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VAR, VA, and 4 Quadrant Metering

TESCO's Meter School

TESCOOL

Monday, July 10th, 2023

1:45 PM – 2:45 PM

Nathaniel Dunn

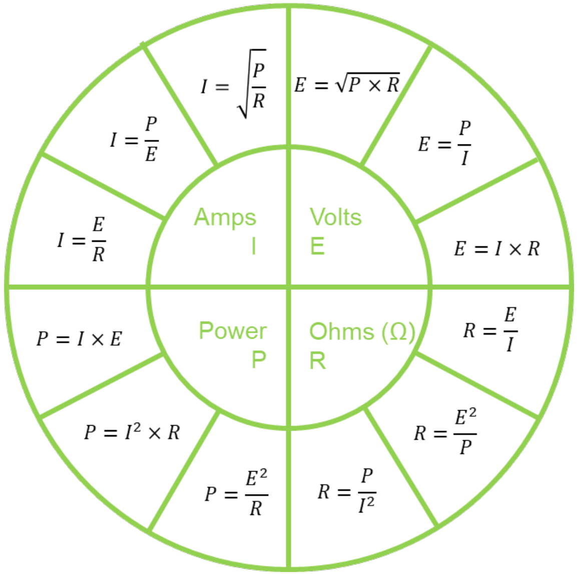
VAR, VA, and 4 Quadrant Metering

Agenda

Ohm’s Law and Power Calculations

Ohm's Law

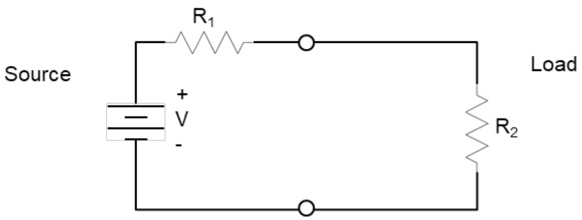
- Ohm's Law provides basic formulas used for calculating power.
- The law states that the current, I, through a conductor is directly proportional to the voltage, E.
- The figure to the right provides all the power related formulas derived from Ohm's Law.



Ohm'sLaw

Basic Circuits

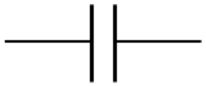
- In a basic DC circuit, we can use Ohm's Law to calculate the current for this circuit
- $$I = \frac{E}{R_1 + R_2}$$
- Then we can calculate the power consumed by the load
$$P = I^2 \times R_2$$
- R_1 reflects resistant in line from source to load, and R_2 is the resistance of the load. In most cases R_2 would be much greater than R_1. Thus, most of the power is consumed by the load.
- These are the same basic applied to metering to measure the power and energy consumed by the load.



Capacitance and Inductance

DC vs. AC Circuits

- Capacitors are resistive elements in a circuit that don't have real resistance, but reactance
- In AC circuits they create an induced current that affects the phase relationship between voltage and current for that phase
- A cap bank is an example of a capacitor
- Capacitive Reactance is defined as; $X_C = \dfrac{1}{2\pi f C}$



Capacitance

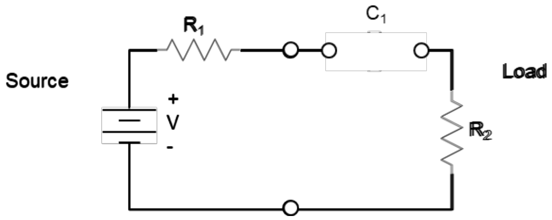
- Inductors similarly are resistive elements in a circuit that don't have real resistance, but reactance
- Like capacitors, in an AC circuit they induce a current into the circuit that affects the phase relationship between voltage and current for that phase
- A transformer is an example of an inductor. Most loads have inductive elements/models
- Inductive Reactance is defined as; $X_L = 2\pi f L$

Inductance

RC and RL Circuits

DC vs. AC Circuits

- Capacitors and inductors behave differently in AC circuits compared to DC circuits
- In DC circuits a Capacitor will look like an open circuit after fully charging; RC time constant



RC and RL Circuits

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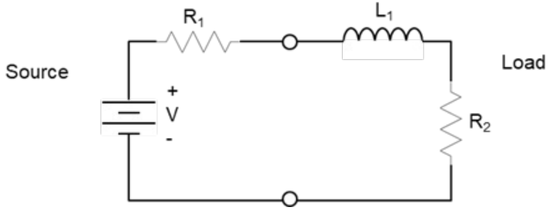
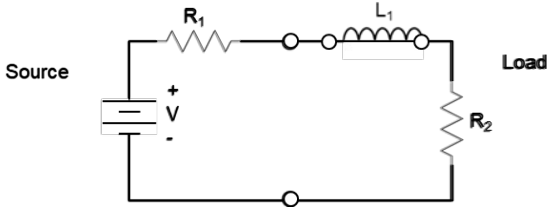


RC AND RL CIRCUITS

DC vs. AC Circuits

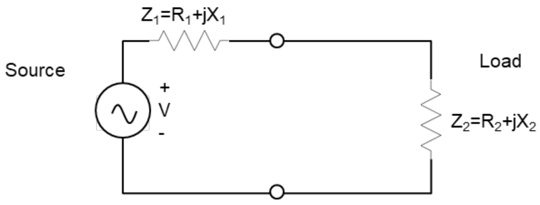
- Capacitors and inductors behave differently in AC circuits compared to DC circuits
- In DC circuits a Capacitor will look like an open circuit after fully charging; RC time constant
- Inductors will look like a short circuit after fully charging; 1/RL time constant



RC AND RL CIRCUITS

DC vs. AC Circuits

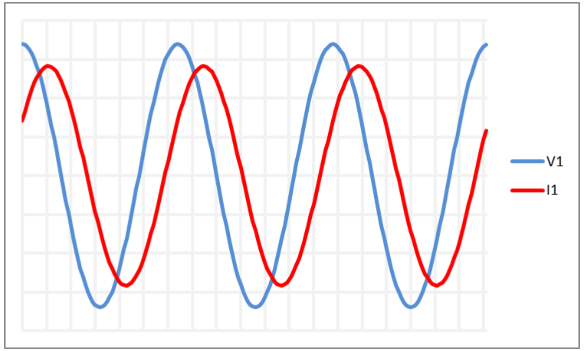
- Capacitors and inductors behave differently in AC circuits compared to DC circuits
- In DC circuits a Capacitor will look like an open circuit after fully charging; RC time constant
- Inductors will look like a short circuit after fully charging; 1/RL time constant
- In AC circuits inductors and capacitors induce a current that causes a phase displacement with the source current. R is replaced with impedance Z; $Z = R + jX$



ELI THE ICE MAN

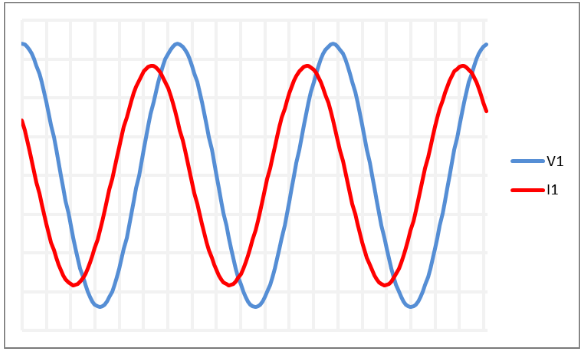
How does inductance and capacitance affect AC power?

- In inductive (L) circuits, voltage (E) leads current (I) - ELI



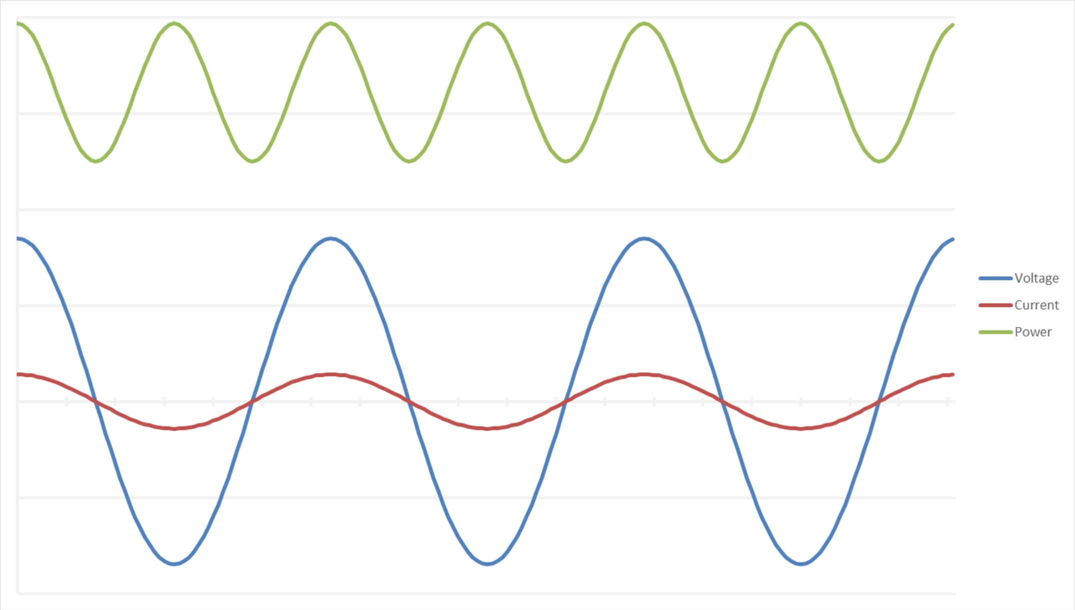
Inductor – Voltage leads Current

- In a capacitive (C) circuit, current (I) leads voltage (V) - ICE



Capacitor – Current leads voltage

AC Power Calculations



$$Single\ Phase\ Real\ Power\ (Watts) = V_{A_{rms}} \times I_{A_{rms}} \times \cos(\emptyset_{V_A} + \emptyset_{I_A})$$

$$Single\ Phase\ Reactive\ Power\ (VARs) = V_{A_{rms}} \times I_{A_{rms}} \times \sin(\emptyset_{V_A} + \emptyset_{I_A})$$

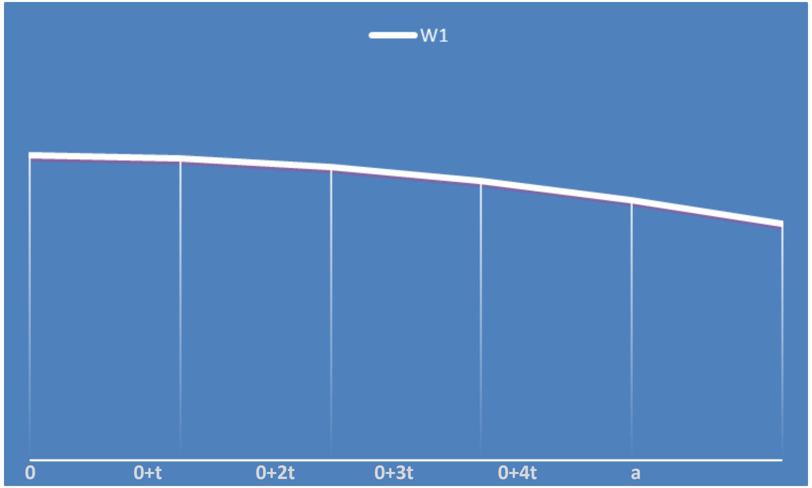
$$Single\ Phase\ Apparent\ Power (VAs) = V_{A_{rms}} \times I_{A_{rms}}$$

