Introduction to Power Factor

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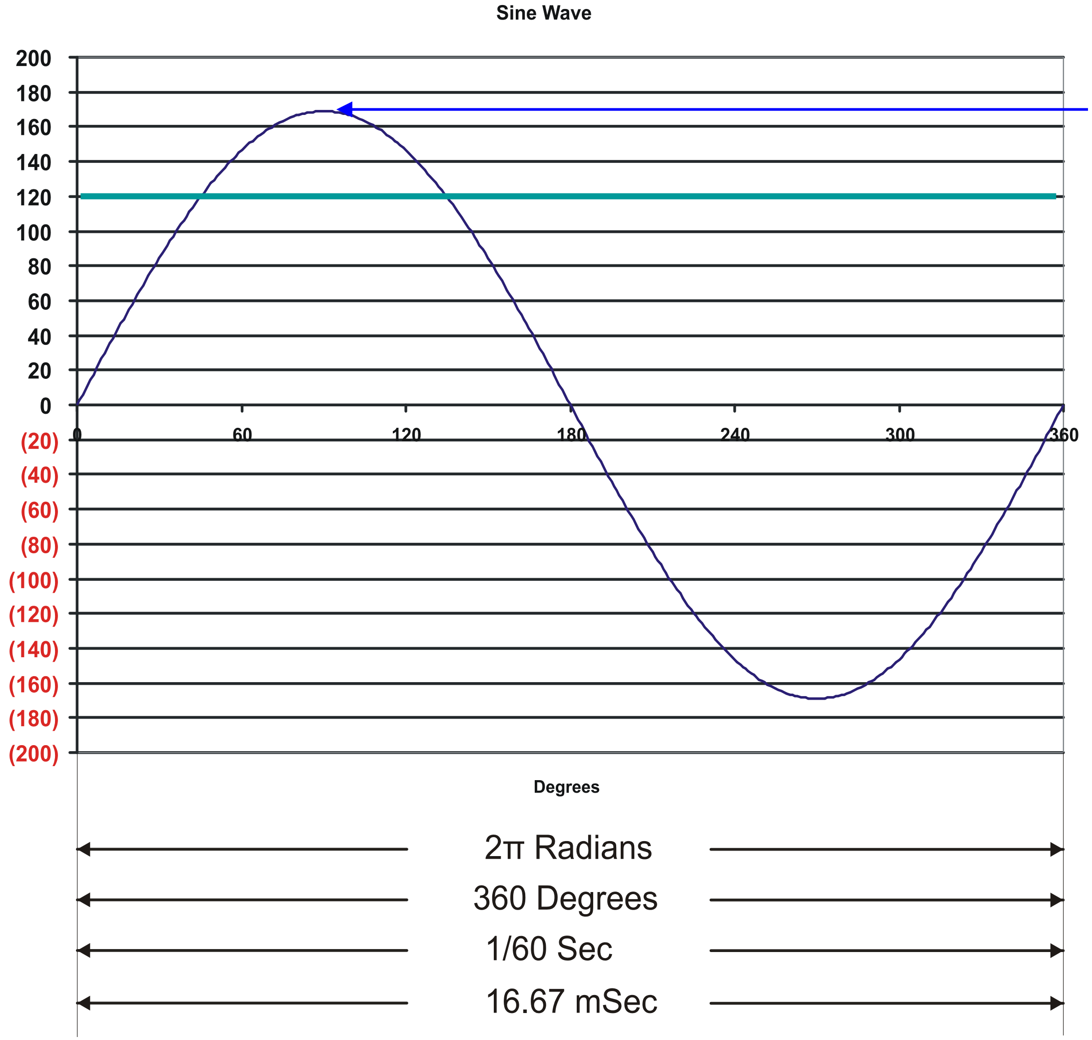
Focus of this Presentation

- Review basic power concepts as they relate to Power Factor (PF)
- Show how resistive, inductive, and capacitive loads affect PF
- Give examples of PF calculations for wye and delta service types

AC Theory Review – Sine Wave



$$V = V_{pk} Sin(2\pi ft - \theta)$$

$$V_{pk} = \sqrt{2} V_{rms}$$

$$V_{rms} = 120V$$

$$V_{pk} = 169V$$

$$\theta = 0°$$

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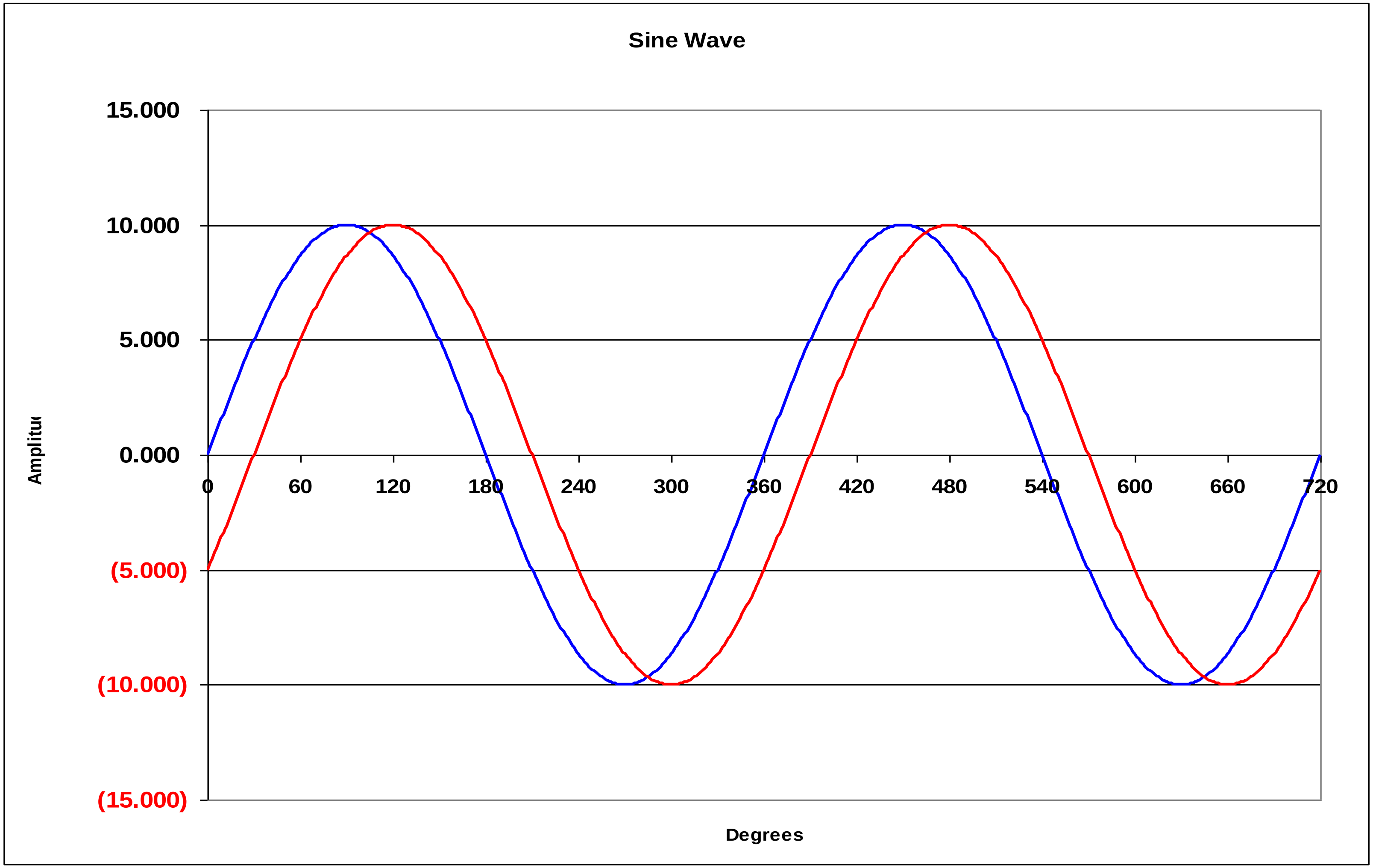
AC Theory Review - Phase



$$V = 10Sin(2\pi ft)$$

$$V = 10Sin(2\pi ft - 30)$$

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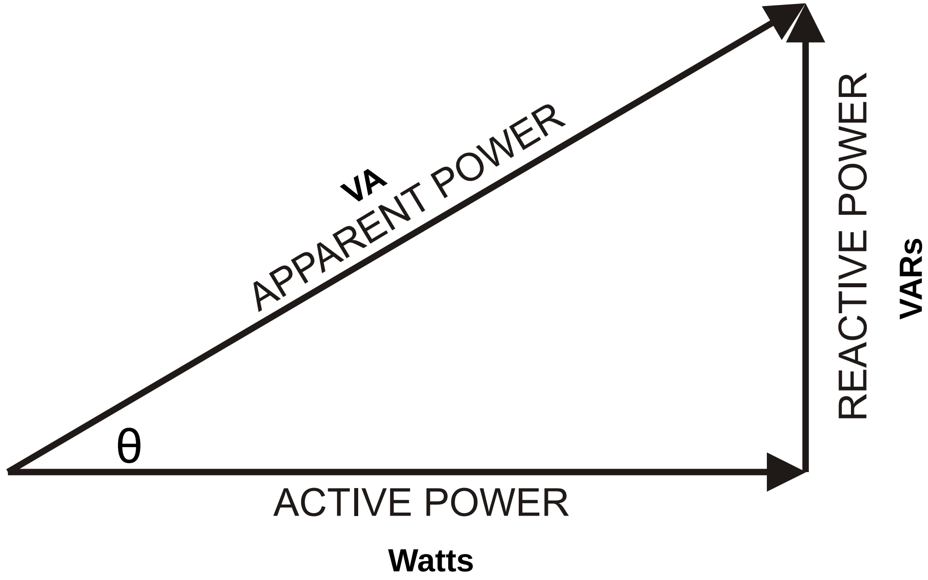
Power Triangle

(Sinusoidal Waveforms)



If V = Sin(ωt) and I = Sin(ωt - θ) (the load is linear)
then

Active Power =	VI*Cos*(θ)	Watts
Reactive Power =	VI*Sin*(θ)	Volt-Amp Reactive (VAR)
Apparent Power =	VI	Volt-Amp (VA)

Watt, VAR, and VA

Watt - useful power that does real work at the load – light a bulb or turn a motor

VAR – non-useful power that is required to drive the inductance or capacitance of a power line

VA – the total power in the system; the vector sum of Watts and VARs

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Watt, VAR, and VA

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Power Factor Definition:

Power Factor represents the ratio of active power (Watts) to the total power (VA) in a system.

It is a representation of the percentage of useful work being done.

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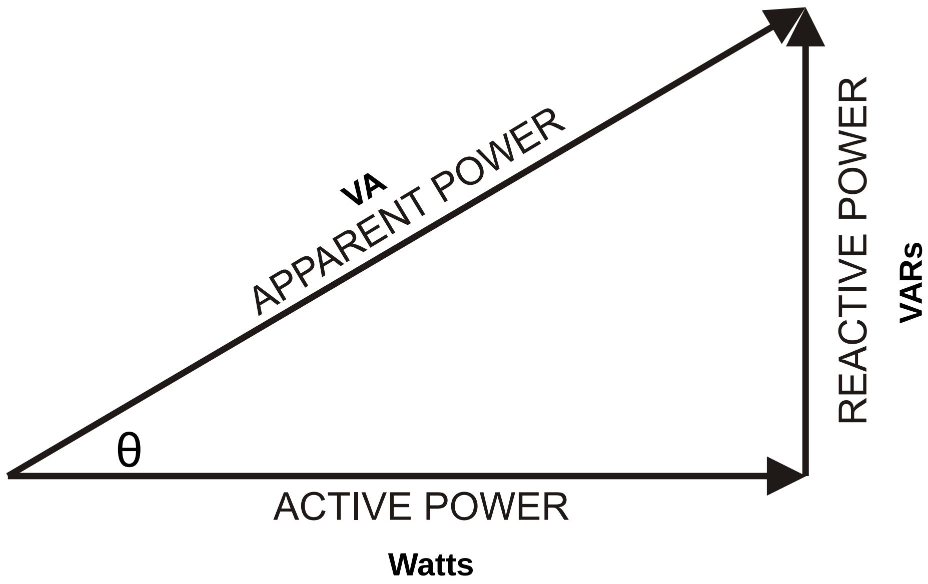
Power Factor Definition



