Four Quadrant Metering

Prepared by Tom Lawton, TESCO

For Mississippi Meter School
Thursday, October 24, 2019

Concepts to be Discussed

- What does four Quadrant metering mean?
- When am I interested in four quadrant metering?
- How is this information used if not for billing?
- How will I use this as a meter tech/engineer?
- Why will this be important in the future?

Four Quadrant Metering

Four quadrant metering can be used to understand individually or collectively;

- Real Power consumed by the end user
- Apparent Power delivered by the Utility
- Real Power delivered to the utility by an end user's generation source
- Apparent Power generated by the end user's generation source

Having these measurements allows for the calculation of Reactive Power, VA and VARS as well as providing kWh for billing purposes.

Power and Energy

There are 3 factors that make up what is called "Power and Energy".

- "Apparent" Power and Energy
- "Real" Power and Energy
- "Reactive" Power and Energy

Real Power

- The practical unit of active power which is defined as the rate at which energy is delivered to a circuit. Sometimes called Watts or Power. Also known as potential/available power.

Apparent Power

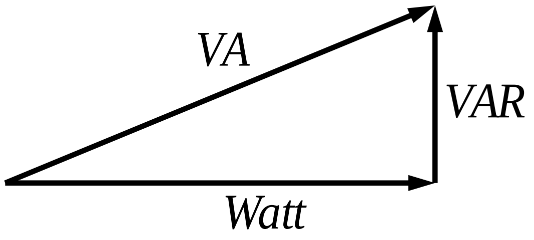
- The product of the volts and the total current which flows because of the voltage. Sometimes called volt-amperes

Reactive Power

- The out-of-phase component of the total volt-amperes in a circuit which includes inductive or capacitive reactance. Sometimes called reactive volt-amperes or vars.

Reactive Metering – Definitions

Review of the Power Triangle



$$VA_V = \sqrt{W^2 + VAR^2}$$

Real Power	Working Power (Performs work) Measured in **Watts**
Apparent Power	Power supplied by the utility (The full effort) Measured in **VA**
Reactive Power	Magnetizing Power (Performs no work, imaginary) Measured in **Vars**

Power factor of Beer…..

Pour yourself a beer

- The amount of beer we will call kW. You can drink the beer, therefore it is useful.
- The amount of foam is kVAR. You can't drink the foam, therefore it isn't useful.
- The total amount in the glass is kVA. You need a glass sized for both the beer and the foam.

Look at the two examples on the left.

- Good power factor, low foam or kVAR.
- Bad power factor, high foam or KVAR.

Energy Components

- Voltage associated with Current produces Power applied over Time is Energy: Volts (V) X Amps (A) X Time (H) = Energy (**VAH**)

- Volts (V) X Working Current (A) X Time (H) = **Real** Energy
  - **kWh**- Does Real Work, this is typically customer billing register.
  - 240v x 48 amps x 3 hours = 34.56 kilowatt hours (kWh)

- Volts (V) X Total Current (A) X Time (H) = **Apparent** Energy
  - **VAh** - Supplied by Utilities.
  - 240v x 48 amps/0.95 PF x 3 hours = 36.38 VAh

- Volts (V) X Reactive Current (A) X Time (H) = **Reactive** Energy
  - **VARh** - Magnetizing Energy, system loss.
  - 240v x 48 amps x .05 x 3 hours = 1.82 VARh
  - 36.38 kWh – 34.56 kWh = 1.82 VARh

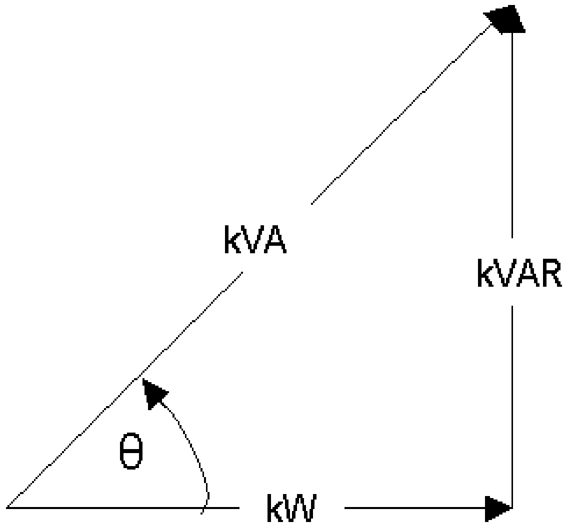
Reactive Metering – Definitions

What is your Power Factor?

- Defined to be active power divided by apparent power
- Watts divided by volt-amperes
- KW/KVA (11.52 kW/12.13 kVA = .95 PF)
- Measure of power system delivery/consumption efficiency

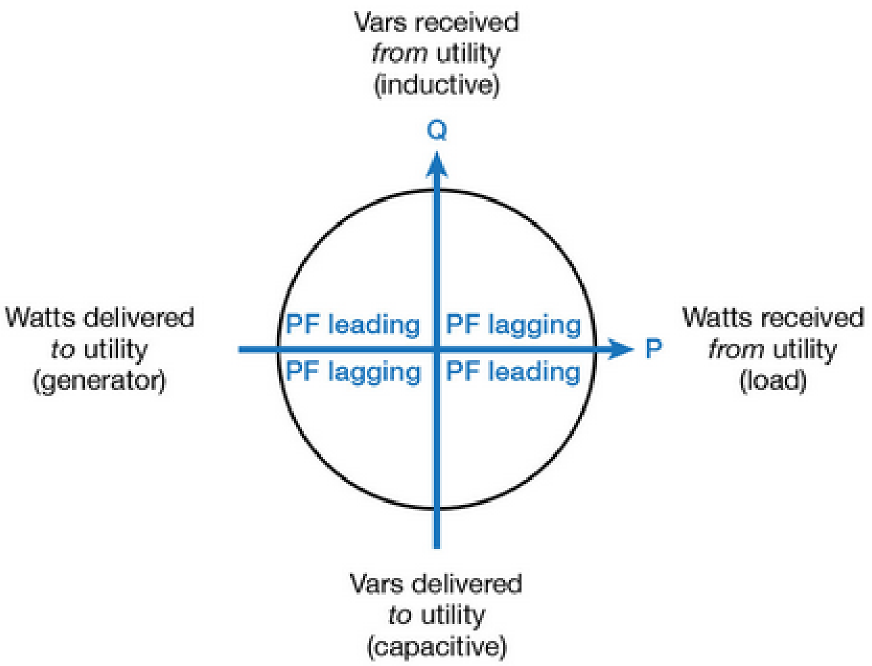
$PF = COS\theta$ where θ is the angle as shown:

