TESCO METERING

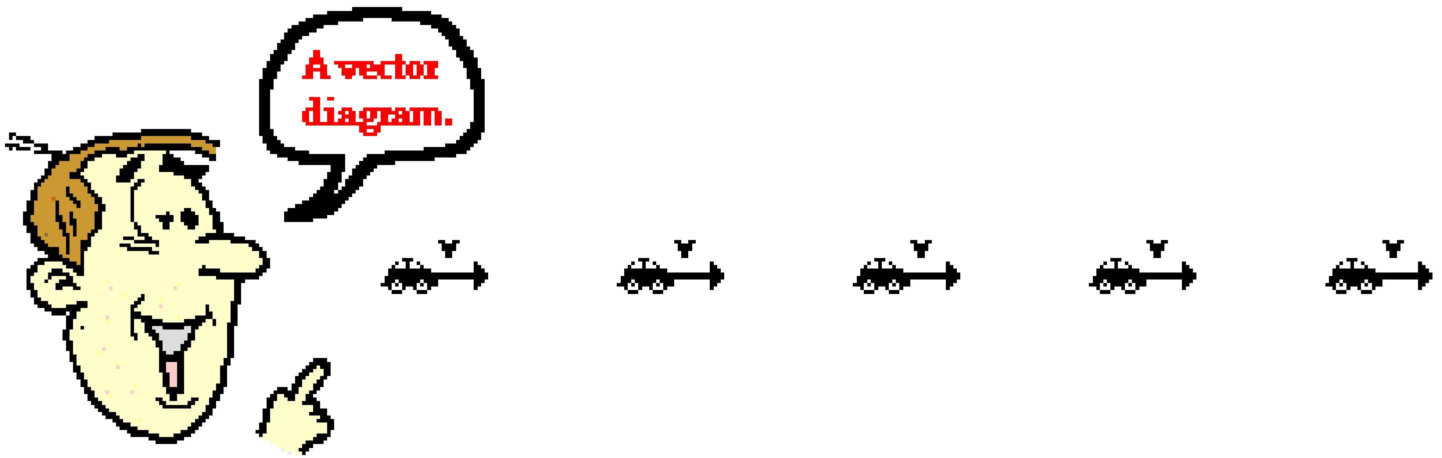
Practical Use of Vectors in Electric Metering and Field Testing at Instrument Rated Services

TESCO's Meter School
TESCOOL
July 20-23, 2025

July 22, 2025
8:45 AM -10:15 AM
Carl Chermak

Symbolic Representation

- 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:

Watts = Voltage x Current x

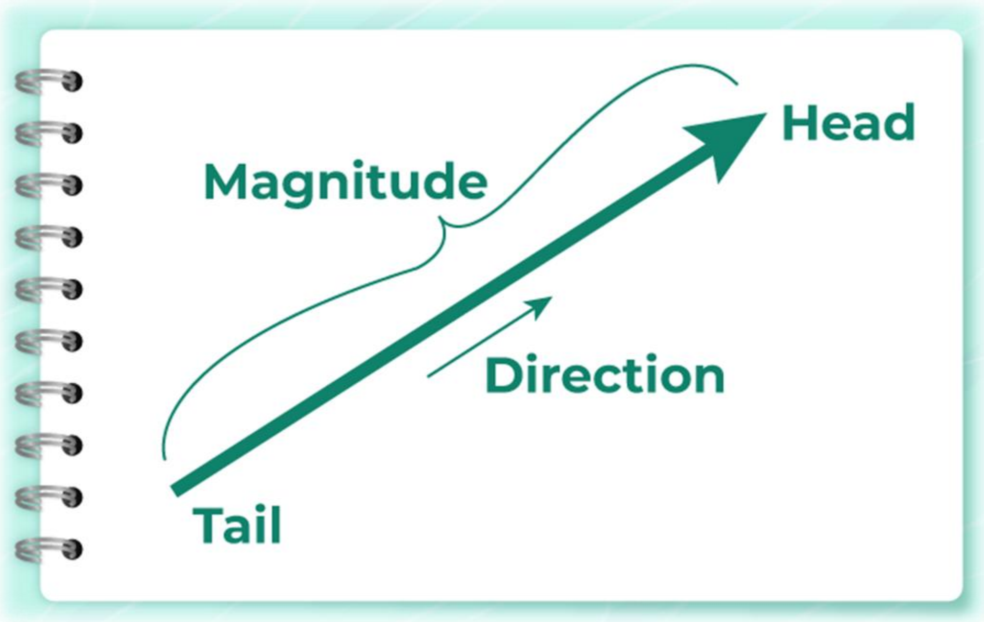
Power Factor Mathematically:

$$Watts = V \times I \times \cos\theta$$

What is a Vector?

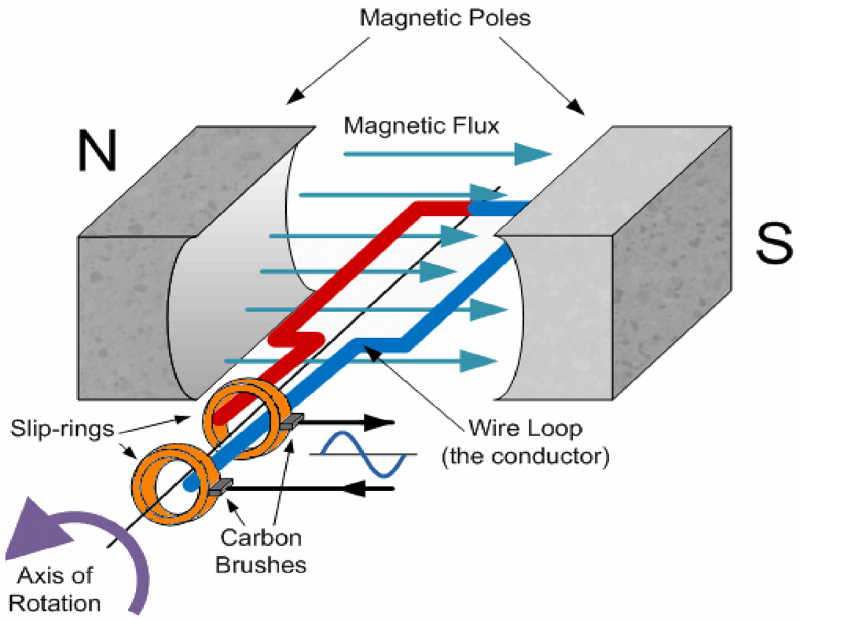
A measurement that takes two numbers to represent.

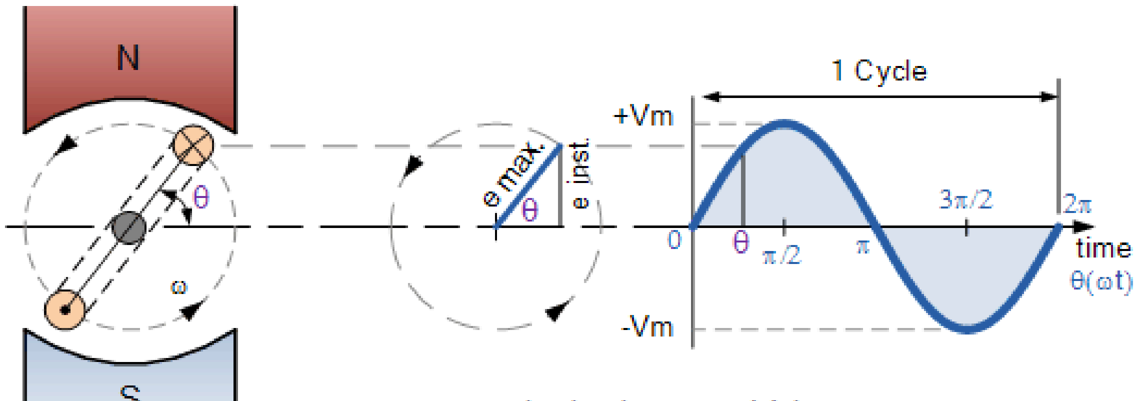
BOTH a magnitude (size) and direction



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.