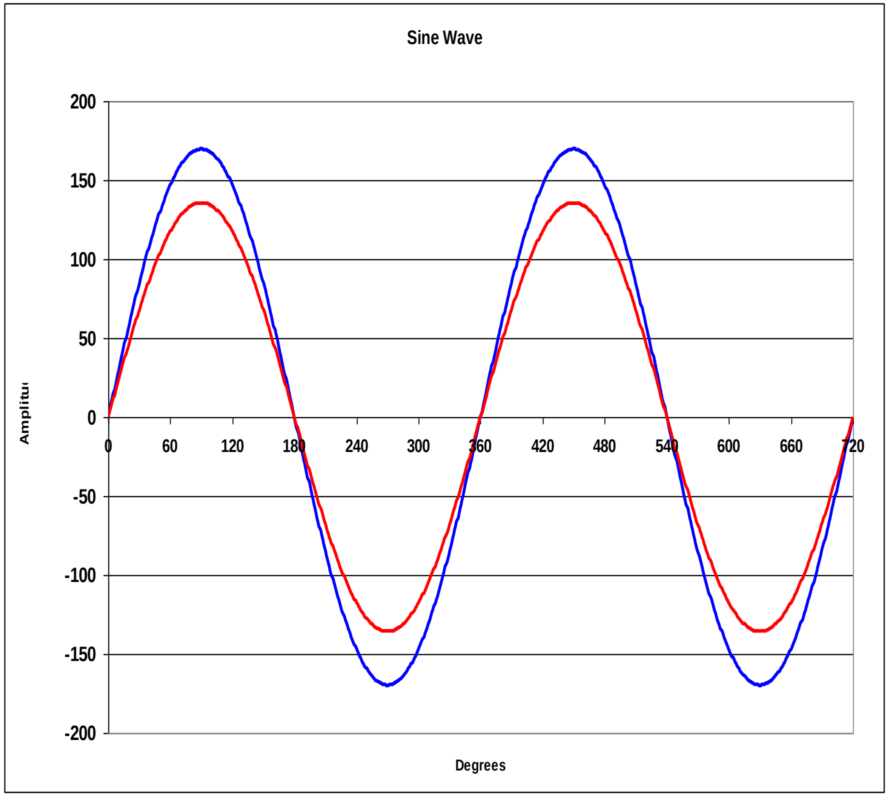
Power Factor = Active / Apparent Power

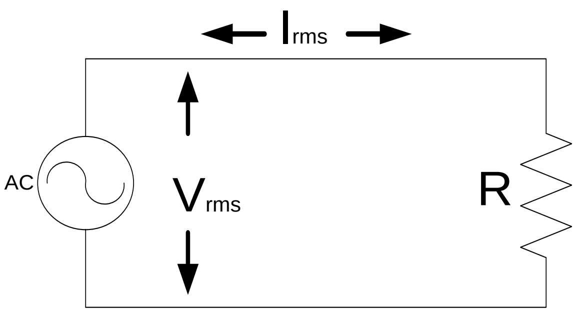
= Watts / VA

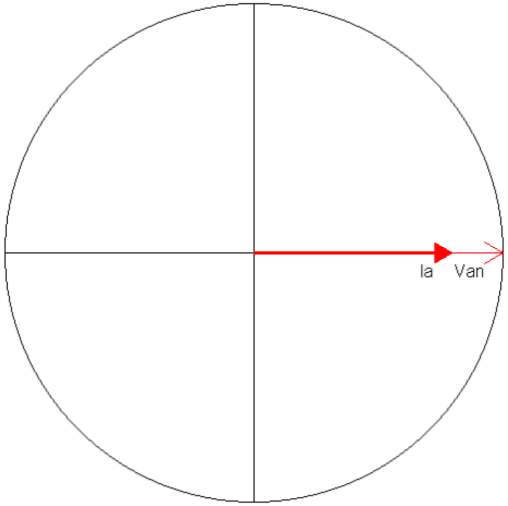
= $Cos(\theta)$

Power Factor can range from 1 to 0

Resistive Load

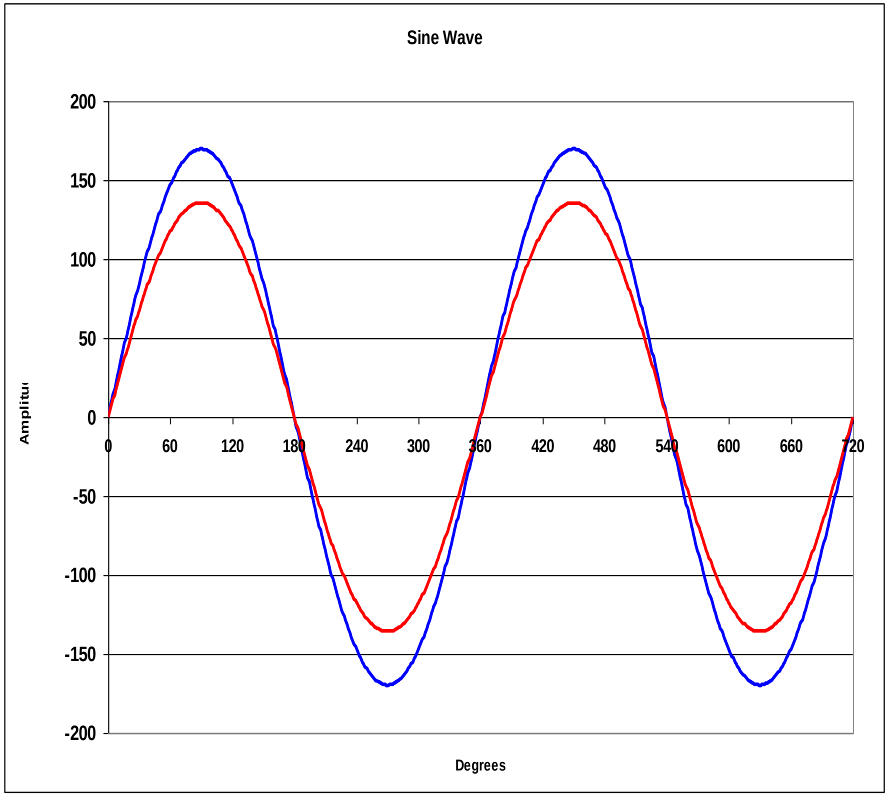


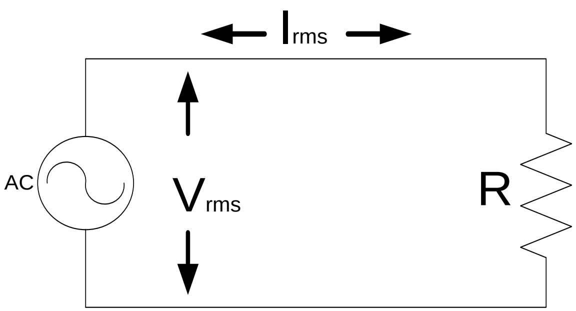




A purely resistive load has ZERO phase angle

Resistive Load





Resistive Example:
V = 120V
I = 10A
Θ = 0°
Cos 0° = 1
Sin 0° = 0

Active Power (W) = V I cos (θ) = 120 * 10 * 1 = 1200 W
Reactive Power (VAR) = V I sin (θ) = 120 * 10 * 0 = 0 VAR
Apparent Power (VA) = V I = 120 * 10 = 1200 VA

PF = W / VA = cos (θ) = 1

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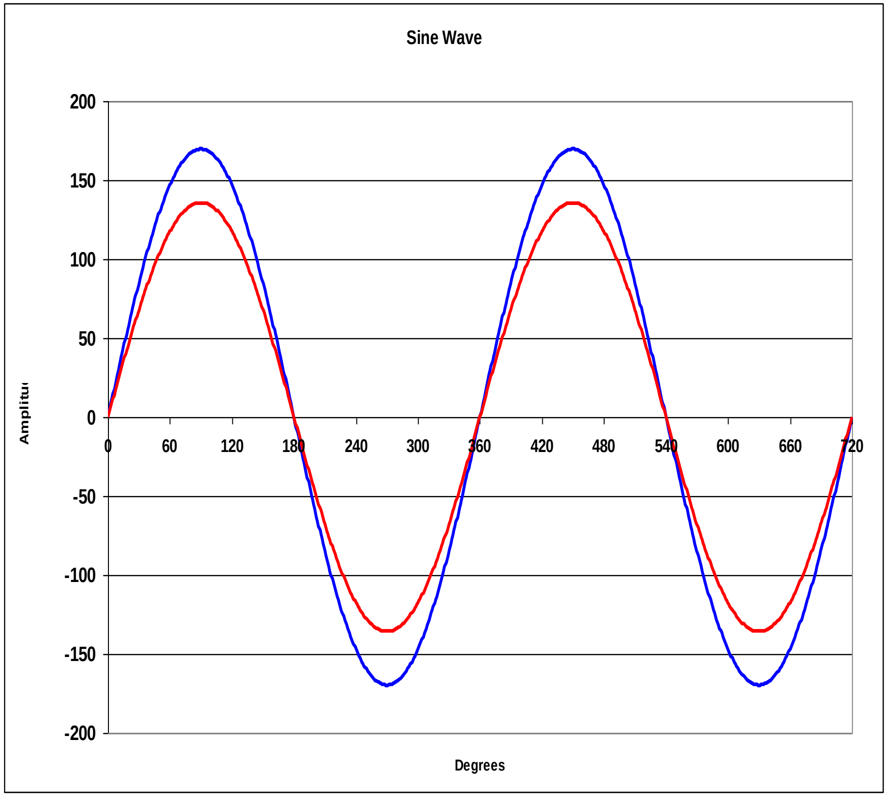
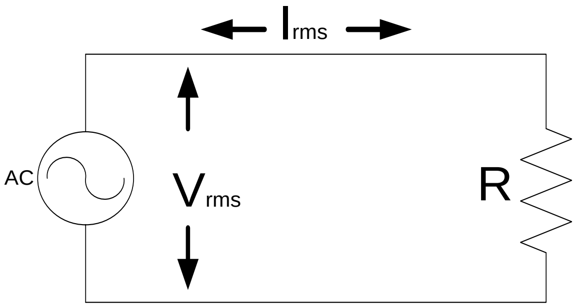
Resistive Load



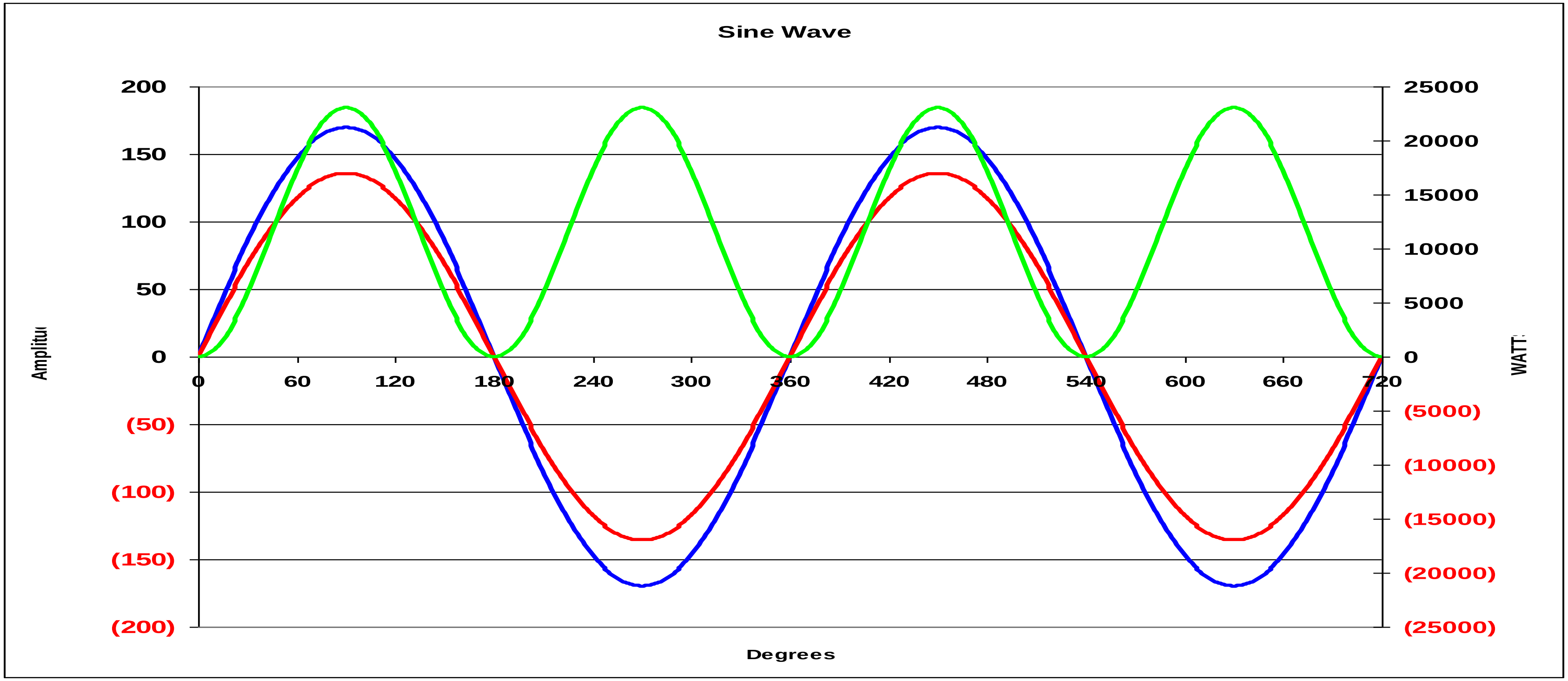


A purely resistive load will:

- Only create Watts
- Create NO VARs
- Have a PF = 1

Resistive Load

For a resistive load: $p = vi = 2VISin^2(\omega t) = VI(1 - Cos(2\omega t))$



A resistive load consumes only Watts, so the power will always be delivered (positive).

