Optimization of Solar Energy by Power Factor Correction

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Purpose

- Optimize the electrical power generated in a photovoltaic plant by correcting the Power Factor
- Examine and analyze Power Factor
- Improve Power Factor by decreasing the reactive power
- Analyze the effect of installing a capacitor in a circuit with an inductive reactive power
- Explore and understand the benefits of improving Power Factor

Abstract

The power factor of the water pumps from the Organic Research Garden and Chickee Hut, which are powered by the solar station, were measured, calculated, and corrected. By using a Fluke 43B Single Phase Power Quality Analyzer, the values of real and apparent power were obtained, and with these values, the reactive power and power factors were deduced. The computer software that was used to provide the numerical results was Excel and MatCad, which gathered these results from the manually implemented formulas. Based on these results, it was concluded that the water pump for the Organic Research Garden required the installation of a 177 µF capacitor in its circuit, whereas the water pump from the Chickee Hut required the installation of a 120 µF capacitor. The effect of adding the corresponding capacitors to each of respective water pumps' circuits resulted in a rise in power factor from 0.76 to 0.98 for the Organic Research Garden and 0.82 to 0.98 for the Chickee Hut. Upon analyzing the amount of energy saved by this correction every year, total energy savings would be 163.80 kWh/year for the water pump from the Organic Research Garden and 6.09kWh/year for the Chickee Hut water pump.

Instrumentation

Specifications

Input impedance

1 MΩ, 20 pF

Voltage rating

600 V rms, CAT III

True-rms voltage
(AC + DC)

Ranges

5.000 V, 50.00 V, 500.0 V, 1250 V

Power
PF power factor
Range
0 - 1.0
Ranges
50.00 A, 500.0 A, 5.000 kA, 50.00 kA, 1250 kA
Accuracy
±(1% + 10 counts)
Frequency
Ranges
10.0 to 15.0 kHz

Fluke 43B Single Phase Power Quality Analyzer

What is Power Factor

- Power factor is a measure of how effectively electricity is being used. It can be expressed as the ratio of Real power to apparent power.

- Various types of power are at work to provide electrical power:
  - Real Power (…what is obtained, kW)
  - Reactive Power (power not used to perform work, kVAR)
  - Apparent Power (….what is paid for, including both working and apparent power, kVA)

Working Formulas

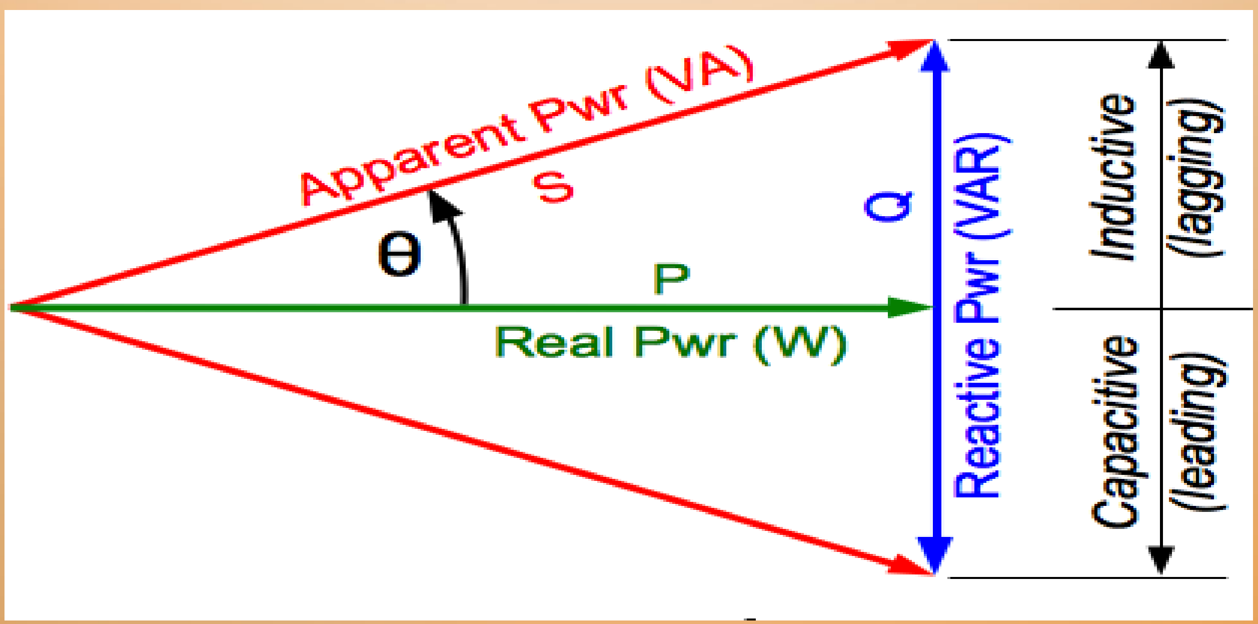
1) $i = Im \cos(wt)$
2) $v = Vm \cos(wt + \theta_1)$
3) $A = Irms\ Vrms$
4) $p = Irms\ Vrms \cos(\theta_1)(1+\cos(2wt))$
5) $r = Irms\ Vrms \sin(2wt) \sin(\theta_1)$
6) $a = p + r$