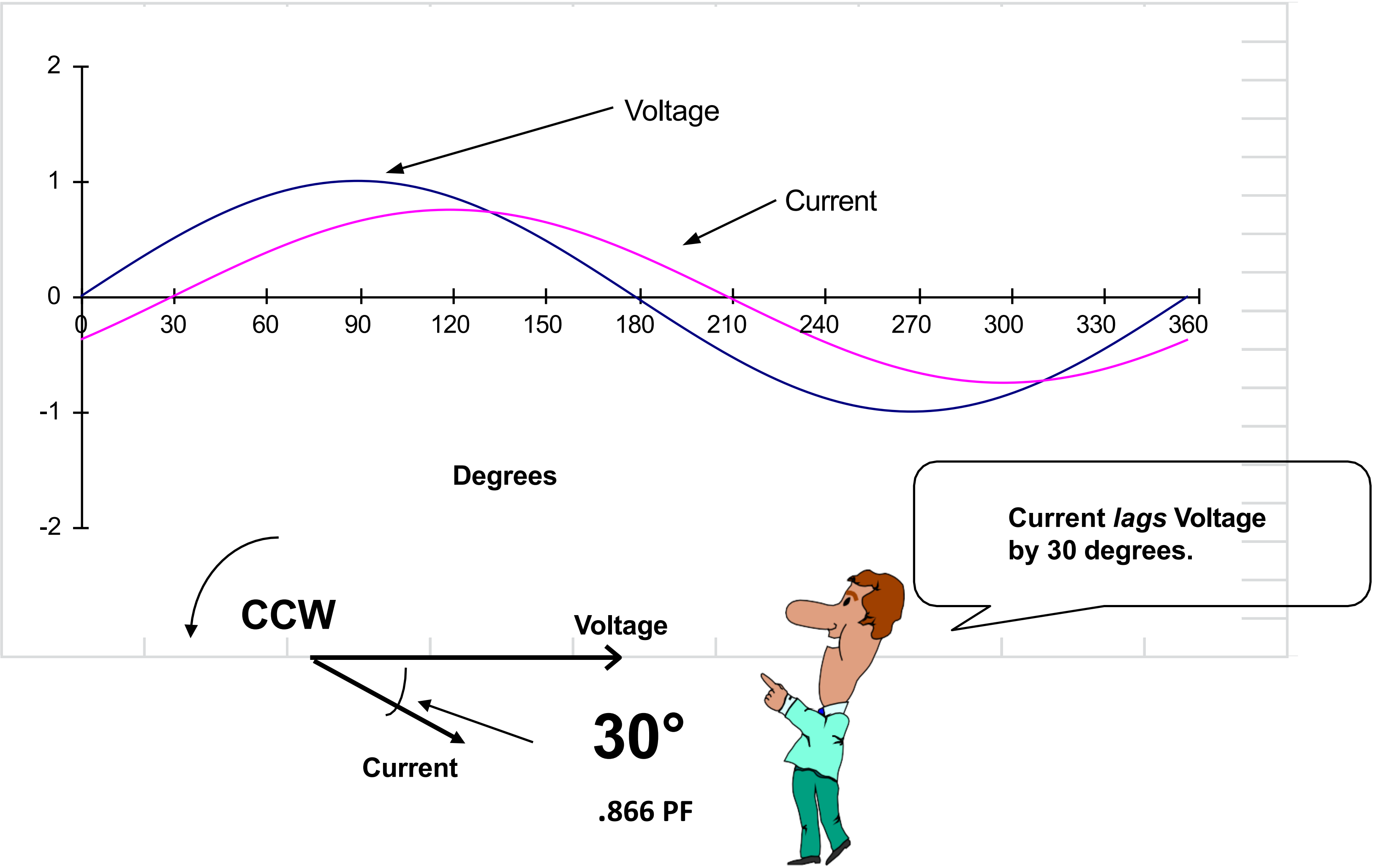


Instantaneous Value

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

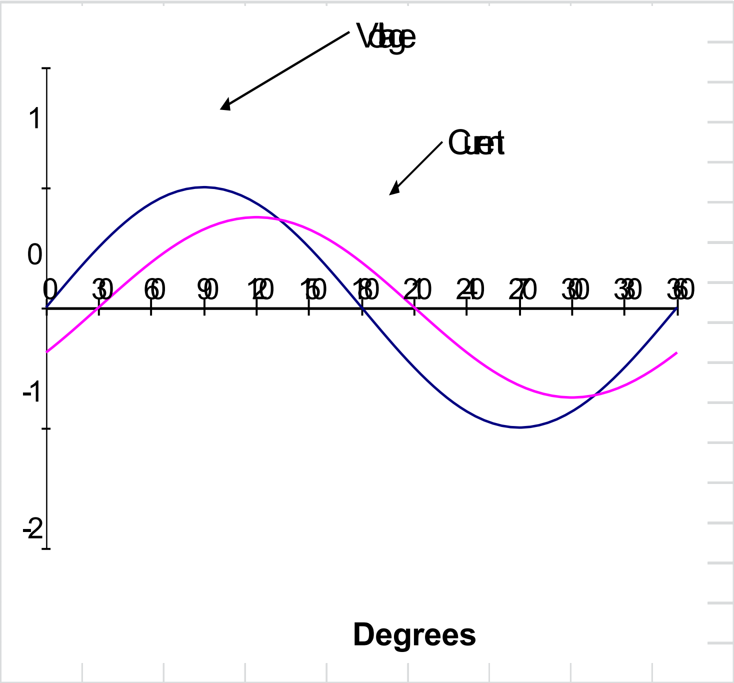
4

“Time” in Degrees



“Time” in Degrees

1



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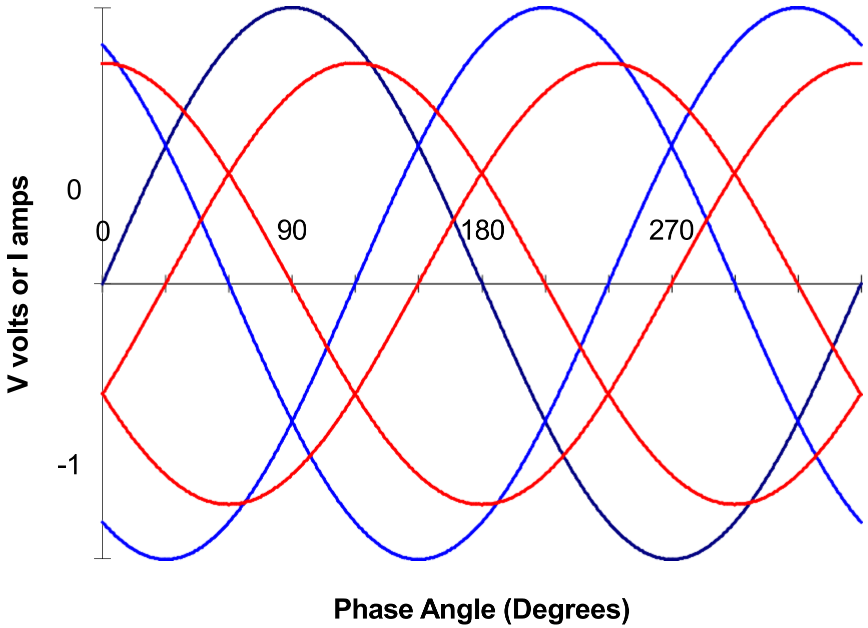
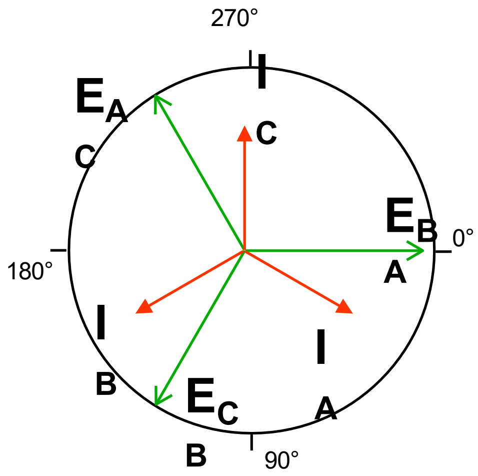
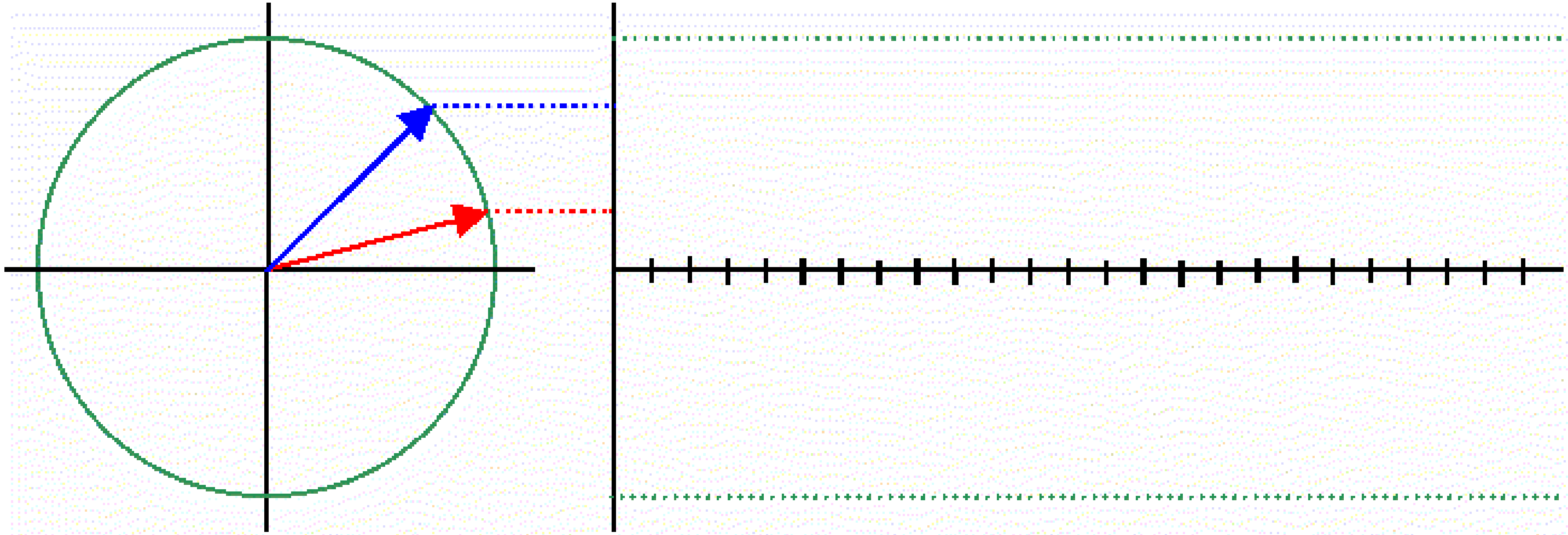




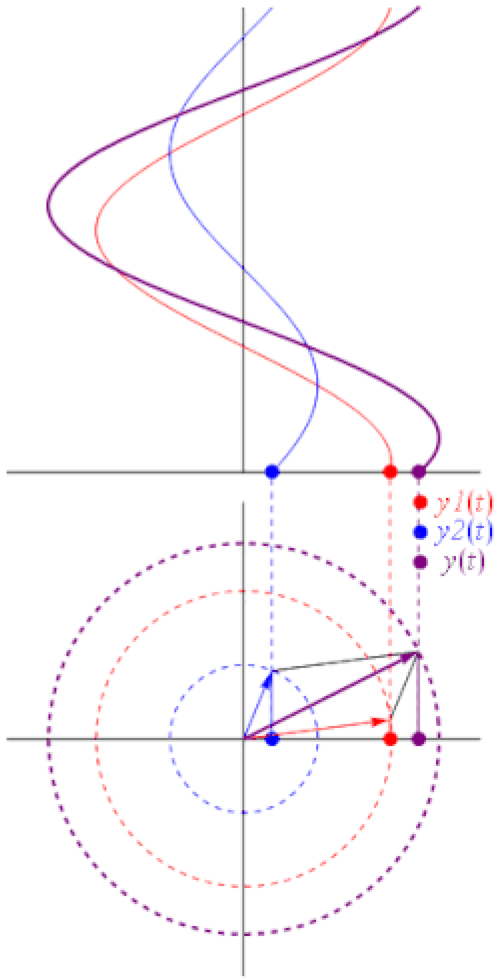
AC Voltage and Current



Vectors or Phasors are…

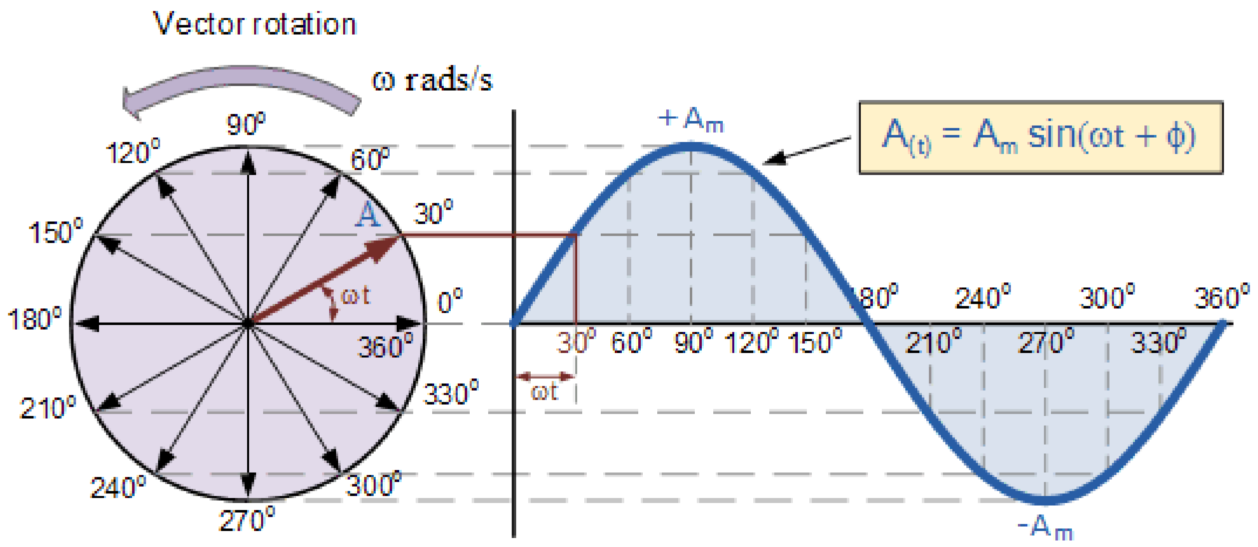
A Symbolic Representation of the relationship of the voltage and current

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



The Phasor Diagram

- 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.

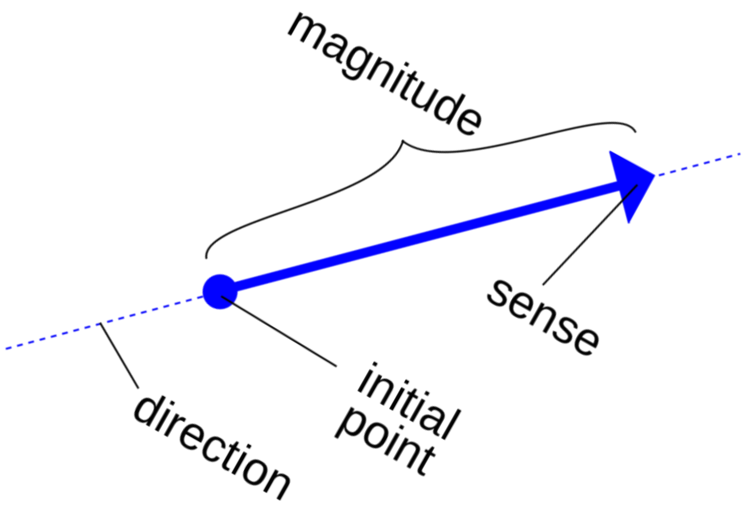


Rotating Phasor

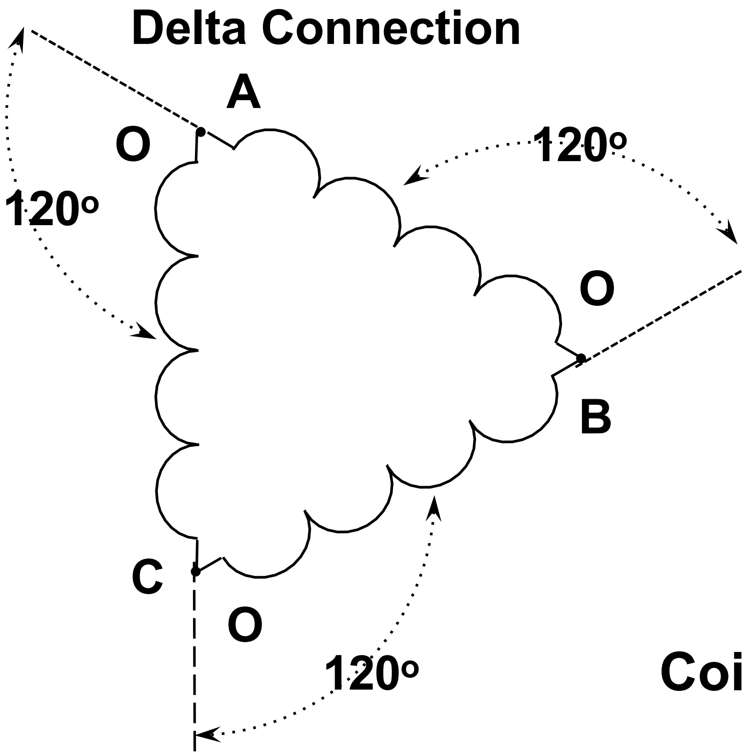
Sinusoidal Waveform in the Time Domain

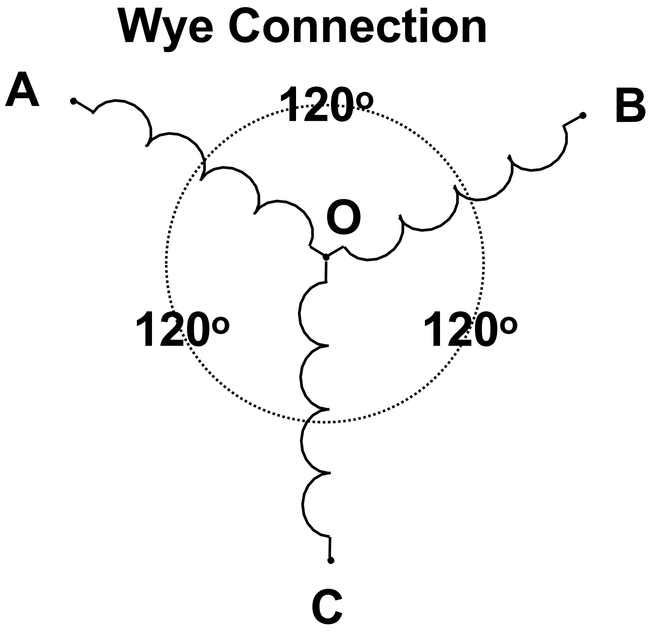
Representing *Voltage(E)* & Current (*I*) with Lines