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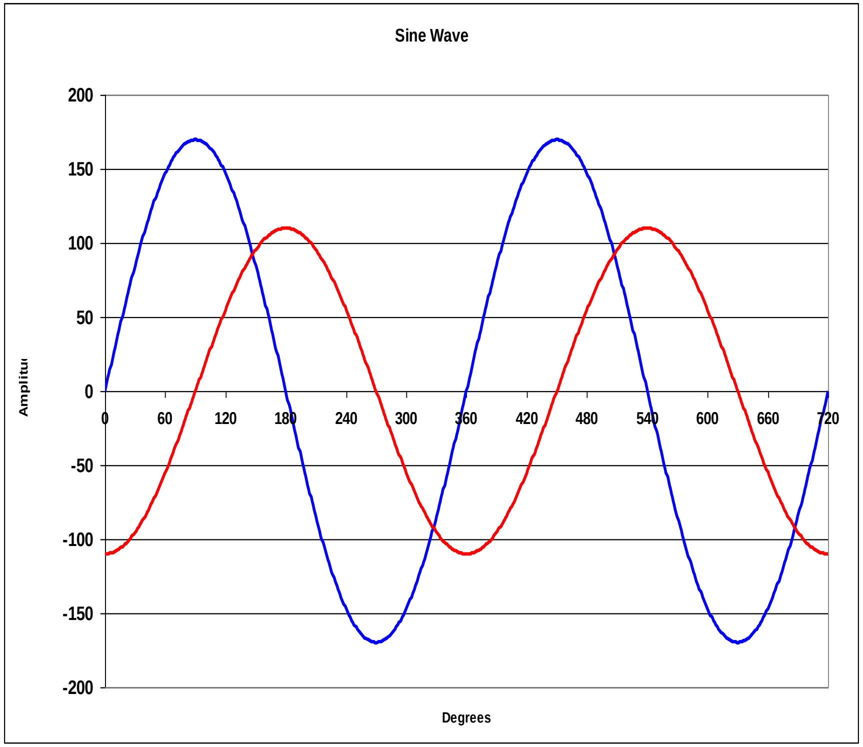
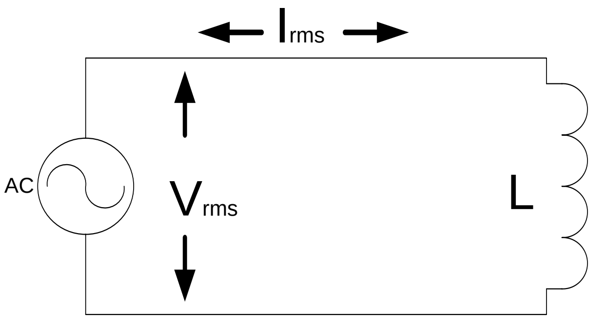
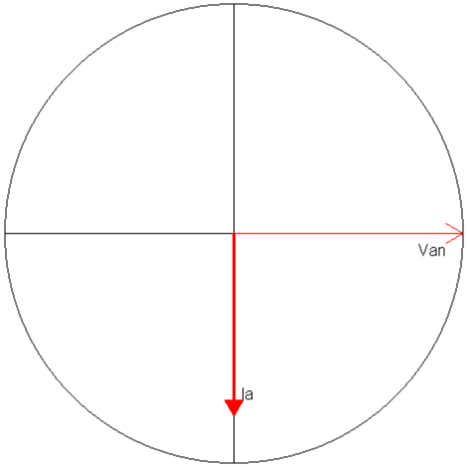
Inductive Load

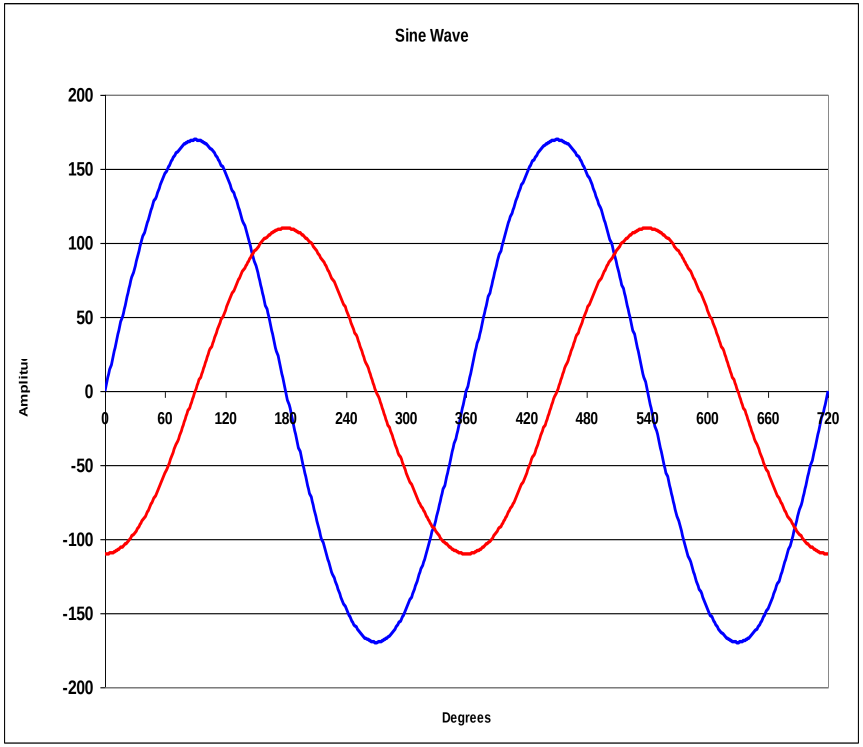


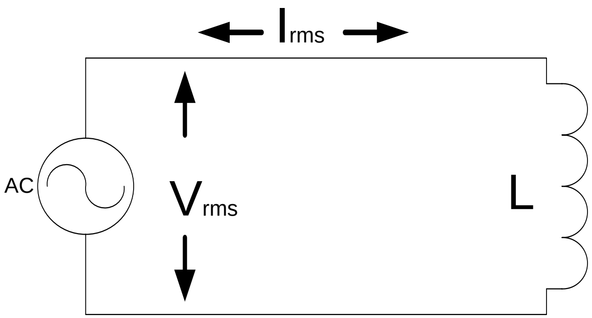




A purely inductive load has +90° phase angle

Inductive Load





Inductive Example:
V = 120V
I = 10A
Θ = 90°
Cos 90° = 0
Sin 90° = +1

Active Power (W) = V I cos (θ) = 120 * 10 * 0 = 0 W
Reactive Power (VAR) = V I sin (θ) = 120 * 10 * +1 = +1200 VAR
Apparent Power (VA) = V I = 120 * 10 = 1200 VA

PF = W / VA = cos (θ) = 0

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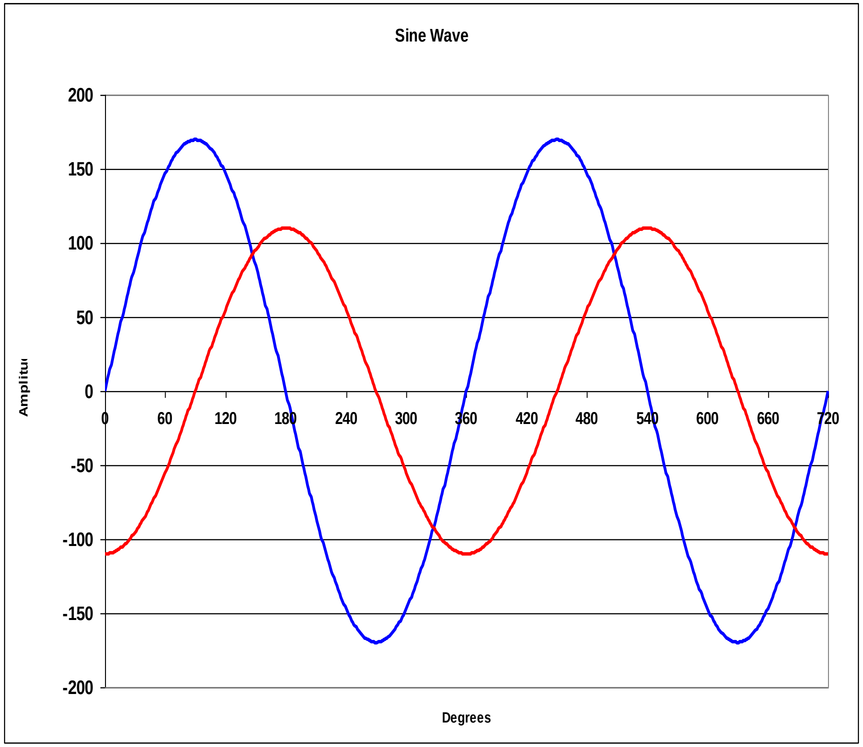
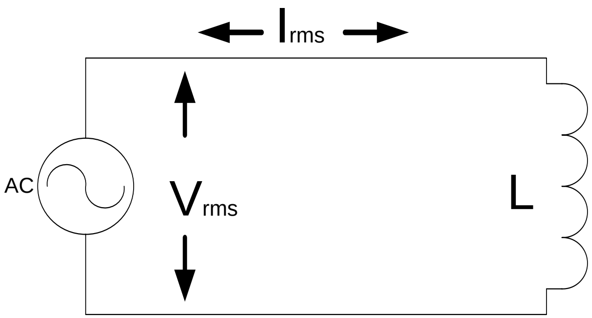
Inductive Load





A purely inductive load will:

- Only create positive VARs
- Create NO Watts
- Have a PF = 0

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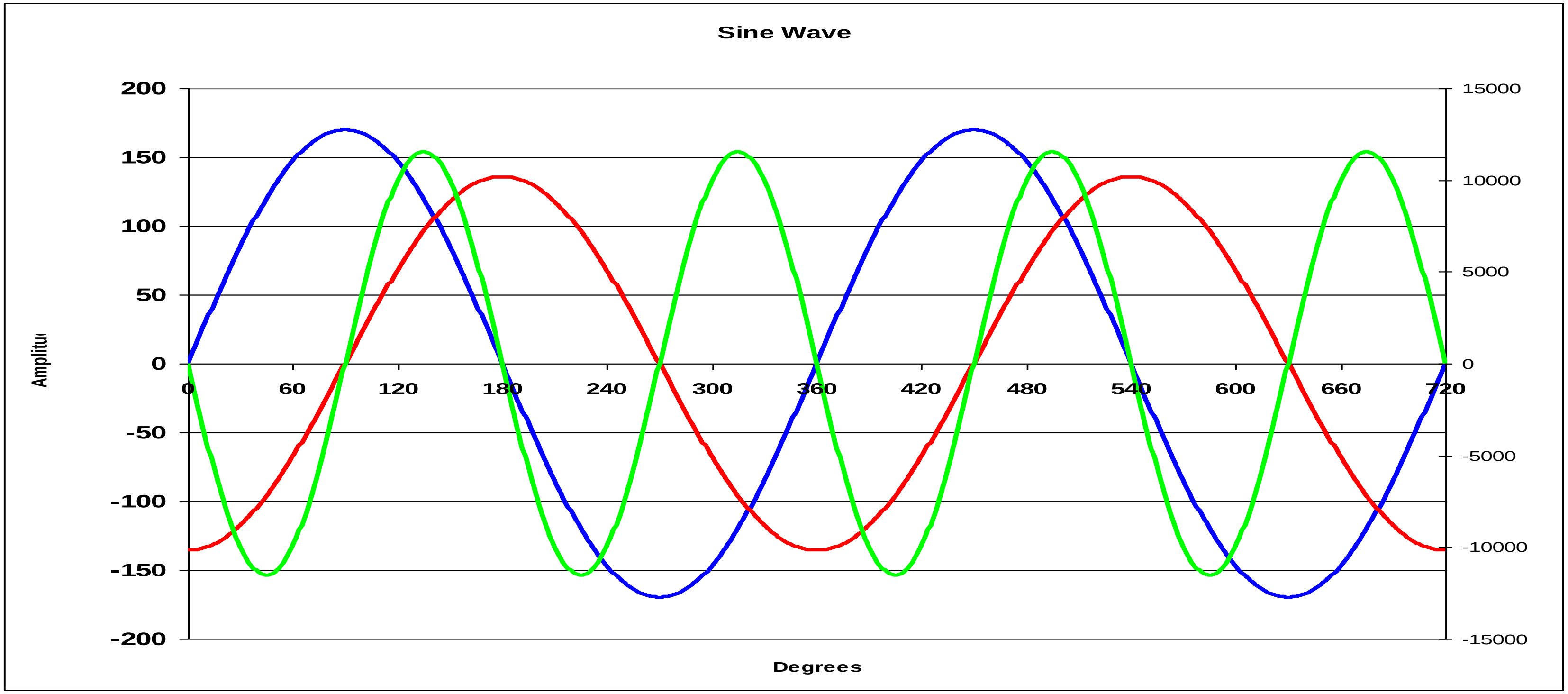
Inductive Load

For an inductive load: $p = vi = 2VISin(\omega t)Sin(\omega t - 90) = -VISin(2\omega t)$



An inductive load consumes receives and delivers equal amounts of power, so the net active power (Watts) is ZERO And the reactive load is 100%!

