Troubleshooting with Vectors

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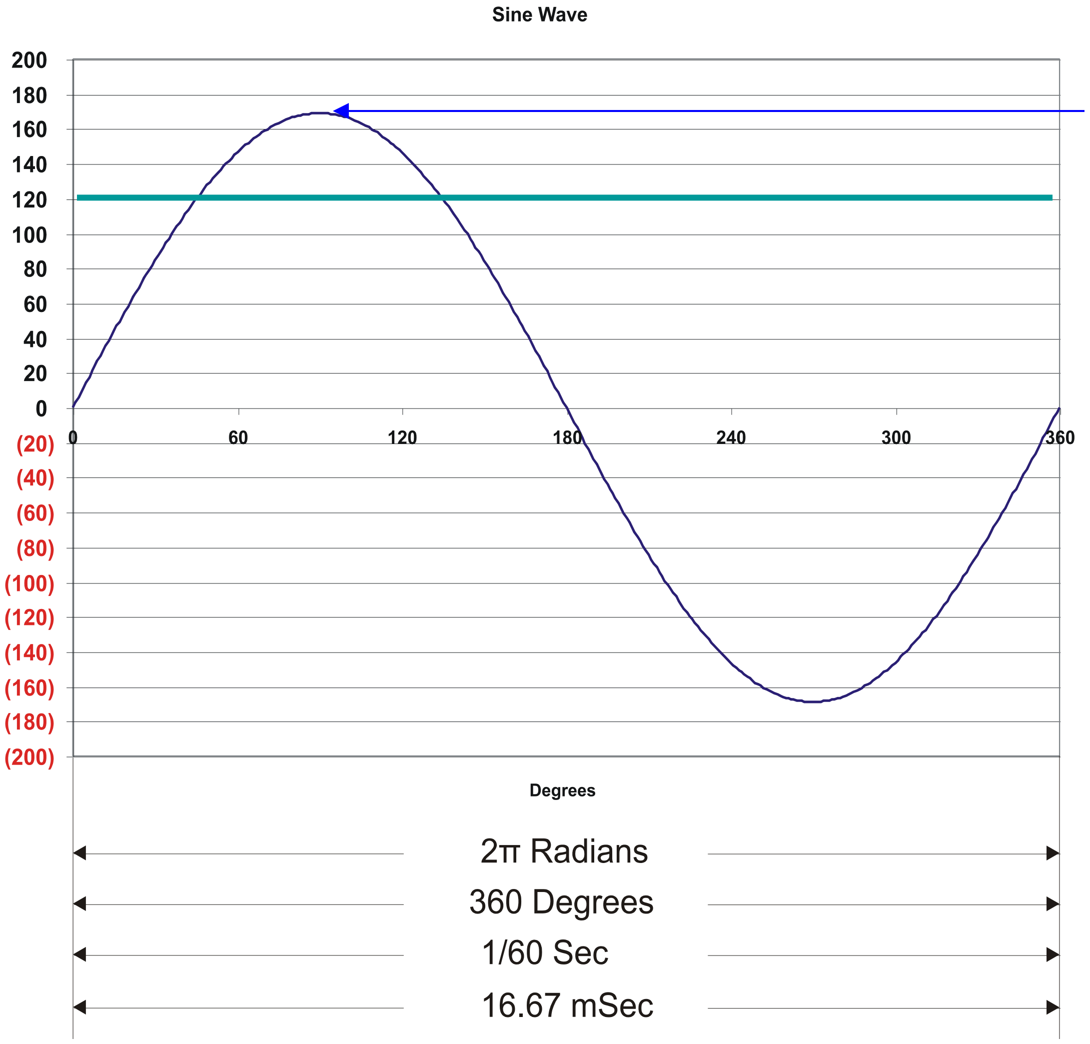
AC Theory Review – Sine Wave



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

Where Vpk is peak voltage
f is frequency
t is time
θ (theta) is phase

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

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

$$V_{rms} = 120V$$

$$V_{pk} = 169V$$

$$f = 60Hz$$

$$\theta = 0°$$

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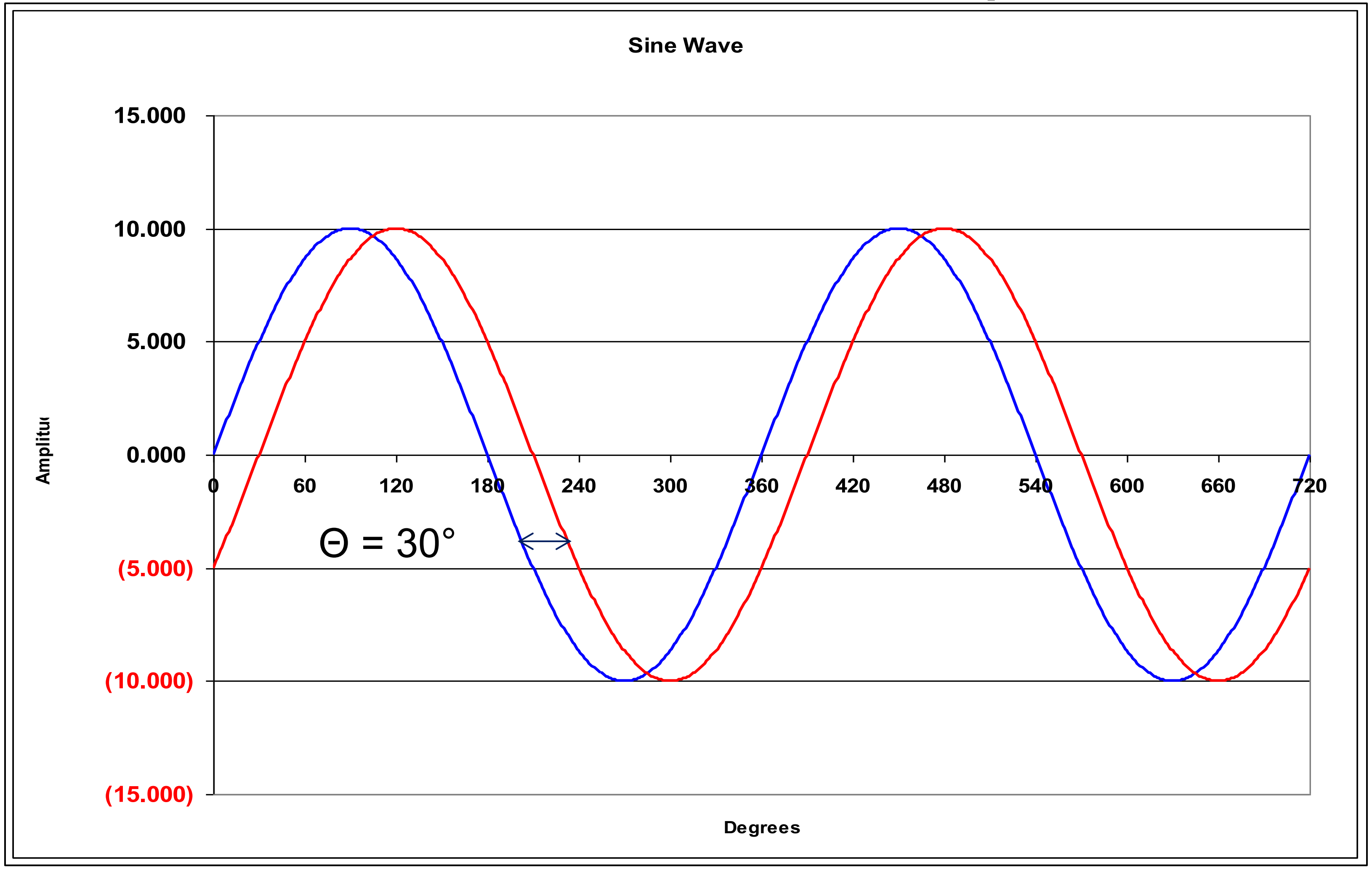
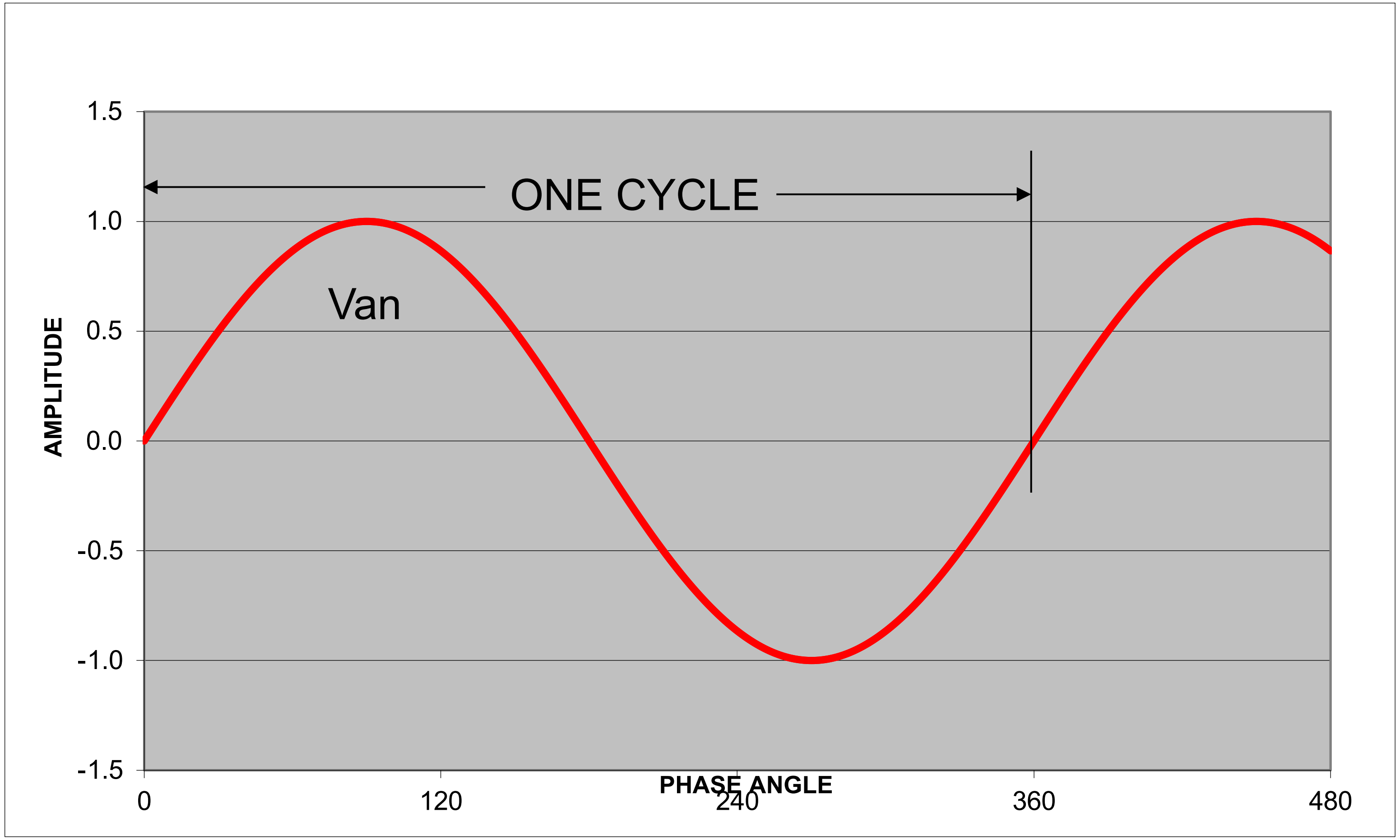
Phase Relationship



Current is lagging Voltage by 30˚

Three Phase Theory

Single Phase - Voltage Plot



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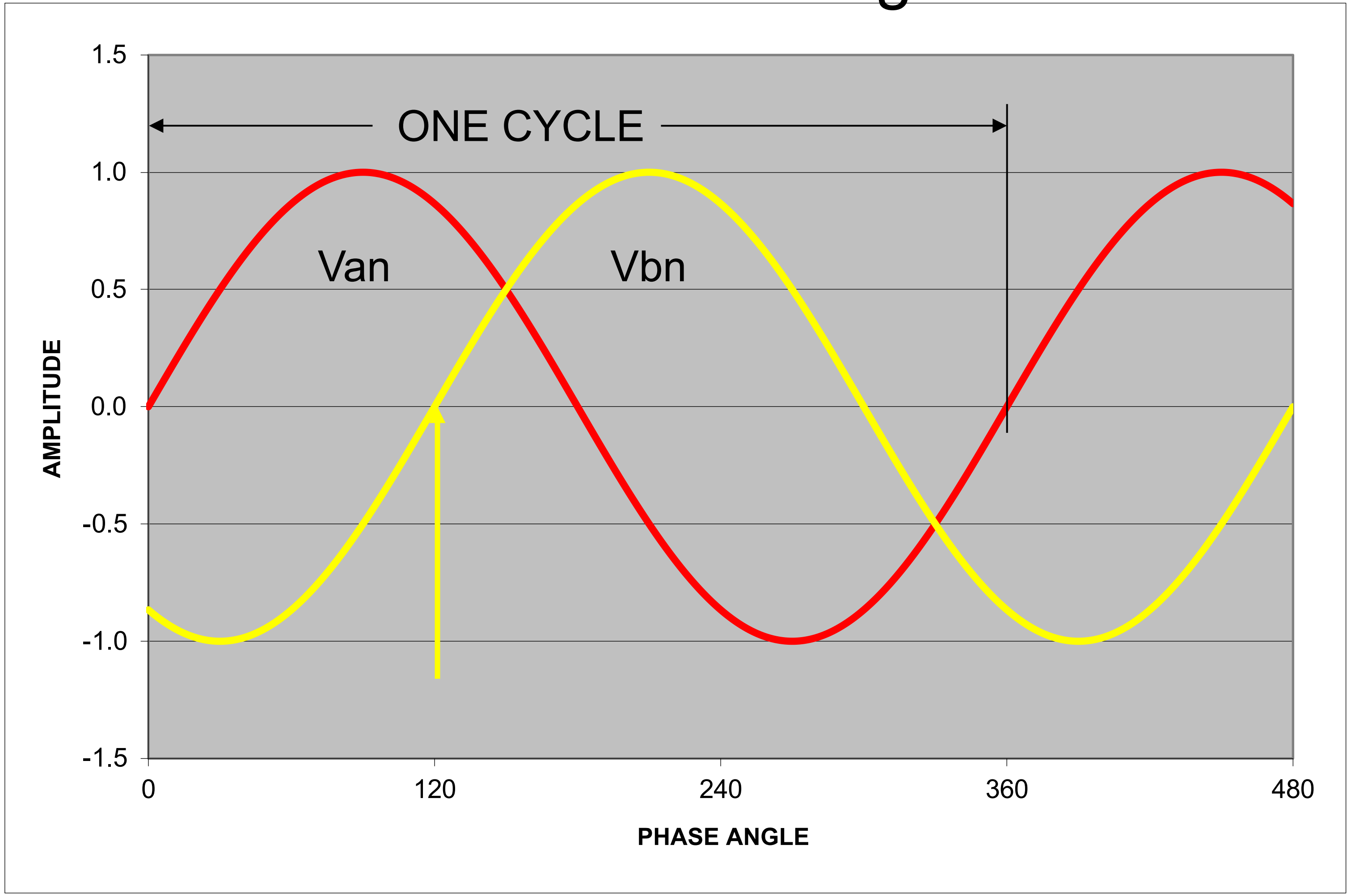
Three Phase Theory