$w = 2\pi f$

$pf1 = \cos(\theta_1)$

$pf2 = \cos(\theta_2)$

Power Factor (PF)



PF = P/S

= Cos(θ)

How to Improve PF

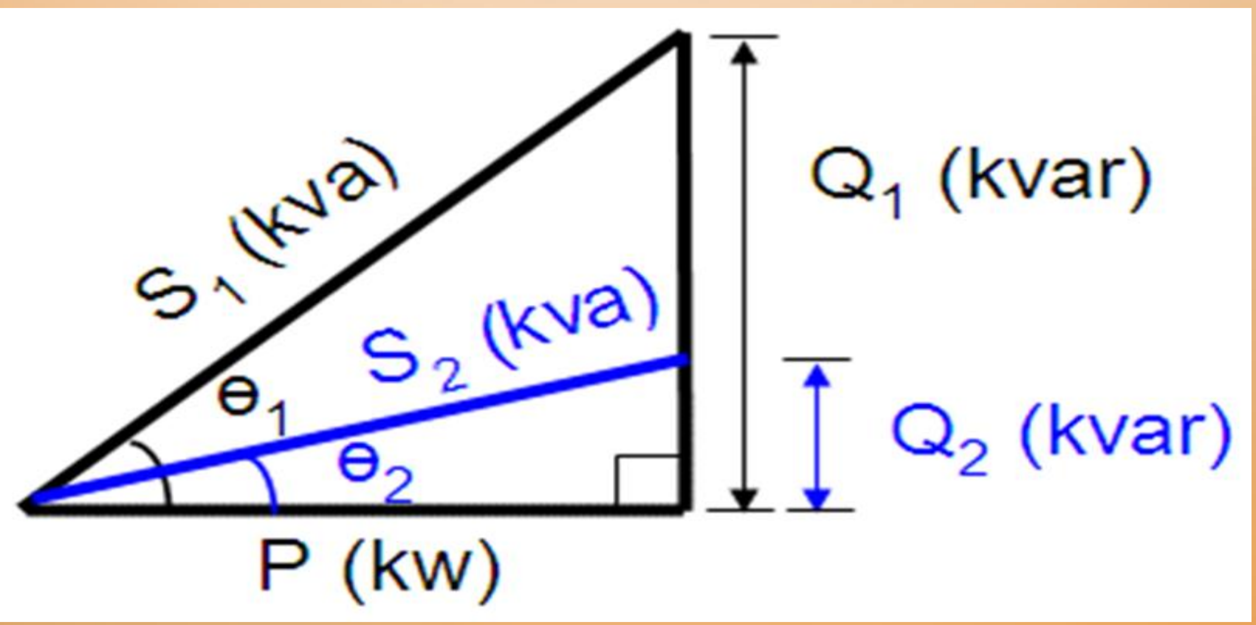
- To increase the power factor, reactive power must be reduced.