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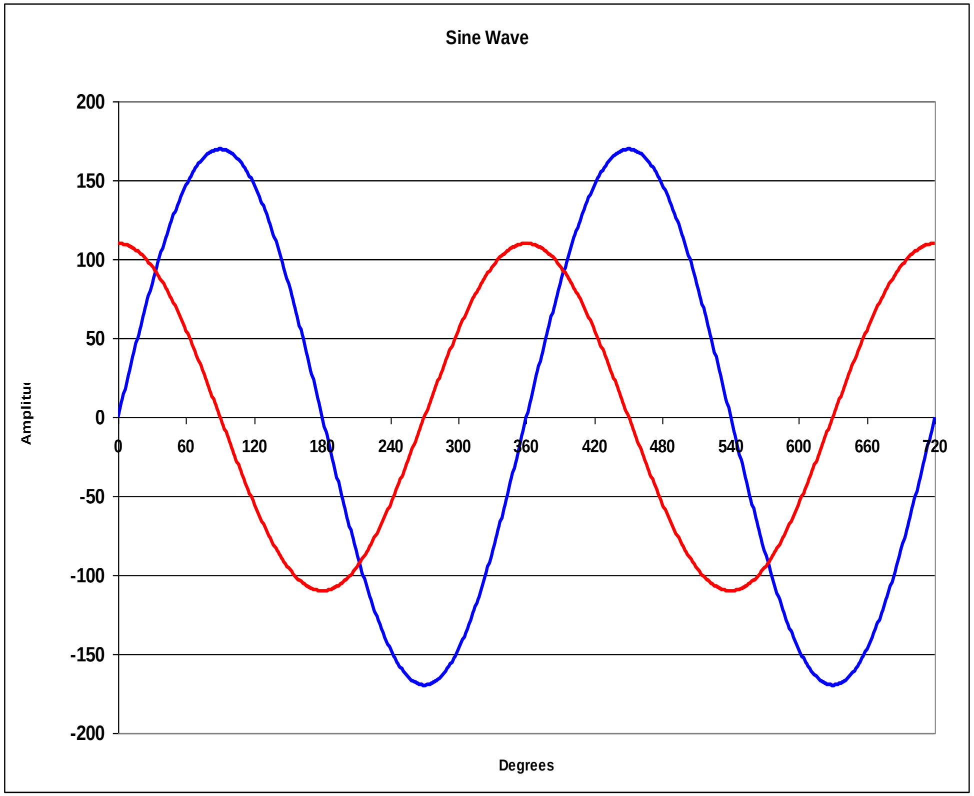
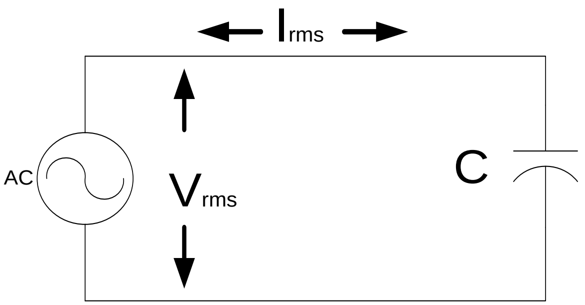
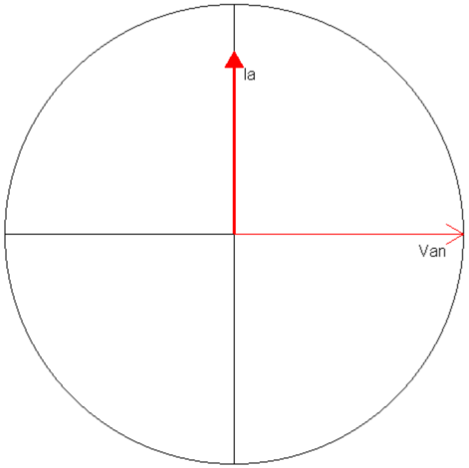
Capacitive Load

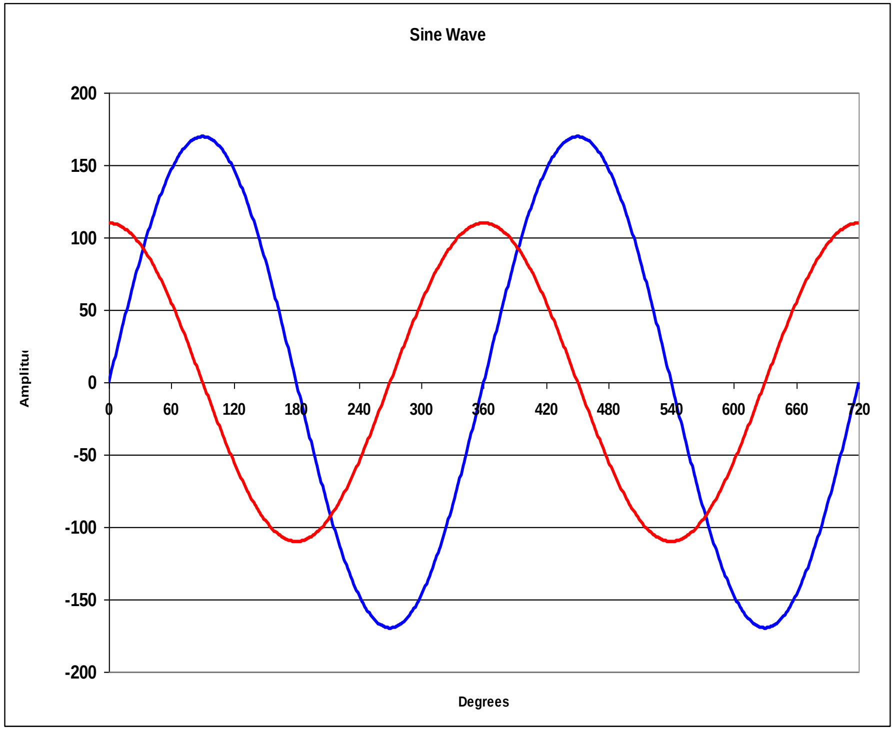


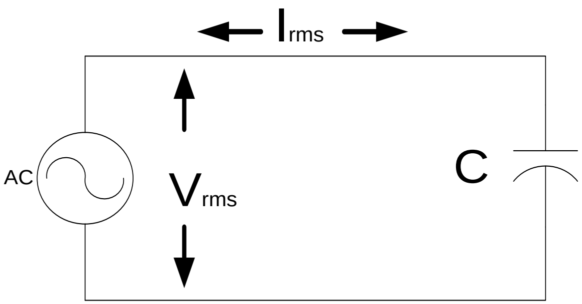




A purely capacitive load has -90° phase angle

Capacitive Load





Inductive Example:
V = 120V
I = 10A
Θ = -90°
Cos -90° = 0
Sin -90° = -1

Active Power (W) = V I cos (θ) = 120 * 10 * 0 = 0 W
Reactive Power (VAR) = V I sin (θ) = 120 * 10 * -1 = -1200 VAR
Apparent Power (VA) = V I = 120 * 10 = 1200 VA

PF = W / VA = cos (θ) = 0

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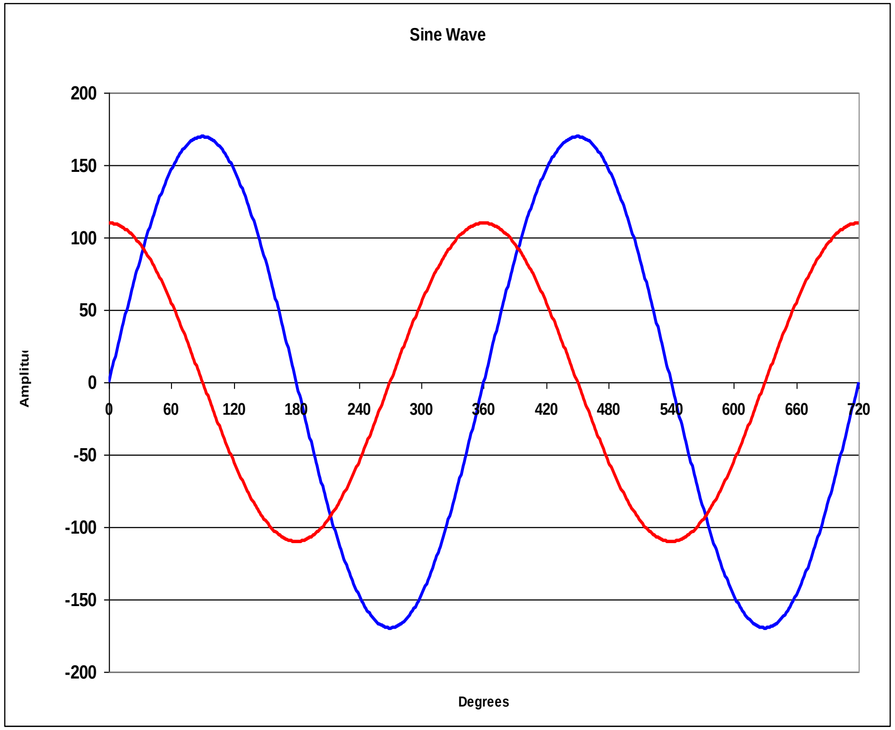
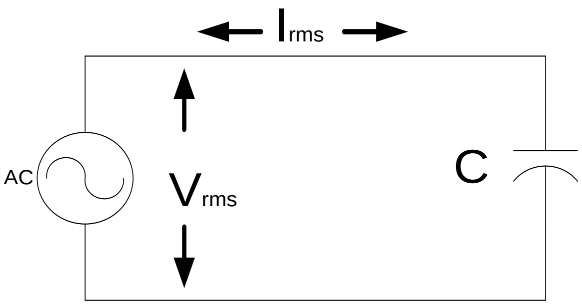
Capacitive Load





A purely capacitive load will:

- Only create negative VARs
- Create NO Watts
- Have a PF = 0

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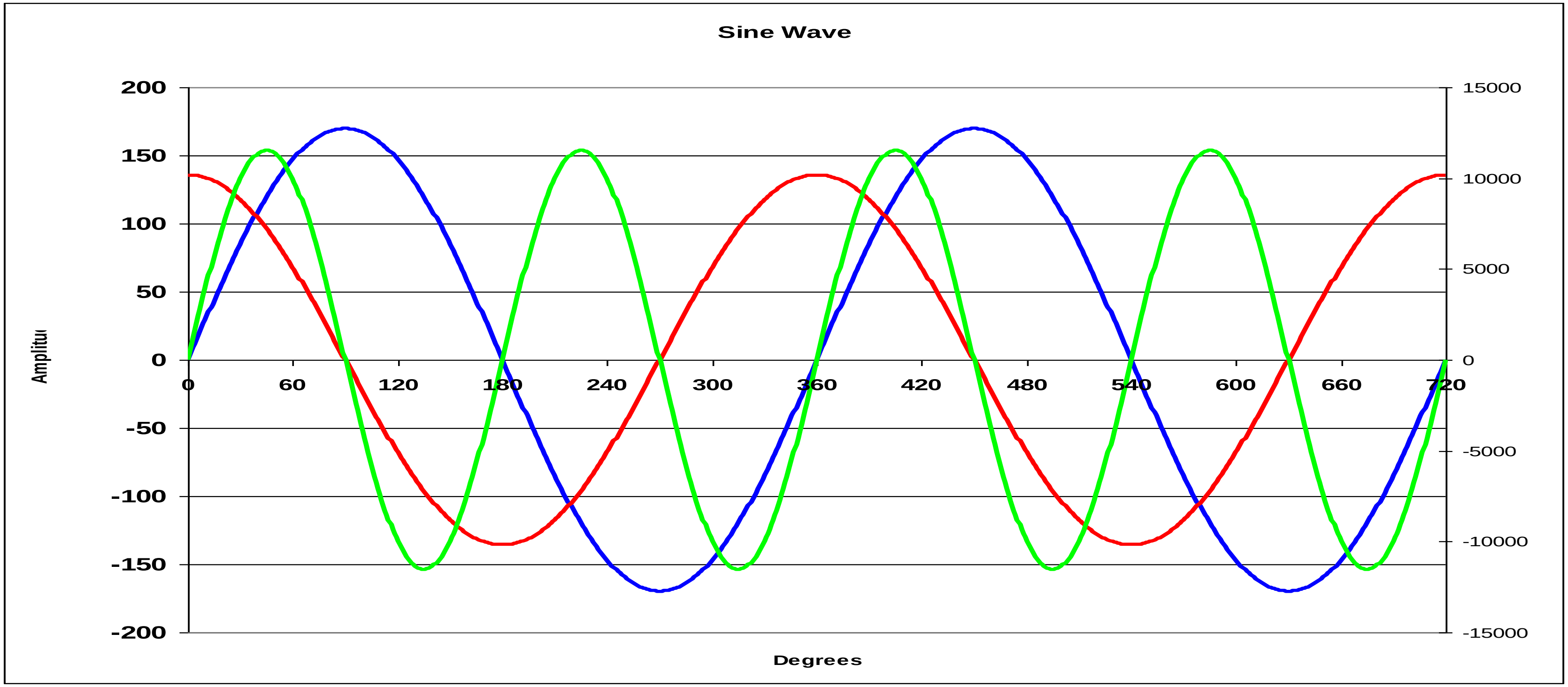
AC Theory – Instantaneous Power

For an capacitive load: $p = vi = 2VISin(\omega t)Sin(\omega t + 90) = VISin(2\omega t)$



$V = 120\sqrt{2}Sin(2\pi ft)$

$I = 96\sqrt{2}Sin(2\pi ft + 90)$

$P = 11520Sin(2\pi ft)$

P = 0 Watts

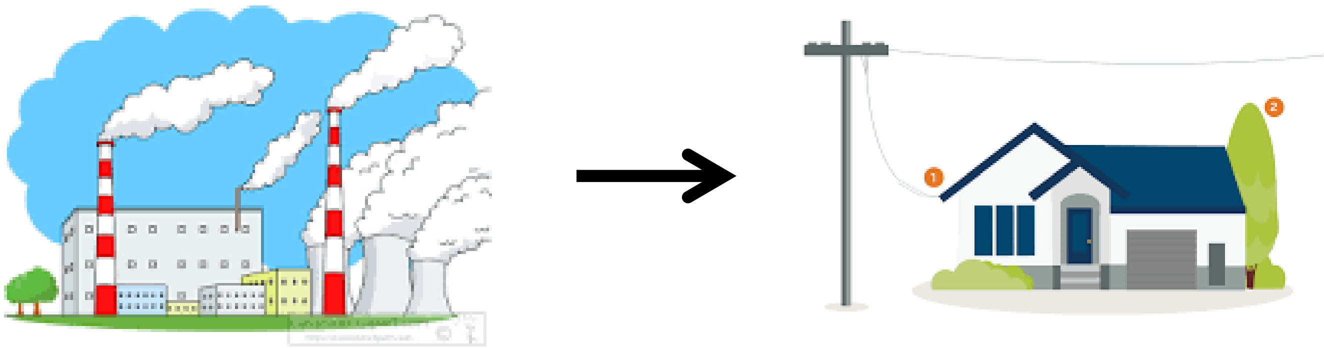
Inductance Vs Capacitance

- More inductance creates more VAR, less W, and lower PF
- Capacitance is added to an inductive load to reduce VAR, raise W, and raise PF
- Ideally, we want all loads to have a PF = 1