- **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).**



Placing Coils in Order





Coils connected together

and placed on an alternator in order

OA, OB, and OC

(Changing Coil order changes *Sequence*)

Drawing the Phasor

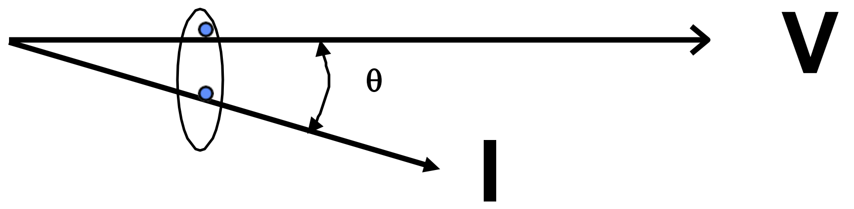
General Guidelines

- 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” arrowhead on voltage line(s).
- Use “closed” (or filled in) arrowhead on current line(s).
- Label all voltages and currents by phase.
- Indicate Phase Rotation (counter-clockwise assumed if not noted).

- **Watthour 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:**

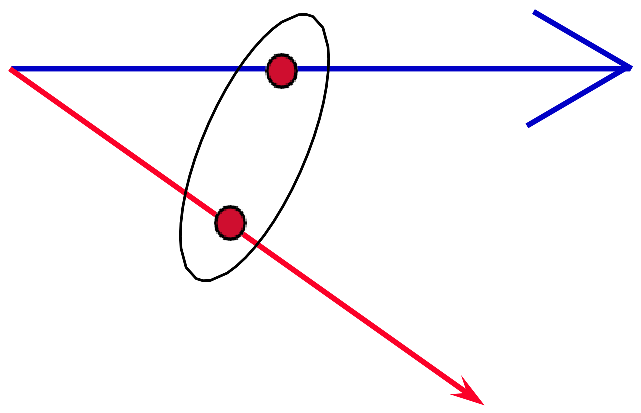
$$Watts = V \times I \times \cos\theta$$

VECTORIALLY

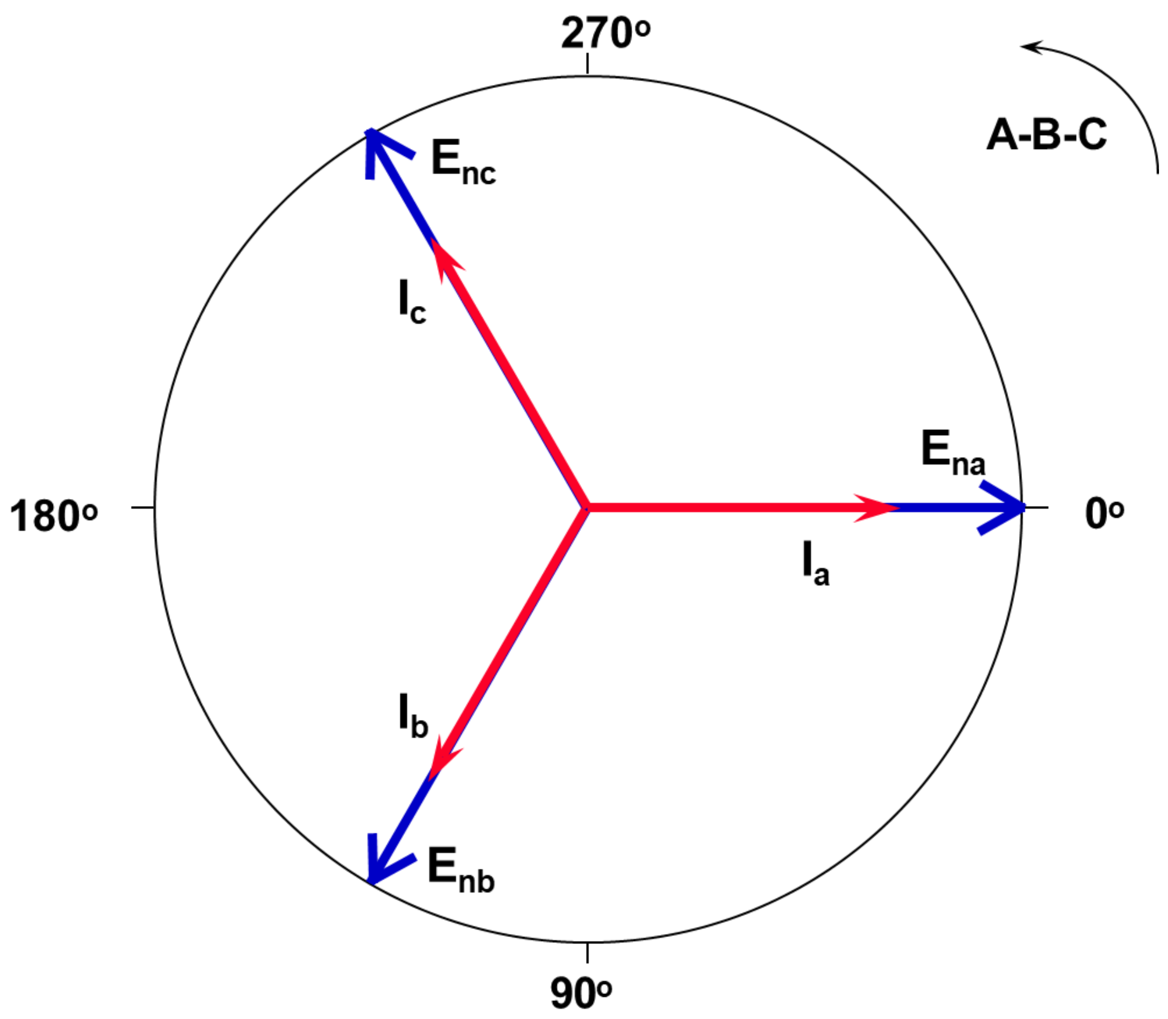


Analyzing the Phasor Picture

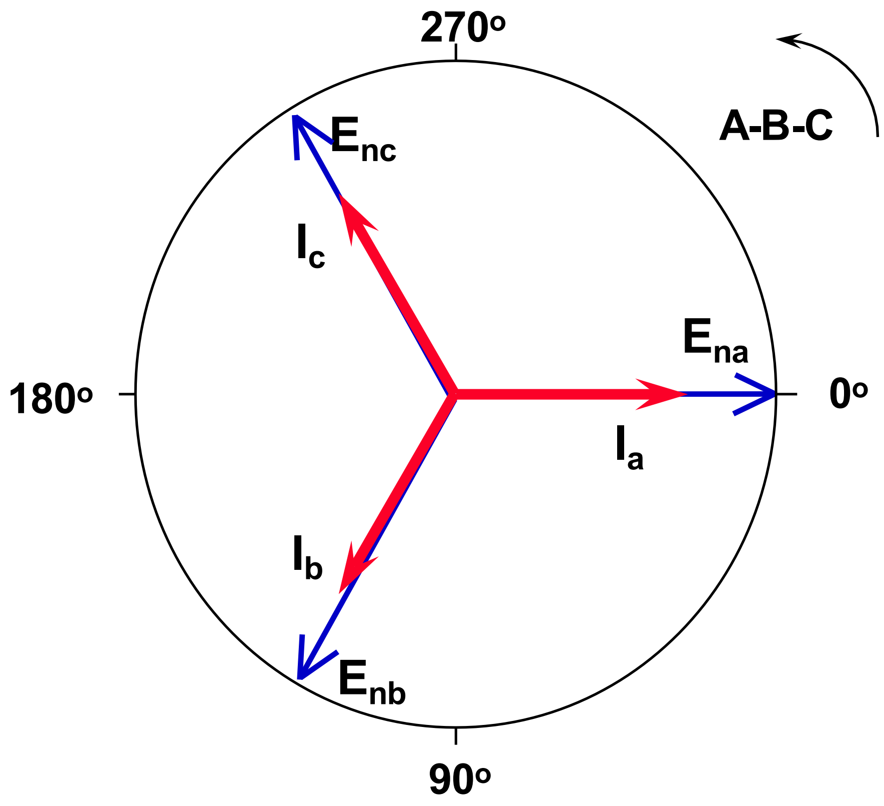
- Both voltage & current are required in each meter element (stator) for that element to have an effect on registration.
- Time relationship (degrees separation) between voltage & current acting together on each element will determine that element's effect.
- Only angles of less than 90 Degrees between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