So…



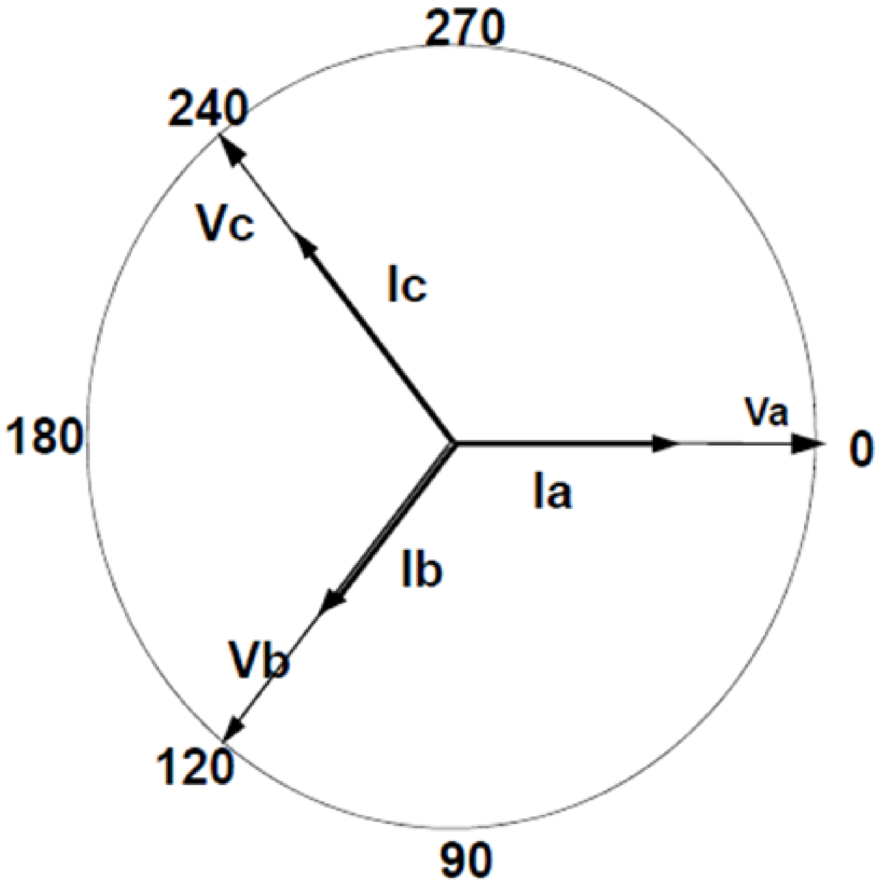
Leading and Lagging PF

- Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle.
- Capacitive loads are leading (current leads voltage)
- Inductive loads are lagging (current lags voltage).



THE EASTERN SPECIALTY COMPANY

Meter Services 4-Wire Wye



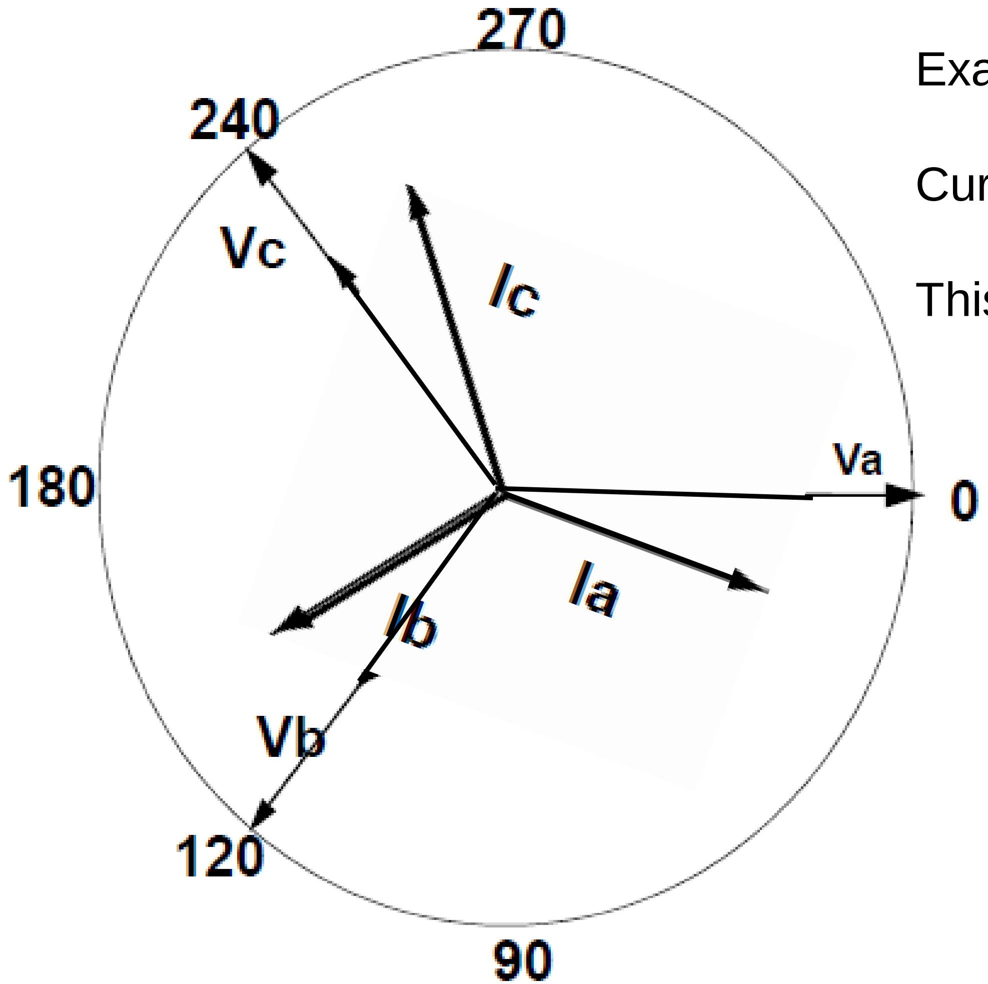
Phasor Diagram for 3-element, 4-wire Wye connected service

