THE EASTERN SPECIALTY COMPANY

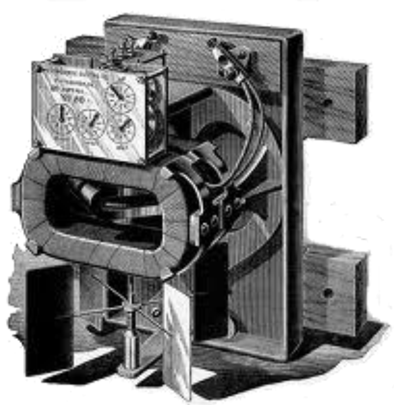
ADVANCED POLYPHASE METERING

PRESENTED BY JOHN KRETZSCHMAR

JUNE 20, 2017

THEN – NOW – TOMORROW?

METERS



First Meters mid-1990s

Westinghouse 1905

2005

2006

2014

2025 ???

THEN – NOW – TOMORROW?
LOADS

YESTERDAY

TODAY

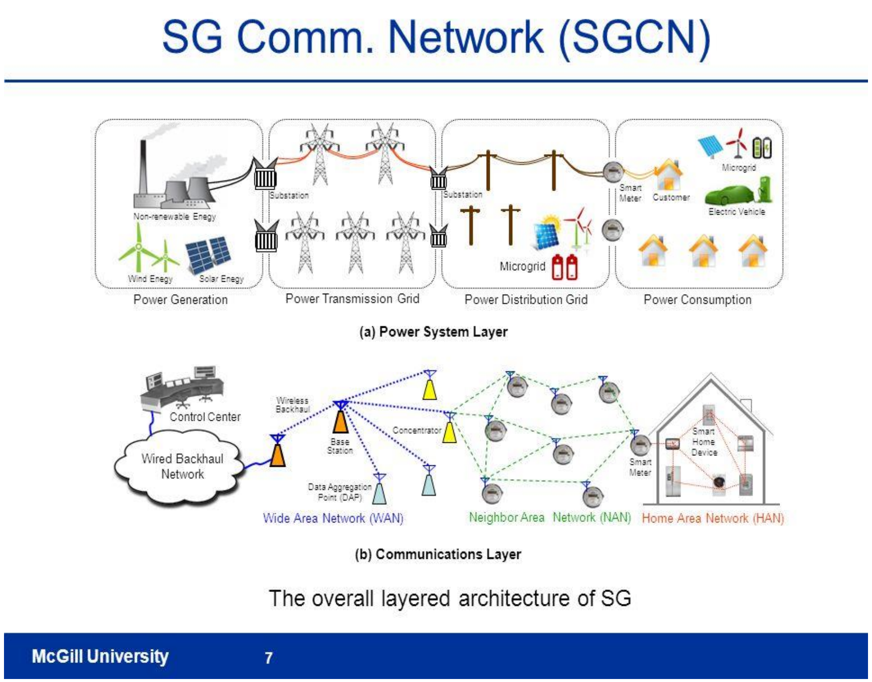
THEN – NOW – TOMORROW?
LOADS

TODAY

THEN – NOW – TOMORROW?
COMMUNICATIONS

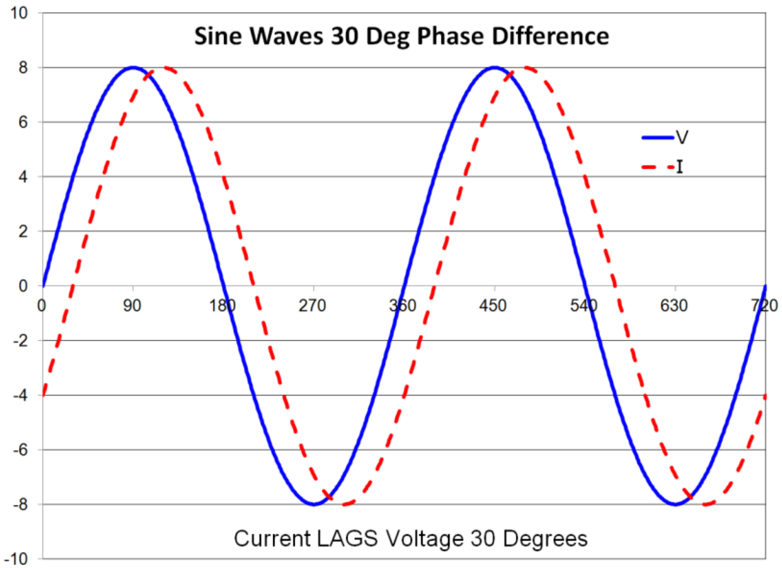
THEN

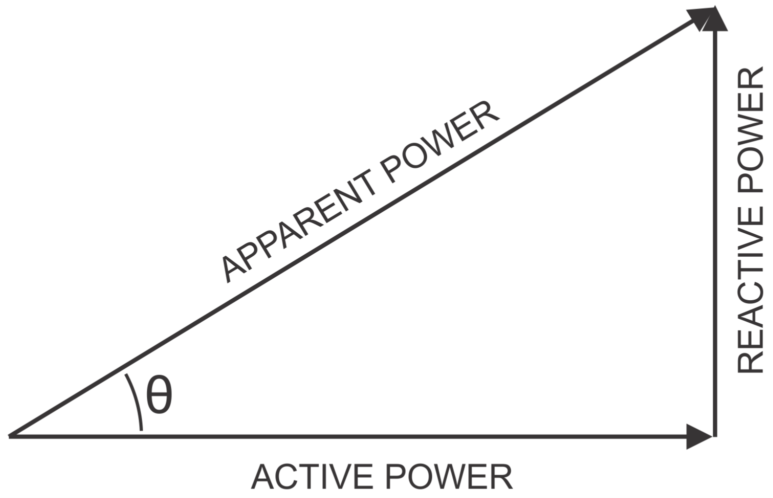
NOW



WHY DO THESE CHANGES MATTER?

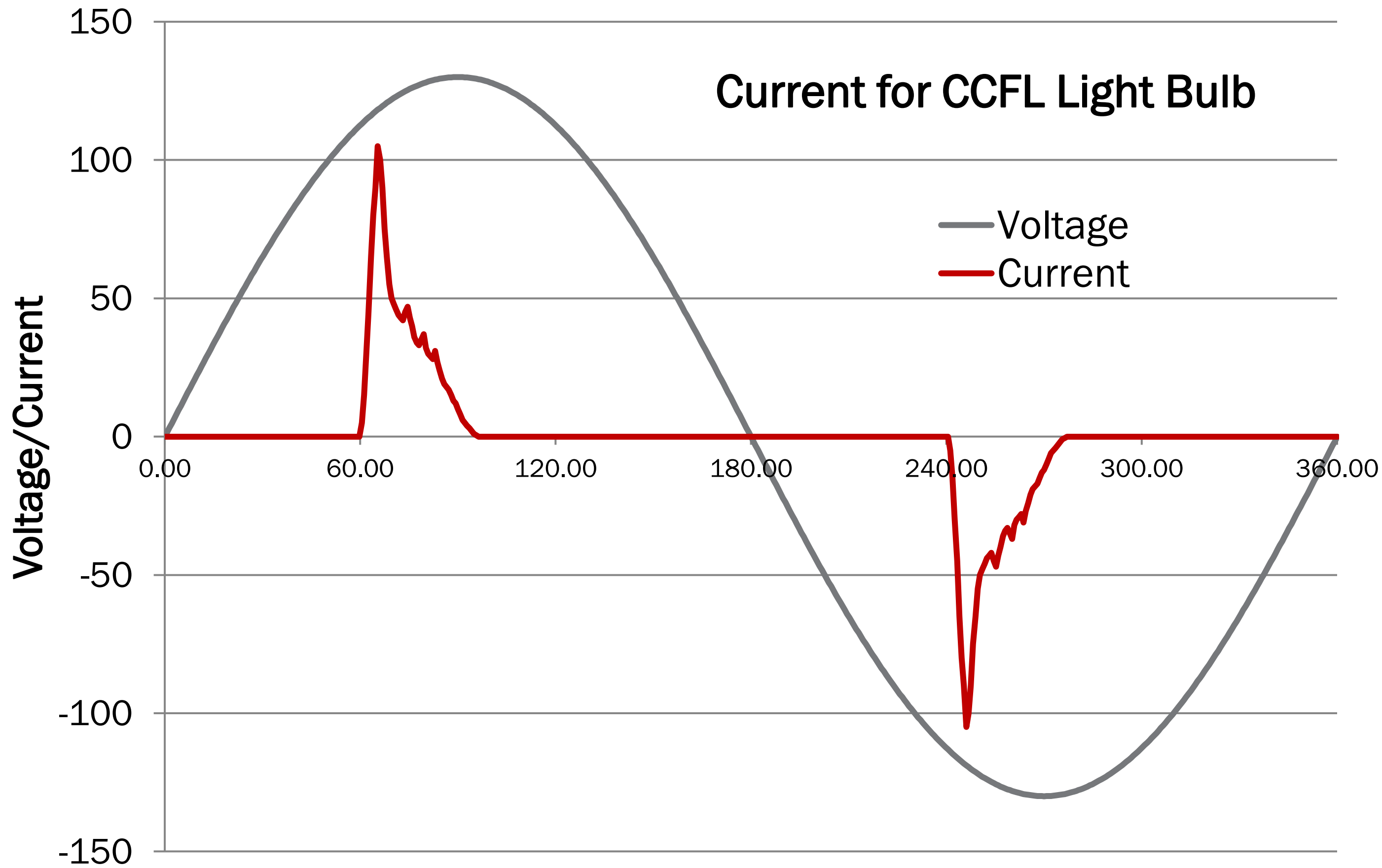
- Changes to our loads have changed the basic computations of metering
- When loads were linear the power triangle was all we needed to know





WHY DO THESE CHANGES MATTER?

Today's loads look more like these



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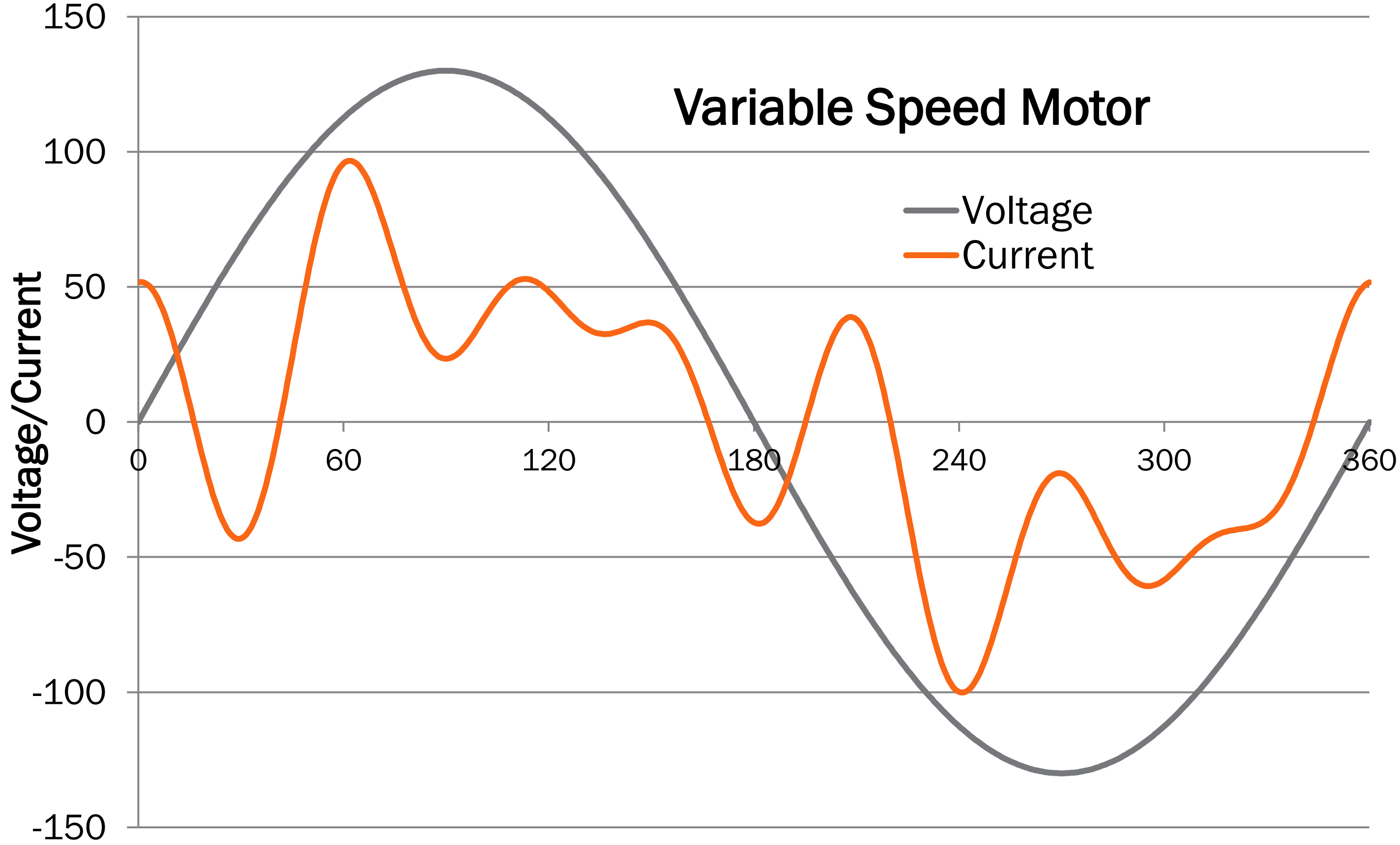

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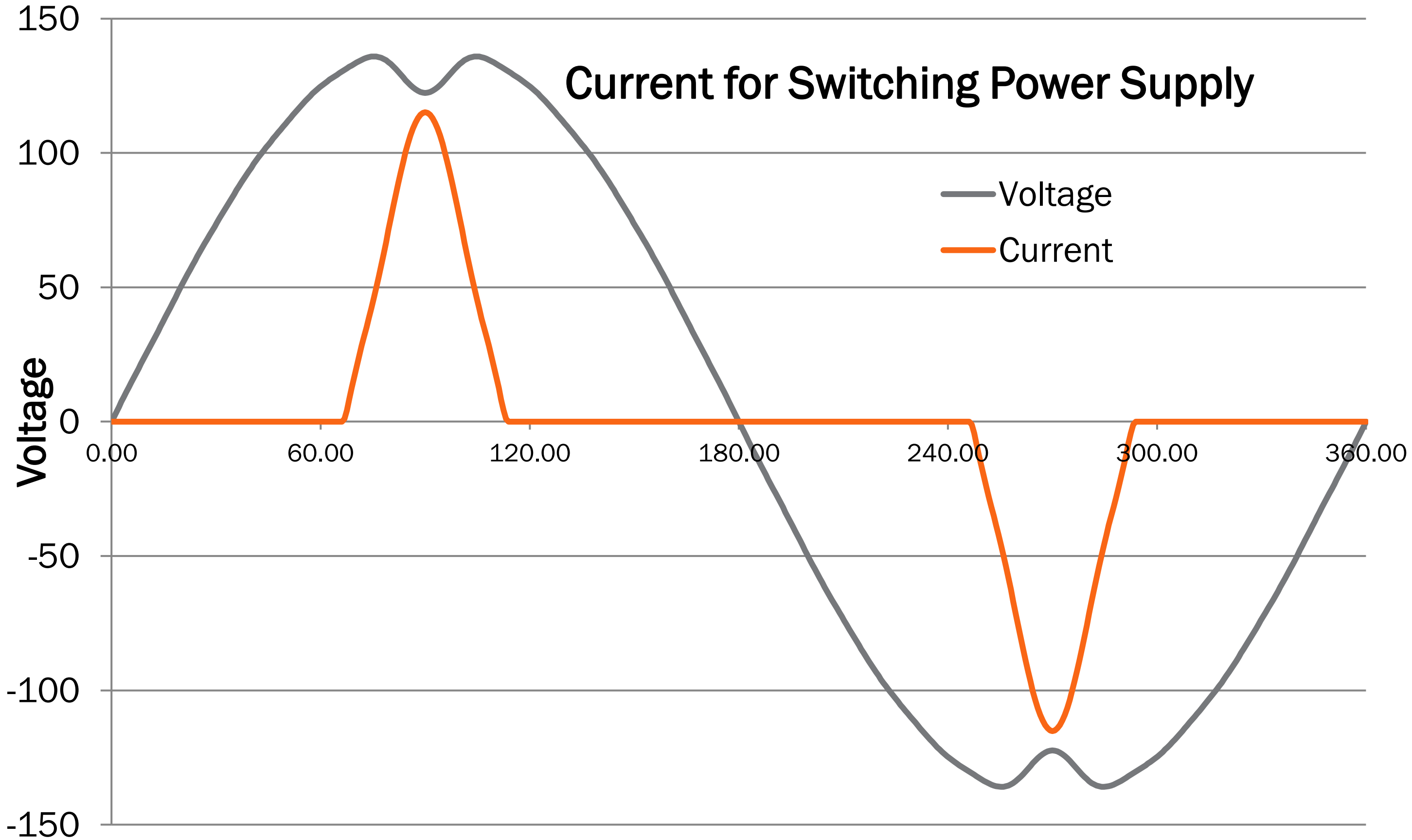
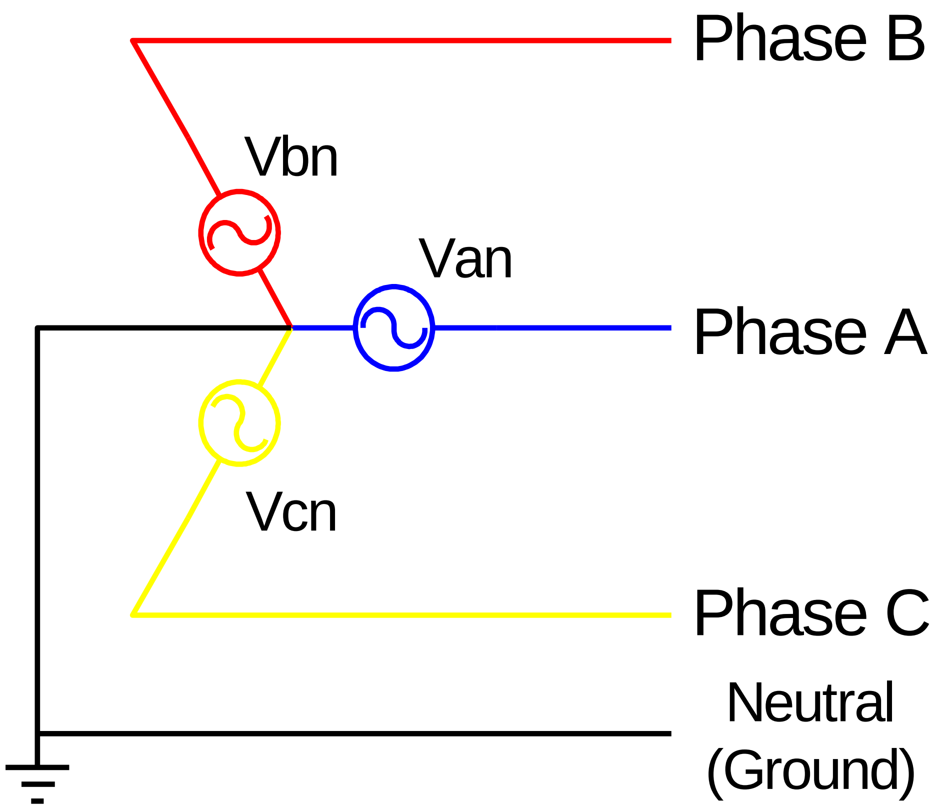


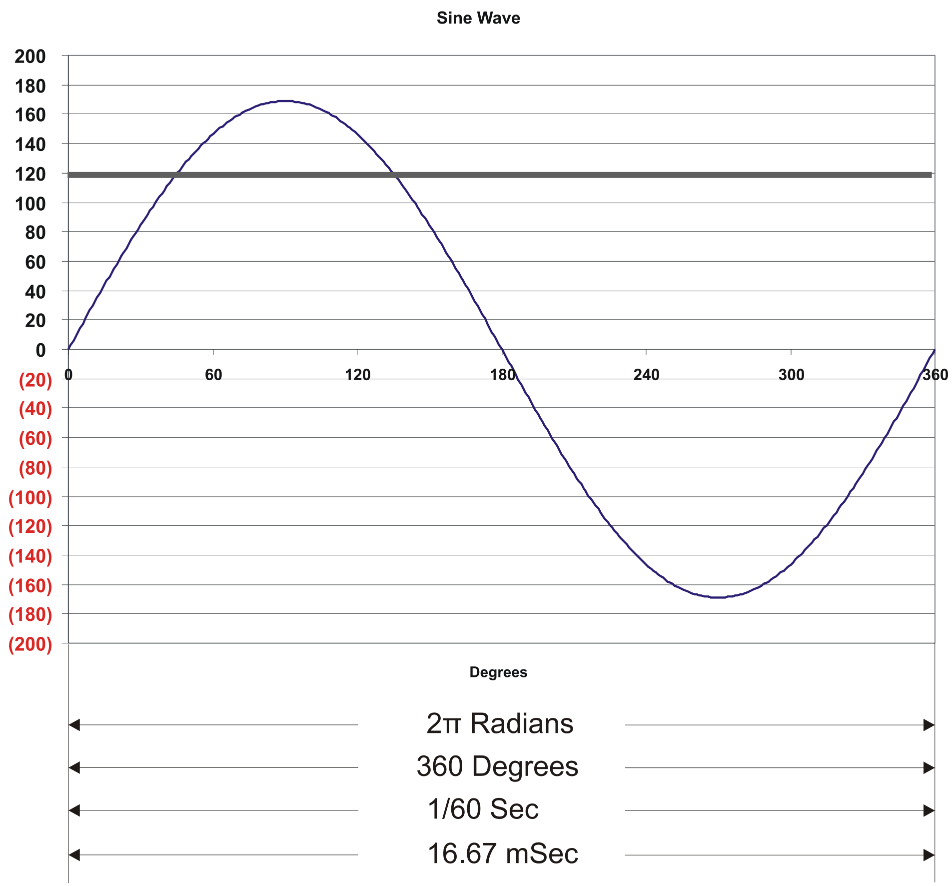
THREE PHASE POWER
INTRODUCTION



Basic Assumptions

- Three AC voltage sources
- Voltages Displaced in time
- Each sinusoidal
- Identical in Amplitude