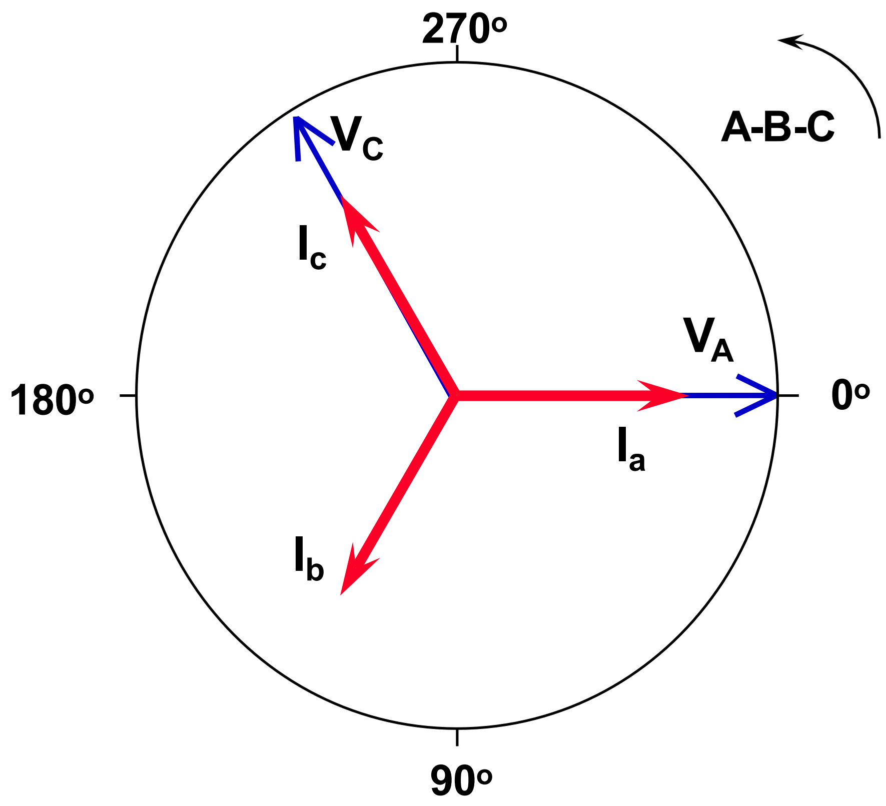
The Phasor Diagram



Service & Meter Phasors



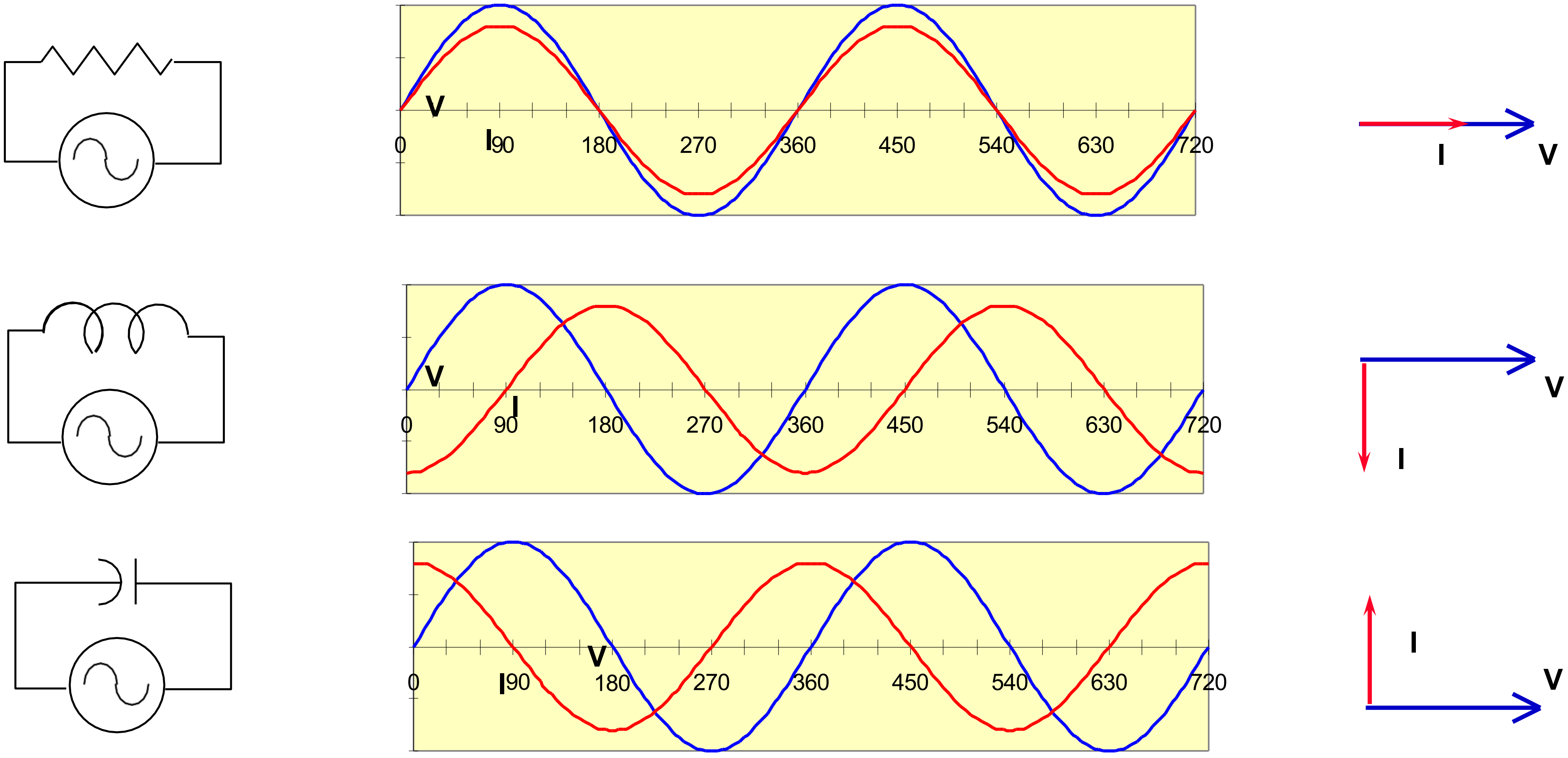
Service Phasors



Meter Phasors

2 ½ Element

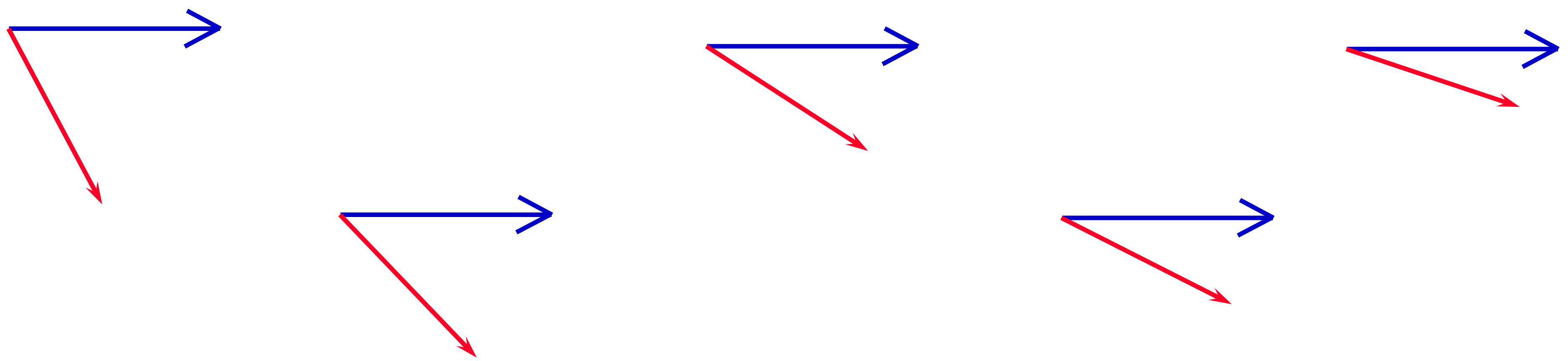
Load Caused Phase Angles



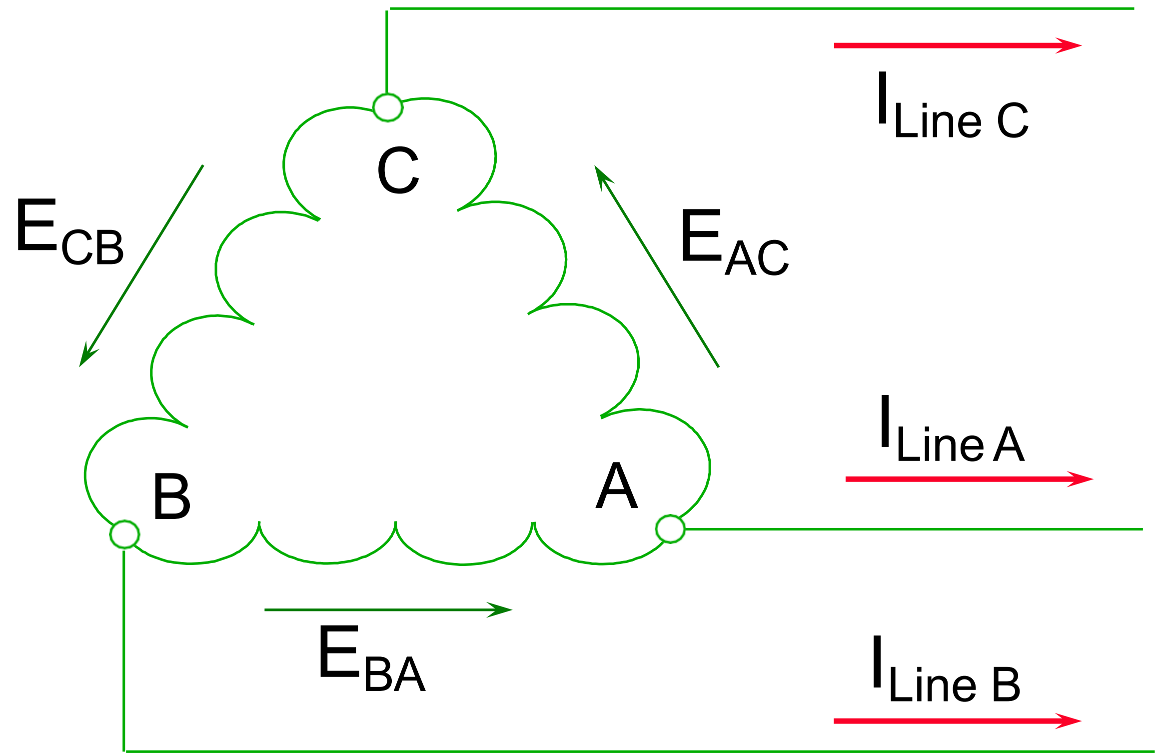
Effect of Power Factor

- We represent energy as: $Energy = E \times I \times \cos\theta \times t$
  - θ is the angle between V and I
  - Cos θ is also known as Power Factor
- What θ values give with these lagging Power Factors?

Power Factor	0.50	0.70	0.85	0.90	0.95
Phase Angle	60°	45.6°	31.8°	25.8°	18.2°



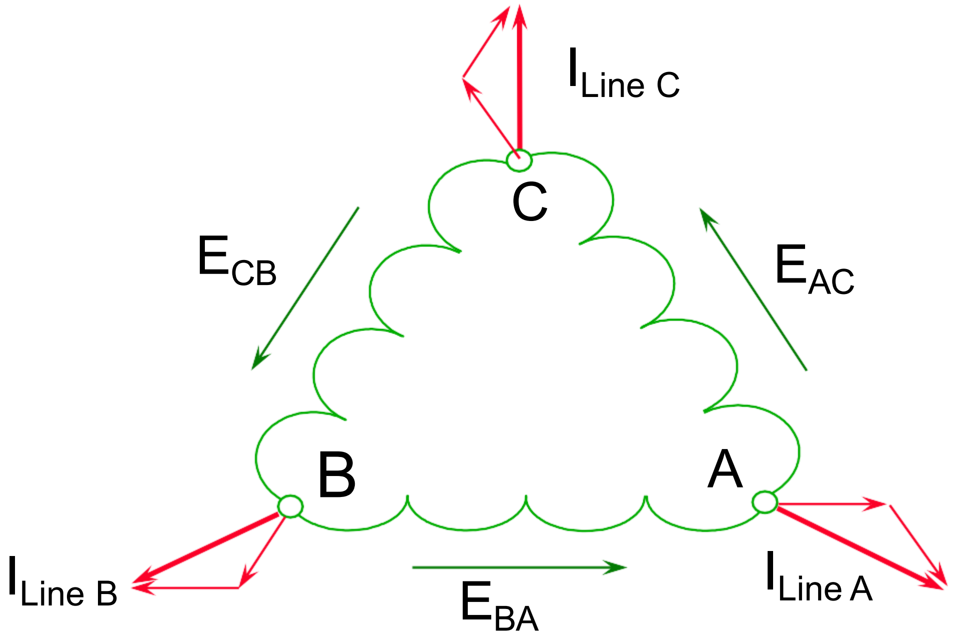
Three Wire Delta Source

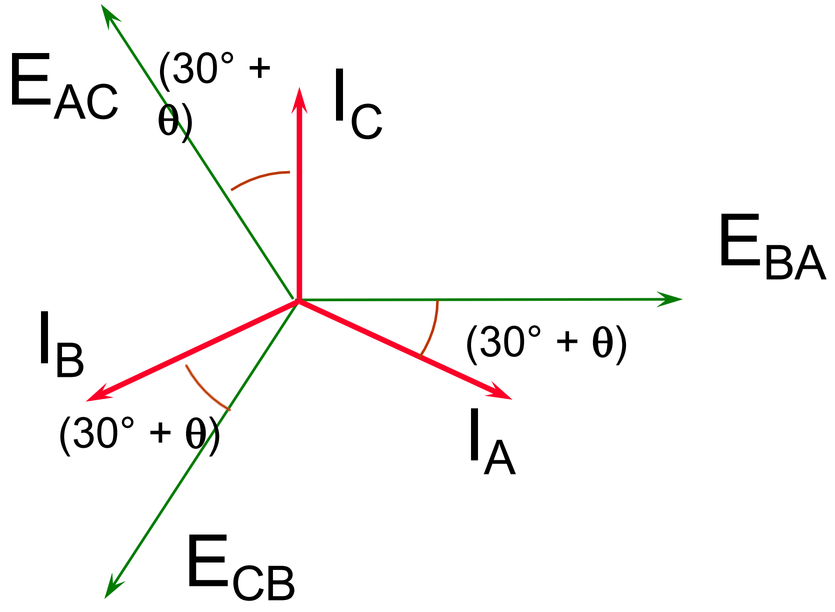


With pure resistance balanced three-phase load, the current in each supply transformer is in phase with the voltage across each transformer.