- When calculating AC power you must account for the phase angle difference between the voltage and current signals.
- You will notice there are 3 calculations for AC single phase power. We will cover the differences in more detail later
- The signals to the left are at unity PF
- The base formula of AC power is still;

P = I X E

AC Power Calculations

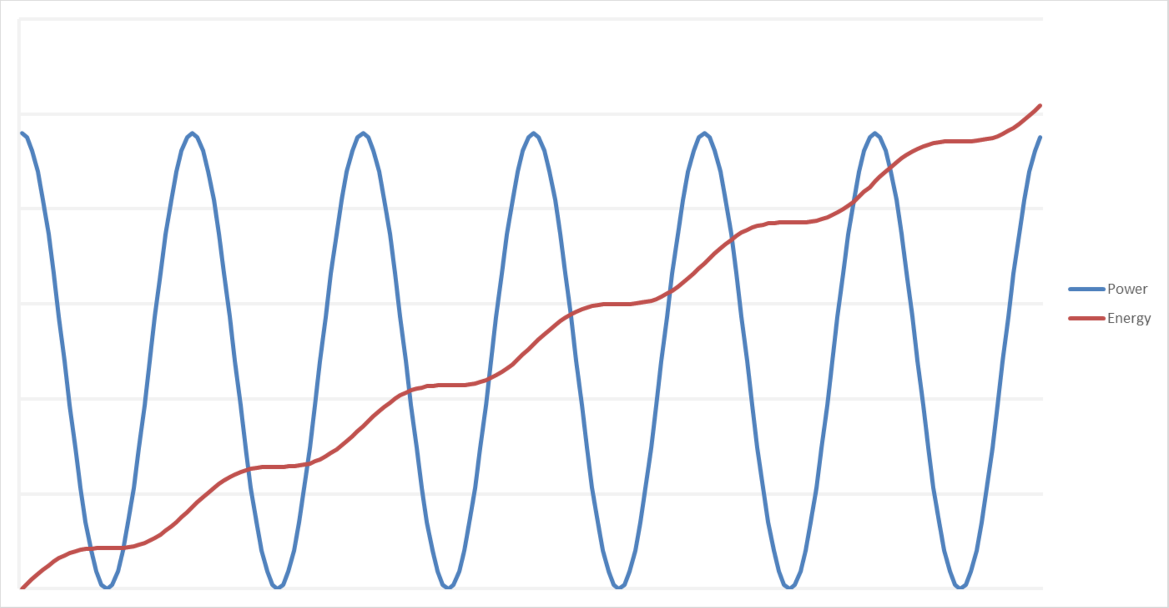
Calculating Energy



$$\int_0^a A\times B\times\cos(Ct)\,dt$$

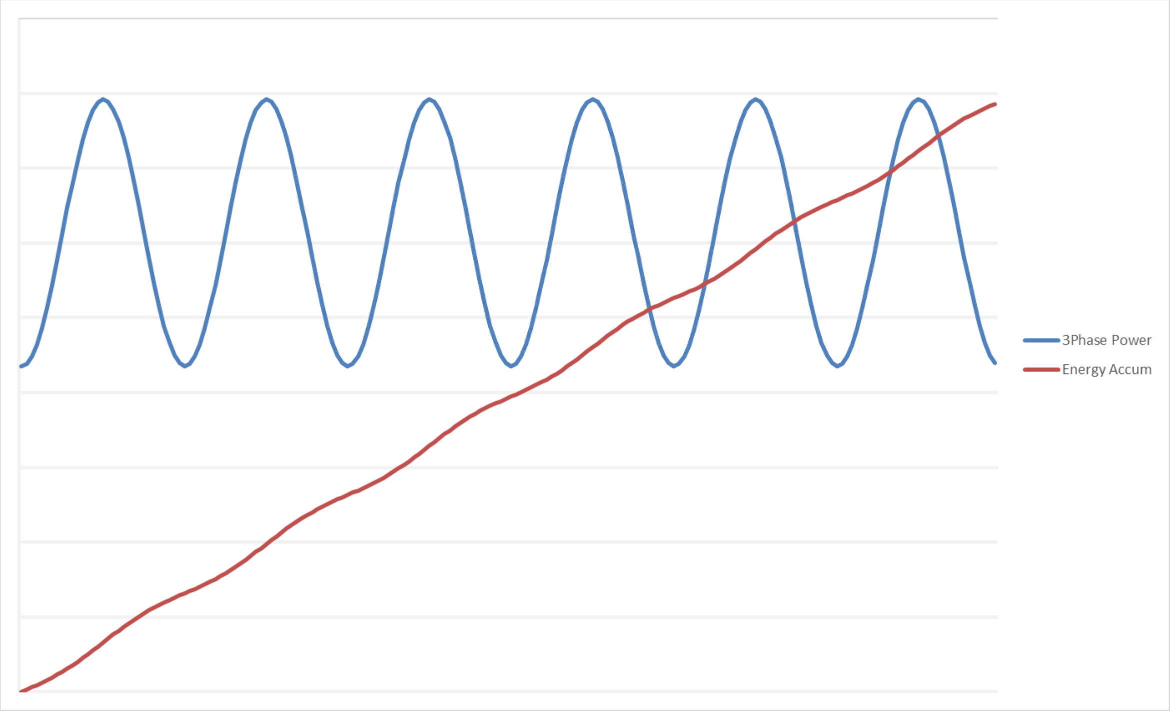
- A, B, and C are constant in the equation
- Energy can be simplified at calculating the area under the curve
- High sampling rates provide small distances between data points and reduce error introduce from noise by keeping the line between points flat
- Energy is the sum of the area of each section using the trapezoid formula for area

Single Phase Power & Energy



- Energy accumulation on a sample-by-sample analysis
- Energy accumulation accelerates at peaks and decreases at negative peaks
- When power wave crosses X axis energy will fall, or have a negative slope
- Higher sampling rates provided a more rounded curve, and increase accuracy

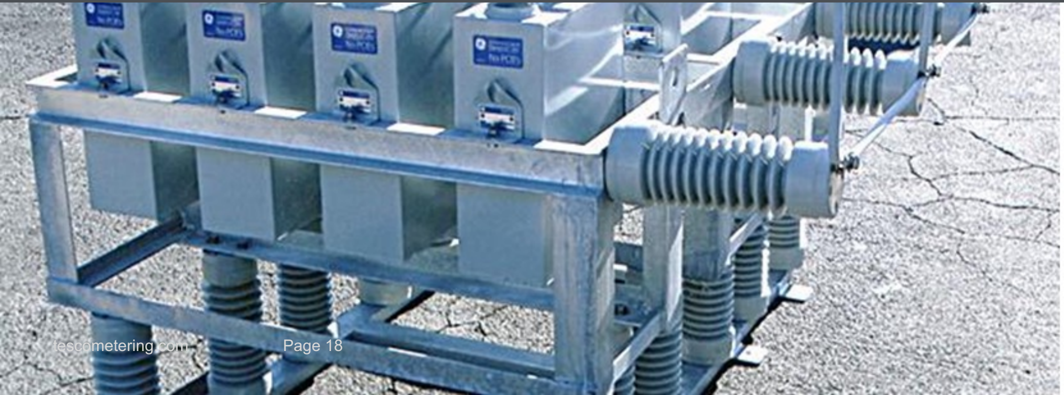
3 Phase Power & Energy (Balanced)



- In a balanced 3 phase load, the power total is constant on a sample by sample analysis!
- Energy accumulates in a linear progression
- This is only true when power is balanced
- When power is unbalanced the energy accumulation isn't linear

VARs and VAs Calculations

The Power Triangle



What Are VARs and VAs

- VA stands for Volt-Amps
  - VA represents the total demand of a load
  - It doesn't account for phase relationship in calculation, and is determined by the magnitude of voltage and current

$$Single\ Phase\ Apparent\ Power(VAs) = V_{A_{rms}} \times I_{A_{rms}}$$

- VAR stands for Volt-Amps Reactive
  - VARs represents the power lost to reactive components, usually as heat.
  - VARs are a result of reactive loads like inductors and capacitors
  - Calculation for VARs is very similar to calculation for power but uses the sin function instead of cosine.

$$Single\ Phase\ Reactive\ Power\ (VARs) = V_{A_{rms}} \times I_{A_{rms}} \times \sin(\emptyset_{V_A} + \emptyset_{I_A})$$

Single Phase Power Calculations

- Active power (P) is defined by the following calculation;

$$Single\ Phase\ Real\ Power\ (Watts) = V_{A_{rms}} \times I_{A_{rms}} \times \cos(\emptyset_{V_A} + \emptyset_{I_A})$$

- Reactive power (Q) is defined by the following calculation;

$$Single\ Phase\ Reactive\ Power\ (VARs) = V_{A_{rms}} \times I_{A_{rms}} \times \sin(\emptyset_{V_A} + \emptyset_{I_A})$$

- Apparent power (S) is defined by the following calculation;

$$Single\ Phase\ Apparent\ Power(VAs) = V_{A_{rms}} \times I_{A_{rms}}$$

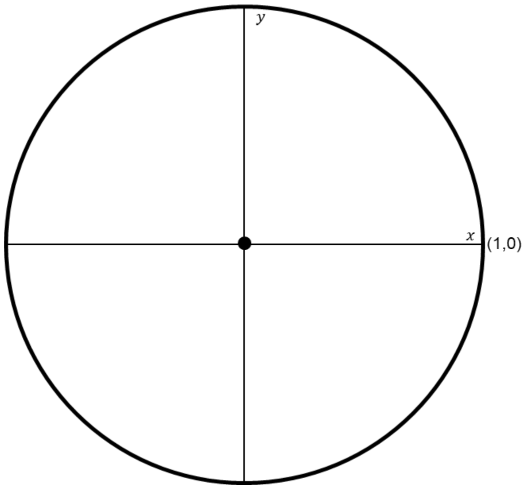
- And the relationship between all three of these quantities is;

$$S = \sqrt{R^2 + Q^2}$$

UNITY CIRCLE

Understanding Sine/Cosine Relationships

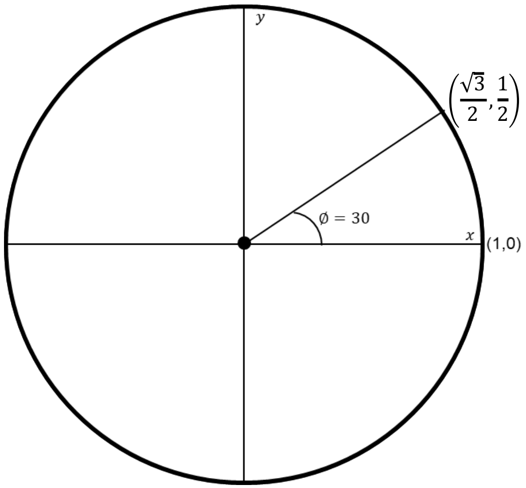
- Trigonometric functions like sine/cosine have a triangular relationship that relates to power
- In the AC power calculations, you'll notice that real power calculation include the cosine function
- VARs use the sine function.
- When you calculate out the unity circle the cos(x) value also correlates to PF
- Cos(0) = 1, and sin(0) = 0, Unity PF