Form 9S or 10A

Form 16S or 16A

Form 16K

Inductive Load - Lagging



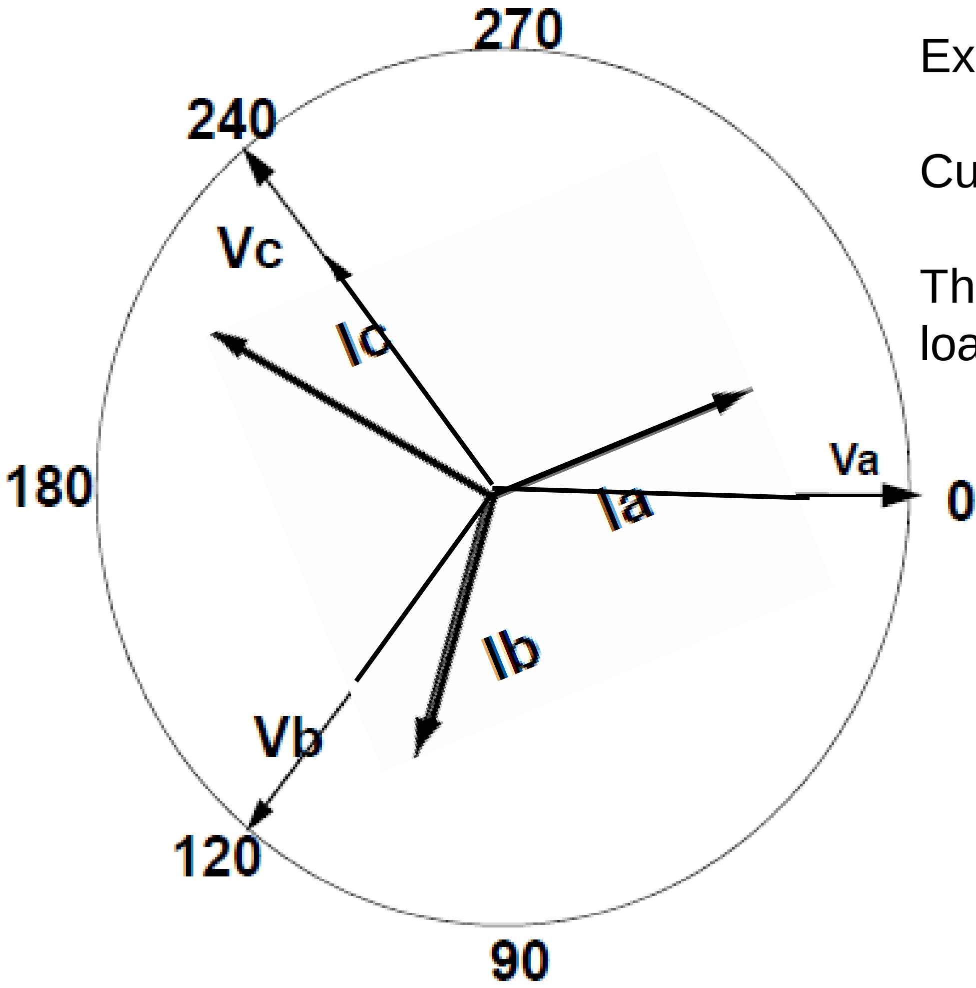
Example of 4 wire wye where:

Current **LAGs** the Voltage

This would be an **Inductive** load

THE EASTERN SPECIALTY COMPANY

Capacitive Load - Leading



Example of 4 wire wye where:

Current **LEADS** the Voltage

This would be an **CAPACITIVE** load

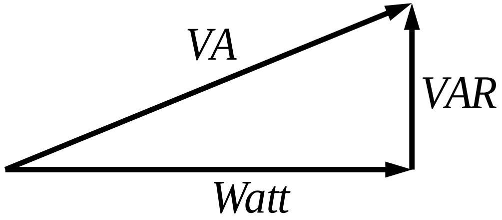
Solid State Metering Technology

Two methods of developing KVA: Vectorial or Arithmetic

Arithmetic

$$VA_{RMS} = V_{RMS} \times I_{RMS}$$

Vectorial
i.e. TDM



KVA 4 Wire 'Y' Unbalanced Loads

- **For an unbalanced Polyphase load is VA_V or VA_{RMS} correct?**
- **Both are correct, they just measure different quantities**.

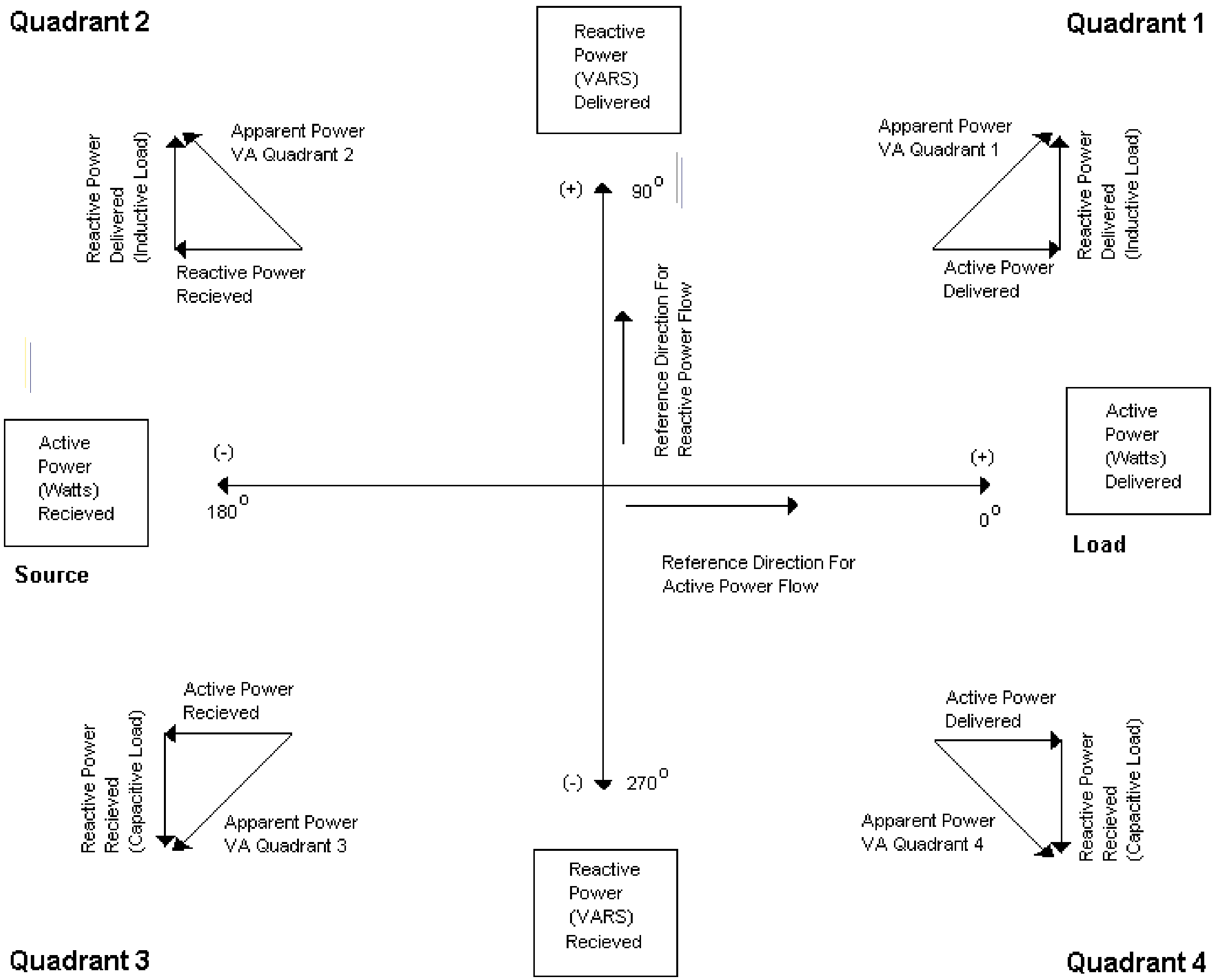
- Vector VA (VA_V)
  - Measures load characteristics, "Load Efficiency"
  - An accurate indicator of load VA
  - The end user controls the load and hence controls VA_V
- Arithmetic VA (VA_{RMS})
  - Measures source characteristics, "Source Efficiency"
  - An accurate indicator of the VA needed to supply the load
  - The utility controls the source used to supply the load hence VA_{RMS}
  - $VA_{RMS} \geq VA_V$

