (size) and direction



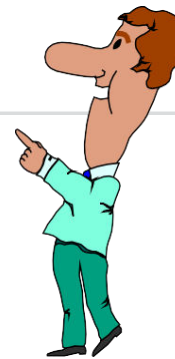
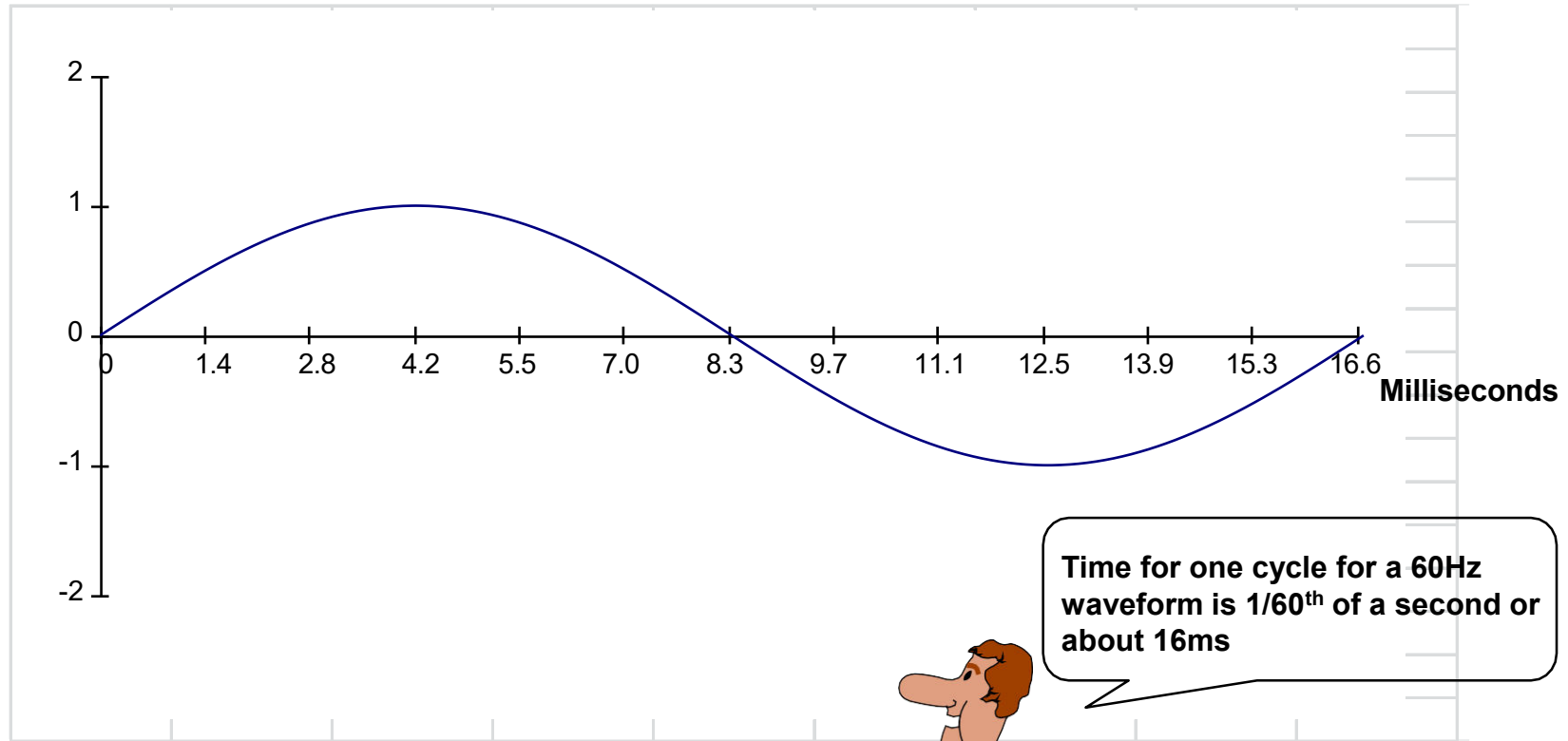
Origination of a Sinusoid

- By Electromagnetic Induction, a single wire conductor passing through a permanent magnetic field and cutting the lines of magnetic flux, will produce an ElectroMotive Force (EMF).
- Due to the constant rotation, the EMF is different at each moment in time. The instantaneous value at each moment is considered the Instantaneous Voltage. Commonly, the symbol **E** and **V** are interchanged to represent voltage values.



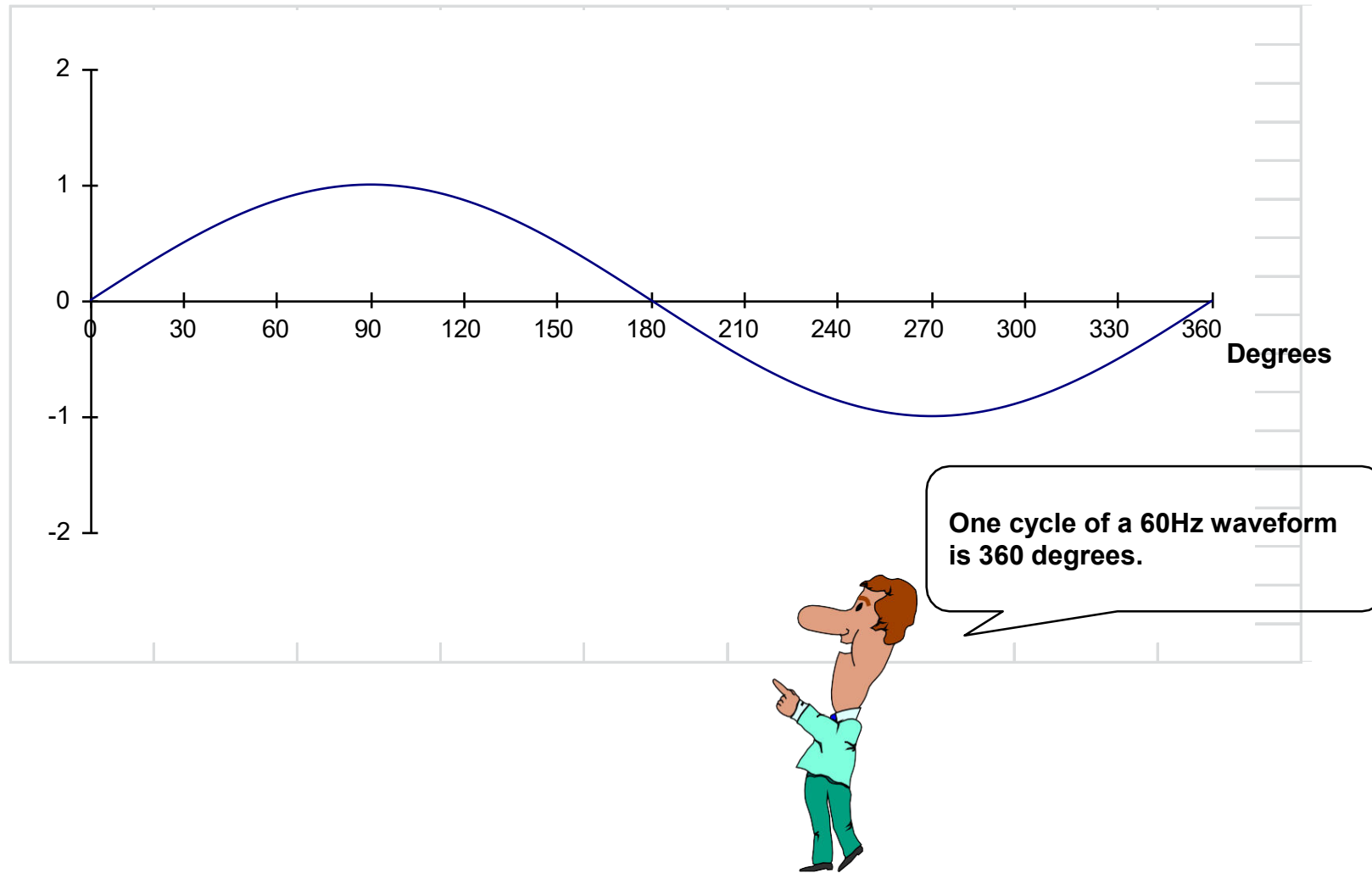
Reference: <https://www.electronics-tutorials.ws/accircuits/sinusoidal-waveform.html>