- Adding capacitors in an inductive reactive circuit increases the power factor.

- Power Factor can be improved to 95% or more.

- When the PF is increased, the apparent power (what is paid for) approaches the real power (what is obtained), thus decreasing the operation costs.

Power Factor Correction



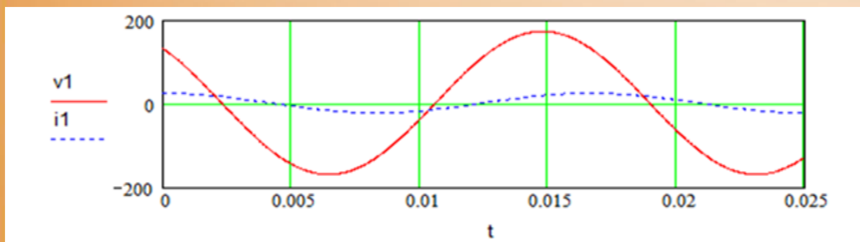
Formula to correct the PF

$$C = \frac{Q_1 - Q_2}{2\,\pi\, f V_{rms}{}^2}\, 10^9\ \mu\mathrm{F}$$

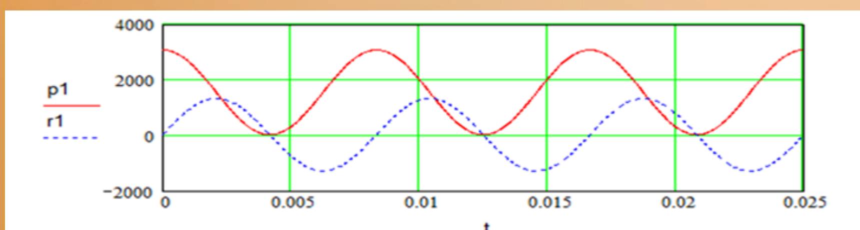
C : Capacitance added to the inductive circuit (μF).
Q1: reactive power without the added capacitor (kVAR).
Q2: reactive power with the added capacitor (kVAR).
f: power source frequency (Hz).
Vrms: Source root mean square voltage value (V).

Organic Research Garden water pump circuit

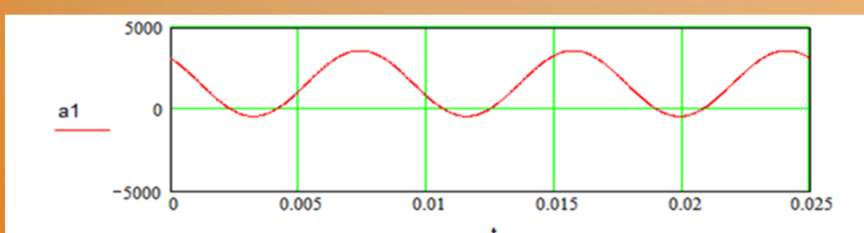
Without capacitor: PF 0.76



Graph 1. Shows offset of the Current from the Voltage. Current and Voltage are 40.5^0 out of phase.

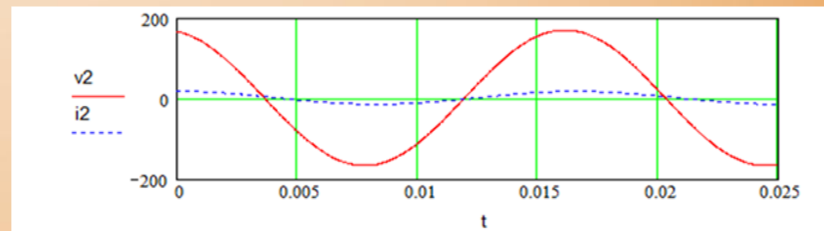


Graph 2. Real Power (p) vs. Reactive Power (r). Reactive power produces additional energy wasted in the circuit.