Unity Circle

Understanding Sine/Cosine Relationships

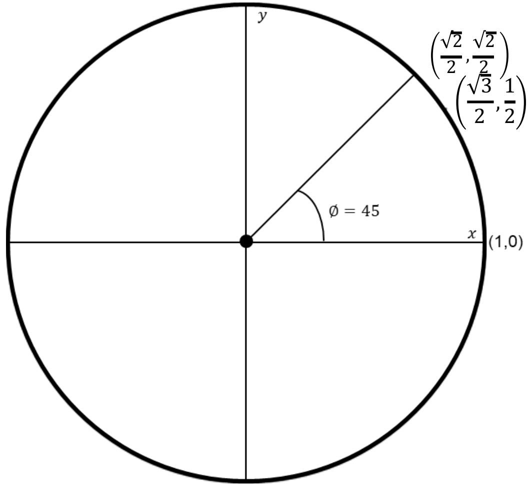
- We’ll also look at some common reference points, and their PF values
- 30 degrees-
  - cos(30) = 0.866
  - sin(30) = 0.5
  - PF = 86.7%



Unity Circle

Understanding Sine/Cosine Relationships

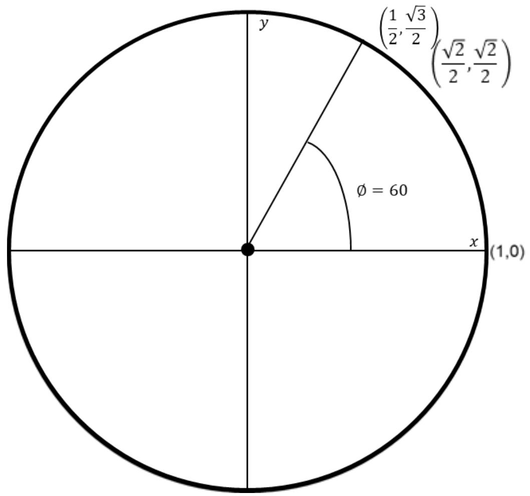
- We’ll also look at some common reference points, and their PF values
- 45 degrees-
- cos(45) = 0.707
- sin(45) = 0.707
- PF = 70.7%



Unity Circle

Understanding Sine/Cosine Relationships

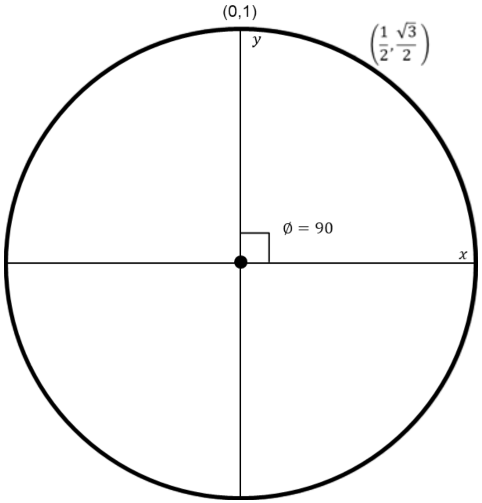
- We'll also look at some common reference points, and their PF values
- 60 degrees-
- $\cos(60) = 0.5$
- $\sin(60) = 0.866$
- PF = 50%



Unity Circle

Understanding Sine/Cosine Relationships

- We’ll also look at some common reference points, and their PF values
- 90 degrees-
- cos(90) = 0
- sin(90) = 1
- PF = 0%



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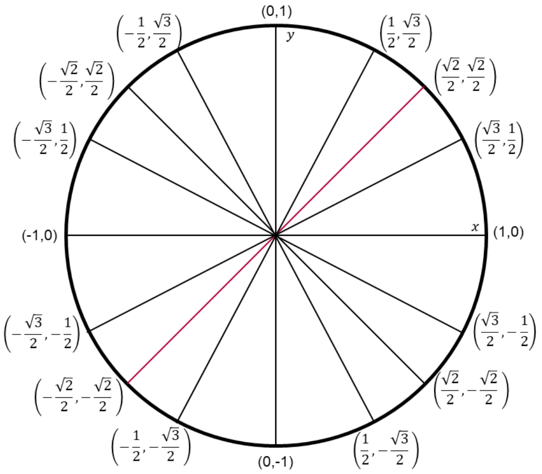
Unity Circle

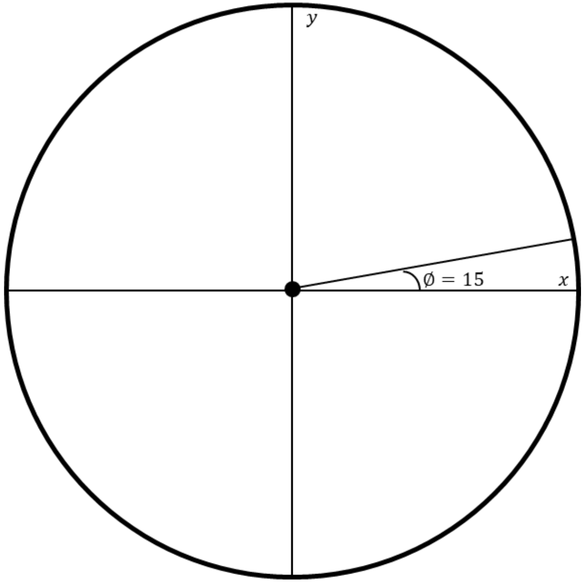
Understanding Sine/Cosine Relationships

- We can populate the rest if the unity circle the same values for every multiple of 30, 45, 60, and 90 degrees
- This can be used to quickly identify watt/var relationships and PF at specific points
- We calculate the X and Y axis using cosine and sine functions. Similar to calculate watts and vars
- Apparent power is also represented in the unity circle by the radius



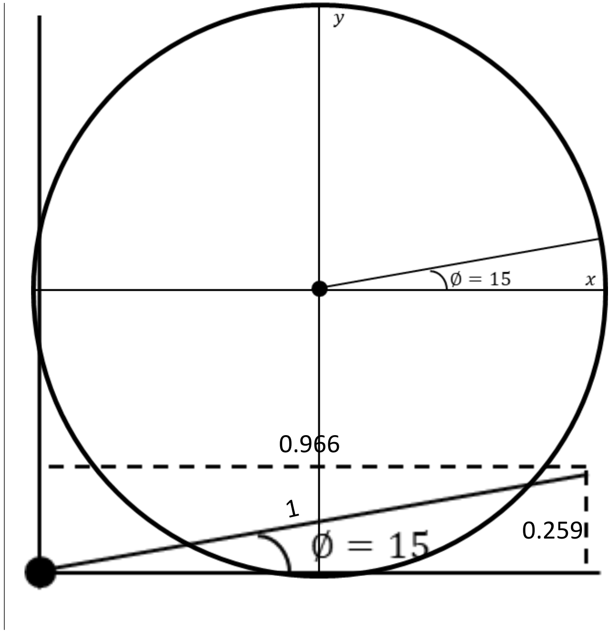
POWER TRIANGLE

- The unity circle ties directly into the power triangle and 4 quadrant metering
- We're going to calculate power at 15 degrees.



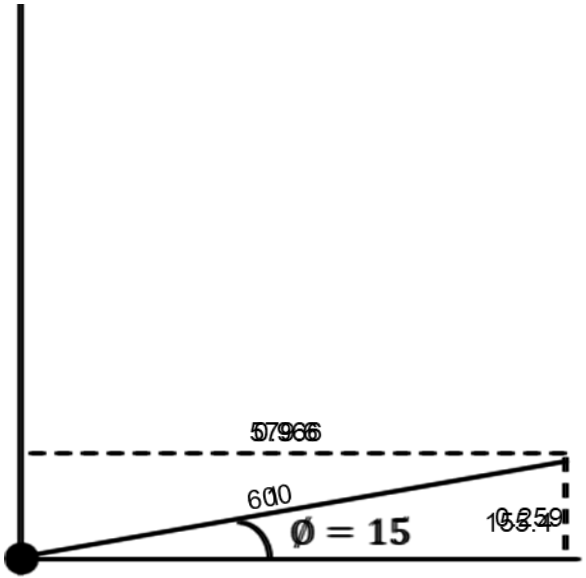
POWER TRIANGLE

- The unity circle ties directly into the power triangle and 4 quadrant metering
- We're going to calculate power at 15 degrees.
  - Cos(15) = 0.966
  - Sin(15) = 0.259
  - PF = 96.6%



Power Triangle

- The unity circle ties directly into the power triangle and 4 quadrant metering
- Next, we'll assume 120 V_{rms} and 5 A_{rms}
  - This comes to 600 VA
  - 600 VA * 0.966 = 579.6 W
  - 600 VA * 0.259 = 155.4 VAR



POWER CALCULATIONS

- Next we'll use the AC power calculations;

  P = 120 * 5 * cos(15) = 579.6 W

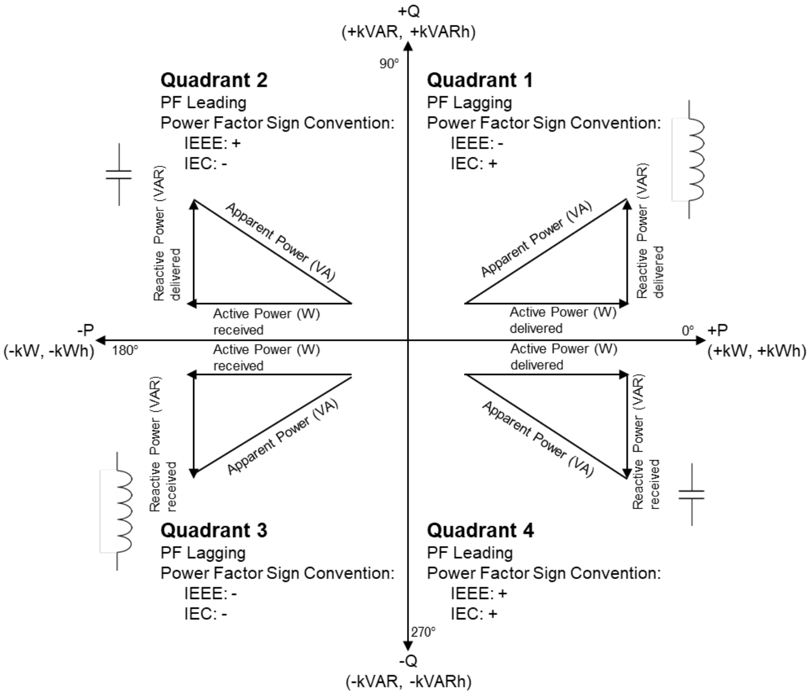
  Q = 120 * 5 * sin(15) = 155.3 VAR

  S = 120 * 5 = 600 VA

  PF = P/S = W/VA = 579.6/600 = 0.966

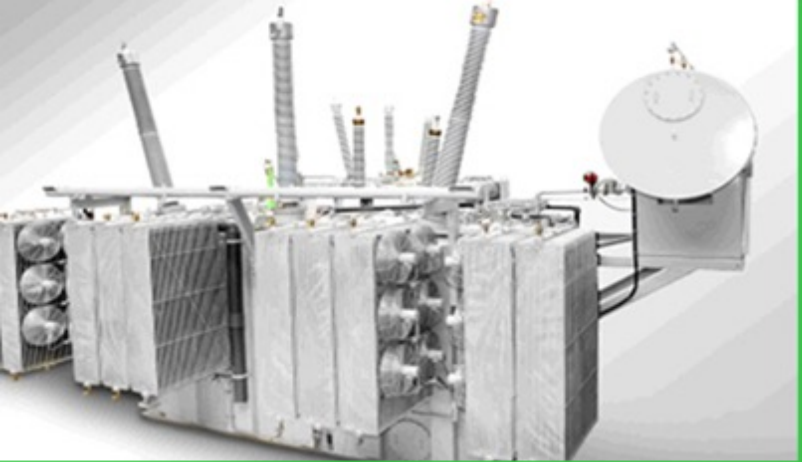
- Understanding the unity circle and the mathematical relationship between P, S, and Q will help understanding 4 quadrant metering