AC THEORY – SINE WAVE



$$V = Sin(\theta) \bullet V_{\max}$$

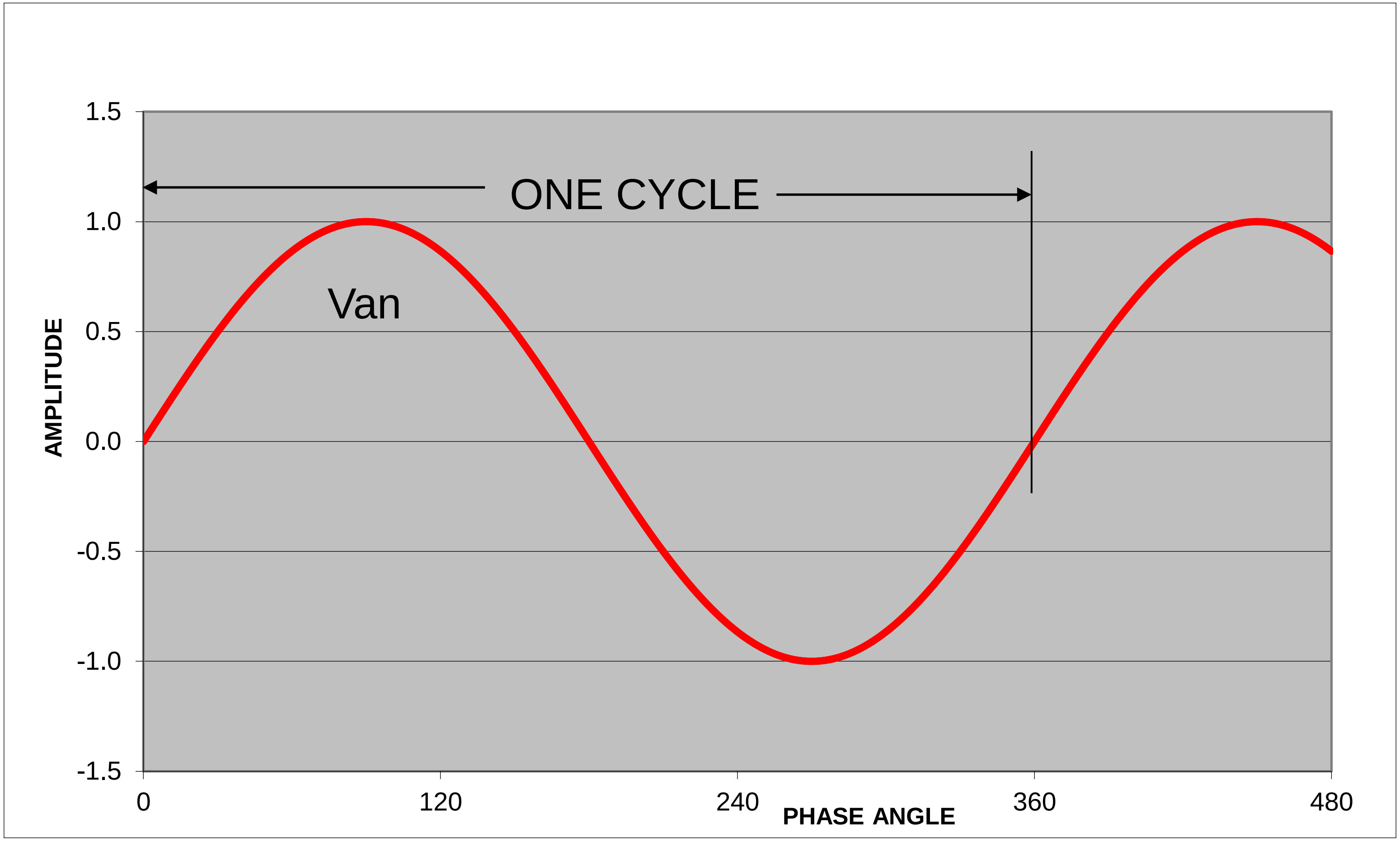
$$V_{pk} = 169$$

$$V_{RMS} = V_{\max} \bullet 0.707$$

$$V_{rms} = 120$$

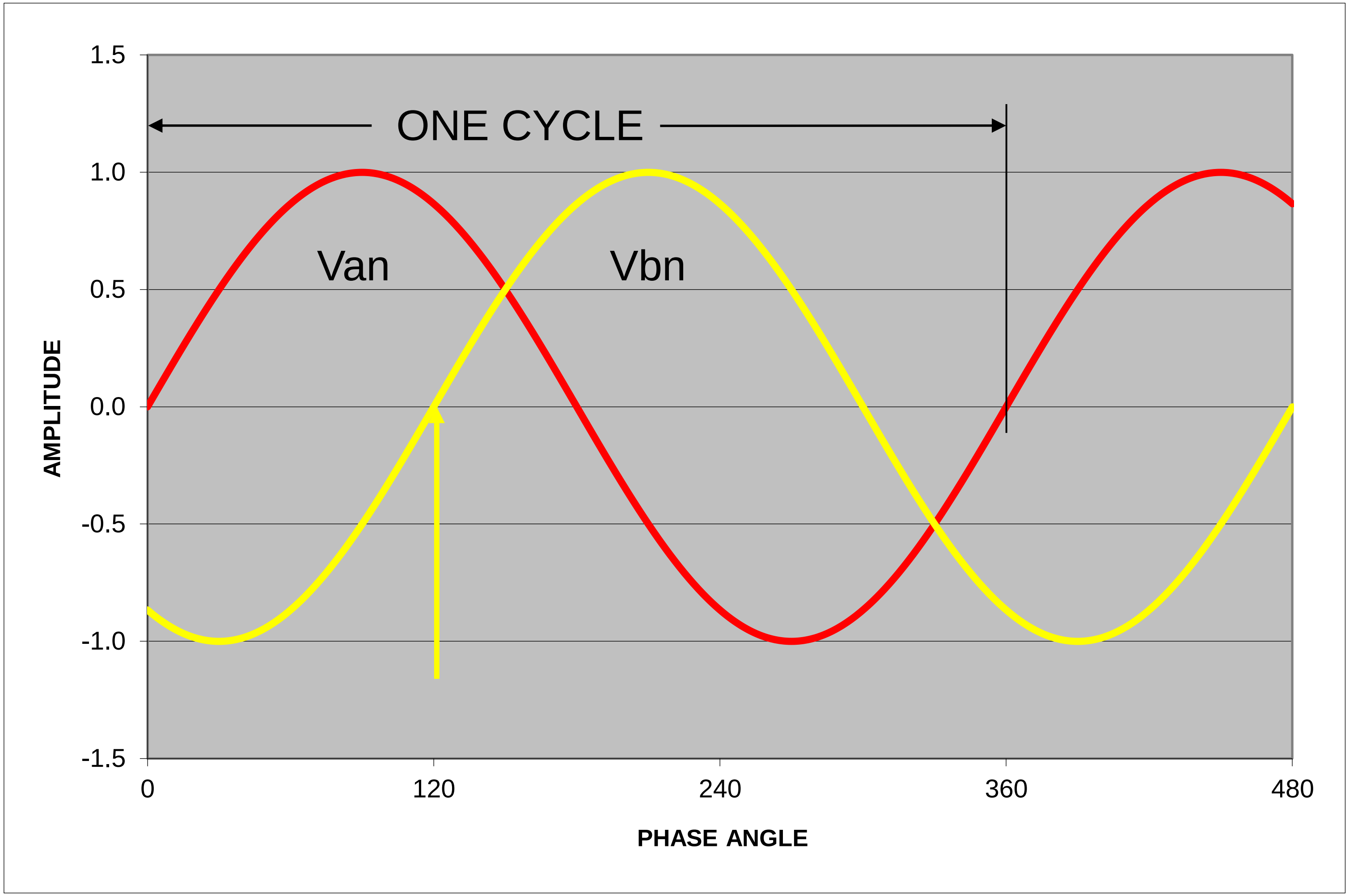
THREE PHASE THEORY

SINGLE PHASE - VOLTAGE PLOT



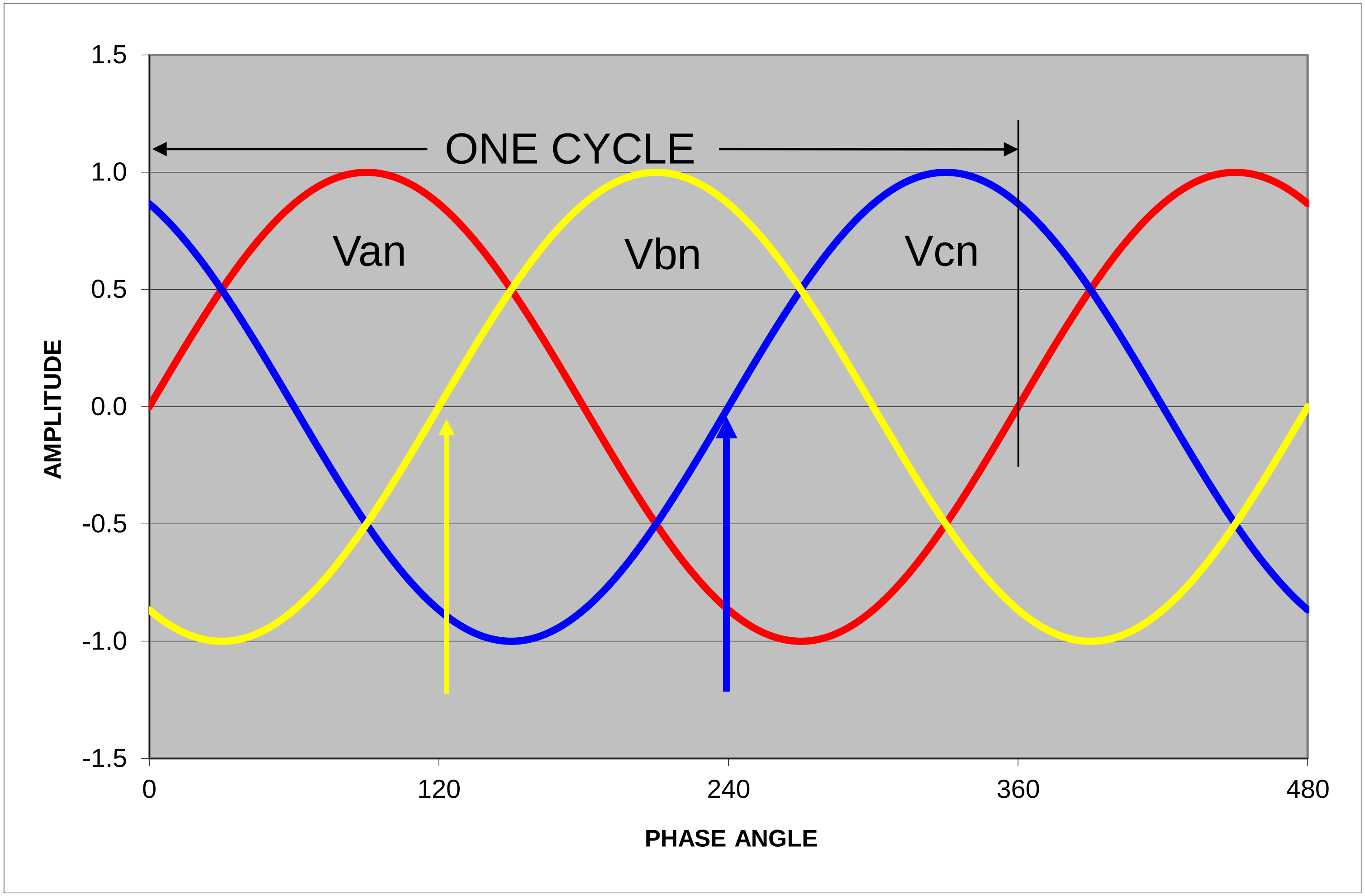
THREE PHASE THEORY

TWO PHASES - VOLTAGE PLOT



THREE PHASE THEORY

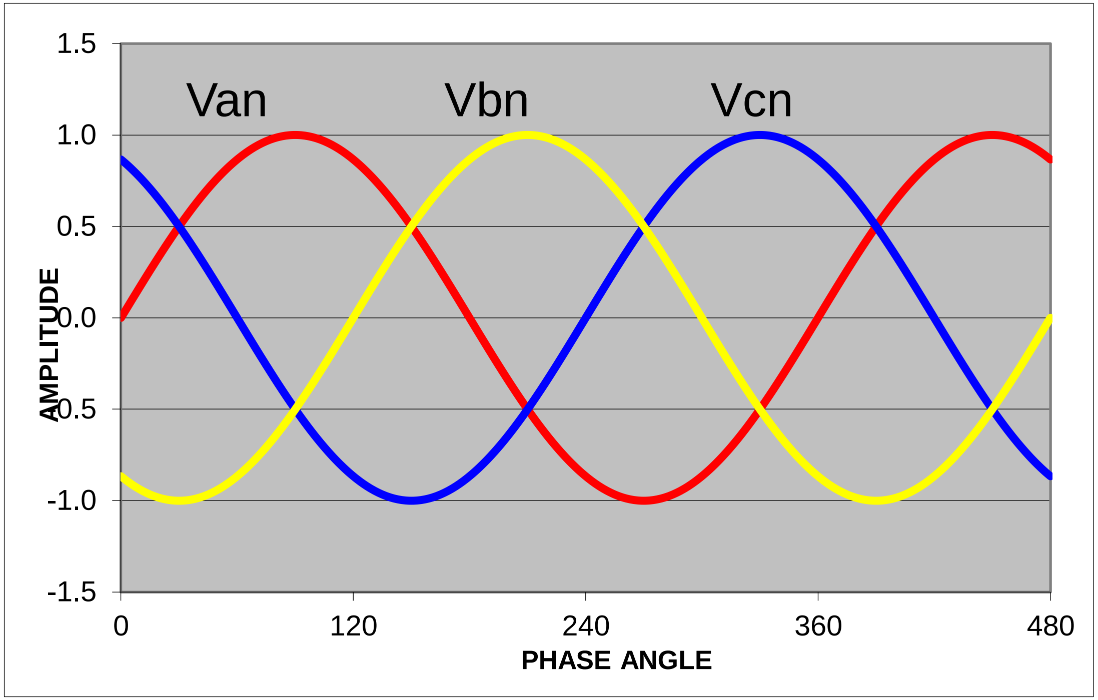
THREE PHASE - VOLTAGE PLOT



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.

THREE PHASE POWER
BASIC CONCEPT – PHASE ROTATION

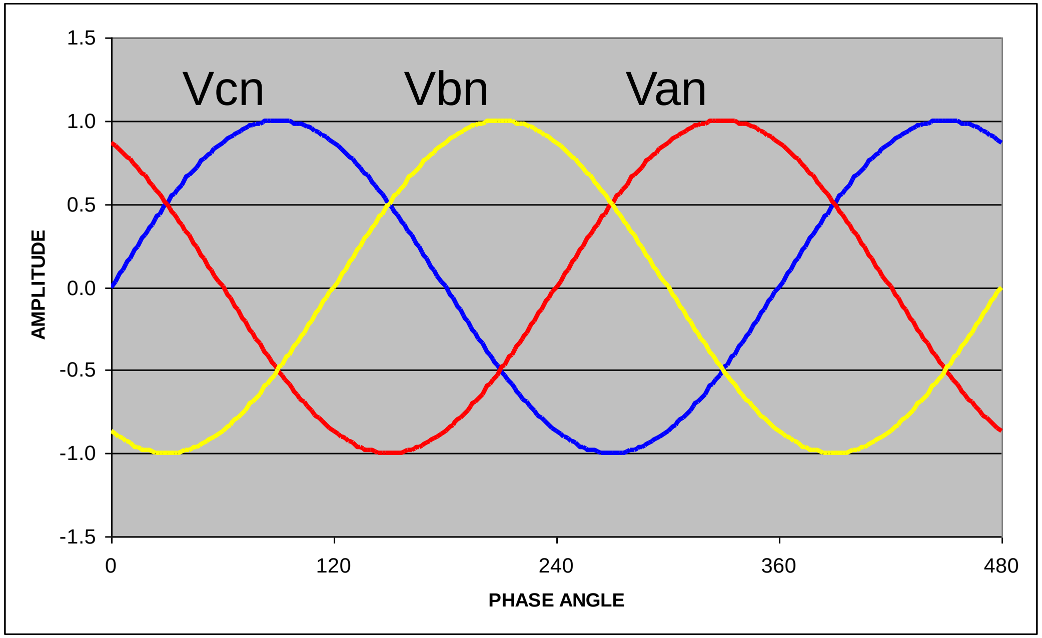
Phase Rotation:

The order in which the phases reach peak voltage.

There are only two possible sequences:

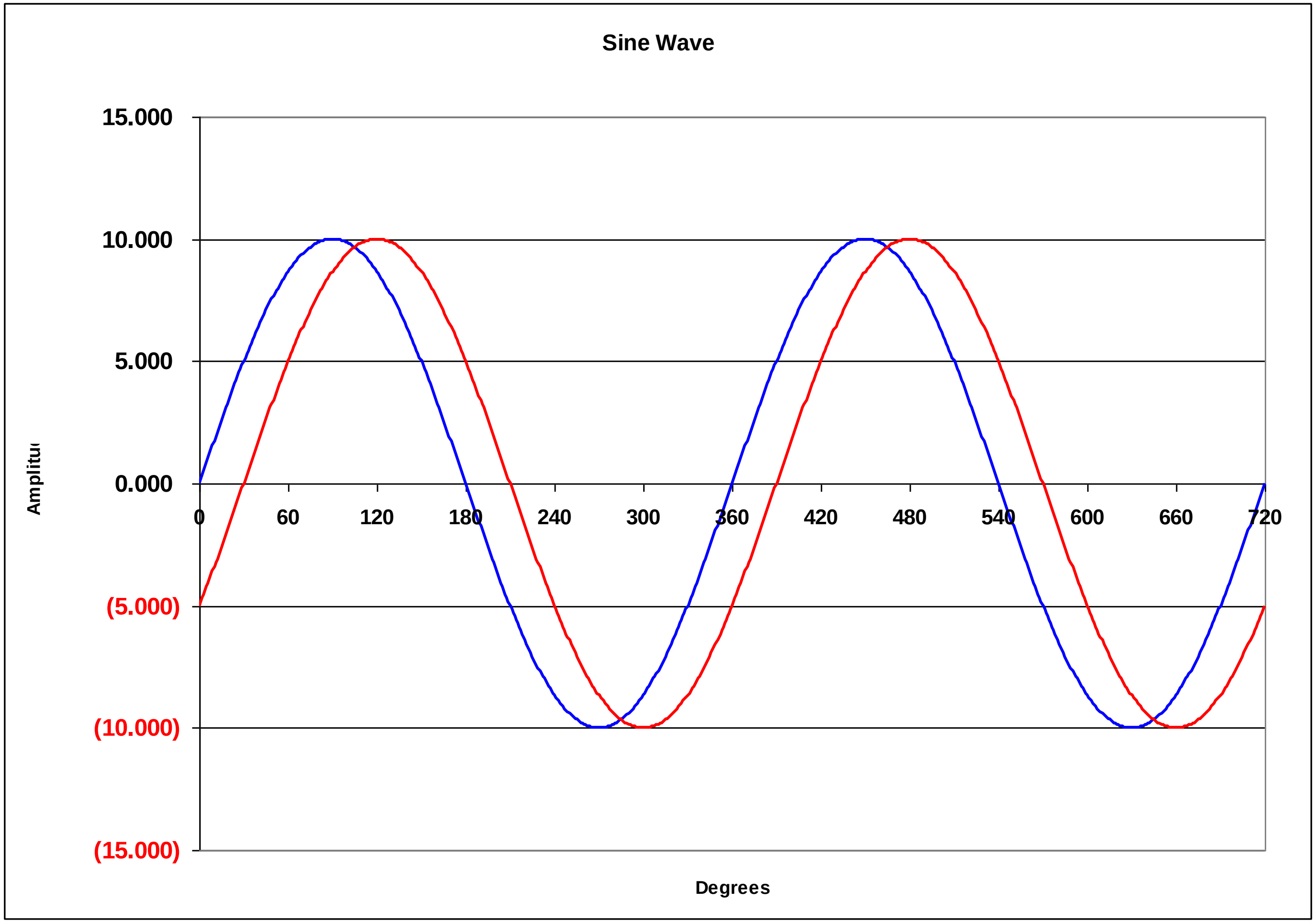
A-B-C (previous slide)

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.