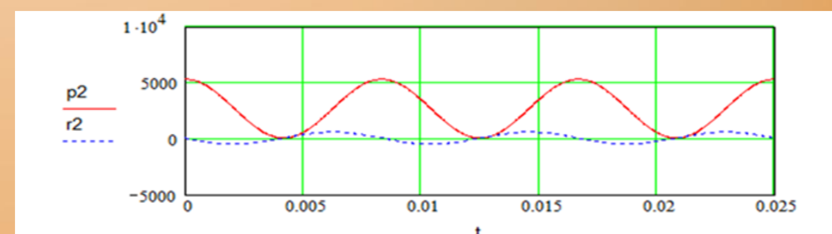


Graph 3. Apparent Power slightly shifts negatively due to problems with the system's power factor before the correction.

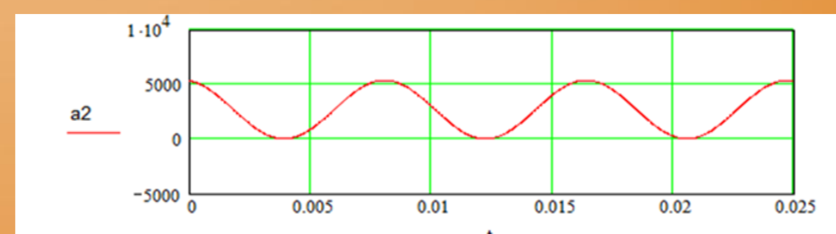
With capacitor: PF 0.98



Graph 4. Shows offset of the Current from the Voltage. Current and Voltage are 11.5^0 out of phase.



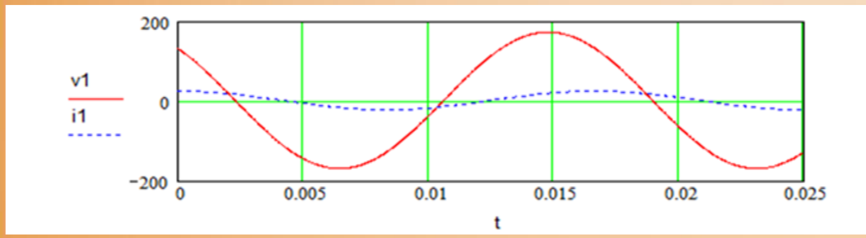
Graph 5. Correction of Reactive Power. Reactive power was greatly reduced after correcting the power factor.



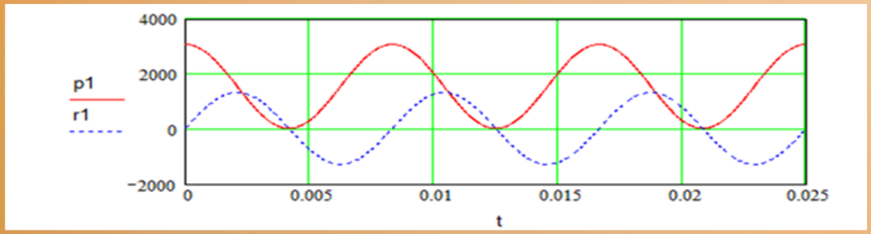
Graph 6. Apparent Power after the power factor correction. Graph shows the shift after the power factor nears 0.98.

Chickee Hut water pump circuit

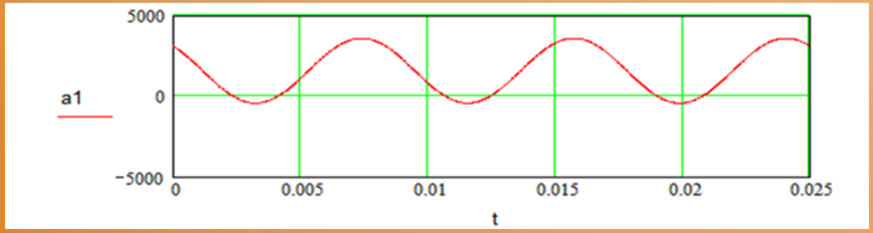
Without capacitor: PF 0.82



Graph 1. Shows offset of the Current from the Voltage. Current and Voltage are 35^0 out of phase.