Drawing Source Phasors

Phasor diagram for delta-connected three-phase system with three-phase delta-connected resistance load

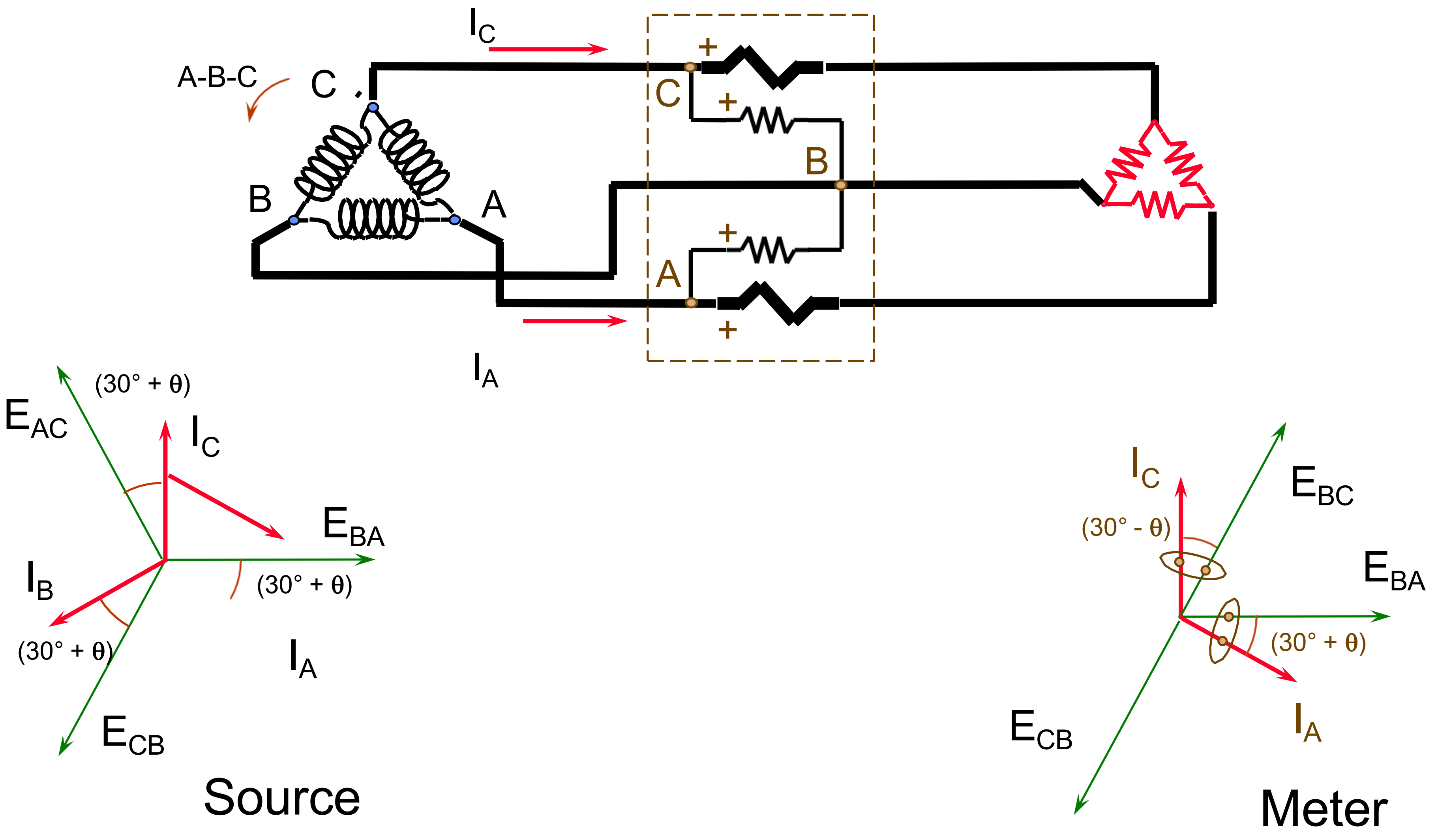




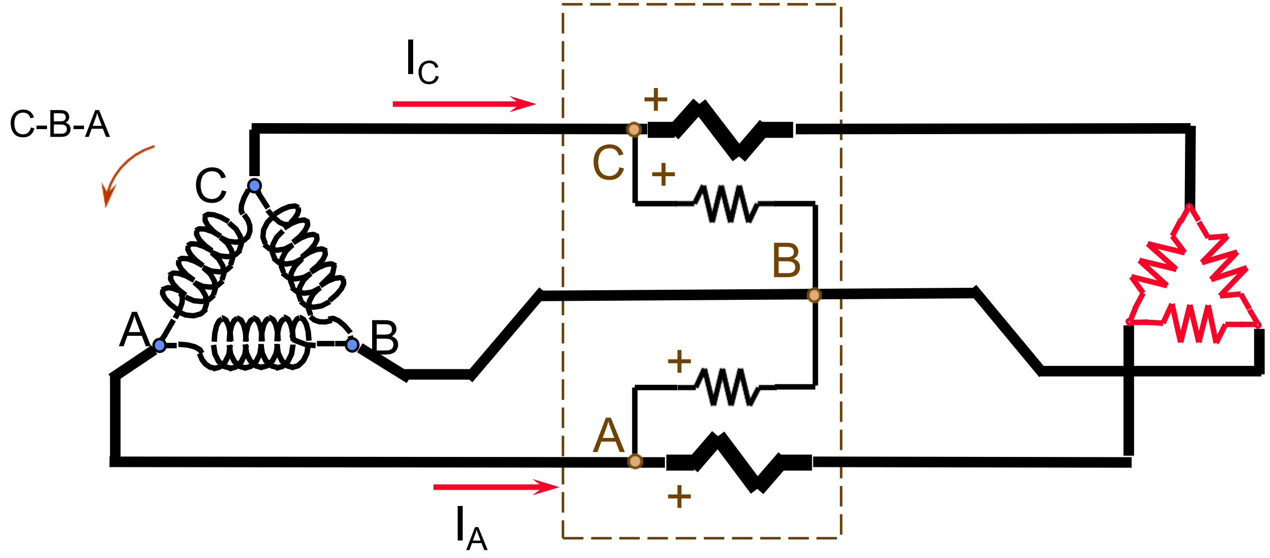
Phase voltages = E_{BA}, E_{CB}, & E_{AC}

Line currents = I_A, I_B, & I_C

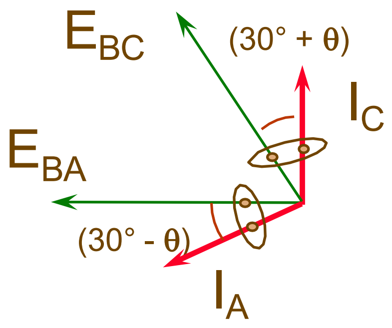
Phasors for Source & Meter



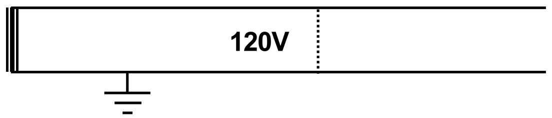
Phase Sequence CBA



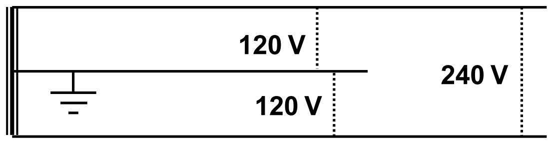
C-B-A
Meter
Phasors



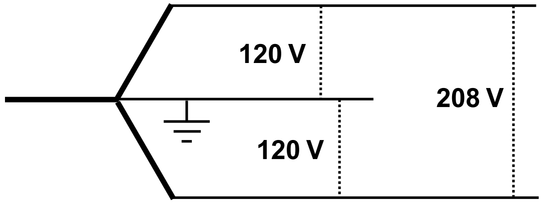
Common Distribution Circuits



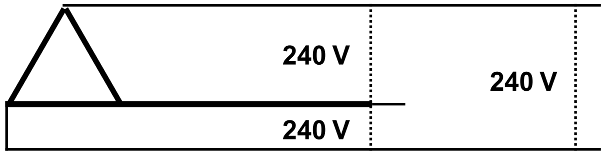
Two-Wire Single Phase



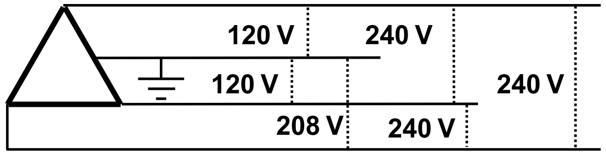
Three-Wire Single Phase



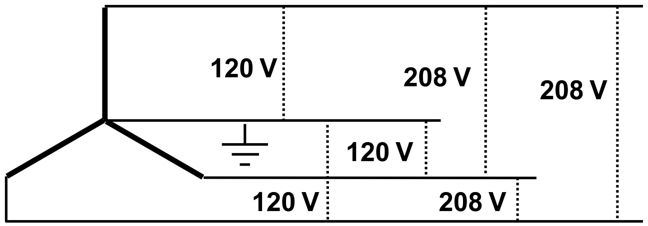
Three-Wire Network



Three-Wire Three Phase Delta



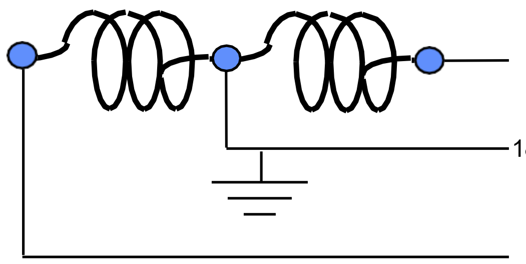
Four-Wire Three Phase Delta



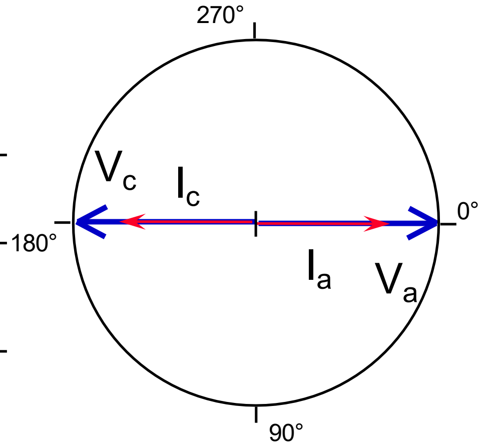
Four-Wire Three Phase Wye

1φ Expected Meter Phasors

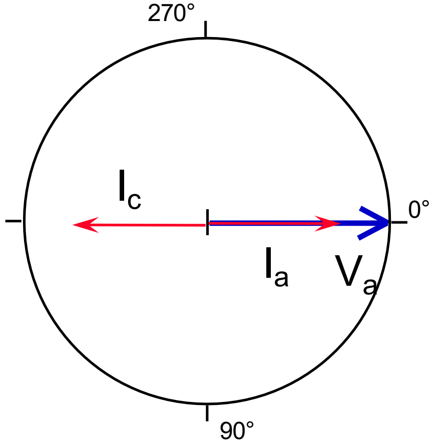
(BALANCED LOAD AT POWER FACTOR = 1, ABC PHASE SEQUENCE)