Power Factor Calculations

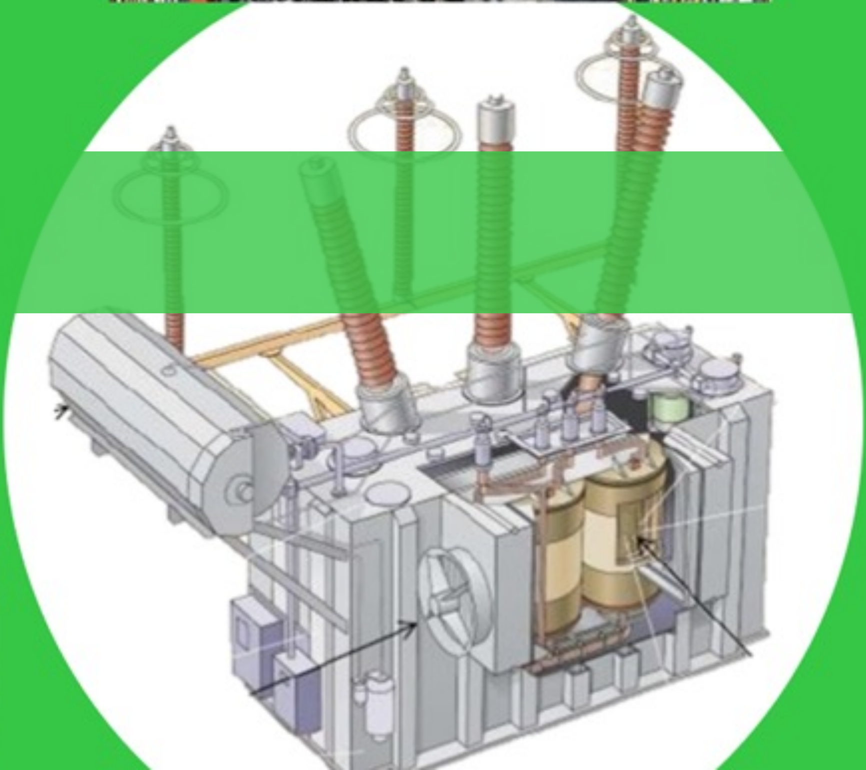


$$PF = \frac{Active\ Power\ (W)}{Apparent\ Power\ (VA)}$$

- Calculation to PF is straight forward, but there are 2 common sign conventions for PF
- IEC: Positive Active Power is Positive PF
- IEEE: Leading PF is positive, and Lagging is negative



Sources of Reactance



Source of Reactance

- Most AC loads have some amount of inductance
- Transformers are essentially large inductors and major sources of inductive reactance
- Cap banks are large capacitors used to offset inductive reactance on the system
- Base load power plants like coal, natural gas, and nuclear have good control on power factor output
- Transmission lines also have impedance that is directly proportional to the length of the line
- Power lines also have some capacitance between earth ground. A capacitor is essentially 2 electrical plates with a dielectric between them, like air.

Power Lines

- Any powerline of enough length will generate losses
- Longer lines will have greater losses, and see voltage drop
- Can calculate impedance from cross sectional area of cable, number of cable, and length

Transformers

- Power transformers used to step and step down voltage have core and wiring losses associated with them
- A power transformer is basically a large inductor and most of the losses are lost as heat and represented as VARs
- Transformer losses can be found on the manufacturers test report

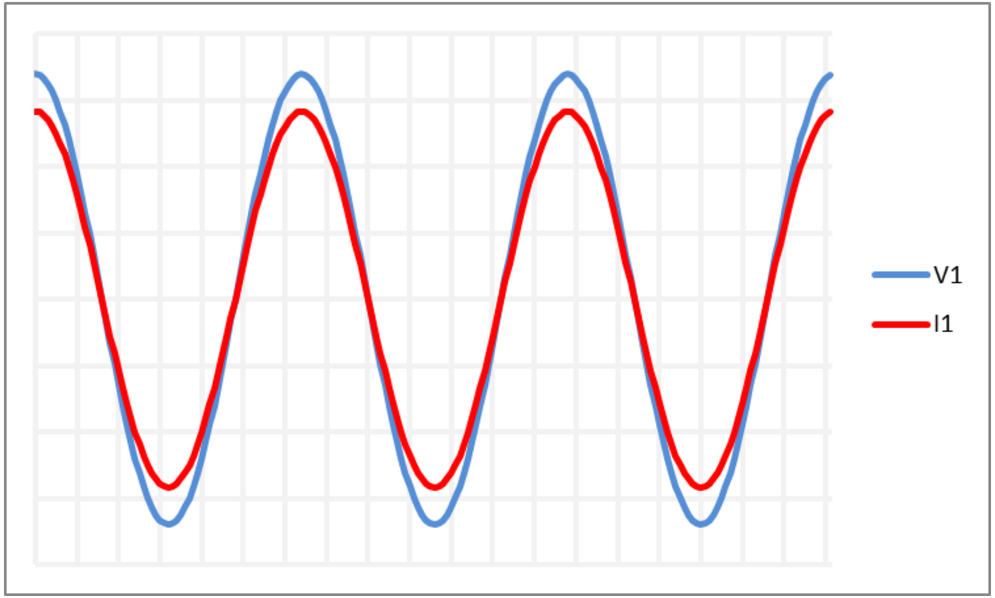
Capacitor Banks

- Capacitor banks are used for VAR correction and voltage optimization
- They're basically large caps, and are rated in VARs at system frequency
- They do consume a small amount of active power as well

Customer Loads

- Customer loads will vary from residential to commercial and industrial loads
- PF may vary from 85% up to 95%+
- Most agreements with large customers have minimum PF requirements
- Customers are only billed on Watts, so poor PF is essentially lost revenue