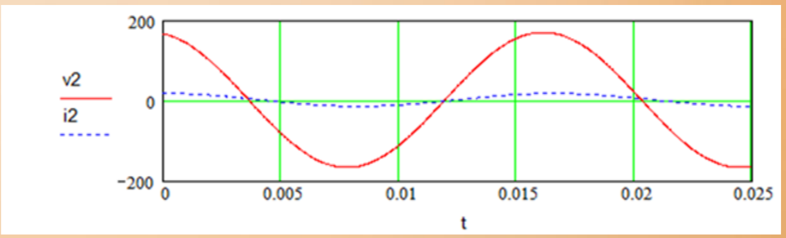


Graph 2. Real Power (p) vs. Reactive Power (r). Reactive power produces additional energy wasted in the circuit.



Graph 3. Apparent Power slightly shifts negatively due to problems with the system's power factor before the correction.

With capacitor: PF 0.98



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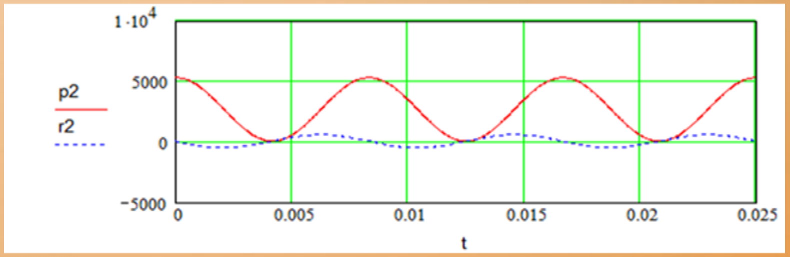

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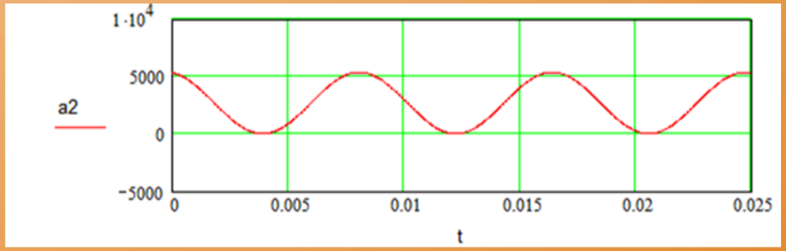

Graph 6. Apparent Power after the power factor correction. Graph shows the shift after the power factor nears 0.98.

Experimental Results

- Organic Research Garden
  - Original Power Factor of system = 0.76
  - Our target PF was 0.98

Power Factor	Apparent Power (kVA)	Reactive Power (kVAR)	Real Power (kW)
0.76	2.01	1.29	1.53
0.98	1.56	0.31	1.53
Difference	22%		

This table shows the change in power factor, reactive power (kVAR), and real power (kw), when the capacitor was implemented and the power factor corrected.

Experimental Results

- Chickee Hut
  - Original Power Factor of system = 0.82
  - Our target PF was 0.98

Power Factor	Apparent Power (kVA)	Reactive Power (kVAR)	Real Power (kW)
0.82	1.60	0.91	1.31
0.98	1.34	0.27	1.31
Difference	16%		

This table shows the change in power factor, reactive power (kVAR), and real power (kw), when the capacitor was implemented and the power factor corrected.

Conclusion

- Improving the power factor can maximize current-carrying capacity, reduce power losses, and lower electric bills.

- As a result, w/o the installed capacitor, 1467kWh/year was consumed in the Organic Research Garden and 1168 kWh/year in the Chickee Hut. However, with the installed capacitor it was reduce to 1139kWh/year and 978 kWh/year respectively, saving 518 kWh/year (20%).

- The application of this technique in other areas of STU can save tens of thousands of dollars a year in electricity.

References

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- Power factor correction: A guide for the plant engineer. Technical Data SA026070001E. Nov. 2010
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Acknowledgments

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