Four Quadrant Metering

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Agenda

- Review of Watts, VAR, and VA
- Overview of Four Quadrant Metering
- Vector Diagrams in Four Quadrants
- How do you meter four quadrants?
- Examples of sites using four quadrant metering
- Verification of four quadrant sites

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Watt, VAR, and VA

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

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

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

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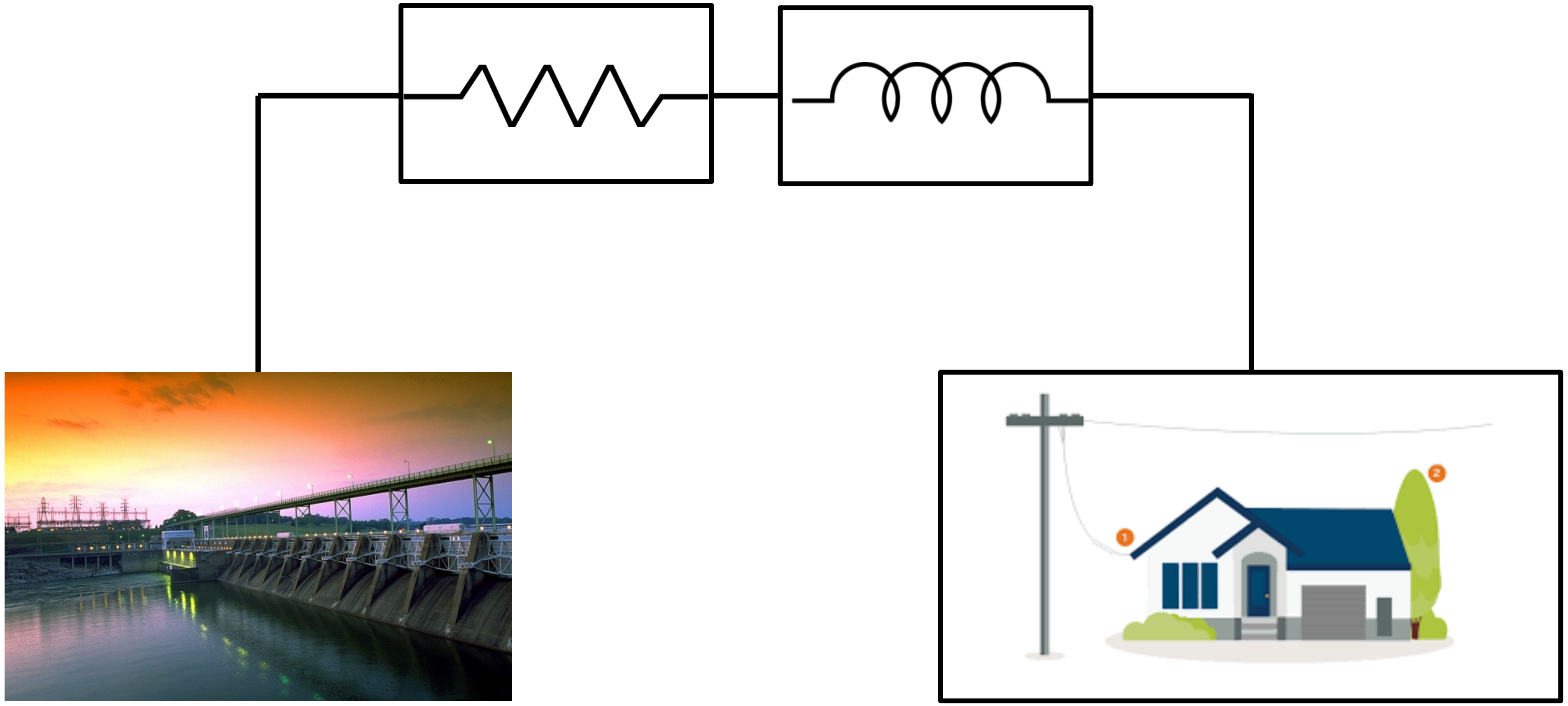
Watt, VAR, and VA

Where do VARs come from?



Inductance in the power transmission line lowers power factor and increases VARs!

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Four Quadrant Metering

Quadrant	Power Factor	Watts	VARs
1	Lag	Delivered (+)	Delivered (+)
2	Lead	Received (-)	Delivered (+)
3	Lag	Received (-)	Received (-)
4	Lead	Delivered (+)	Received (-)

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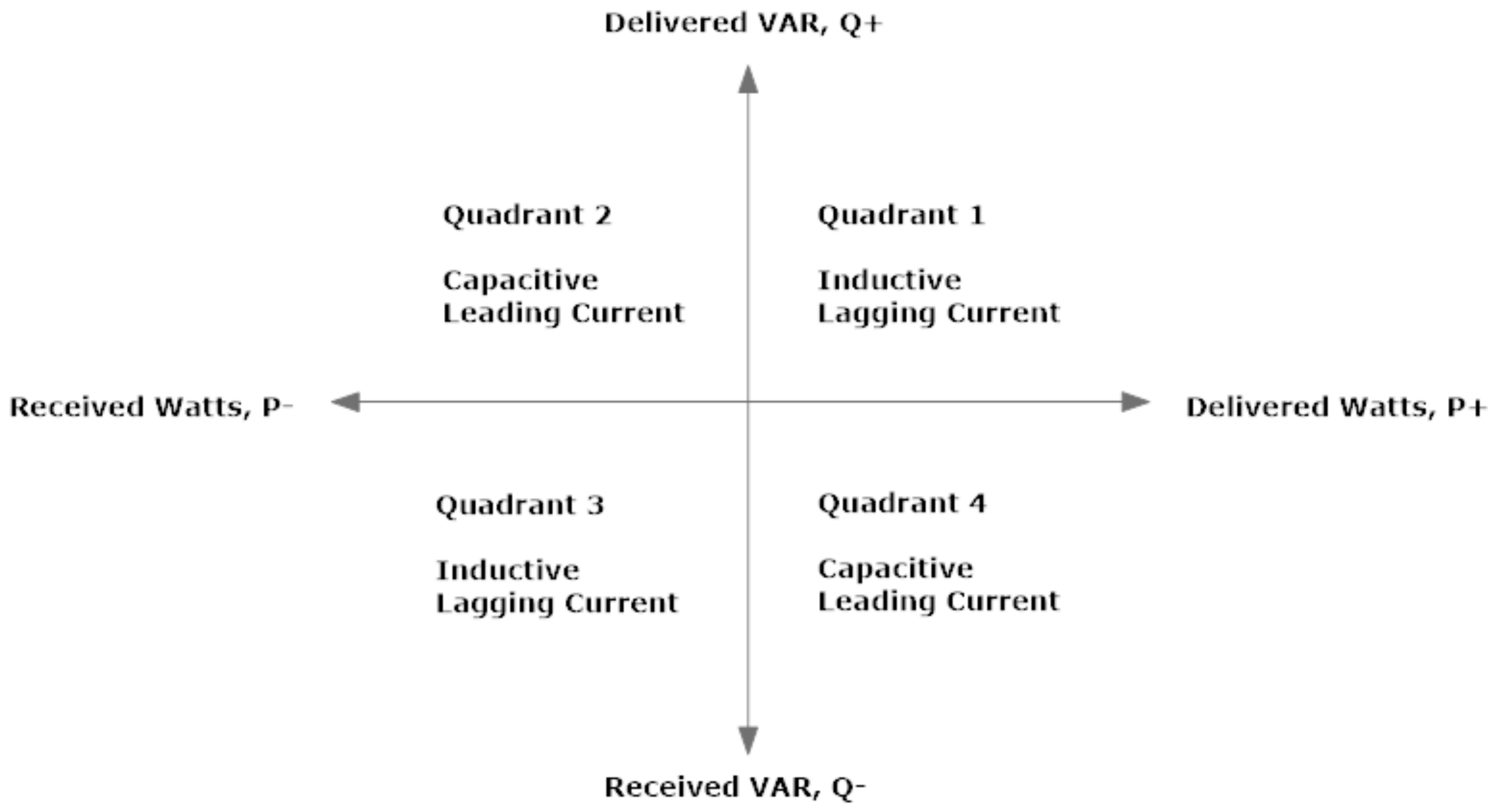
Four Quadrant Metering