Two Phases - Voltage Plot



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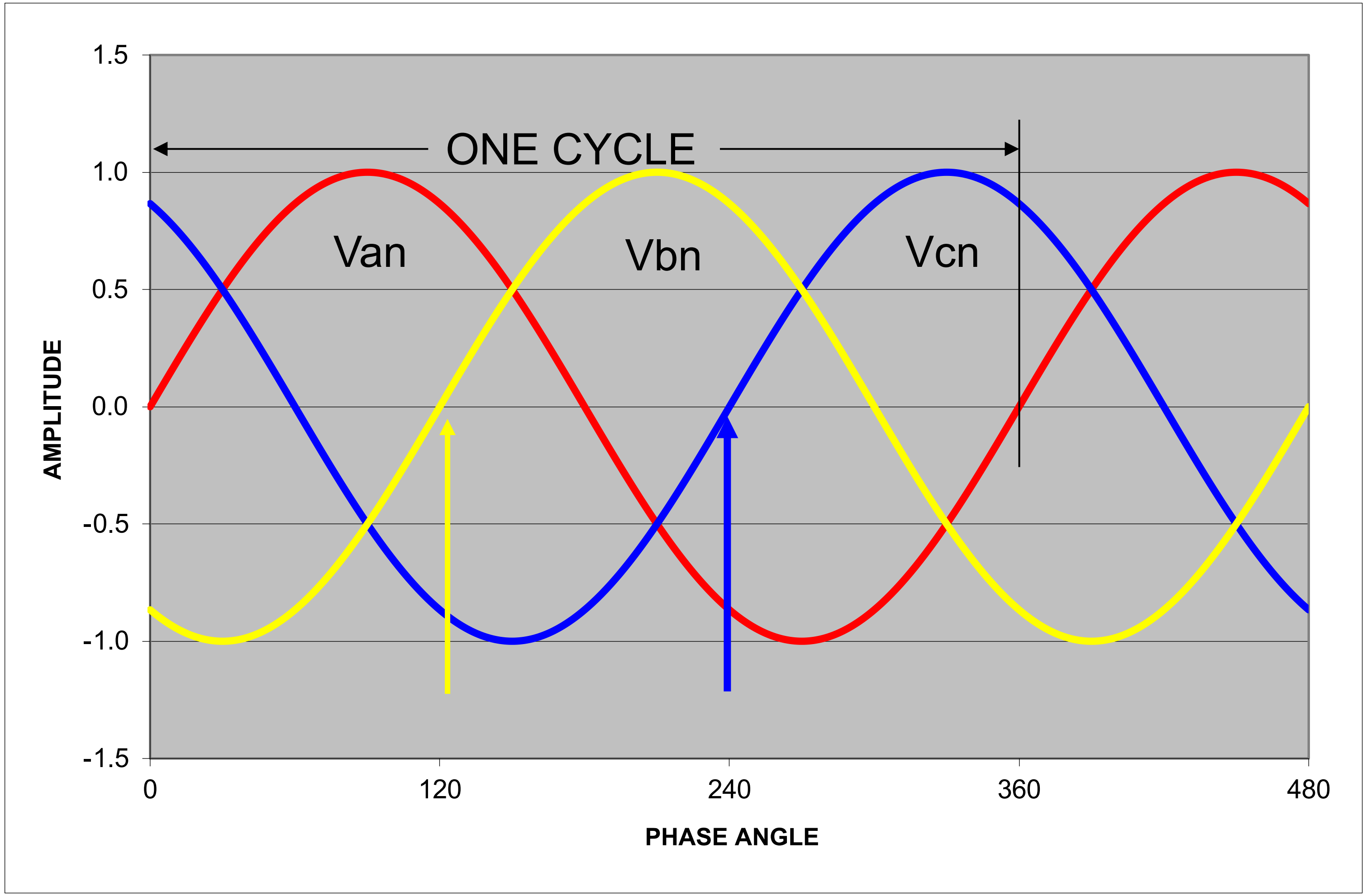
Three Phase Theory

Three Phase - Voltage Plot

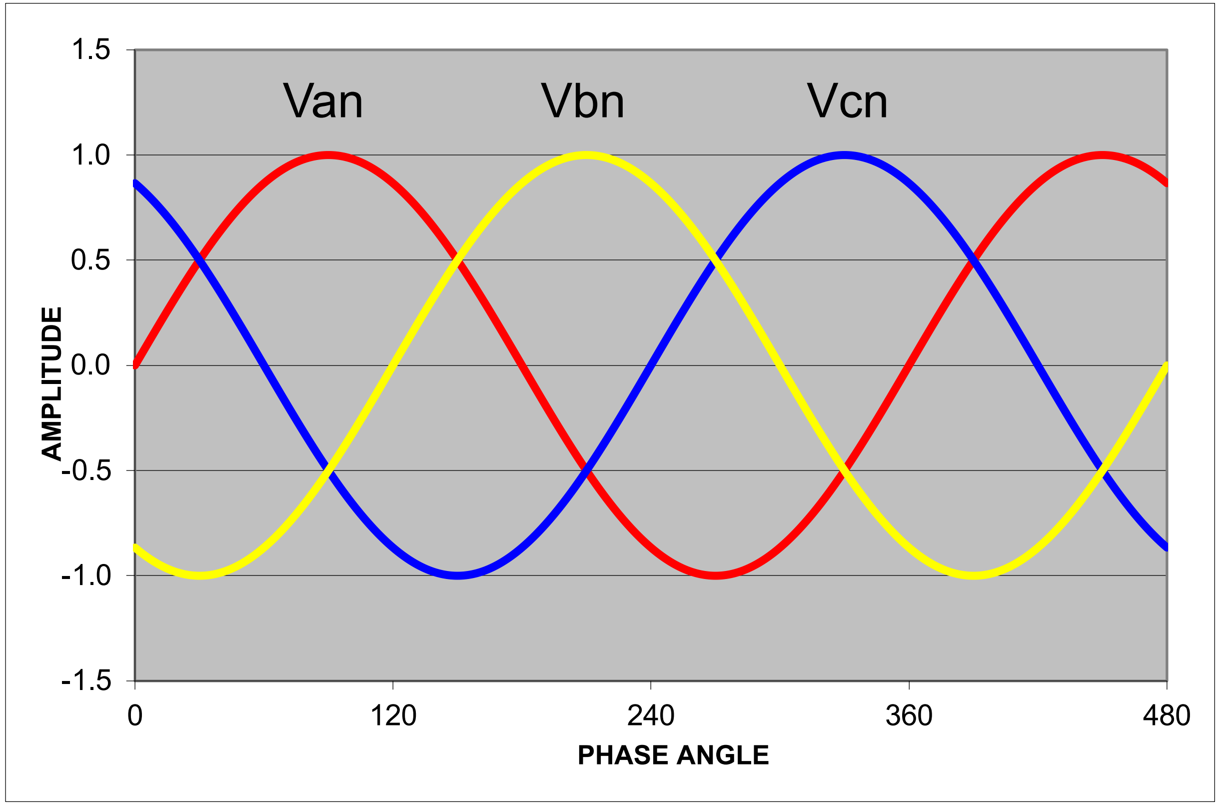


Three Phase Power

At the Generator

Three voltage vectors each separated by 120°.

Peak voltages essentially equal.



Most of what makes three phase systems seem complex is what we do to this simple picture in the delivery system and loads.

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Three Phase Power

Basic Concept – Phase Rotation

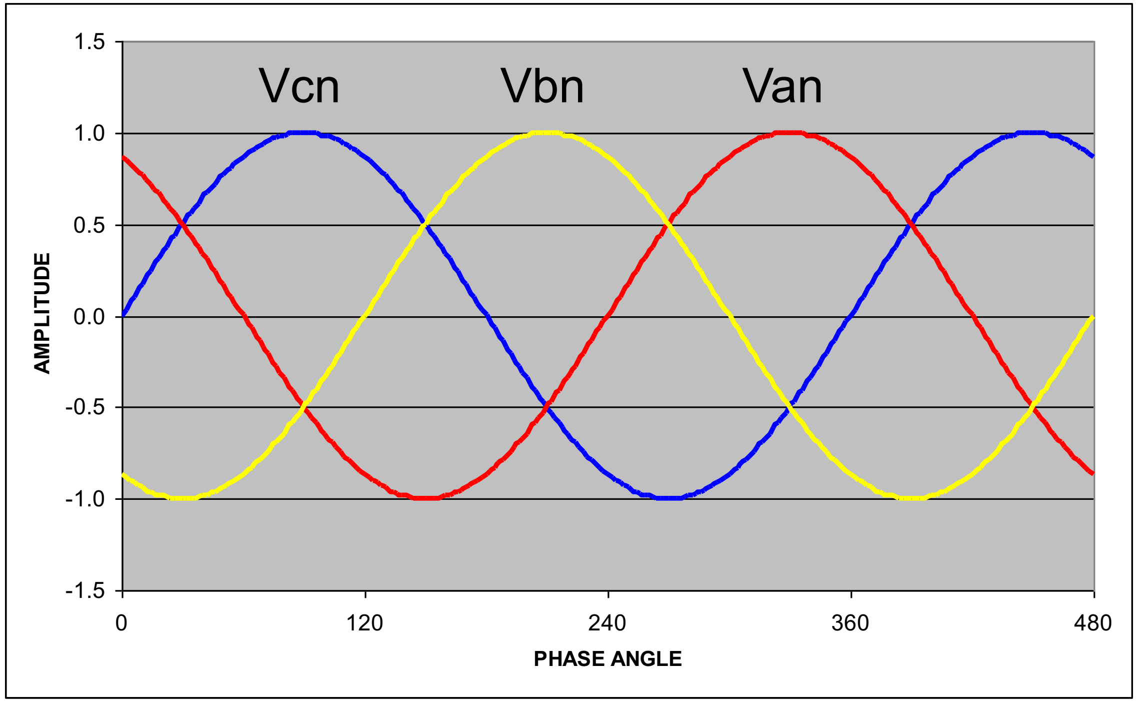
Phase Rotation:

The order in which the phases reach peak voltage.

There are only two possible sequences:

A-B-C (previous slide)

C-B-A (this slide)



Phase rotation is important because the direction of rotation of a three phase motor is determined by the phase order.

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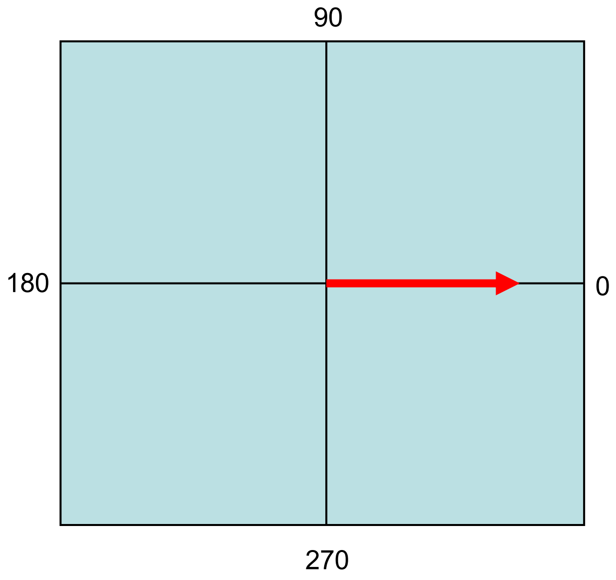
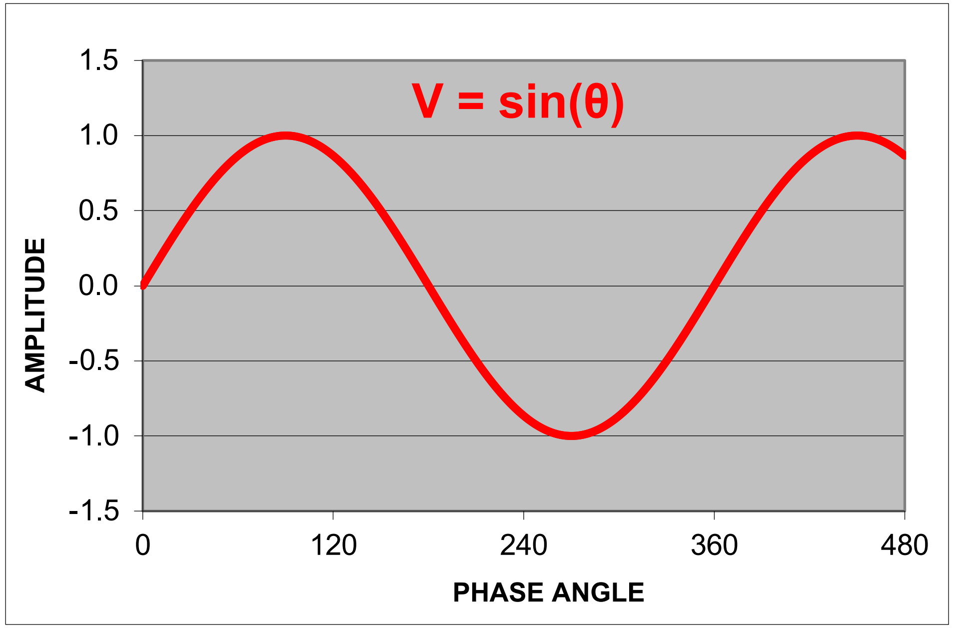
Three Phase Theory

Phasors and Vector Notation

- Phasors are a graphical means of representing the amplitude and phase relationships of voltages and currents.