“Time” in Degrees

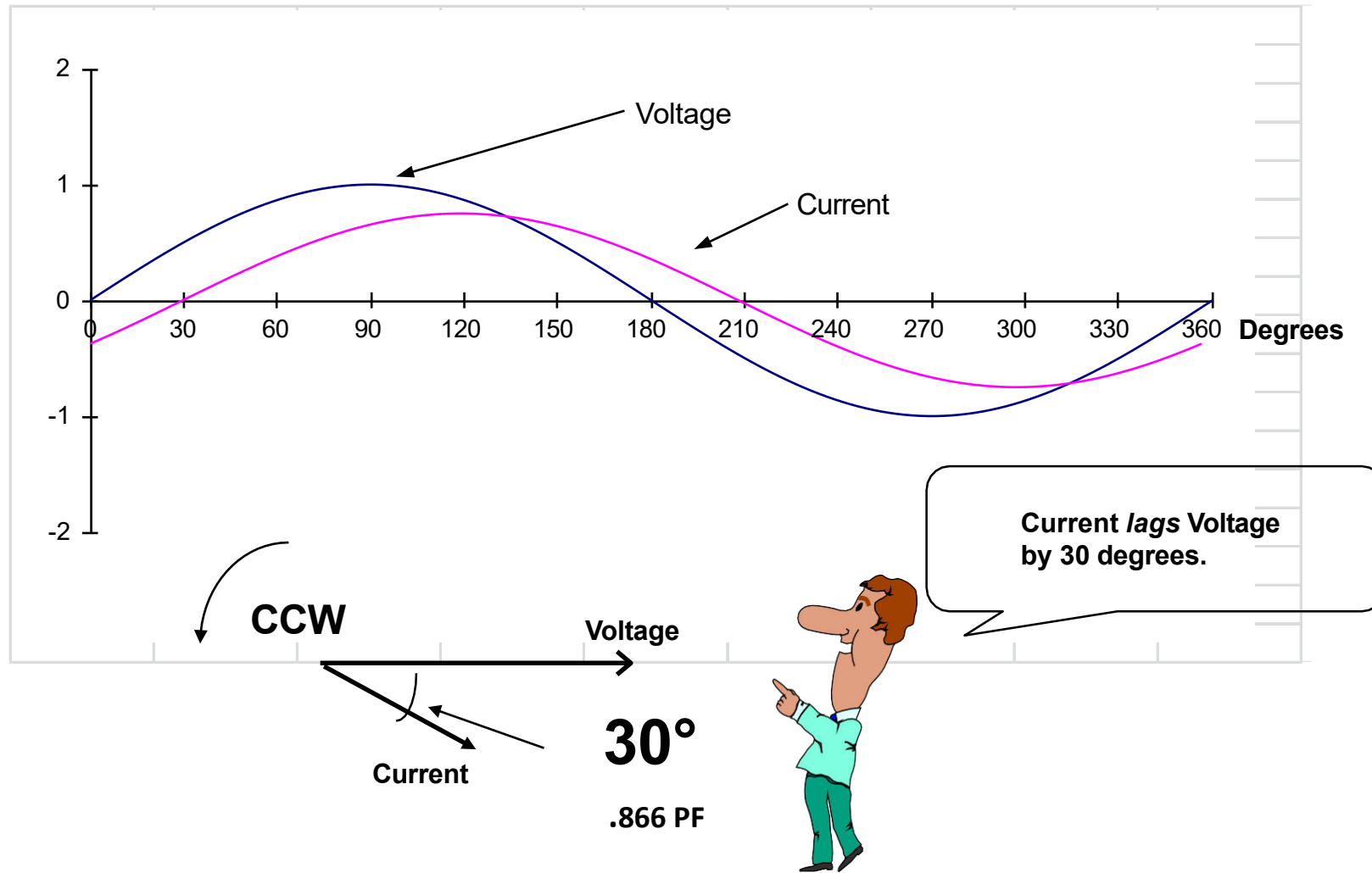


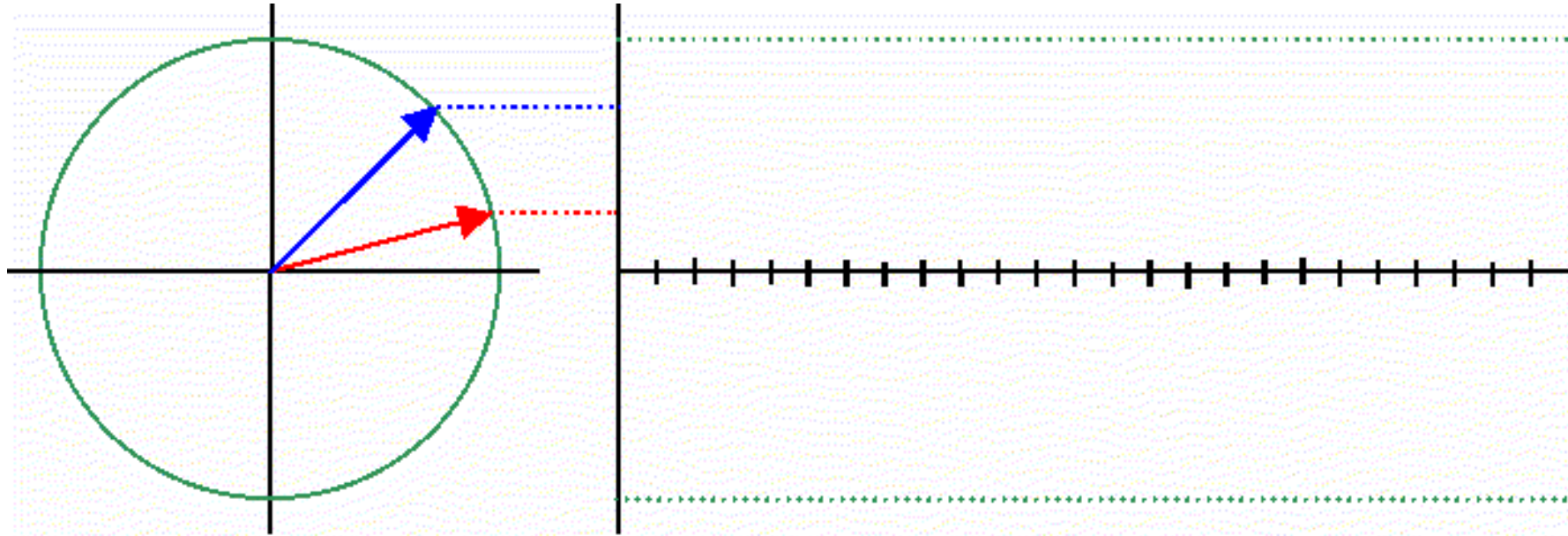
Time for one cycle for a 60Hz waveform is $1/60^{\text{th}}$ of a second or about 16ms