AC THEORY - PHASE

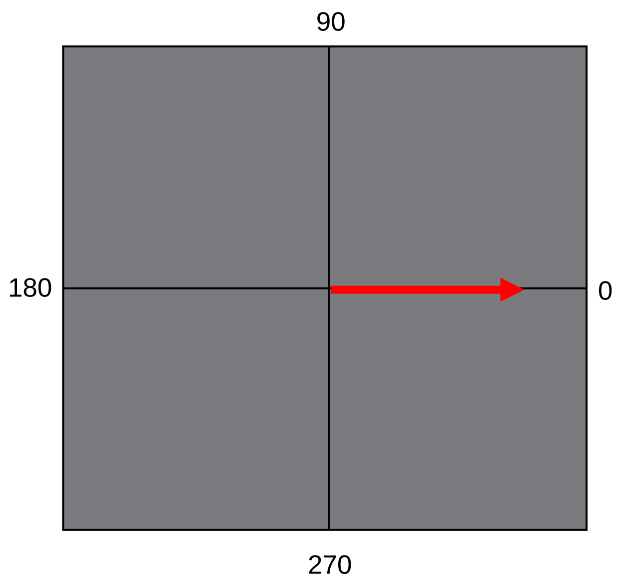


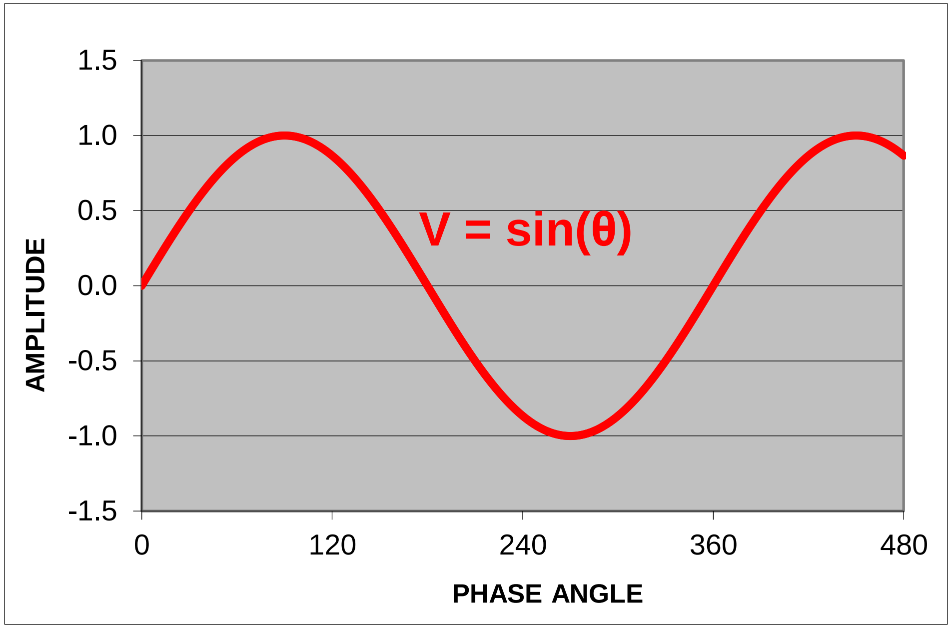
$$V = 10Sin(2\pi ft)$$

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

THREE PHASE THEORY
PHASORS AND VECTOR NOTATION

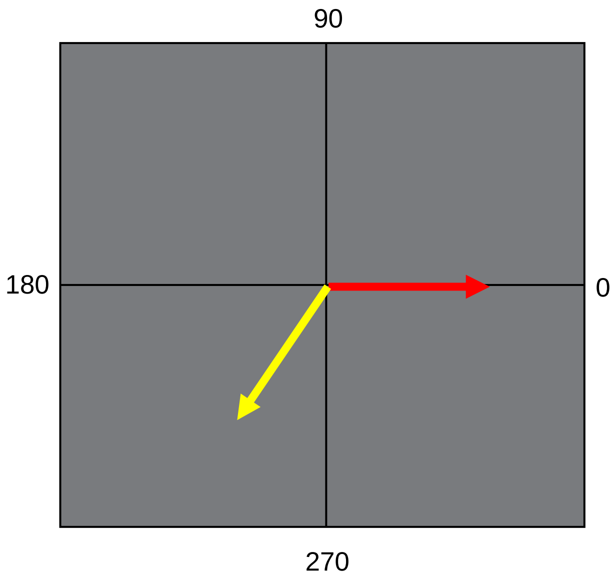
- Phasors are a graphical means of representing the amplitude and phase <u>relationships</u> of voltages and currents.

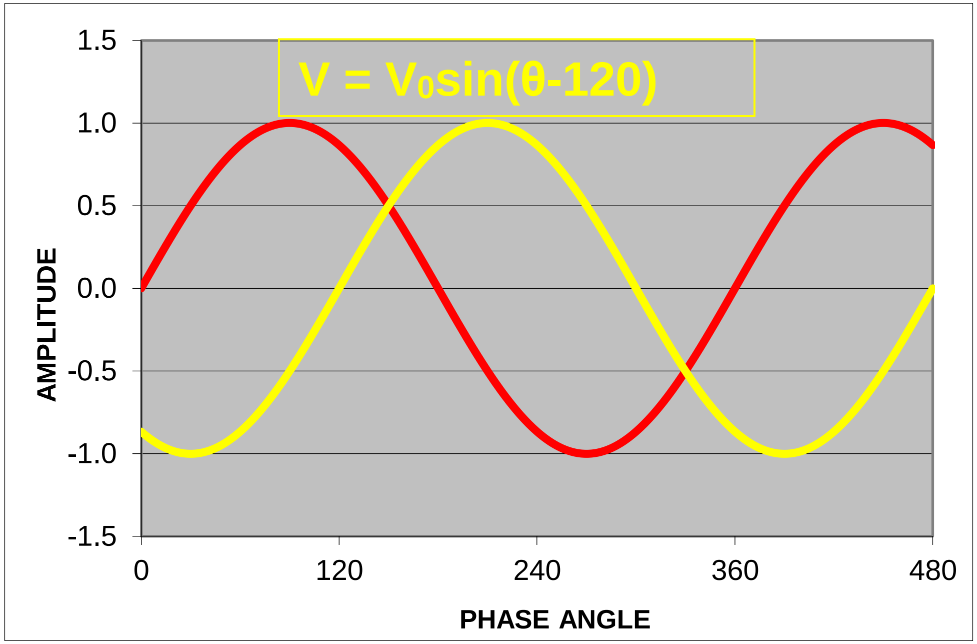




THREE PHASE POWER
PHASORS AND VECTOR NOTATION

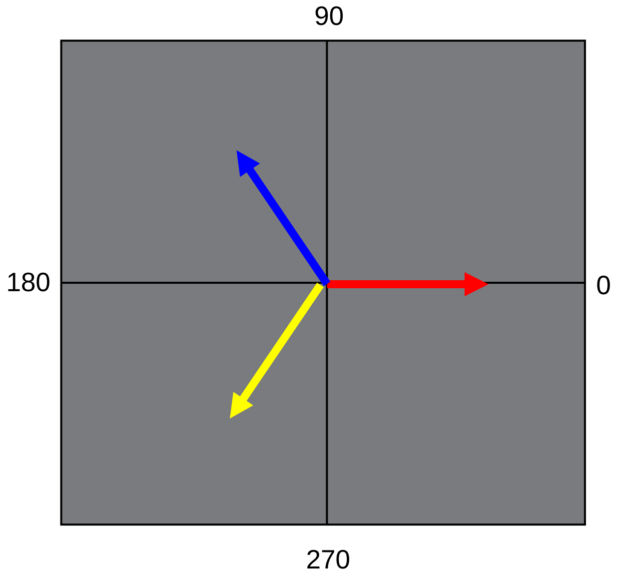
- As stated in the Handbook of Electricity Metering, by common consent, counterclockwise phase rotation has been chosen for general use in phasor diagrams.

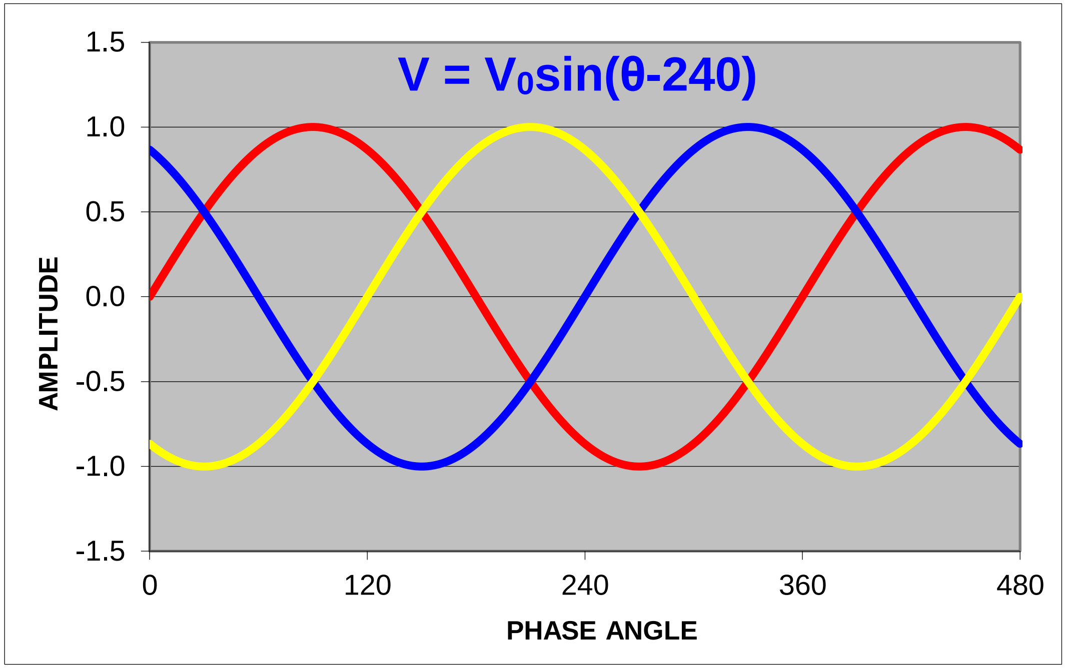




THREE PHASE POWER
PHASORS AND VECTOR NOTATION

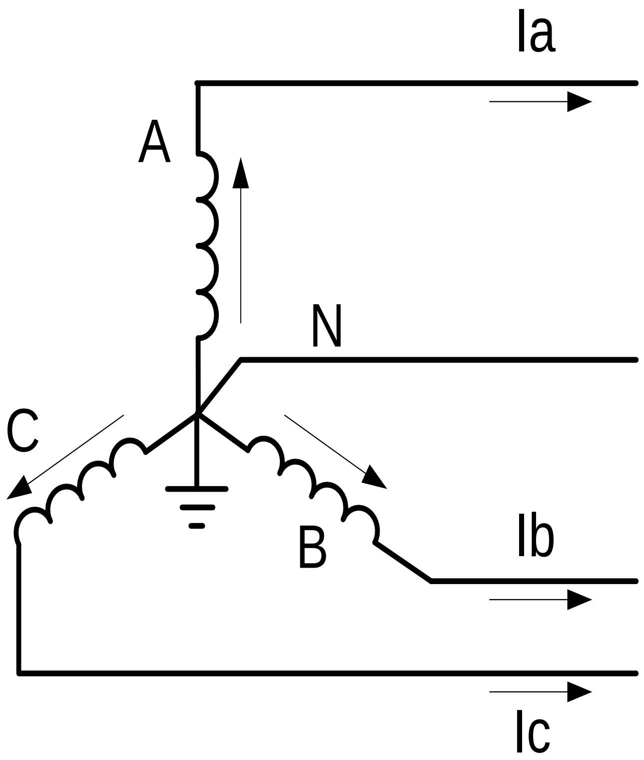
- The phasor diagram for a simple 3-phase system has three voltage phasors equally spaced at 120° intervals.
- Going clockwise the order is A – B – C.





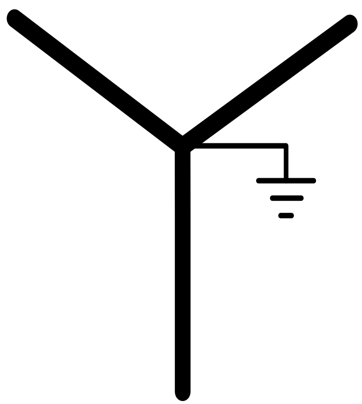
THREE PHASE THEORY
SYMBOLS AND CONVENTIONS

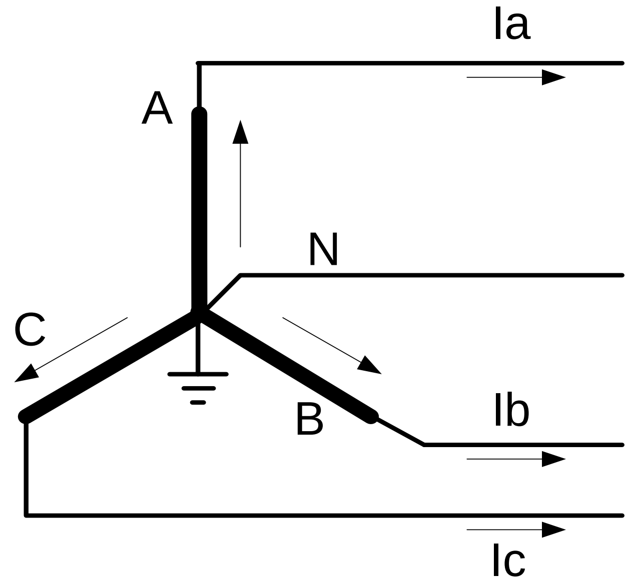
- **Systems formed by interconnecting secondaries of 3 single phase transformers.**
- **Generally primaries are not show unless details of actual transformer are being discussed.**



THREE PHASE THEORY
SYMBOLS AND CONVENTIONS

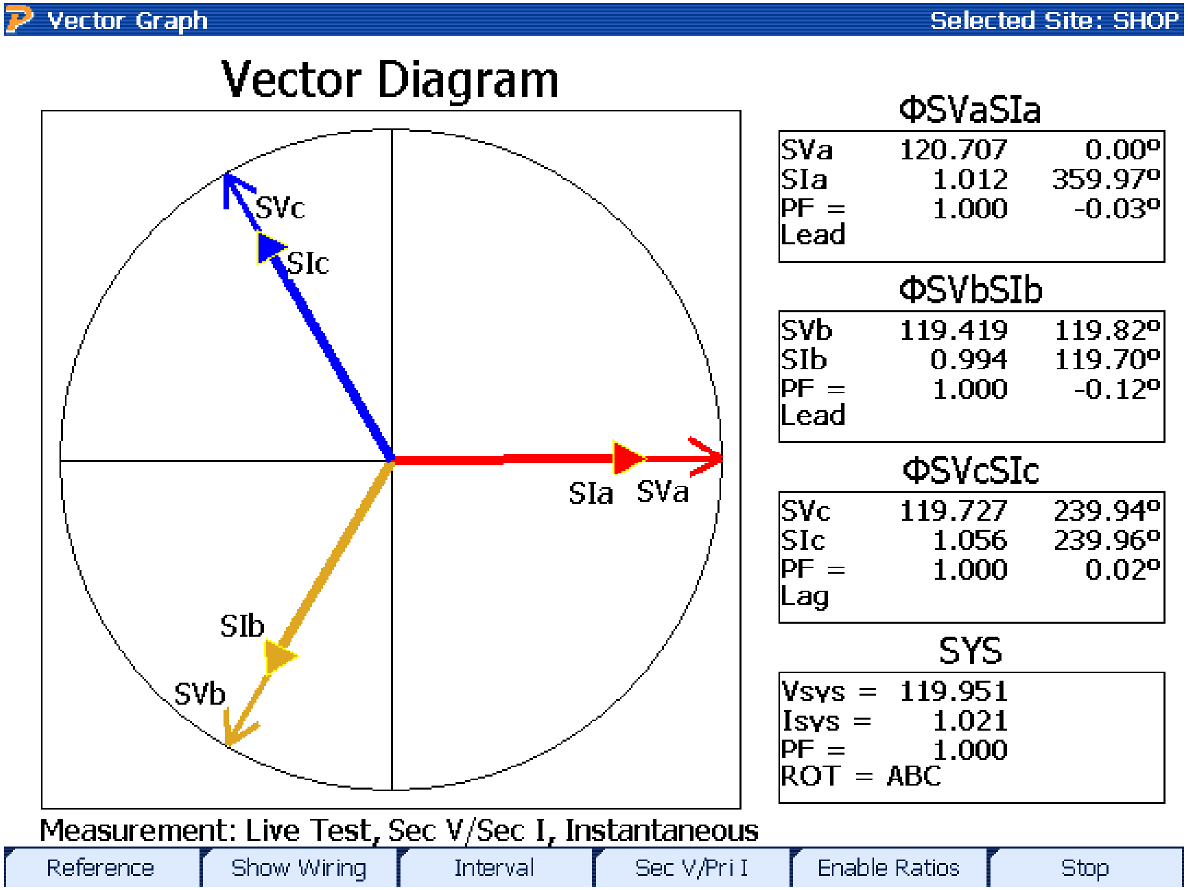
- **Often even the coils are not shown but are replaced by simple line drawings**





3 PHASE, 4-WIRE "Y" SERVICE
0 ° = UNITY POWER FACTOR

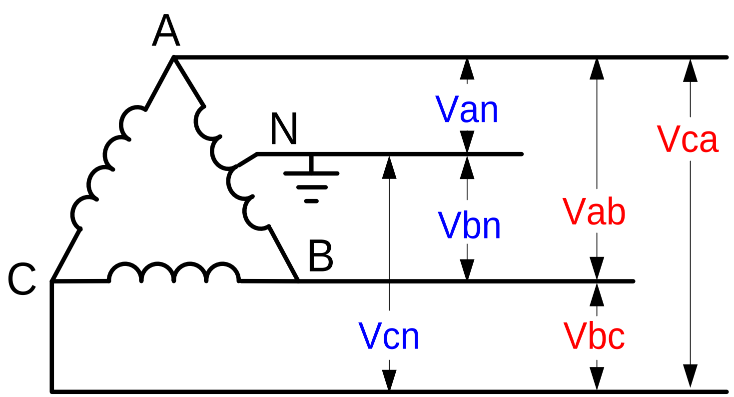
- Three Voltage Phasors
- 120° Apart
- Three Current Phasors
- Aligned with Voltage at PF=1



SYMBOLS AND CONVENTIONS
LABELING

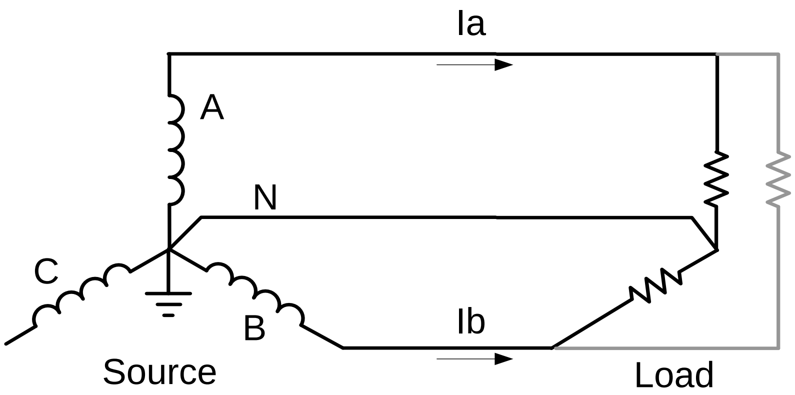
- **Voltages are generally labeled Va, Vb, Vc, Vn for the three phases and neutral**
- **This can be confusing in complex cases**
- **The recommended approach is to use two subscripts so the two points between which the voltage is measured are unambiguous**

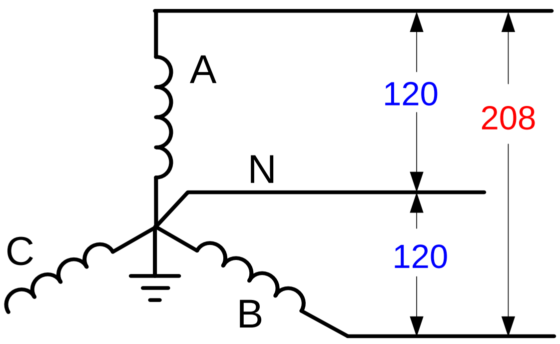
Vab means voltage at “a” as measured relative to “b”.



2 PHASE, 3-WIRE "Y" SERVICE
"NETWORK CONNECTION

Single phase variant of the service.