THE EASTERN SPECIALTY COMPANY

KVA Summary

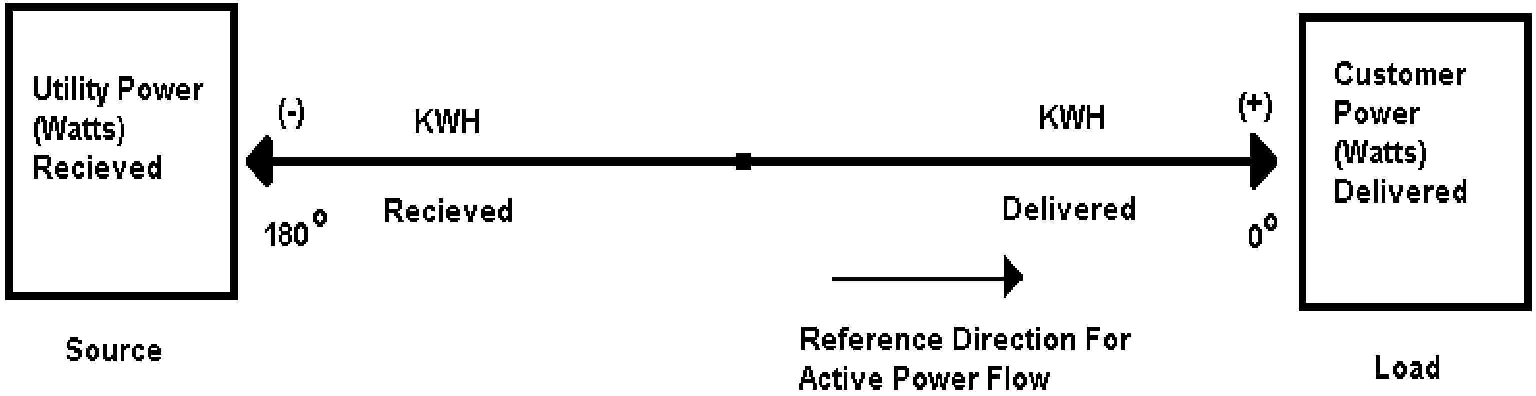
- 2 Wire single phase systems:
  - VA_V and VA_{RMS} yield similar results
- Polyphase systems:
  - VA_V and VA_{RMS} yield similar results for balanced load
  - VA_V and VA_{RMS} yield different results for unbalanced load
- Vector VA (VA_V)
  - Measures load characteristics, “Load Efficiency“
- Arithmetic VA (VA_{RMS})
  - Measures source characteristics, “Source Efficiency”
- Source VA
  - New concept developed by L+G to better measure/calculate the VA required by the Utility to supply the User

4 Quadrant Conventions and Power Flow



THE EASTERN SPECIALTY COMPANY

KWH Power Flow (x) Axis



Active Power (True Power): Watts

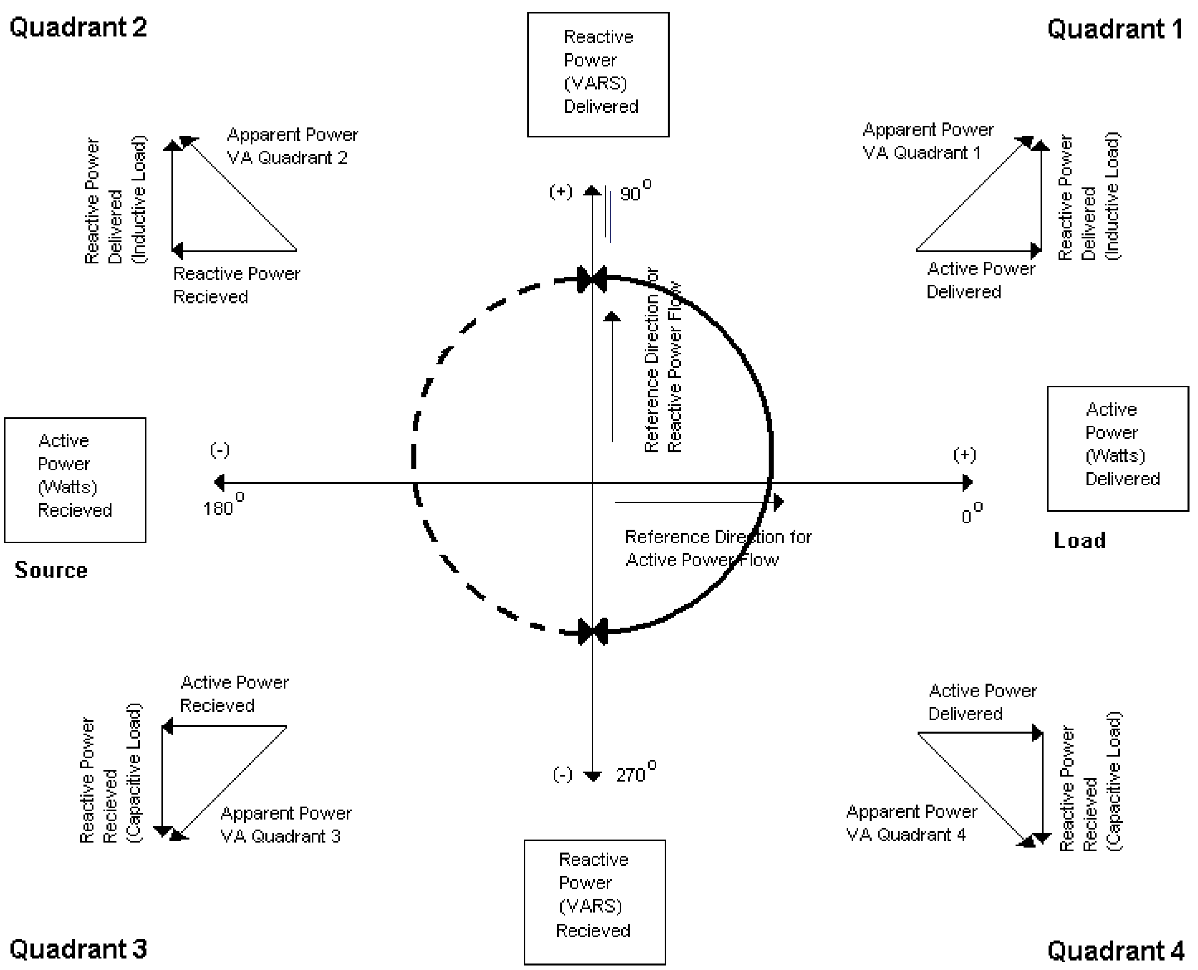
When the Active Power (Watts) flow from the “SOURCE” through the metering point and into the “LOAD” we say the Active Power (Watts) are being DELIVERED. Therefore when the Active Power is being supplied by the “SOURCE” into the load it will be referred to as Delivered Power (Watts) and has a positive sign. **Standard billing determinant's would be Delivered kW/kWh.**