+

=

Delivered vs Received Power



Positive Watts are DELIVERED from the Utility to the Consumer

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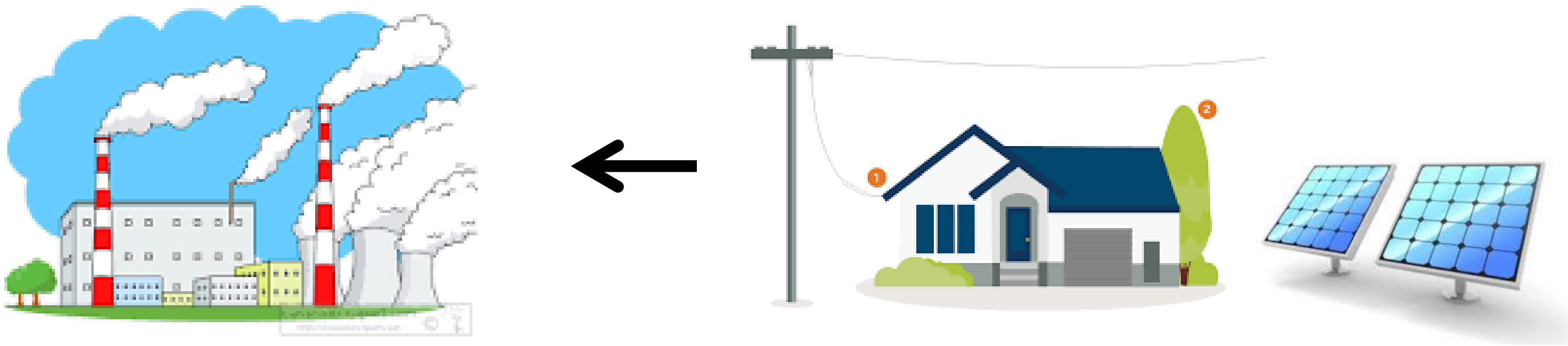
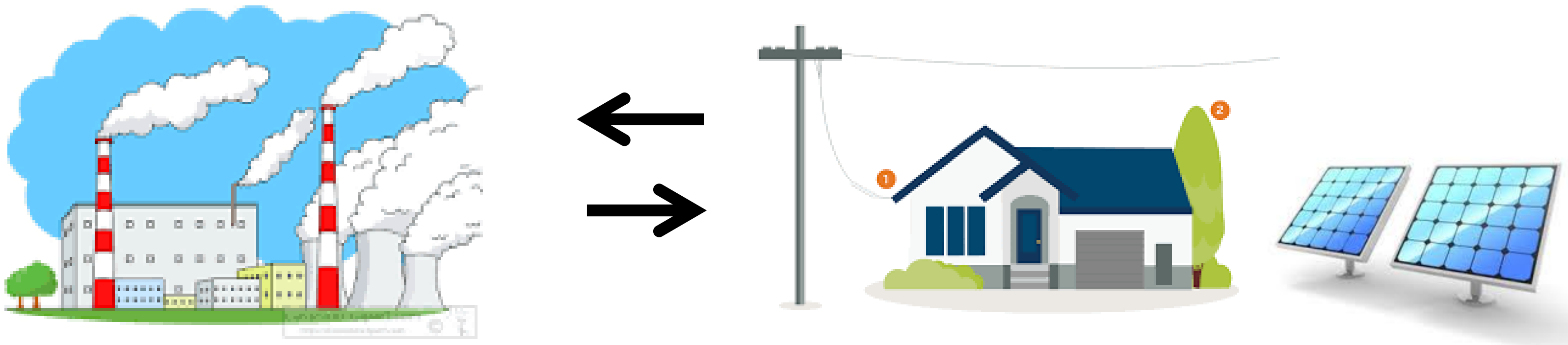
Delivered vs Received Power



Negative Watts are RECEIVED by the Utility from the Consumer

Delivered vs Received Power



Positive and Negative VARs flow in both directions

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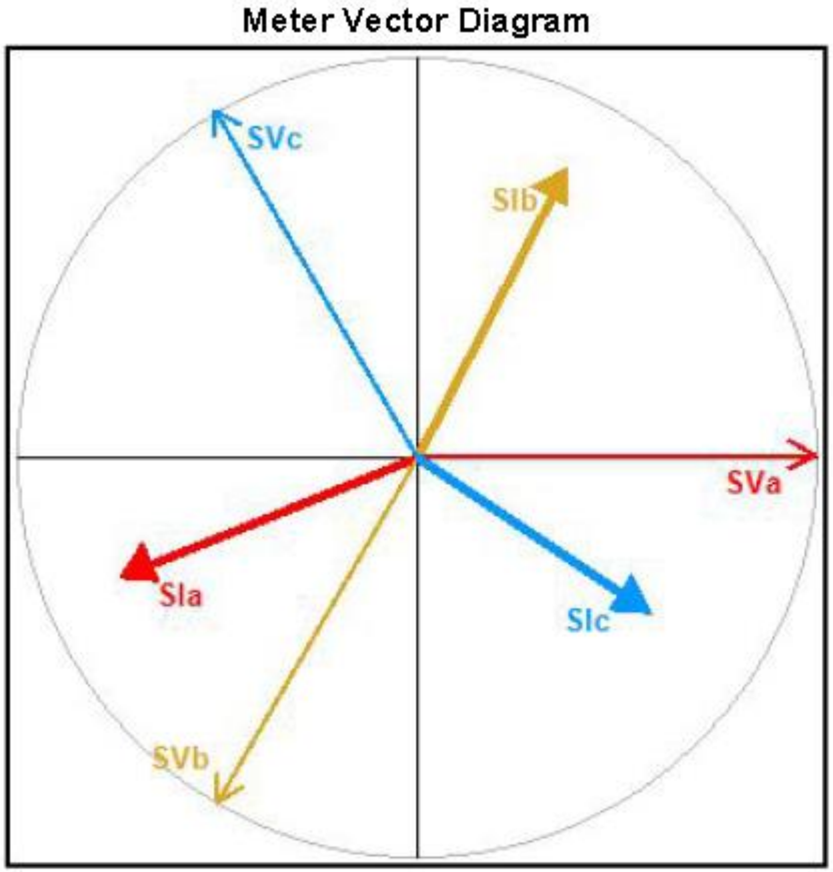
Negative Power Factor?



- The vector diagram for a renewable site may have current vectors 180° out when the site is generating power.
- Whr, VARhr, and PF may also be negative when generating power.
- The sign of PF will follow Watts

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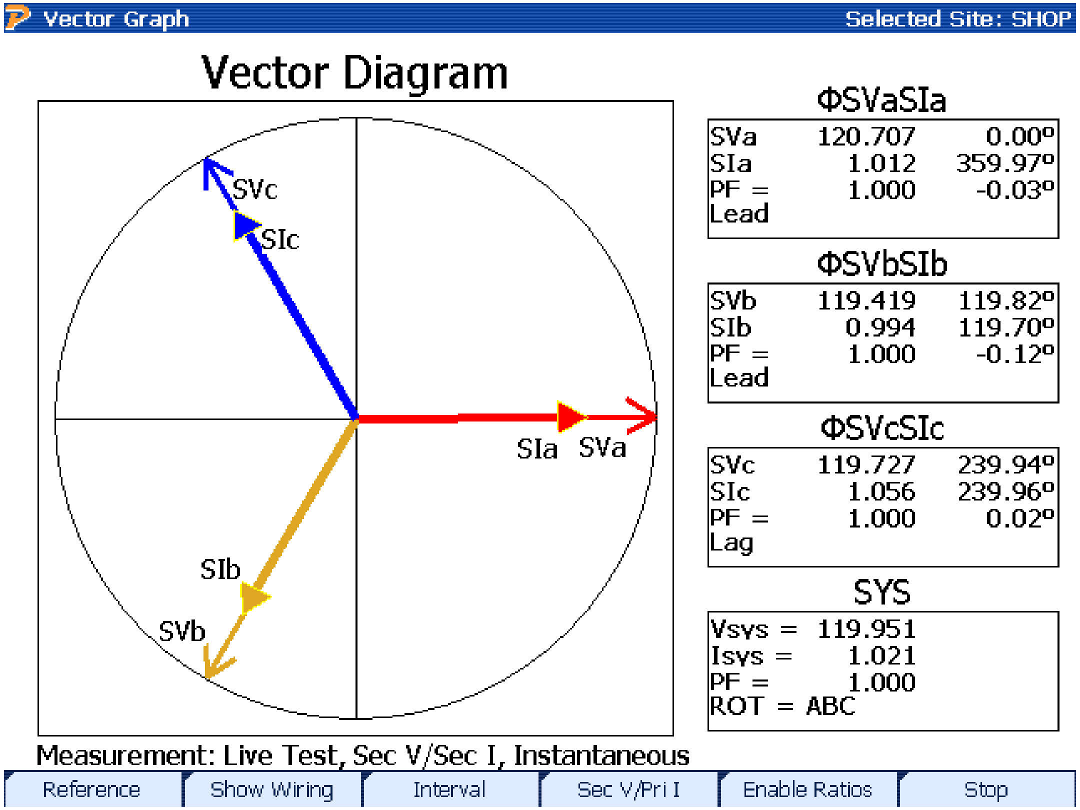
3 Phase, 4-Wire "Y" Service

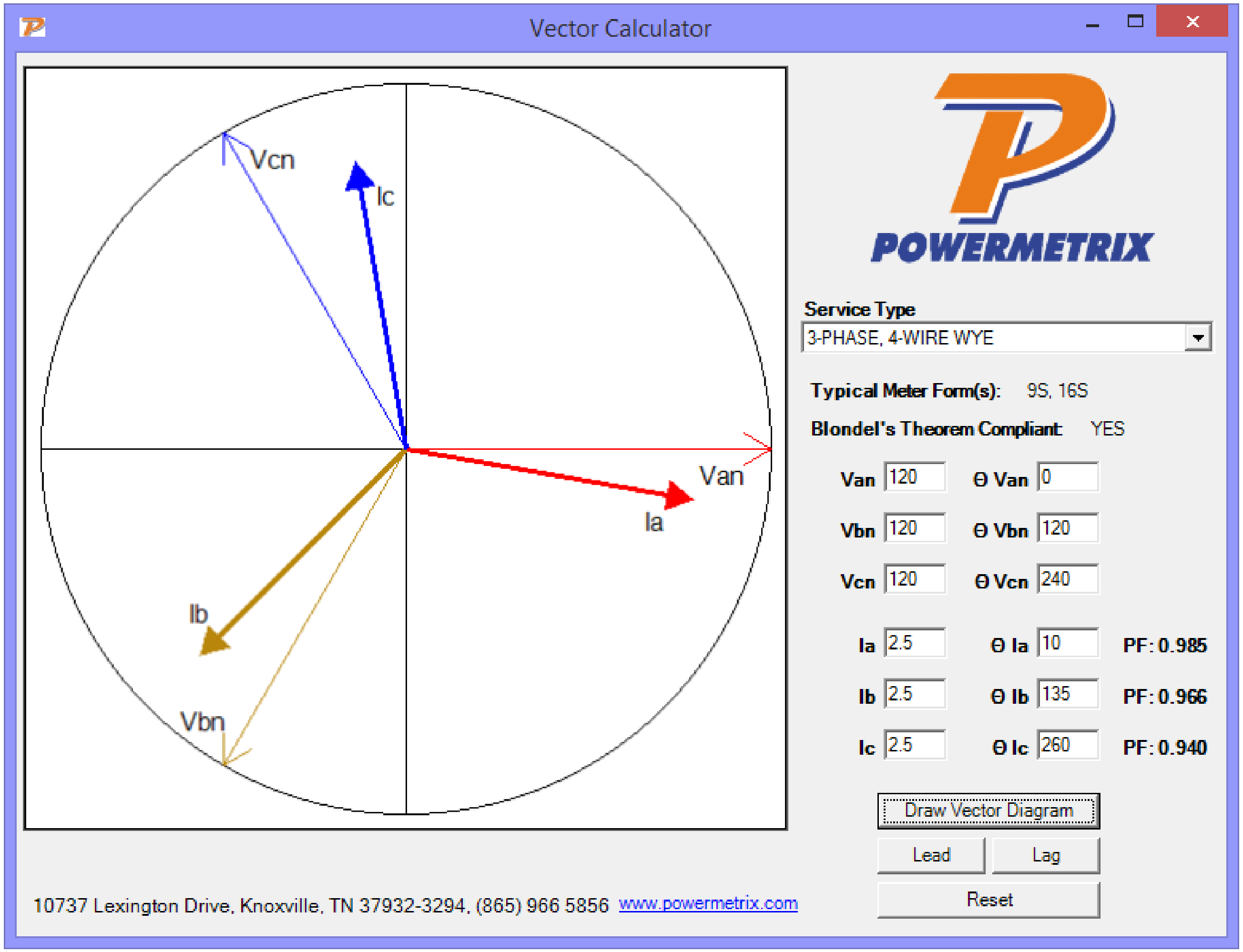
0° = Unity Power Factor

- Three Voltage Phasors
- 120° Apart
- Three Current Phasors
- Aligned with Voltage at PF=1