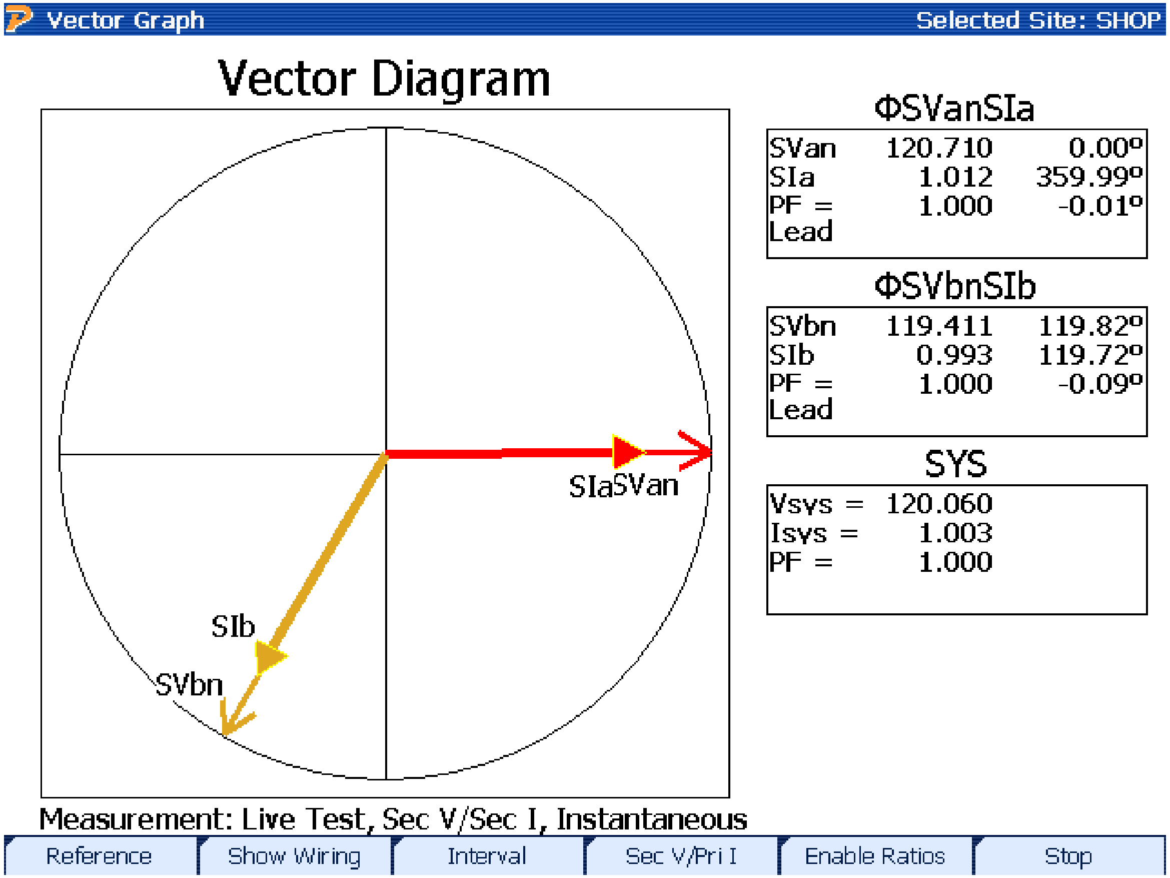


Two voltage sources with their returns connected to a common point.

Provides 208 rather than 240 volts across "high side" wires.

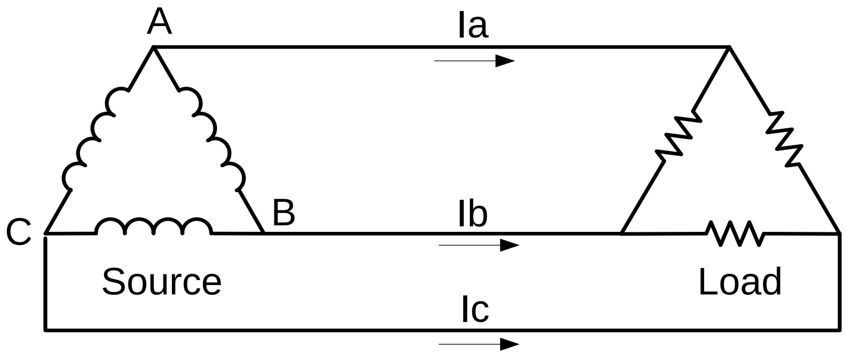
PHASE, 3-WIRE "NETWORK" SERVICE

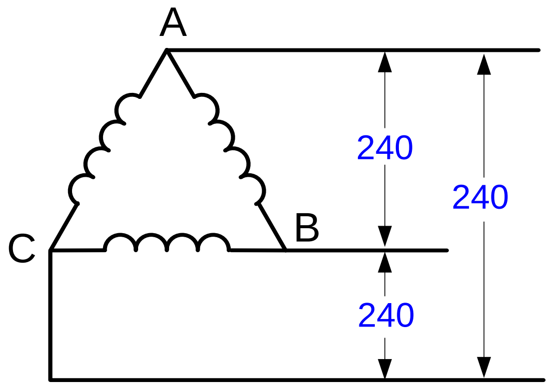
- Two Voltage Phasors
- 120° Apart
- Two Current Phasors
- Aligned with Voltage at PF=1



3 PHASE, 3-WIRE DELTA SERVICE

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

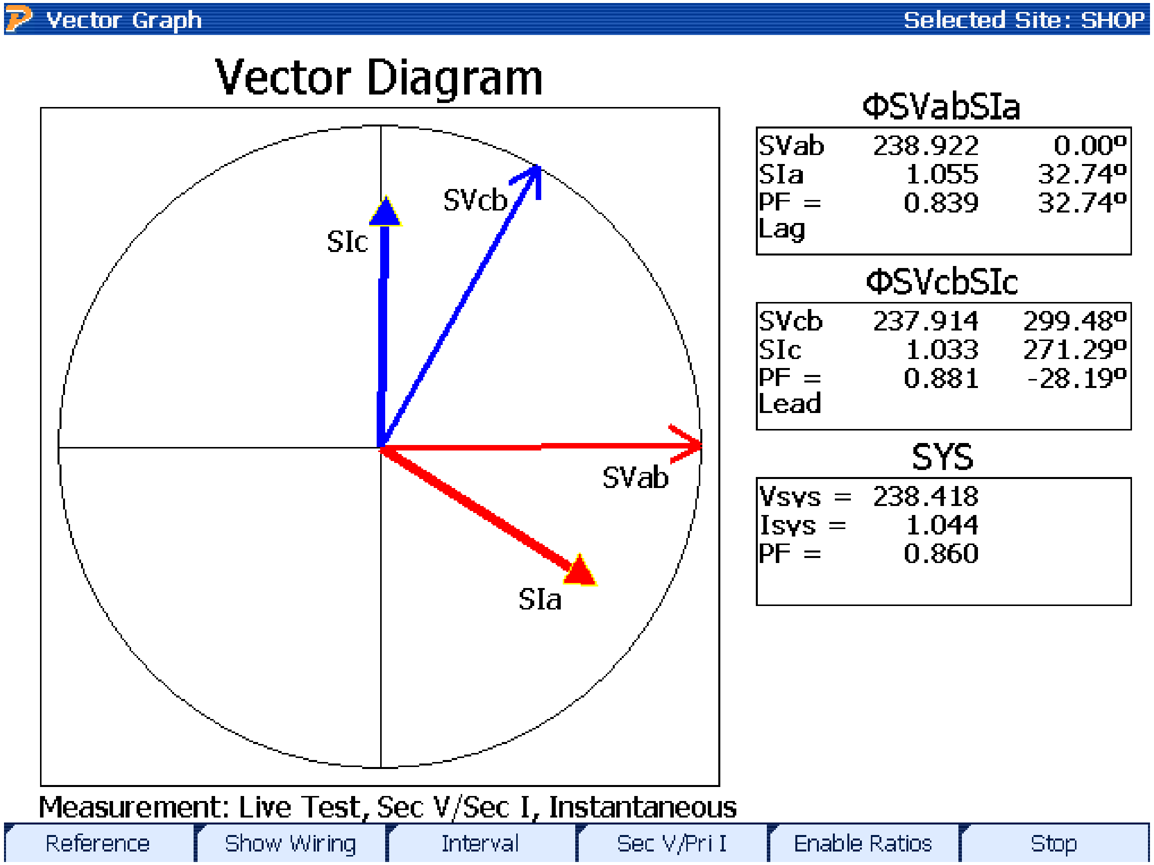




- Voltages normally measured relative to phase B.
- Voltage and current vectors do not align.
- Service is provided even when a phase is grounded.

3 PHASE, 3-WIRE DELTA SERVICE
RESISTIVE LOADS

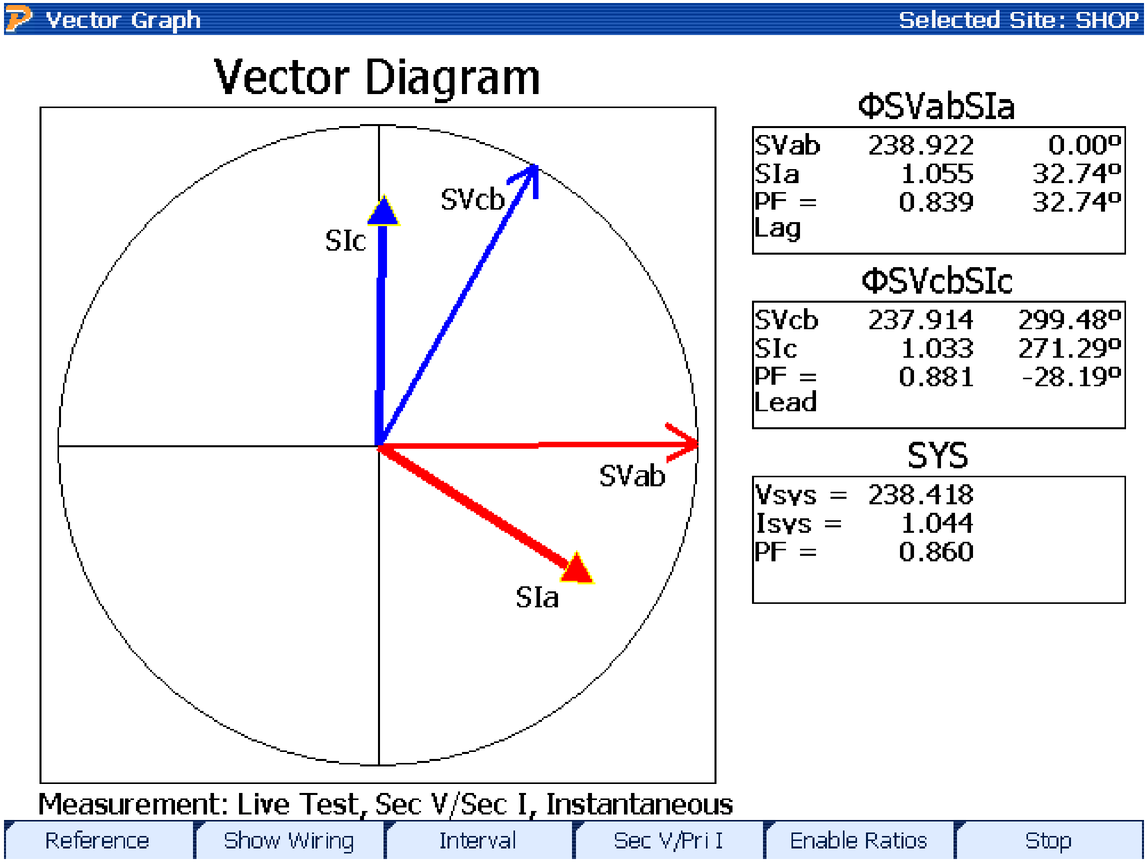
- Two Voltage Phasors
- 60° Apart
- Two Current Phasors
- For a resistive load one current leads by 30° while the other lags by 30°



3 PHASE, 3-WIRE DELTA SERVICE

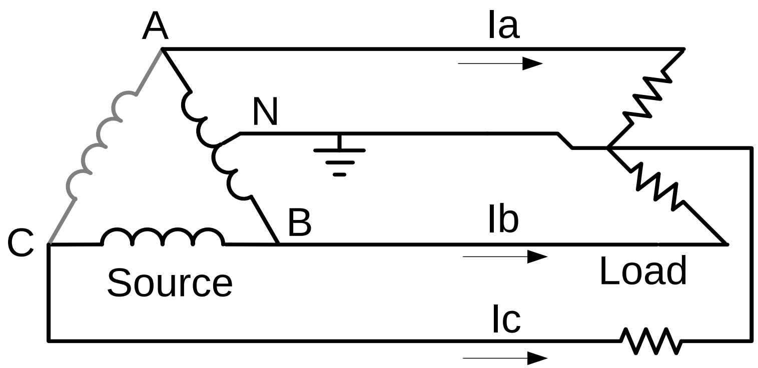
RESISTIVE LOAD

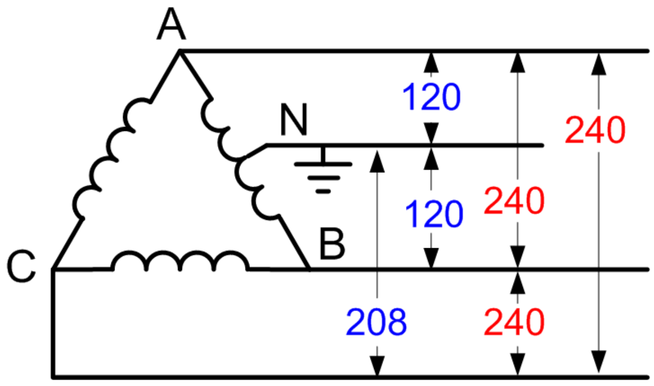
- **Two Voltage Phasors**
- **60° Apart**
- **Two Current Phasors**
- **For a resistive load one current leads by 30° while the other lags by 30°**



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.

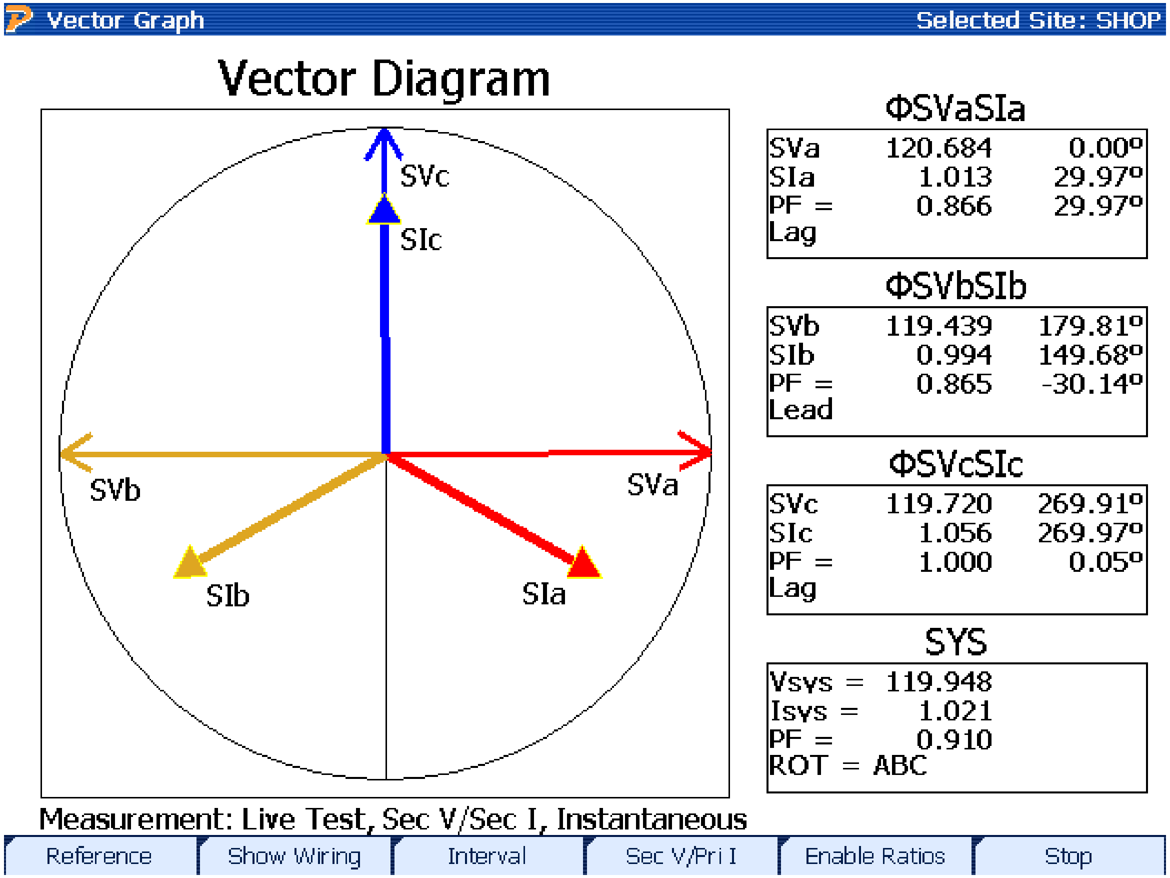




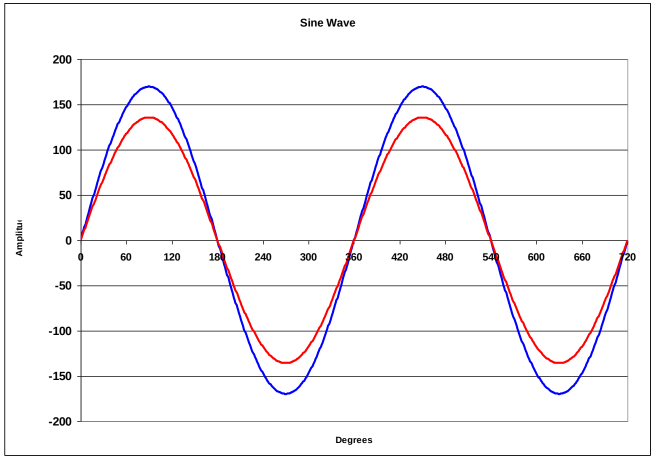
- Voltage phasors form a “T” 90° apart
- Currents are at 120° spacing
- In 120/120/208 form only the “hot” (208) leg has its voltage and current vectors aligned.

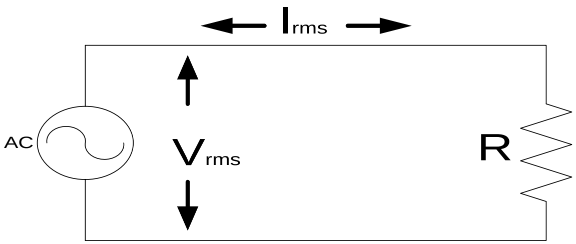
3 PHASE, 4-WIRE DELTA SERVICE
RESISTIVE LOAD

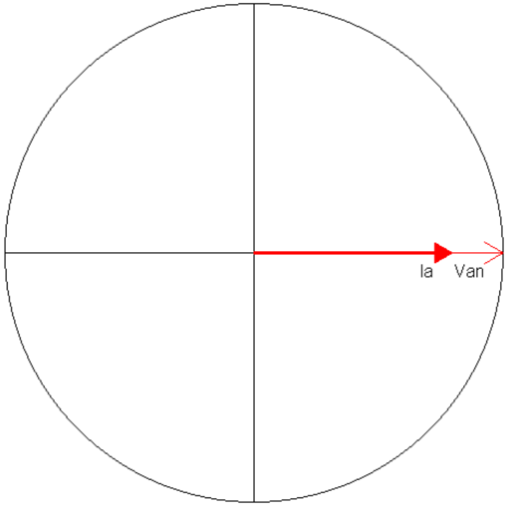
- **Three Voltage Phasors**
- **90° Apart**
- **Three Current Phasors**
- **120° apart**



AC THEORY – RESISTIVE LOAD

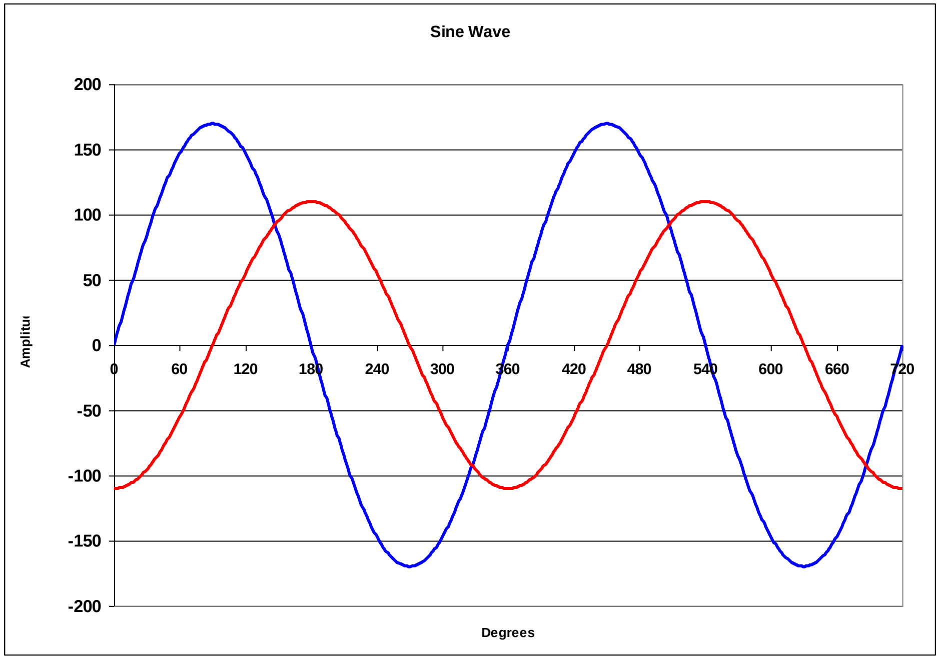


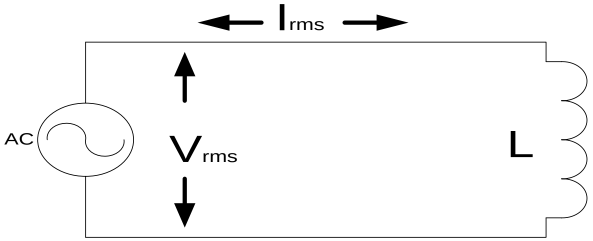


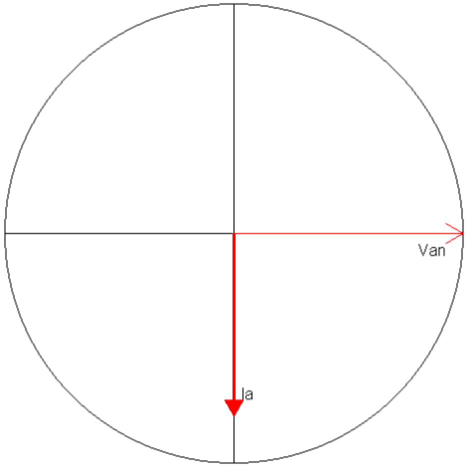


Resistors are measured in Ohms. When an AC voltage is applied to a resistor, the current is in phase. A resistive load is considered a “linear” load because when the voltage is sinusoidal the current is also sinusoidal.