IDENTIFYING POWER FROM VOLTAGE AND CURRENT SIGNALS



- What can you tell me about these signals and their power measurements-

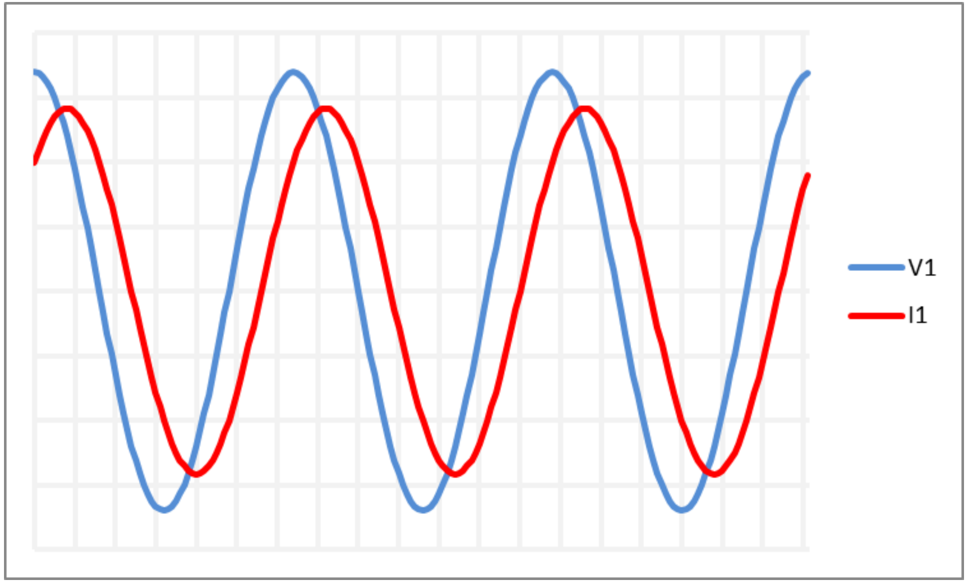
  P = S

  Q = 0

  PF = 100% or Unity

  Delivered Watts

Identifying Power from Voltage and Current Signals



- What can you tell me about these signals and their power measurements-

  Voltage leads Current

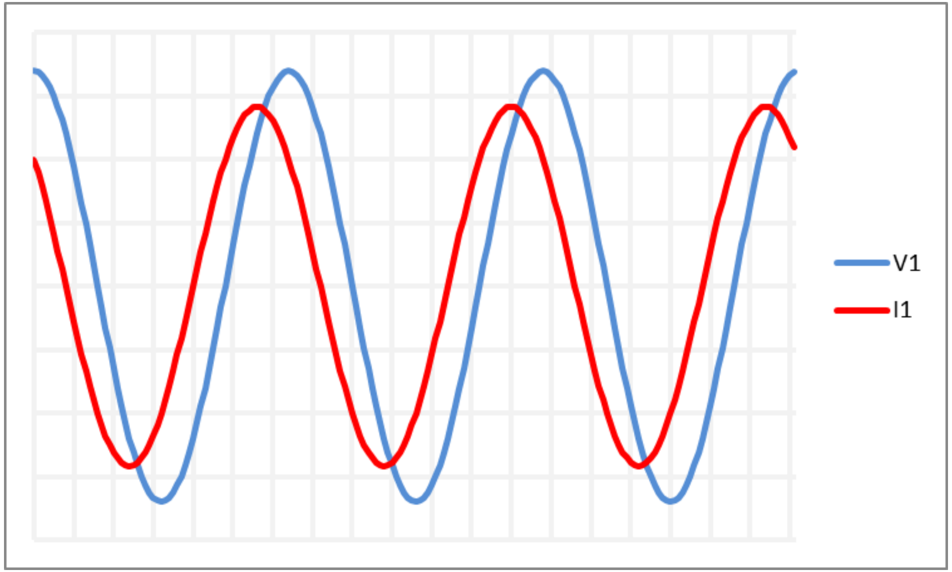
  Inductive Load

  P=Q

  Active Power Delivered

  Reactive Power Delivered

IDENTIFYING POWER FROM VOLTAGE AND CURRENT SIGNALS



- What can you tell me about these signals and their power measurements-

  Voltage lags Current

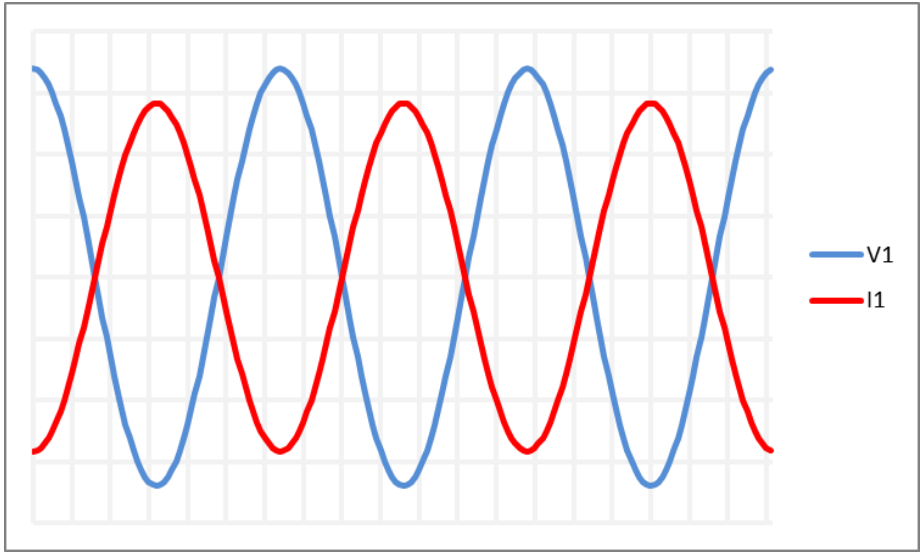
  Capacitive Load

  P=Q

  Active Power Delivered

  Reactive Power Received

Identifying Power from Voltage and Current Signals



- What can you tell me about these signals and their power measurements-

  Current and voltage are 180 degrees apart

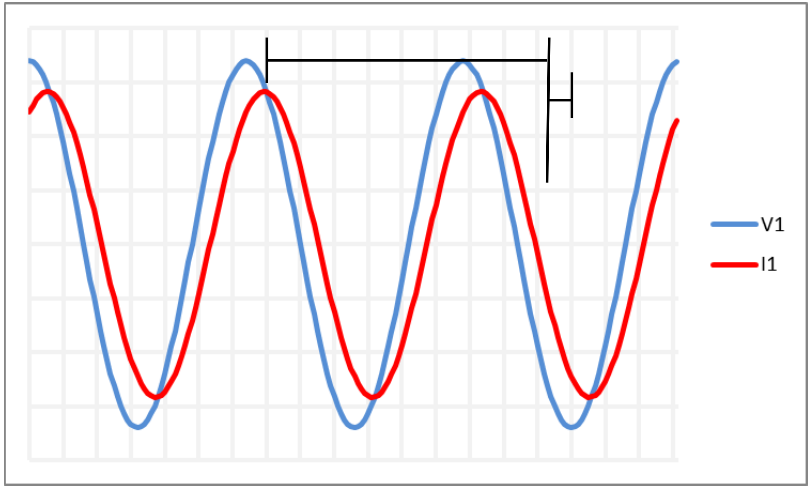
  P = S

  Q = 0

  PF = -100% or Unity

  Received Watts, -P

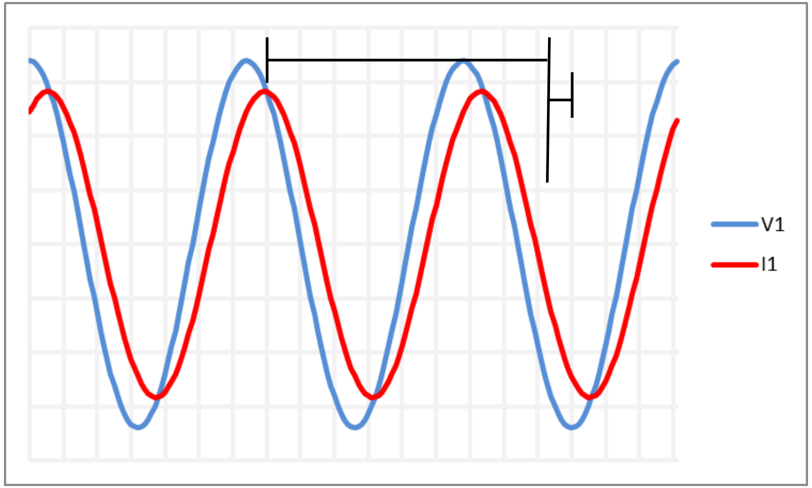
How to Measure Phase Shift



- Distance from Peak to Peak = 1 cycle
- Our electric grid is 60 Hz, or 60 cycles/sec
- 1 cycle/period = 16.6 ms
- V1 peak to I1 peak is phase difference between signals; 1.389 ms
- Voltage leads current tells us this is an inductive circuit
- The phase angle difference between the two signals is-

$$\mathrm{PS} = 360 * \mathrm{td}/\mathrm{p}$$

How to Measure Phase Shift



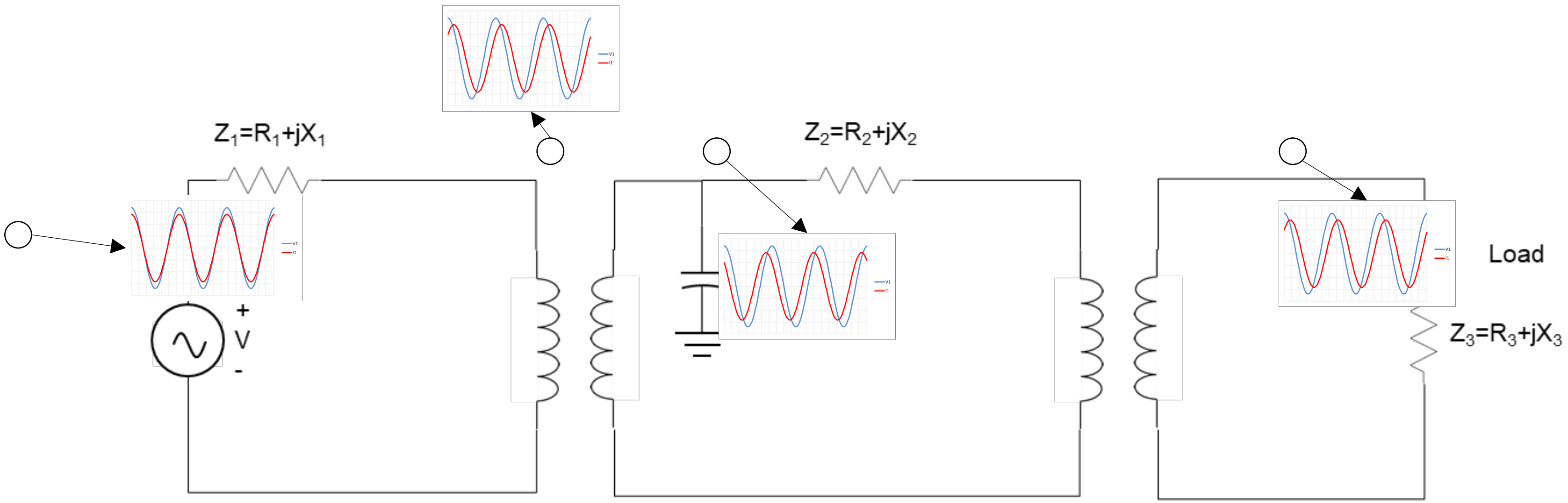
$$PS = 360 * td/p$$

- PS is the phase shift in degrees
- td is time difference
- p is period or length of 1 cycle
- td and p need to use the same measurement, like seconds or milli-seconds
- PS = 360 * (1.389/16.67)

  = 30 degrees

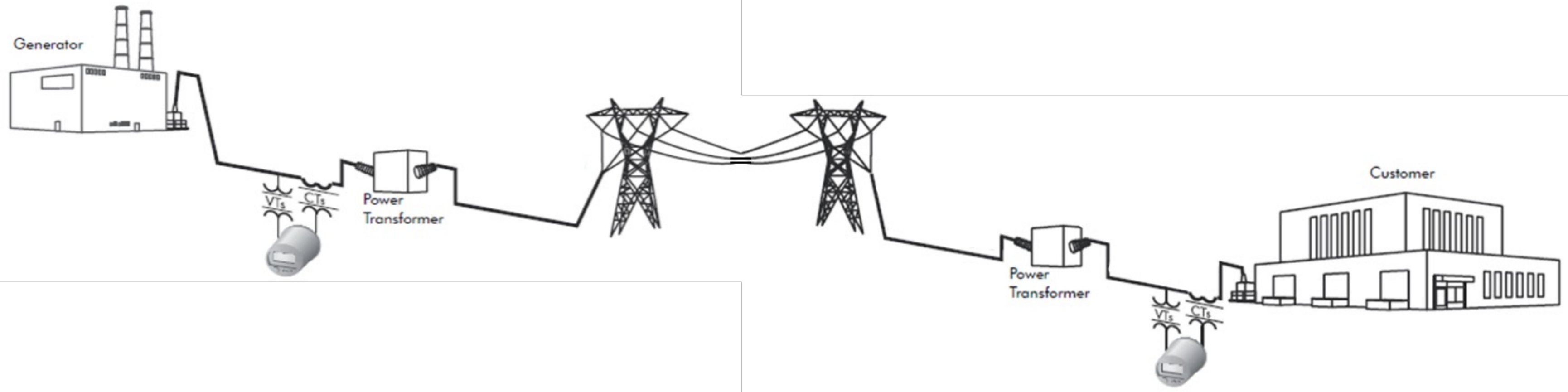
System Overview

Circuit Analysis Point of View

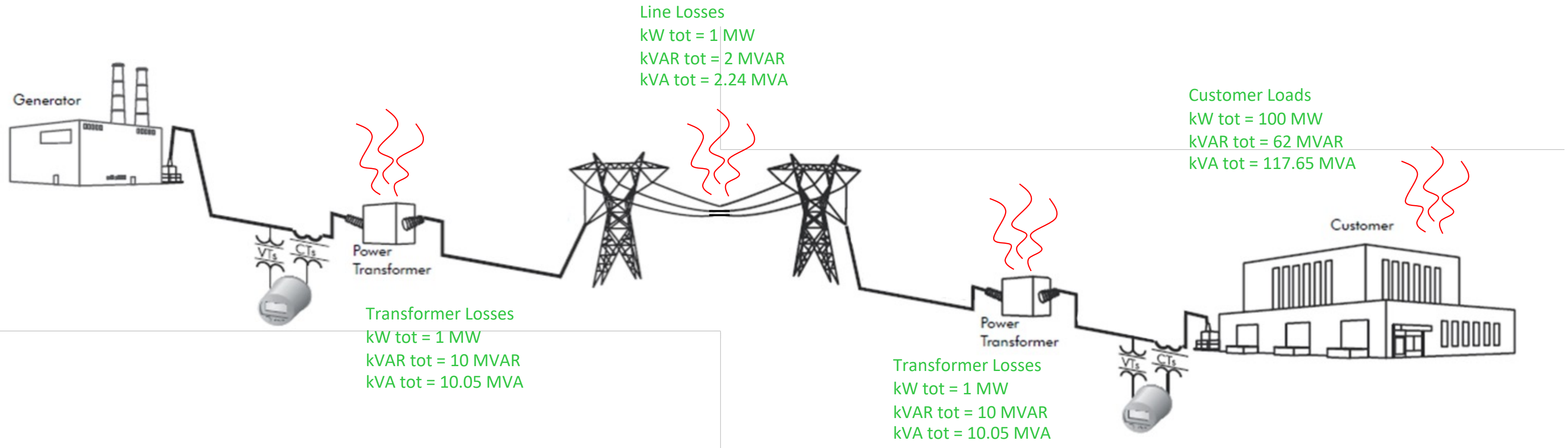


System Overview

Could look something like this



System Overview



This example doesn’t reflect an actual study

MVA demand from all the loads is 140 MVA

Only 103 MW is billed

VARs are a result of reactive loads on the system that are dispersed as heat

METERING W, VAR, VA

Calculating Power

- So far, we've primarily looked at AC power by looking at waveshapes and sampled values
- Power meters analyze these values, and calculate the RMS values for each input
  - In previous formulas I've used RMS values in the power formulas
- Meters can provide high speed RMS values; updates several times a second down to half-cycle RMS values
- Many meters update once a second and provide RMS and fundamental values;
  - RMS values include distortion; sampling rate affects how much distortion is captured
  - Fundamental values only account for the 60 Hz signal