System PF = Average of A, B, and C phase PF

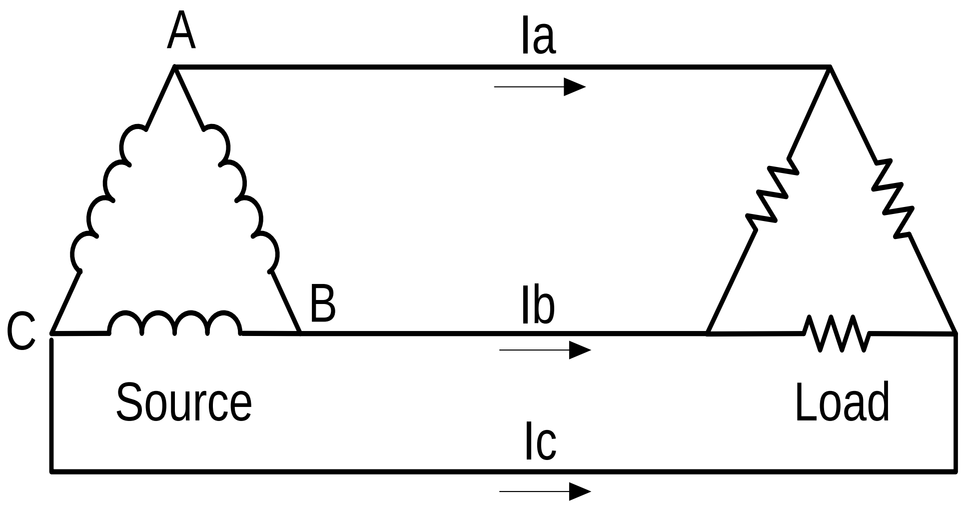
3 Phase, 4-Wire Wye

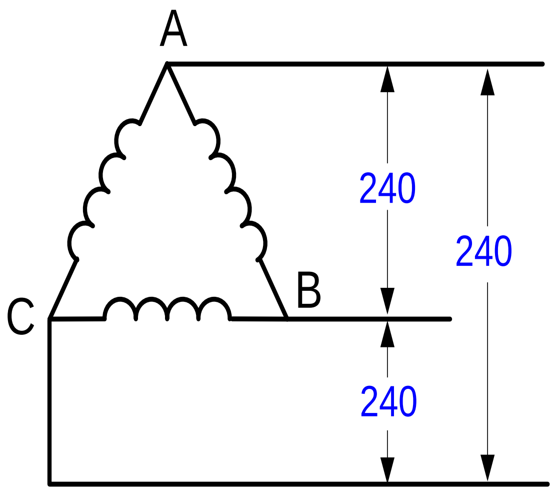


System PF = Average of A, B, and C = 0.964

3 Phase, 3-Wire Delta Service

Common service type for industrial customers. This service has NO neutral.





•Voltages normally measured relative to phase B.

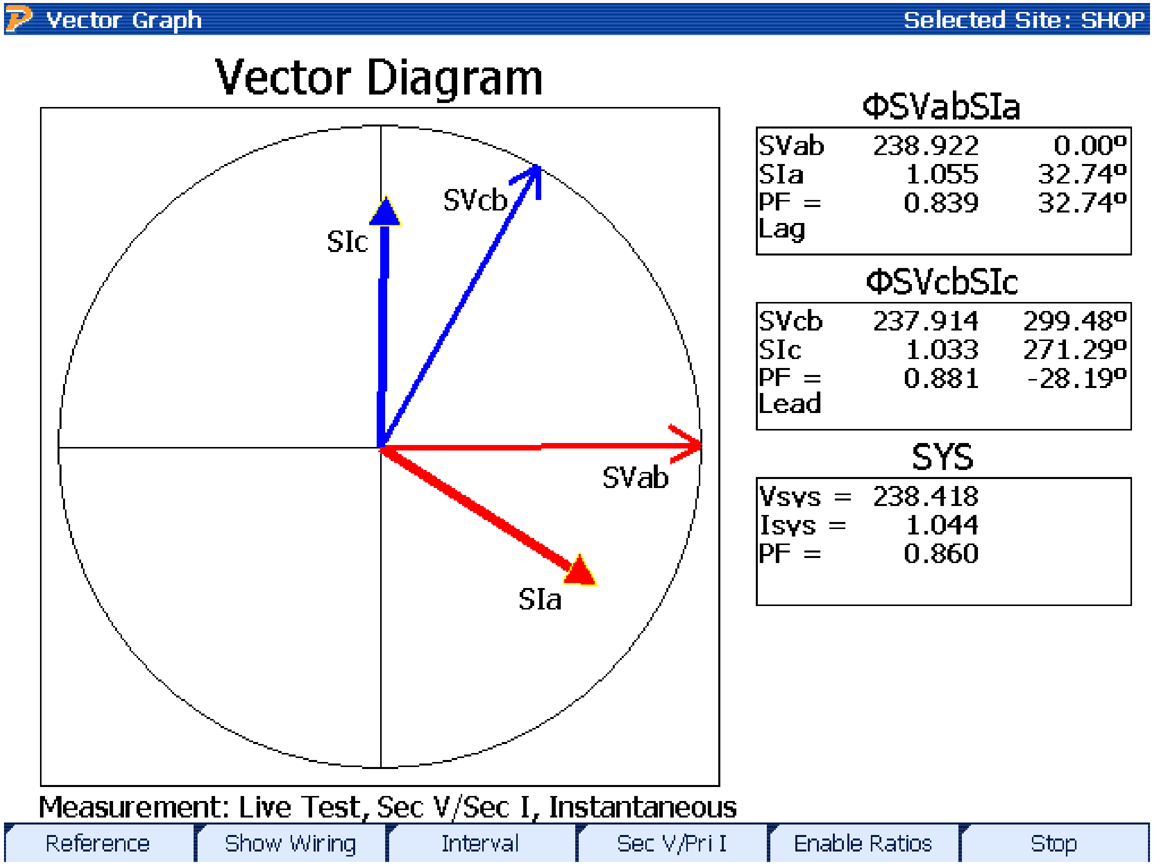
•Voltage and current vectors do not align.

•Service is provided even when a phase is grounded.

3 Phase, 3-Wire Delta Service

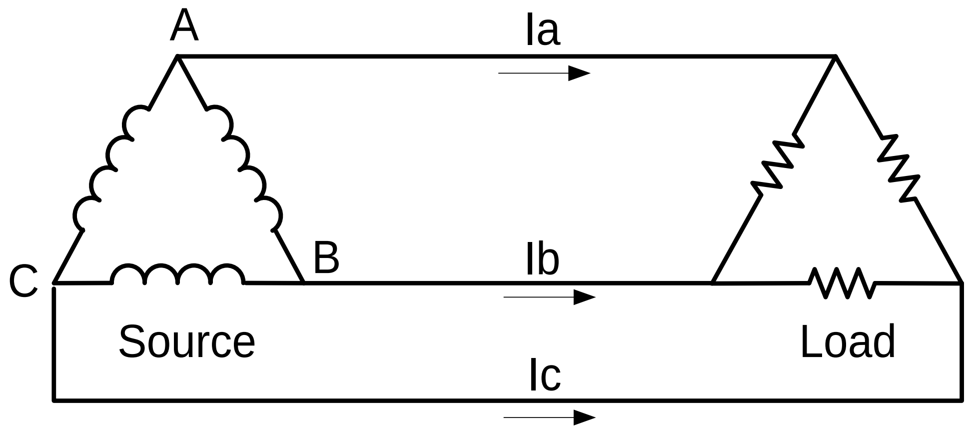
Resistive Loads

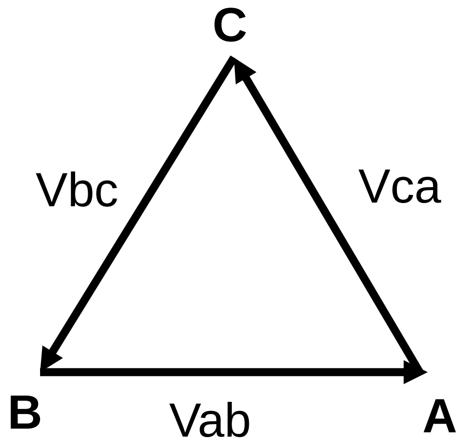
- Two Voltage Phasors
- 60° Apart
- Two Current Phasors
- For a resistive load one current leads by 30° while the other lags by 30°

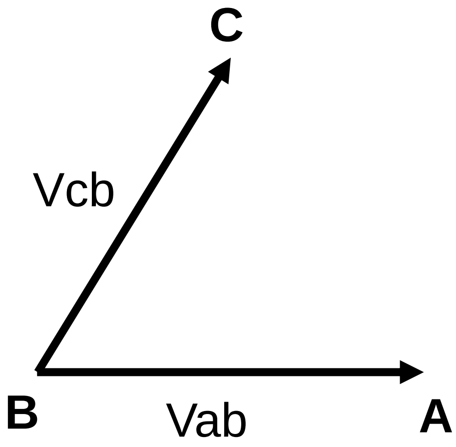


3 Phase, 3-Wire Delta Service

Understanding the Diagram

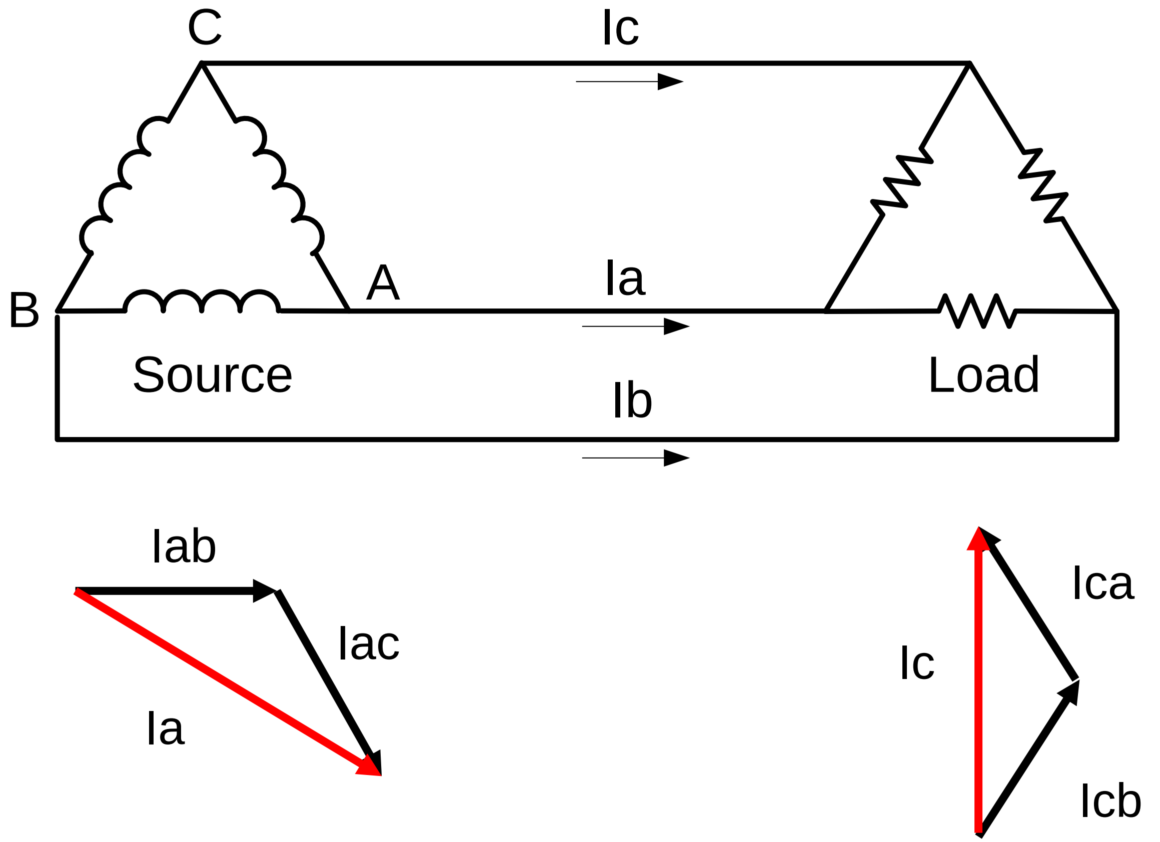






3 Phase, 3-Wire Delta Service

Understanding the Diagram



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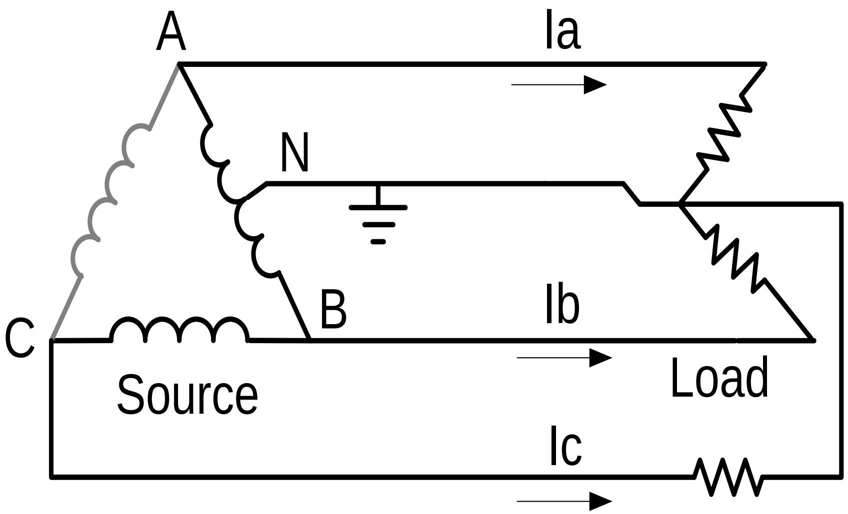
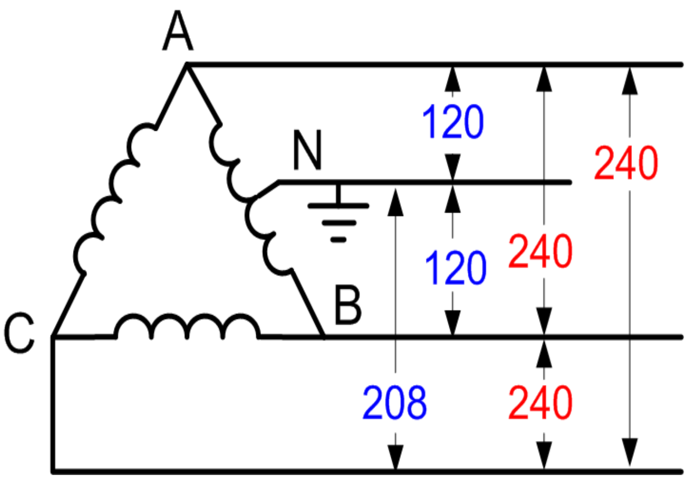
3 Phase, 4-Wire Delta Service

Common service type for industrial customers. Provides a residential like 120/240 service (lighting service) single phase 208 (high side) and even 3 phase 240 V.