AC THEORY – INDUCTIVE LOAD

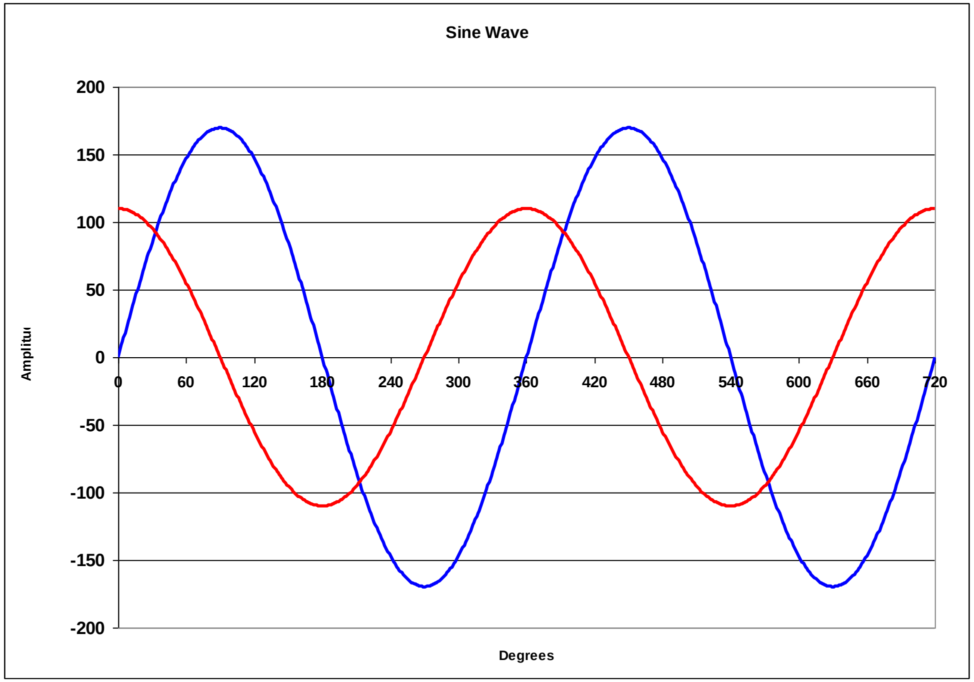


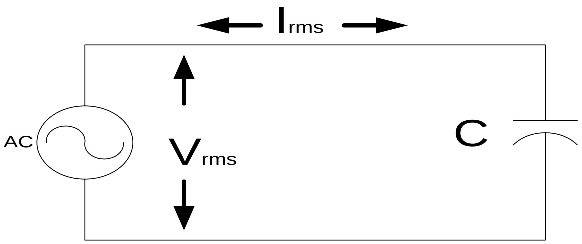


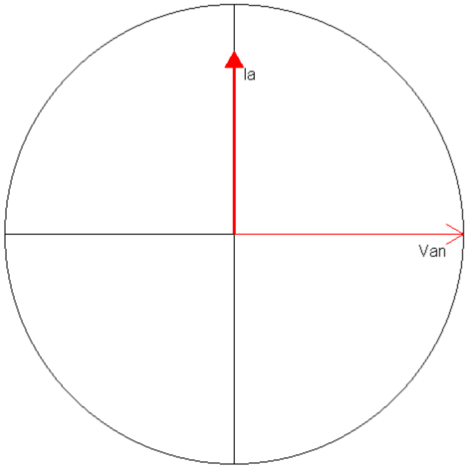


Inductors are measured in Henries. When an AC voltage is applied to an inductor, the current is 90 degrees out of phase. We say the current "lags" the voltage. A inductive load is considered a "linear" load because when the voltage is sinusoidal the current is also sinusoidal.

AC THEORY – CAPACITIVE LOAD







Capacitors are measured in Farads. When an AC voltage is applied to a capacitor, the current is 90 degrees out of phase. We say the current "leads" the voltage. A capacitive load is considered a "linear" load because when the voltage is sinusoidal the current is sinusoidal.

AC THEORY – POWER

- Power is defined as: P = VI
- Since the voltage and current at every point in time for an AC signal is different, we have to distinguish between instantaneous power and average power. Generally when we say "power" we mean average power.
- Average power is only defined over an integral number of cycles.

TIME OUT FOR TRIG (RIGHT TRIANGLES)

The Right Triangle:

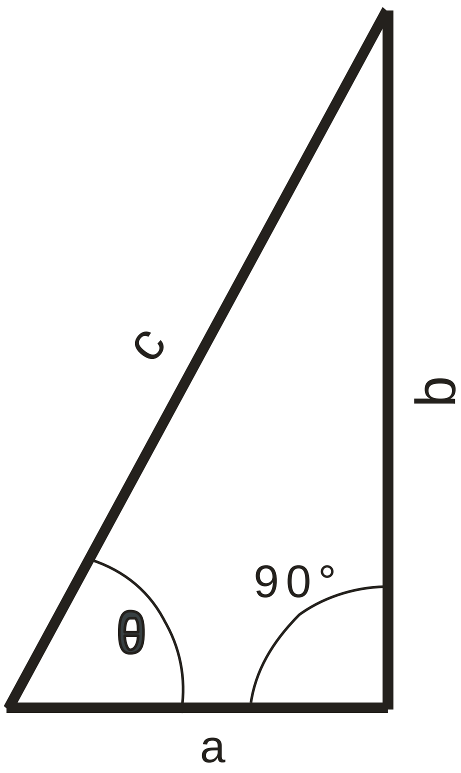
The Pythagorean theory

$Cos(\theta) = \frac{a}{c}$

$c^2 = a^2 + b^2$

$$Sin(\theta) = \frac{b}{c}$$

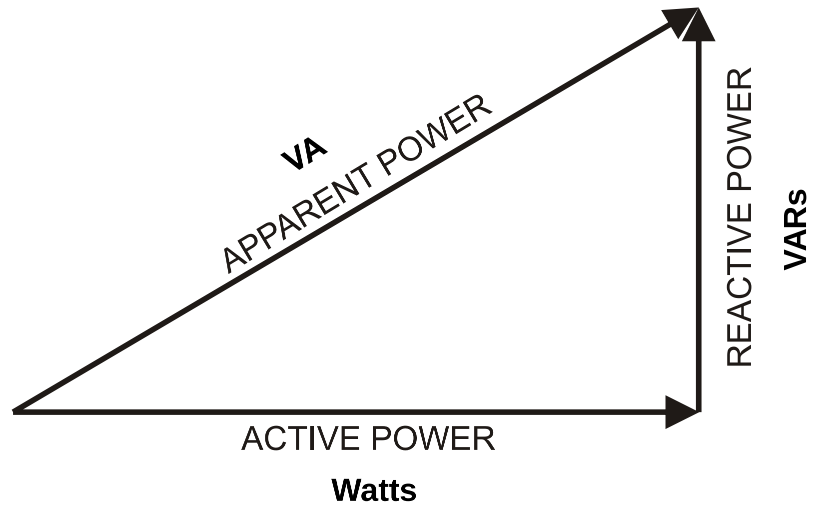
$$Tan(\theta) = \frac{b}{a}$$



AC THEORY – DEFINITIONS

- **Inductive Reactance – The inductive opposition in a AC circuit = X_L**
- **Capacitive Reactance – The capacitive opposition in a AC circuit = X_C**
- **Impedance – Total opposition to the flow of current in an AC circuit which includes resistance, X_L and X_C.**
  - Impedance = Z = $\sqrt{[R^2 + (X_L - X_C)^2]}$
- **Resistive Loads – Light bulbs, heater, etc**
- **Inductive Loads – Electric motors, fans, air conditioners, etc.**
- **Capacitive Loads – Capacitors used to compensate for inductive loads**

AC THEORY – POWER TRIANGLE
(SINUSOIDAL WAVEFORMS)



If $V = \text{Sin}(\omega t)$ and $I = \text{Sin}(\omega t - \theta)$ (the load is linear) then:

Active Power =	$VI\,Cos(\theta)$	Watts
Reactive Power =	$VI\,Sin(\theta)$	VARs
Apparent Power =	VI	VA
Power Factor =	Active/Apparent = $Cos(\theta)$	

AC THEORY – ACTIVE POWER

(REAL POWER (KW))

- **In a circuit that contains only resistance:**
  - **Real Power (kW) = $V_{RMS} * I_{RMS}$**

- **In a circuit that contains resistance and reactance:**
  - **Real Power (kW) = $V_{RMS} * I_{RMS} * COS(\theta)$**

AC THEORY – APPARENT POWER (KVA)

- Kilo-Volt-Amperes (kVA) are the product of Volts and the Total Current which flows because of the voltage.
- In a circuit that contains only resistance, KVA (apparent power) is equal to the Real Power (kW).

- When reactance is introduced into a circuit, and V_{RMS} and I_{RMS} are measured quantities, then:
  - **kVA = V_{RMS} * I_{RMS}**

- In a circuit where only Real Power (kW) and Reactive Power (kVAR) are measured quantities, then:
  - **kVA = $\sqrt{(kW^2 + kVAR^2)}$**

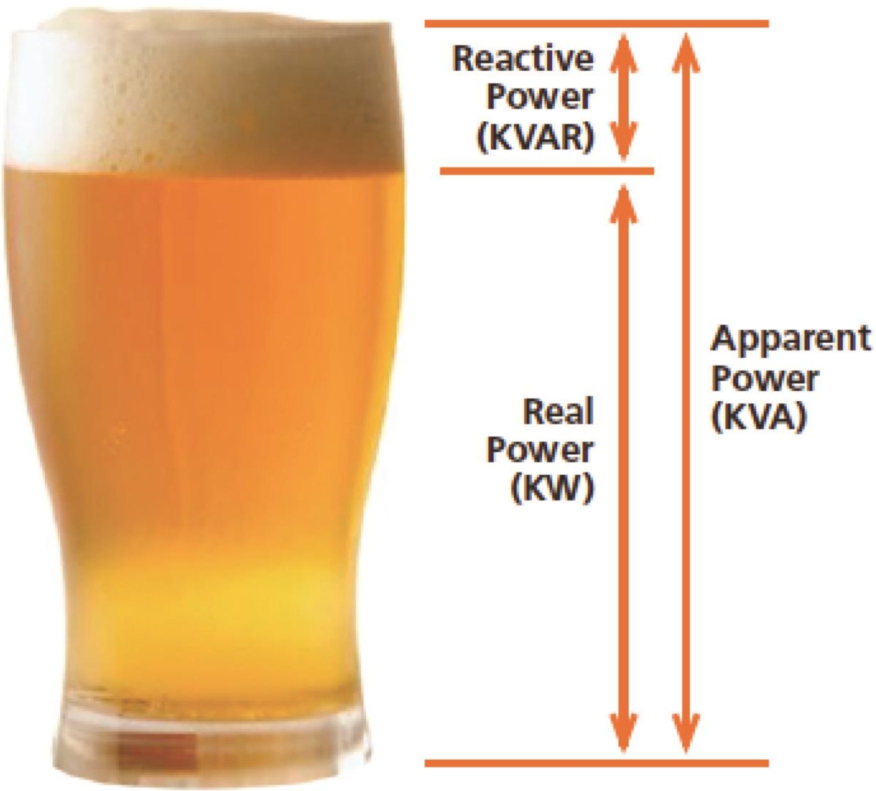
AC THEORY – REACTIVE POWER (KVAR)

- **Reactive Volt Amperes are the product of the total Volt-Amperes and the Sine of the angle of displacement between Voltage and Current.**

  - **Reactive Power (kVAR) = V_{RMS} * I_{RMS} * SIN(θ)**

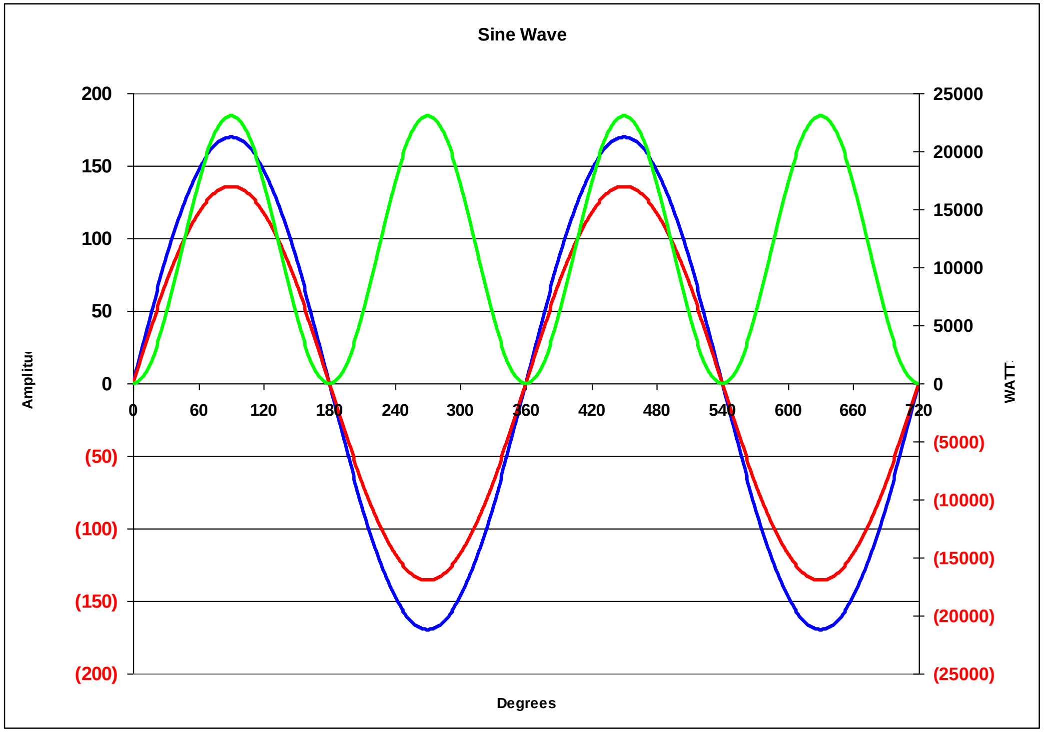
- **kVAR reduces the efficiency in the distribution system, and is *NOT* used to deliver active power (kW) to the load.**

AC THEORY – REACTIVE POWER
(KVAR ANALOGY)



AC THEORY
INSTANTANEOUS POWER

For a resistive load: $p = vi = V_{max} Cos(\omega t + \theta_V) \bullet I_{max} Cos(\omega t + \theta_I)$

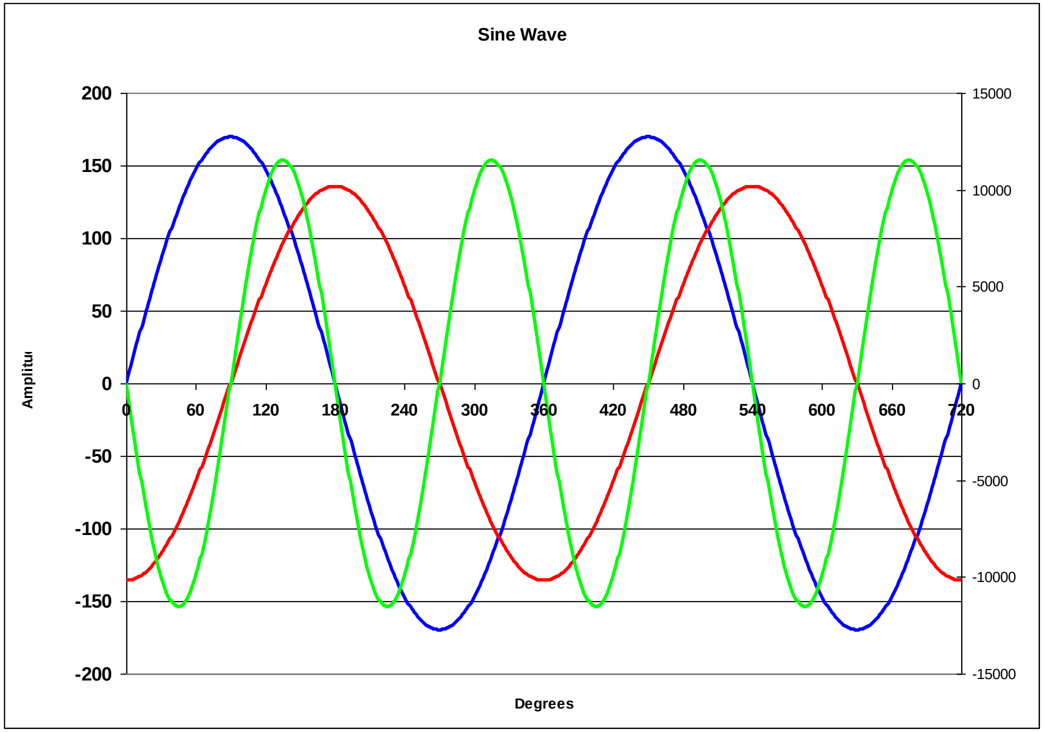


$V = V_{max} Cos(\omega t + \theta_V)$

$I = I_{max} Cos(\omega t + \theta_I)$

AC THEORY
INSTANTANEOUS POWER

For an inductive load: $p = vi = V_{max} Cos(\omega t + \theta_V) \bullet I_{max} Cos(\omega t + \theta_I)$



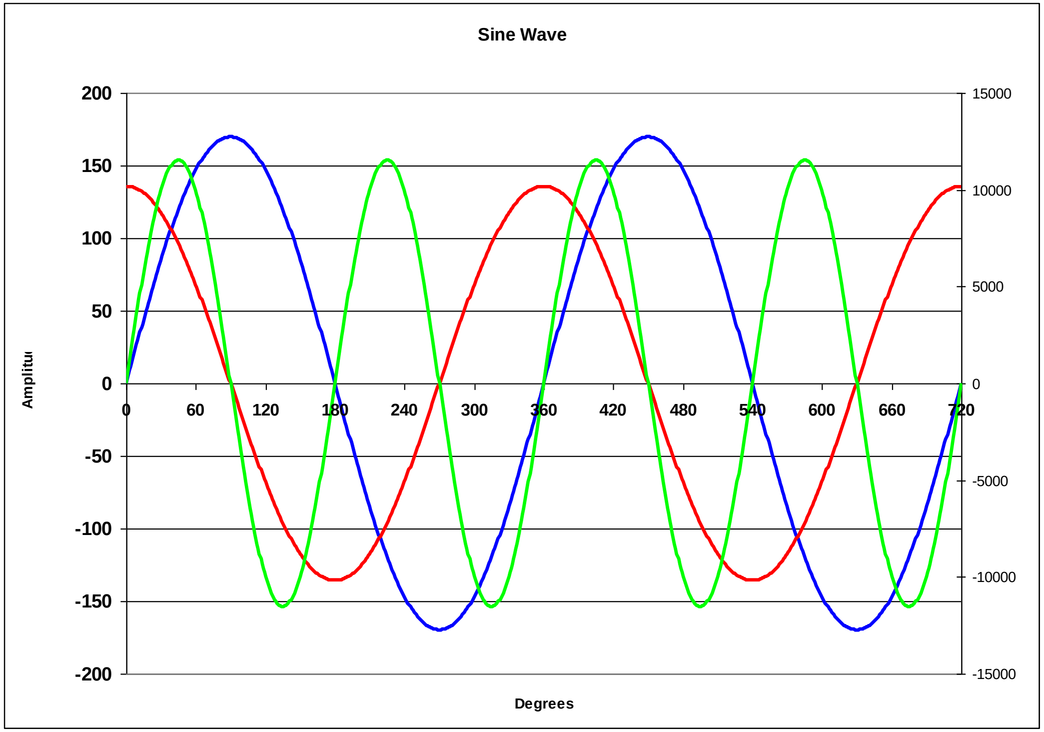
$V = V_{max} Cos(\omega t + \theta_V)$

$I = I_{max} Cos(\omega t + \theta_I)$

AC THEORY

INSTANTANEOUS POWER

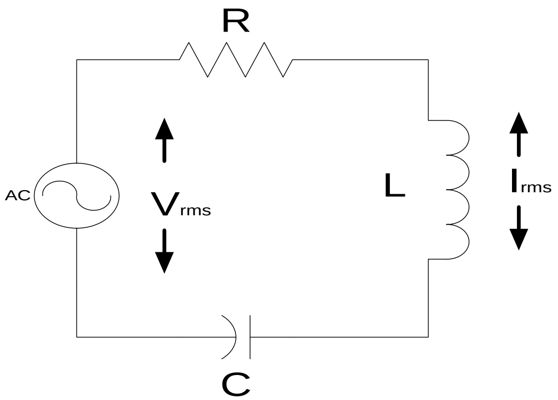
For a capacitive load: $p = vi = V_{max}\,Cos(\omega t + \theta_V) \bullet I_{max}\,Cos(\omega t + \theta_I)$



