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SMT ENGINEERING, LLC

# KVAR Demo Unit Evaluation for The Buelt Corporation - DRAFT VERSION
**July 17, 2007**

On Thursday July 5, a meeting was held between Rick Pecore of SMT Engineering, LLC and Kenneth Buelt of The Buelt Corporation (Buelt). An apparatus known as the "KVAR Demo Unit" from KVAR Energy Savings, Inc was presented and discussed. Sample units were left with SMT Engineering to perform an independent investigation of the device's operation and performance.

## Theory

The KVAR Demo unit operates on a simple principle of power factor compensation, and is generally directed towards motor loads. A typical motor presents a primarily inductive load, meaning that current will lag voltage (for a 60Hz sinusoidal voltage, this means the current peak will occur up to 4.17ms after the voltage peak). A typical motor may have a phase shift of 75°, which corresponds to a power factor of cosine 75° = 0.26. By comparison, a pure inductor would present a phase angle of 90°, for a power factor of 0.

A dual element to an inductor is a capacitor, which creates a current waveform that leads voltage (for a 60Hz sinusoidal voltage, this means the current peak will occur up to 4.17ms before the voltage peak). Thus an ideal capacitor will have a current phase angle of –90° relative to voltage.

Also of note is that a resistive load presents a phase shift of 0°, as current and voltage are always in phase. This yields a power factor of 1, with current peaks exactly synchronized to voltage peaks.

If an electrical device is required to deliver a specific amount of power (watts = volts * amps), then the amount of current that must be delivered to the device will be influenced by its power factor. For a load with PF = 1, the current required is at a minimum. This is because the voltage and current waveforms are exactly in phase, thus the current peak occurs with the voltage peak, thereby delivering power very efficiently. However, as power factor drops (as with an inductive load)), power delivery becomes less efficient. This is because the current peaks begin to lag the voltage peaks. With this situation, the current peaks must be larger to achieve the same power levels. This is why a low power factor is undesirable.

An important note here is that unless PF = 1, you cannot measure AC voltage, and then measure AC current, and simply multiply to determine power. This is because of the phase dependency described above. An extreme case is PF = 0, with a 90° phase shift between current and voltage. This would result in a power of 0 watts, even though current and voltage are both non-zero. This is why a power meter is helpful in taking such measurements. Otherwise, power must be determined by integrating the product of instantaneous voltage and current throughout one period of the AC waveform.

Now, as current peaks increase with falling power factor, the inefficiencies in the system grow with the square of increasing current. This is because power is dissipated in the wiring leading up to a load. This wiring acts as a resistor, with power loss calculated as $I^2 * R$. Thus if current increases by 4x, then the associated power loss increases by 16x. This is where the power savings lies with power factor compensation.

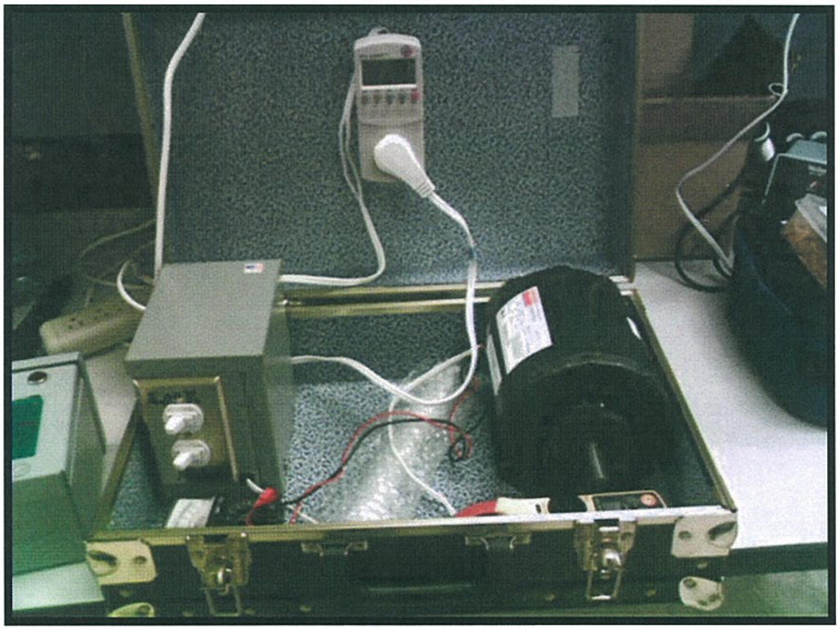
Of course, in addition to reducing $I^2 * R$ losses within a home or factory, power factor improvement is to the advantage of a utility company. A very low (poor) power factor requires high peak currents, which ultimately demands a larger electrical infrastructure. Generators, transformers, and distribution lines must all be larger than would be needed for a higher power factor.

In order to improve the power factor of an inductive load, a capacitor can be added across the load. This introduces a leading current (capacitor) to compensate for the lagging current of the load (inductor). The vector sum of these two currents will neutralize the reactive components, resulting in a load that appears much more resistive (PF = 1) than either element individually.

It is important to note that current flow into the motor does not change as the result of this method; it is only the current delivered from the source to the capacitor / motor combination that is affected.

## Initial Inspection

Buelt provided two sample units. The first was part of a complete demonstration system within a carrying case. The sample unit included a simulated wall outlet with an attached "Kill-A-Watt" power meter, which is a low-cost device for monitoring power from a standard 120Vac outlet. This meter fed the sample KVAR box, which included two switches. The first switch would turn the motor ON and OFF, while the second switch would enable and disable the power factor compensation feature. The output of the KVAR box was then connected directly to a Dayton 5K917 1/3HP split phase motor, rated for 5.6A nominal.