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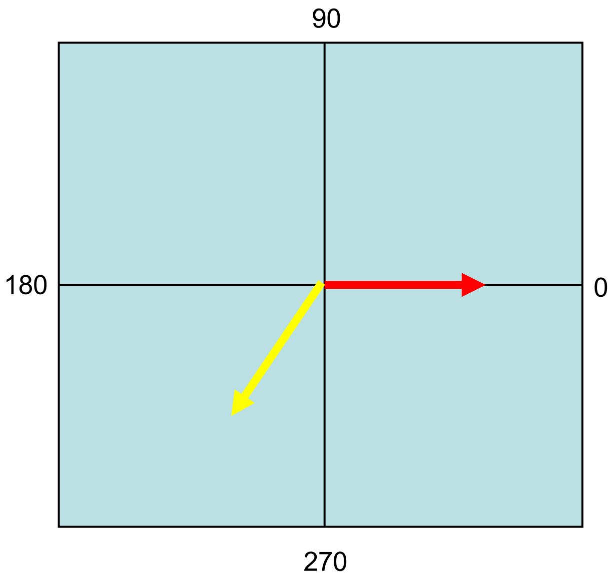
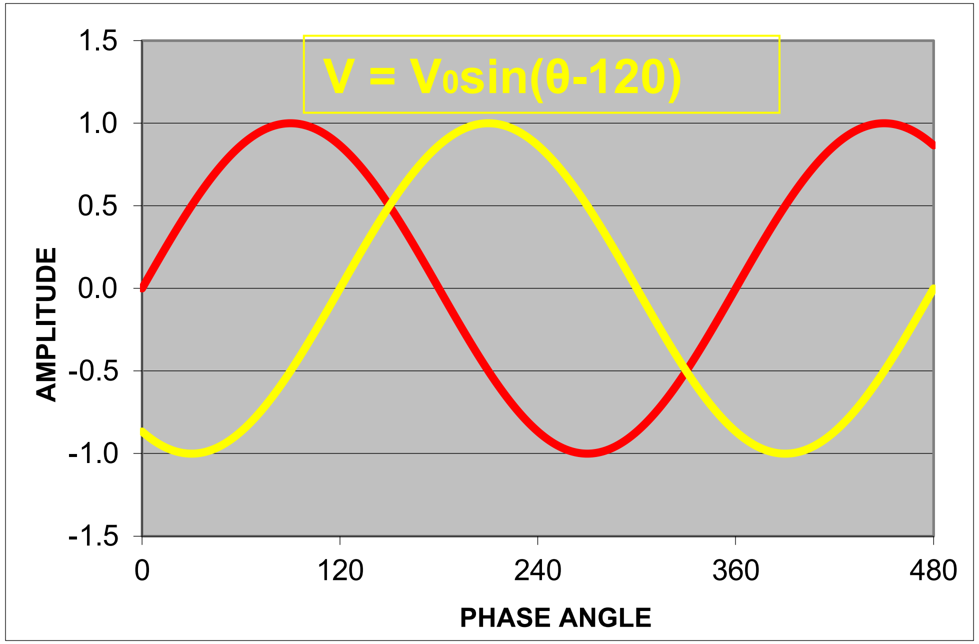
Three Phase Power

Phasors and Vector Notation

- As stated in the Handbook of Electricity Metering, by common consent, counterclockwise phase rotation has been chosen for general use in phasor diagrams.





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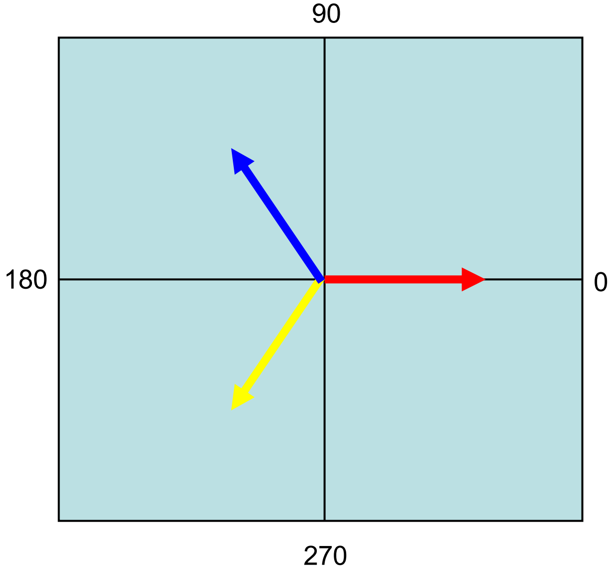
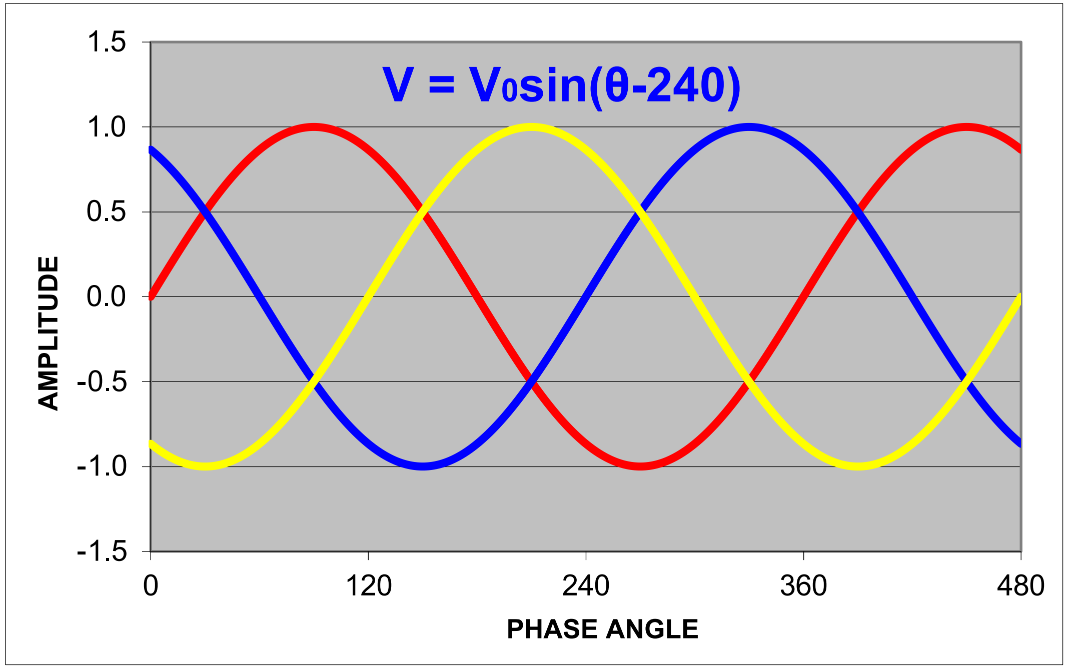
Three Phase Power

Phasors and Vector Notation

- The phasor diagram for a simple 3-phase system has three voltage phasors equally spaced at 120° intervals.
- Going clockwise the order is A – B – C.





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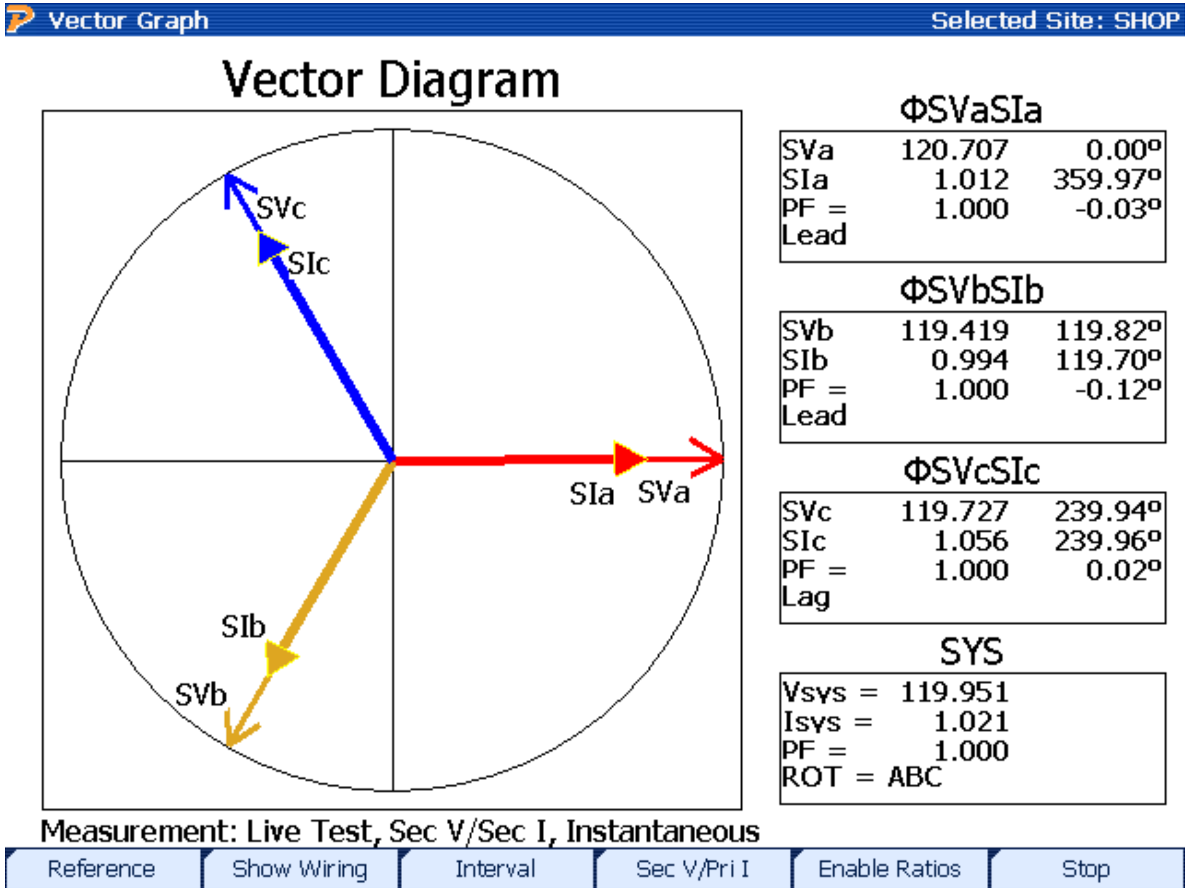
3 Phase, 4-Wire "Y" Service

0° = Unity Power Factor

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



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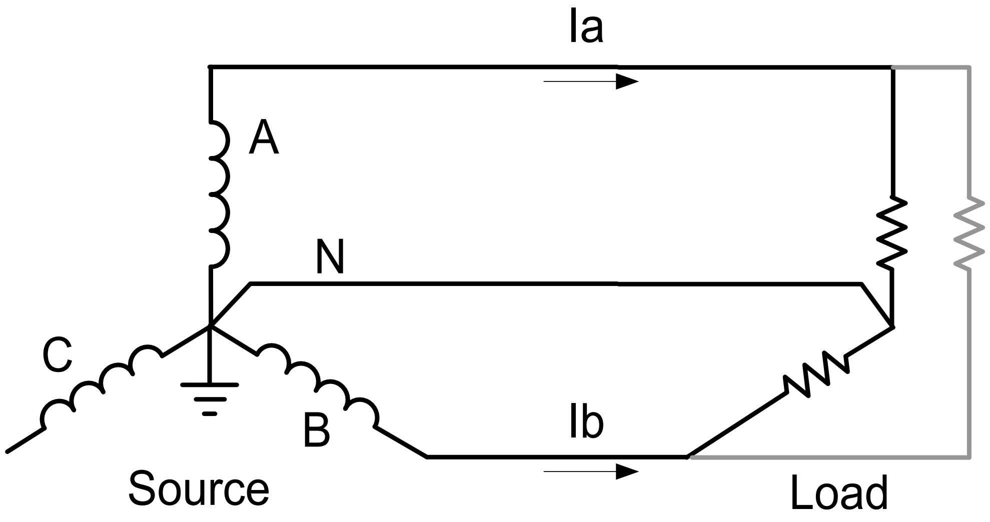
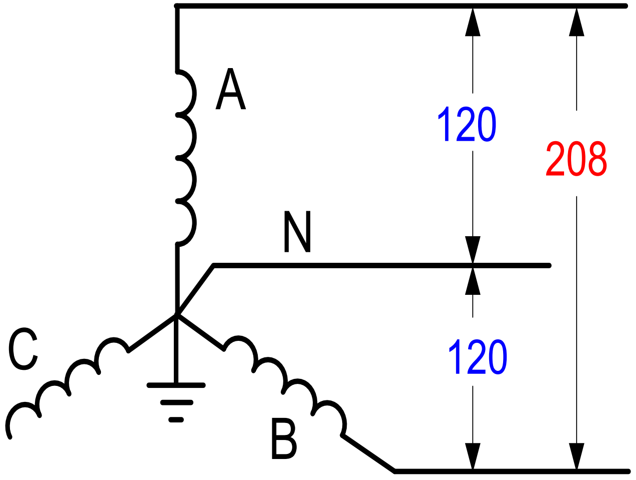
2 Phase, 3-Wire “Y” Service

“Network Connection”

Single phase variant of the service.