$V = V_{max}\,Cos(\omega t + \theta_V)$

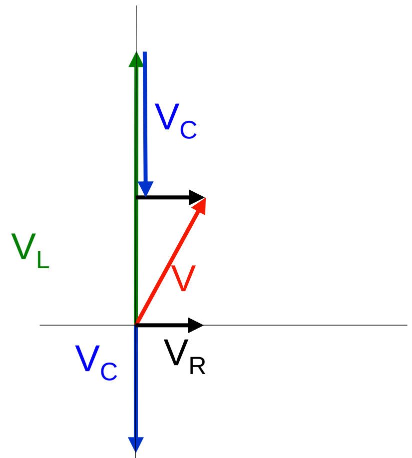
$I = I_{max}\,Cos(\omega t + \theta_I)$

AC THEORY – COMPLEX CIRCUITS



Amplitude (Current)

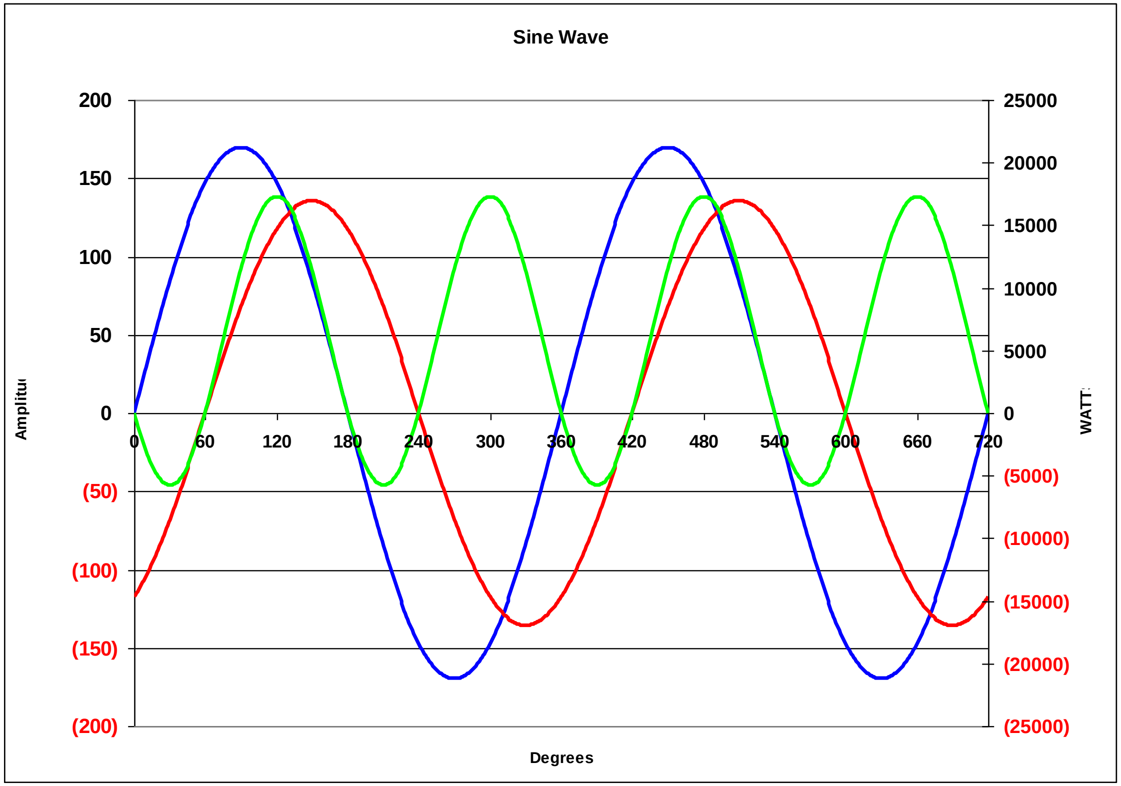
$$I = \frac{V}{\sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2}}$$



Phase (Current)

$$\varphi = ArcTan\left[\frac{(\omega L - \frac{1}{\omega C})}{R}\right]$$

AC THEORY – INSTANTANEOUS POWER



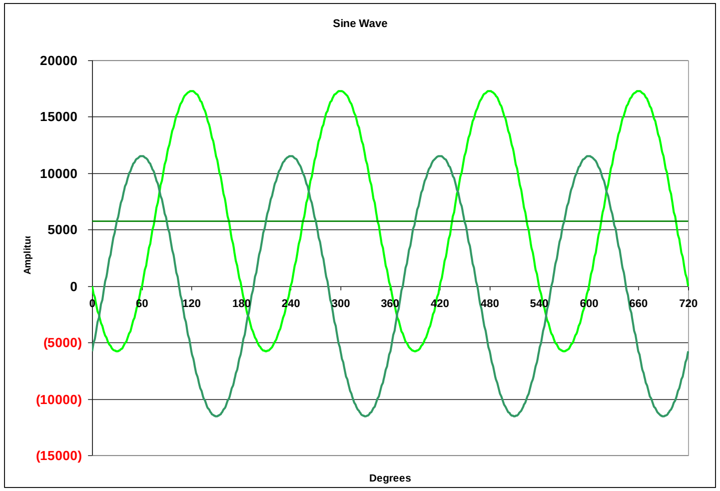
$$V = 120\sqrt{2}Sin(2\pi ft)$$

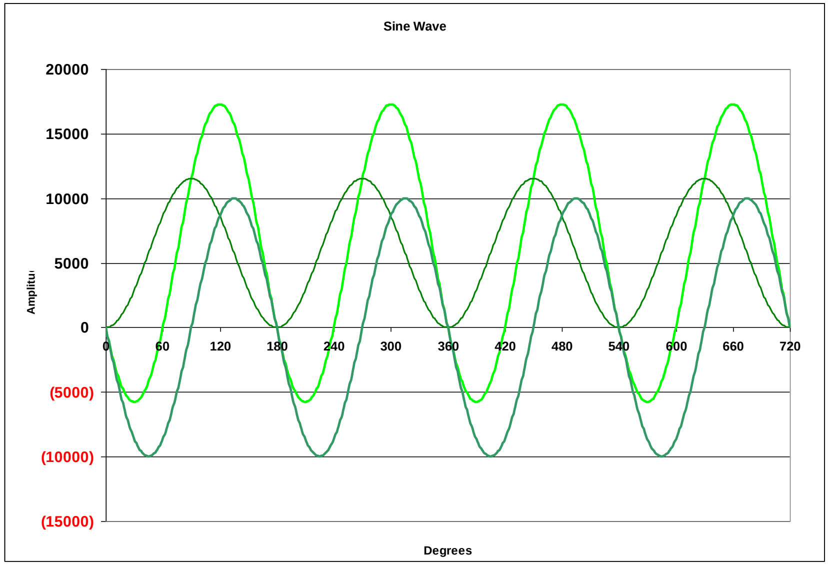
$$I = 96\sqrt{2}Sin(2\pi ft - 60)$$

$$P = VI = 23040(Cos(60°) + Cos(4\pi ft - 60°)) = 19953 - 23040 Cos(4\pi ft - 60°)$$

AC THEORY – INSTANTANEOUS POWER

From IEEE1459 instantaneous power can be written in several forms:





Active Power Reactive Power

$$p = VI\cos\theta - VI\cos(2\omega t - \theta)$$

$$p = VI\cos\theta[1 - \cos(2\omega t)] - VI\sin\theta\sin(2\omega t)$$

THREE PHASE POWER
BLONDEL'S THEOREM

If energy be supplied to any system of conductors through N wires, the total power in the system is given by the algebraic sum of the readings of N wattmeters, so arranged that each of the N wires contains one current coil, the corresponding voltage 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.

THREE PHASE POWER
BLONDEL'S THEOREM

- **Simply put – We can measure the power in a N wire system by measuring the power in N-1 conductors.**

- **For example, in a 4-wire, 3-phase system we need to measure the power in 3 circuits.**

THREE PHASE POWER
BLONDEL'S THEOREM

- **In practice, Blondel's Theorem is not strictly adhered to in all applications.**

- **Meter manufacturers have found ways to design meters that allow adequate accuracy without the required number of stators.**

THREE PHASE POWER
BLONDEL'S THEOREM

- **One such meter is the common (form 2S) house meter.**
- **It is a single stator meter that is specifically designed to meter a 3-wire circuit.**

THREE PHASE POWER
BLONDEL'S THEOREM

- **Additionally, other meters may be connected in configurations, which may also provide adequate levels of accuracy without the required number of stators.**

- **These are often referred to as Non-Blondel configurations.**

THREE PHASE POWER
BLONDEL'S THEOREM

Why are Non-Blondel circuits challenging?

- Makes the assumption that the service voltages are balanced.

- The assumption may not be true so there are likely to be measurement errors.

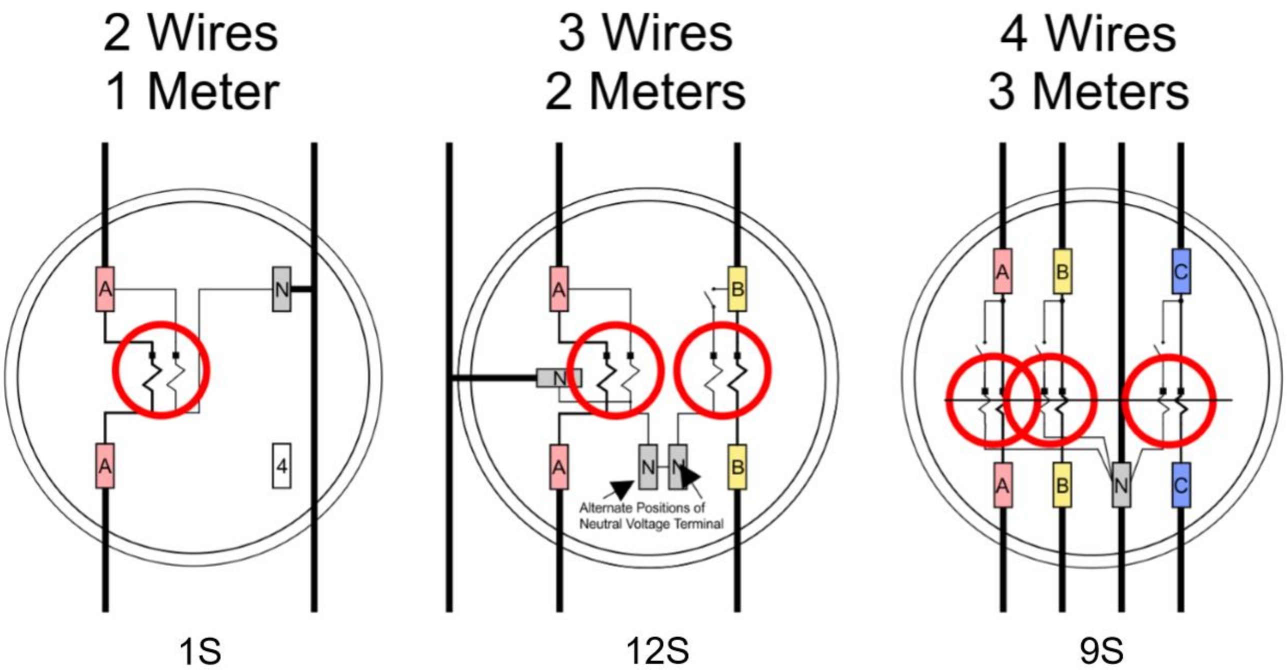
THREE PHASE POWER
BLONDEL'S THEOREM

Why are Non-Blondel meters used?

- Fewer elements in the meter means lower meter costs.
- Fewer PTs and CTs mean lower installation costs.

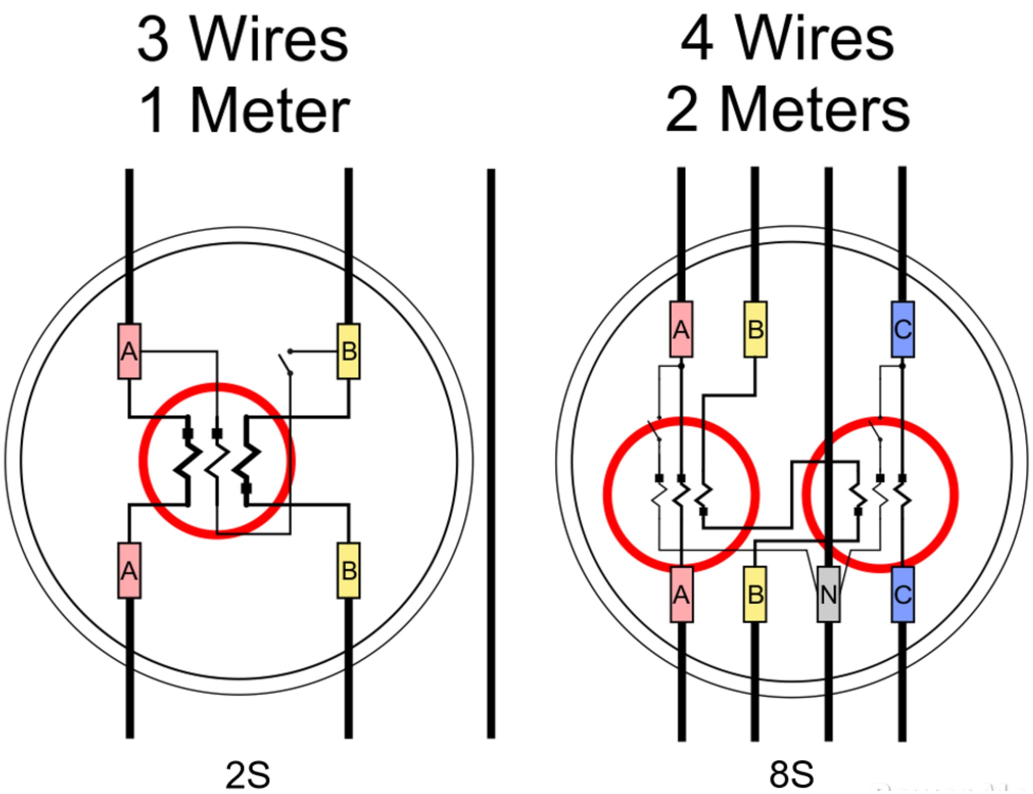
THREE PHASE POWER
BLONDEL'S THEOREM

Blondel Compliant

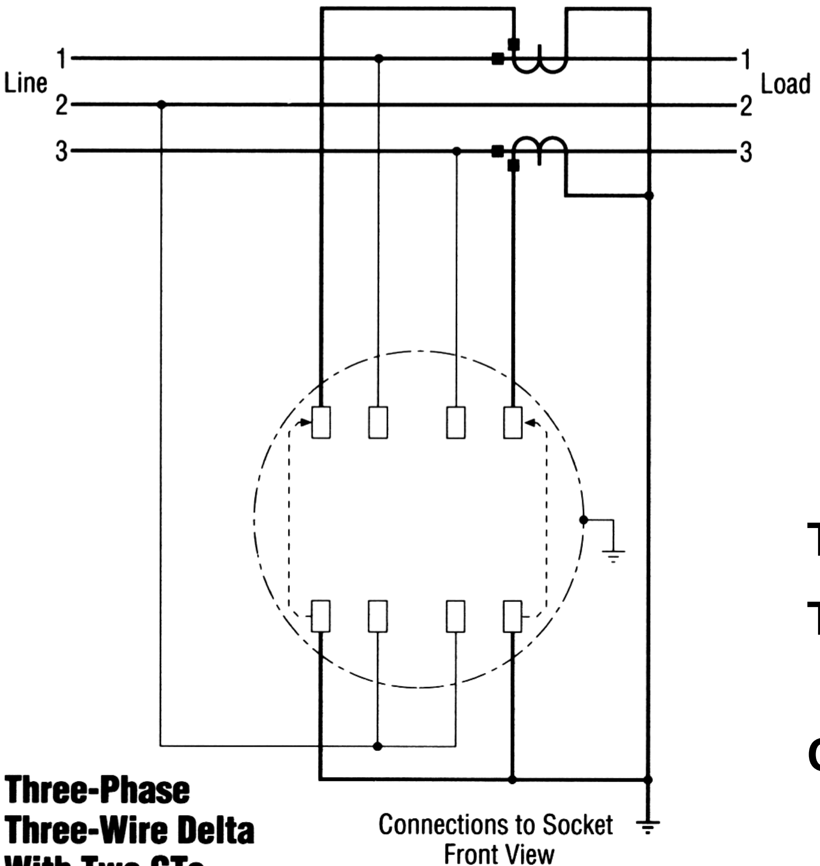


THREE PHASE POWER
BLONDEL'S THEOREM

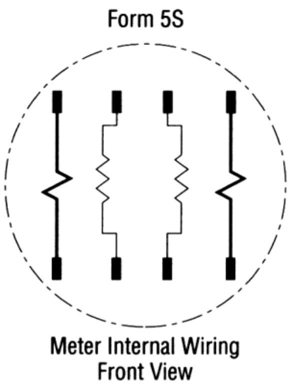
Non-Blondel Compliant



BLONDEL'S THEOREM



Three-Phase Three-Wire Delta With Two CTs



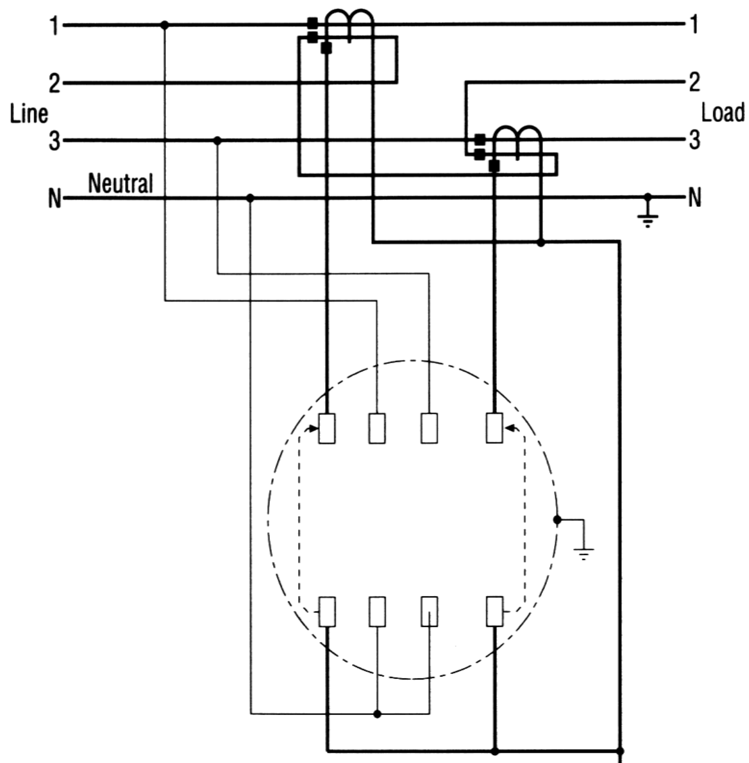
Three wires

Two voltage measurements with one side common to Line 2

Current measurements on lines 1 & 3.

This satisfies Blondel's Theorem.

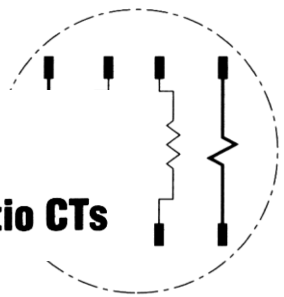
BLONDEL'S THEOREM



Connections to Socket
Front View

Three-Phase
Four-Wire Wye
With Two Equal-Ratio CTs

Form 5S



Meter Internal Wiring
Front View

Four wires

Two voltage measurements to neutral

Current measurements are on lines 1 and 3 but not line 2.