When the Active Power (Watts) flow from the “LOAD” through the metering point and into the “SOURCE” we say the Active Power (Watts) are being RECEIVED. Therefore when the Active Power is being supplied by the “LOAD” into the source it will be referred to as Received Power (Watts) and has a negative sign. **Standard billing determinant's would be Received kW/kWh**.

Terms (Standard from the above illustration):
Delivered Kw/kWh (Q1 + Q4)
Received kW/kWh (Q2 + Q3)

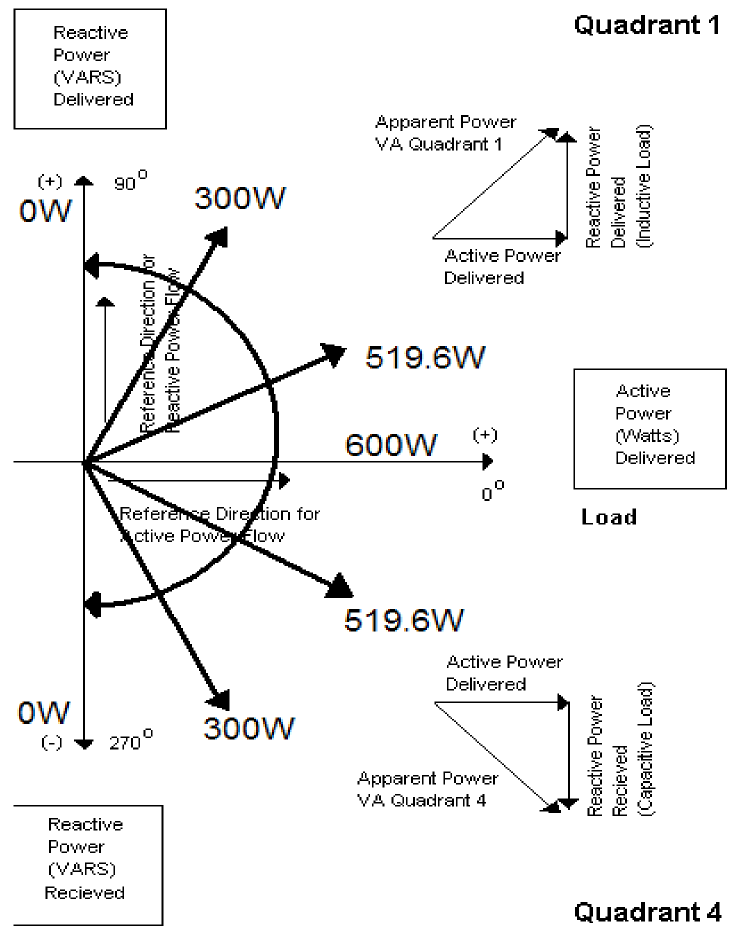
Note: The Active Power is always on the x axis and does not fall into any of the four quadrants. Active power does not lead or lag it is delivered or received.

Quadrant Conventions

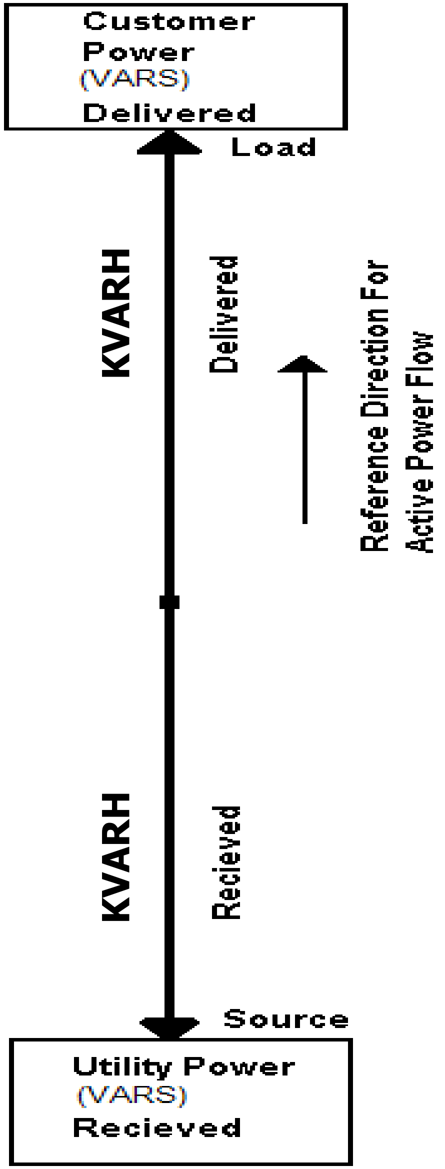


Power Factor Effects

- $E = 120V, I = 5A, PF = 1.0 \angle 0^0$
  $W = E*I*PF(Cos \angle 0^0)$
  $W = 600$
- $E = 120V, I = 5A, PF = .866 \angle 30^0$
  $W = E*I*PF(Cos \angle 30^0)$
  $W = 519.6$
- $E = 120V, I = 5A, PF = .500 \angle 60^0$
  $W = E*I*PF(Cos \angle 60^0)$
  $W = 300$
- $E = 120V, I = 5A, PF = 0 \angle 90^0$
  $W = E*I*PF(Cos \angle 90^0)$
  $W = 0$



KVARH Power Flow (Y Axis)