“Time” in Degrees



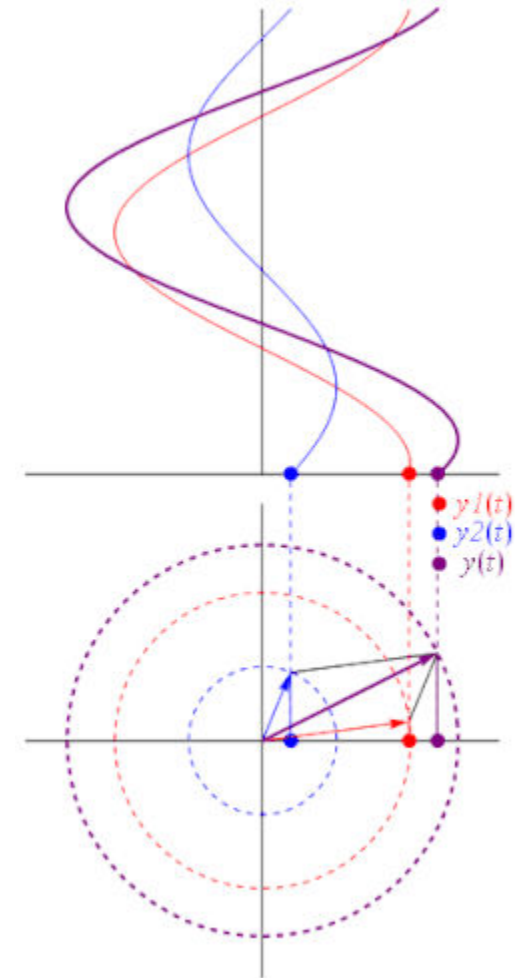
Voltage vs. Current Phase



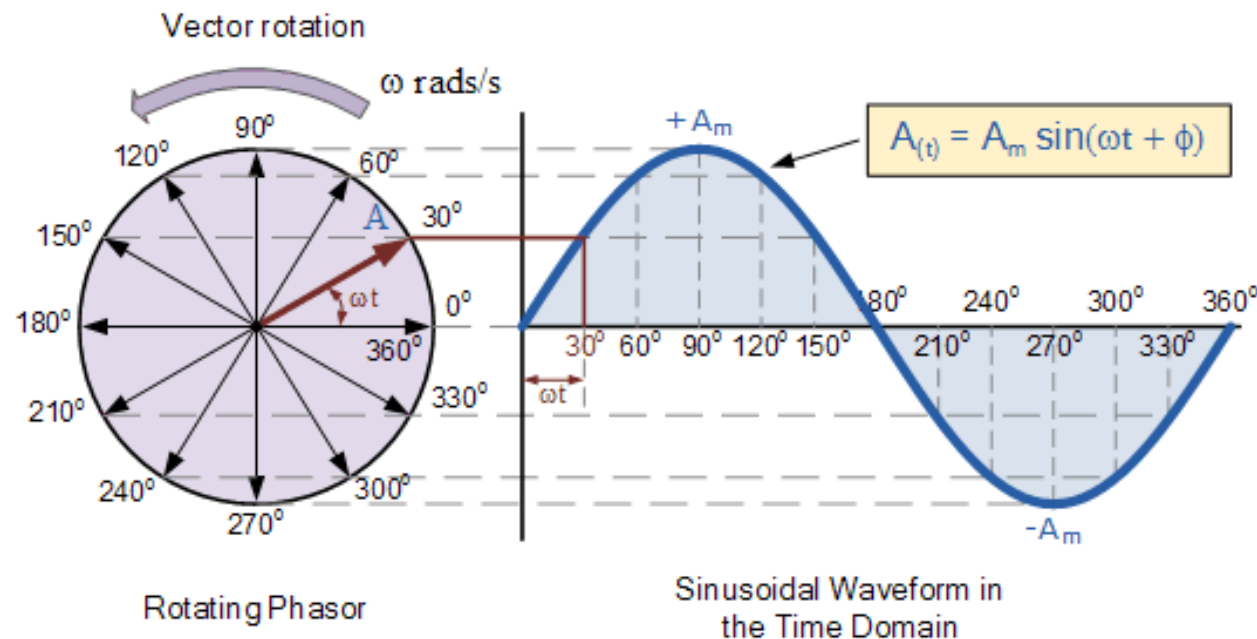


A Symbolic Representation of the relationship of the voltage and current

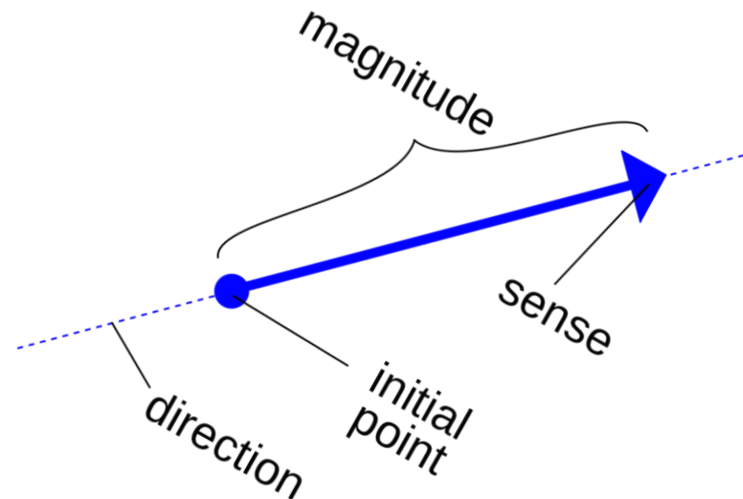
- **Vectors & Vector Diagrams**
 - **SIMPLE.** Used to Represent Electrical Quantities.
 - **QUICK.** Saves time.
 - **Vastly more effective**
 - **Also referred to as “Phasors”**



- A phasor diagram is a method of expressing the magnitudes and time relationships (or phase angle relationships) between two or more sinusoidal quantities of the same frequency.
- Each alternating quantity having the same frequency can be represented on the same diagram by additional lines. Their time relationship will determine the angle between the lines.
- The phasor diagram is a “snap-shot” of the set of lines at an instant in time. The instant is generally chosen to be the time at which the voltage passes through zero in the positive direction. If there is more than one voltage, the instant at which phase A voltage passes through zero is chosen.



- Vectors all have **MAGNITUDE** and **DIRECTION**
- Line length can represent **MAGNITUDE**.
- Line with arrowhead in a given direction indicates that quantity's relationship to any other quantity being represented.
- **DIRECTION:** Angles between lines take on significance. They represent time (shown in degrees instead of seconds).



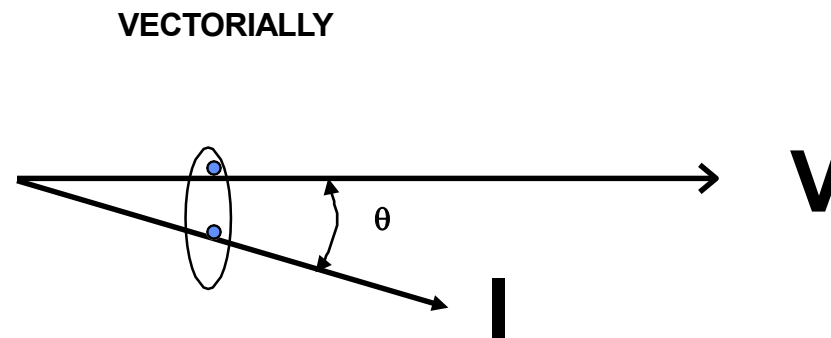


General Guidelines

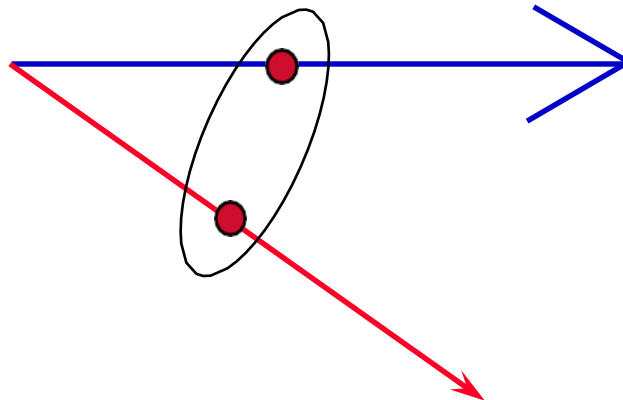
- Complete circle (360 Degrees) equal one cycle of the frequency displayed.
- **One component (Usually Phase A voltage) becomes the reference and is placed at zero degrees.**
- Use “open” or narrow “closed” arrowhead for voltage.
- Use “closed” or thick “closed” arrowhead for current.
- Label all voltages and currents by phase.
- Indicate Phase Rotation (counter-clockwise assumed if not noted).

- **Watt-hour meter theory review:**
 - If we apply “V” volts and “I” amps to a meter, and the phase angle between the voltage and current is some angle θ , the meter speed will be proportional to:

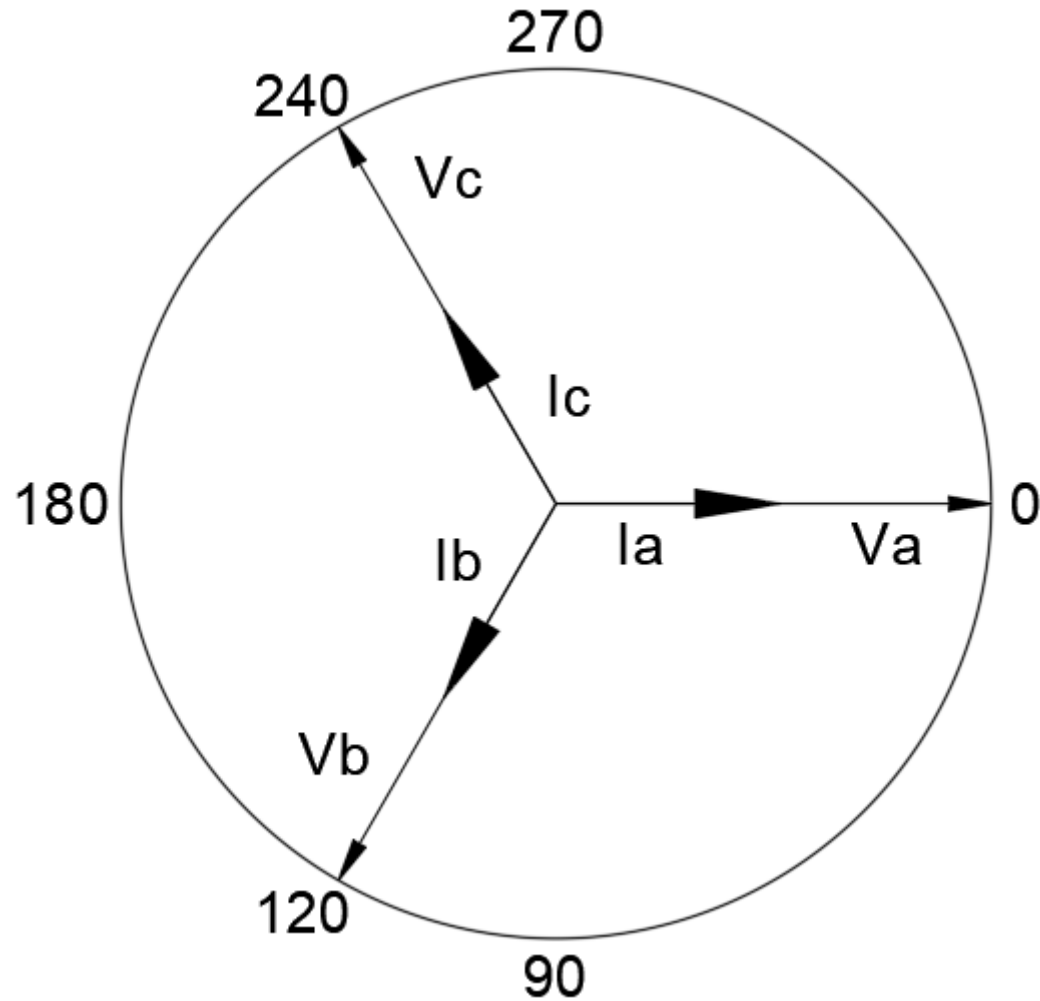
$$\text{Watts (or Active Power)} = V \times I \times \cos \theta$$



- **Both voltage & current are required in each meter element (stator) for that element to have an effect on registration.**
- **Time relationship (degrees separation) between voltage & current acting together on each element will determine that element's effect.**
- **Only angles of less than 90 Degrees between the current and voltage on any meter element will cause positive wathour registration.**