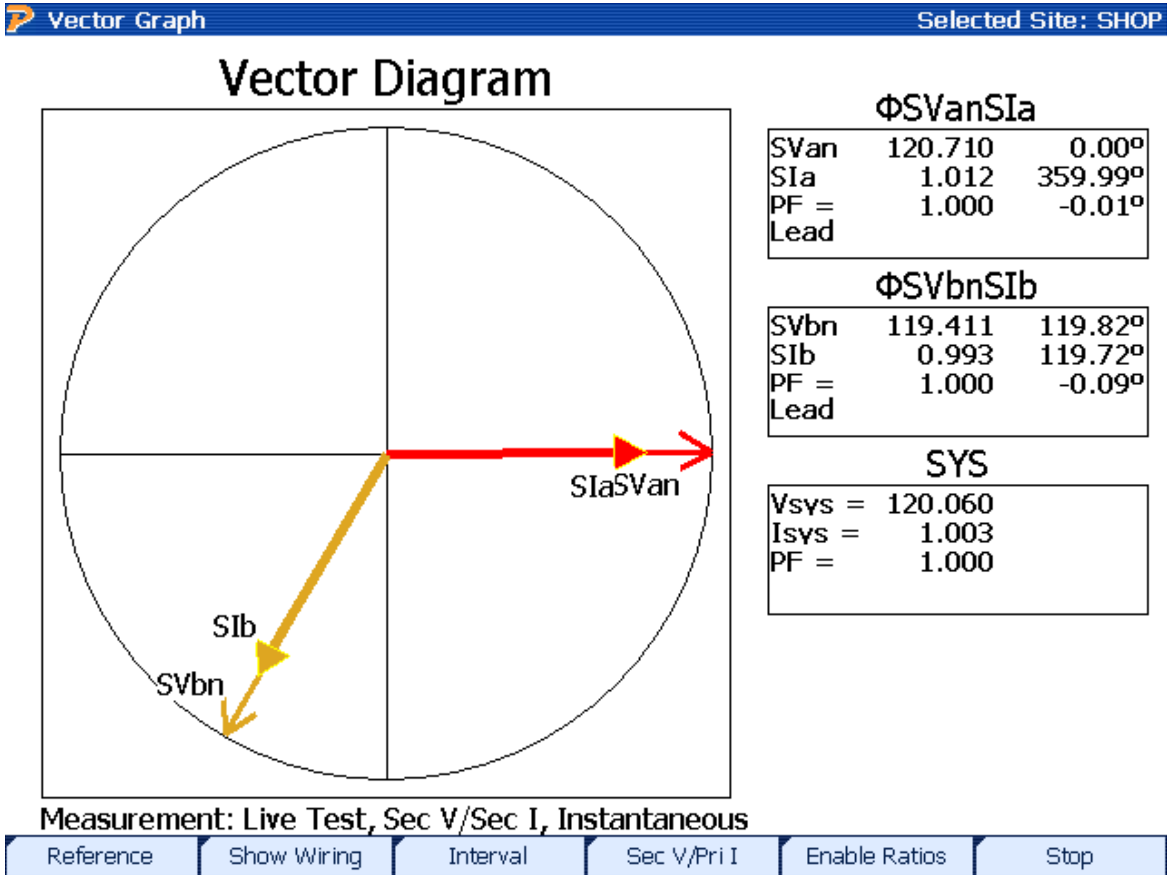


Two voltage sources with their returns connected to a common point.

Provides 208 rather than 240 volts across “high side” wires.

2 Phase, 3-Wire "Network" Service

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



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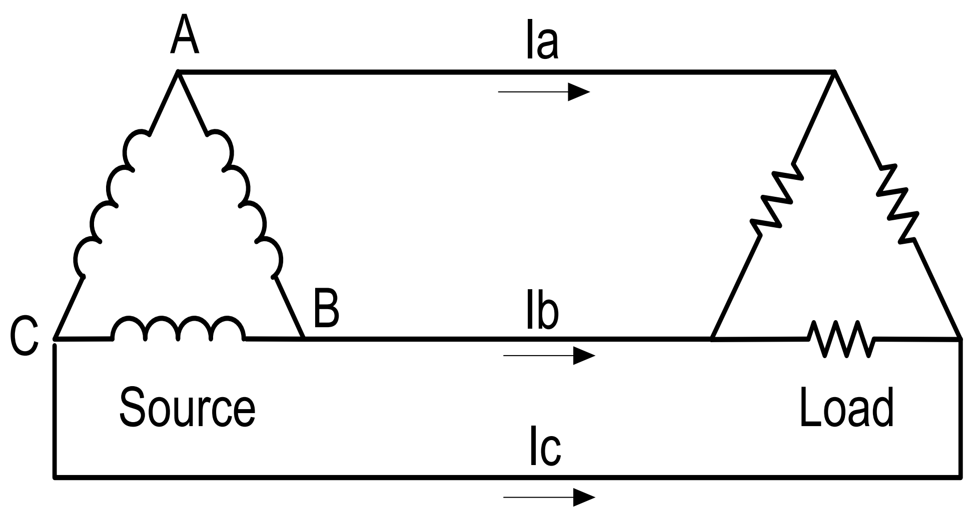
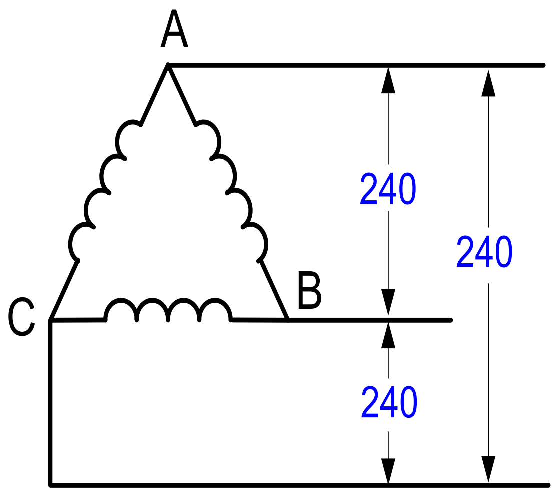
3 Phase, 3-Wire Delta Service

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



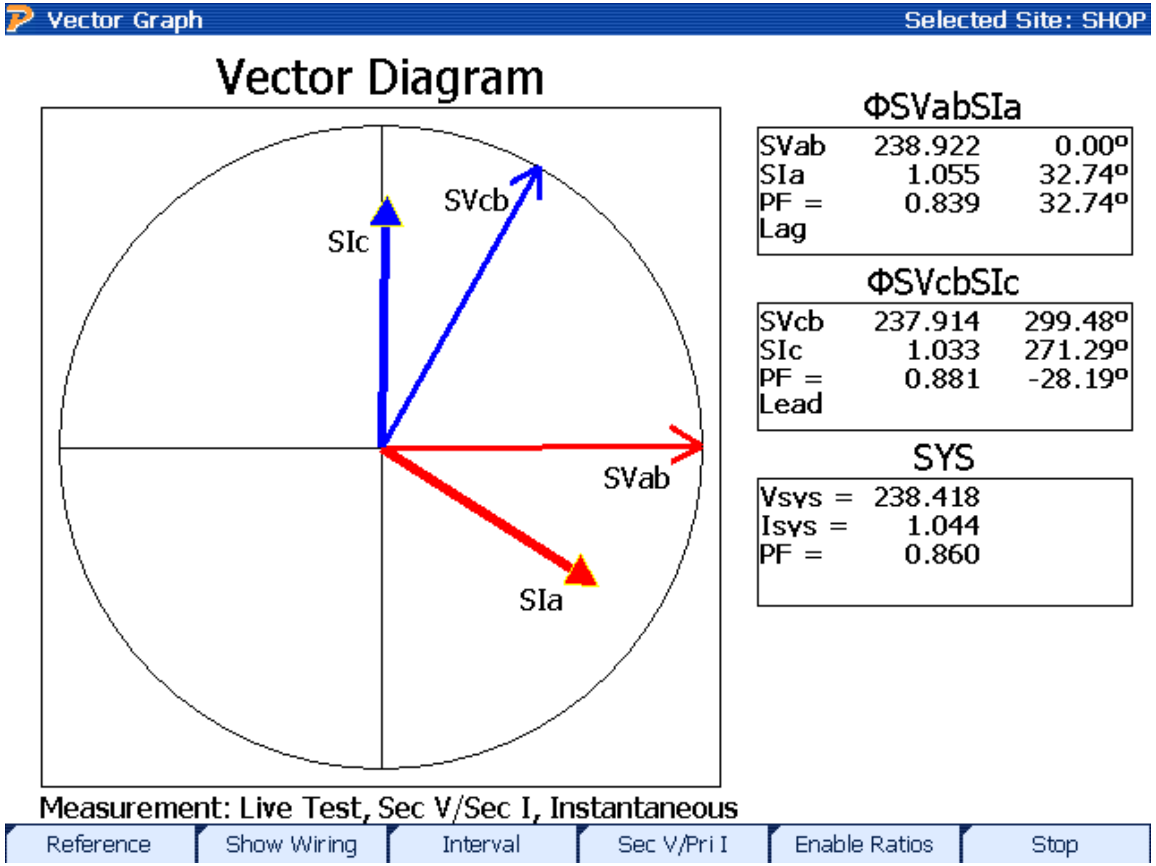


- Voltages normally measured relative to phase B.
- Voltage and current vectors do not align.
- Service is provided even when a phase is grounded.

3 Phase, 3-Wire Delta Service

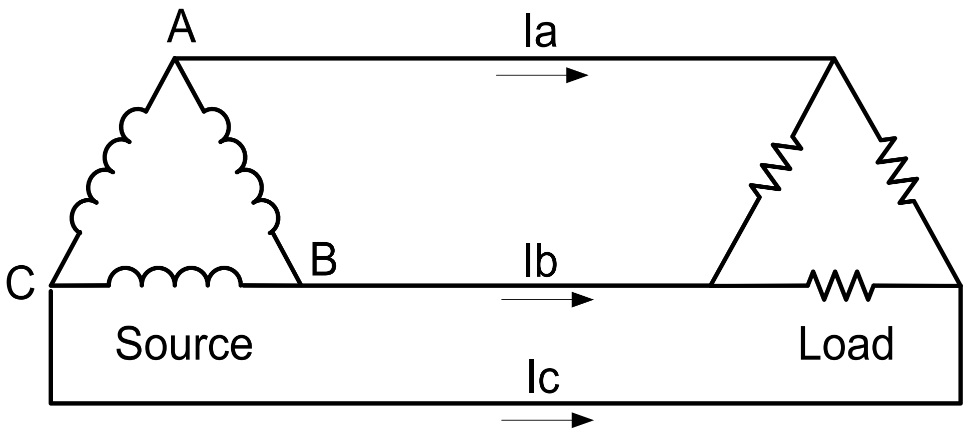
Resistive Loads

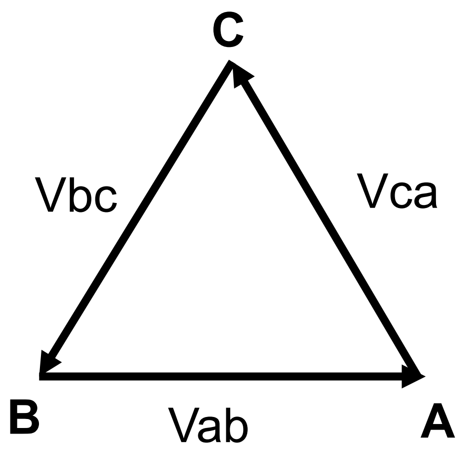
- Two Voltage Phasors
- 60° Apart
- Two Current Phasors
- For a resistive load one current leads by 30° while the other lags by 30°