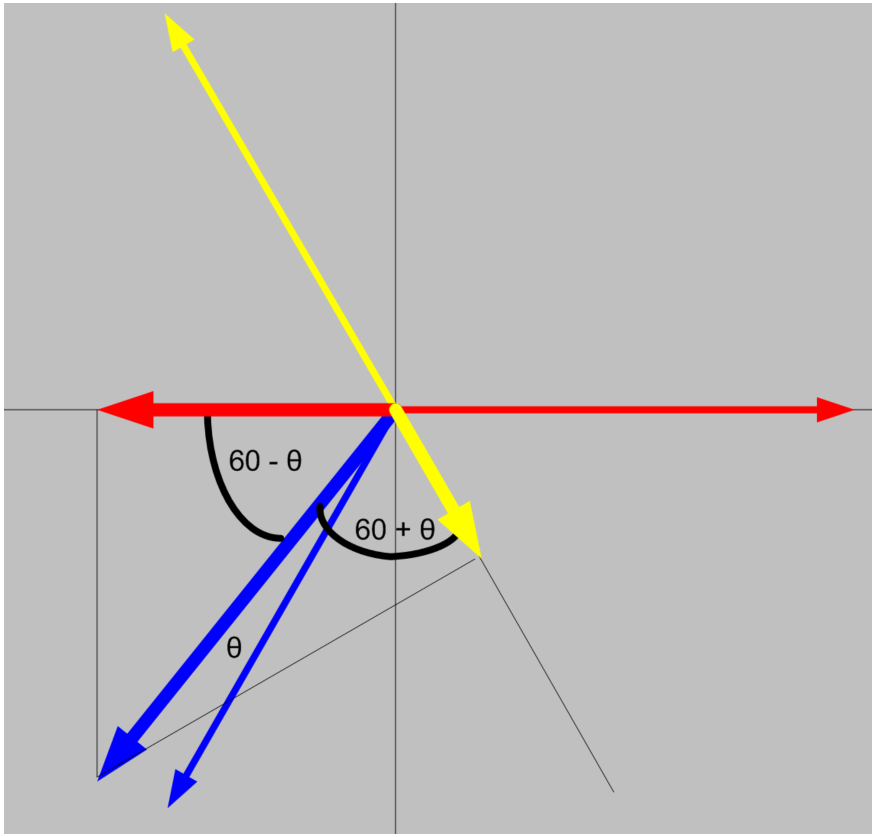
This DOES NOT satisfy Blondel's Theorem.

BLONDEL'S THEOREM

In the previous example:

- What are the "ASSUMPTIONS"?
- When do we get errors?

BLONDEL'S THEOREM



BLONDEL'S THEOREM

- **Phase B power would be:**
  - $P = V_b I_b \cos\theta$
- **But we aren't measuring Vb**
- **What we are measuring is:**
  - $I_b V_a \cos(60 - \theta) + I_b V_c \cos(60 + \theta)$

BLONDEL'S THEOREM

$Pb = IbVaCos(60 - \theta) + IbVcCos(60 + \theta)$

Applying the trig identity

- $IbVa(Cos(60)Cos(\theta) + Sin(60)Sin(\theta))$
  $IbVc\ (Cos(60)Cos(\theta) - Sin(60)Sin(\theta))$
- $Ib(Va+Vc)0.5Cos(\theta) + Ib(Vc-Va)\ 0.866Sin(\theta)$

Assuming

- Assume $Vb = Va = Vc$
- And, they are exactly 120° apart

$Pb = Ib(2Vb)(0.5Cos\theta) = IbVbCos\theta$

BLONDEL'S THEOREM

- If Va ≠ Vb ≠ Vc then the error is
- %Error =

-Ib{(Va+Vc)/(2Vb) - (Va-Vc) 0.866Sin(θ)/(VbCos(θ))

How big is this in reality? If

Va=117, Vb=120, Vc=119, PF=1 then E=-1.67%

Va=117, Vb=116, Vc=119, PF=.866 then E=-1.67%

AC THEORY – POWER

- Power is defined as: P = VI
- Since the voltage and current at every point in time for an AC signal is different, we have to distinguish between instantaneous power and average power.
- Generally when we say “power” we mean average power.
- Average power is only defined over an integer number of cycles.

HARMONICS
CURSE OF THE MODERN WORLD

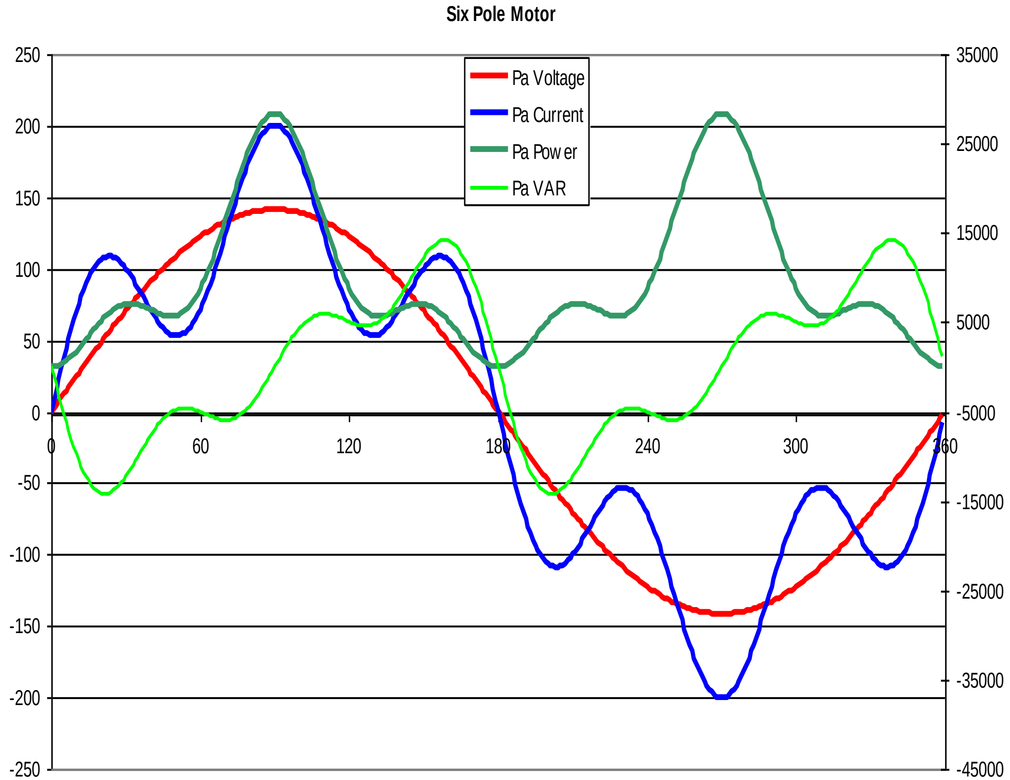
- **Every thing discussed so far was based on "Linear" loads.**
  - For linear loads the current is always a simple sine wave. Everything we have discussed is true.
- **For nearly a century after AC power was in use ALL loads were linear.**
- **Today, many loads are NON-LINEAR.**

HARMONICS - DEFINITION

- Non-sinusoidal complex waveforms are constructed by “adding” together a series of sine wave frequencies known as “Harmonics.”
- Harmonics is the generalized term used to describe the distortion of a sinusoidal waveform by waveforms of different frequencies.

HARMONIC LOAD WAVEFORM

Eq.#	Quantity	Phase A
1	V(rms) (Direct Sum)	100
2	I(rms) (Direct Sum)	108
3	V(rms) (Fourier)	100
4	I(rms) (Fourier)	108
5	Pa = (∫ V(t)I(t)dt)	10000
6	Pb = ½∑V*n*In**cos**(θ)	10000
7	Q = ½∑VnIn**sin**(θ)	0.000
8	Sa = Sqrt(P^2 +Q^2)	10000
9	Sb = Vrms*Irms(DS)	10833
10	Sc = Vrms*Irms(F)	10833
13	PF = Pa/Sa	1.000
14	PF = Pb/Sb	0.923
15	PF = Pb/Sc	0.923



$V = 100\mathrm{Sin}(\omega t)$ $\quad$ $I = 100\mathrm{Sin}(\omega t) + 42\mathrm{Sin}(5\ \omega t)$

HARMONIC LOAD WAVEFORM

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9	Sb = Vrms*Irms(DS)	10833
10	Sc = Vrms*Irms(F)	10833
13	PF = Pa/Sa	1.000
14	PF = Pb/Sb	0.923
15	PF = Pb/Sc	0.923

Important things to note:

- Because the voltage is NOT distorted, the harmonic in the current does not contribute to active power.
- It does contribute to the Apparent power.
- Does the Power Triangle hold

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

- There is considerable disagreement about the definition of various power quantities when harmonics are present.

V = 100Sin(ωt) I = 100Sin(ωt) + 42Sin(5 ωt)

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

3 PHASE POWER MEASUREMENT

Arithmetic vs Vectoral

- Both a magnitude and a direction must be specified for a vector quantity.
- In contrast, a scalar quantity which can be quantified with just a number.
- Any number of vector quantities of the same type (i.e., same units) can be combined by basic vector operations.

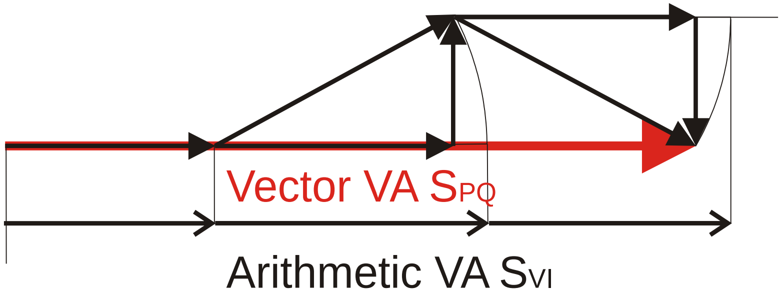
3 PHASE POWER MEASUREMENT

VAR and VA calculations can lead to some strange results:

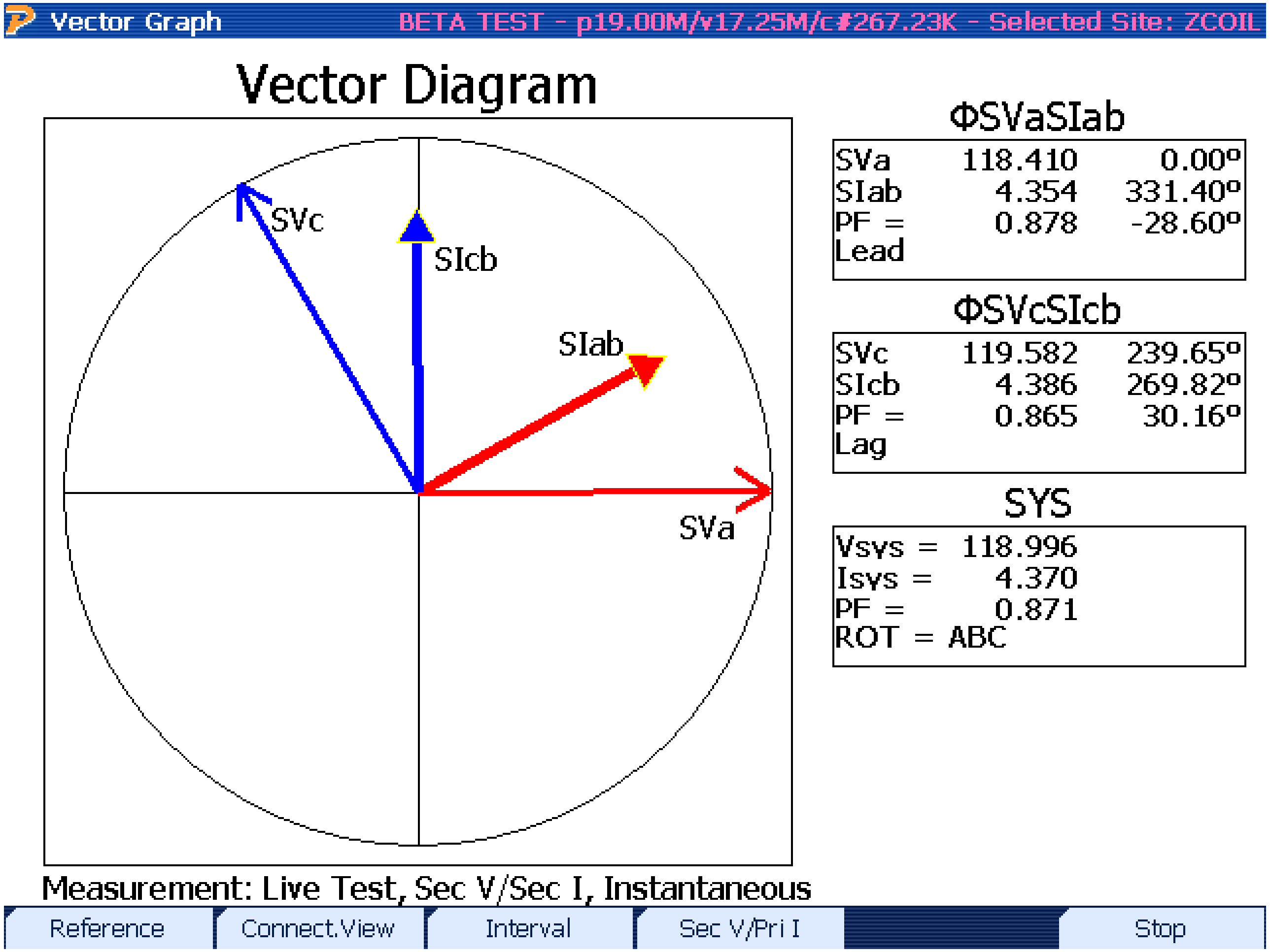
- If we define

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

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

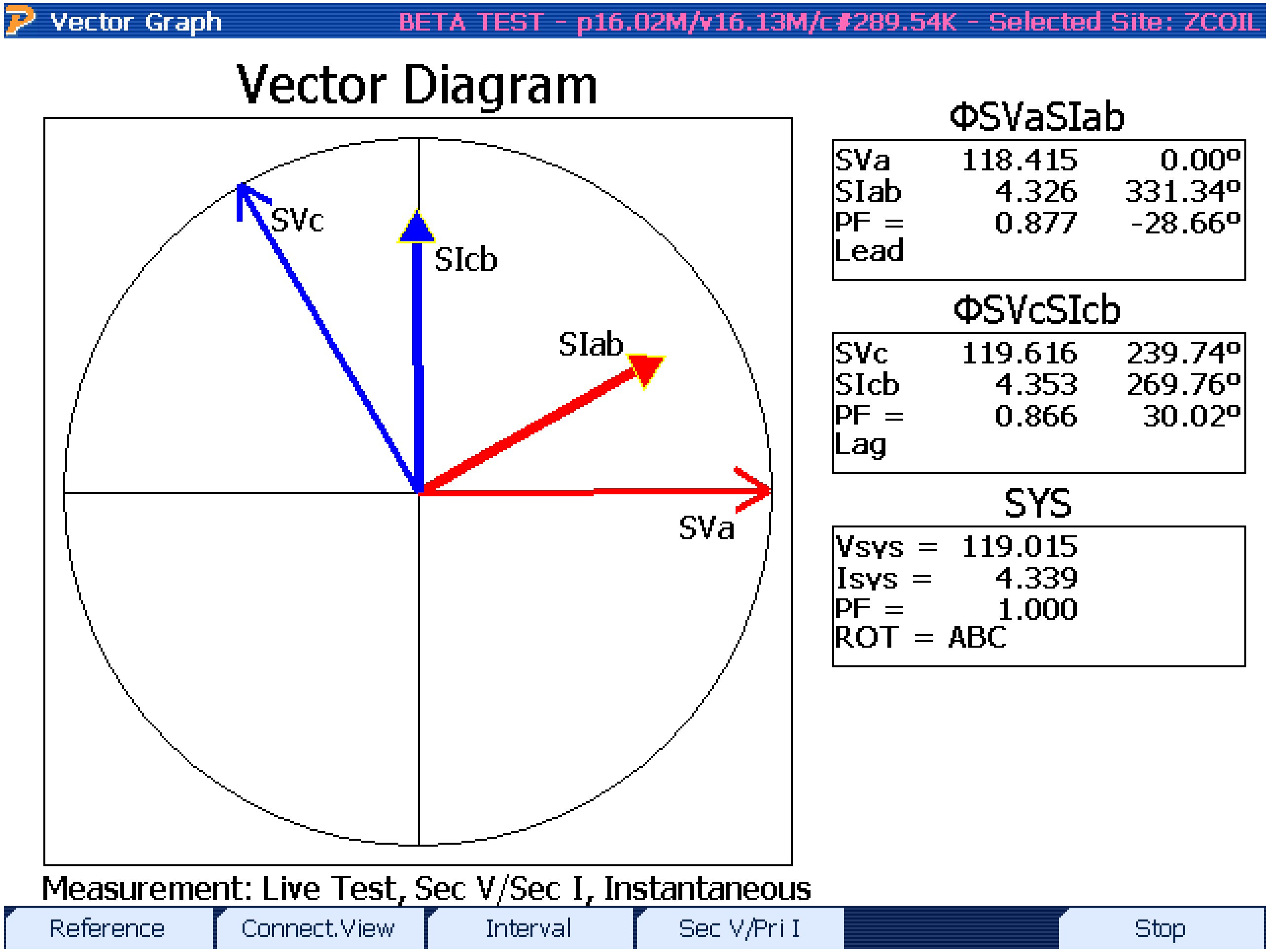


3 PHASE POWER MEASUREMENT



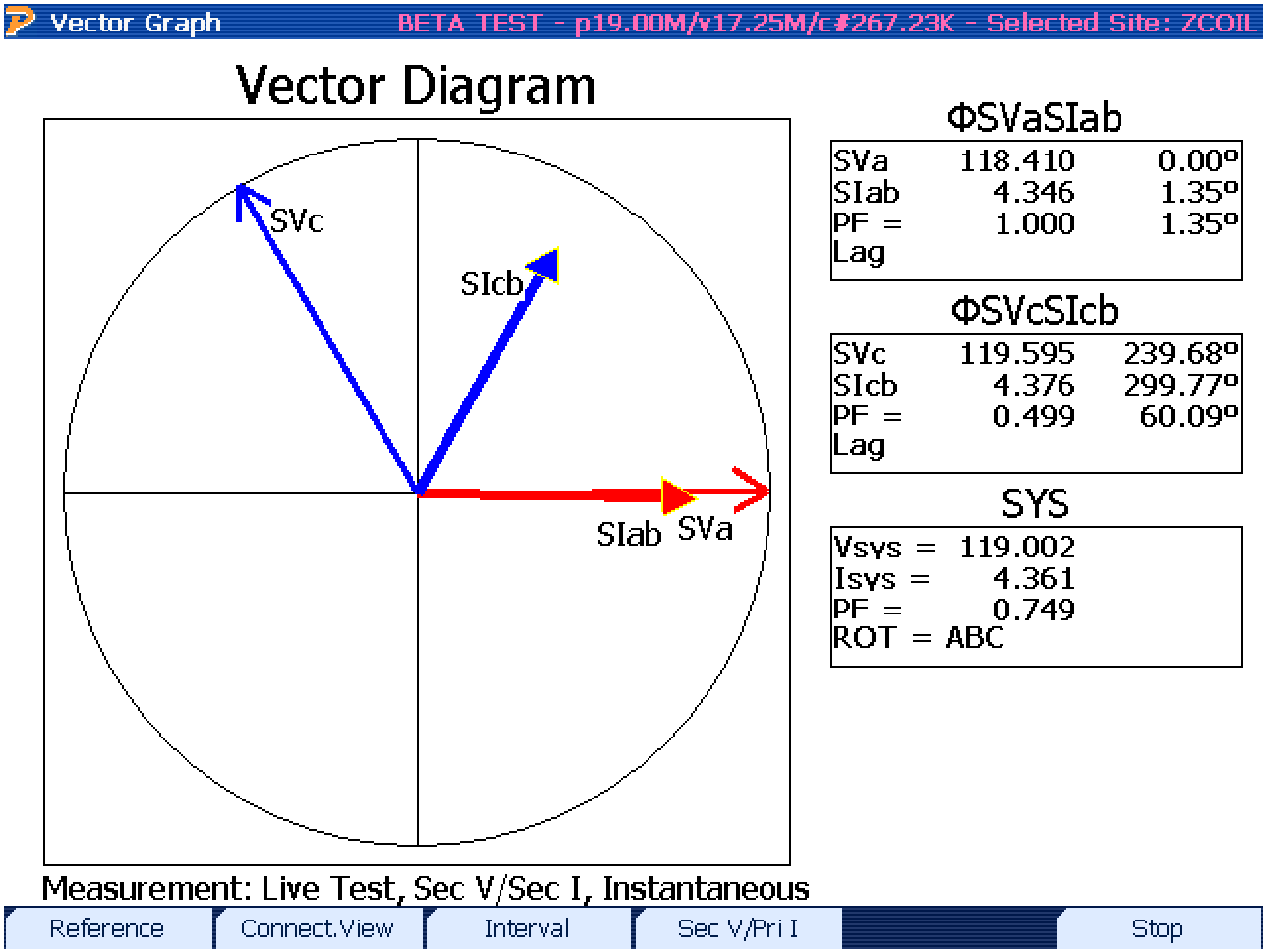
Arithmetic Calculation - Form 6 – 4 Wire Y Site
Voltages and Currents Aligned at 0°