The Phasor Diagram



Phasor Diagram for 3-element,
4-wire Wye connected service

Form 9S or 9A

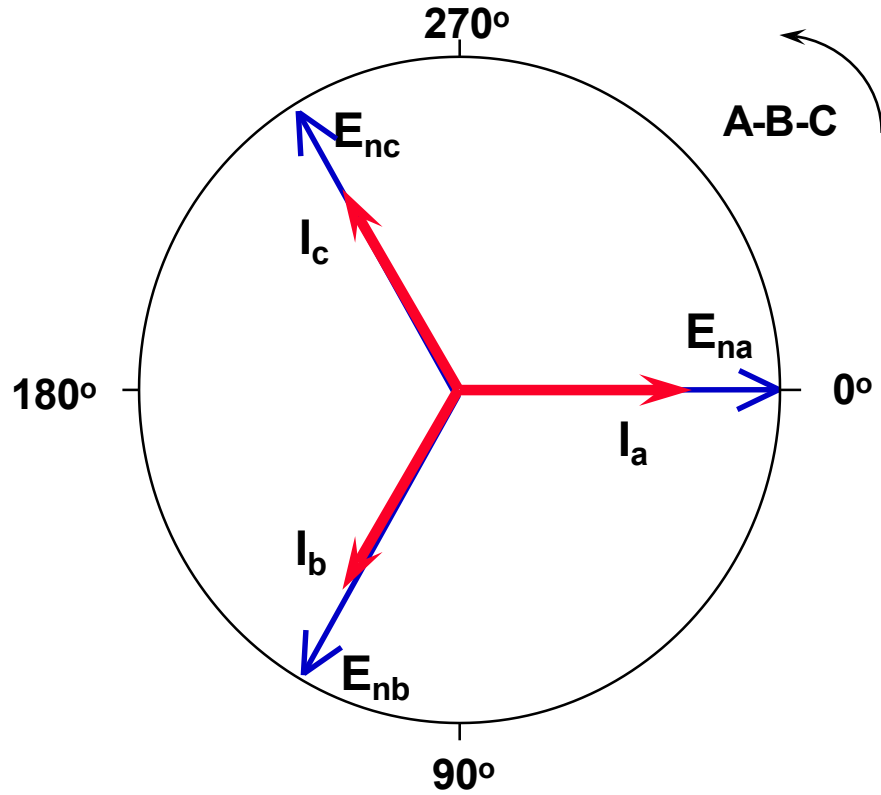
Form 16S or 16A

Form 16K

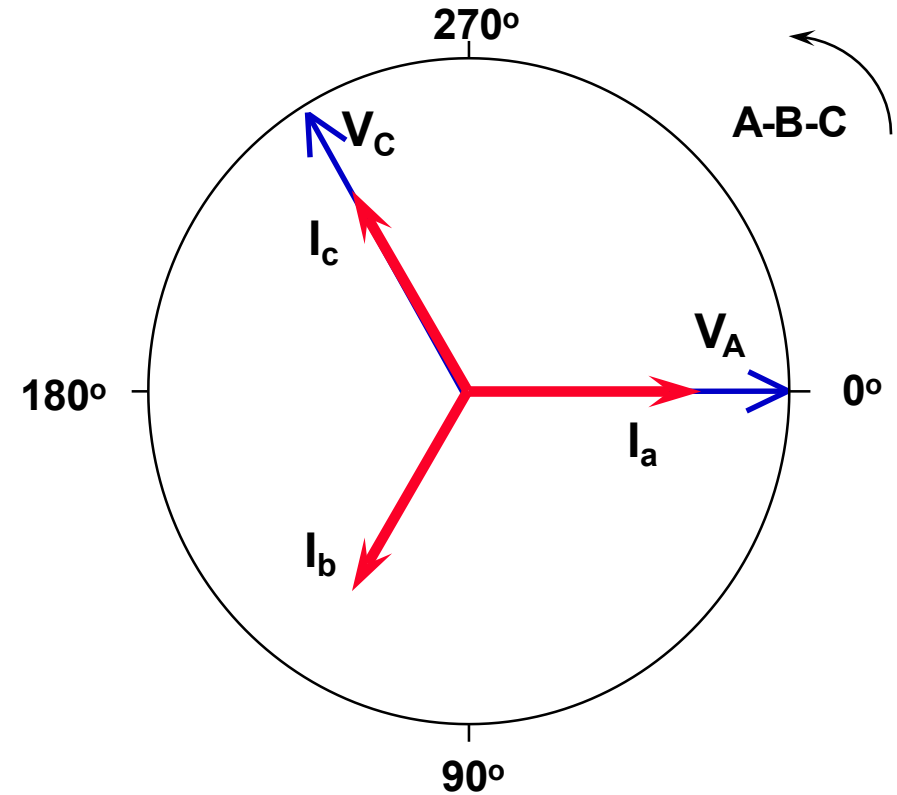


TESCO METERING

Service & Meter Phasors



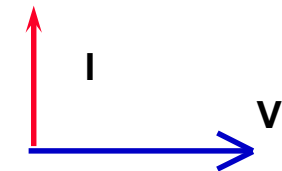
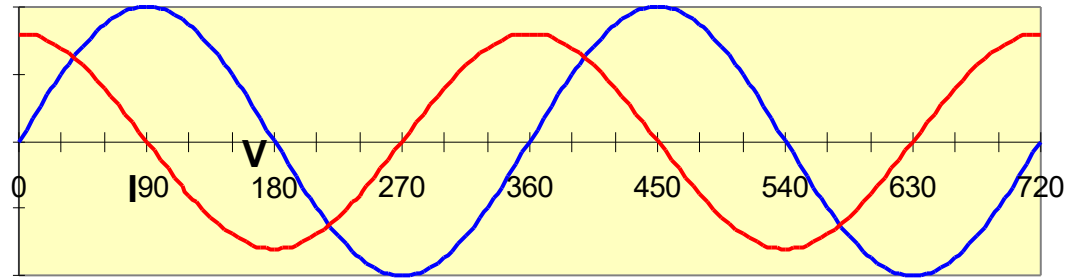
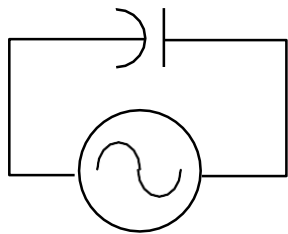
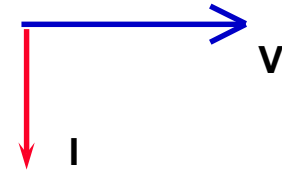
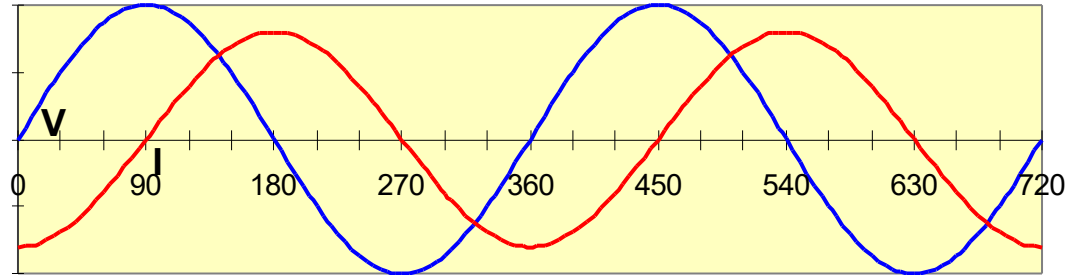
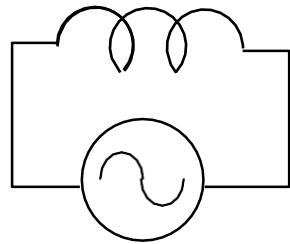
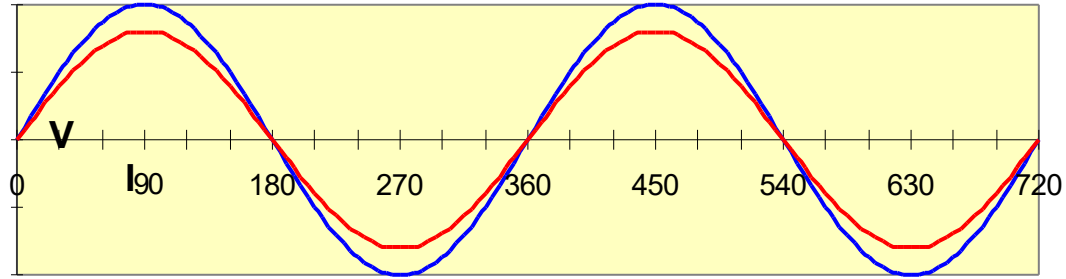
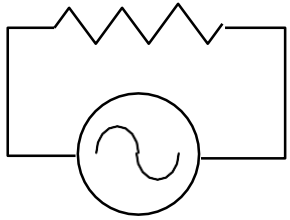
Service Phasors