RMS Values

Root Mean Square of Data Points

- RMS refers to the root of the average of the squares for a set a data
- For our purposes these are the sampled values.
- To the right is an example set for a signal that samples at 8 samples/cycle

V1
169.71
120.00
0.00
-120.00
-169.71
-120.00
0.00
120.00

RMS Values

Root Mean Square of Data Points

- RMS refers to the root of the average of the squares for a set a data
- For our purposes these are the sampled values.
- To the right is an example set for a signal that samples at 8 samples/cycle
- First Step is to square all the sampled values

	V1	V1	Square
	169.71	169.71	28800.00
	120.00	120.00	14400.00
	0.00	0.00	0.00
	-120.00	-120.00	14400.00
	-169.71	-169.71	28800.00
	-120.00	-120.00	14400.00
	0.00	0.00	0.00
	120.00	120.00	14400.00

RMS Values

Root Mean Square of Data Points

- RMS refers to the root of the average of the squares for a set a data
- For our purposes these are the sampled values.
- To the right is an example set for a signal that samples at 8 samples/cycle
- First Step is to square all the sampled values
- Then, calculate the average of the squares

	V1	V1	Square	Square	Mean
	169.71	169.71	28800.00	28800.00	14400.00
	120.00	120.00	14400.00	14400.00	
	0.00	0.00	0.00	0.00	
	-120.00	-120.00	14400.00	14400.00	
	-169.71	-169.71	28800.00	28800.00	
	-120.00	-120.00	14400.00	14400.00	
	0.00	0.00	0.00	0.00	
	120.00	120.00	14400.00	14400.00	

RMS VALUES

Root Mean Square of Data Points

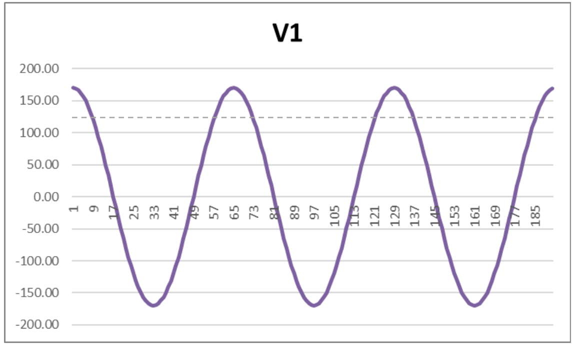
- RMS refers to the root of the average of the squares for a set a data
- For our purposes these are the sampled values.
- To the right is an example set for a signal that samples at 8 samples/cycle
- First Step is to square all the sampled values
- Then, calculate the average of the squares
- Finally, calculate the square root of the average, of the squares

V1	Square	Mean	Root
169.71	28800.00	14400.00	120
120.00	14400.00		
0.00	0.00		
-120.00	14400.00		
-169.71	28800.00		
-120.00	14400.00		
0.00	0.00		
120.00	14400.00		

RMS Values

Root Mean Square of Data Points

- RMS refers to the root of the average of the squares for a set a data
- For our purposes these are the sampled values.
- To the right is an example set for a signal that samples at 8 samples/cycle
- First Step is to square all the sampled values
- Then, calculate the average of the squares
- Finally, calculate the square root of the average, of the squares
- More simply, the RMS value can be calculated by taking the peak and dividing by the square root of 2.
- RMS is also the equivalent DC voltage level



$$V_{RMS} = \frac{V_{PEAK}}{\sqrt{2}} = \frac{169.71}{\sqrt{2}} = 120\ V$$

3-Phase Power Calculations

Root Mean Square of Data Points

- Calculations for 3 element connected meters

$$3\ Phase\ Active\ Power\ (Watts) = V_{A_{rms}} \times I_{A_{rms}} \times \cos(\emptyset_{V_A} + \emptyset_{I_A}) + V_{B_{rms}} \times I_{B_{rms}} \times \cos(\emptyset_{V_B} + \emptyset_{I_B}) + V_{C_{rms}} \times I_{C_{rms}} \times \cos(\emptyset_{V_C} + \emptyset_{I_C})$$

$$3\ Phase\ Active\ Power\ (VARs) = V_{A_{rms}} \times I_{A_{rms}} \times \sin(\emptyset_{V_A} + \emptyset_{I_A}) + V_{B_{rms}} \times I_{B_{rms}} \times \sin(\emptyset_{V_B} + \emptyset_{I_B}) + V_{C_{rms}} \times I_{C_{rms}} \times \sin(\emptyset_{V_C} + \emptyset_{I_C})$$

$$3\ Phase\ Active\ Power\ (VAs) = V_{A_{rms}} \times I_{A_{rms}} + V_{B_{rms}} \times I_{B_{rms}} + V_{C_{rms}} \times I_{C_{rms}}$$

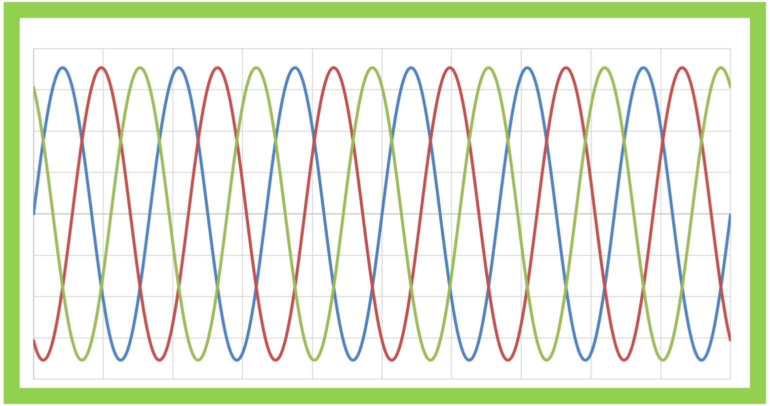
- Calculations for 2 element connected meters

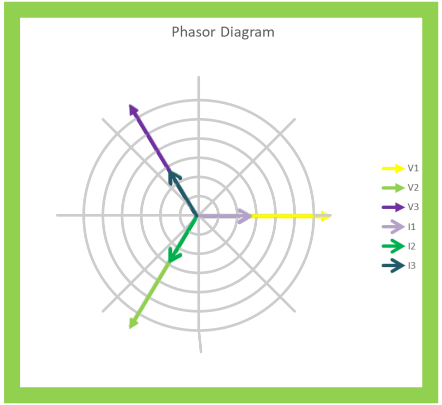
$$3\ Phase\ Active\ Power\ (Watts) = V_{AB_{rms}} \times I_{A_{rms}} \times \cos(\emptyset_{V_{AB}} + \emptyset_{I_A}) + V_{BC_{rms}} \times I_{B_{rms}} \times \cos(\emptyset_{V_{BC}} + \emptyset_{I_B})$$

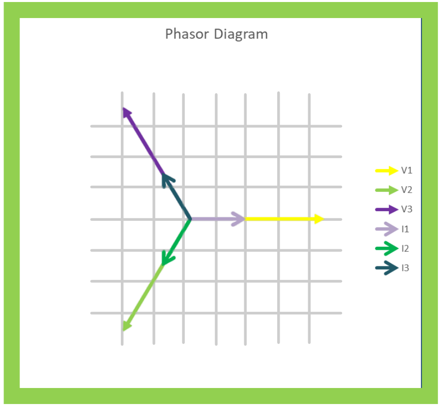
$$3\ Phase\ Active\ Power\ (VARs) = V_{AB_{rms}} \times I_{AB_{rms}} \times \sin(\emptyset_{V_{AB}} + \emptyset_{I_A}) + V_{BC_{rms}} \times I_{B_{rms}} \times \sin(\emptyset_{V_{BC}} + \emptyset_{I_B})$$

$$3\ Phase\ Active\ Power\ (VAs) = V_{AB_{rms}} \times I_{A_{rms}} + V_{BC_{rms}} \times I_{B_{rms}}$$

Complex Calculations







$$C = A * \sin(2\pi f t + \theta)$$

- The waveshape form is:
  - A indicates the peak magnitude of the signal
  - 2Ωf is the angular frequency
  - t represents time, usually reference to 0
  - θ indicates displacement to reference signal in radians

$$C = Z\angle\theta$$

- The polar form is:
  - Z indicates magnitude only
  - The phase angle (θ) is measured counterclockwise from the positive real axis

$$C = X + jY$$

- The rectangular form is:
  - X indicates the real axis
  - jY indicates the imaginary axis

COMPLEX VALUES

- The previous 3 calculations are all used to calculate correlated values for voltage and current signals
- Samples values are used to calculate RMS and phase angle values used in polar coordinates
- Polar coordinate and rectangular coordinates represent the same values, but in different forms
  - Polar coordinates are ideal for comparing the phasor relationship between voltage and current elements
  - Rectangular coordinates are helpful for applying complex math to phasor values
- Complex Math
  - You can multiply and divide polar coordinate, but cannon add and subtract
  - You can add and subtract rectangular values for Net calculations