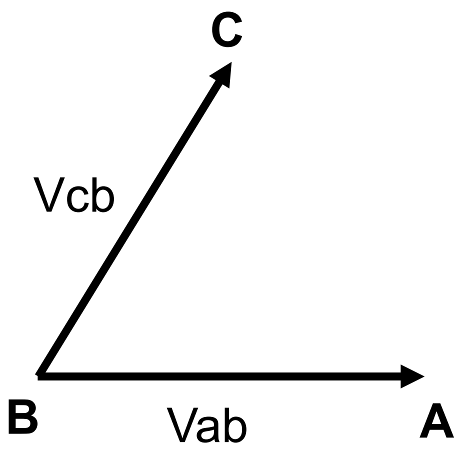


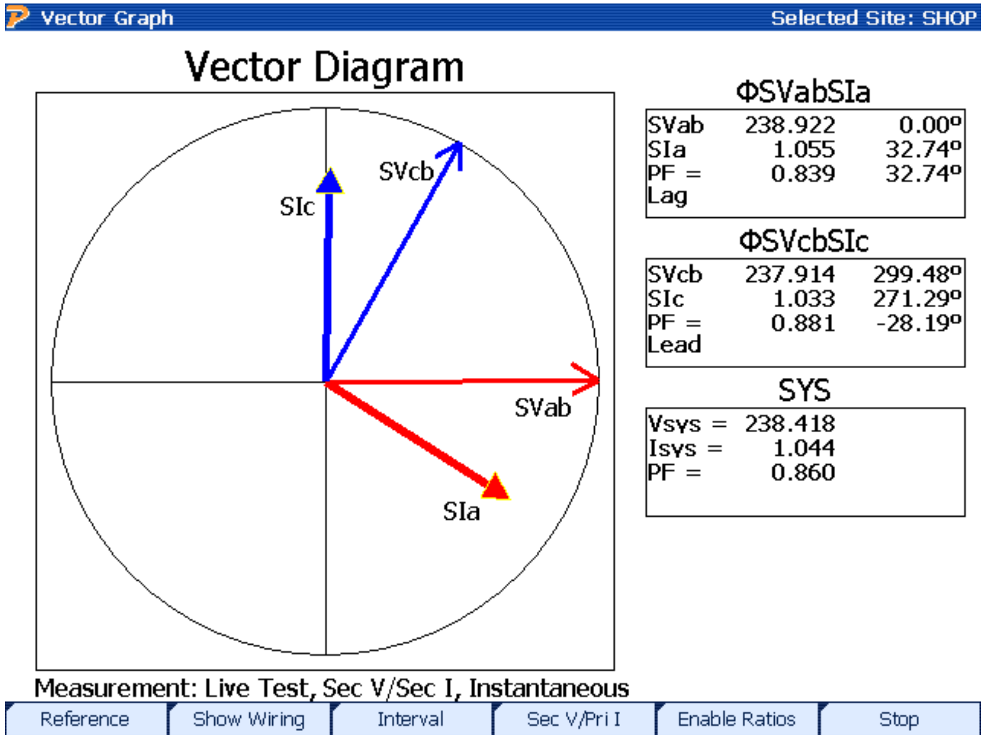
3 Phase, 3-Wire Delta Service

Understanding the Diagram



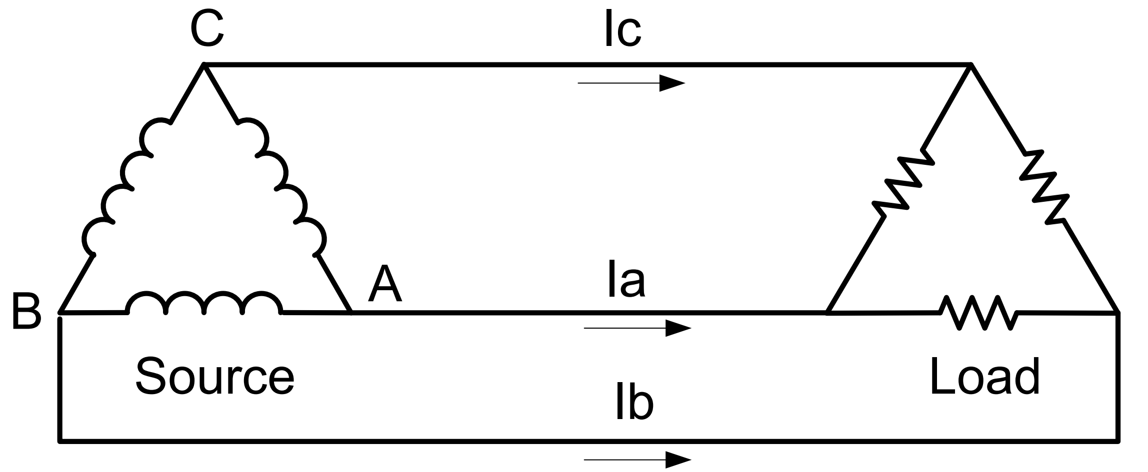


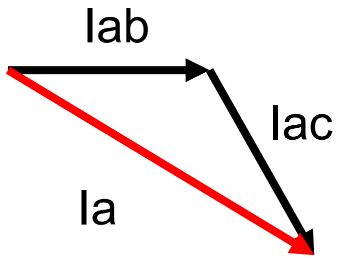


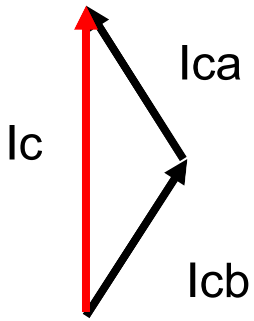


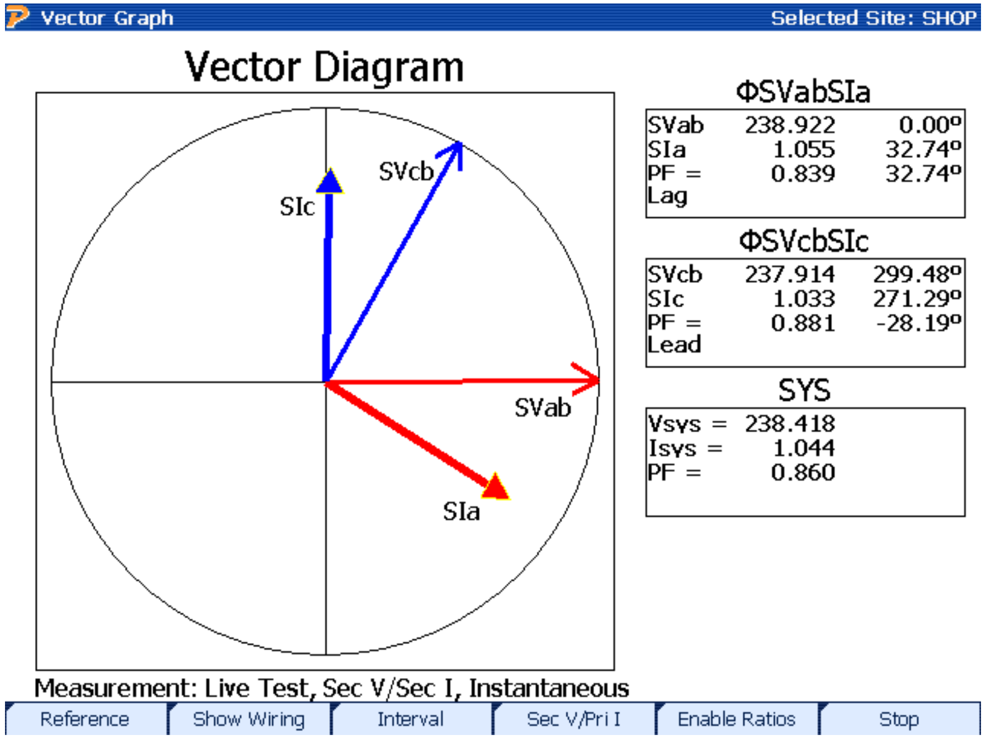
3 Phase, 3-Wire Delta Service

Understanding the Diagram









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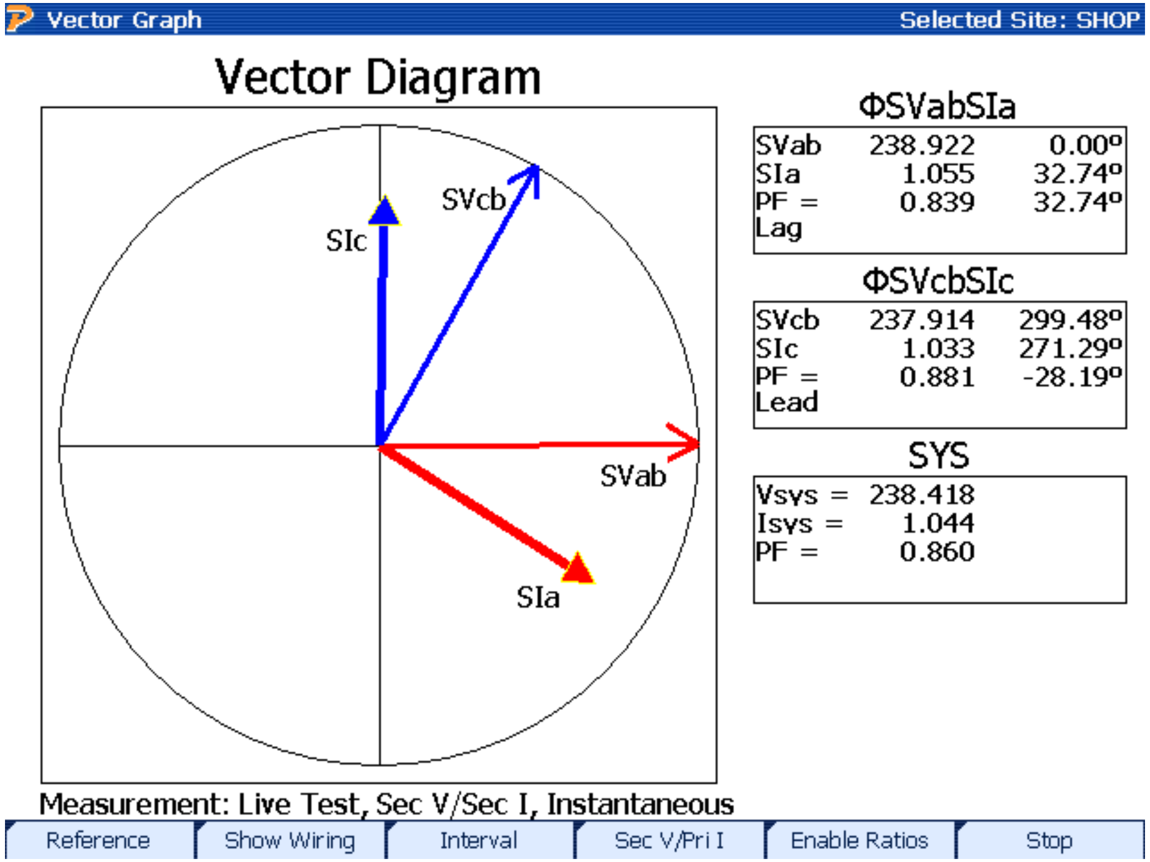
3 Phase, 3-Wire Delta Service

Resistive Load

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



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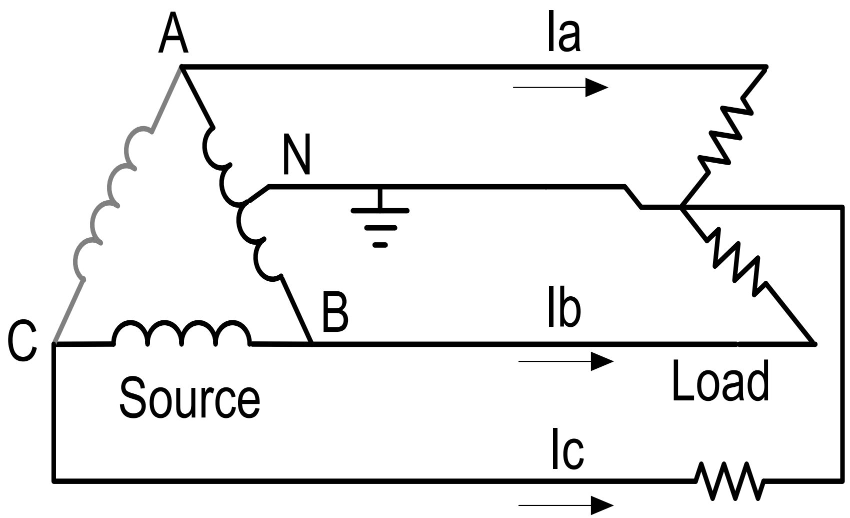
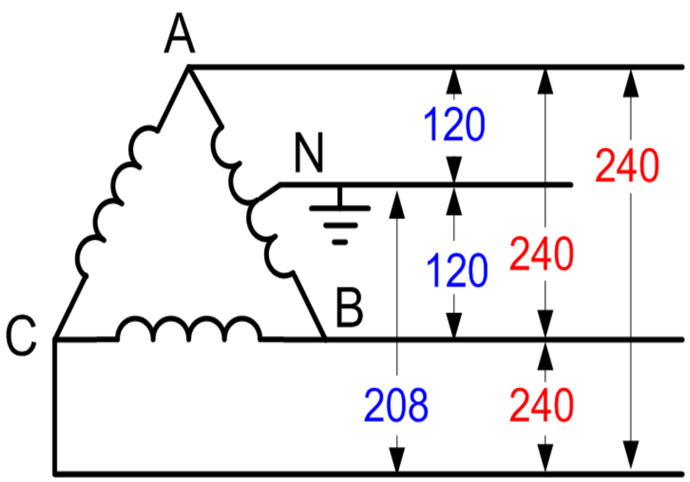
3 Phase, 4-Wire Delta Service