Delivered power goes from the utility to the customer
Received power goes from the customer to the utility

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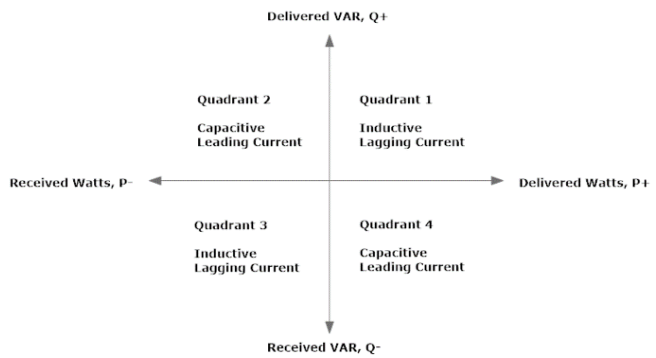
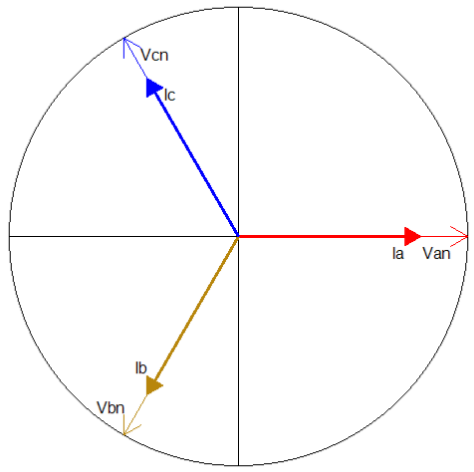
IMPORTANT!

The four quadrants shown in the last slide are NOT the same as a typical vector diagram!





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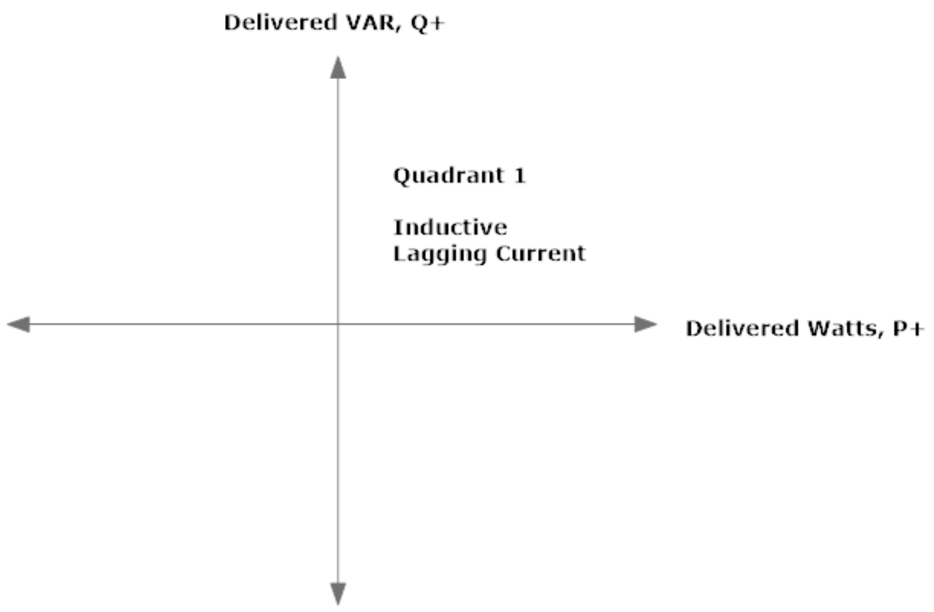
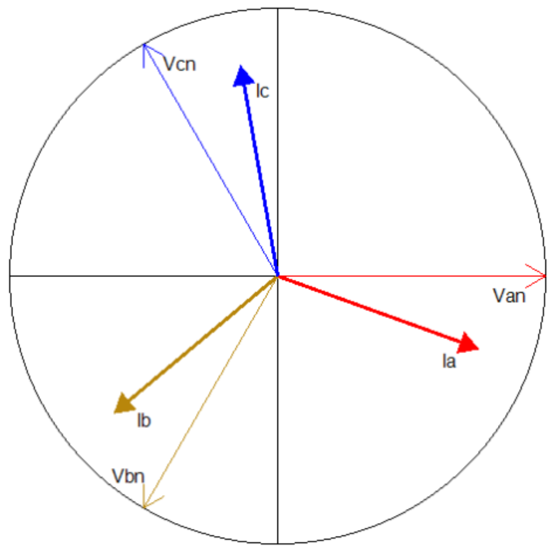
Quadrant 1