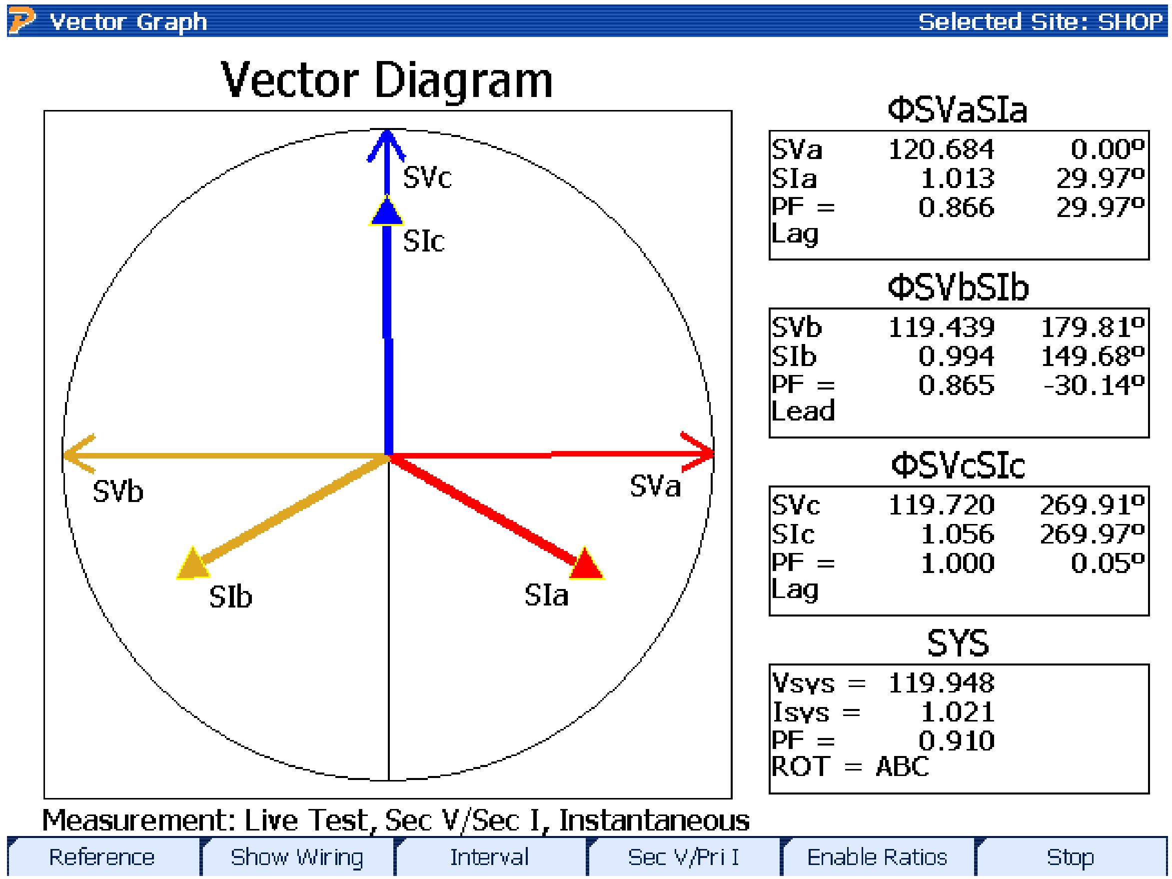


- Voltage phasors form a “T” 90° apart
- Currents are at 120° spacing
- In 120/120/208 form only the “hot” (208) leg has its voltage and current vectors aligned.

3 Phase, 4-Wire Delta Service

Resistive Load

- Three Voltage Phasors
- 90° Apart
- Three Current Phasors
- 120° apart



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3 Phase Power Measurement

- We have discussed how to measure and view power quantities (W, VARs, VA) in a single phase case.
- How do we combine them in a multi-phase system?
- Two common approaches:
  - Arithmetic
  - Vectorial

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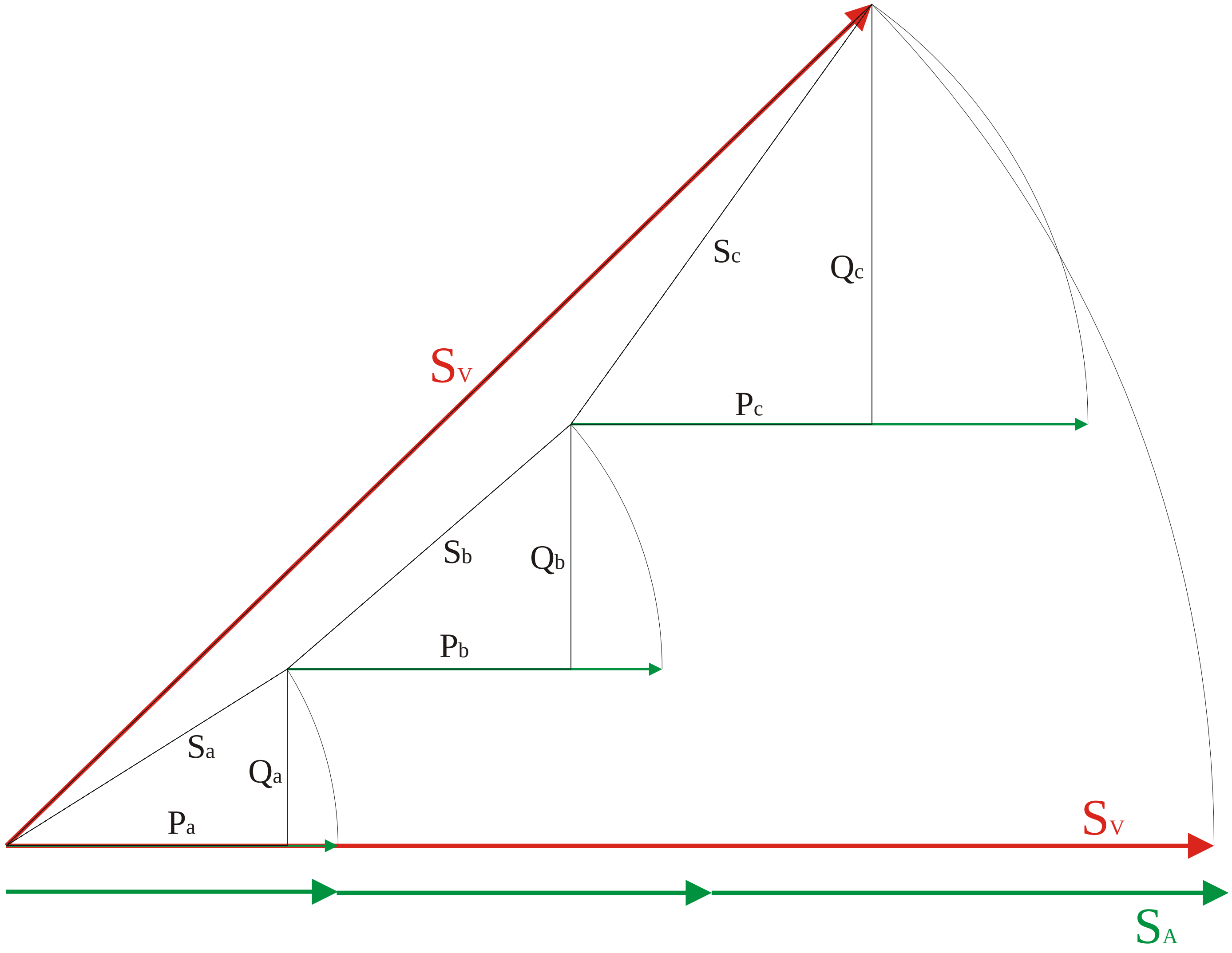
3 Phase Power Measurement



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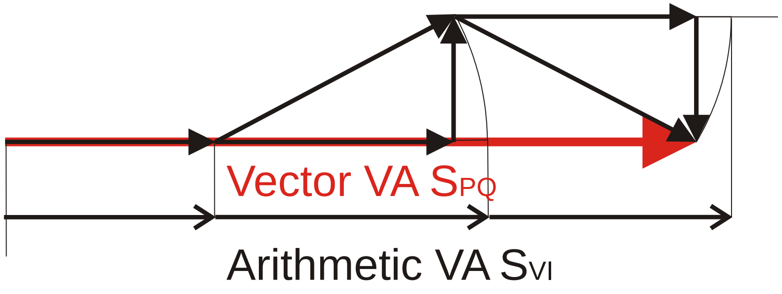
3 Phase Power Measurement

- VAR and VA calculations can lead to some strange results:
  - If we define

$$VA = \sqrt{(W_A + W_B + W_C)^2 + (Q_A + Q_B + Q_C)^2}$$

PH	W	Q	VA
A	100	0	100
B	120	55	132
C	120	-55	132
Arithmetic VA			364
Vector VA			340



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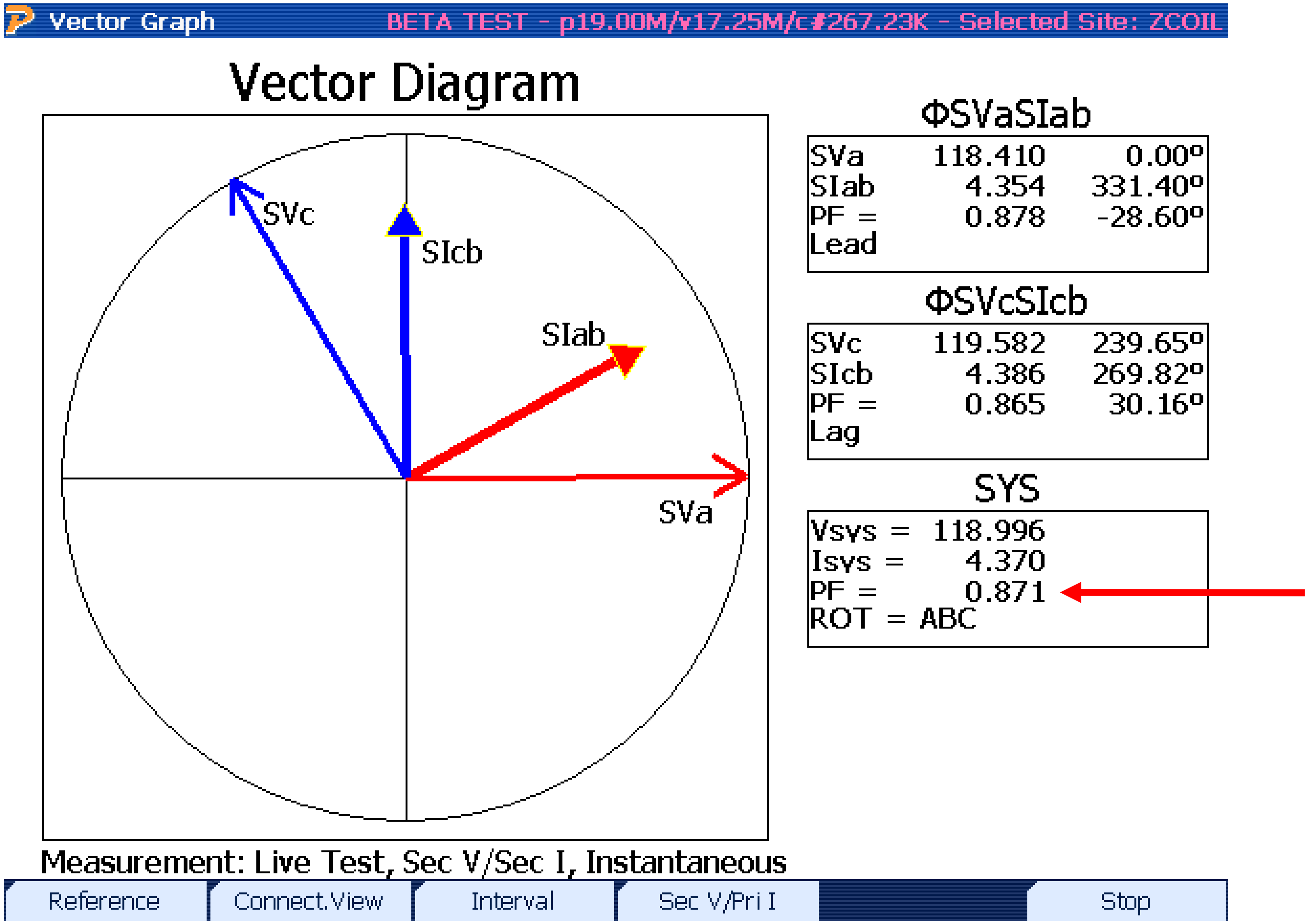
3 Phase Power Measurement