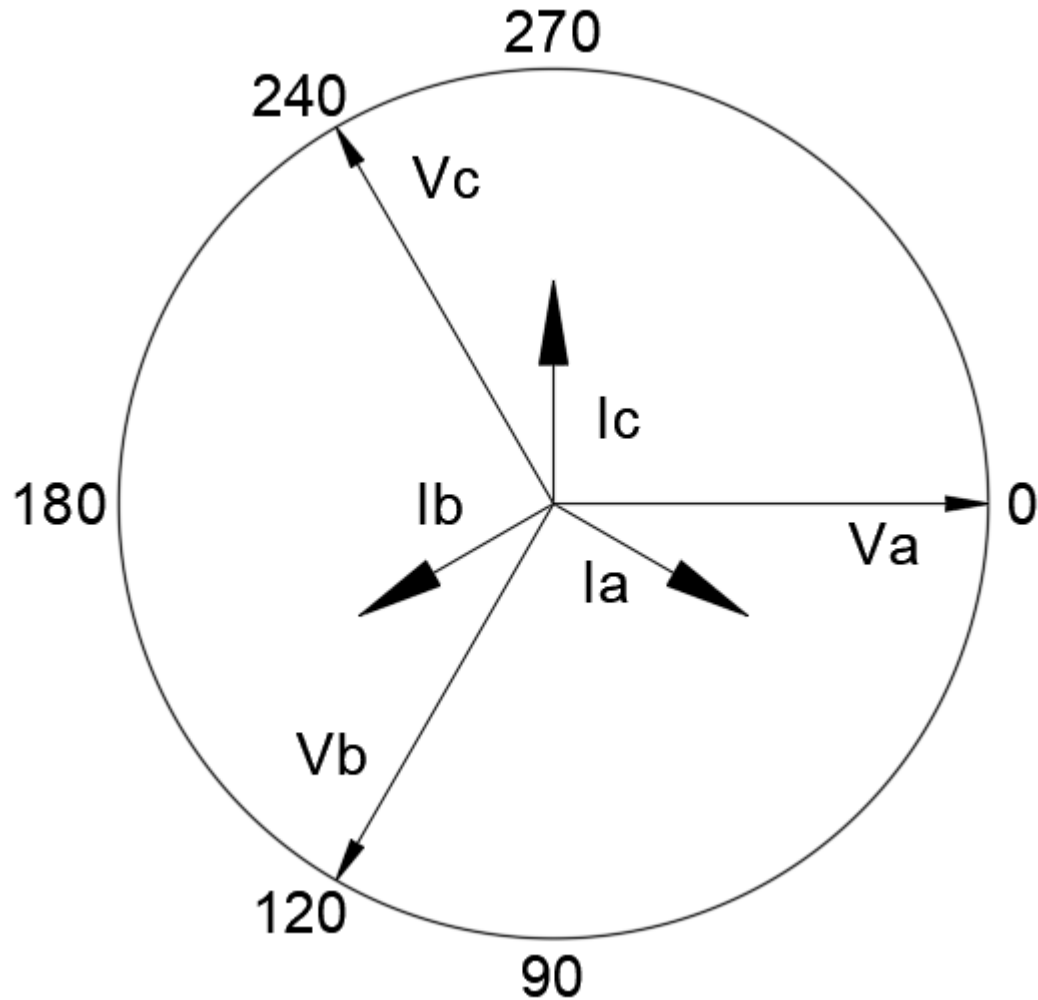


Meter Phasors

2 1/2 Element

Load Caused Phase Angles



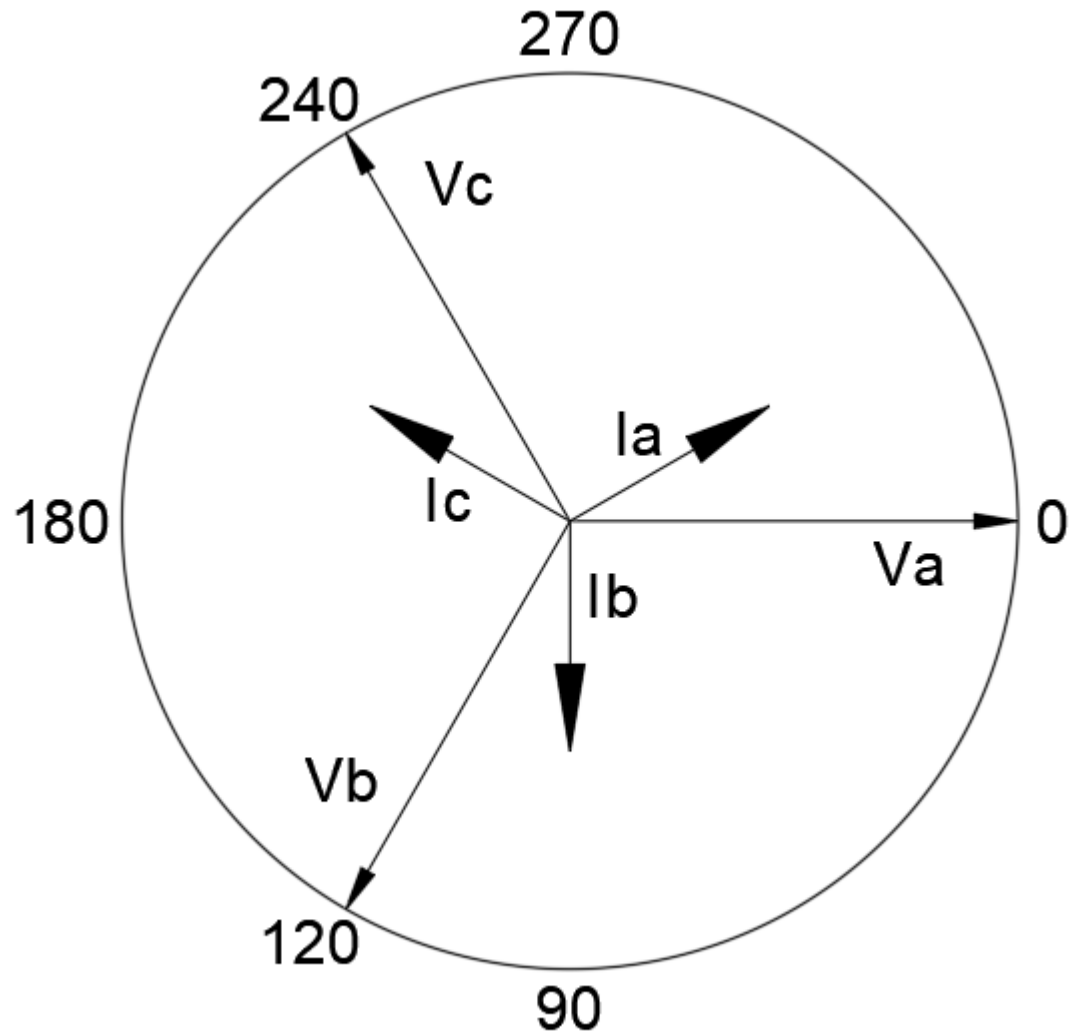


Example of 4 wire wye where:

Current **LAGS** the Voltage

This would be an **Inductive** load

Capacitive Load - Leading



Example of 4 wire wye where:

Current **LEADS** the Voltage

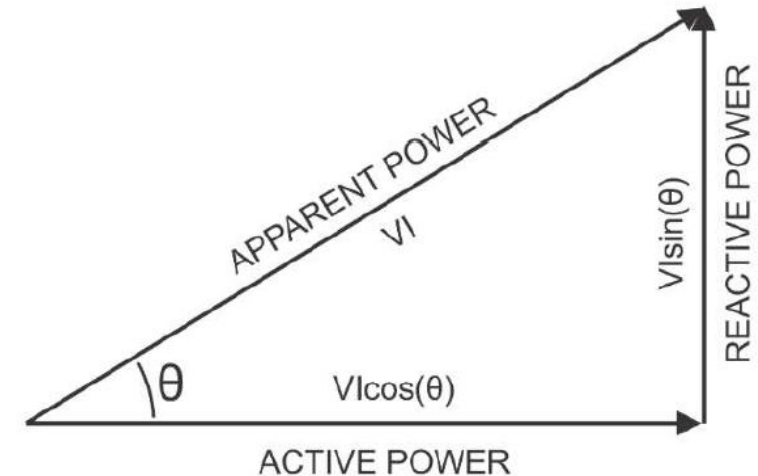
This would be a **CAPACITIVE** load

Review of the Power Triangle

Apparent Power (S) Total Power supplied by the utility
(The full effort)
Measured in **VA**