Reactive Power: Vars

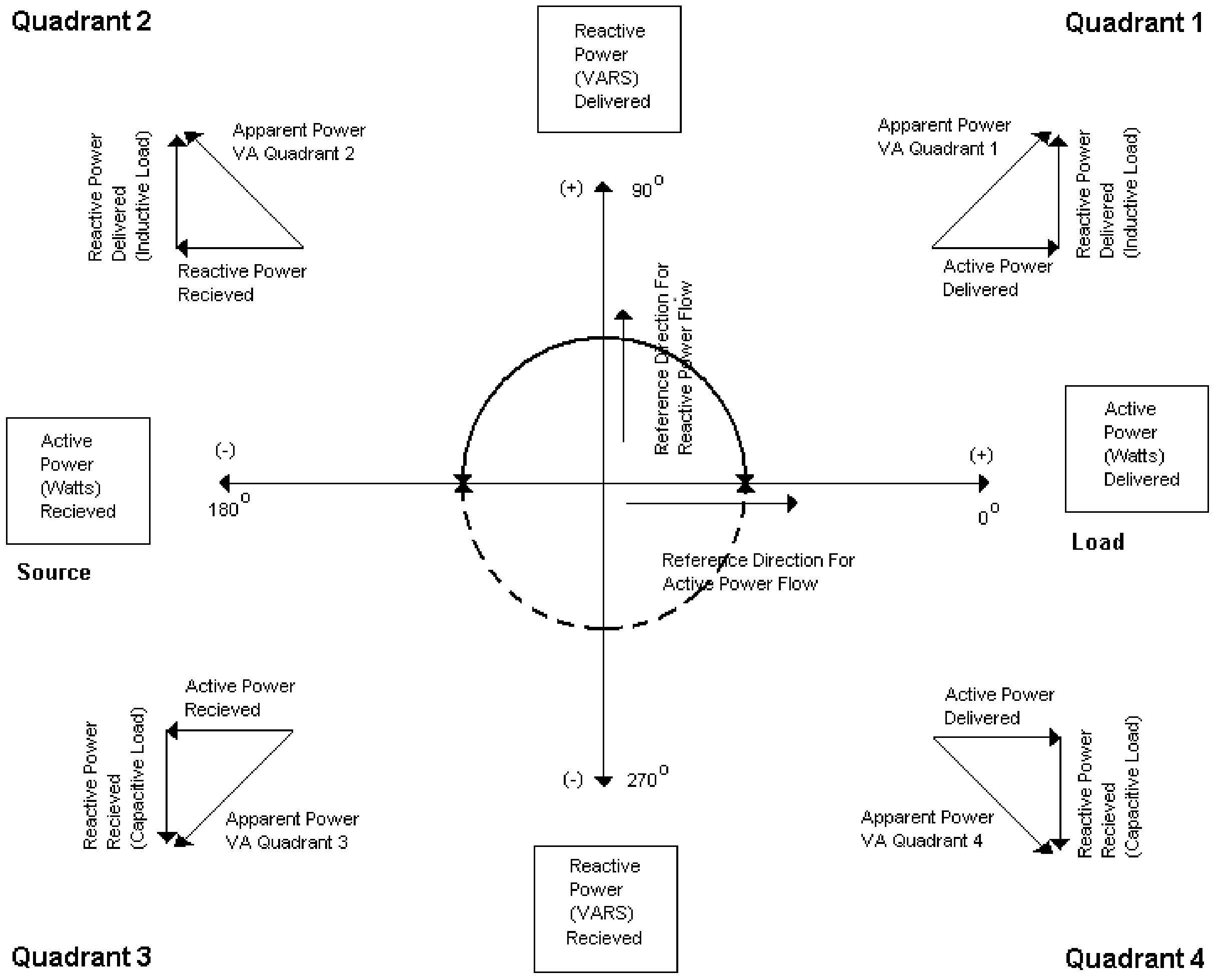
When the Reactive Power (Vars) flow from the “SOURCE” through the metering point and into the “LOAD” we say the Reactive Power (Vars) are being DELIVERED. Therefore when the Reactive Power is being supplied by the “SOURCE” into the load it will be referred to as Delivered Reactive Power (Vars) and have a positive sign.

When the Reactive Power (Vars) flow from the “LOAD” through the metering point and into the “SOURCE” we say the Reactive Power (Vars) are being RECEIVED. Therefore when the Reactive Power is being supplied by the “LOAD” into the source it will be referred to as Received Reactive Power (Vars) and have a negative sign.

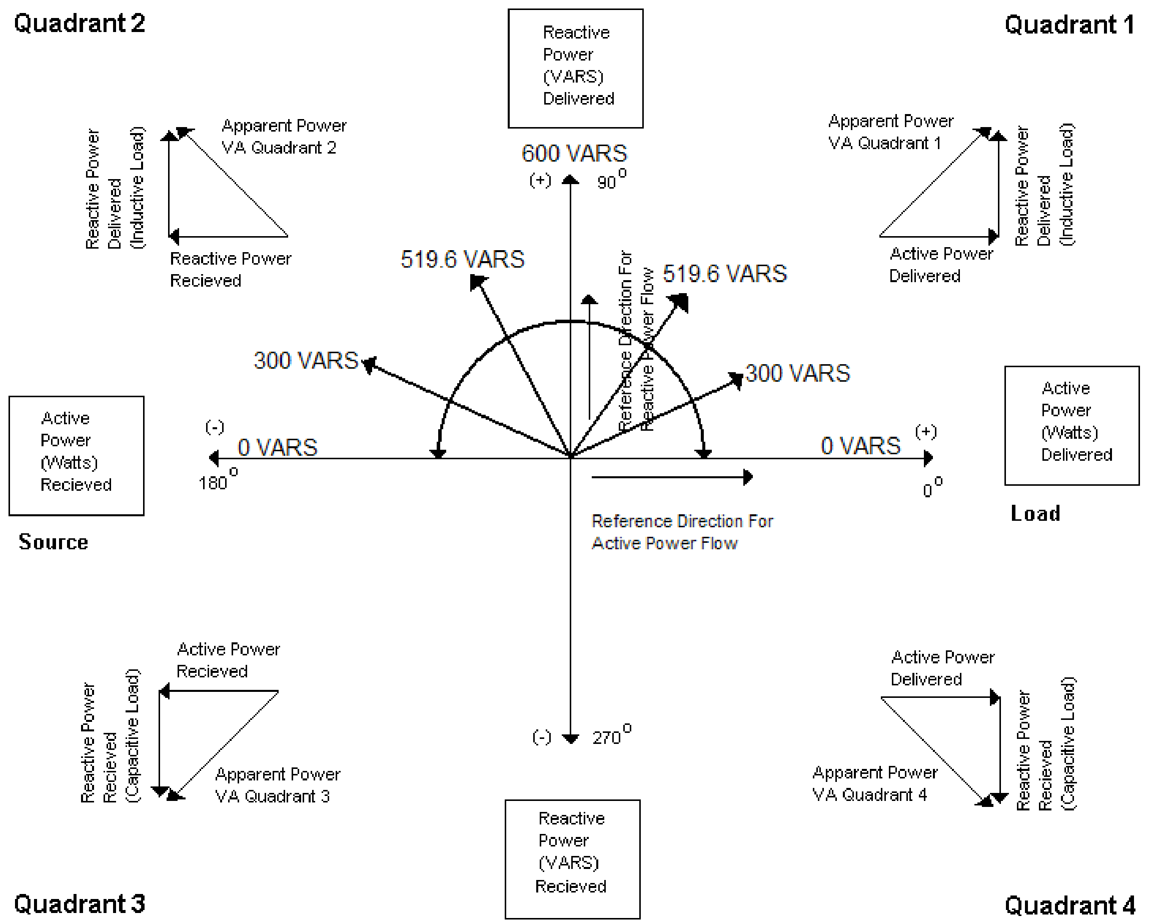
Note: The Reactive Power is always on the y axis and does not fall into any of the four quadrants. Reactive power does not lead or lag it is delivered or received.