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

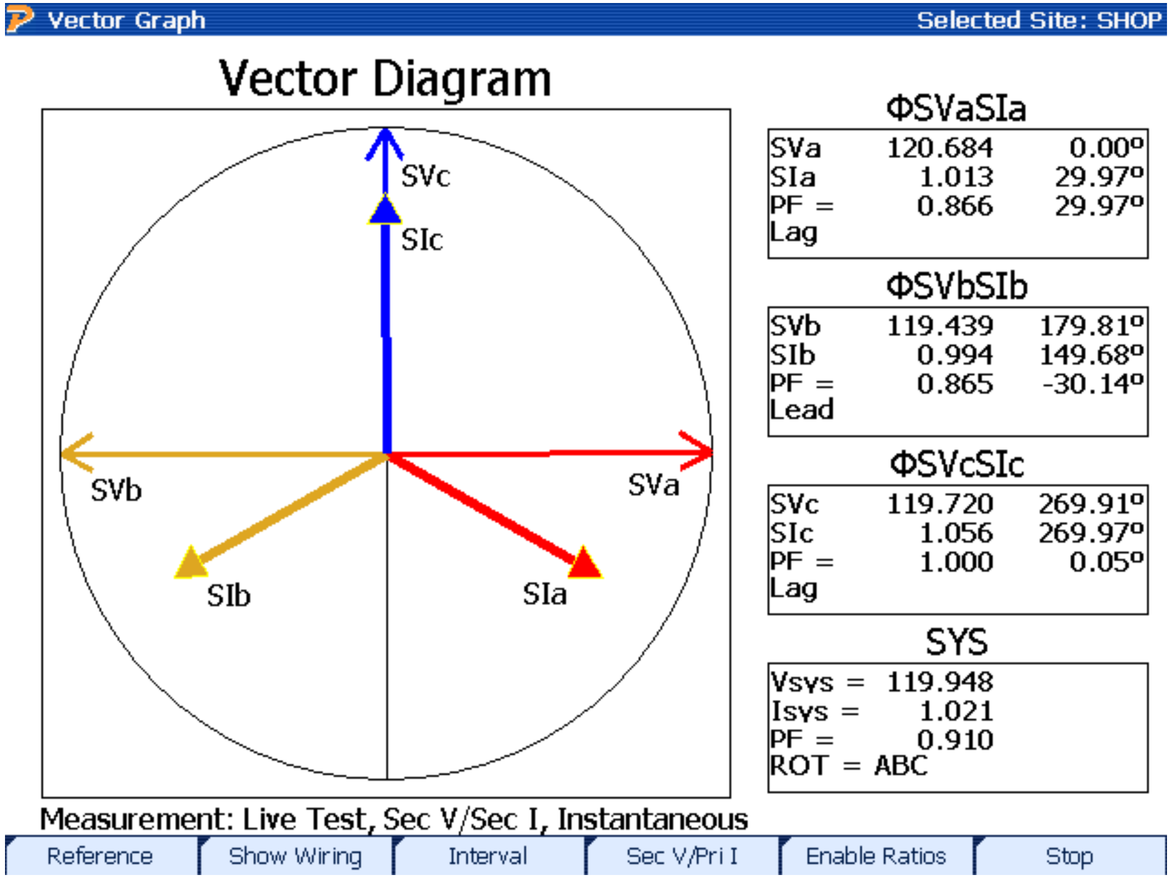
•Currents are at 120° spacing

•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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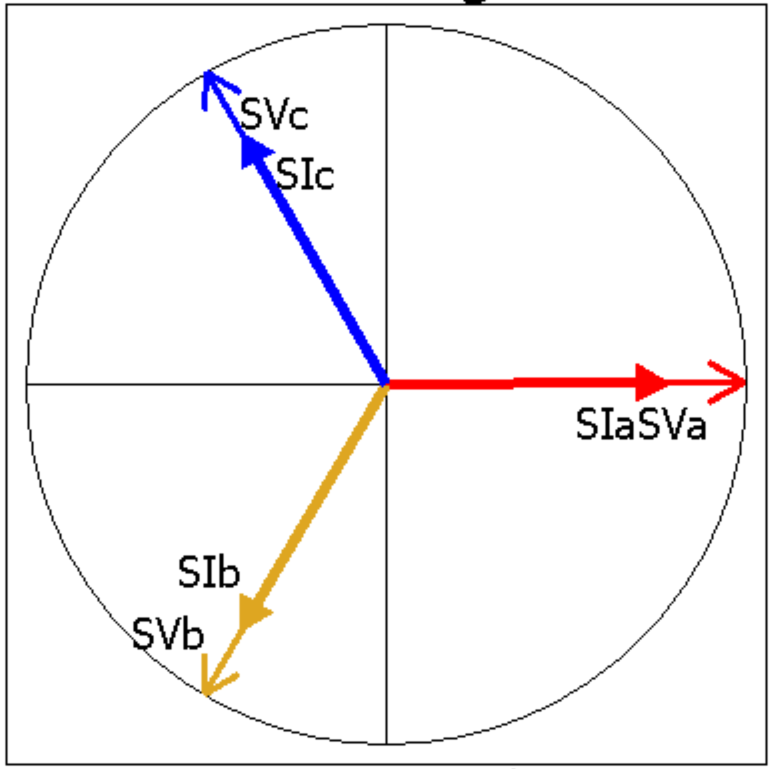
Troubleshooting with Vectors

Vector Graph | Batt [3302 90%][335 90%] | Site: None

Vector Diagram



SVaSIa

SVa	120.324	0.00°
SIa	2.457	0.18°
PF =	1.000	-0.18°

SVbSIb

SVb	120.324	120.15°
SIb	2.463	120.08°
PF =	1.000	0.07°

SVcSIc

SVc	120.301	240.04°
SIc	2.463	240.30°
PF =	1.000	-0.26°

Sys

Vsys =	120.316
Isys =	2.461
PF =	1.000
ROT = ABC	

Measurement:Last Test Sec V/Sec I, Instantaneous

Restart

Ideal 9S 4WY Service

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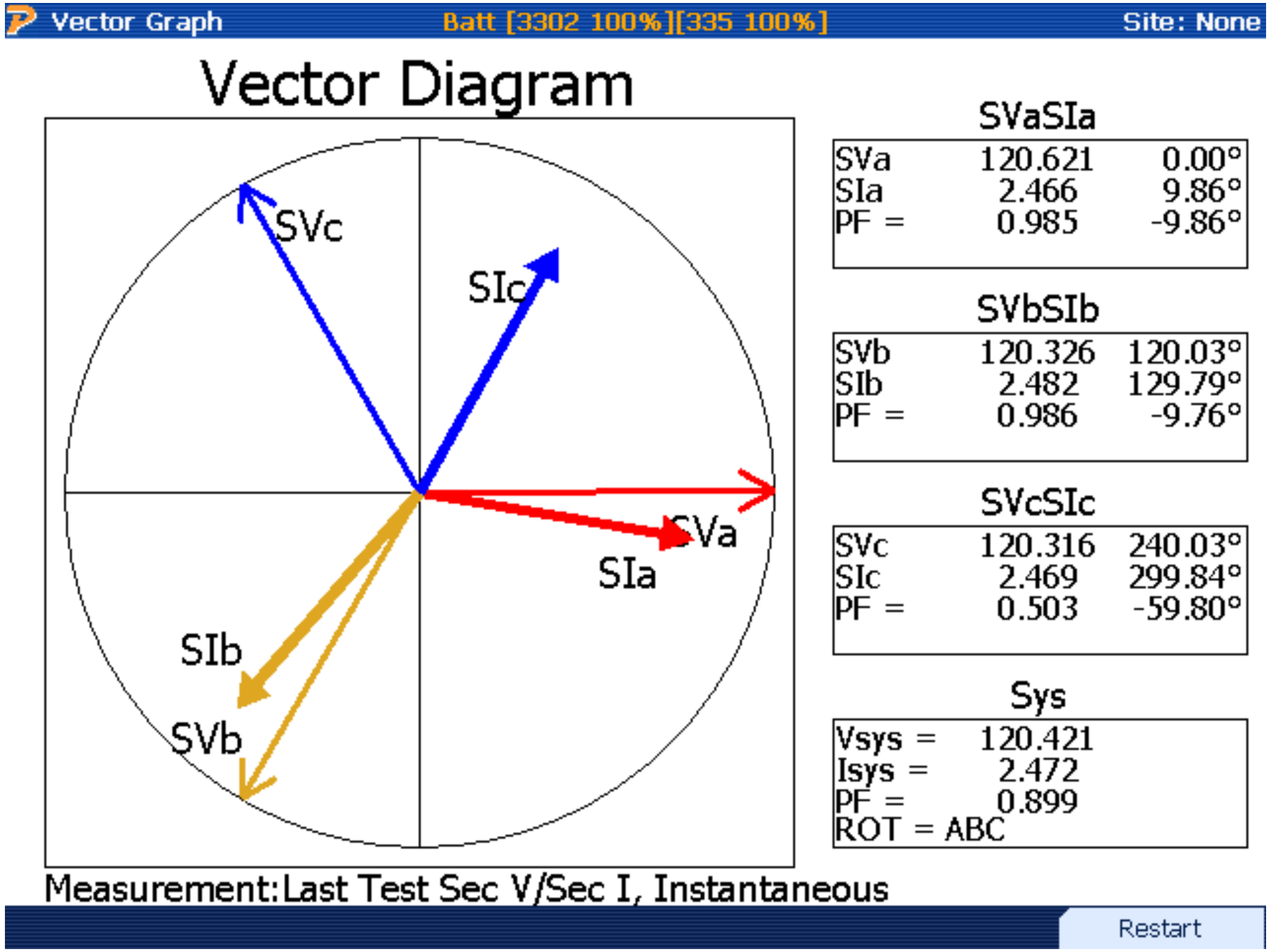
Troubleshooting with Vectors

- Always know what the ideal vector looks like
- Use the reference vector on your analyzer
- Look for deviations from the norm

Troubleshooting with Vectors



Phase C has a highly inductive load

Low PF on C Phase

- W = V * I * PF

- Low power factor will lead to lower active power (Watts) measurement on C phase

- May need to impose a power factor penalty or add capacitance to correct power factor

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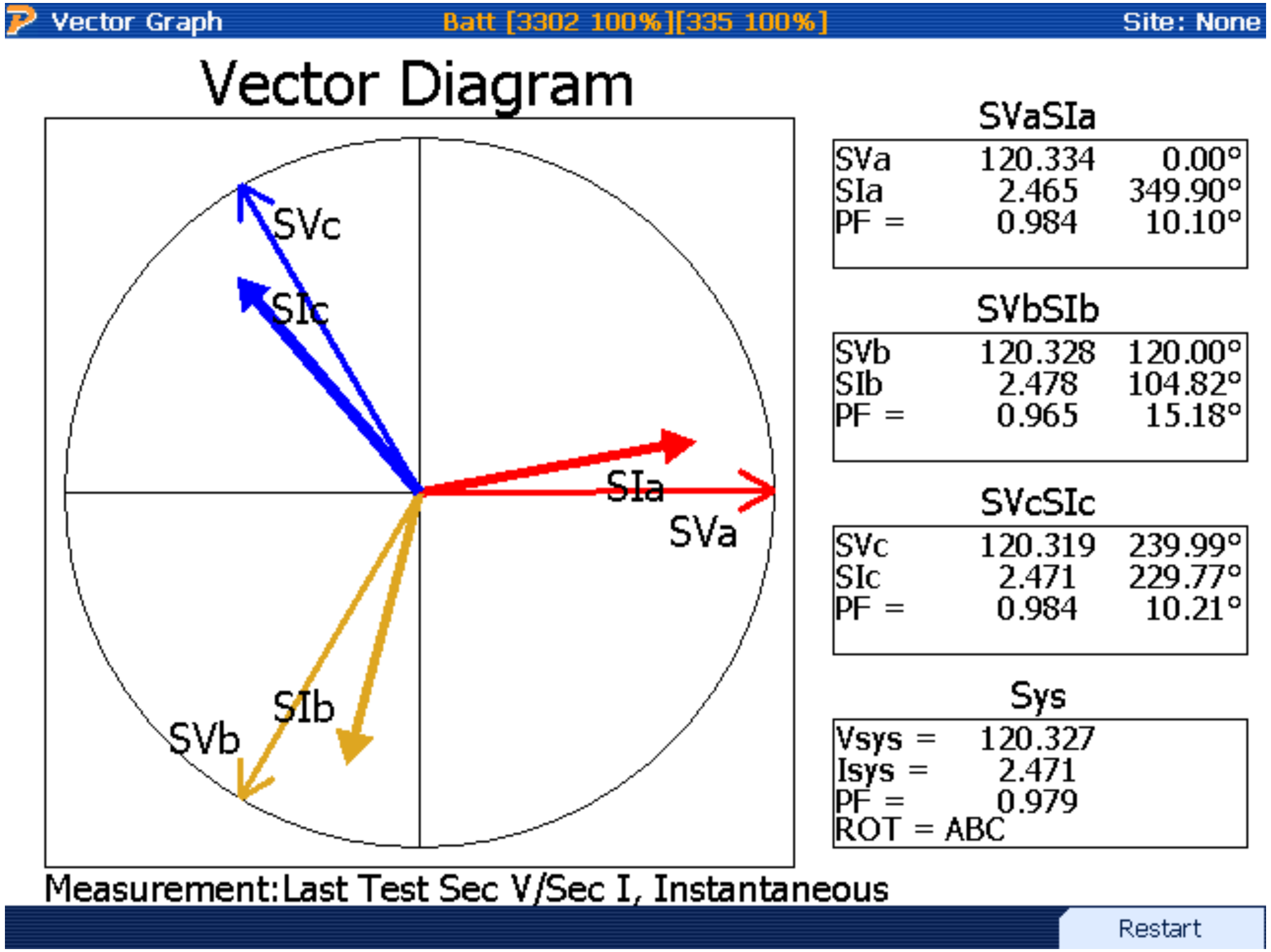
Troubleshooting with Vectors



All phases are leading

Leading Phase Angle

- Capacitor bank switched in causes leading phase angle

- Not a problem unless there is excessive capacitance leading to low power factor

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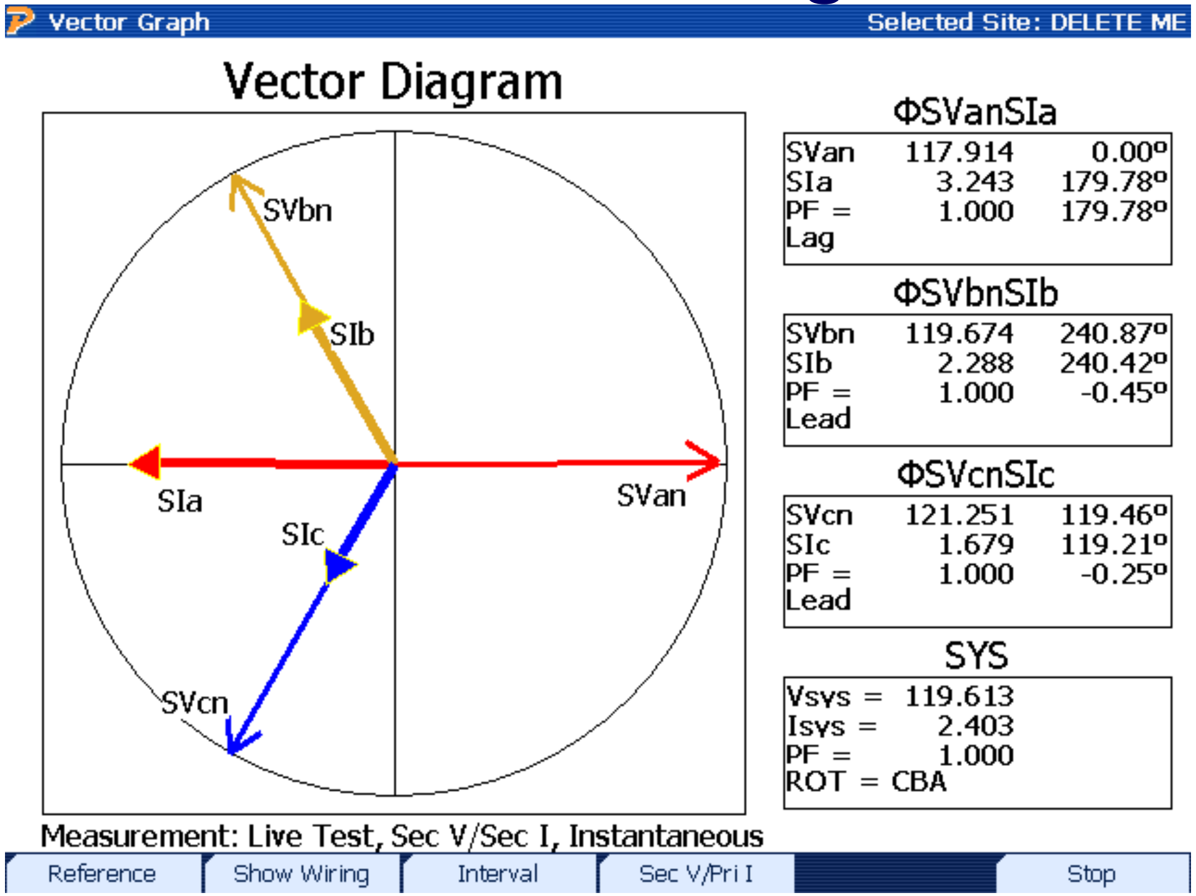
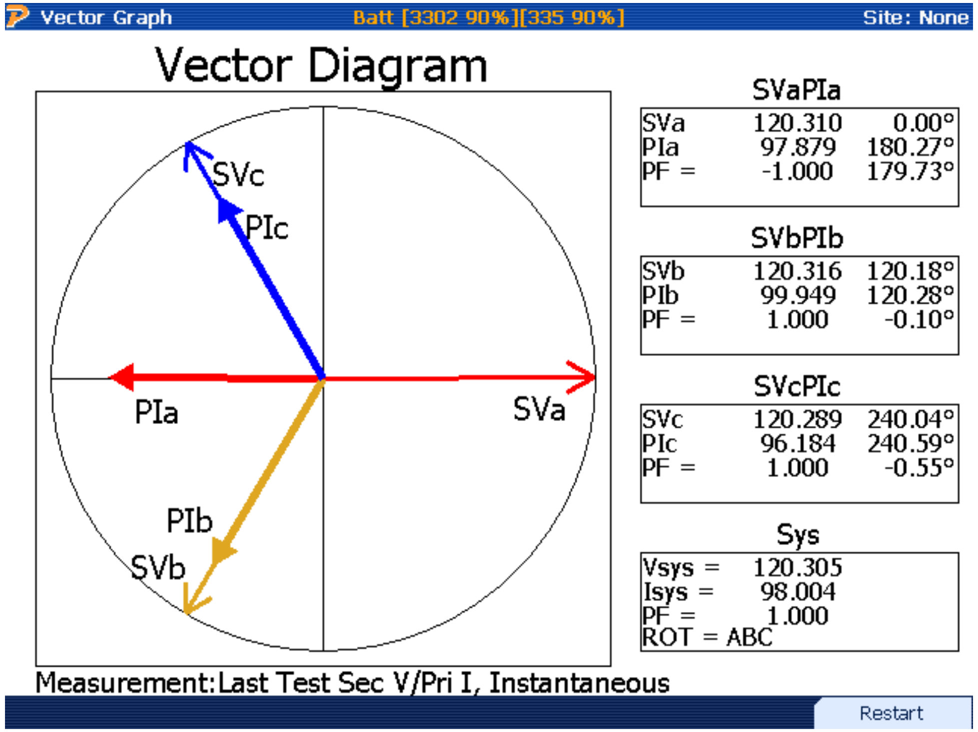
Troubleshooting with Vectors