- Most common quadrant
- Inductive load

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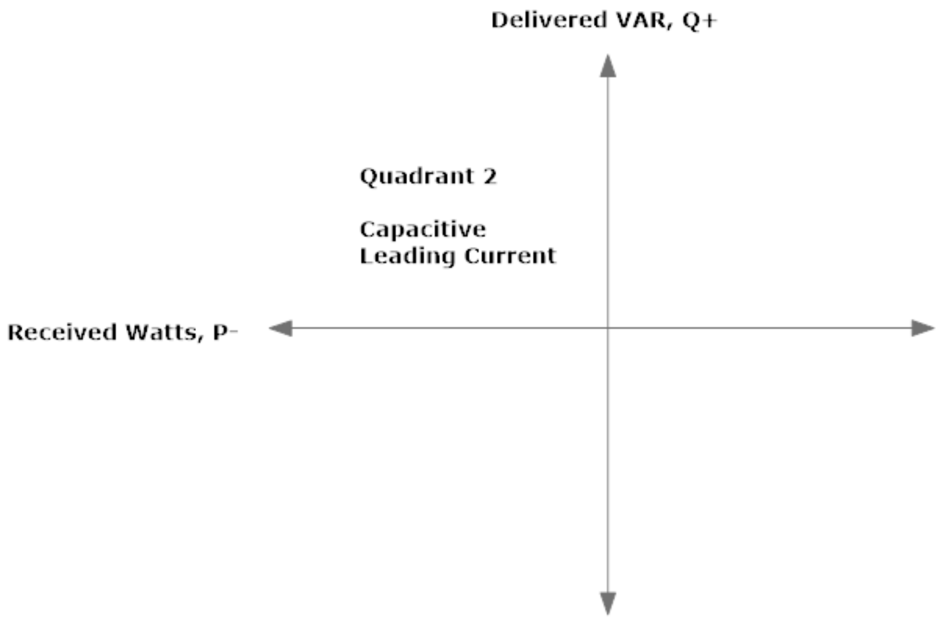
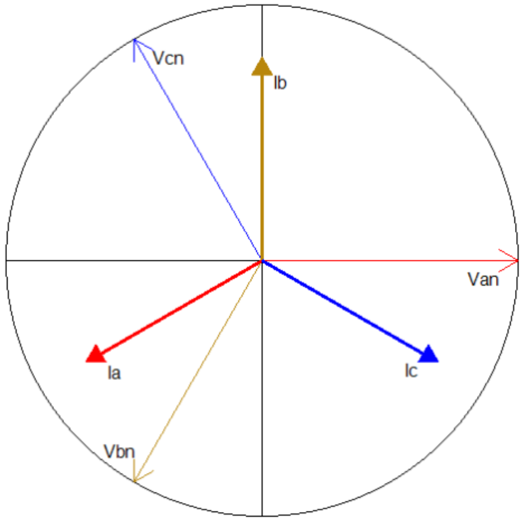
Quadrant 2





Renewable sites with a capacitive load

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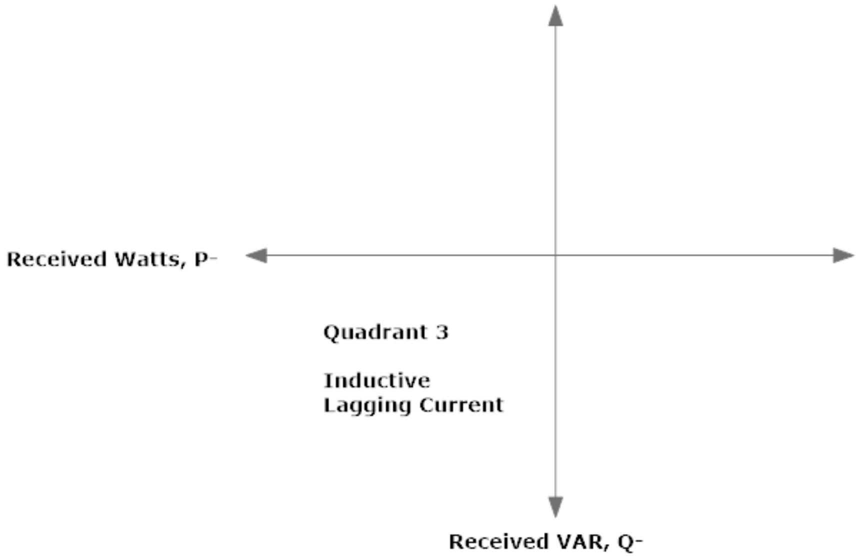
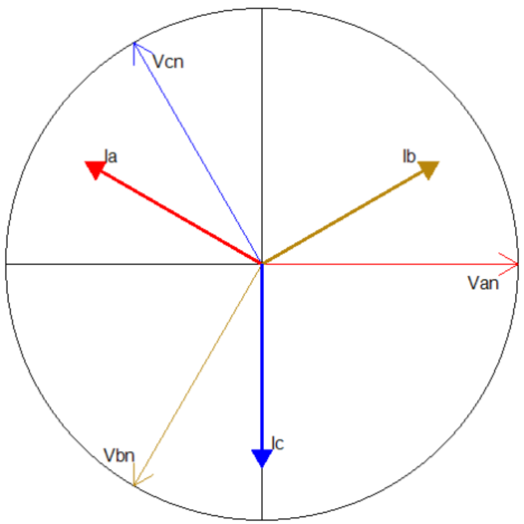
Quadrant 3





Renewable sites with a inductive load

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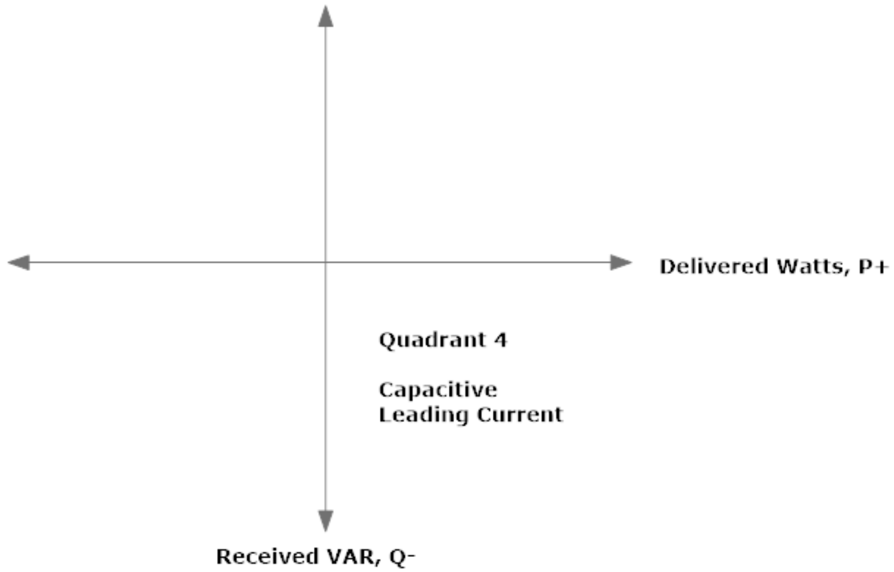
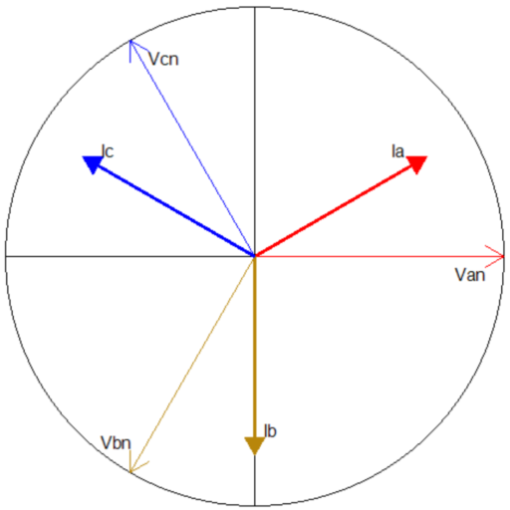
Quadrant 4





Light load on a standard site with a capacitor bank

How are 4 quadrants metered?