Active Power (P) Working Power
(Performs the work)
Measured in **Watts**

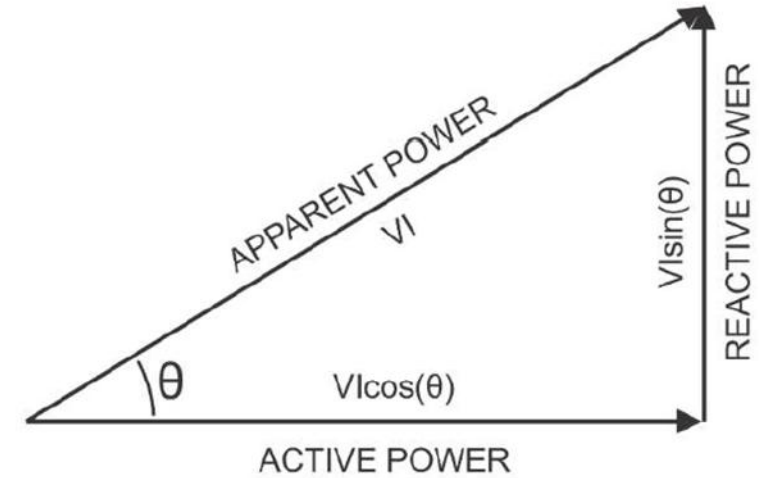
Reactive Power (Q) Magnetizing Power
(Performs no work)
Measured in **Vars**



$$S^2 = P^2 + Q^2 \quad \longrightarrow \quad S = \sqrt{P^2 + Q^2}$$

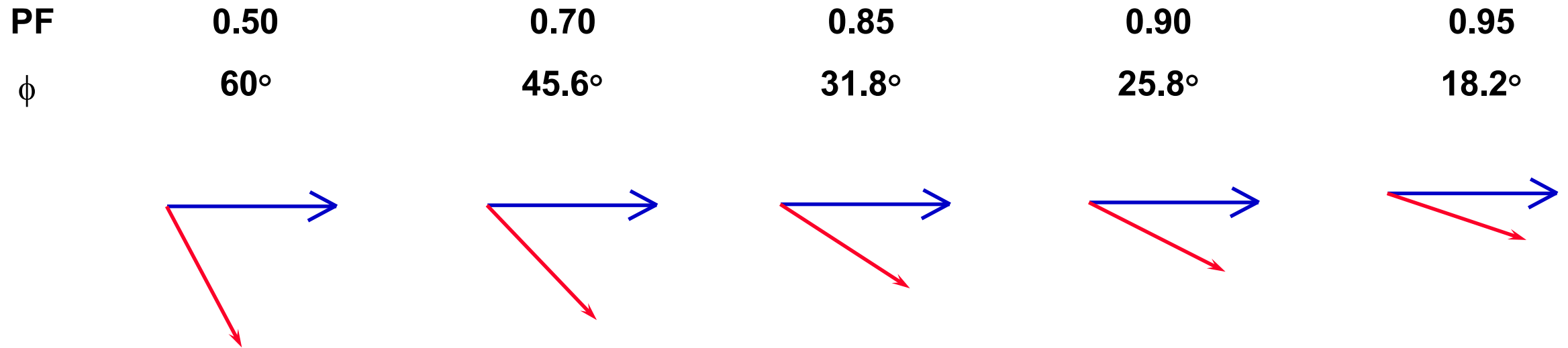
What is your Power Factor?

- If we consider again just the fundamental frequency, power factor (PF) can be defined as Active Power divided by Apparent Power, or Watts divided by Volt-Amperes
- $PF = P/S = VI \cos\theta / VI = \cos\theta$
- KW/VA (11.52 kW/12.13 kVA = .95 PF)
- $\cos 18.19^\circ = .95 \text{ PF}$
- Measure of power system delivery vs. consumption efficiency

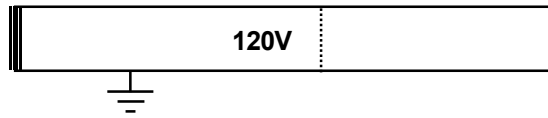


Energy = Power x Time

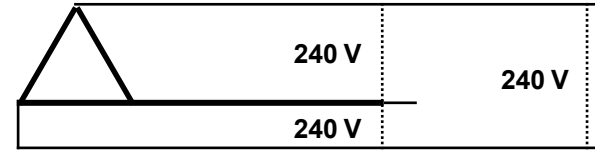
- So Energy (Wh) = V x I x PF x T
- $PF = P/S = VI \cos\phi / VI = \cos\phi$
- Measure of power system delivery vs. consumption efficiency



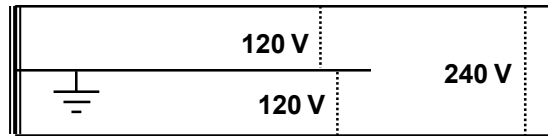
Common Distribution Circuits



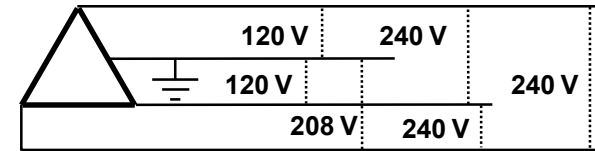
**Two-Wire
Single Phase**



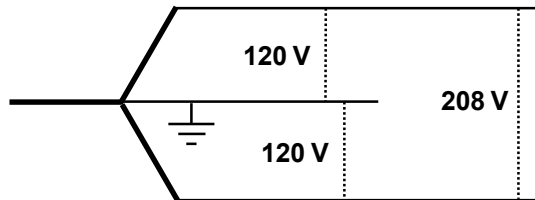
**Three-Wire
Three Phase
Delta**



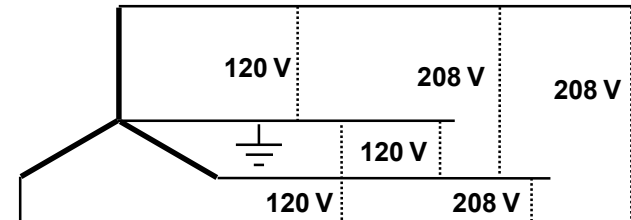
**Three-Wire
Single Phase**



**Four-Wire
Three Phase
Delta**



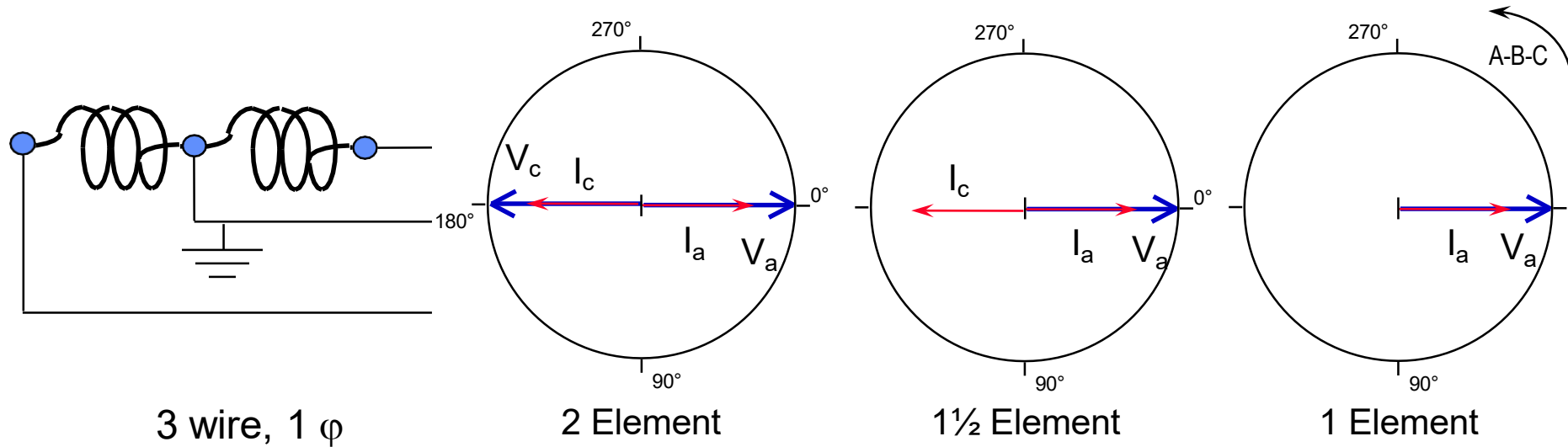
**Three-Wire
Network**



**Four-Wire
Three Phase
Wye**

1 ϕ Expected Meter Phasors

(BALANCED LOAD AT POWER FACTOR = 1, ABC PHASE SEQUENCE)