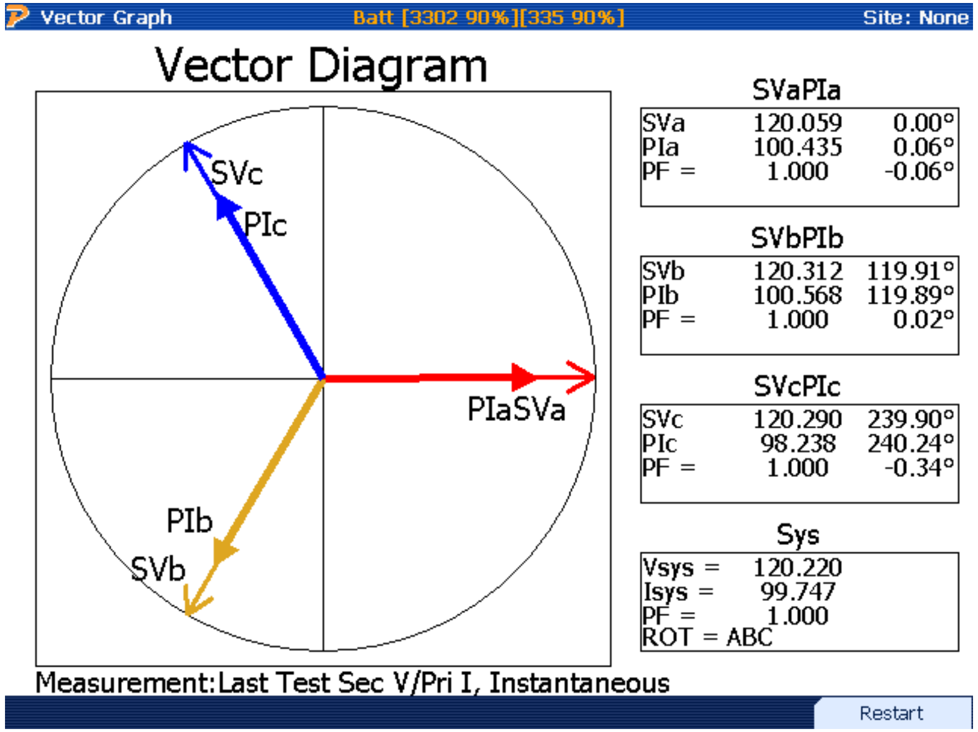
What's Wrong?



Phase A current is reversed

Check the Primary!





CT may be reversed on the primary or secondary side

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Backwards CT = ??? $$$

- kW = Va * Ia * Cos θ + Vb * Ib * Cos θ + Vc * Ic * Cos θ
- Cos 180 on phase A makes this NEGATIVE power!
- Reading will be 66% low assuming a balanced current load!

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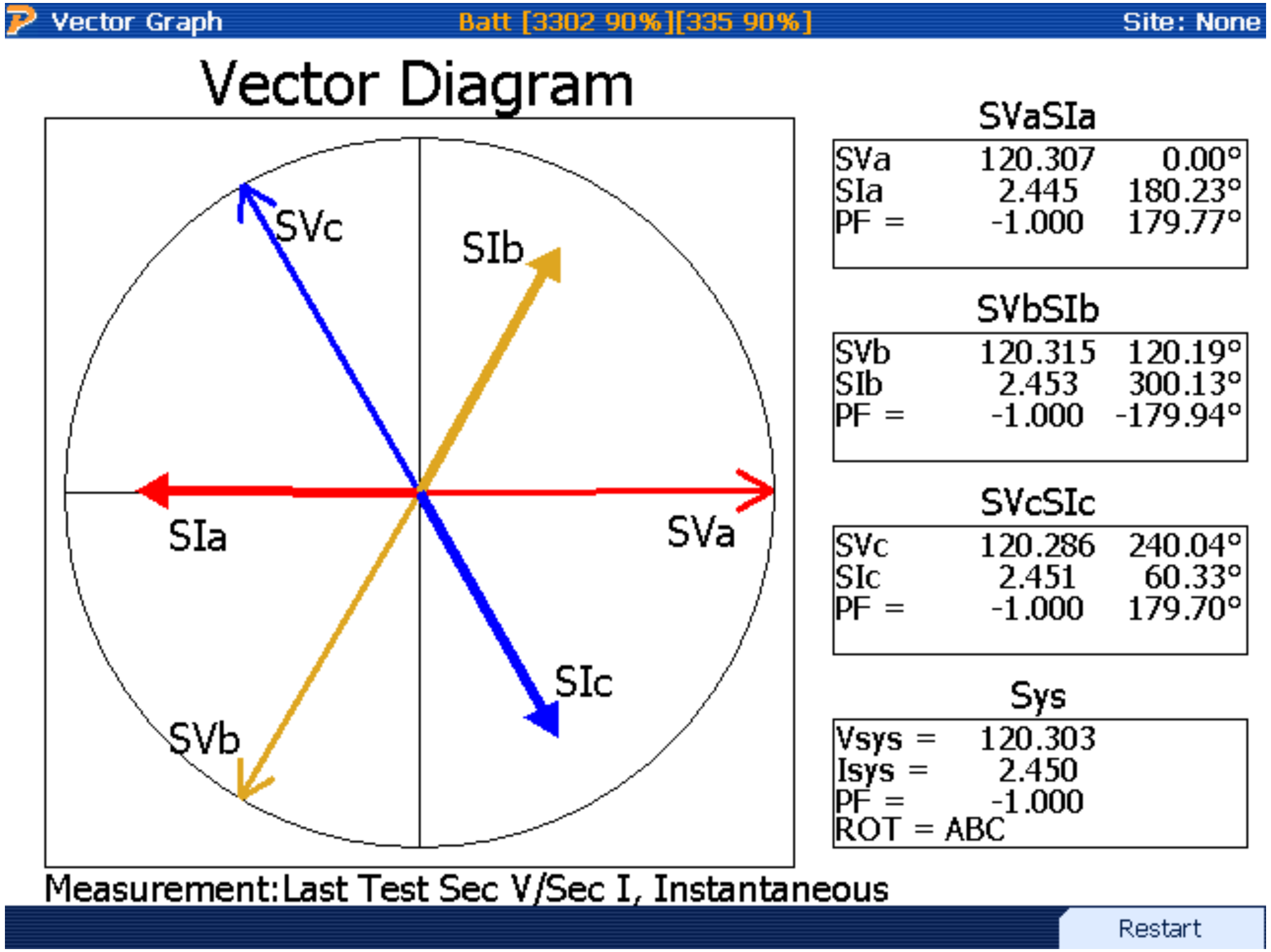
Troubleshooting with Vectors



All current vectors are reversed

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All current vectors reversed

- All CTs are reversed
- Test equipment may be backwards
- Perfectly normal vector for a solar installation

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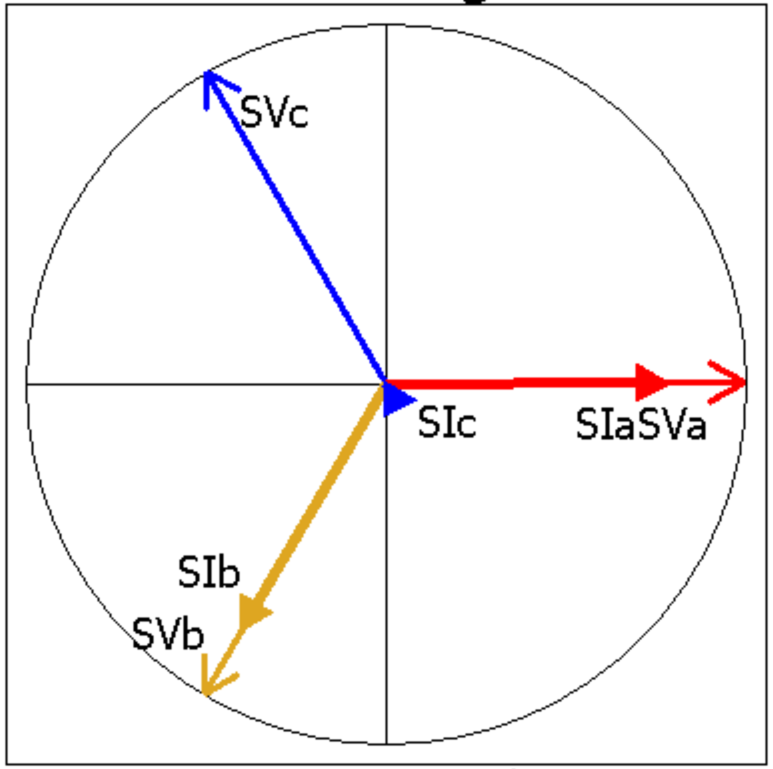
Troubleshooting with Vectors

Vector Graph Batt [3302 90%][335 90%] Site: None

Vector Diagram



SVaSIa

SVa	120.025	0.00°
SIa	2.443	0.20°
PF =	1.000	-0.20°

SVbSIb

SVb	120.311	120.16°
SIb	2.449	120.09°
PF =	1.000	0.07°

SVcSIc

SVc	120.283	240.00°
SIc	0.034	241.34°
PF =	1.000	-1.34°

Sys

Vsys =	120.206
Isys =	1.642
PF =	1.000
ROT = ABC	

Measurement:Last Test Sec V/Sec I, Instantaneous

Restart

Phase C current is low

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Low Secondary Current

- Check for shunted CT
- Test switch may be shunted
- CT wiring is bad. Look for set screws on the wire insulator.
- 33% loss of revenue

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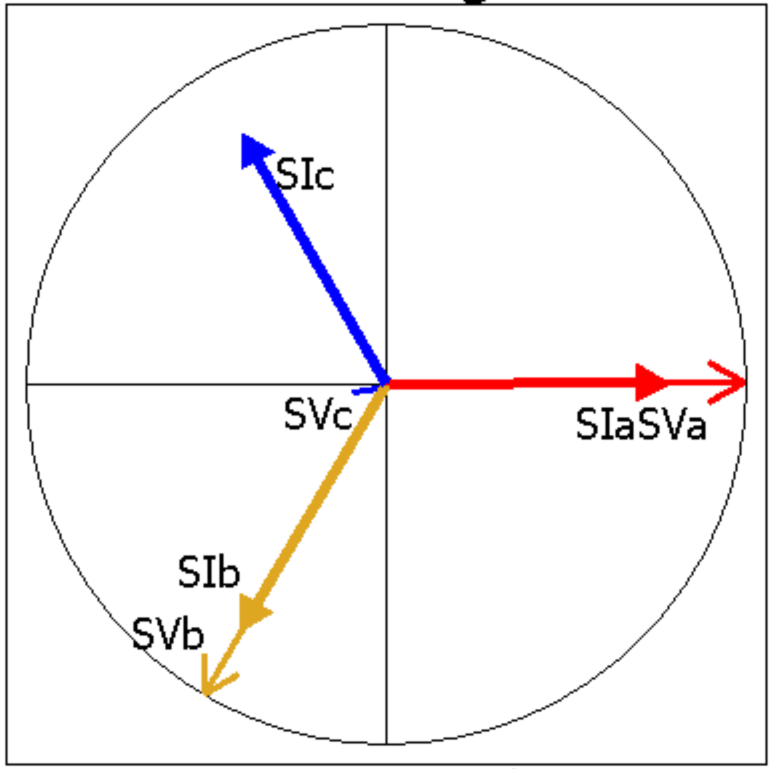
Troubleshooting with Vectors