- Old approach – use two meters
- Mechanical meter with detents
- Possible problems with VARhr meters
- Solid state meters can perform true 4 quadrant metering
- Solid state metering can also be used for net energy metering

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Net Energy Metering

- Net metering allows a customer to be credited or paid for excess energy generated from renewable resources
- In some cases, net energy is credited at the full energy rate
- States limit the amount of excess energy that can be credited to the customer

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Net Energy Example

- Customer consumes 500kWh from the utility at $0.10/kWh

  500kWh * $0.10/kWh = $50 due to utility

- Customer puts back 100kWh to the utility at $0.05/kWh

  100kWh * $0.05/kWh = $5 due to customer

  Net bill = $50 - $5 = $45 due to utility

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Renewable Metering

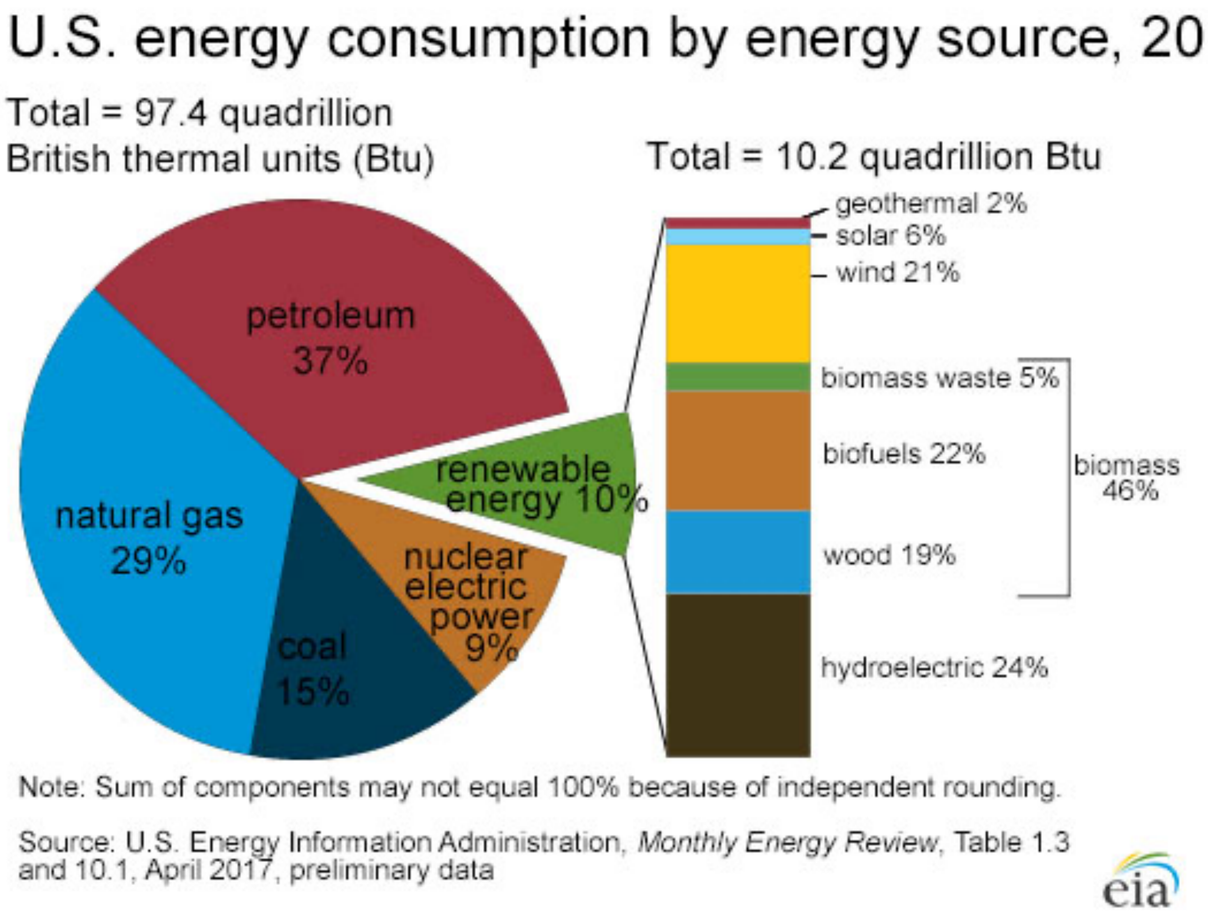
- Renewable sites can generate excess energy that can be put back on the grid
- This requires a means to measure power *received* back on to the electrical grid
- Originally, two meters were used – one for power delivered to the customer, and one for received power to the utility
- Modern meters can measure energy flow in both directions – 4 quadrant metering

What is a renewable site?

A renewable site can produce its own energy using a resource that is naturally replenished.