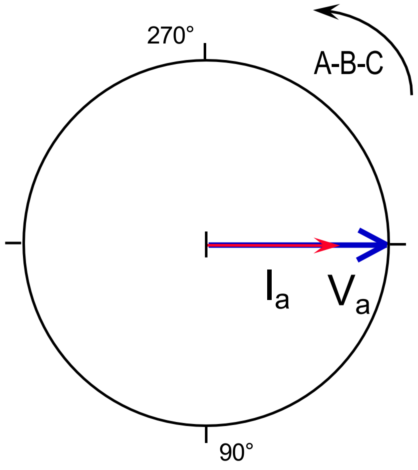
3 wire, 1 φ



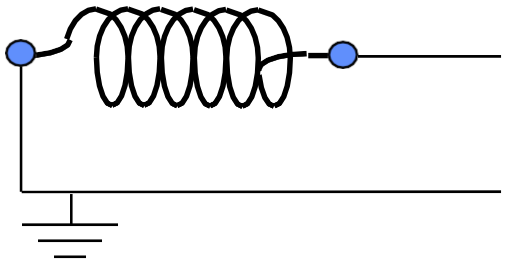
2 Element



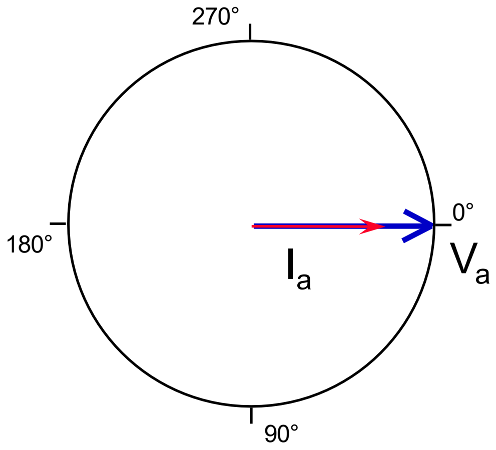
1½ Element



1 Element



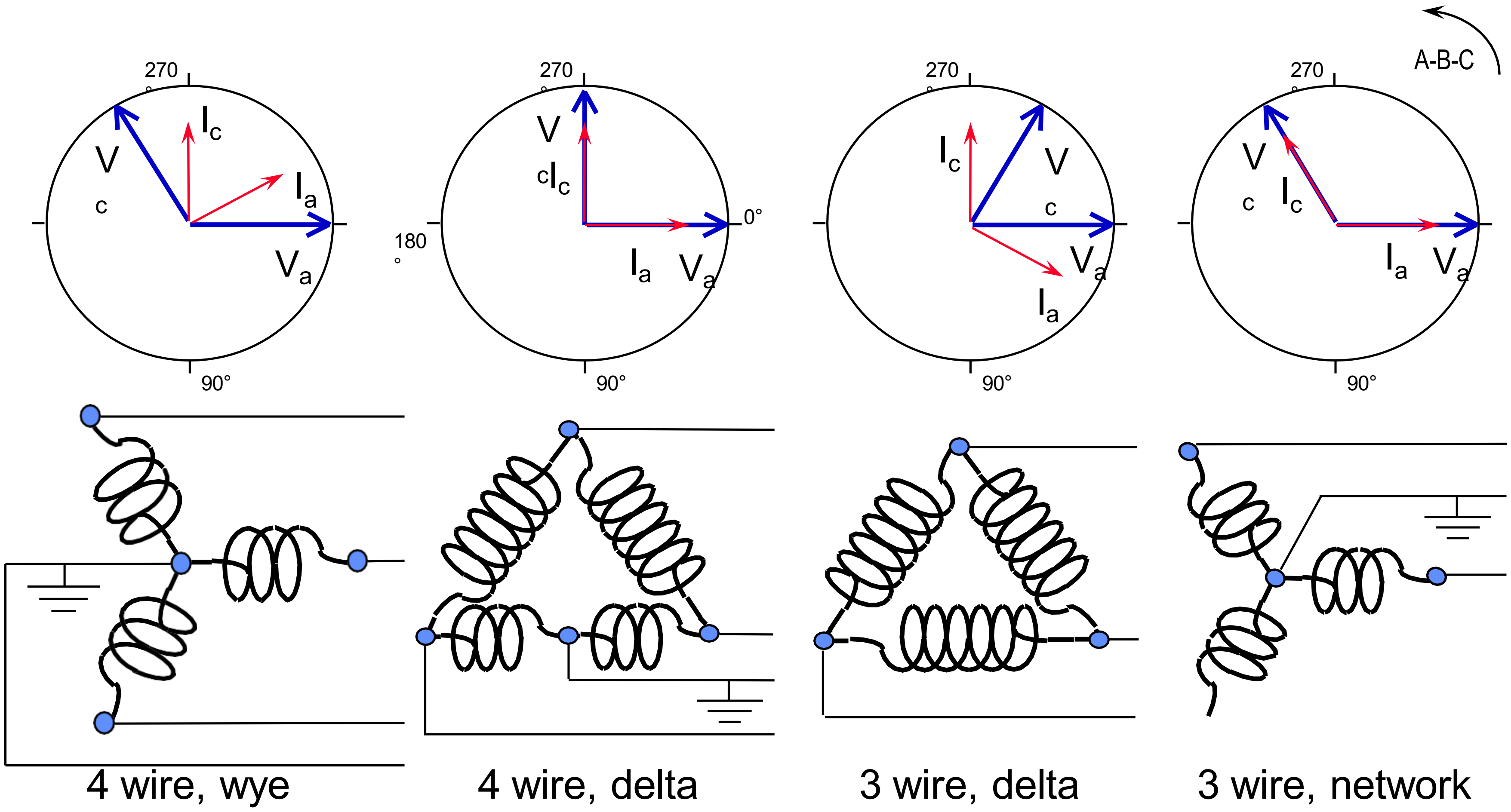
2 wire, 1 φ



1 Element

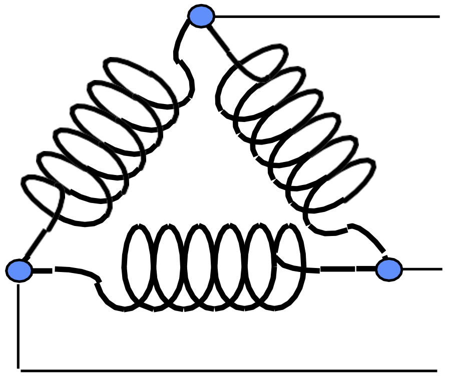
2 Element Expected Meter Phasors

(Balanced load at Power Factor = 1, ABC Phase Sequence)

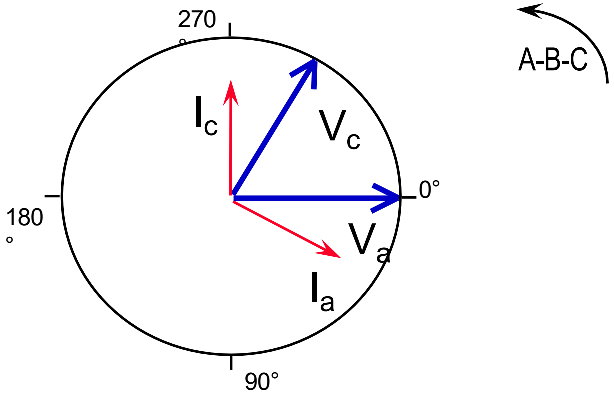


Expected Meter Phasors

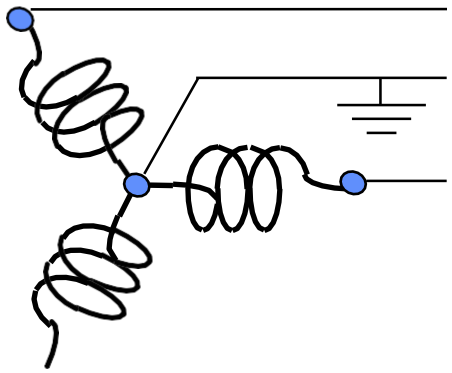
(AT POWER FACTOR = 1, ABC PHASE SEQUENCE)



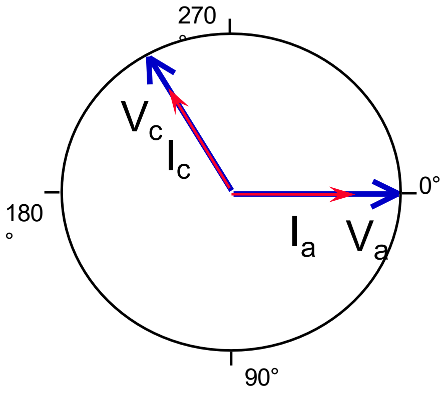
3 wire, delta



2 Element



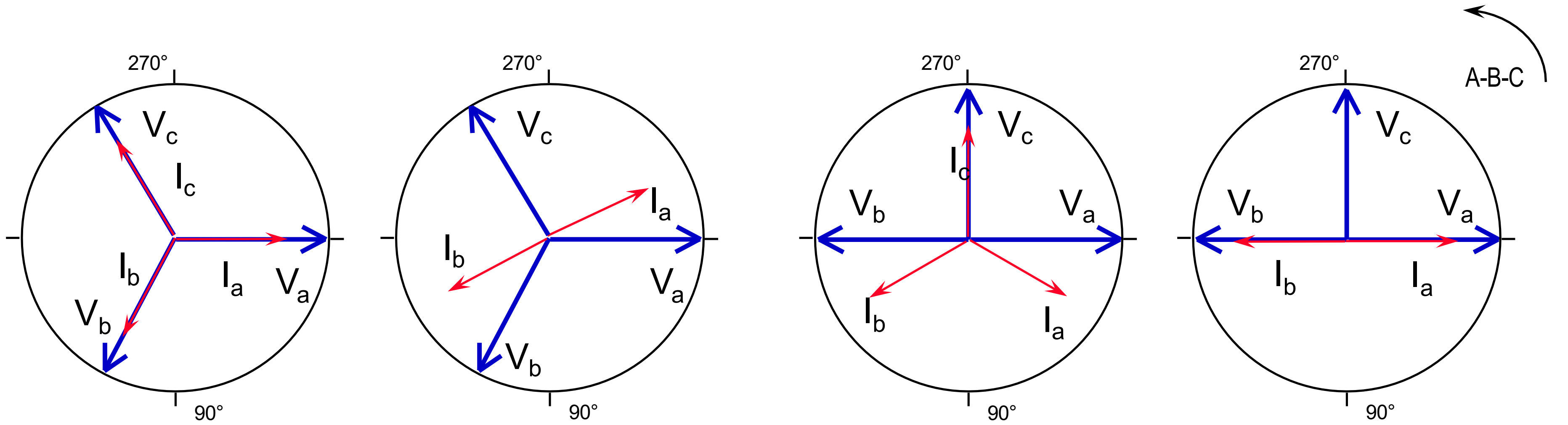
3 wire, network



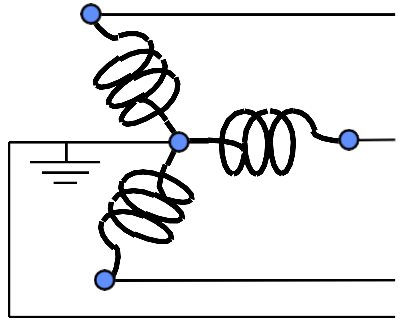
2 Element

3 Element Expected Meter Phasors

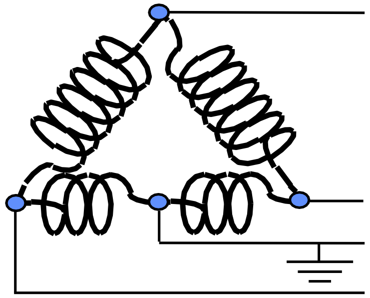
(AT POWER FACTOR = 1, ABC PHASE SEQUENCE)



Balanced Polyphase Load | Single phase Load Connected A to B | Balanced Polyphase Load | Single phase Load Connected A to B



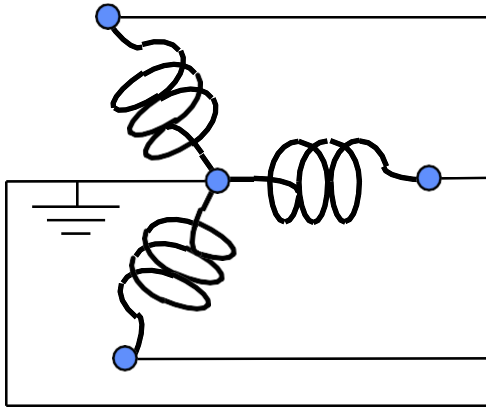
4 wire, wye



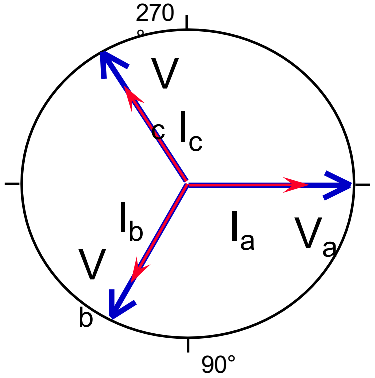
4 wire, delta

Expected Meter Phasors

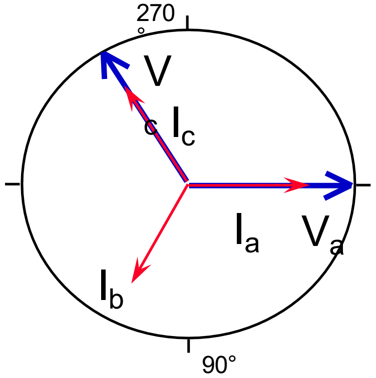
(AT POWER FACTOR = 1, ABC PHASE SEQUENCE)



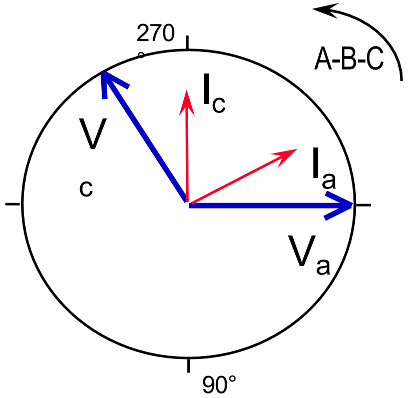
4 wire, wye



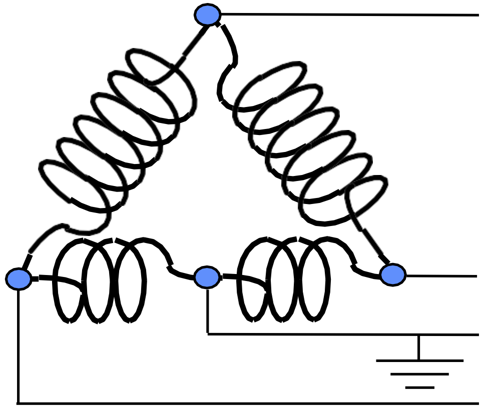
3 Element



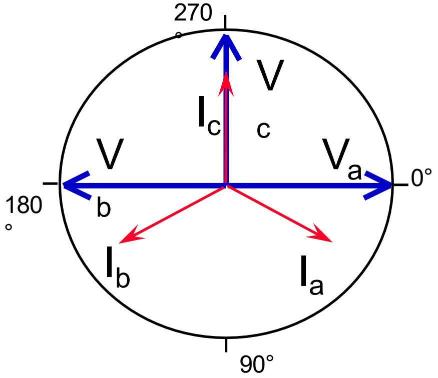
2½ Element



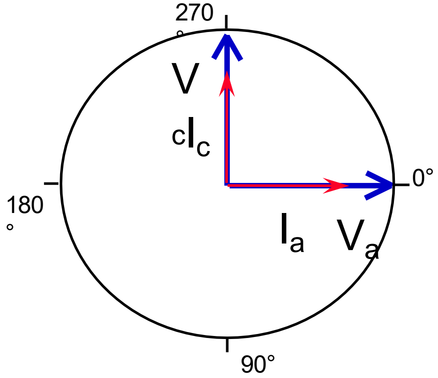
2 Element



4 wire, delta



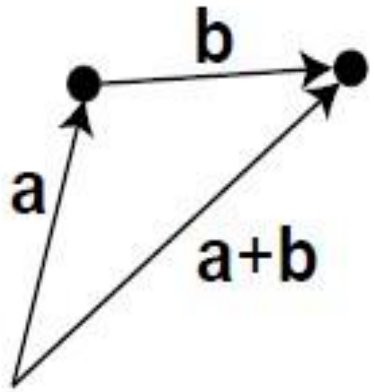
3 Element



2 Element

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

Vector Addition

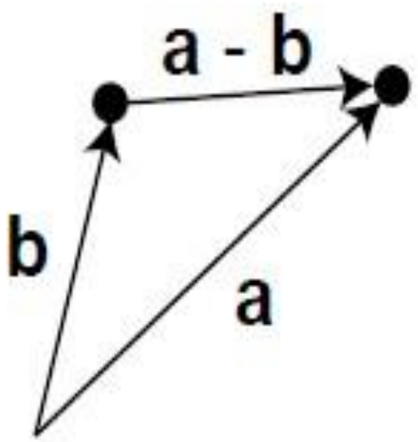


Addition of vectors can be expressed by a diagram. Placing the vectors end to end, the vector from the start of the first vector to the end of the second vector is the sum of the vectors. One way to think of this is that we start at the beginning of the first vector, travel along that vector to its end, 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 $a_y + b_y$.