Terms (Standard from the above illustration):
Delivered Kvar/Kvarh (Q1 + Q2)
Received Kvar/Kvarh (Q3 + Q4)

Quadrant Conventions



PF effect on KVARH Energy



THE EASTERN SPECIALTY COMPANY

Summary

Power Values (Kw/kwh, Kvar/Kvarh, and Kva/Kvah): The best naming convention would be to stay with Delivered and Received.

Leading and Lagging: Use these terms for describing the relationship of current to voltage. Leading and Lagging is normally viewed from the perspective of the supplier of active energy.

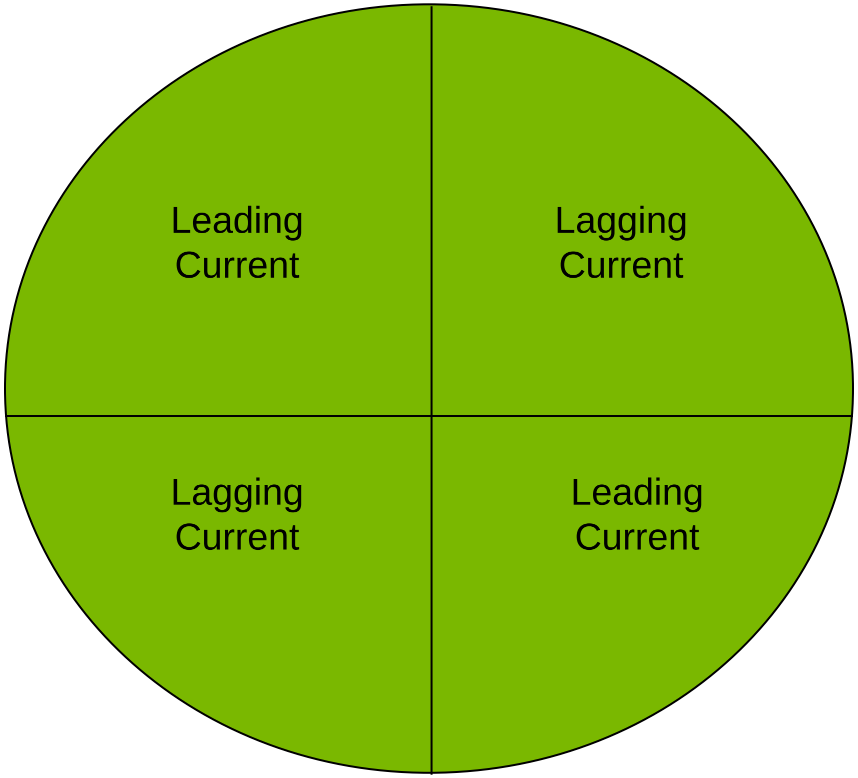
Power Factor: Is the ratio between true and apparent power. Power factor does not lead or lag and has no sign. Power factor is normally viewed from the perspective of the supplier of active energy.

Current Lead/Lag

Reactive Power Delivered to the Load

SOURCE Received Power

Active Power Delivered from the Load



LOAD Delivered Power

Active Power Delivered to the Load

Reactive Power Received from the Load

THE EASTERN SPECIALTY COMPANY

Deriving KVA from KWH and KVRH Data?

First BIG question, What does the Billing RATE require?

The meter can record Delivered and Received KWH

1) Delivered KWH
2) Received KWH

The meter can record all/any of the 4 KVRH quadrants individually

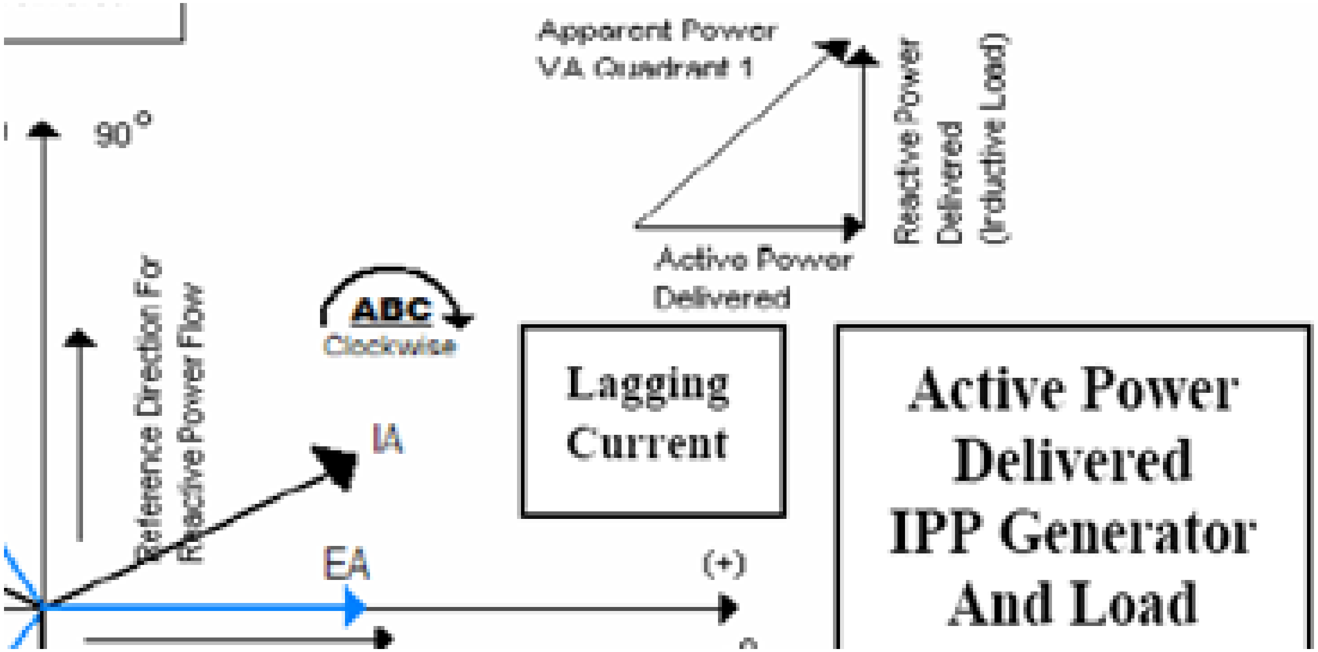
1) Quadrant 1 KVRH
2) Quadrant 2 KVRH
3) Quadrant 3 KVRH
4) Quadrant 4 KVRH

Or, the meter can "qualify" what quadrants make up Received and Delivered KVRH definitions thru program definitions.