Renewable Site Statistics



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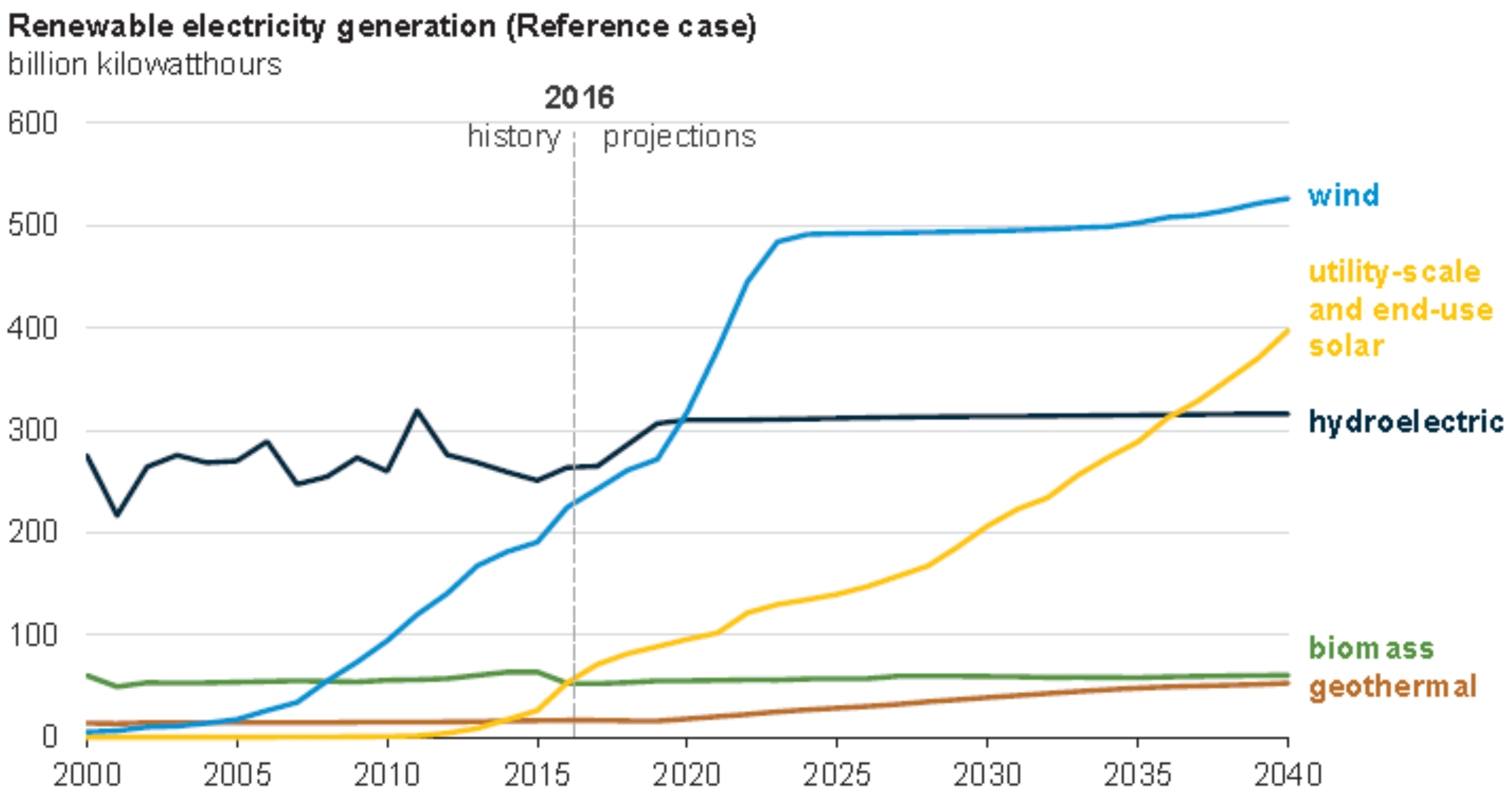
Renewable Site Statistics



Renewable Site Statistics

- Renewable energy accounted for 10% of total power consumption in the US in 2016

- Solar and wind are the largest growing segments in the US and represent the majority of new renewable metering installations. Both segments should double their output in the next 5 years.

Source: www.eia.gov

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Case Study #1
East Knox Solar Array

1MW Solar Farm in Knoxville, TN
4608 Panels - Built 2010

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East Knox Solar Array

Four DC-AC Inverters
8.4kV Transformer

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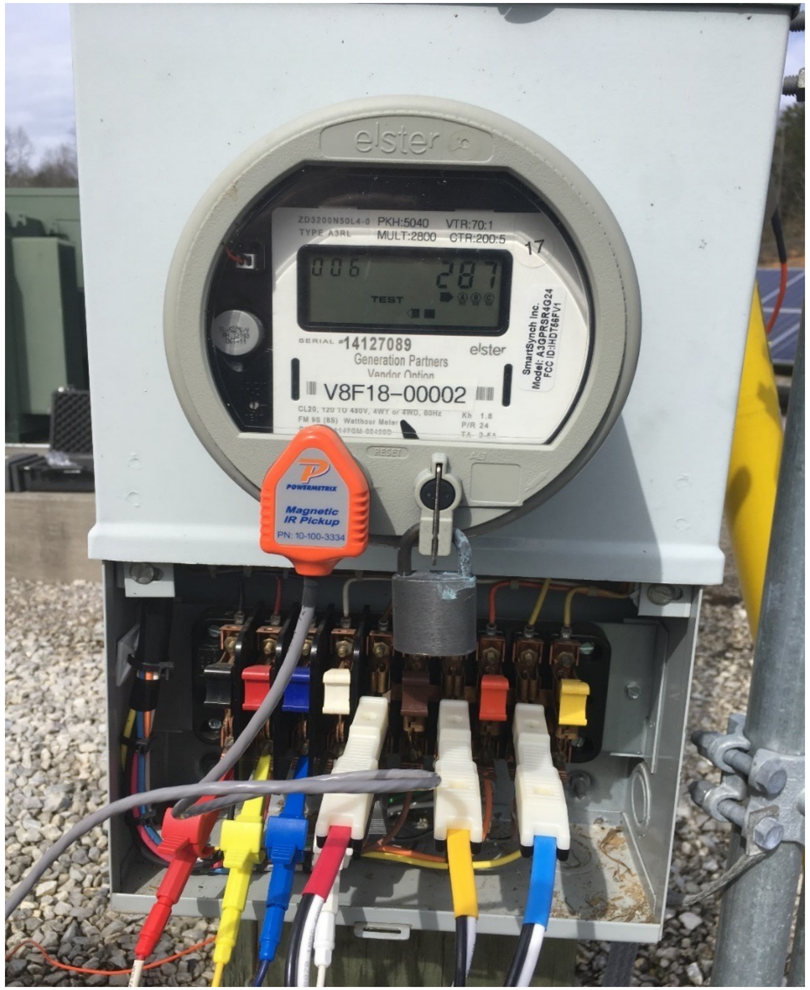
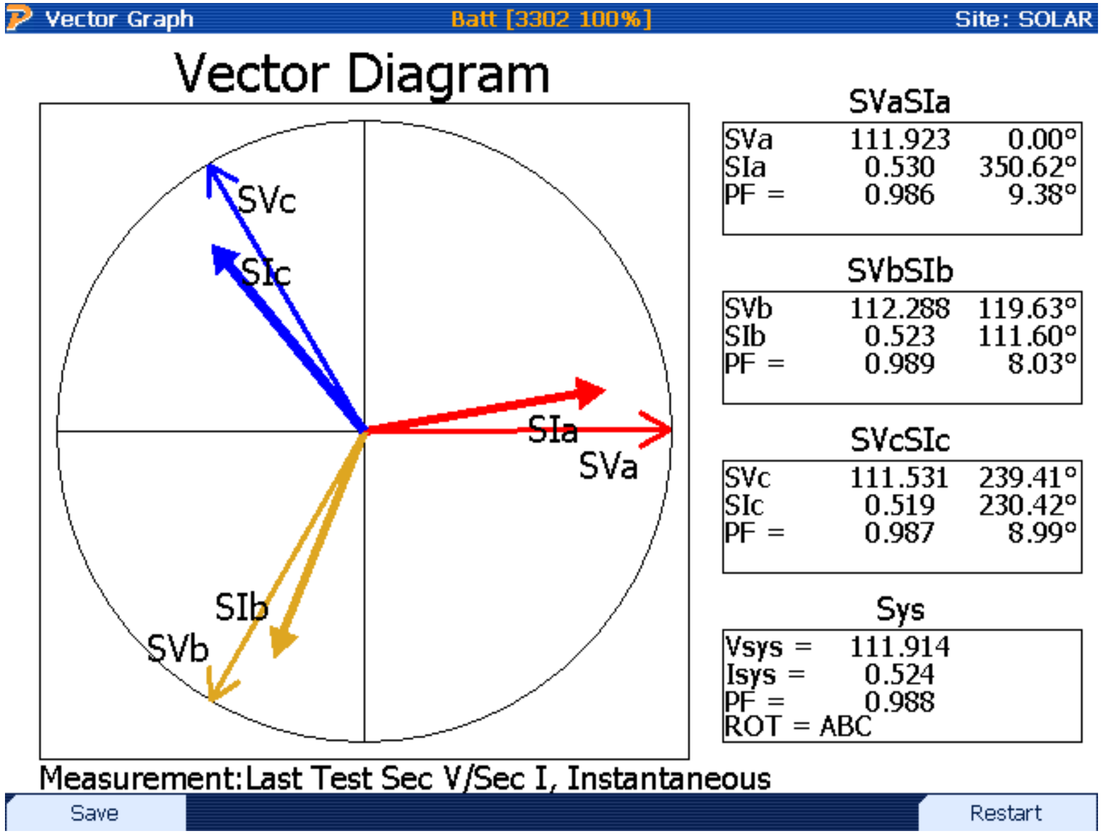
East Knox Solar Array