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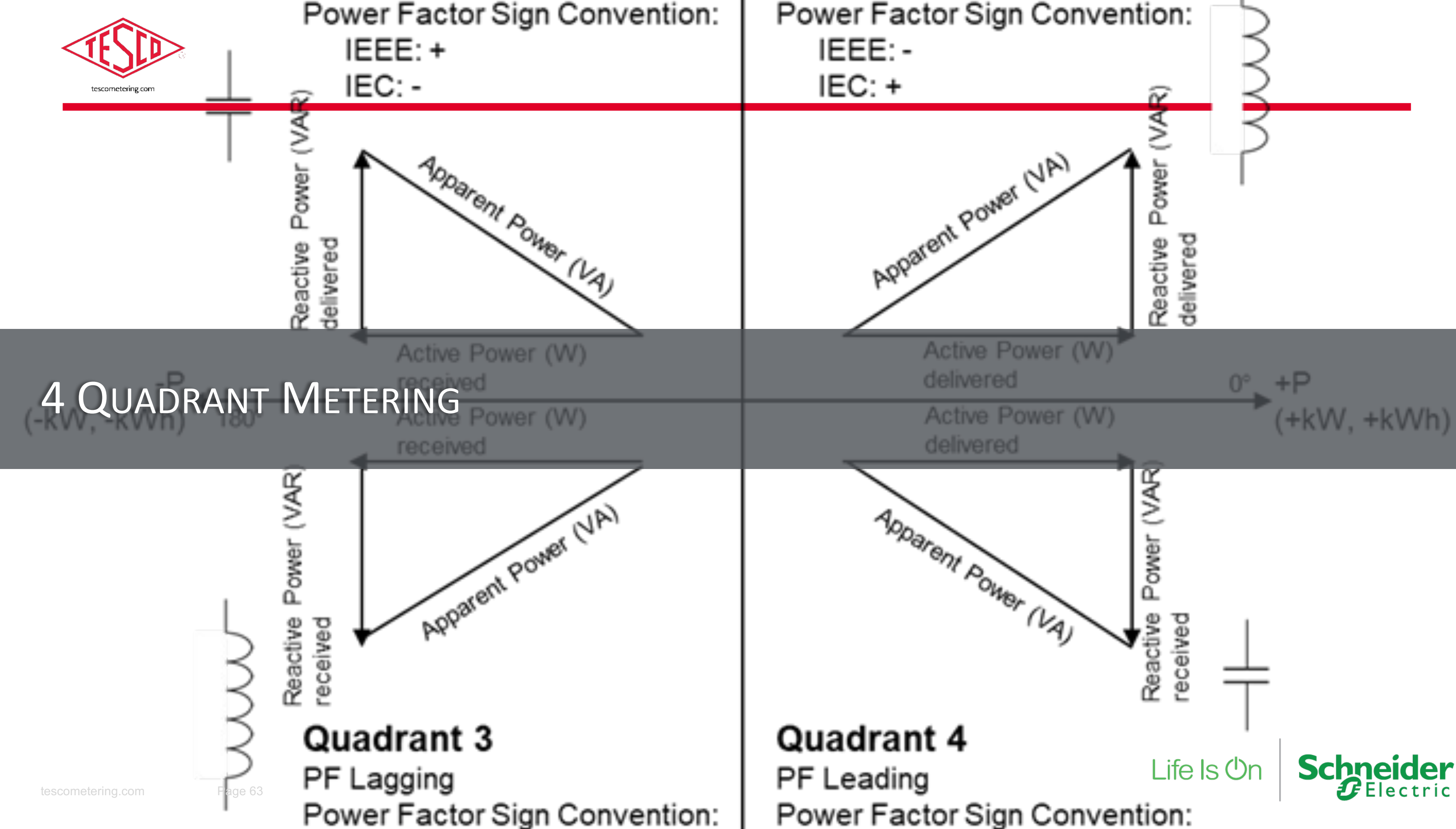
Energy Meter Quantities

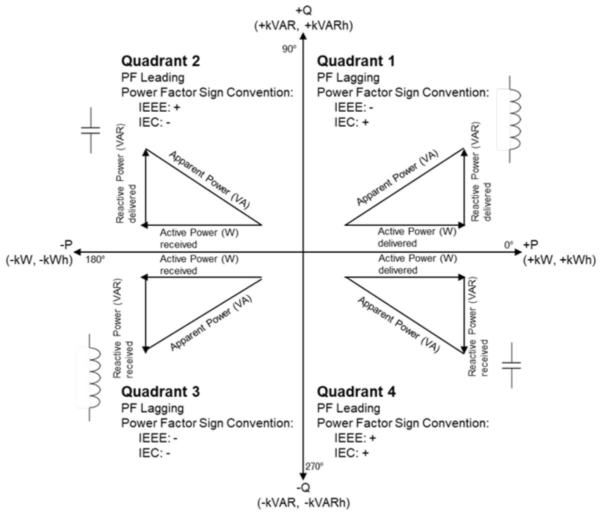
- Meters today provide real time outputs for;
  - Active Power & Energy
  - Reactive Power & Energy
  - Volt-Amp Power & Energy
  - Per phase values for volts, amps, and power
  - 4 quadrant, bi-directional metering
  - And more…!
- Data can be collected real time utilizing SCADA, or through data recorders connected to a billing system like MV90

4 Quadrant Metering



4 Metering Quadrants

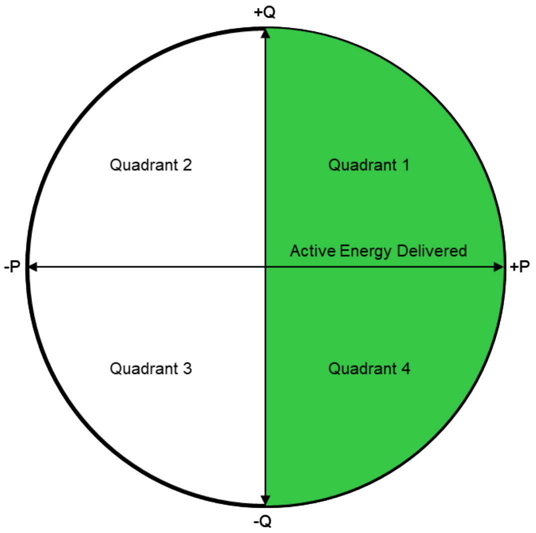
- Power can be broken into 4 quadrants based on direction of active power and reactive power
  - +P and +Q is upper right – Quadrant 1
  - -P and +Q is upper left – Quadrant 2
  - -P and -Q is lower left – Quadrant 3
  - +P and -Q is lower right – Quadrant 4



Power Circle

Quadrant or Quantity

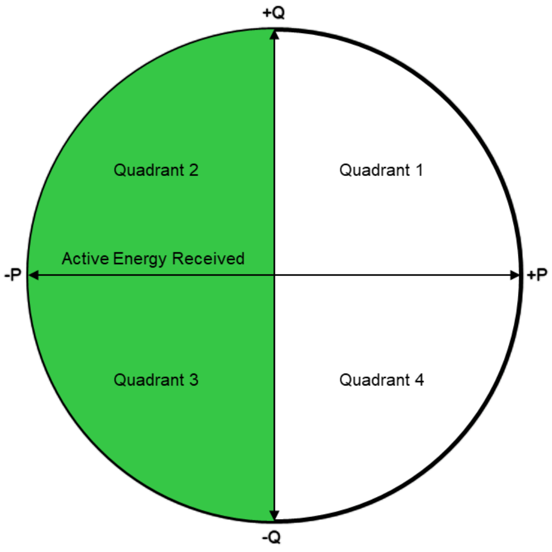
- Active energy delivered is Q1+Q4



Power Circle

Quadrant or Quantity

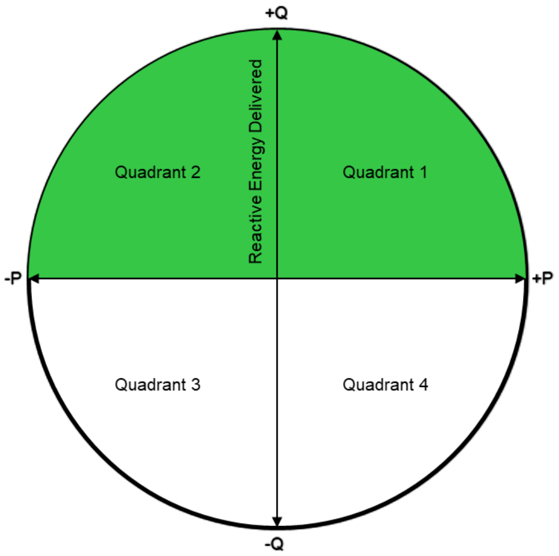
- Active energy delivered is Q1+Q4
- Active energy received is Q2+Q3



Power Circle

Quadrant or Quantity

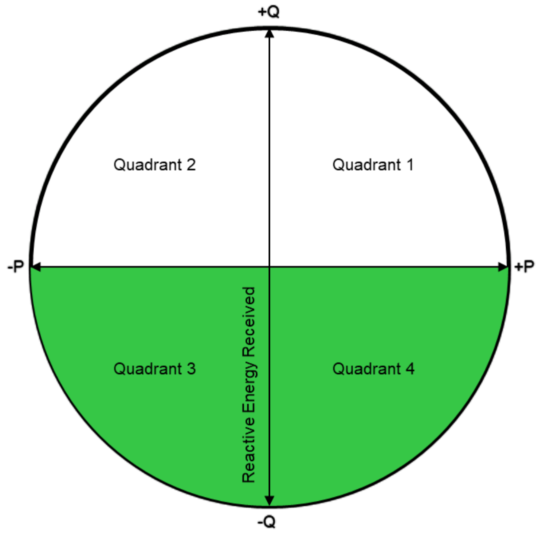
- Active energy delivered is Q1+Q4
- Active energy received is Q2+Q3
- Reactive energy delivered is Q1+Q2



POWER CIRCLE

Quadrant or Quantity

- Active energy delivered is Q1+Q4
- Active energy received is Q2+Q3
- Reactive energy delivered is Q1+Q2
- Reactive energy received is Q3+Q4



4 Quadrant Metering

- Most customer loads will fall into Quadrant 1, from utility perspective
  - Active power is delivered to customer
  - Most customers will have an inductive impedance which will have reactive power delivered
  - Customers with PF correction may have near unity or reactive power received
- Bi-directional meters will primarily fall into Q1 and Q3
  - Active power delivered and reactive power delivered
  - Active power received and reactive power received
- Loads in Q2 and Q4 has greater capacitive reactance than inductive, most likely due to PF correction devices
- Some generators can output power in Q4 to compensate for low system PF

4 Quadrant Metering Recorders

- Configuration 1 captures all active and reactive energy
- Configuration 2 captures all active energy, and only reactive energy in inductive quadrants
- Configuration 3 captures all active and reactive energy, but splits out reactive energy into quadrants

- Preference depends on what power factor correction a customer uses and how to capture it