Example

As an example, The rate requires KVA for Q1 only. This represents and Inductive load for Delivered Power.

Q1



If you set up the calculation to Ignore received KWH(Q2 or Q3) as well as ignore any leading KVRH (Q4) then the above billing determinant can be honored.

KVRH Terms and "Qualifications" of Concern

Program definitions for meter software needs to be understood. Most programming software allows the user to make choices of how KVRH's are measured and utilized. Below are some of the terms and their meanings.

Delivered KVRH – usually a choice of (Q1+Q2) or (Q1+Q4)

Received KVRH – usually a choice of (Q3+Q4) or (Q2+Q3)

Leading – This refers to a Capacitive load, Q4 for Delivered, Q2 for Received

Lagging - This refers to a Inductive load, Q1 for Delivered, Q3 for Received

Ignore - This is usually a choice to ignore any leading KVRH

Add – This allows the leading and lagging KVRH to be added together.

Net – This choice will allow the lagging KVRH to be subtracted from leading KVRH

Deriving KVA from Load Profile

Del KVRH = (Q1+Q2), Rec KVRH = (Q3+Q4)

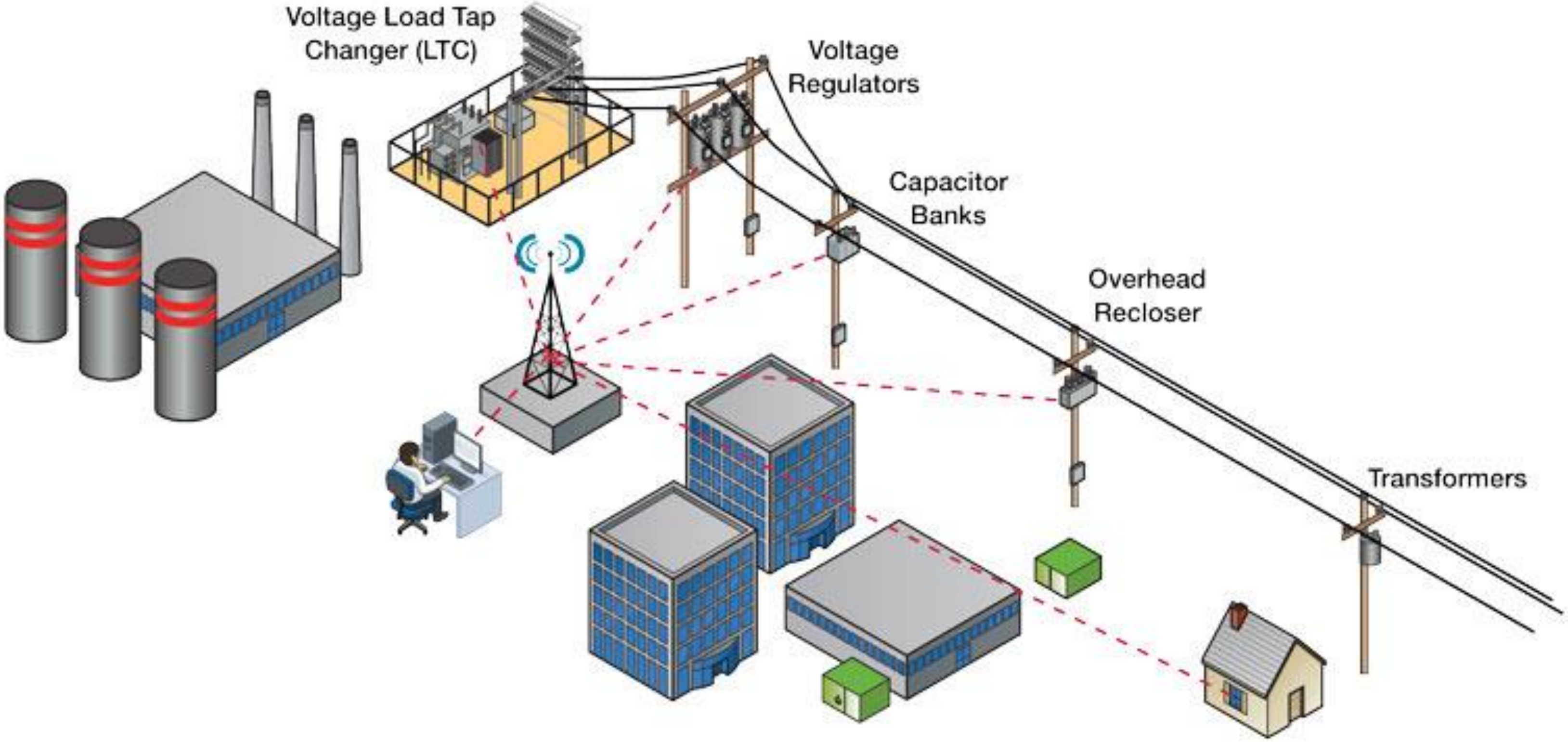
Load Profile	**Q1**	**Q2**	**Q3**	**Q4**
1) Del KWH	**X**			**X**
2)Del KVRH	**X**	**X**		
3)Rec KWH		**X**	**X**	
4)Rec KVRH			**X**	**X**

KVARH Loads are not going to get better….

- Virtually every device we now use has a switching power supply. NOTE: There is some talk of moving to DC only power and metering for households as virtually everything we run in our house could be powered through DC.

- Industrial controllers for manufacturing and HVAC are forcing us away from a Unity PF. Everywhere we turn there is an increasing difference between Apparent Power and Delivered Power. We need to identify and quantify these “losses” and correct or meter them appropriately.

Using KVA Data to Manage your GRID



Benefits From Billing C&I on KVA

- Reduce system heat losses
- Provide data for sizing of electrical equipment
- Provide a measure of efficiency
- Help improve the efficiency of the Grid
- Potential for increased revenues?
- Opportunity to offer more services
- Provide a more equitable billing scenario? As has always been the case Utility Customers with a good PF are compensating for those with a bad PF.

Concepts Covered

- What does four Quadrant metering mean?
- When am I interested in four quadrant metering?
- How is this information used if not for billing?
- How will I use this as a meter tech/engineer?
- Why will this be important in the future?

Questions and Discussion

Tom Lawton

tom.lawton@tescometering.com

TESCO – The Eastern Specialty Company

Bristol, PA

215-785-2338

This presentation can also be found under Meter Conferences and Schools on the TESCO website:
www.tescometering.com