- Local utility monitors energy with one bi-directional form 9S meter
- 200:5 CTs
- 70:1 PTs

East Knox Solar Array



- Current vectors are LEADING
- Meter is setup so that positive energy flow is from the solar array to the utility

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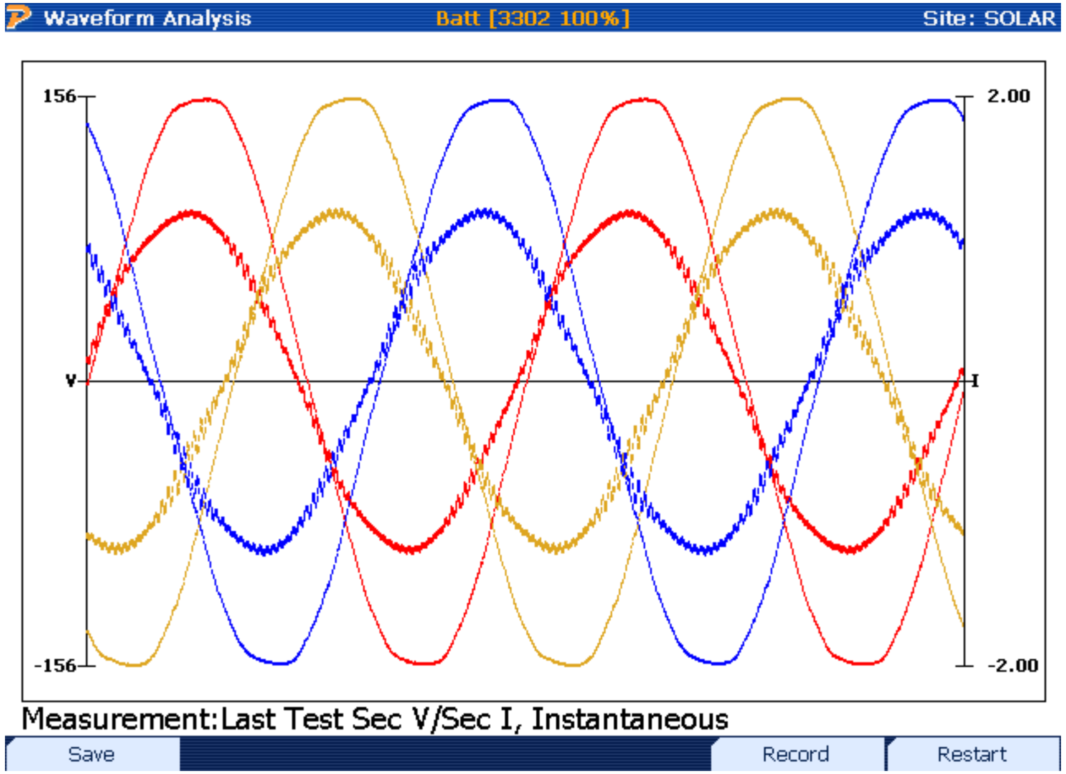
East Knox Solar Array



- Power outputs are well filtered
- Harmonics are >70th harmonic
- Meter should have no problems

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East Knox Solar Array

Customer Load Test Results   Batt [3302 100%]   Site: SOLAR

Customer Load Meter Test
Registration

% Registration	99.994

Test Info

Time(sec)	113.505
Time Left	0.000
Pulses Exp	3.0002
Pulses Act	3.0000
Meter PF	0.9852

Sys Info

Wh	5.4003
VAh	5.4814
VARh	-0.9389
V	111.962
I	0.5182

Test Complete

Restart | Edit Test Notes | View Trend | Done

- Customer Load Meter Test has excellent results
- Note NEGATIVE VARh due to leading current

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- Overhead CTs are testing using a high voltage current probe to measure primary current
- Pay attention to the polarity of the CT
- Secondary current is available at the meter test switch

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CT Testing Results | Batt [3302 90%] | Site: None

Measured Ratio: 200.00 PASS A

Nameplate Ratio: 200 : 5
Ratio Error (%): 0.00%
Phase Error (degrees): 0.238°
Primary Amps: 18.93
Secondary Amps: 0.473
Phase Error (minutes): 14' 16"

Measured Ratio: 200.99 PASS B

Nameplate Ratio: 200 : 5
Ratio Error (%): 0.49%
Phase Error (degrees): 0.014°
Primary Amps: 16.99
Secondary Amps: 0.423
Phase Error (minutes): 0' 49"

Measured Ratio: 200.24 PASS C

Nameplate Ratio: 200 : 5
Ratio Error (%): 0.12%
Phase Error (degrees): 0.280°
Primary Amps: 16.43
Secondary Amps: 0.410
Phase Error (minutes): 16' 49"

Graphs | Exit

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East Knox Solar Array

Capture Burden Measurement Batt [3302 90%] Site: None

Total Burden (Ohms): 0.1955 A

Length: Feet:	70.00	Volts:	0.03
Diameter: AWG:	12.00	Amps:	0.3685
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0843