Arithmetic Calculation - Form 6 – 4 Wire Y Site
Voltages and Currents Aligned at 0°

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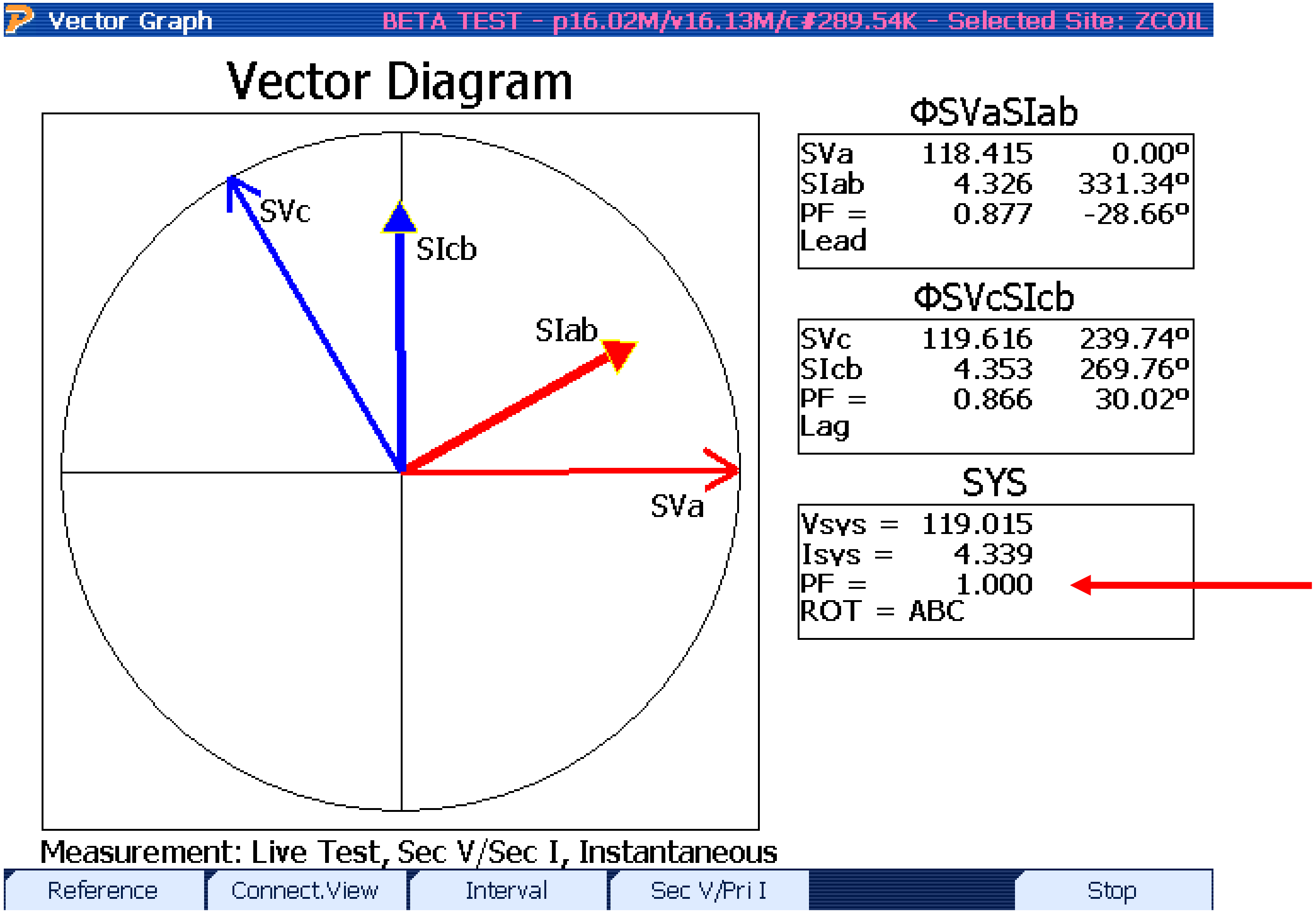
3 Phase Power Measurement



Vector Calculation - Form 6 – 4 Wire Y Site
Voltages and Currents Aligned at 0°

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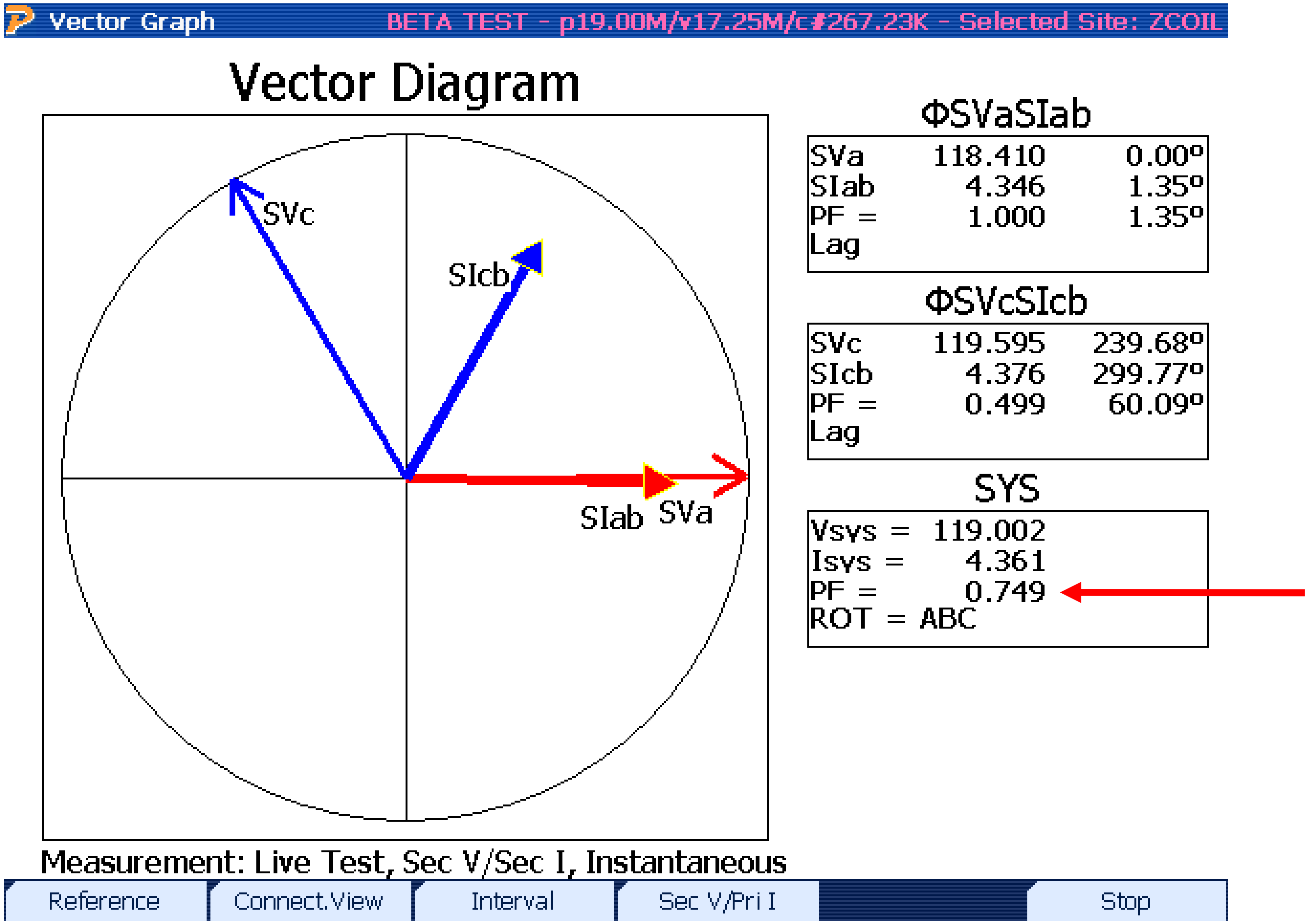
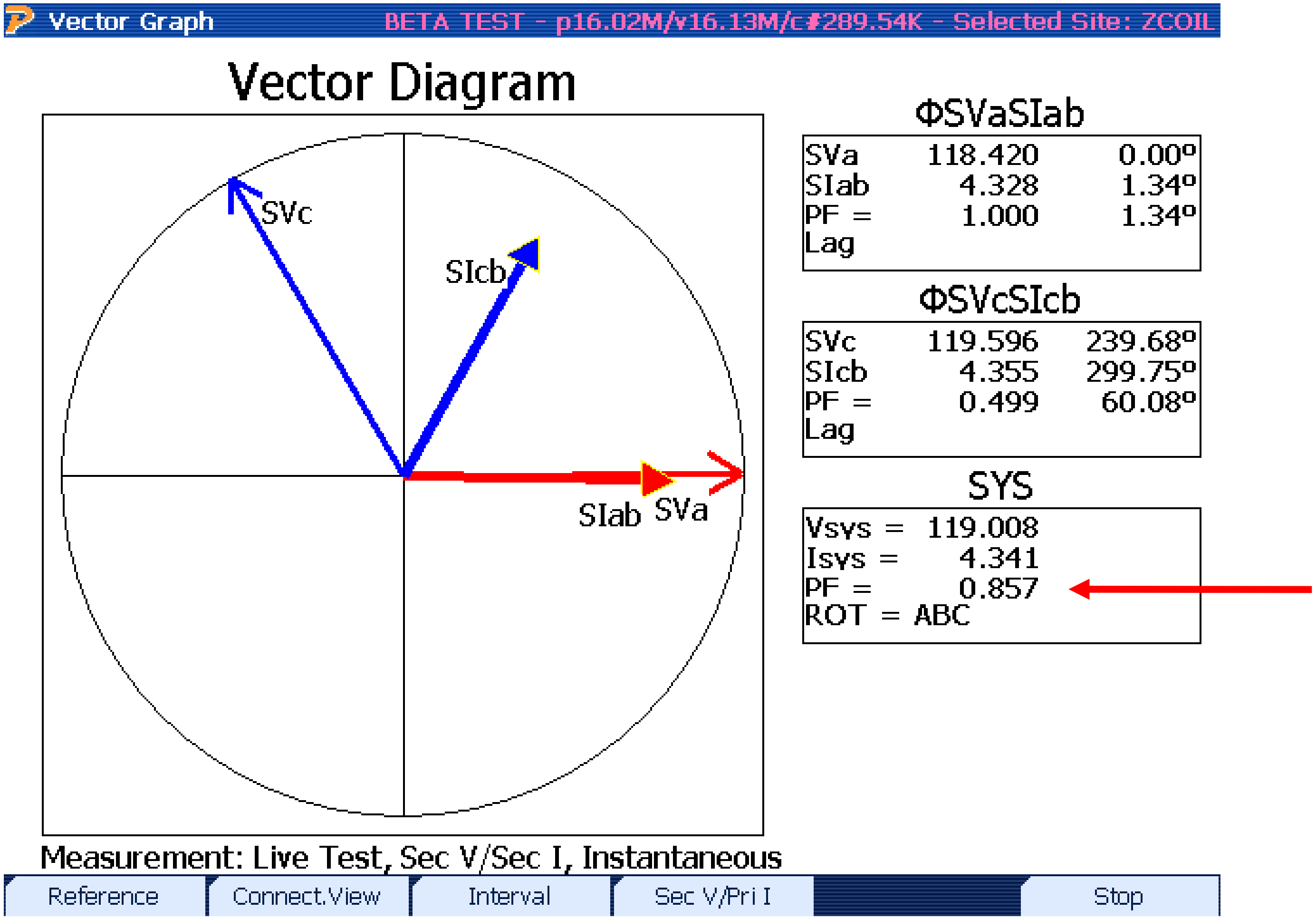
3 Phase Power Measurement



Arithmetic Calculation - Form 6 – 4 Wire Y Site

Currents All shifted by 30°

3 Phase Power Measurement



Vector Calculation - Form 6 – 4 Wire Y Site
Currents All shifted by 30°

Displacement and Distortion Power Factor

Displacement and Distortion PF are used in systems that are non-linear (contain harmonics)

Displacement PF = cos (θ_1) where "1" represents the fundamental frequency (60Hz) ONLY

Distortion PF = $1/\sqrt{1 + THD^2}$

True PF = Displacement PF * Distortion PF

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Total Harmonic Distortion (THD)

THD is a measurement of the ratio of the sum of the harmonic power to the power of the fundamental frequency.

$$THD := \frac{\sqrt{\sum_{n=2}^{4} (V_n)^2}}{V_1}$$

This is an equation for a waveform with 3 harmonics.
V_1 is the fundamental (60Hz)
V_2 is the 2^{nd} harmonic (120Hz)
V_3 is the 3^{rd} harmonic (180Hz)
V_4 is the 4^{th} fundamental (240Hz)

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Summary

- Power Factor is the ratio of useful power (Watts) to total power (VA) in a system
- PF decreases with inductance, and increase with capacitance
- An ideal system has a PF = 1, which represents 100% active, useful power being delivered to the load
- PF calculations may differ depending on the metering

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Questions?

Comments?

Thank you for your time!

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