Vector Subtraction

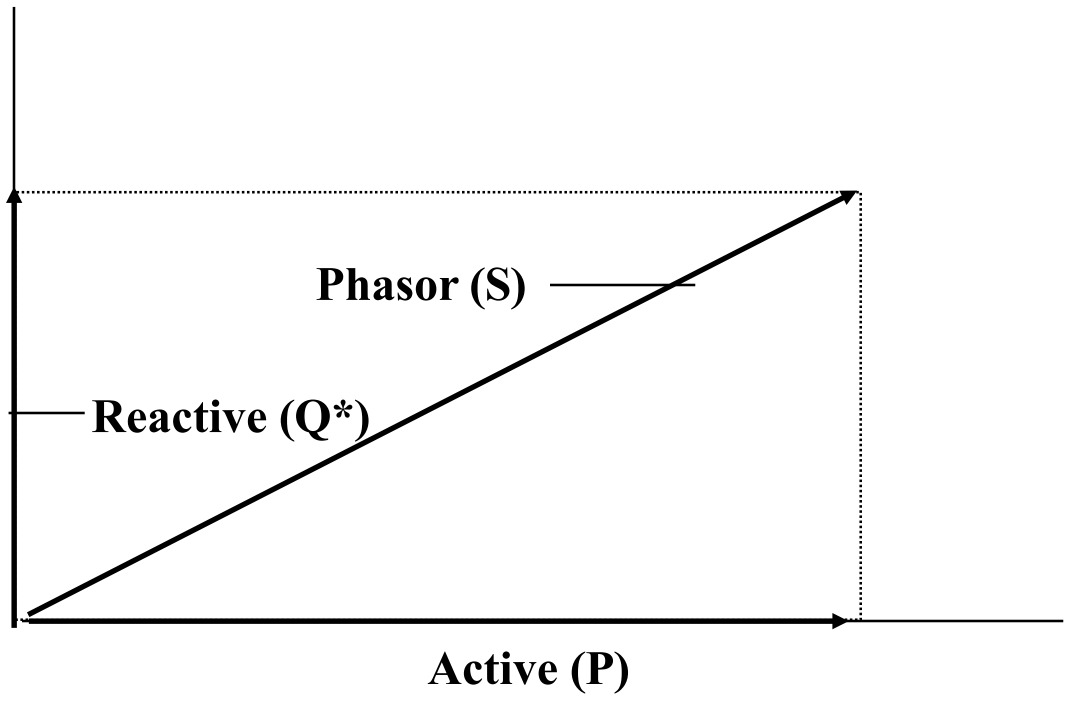


Subtraction of vectors can be shown in diagram form by placing the starting points of the two vectors together, and then constructing an arrow from the head of the second vector in the subtraction to the head of the first vector. Algebraically, we subtract corresponding terms:

Vector Subtraction

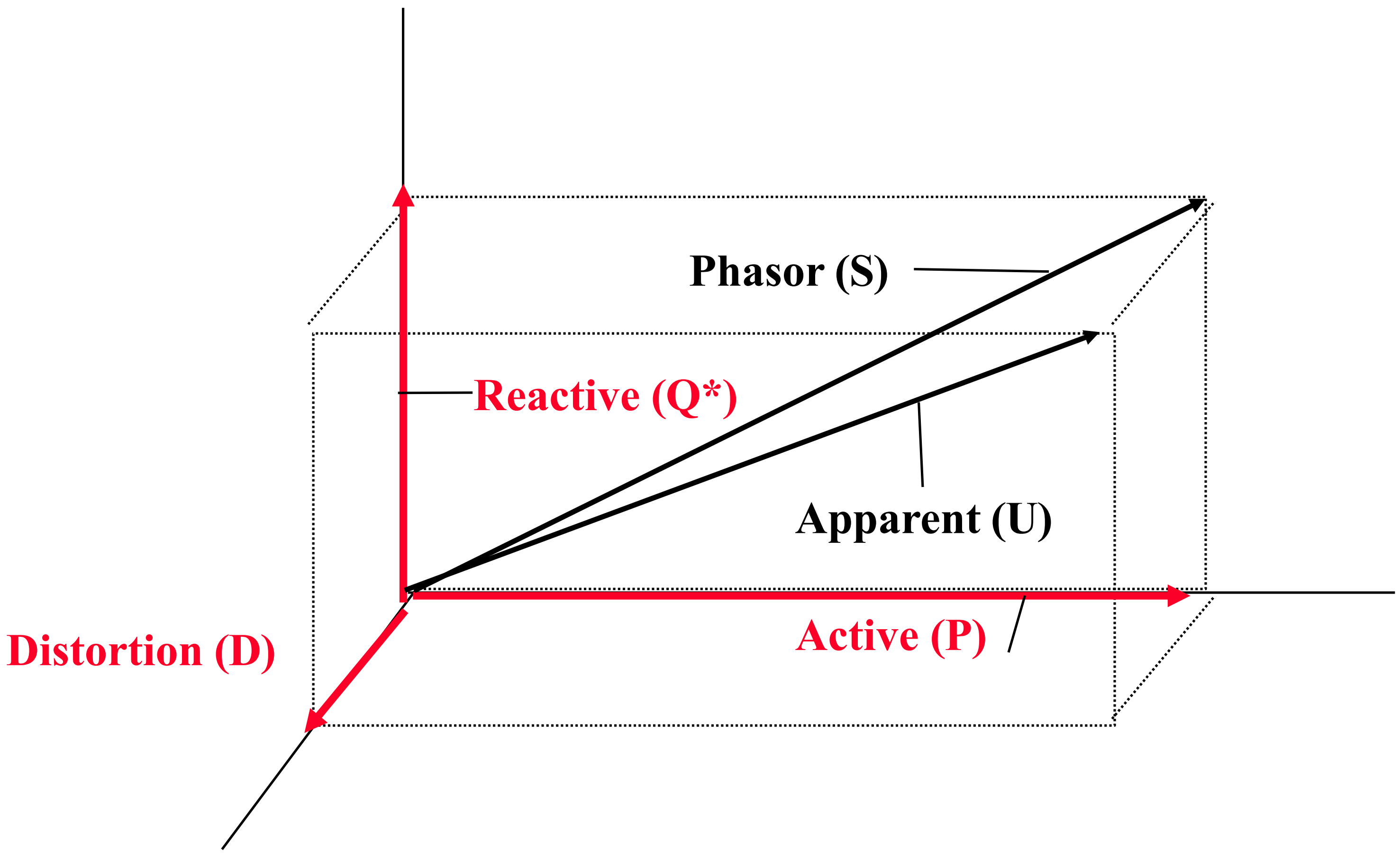
$$\mathbf{a} - \mathbf{b} = \begin{bmatrix} a_x \\ a_y \end{bmatrix} - \begin{bmatrix} b_x \\ b_y \end{bmatrix} = \begin{bmatrix} a_x - b_x \\ a_y - b_y \end{bmatrix}.$$

AC Powers



*Not the “Q” of Q-hour metering

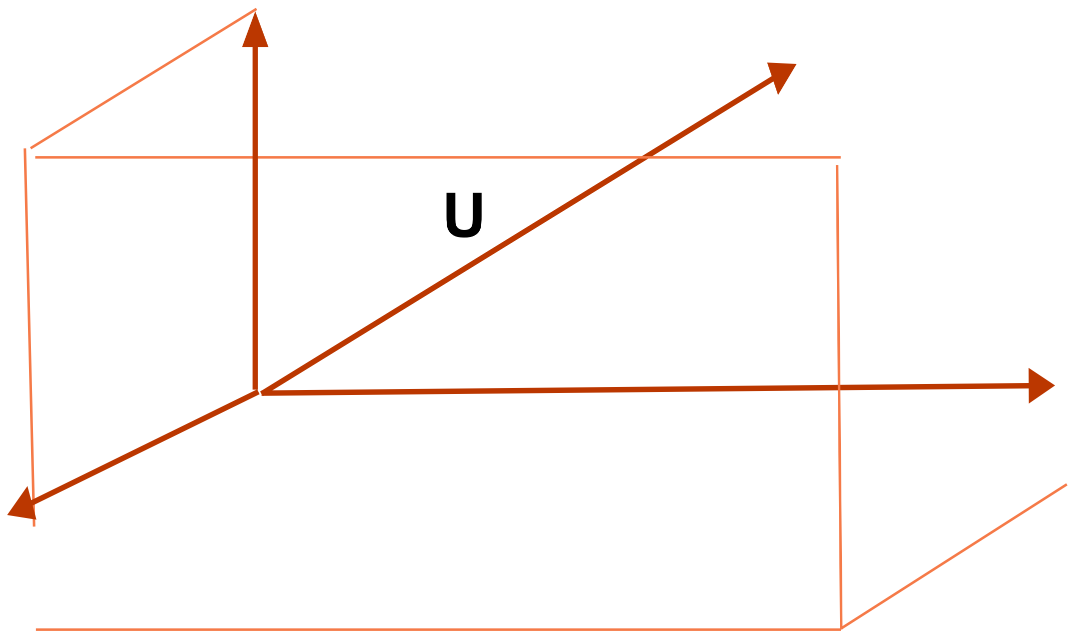
AC Powers



*Not the “Q” of Q-hour metering

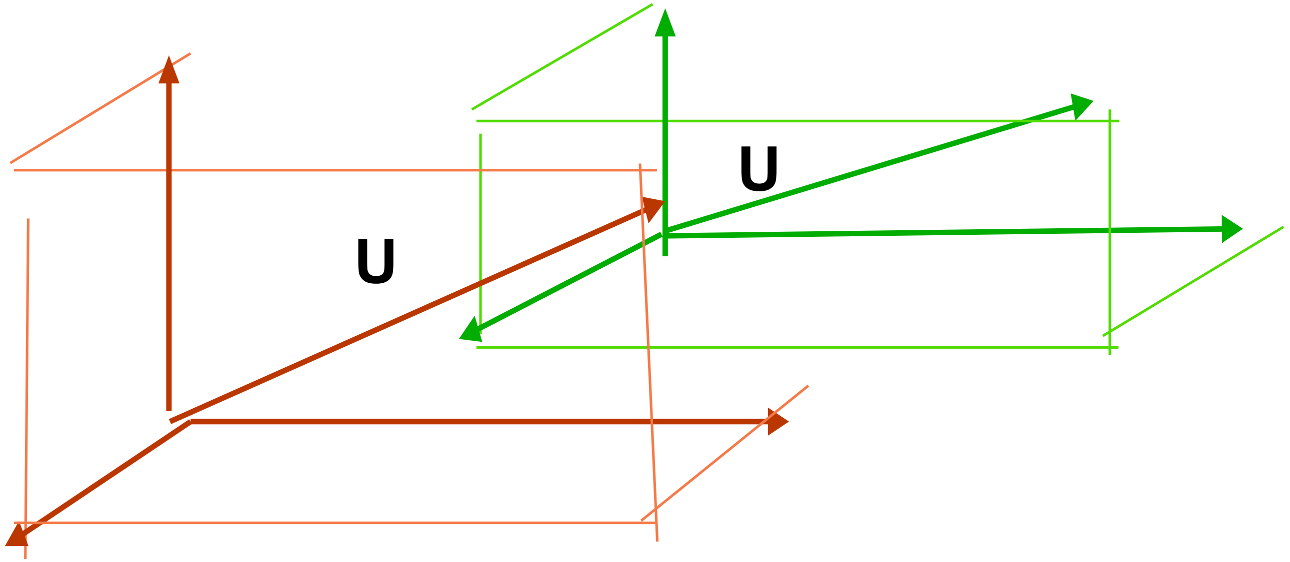
How is 3 Apparent Power calculated?