Total Burden (Ohms): 0.1504 B

Length: Feet:	70.00	Volts:	0.01
Diameter: AWG:	12.00	Amps:	0.3597
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0393

Total Burden (Ohms): 0.1688 C

Length: Feet:	70.00	Volts:	0.02
Diameter: AWG:	12.00	Amps:	0.3580
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0577

Direct Burden Measurement gives the EXACT burden on the secondary

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Case Study #2
Gila River PV Power Plant

87kW Solar Farm at Hu Hu Kam Hospital
Sacaton, AZ

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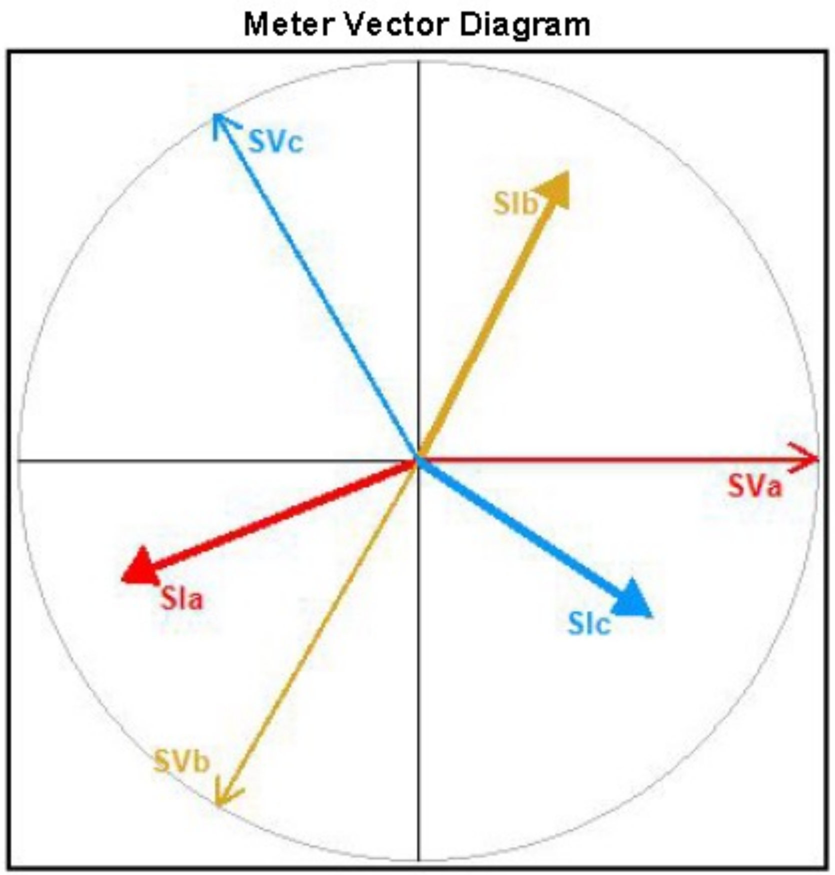
Gila River PV Power Plant



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

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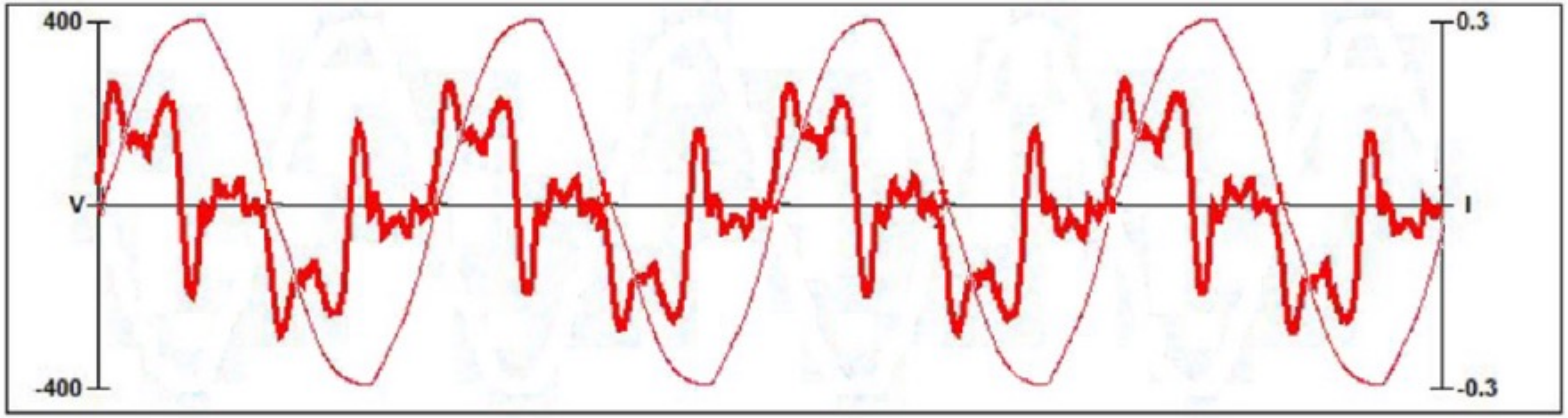
Gila River PV Power Plant



Voltage and Current Harmonics

V THD = 2%

I THD = 50 to 60%

Square wave current due to inverter

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Case Study #3
U-Haul – Kingman, AZ

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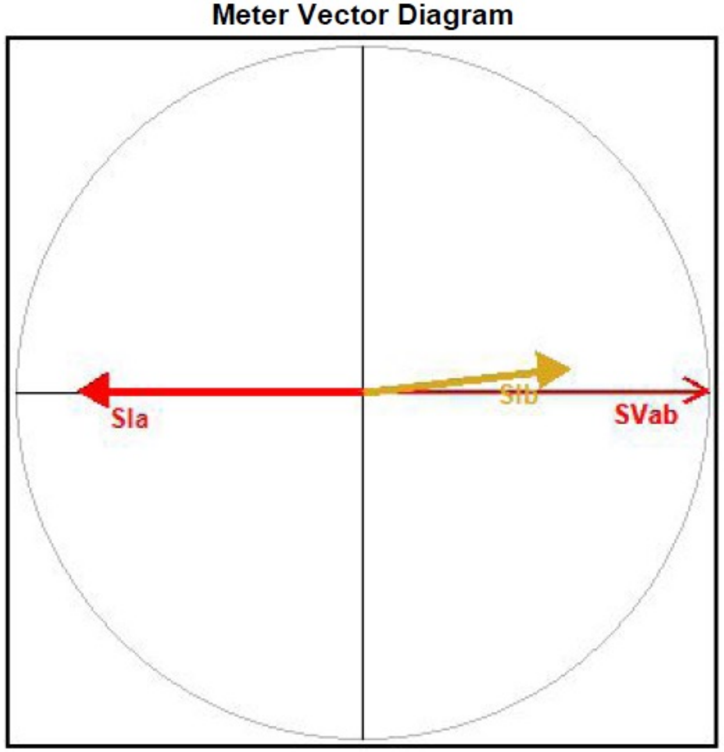
U-Haul – Kingman, AZ