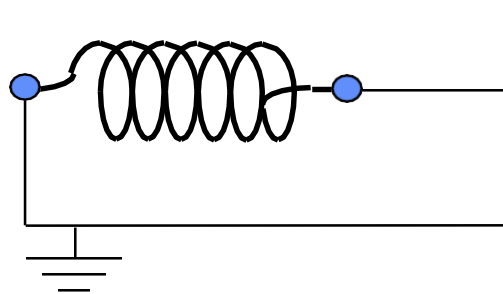


3 wire, 1 ϕ

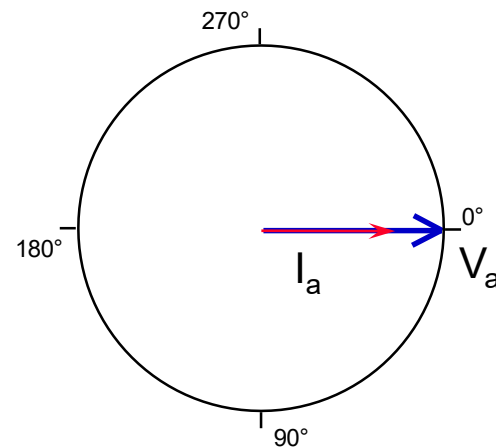
2 Element

1½ Element

1 Element



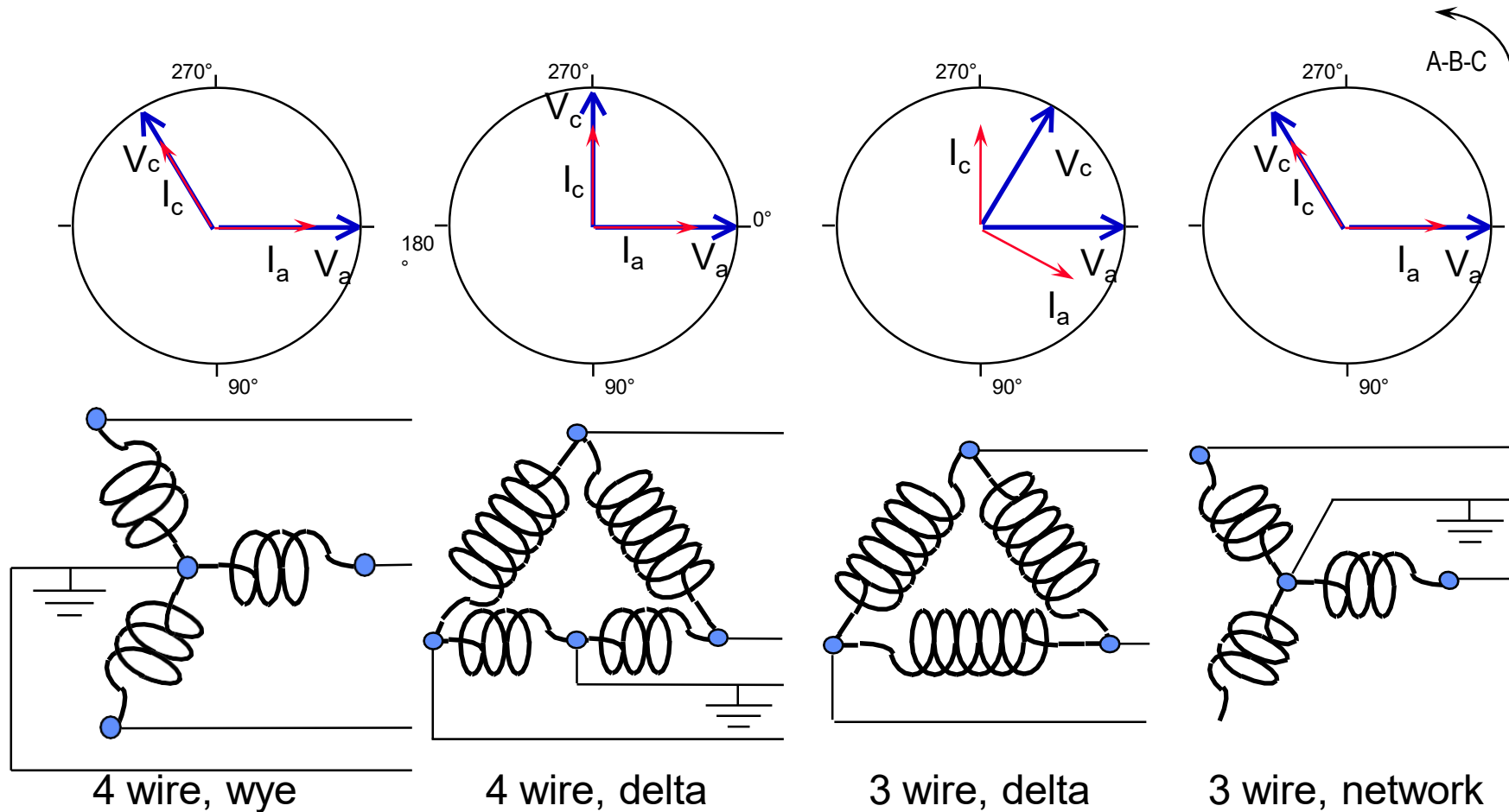
2 wire, 1 ϕ



1 Element

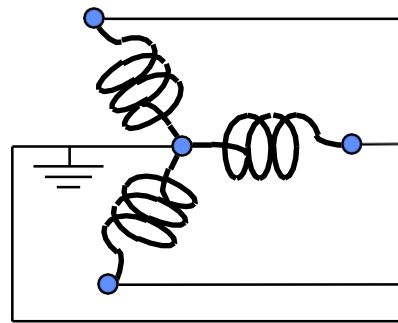
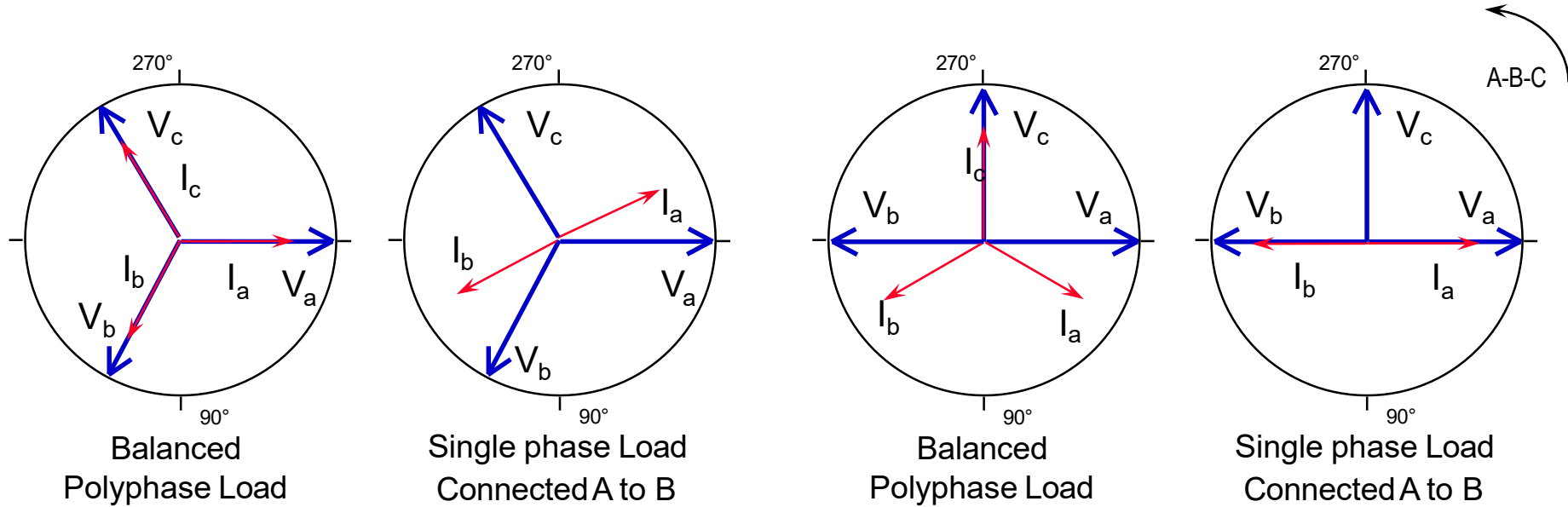
2 Element Expected Meter Phasors

(BALANCED LOAD AT POWER FACTOR = 1, ABC PHASE SEQUENCE)

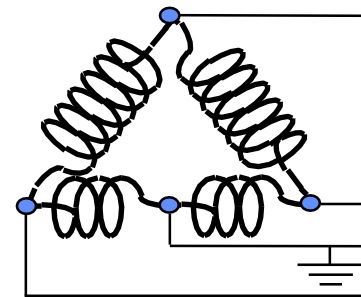


3 Element Expected Meter Phasors

(AT POWER FACTOR = 1, ABC PHASE SEQUENCE)

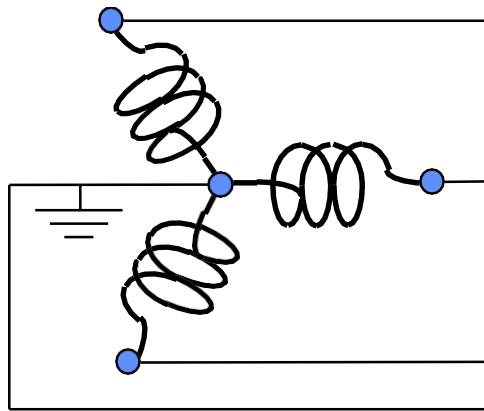


4 wire, wye

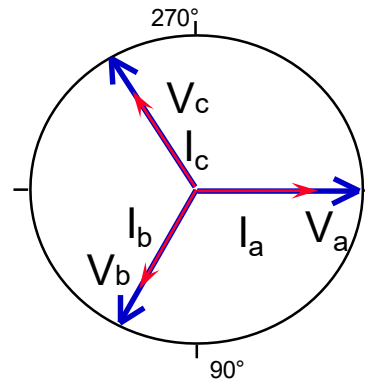


4 wire, delta

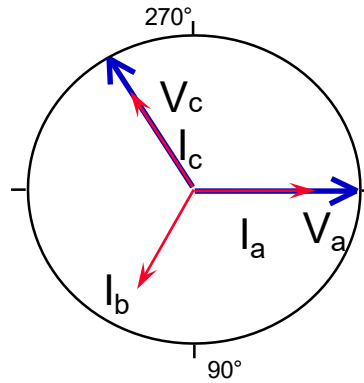
(AT POWER FACTOR = 1, ABC PHASE SEQUENCE)