Vector Graph   Batt [3302 90%][335 90%]   Site: None

Vector Diagram



SVaSIa

SVa	120.017	0.00°
SIa	2.440	0.21°
PF =	1.000	-0.21°

SVbSIb

SVb	120.309	120.17°
SIb	2.447	120.10°
PF =	1.000	0.07°

SVcSIc

SVc	2.474	21.31°
SIc	2.445	240.30°
PF =	-0.777	141.01°

Sys

Vsys =	80.933
Isys =	2.444
PF =	1.000
ROT = CBA	

Measurement:Last Test Sec V/Sec I, Instantaneous

Restart

Phase C voltage is low

Low Voltage

- Check for shorted or overburdened PT
- Test switch may be open or faulty
- Look for set screws on the insulator
- 33% loss of revenue

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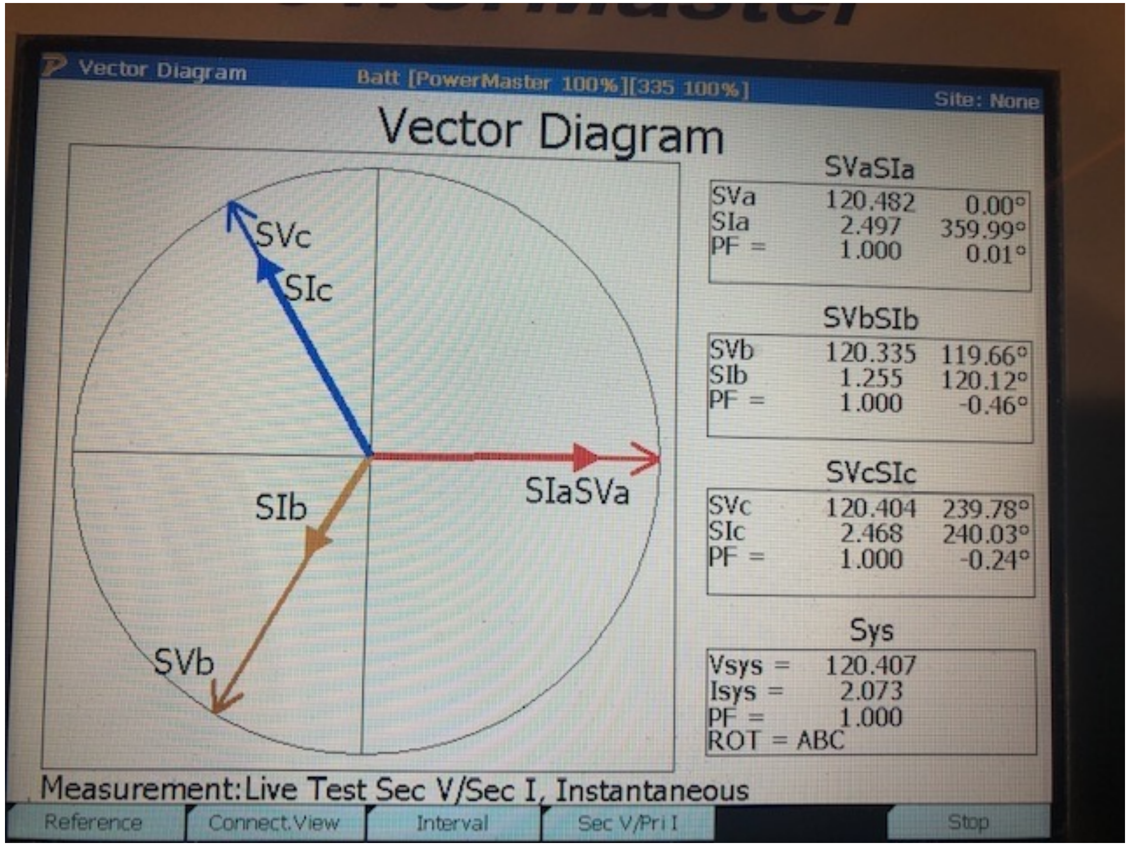
Troubleshooting with Vectors

What's Wrong?



Phase B current is low

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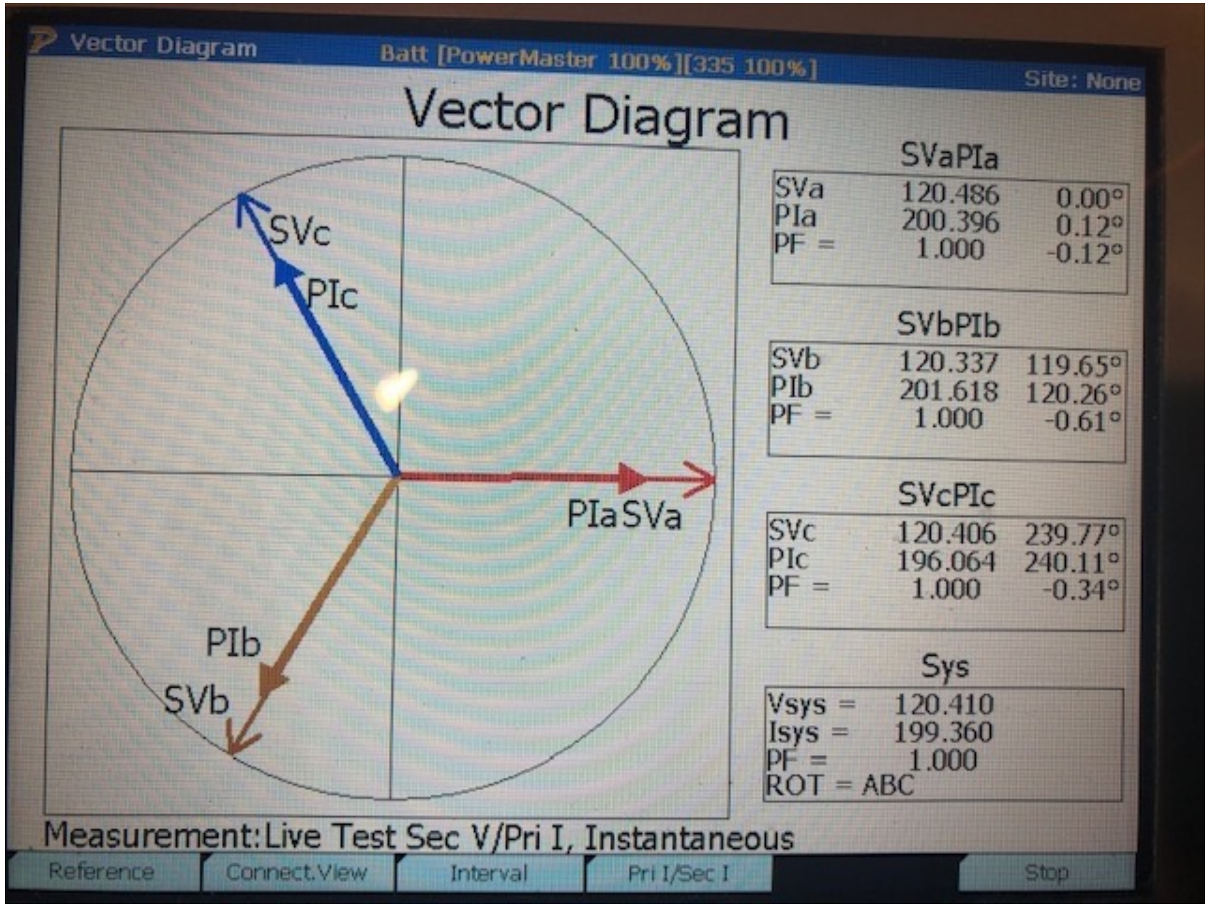
Troubleshooting with Vectors

What's Wrong?



- Primary currents look equal
- Secondary current on B is low
- What is the problem?

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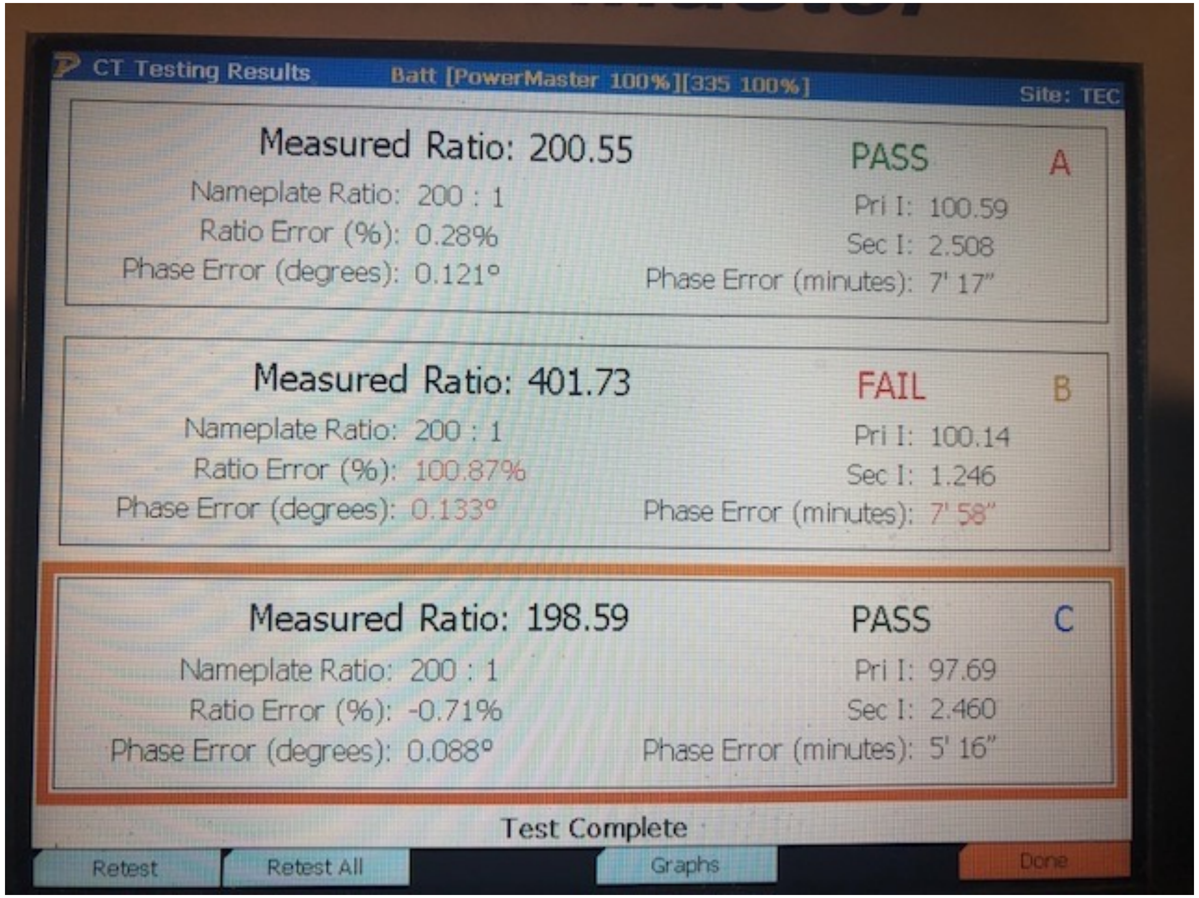
Troubleshooting with Vectors

What's Wrong?



Incorrectly sized CT that was labeled improperly!

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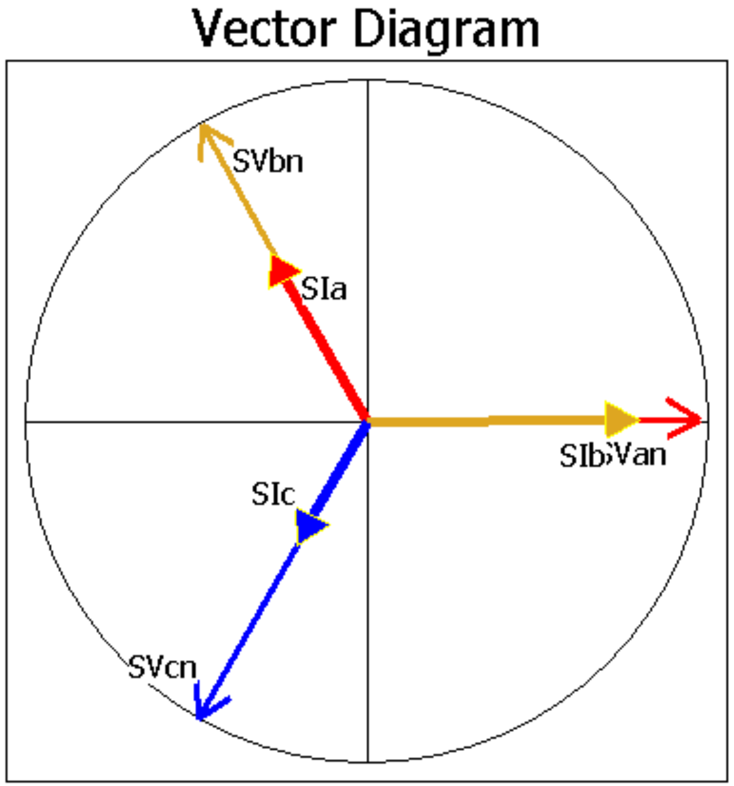
Troubleshooting with Vectors

What's Wrong?

Vector Graph — Selected Site: DELETE ME



ΦSVanSIa

SVan	118.017	0.00º
SIa	2.289	240.46º
PF =	0.493	-119.54º
Lead		

ΦSVbnSIb

SVbn	119.774	240.91º
SIb	3.245	359.77º
PF =	0.482	118.86º
Lag		

ΦSVcnSIc

SVcn	121.387	119.50º
SIc	1.680	119.24º
PF =	1.000	-0.26º
Lead		

SYS

Vsys =	119.726
Isys =	2.405
PF =	0.658
ROT = CBA	

Measurement: Live Test, Sec V/Sec I, Instantaneous

Reference | Show Wiring | Interval | Sec V/Pri I | Stop

Phase A & B CTs swapped.

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Swapped Wire = ??? $$$

- kW = Va * Ia * Cos θ + Vb * Ib * Cos θ + Vc * Ic * Cos θ
- Cos 120 on phase A and B makes this NEGATIVE power!
- Reading will be 0W assuming a balanced current load!

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Thank you for your time!

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