Power Data

Power Pair	Wh	VAh	VARh
Vab-Ia	-1.7247	1.7277	-0.0092
Vab-Ib	-1.2472	1.2585	0.1411
Sys	-2.9719	2.9749	0.1319

- Single Phase – 3 wire Form 4S meter
- Power was being put back on the grid - Negative Watts
- Meter registration was -100.9%

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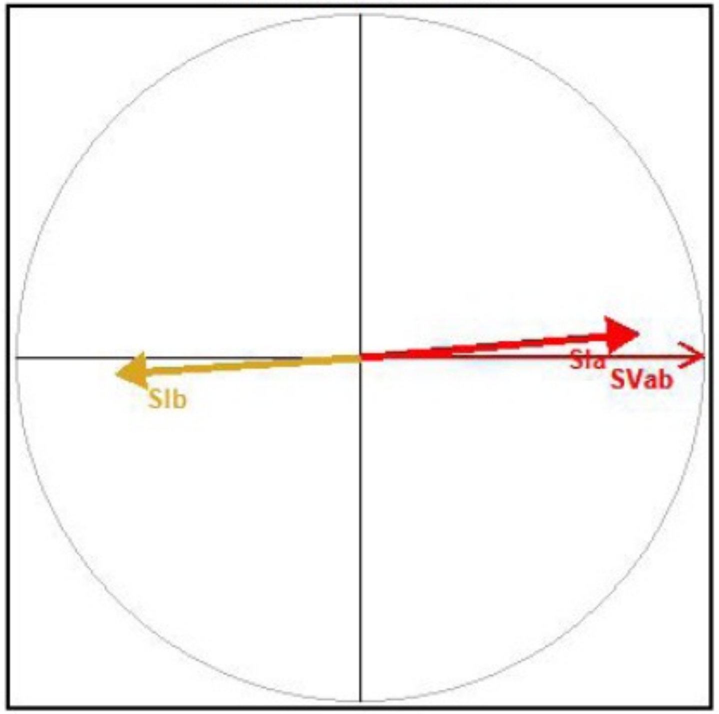
U-Haul – Kingman, AZ

Meter Vector Diagram



Power Data

Power Pair	Wh	VAh	VARh
Vab-Ia	1.6058	1.6137	-0.1320
Vab-Ib	1.3897	1.3958	-0.1009
Sys	2.9954	3.0045	-0.2330

- Single Phase – 3 wire Form 4S meter
- Power was being delivered to the customer - Positive Watts
- Meter registration was +100.15%

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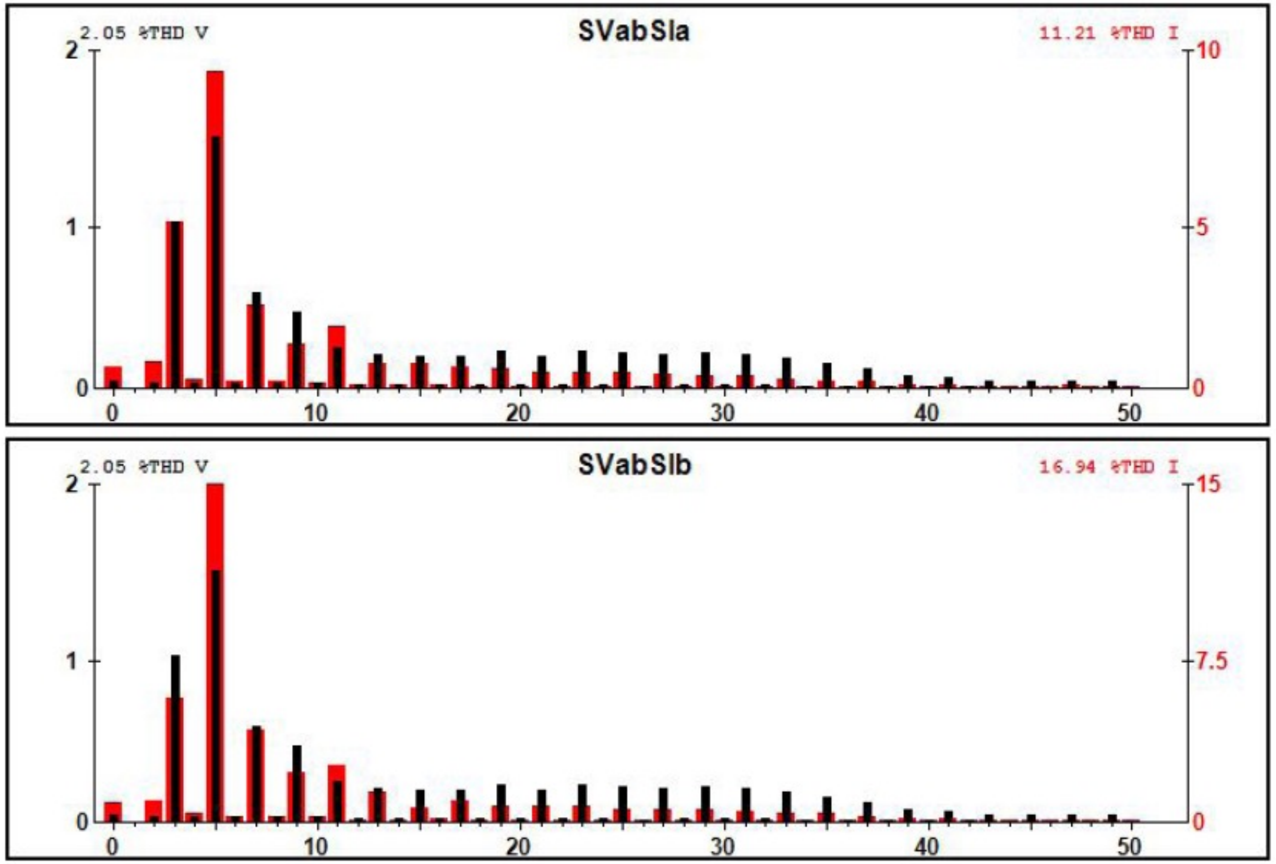
U-Haul – Kingman, AZ



Voltage THD < 3%
Current THD < 17%
Mostly odd harmonics due to inverter

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Renewable Site Verification

- Renewable sites should be tested for energy flow in both directions.
- This will require the use of a load box.
- If the site is not generating power, a phantom load test will be required.
- Always check your CTs and PTs – The meter is only as good as the information it receives from the ITs!

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Summary

- Wind and solar sites will produce many new metering sites over the next 6 to 20 years
- Four quadrant metering is required for bidirectional energy sites
- Check energy flow in both directions

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