Channel 1: kWh del
Channel 2: kWh rec
Channel 3: kVARh del
Channel 4: kVARh rec

Configuration 1

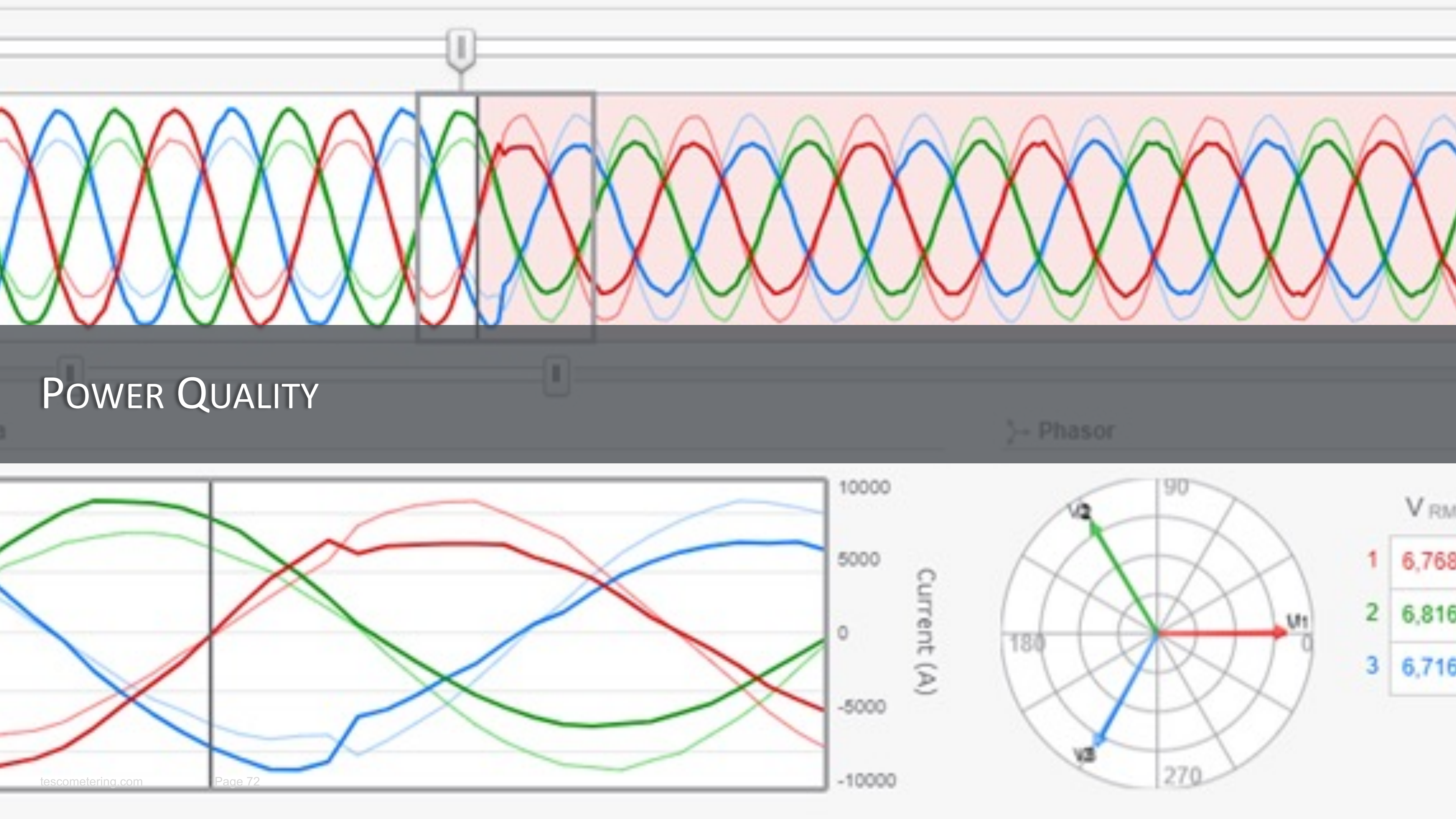
Channel 1: kWh del
Channel 2: kWh rec
Channel 3: kVARh Q1
Channel 4: kVARh Q3

Configuration 2

Channel 1: kWh del
Channel 2: kWh rec
Channel 3: kVARh Q1
Channel 4: kVARh Q2
Channel 5: kVARh Q3
Channel 6: kVARh Q4

Configuration 3

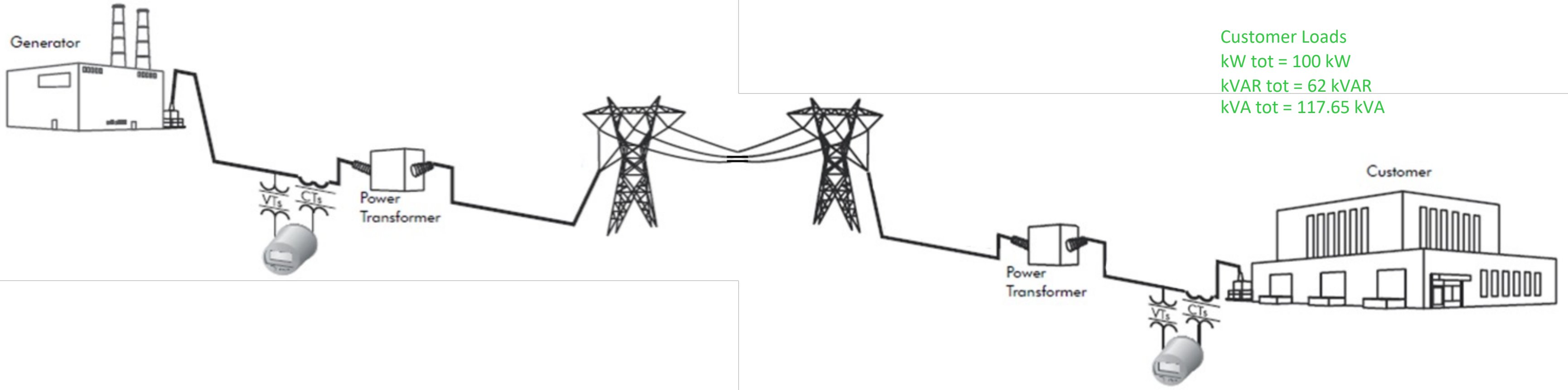
Power Quality



PF and Voltage Loss

- We'll focus on Power Factor and Voltage Loss
  - Poor PF can increase demand on the system that can't be recovered
  - Lines with significant impedance will see voltage loss over long distances
- Corrective devices
  - Cap Banks
  - Voltage Regulators and Transformer Tap Settings
  - Generator and inverter reactive power setpoints
  - Static Var Compensators
- VVO Software

PF Example



This customer is at 85% PF, and is only billed active energy

Let's assume $0.10 kWh.

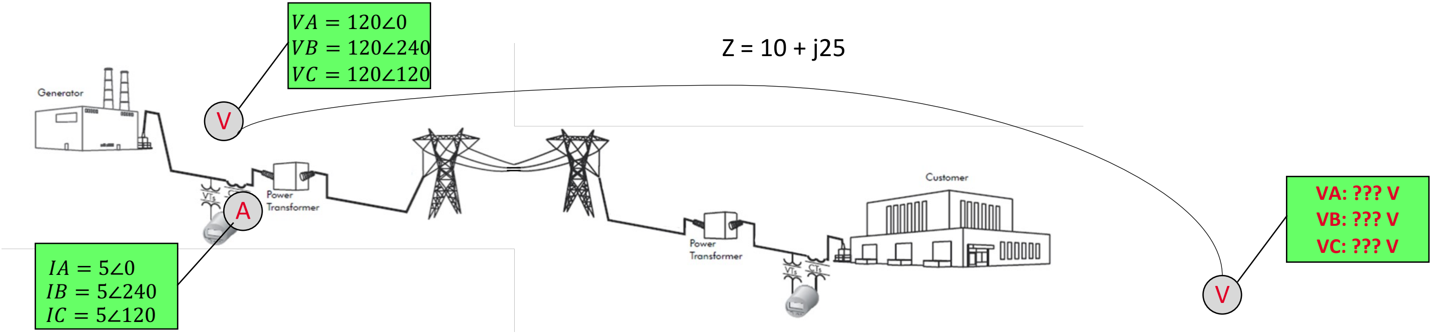
- Usage bill at 85% PF would be ~$7.2k
- If PF could be increased to 90% PF for month usage bill ~$7.6k

That's roughly $400 a month or $5k a year

For MW customers the cost will scale by that much!

If you have 100 similar customers that could be $500k a year

VOLTAGE LOSS EXAMPLE



VA Demand at Generator would be 1800 VA (secondary)

Accounting for power losses ($I^2 * Z$) across system using supplied impedance. VA at customer is 1671.

Current remaining constant, calculate V to be-

VA 111 V
VB 111 V
VC 111 V

VVO Devices

CAPACITOR BANKS

- Capacitor banks are used for VAR correction and voltage optimization
- They're basically large caps, and are rated in VARs at system frequency
- They do consume a small amount of active power as well

VOLTAGE REGULATOR AND TRANSFORMER TAP SETTINGS

- A power distribution voltage regulator is an auto transformer that can step-up or step-down voltage to provide consistent system voltage levels. A voltage regulator control senses system voltage and commands the tap changer to operate when voltage changes are needed.
- This can be done with power transformers with multiple tap settings to accomplish the same goal

GENERATOR CONTROL

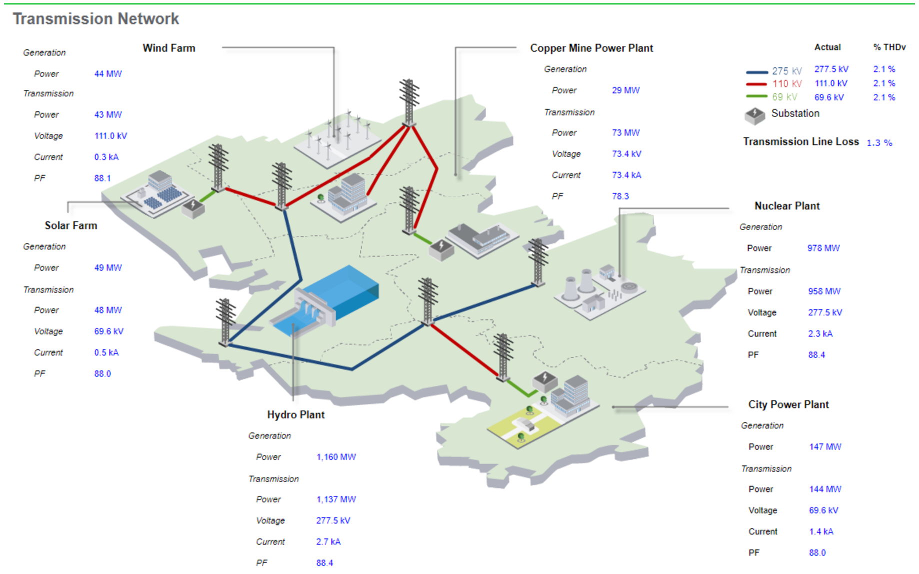
- Generators are capable of operating at leading power factors, but will reduce kVA output
- Reactive capability curve provides kVA and kVAR capability at different setpoints
- Synchronous generators can be setup as a synchronous condenser to pull VARs off the system

STATIC VAR COMPENSATOR

- A static VAR compensator (SVC) is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks
- The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:
- Connected to the power system, to regulate the transmission voltage ("transmission SVC")
- Connected near large industrial loads, to improve power quality ("industrial SVC")

Volt/VAR Optimization Software

- Volt/VAR Optimization (VVO) optimally manages system-wide voltage levels and reactive power flow to achieve efficient distribution grid operation.
- VVO assists distribution operators reduce system losses, peak demand or energy consumption using Conservation Voltage Reduction (CVR) techniques.



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