- **To calculate Apparent power (U), first add the components for the phases together.**



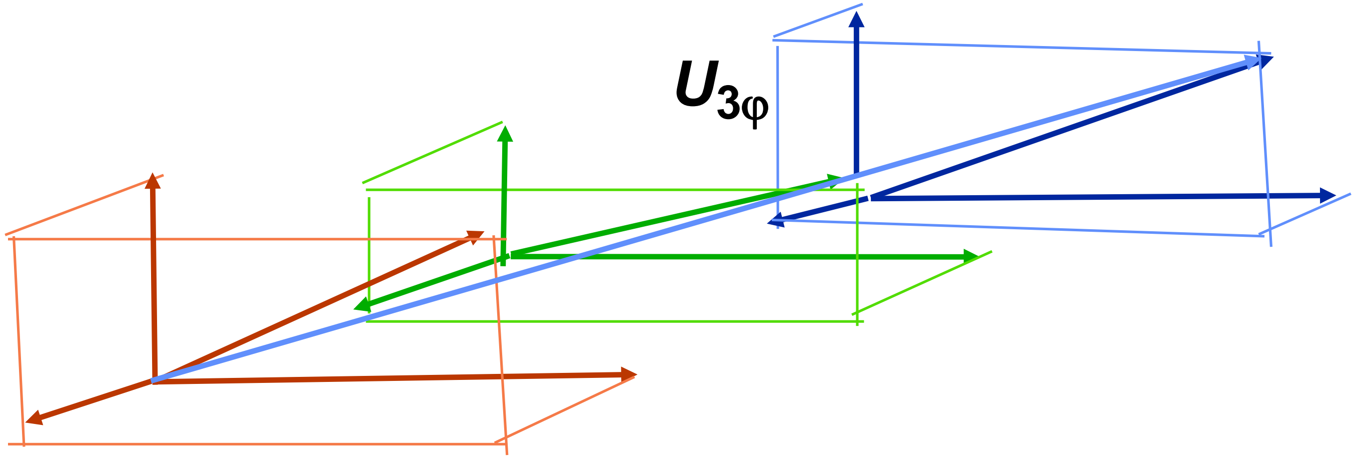
How is 3φ Apparent Power calculated?

- **To calculate Apparent power (U), first add the components for the phases together.**



How is 3φ Apparent Power calculated?

- **To calculate Apparent power (U), first add the components for the phases together, then solve for U.**



$$U_{3\varphi} = \sqrt{(P_A + P_B + P_C)^2 + (Q_A + Q_B + Q_C)^2 + (D_A + D_B + D_C)^2}$$

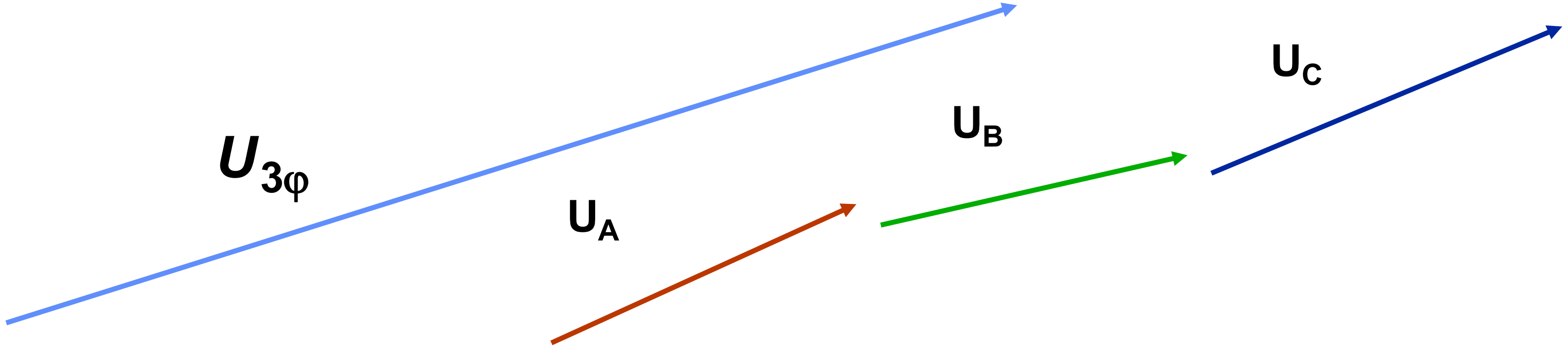
$$S = \sqrt{(P_A + P_B + P_C)^2 + (Q_A + Q_B + Q_C)^2}$$

$$U_{(arith)} = U_A + U_B + U_C$$

Apparent Power vs. Arithmetic Apparent Power

- **To calculate Apparent power (U), first add the components for the phases together, then solve for U.**

$$U_{3\varphi} = \sqrt{(P_A + P_B + P_C)^2 + (Q_A + Q_B + Q_C)^2 + (D_A + D_B + D_C)^2}$$



- **To calculate *Arithmetic* Apparent power, add the Apparent power magnitudes of the three individual phases.**

$$U_{Arithmetic} = U_A + U_B + U_C$$

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All KVAs are not Created Equal

Power Calculations

POWERS		Phase A	Phase B	Phase C	Total Active
	(P)	3626.4	2880.0	2833.0	9339.4
Reactive	(Q)	317.3	2146.0	2112.0	4575.3
Distortion	(D)	0.0	1102.6	1784.5	2887.1
Apparent	(U)	3640	3757	3959	

PHASOR	(S)	$(VA)_{Total}$ =	10,400	PF = 89.8
APPARENT	(U)	$(VA)_{Total}$ =	10,793	PF = 86.5
ARITH.	(U_{arth})	$(VA)_{Total}$ =	11,356	PF = 82.2

- **Which "kVA" calculation method is correct?**
  - They all are "correct", by definition.
  - Each utility needs to decide which value is appropriate for their own needs.
  - Phasor Power is what results from calculations based on traditional kWh and kvarh meter readings, using a Phase- Shifting Transformer.
  - Apparent Power provides more complete picture of "cost of service", expected answers under all conditions.
  - Arithmetic Apparent Power may provide unexpected results (low PF, high kVA) for asymmetrical or unbalanced conditions.

Phase "X" Formulae

RMS Potential,	$E_X = \sqrt{\sum_{h=1}^{H} E_{Xh}^2}$	$(Volts)$
RMS Current,	$I_X = \sqrt{\sum_{h=1}^{H} I_{Xh}^2}$	$(Amperes)$
Apparent Power,	$U_X = E_X I_X$	(kVA)
Active Power,	$P_X = \sum_{h=1}^{H} E_{Xh} I_{Xh} \cos(\alpha_{Xh} - \beta_{Xh})$	(kW)
Reactive Power,	$Q_X = \sum_{h=1}^{H} E_{Xh} I_{Xh} \sin(\alpha_{Xh} - \beta_{Xh})$	$(k\,\text{var})$
Distortion Power,	$D_X = \pm\sqrt{U_X^2 - P_X^2 - Q_X^2}$	(kVA)
Phasor Power,	$S_X = +\sqrt{P_X^2 + Q_X^2}$	(kVA)
Fictitious Power,	$F_X = +\sqrt{U_X^2 - P_X^2}$	(kVA) (a.k.a. "Fuzzy vars")
Nonreactive Power,	$N_X = +\sqrt{U_X^2 - Q_X^2}$	(kVA)

E_{xh} and I_{xh} are the RMS voltage and amperage of harmonic h. α_{xh} and β_{xh} are the phase angles of the voltage and current of harmonic h with respect to the reference time-frame. H is the highest harmonic ordinal.

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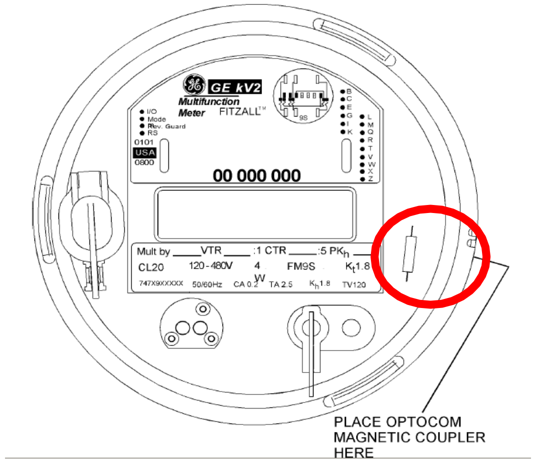
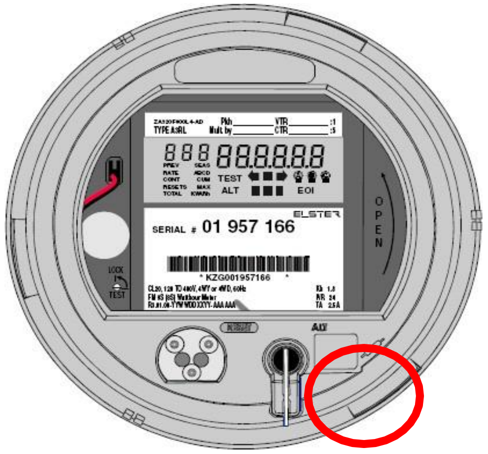
Different Meters

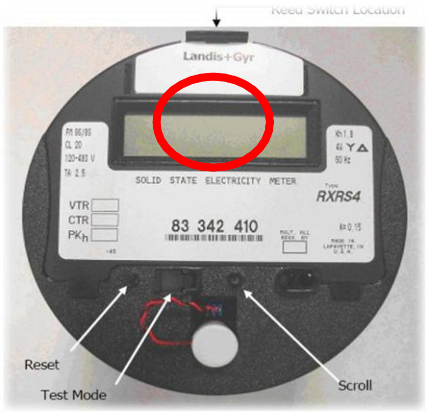
Aclara kV2c Meter



Honeywell A3



Landis + Gyr S4e



Itron Sentinel

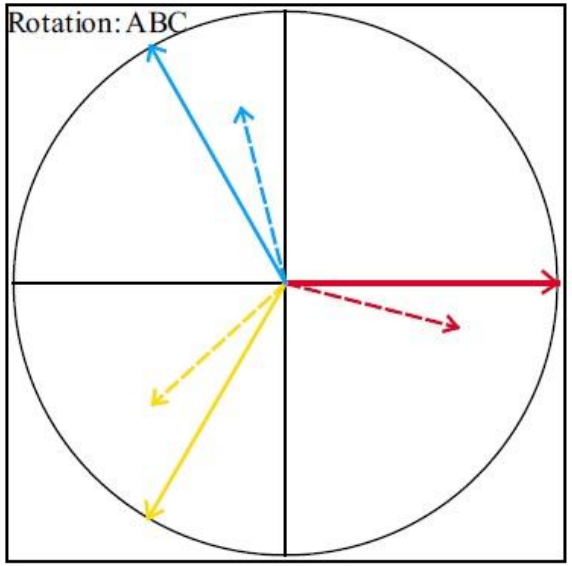
Sensus Icon APX

Phase Rotation & Site Measurements

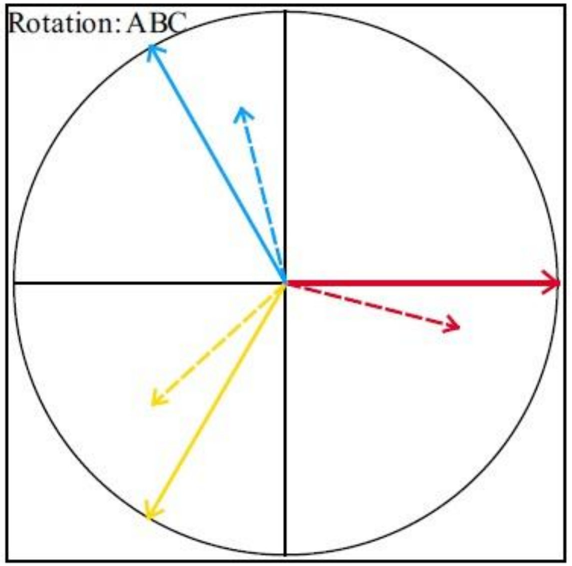
Site Measurements

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

Course Feedback

Please Take a Few Minutes To Provide Feeback About The Course & Instructor

Track 2 - Practical Use of Vectors in Electric Metering 72225 8:45AM
Carl Chermak

Questions?

Carl Chermak

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