3 PHASE POWER MEASUREMENT



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

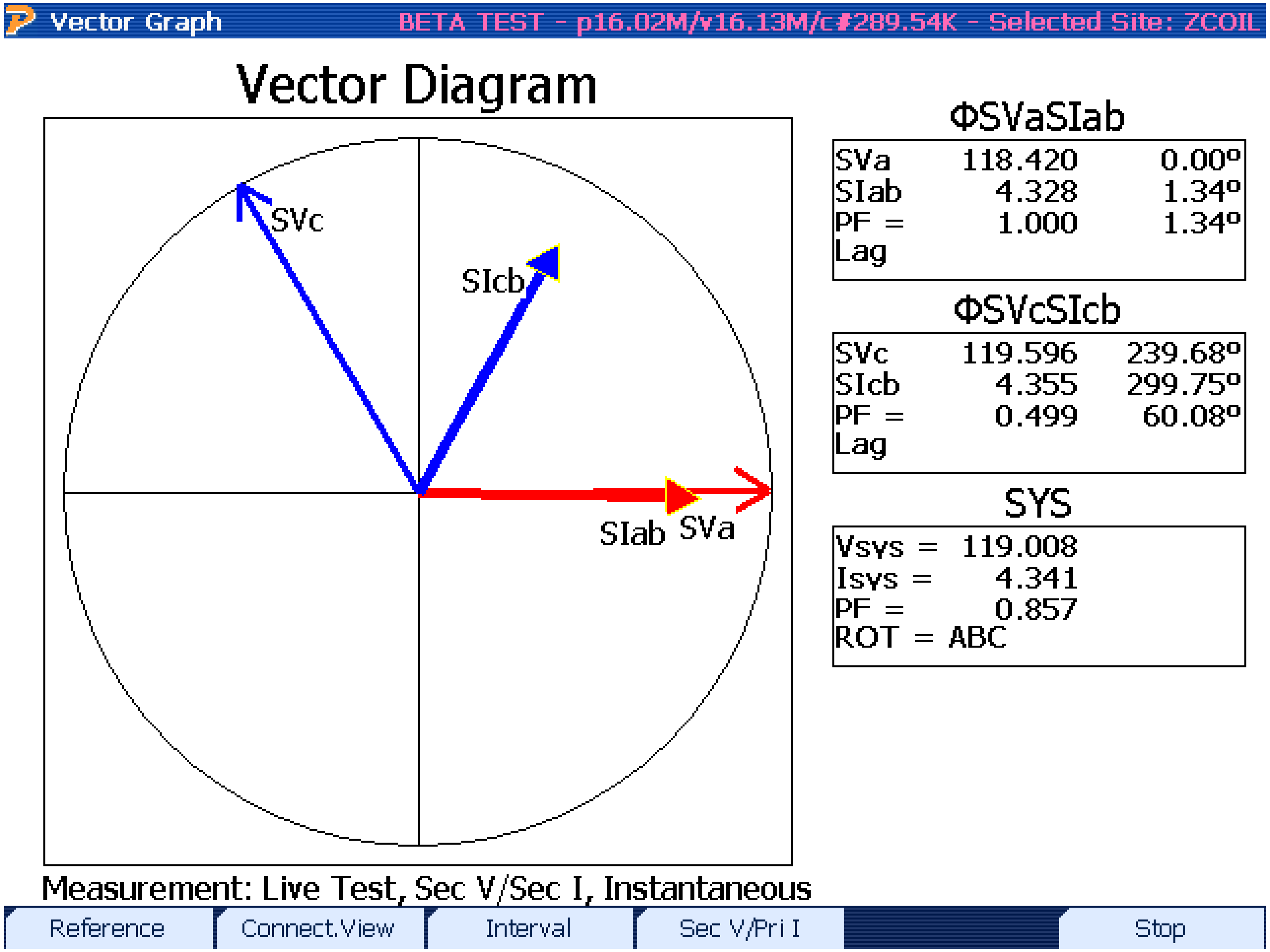
3 PHASE POWER MEASUREMENT



Arithmetic Calculation - Form 6 – 4 Wire Y Site

Currents All shifted by 30°

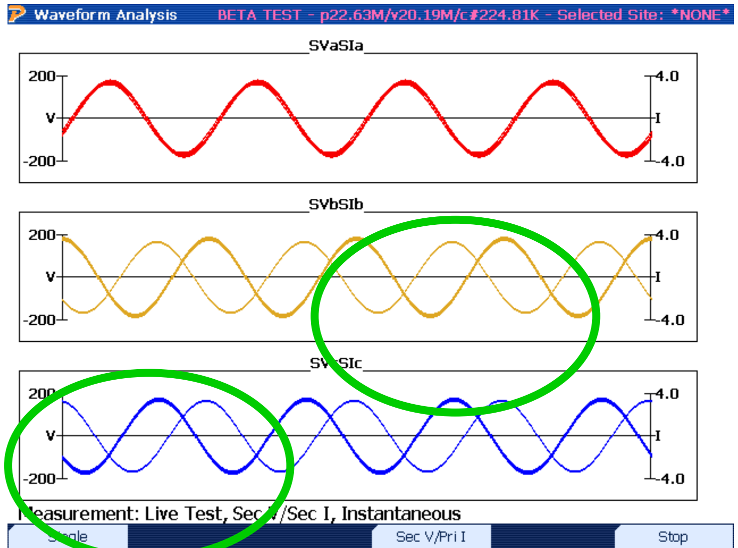
3 PHASE POWER MEASUREMENT

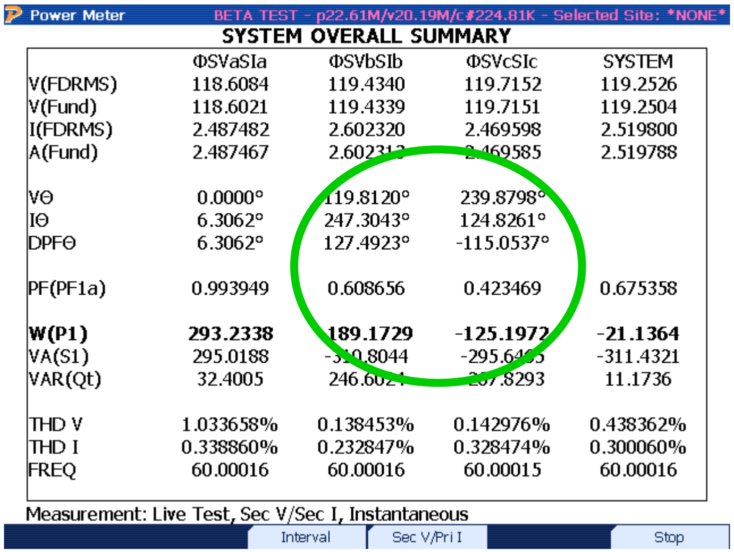


Vector Calculation - Form 6 – 4 Wire Y Site

Currents All shifted by 30°

Actual Field Test Case #1: Lots of Clues!



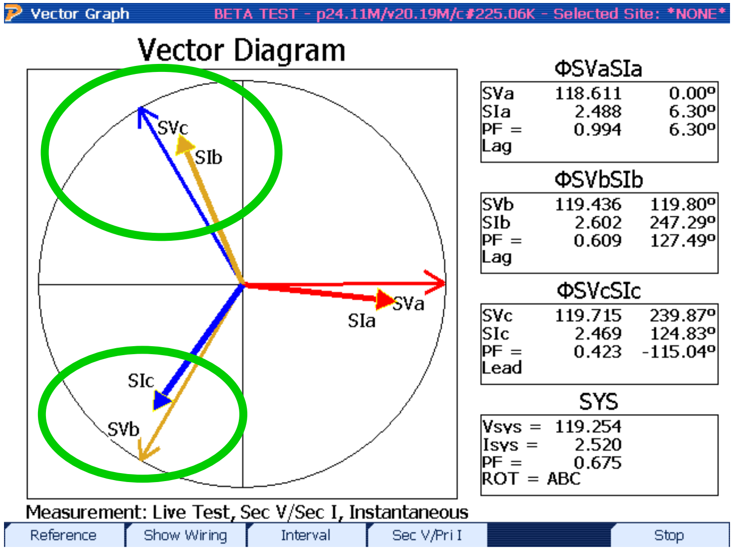

Power Meter BETA TEST - p22.61M/v20.19M/c#224.81K - Selected Site: *NONE*

SYSTEM OVERALL SUMMARY

	ΦSVaSIa	ΦSVbSIb	ΦSVcSIc	SYSTEM
V(FDRMS)	118.6084	119.4340	119.7152	119.2526
V(Fund)	118.6021	119.4339	119.7151	119.2504
I(FDRMS)	2.487482	2.602320	2.469598	2.519800
A(Fund)	2.487467	2.602313	2.469585	2.519788
VΘ	0.0000°	119.8120°	239.8798°	
IΘ	6.3062°	247.3043°	124.8261°	
DPFΘ	6.3062°	127.4923°	-115.0537°	
PF(PF1a)	0.993949	0.608656	0.423469	0.675358
W(P1)	**293.2338**	**189.1729**	**-125.1972**	**-21.1364**
VA(S1)	295.0188	-310.8044	-295.6465	-311.4321
VAR(Qt)	32.4005	246.6024	267.8293	11.1736
THD V	1.033658%	0.138453%	0.142976%	0.438362%
THD I	0.338860%	0.232847%	0.328474%	0.300060%
FREQ	60.00016	60.00016	60.00015	60.00016

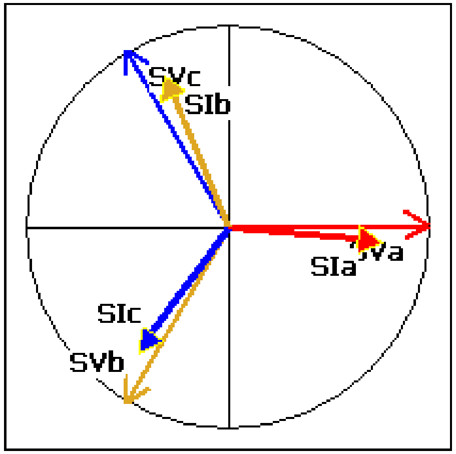
Measurement: Live Test, Sec V/Sec I, Instantaneous

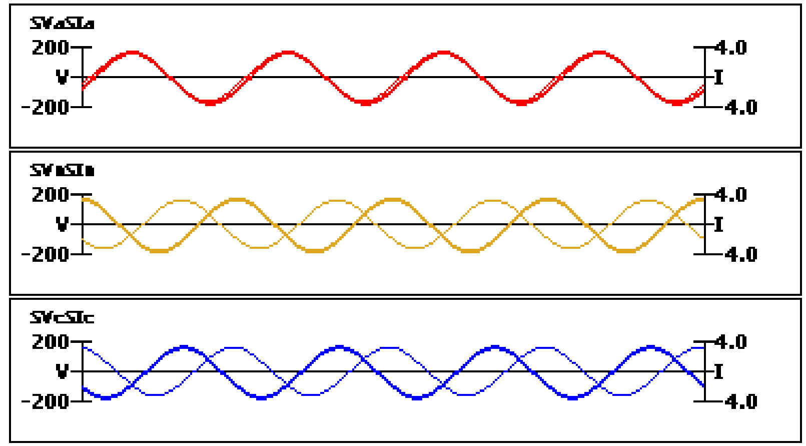
Interval | Sec V/Pri I | Stop



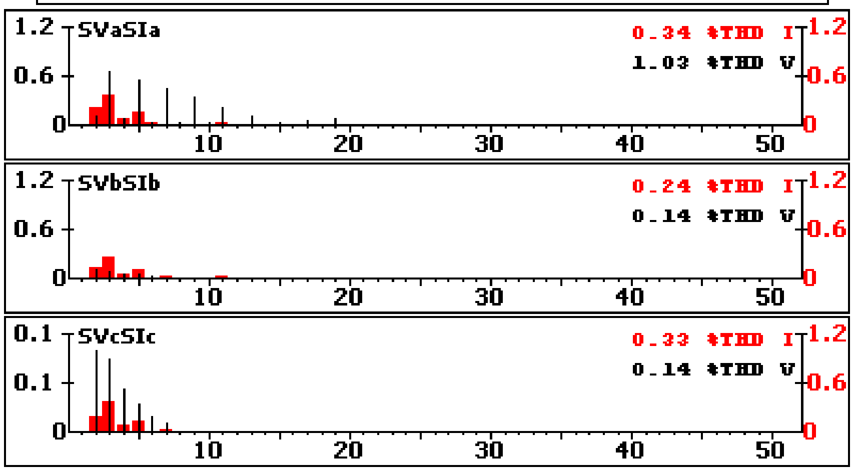
Actual Field Test Case #1: Lots of Clues!

Full Analysis BETA TEST - p22.60M/v20.19M/c#224.81K - Selected Site: *NONE*





	ΦSVaSIa	ΦSVbSIb	ΦSVcSIc	SYSTEM
V(FDRMS)	118.62	119.43	119.71	119.25
V(Fund)	118.61	119.43	119.71	119.25
I(FDRMS)	2.4872	2.6023	2.4696	2.5197
A(Fund)	2.4872	2.6023	2.4696	2.5197
VΘ	0.00°	119.81°	239.88°	
IΘ	6.30°	247.30°	124.83°	
DPFΘ	6.30°	127.49°	-115.06°	
PF(PF1a)	0.9940	0.6086	0.4235	0.6754
W(P1)	**293.22**	**-189.16**	**-125.21**	**-21.15**
VA(S1)	295.00	-310.80	-295.65	-311.44
VAR(Qt)	32.39	246.60	-267.82	11.17
THD V	1.0255%	0.1385%	0.1430%	0.4356%
THD I	0.3445%	0.2373%	0.3332%	0.3050%
FREQ	60.000	60.000	60.000	60.000



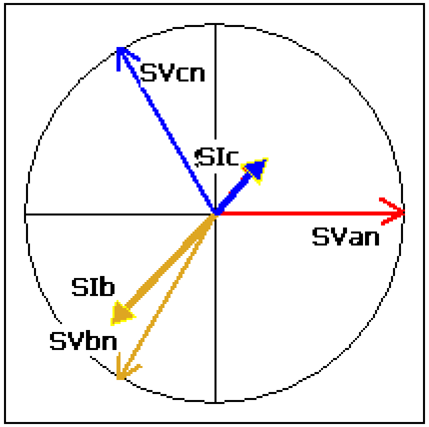
Measurement: Last Test, Sec V/Sec I, Instantaneous

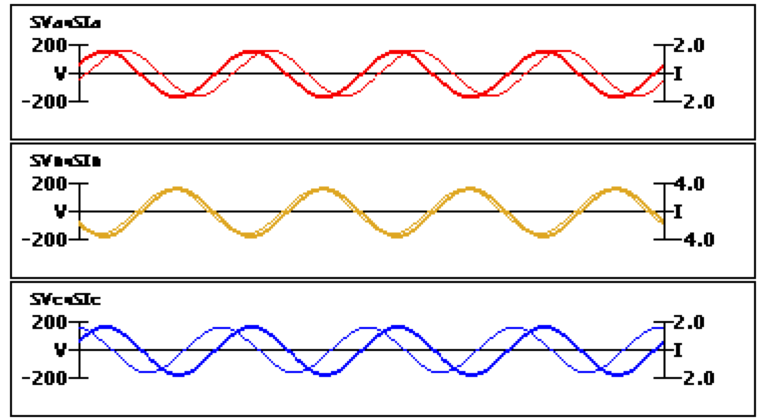
Restart

Phase B & C reversed!

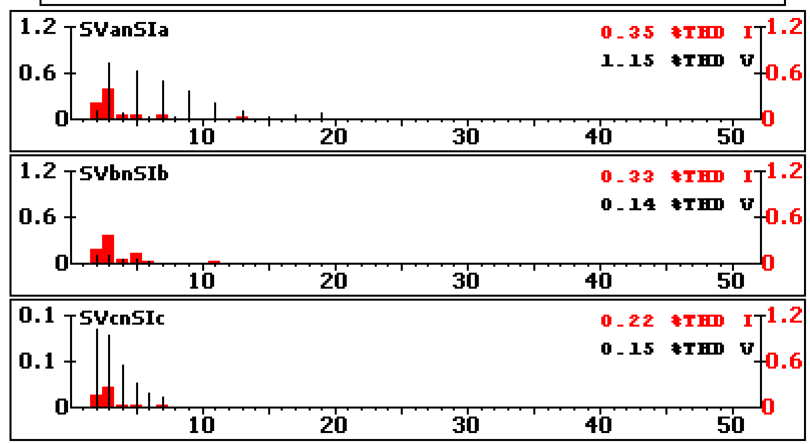
Actual Field Test Case #2

Full Analysis BETA TEST - p21.10M/v19.06M/c#275.40K - Selected Site: DELETE





	ΦSVanSIa	ΦSVbnSIb	ΦSVcnSIc	SYSTEM
V(FDRMS)	118.51	119.44	119.72	119.22
V(Fund)	118.51	119.44	119.72	119.22
I(FDRMS)	1.2056	2.4898	1.2635	1.6530
A(Fund)	1.2056	2.4898	1.2635	1.6529
VΘ	0.00°	119.82°	239.89°	
IΘ	312.87°	132.67°	314.27°	
DPFΘ	-47.125°	12.849°	74.377°	
PF(PF1a)	0.6804	0.9750	0.2693	0.6416
W(P1)	**97.21**	**289.93**	**40.74**	**427.87**
VA(S1)	142.87	297.38	151.27	591.51
VAR(Qt)	-104.70	66.13	145.68	107.11
THD V	1.1485%	0.1409%	0.1453%	0.4783%
THD I	0.3472%	0.3328%	0.2220%	0.3007%
FREQ	59.999	60.000	60.000	60.000



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

There is no problem!

3-Wire Delta load

On a 4-Wire Wye service.

New Revision of C12.20 in 2015

- Polyphase meters tested using polyphase
  - Recommended 2015, required 2020
- Unbalanced load testing required
- Full harmonic testing required
- 0.1% Accuracy Class added
- Specific call out of Non-Blondel applications where C12.20 does not apply
- Detailed requirements and specs for test outputs added

New Revision of C12.20 in 2015

- Tighter reference condition performance specifications
- When using polyphase loading meters must be tested in each configuration used

New Revision of C12.1 in 2015

- 0.5% Accuracy Class added
- Testing required for unbalanced loads
- Testing required under unbalanced conditions
- Tighter reference performance requirements
- Bi-directional energy flow testing
- Extensive update on in-service testing

New Revision of C12.10 in 2015

- Accuracy tests moved here from C12.1
- Much broader safety requirements
- Coordinated effort with UL2735
  - Utilities exempt from UL2735 but only if they own and install the equipment

STANDARDS CHANGES

New Revision of C12.9 in 2014

- Full specifications for test plugs included in standard
  - Ensures safe operation between all switches and all plugs
  - previously some combinations produced safety hazards
- New barrier requirements between switch elements

Communications Standards

- New C12.19 which replaces C12.18 and C12.19 is in ballot process
  - Major changes – major controversy has held up approval for two years
  - Standard will still not guarantee inter-operability
- C12.23 the “Compliance Testing” standard is nearly complete

NEXT GENERATION STANDARDS

ANSI C12.46

- New standard in development to **replace C12.1** and **C12.20**
- Structured like OIML IR-46
- A true digital age standard
- Applies to ALL energy measurements
  - Watts, VA and VAR
  - Contains precise definitions for the quantities based on digitally sampled waveforms

ANSI C12.46

- Covers ALL waveform types
  - sinusoidal, harmonic, time varying
- Defines the meter as everything under the cover
  - If there is auxiliary functions in the meter they must be fully operational during accuracy testing
  - If a option is added to a meter, it must be tested with the option running to remain qualified

ANSI C12.46

- View of accuracy changes
  - Currently changes with respect to reference
  - New approach is absolute error

Philosophy of C12.46 – When a meter is claimed to be of a specific accuracy class, for example , AC 0.2%, then it’s accuracy under all commonly occurring conditions should be within ±0.2% maximum error.

NEW ENERGY DEFINITIONS

Time Domain

Active Power

$$P_t = \frac{1}{N}\sum_n V_i I_i$$

Apparent Power

$$S_t = VA = VrmsIrms = \sqrt{\frac{1}{N}\sum_{i=0}^{i=N-1} V_i^2 \bullet \frac{1}{N}\sum_{i=0}^{i=N-1} I_i^2}$$

Reactive Power

$$Q_t = \sqrt{S^2 - P^2}$$

NEW ENERGY DEFINITIONS

Frequency Domain

Active Power

$$P_f = \sum_n \left| \vec{V}_n \bullet \vec{I}_n \right| = \frac{1}{2} \sum_n (a_{vn} a_{in} + b_{in} b_{vn})$$

$$= \sum_n V_n I_n \cos(\theta_n)$$

Apparent Power

$$S_f = \frac{1}{2} \left[\sum_n (a_{vn}^2 + b_{vn}^2) \sum_n (a_{in}^2 + b_{in}^2) \right]^{1/2}$$

Reactive Power

$$Q_f = \sum_n \left| \vec{V}_n \times \vec{I}_n \right| = \frac{1}{2} \sum_n (a_{vn} b_{in} - a_{in} b_{vn})$$

$$= \sum_n V_n I_n \sin(\theta_n)$$

WHAT DOES THE FUTURE HOLD?

- **Over the next FEW years metering may have a whole new meaning**
- **Do these look like meters to you?**

WHAT DOES THE FUTURE HOLD?

- **Each has an embedded <u>revenue</u> meter**
- **Each claims ANSI C12.1 compliance**

Questions and Discussion

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864-590-2883 (cell)

This presentation can also be found under Meter Conferences and Schools on the TESCO web site:

www.tesco-advent.com