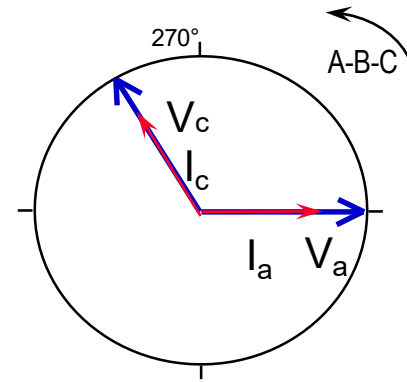
4 wire, wye



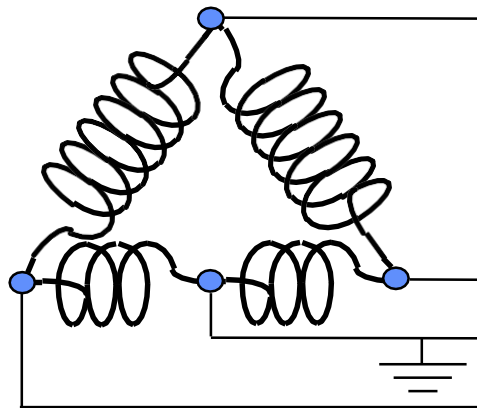
3 Element



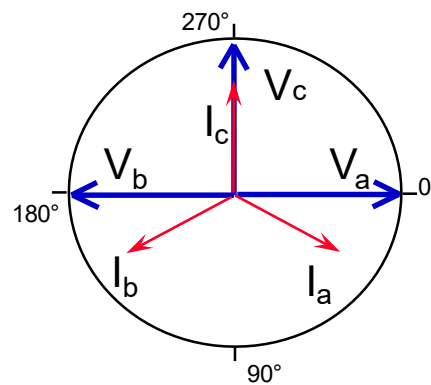
2½ Element



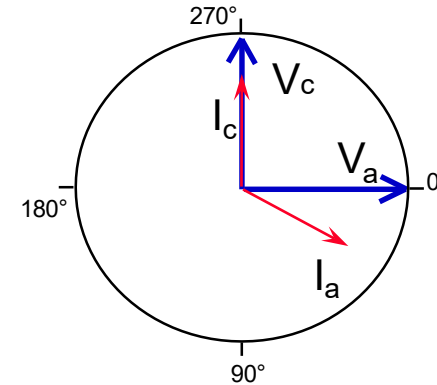
2 Element



4 wire, delta



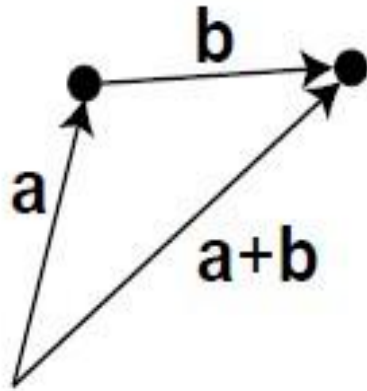
3 Element



2 Element

Let's Talk about Why We Need to Understand Vectors.

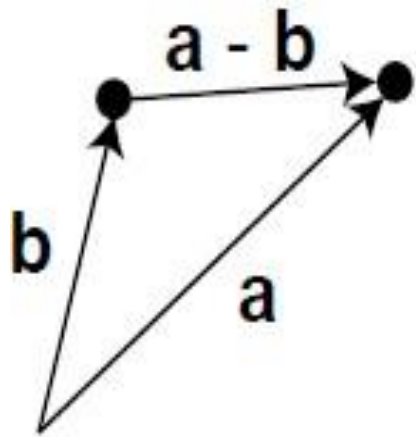




Addition of vectors can be expressed by a diagram. Placing the vectors end to end, the vector from the start of the first vector to the end of the second vector is the sum of the vectors. One way to think of this is that we start at the beginning of the first vector, travel along that vector to its end, and then travel from the start of the second vector to its end. An arrow constructed between the starting and ending points defines a new vector, which is the sum of the original vectors. Algebraically, this is equivalent to adding corresponding terms of the two vectors:

$$\mathbf{a} + \mathbf{b} = \begin{bmatrix} a_x \\ a_y \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \end{bmatrix} = \begin{bmatrix} a_x + b_x \\ a_y + b_y \end{bmatrix}.$$

We can think of this as again making a trip from the start of the first vector to the end of the second vector, but this time traveling first horizontally the distance $a_x + b_x$ and then vertically the distance $a_y + b_y$.



Subtraction of vectors can be shown in diagram form by placing the starting points of the two vectors together, and then constructing an arrow from the head of the second vector in the subtraction to the head of the first vector. Algebraically, we subtract corresponding terms:

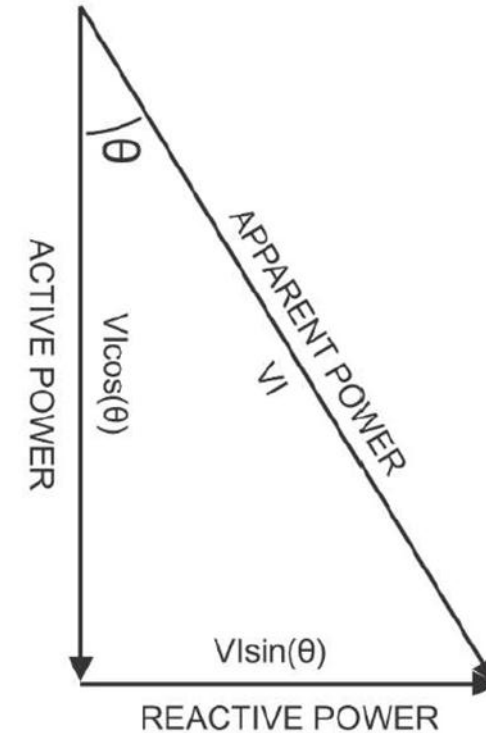
Vector Subtraction
$$\mathbf{a} - \mathbf{b} = \begin{bmatrix} a_x \\ a_y \end{bmatrix} - \begin{bmatrix} b_x \\ b_y \end{bmatrix} = \begin{bmatrix} a_x - b_x \\ a_y - b_y \end{bmatrix}.$$

Vector Addition

- From the previous slides, if you know Active and Reactive Power, you can determine Apparent Power by using vector addition.

Vector Subtraction

- From the previous slides, if you know Active and Apparent Power, you can determine Reactive Power by using vector subtraction.

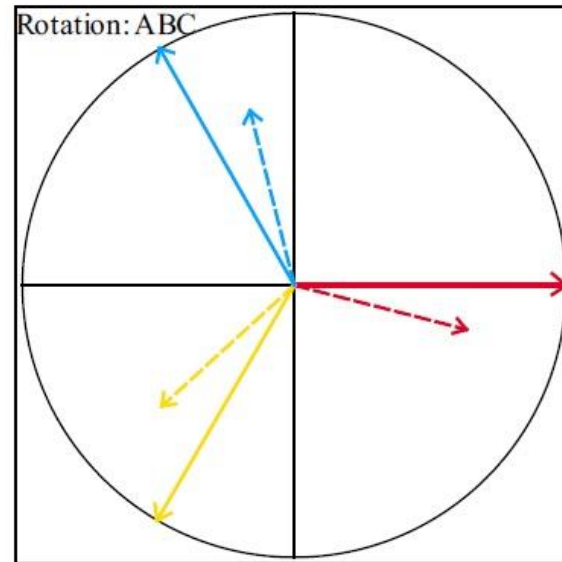


Phase Rotation & Site Measurements

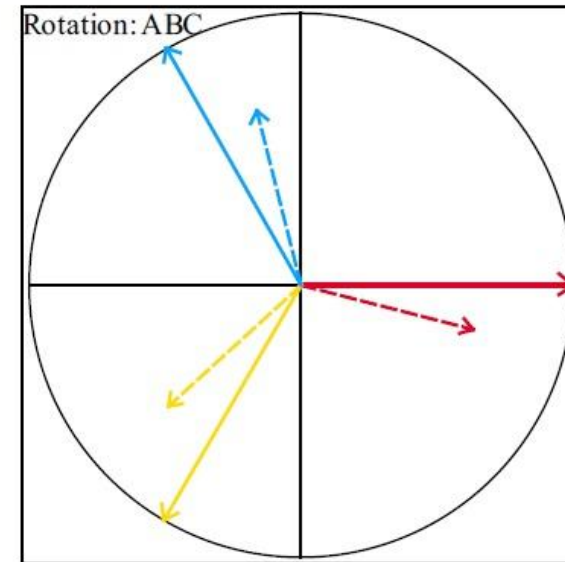
Site Measurements

Phase	Voltage	Voltage Phase	Current	Current Phase	Probe Current	Probe Phase
A	113.605	0.000°	2.901	14.345°	578.355	14.45°
B	114.364	120.147°	3.002	136.931°	599.459	137.140°
C	113.611	240.312°	2.864	256.188°	570.920	256.198°

Secondary Phasor



Primary Phasor



Power

Phase	Watts	VA	VAR	Voltage THD	Current THD	Power Factor	CT Ratio
A	0.354	1.464	0.360	0.016	0.075	0.966	996.98:5
B	1.456	1.525	0.438	0.016	0.073	0.955	998.58:5
C	1.387	1.445	0.393	0.016	0.075	0.959	996.57:5

We would like you to join us in the TESCO Hospitality Suite for networking and more discussions about metering. The discussion will not be exclusively metering.....but we love metering and that is the most common topic.

TESCO Hospitality Suite 301 – Brighton Tower

Monday and Tuesday 8:00 PM – 10:00 PM



We Hope you Can Join Us!



Tom Lawton

President

tom.lawton@tescometering.com



TESCO – The Eastern Specialty Company

Bristol, PA

215.228.0500

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

ISO 9001:2015 Certified Quality Company
ISO 17025:2017 Accredited Laboratory