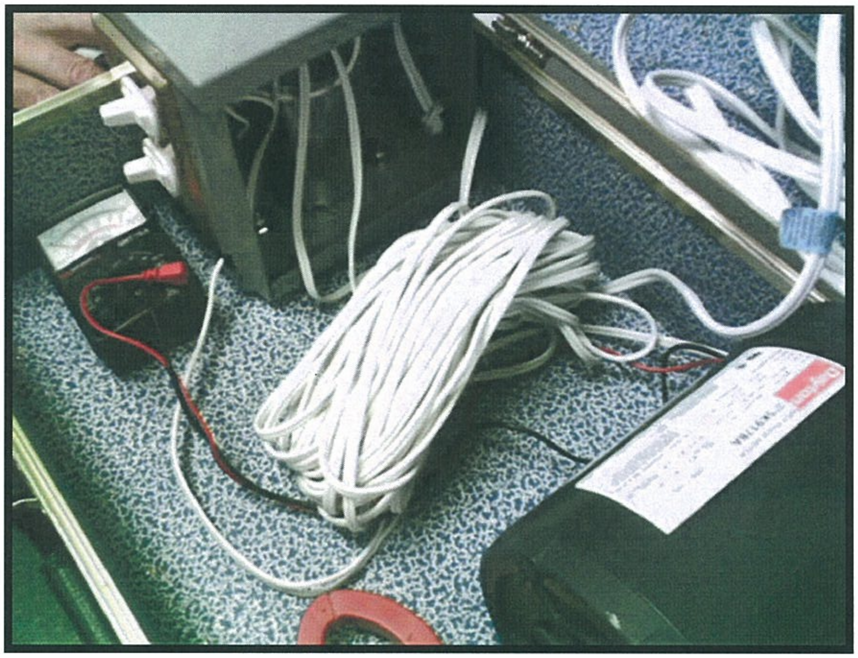


The second sample unit was a stand-alone box designed to be wired directly into a specific 220/240Vac application:

The content of each box was investigated. The first sample contained a single 97F8053S, 120uF, polypropylene film capacitor from GE Capacitor rated for 50/60Hz up to 240Vac:

http://www.newark.com/jsp/level5/module.jsp?moduleId=en_US/7248.xml

In addition, a large bundle of wire was packed into the box:



It was approximately 50 feet of standard 18/2 "zip cord". This is discussed further in the Analysis section below, as the presence of this wire bundle is critical to demonstrating a substantial power savings.

The second sample contained two SP65A-1, 35uF, oil filled, motor run capacitors from Shine Capacitors rated for 50/60Hz up to 240Vac:

http://www.shinecapacitors.com/products/documents/SP65A-1_000.pdf

The second sample was not evaluated further, as it would need to be matched to an appropriate load, and does not differ in principle from the first sample.

## Measurements

The sample setup was provided with a P4400 "Kill A Watt" consumer power meter from P3 International:

http://www.p3international.com/products/special/P4400/P4400-CE.html

This provides a simple means of demonstrating the effectiveness of the product. To validate these results, the sample setup was also evaluated with a Yokogawa WT1600 Digital Power Meter:

The results for each meter are tabulated below. Only readings available for both meters are presented:

| Measurement | Without Compensation | | With Compensation | |
|---|---|---|---|---|
| | Kill A Watt | Yokogawa | Kill A Watt | Yokogawa |
| Volts | 116 | 116.76 | 116 | 116.91 |
| Amps | 5.17 | 5.22 | 1.37 | 1.379 |
| Watts | 170 | 174 | 154 | 158 |
| VAR | 576 | 580 | 43 | 32 |
| VA | 601 | 607 | 160 | 161 |
| PF | 0.28 | 0.2856 | 0.95 | 0.982 |

From this, it can be seen that the unit is effective in substantially reducing VA and current, with a 73% decrease. A power reduction of 9% is also seen.

## Analysis

The key to power savings are losses in the supply conductors. As mentioned previously, the sample setup contained approximately 50 feet of 18/2 wire. Without this wire, the $I^2 * R$ loss would not be as significant, thus the demonstrable power savings would not be as great. However, this is not necessarily an unrealistic representation, as the wiring in a home or factory would be of similar or greater length, though it would be of a larger diameter (#14 AWG minimum).

To represent this mathematically, the resistance of #18 AWG wire is approximately 7Ω per 1,000 feet. The wire bundle used two conductors of approximately 50 feet each, for a total approximate length of 100 feet. This equates to 0.7Ω of resistance. From the previous measurements, we see a current reduction of 3.8A. This yields a calculate $I^2 * R$ loss of 10W, while the measured power loss was 16W. Thus the majority of the power savings is due to the wire bundle within the box, with the shape of the current waveform also making a contribution.

For comparison purposes, this 50 feet of #18 wire is the equivalent of about 125 feet of #14 wire (15A circuit), or 200 feet of #12 wire (20A circuit).

Of course, beyond power savings to a consumer of electricity, an improved power factor presents benefits to the electric utility. As such, additional incentives exist for this technology.

## Conclusion

The concept of using a local capacitor for power factor correction is valid, and is well known in the electrical industry. The supplied system from KVAR Energy demonstrates this concept. In addition, many large suppliers, such as ABB and Square D, offer capacitor-based systems for larger scale power factor compensation. Fringe benefits to this technique include EMI filtering and surge suppression.

The primary challenge to this method lies in its implementation and real-world effects. Some considerations:

- If the capacitor is too large, the power factor may become negative.
- If the capacitor is too small, the full benefit will not be realized.
- Resonance near line frequency must be avoided.
- Harmonics on the AC mains can damage capacitors.
- Variable speed drives and other non-linear loads may not be compatible with this approach.

The target value of capacitance can be calculated based on the load's electrical properties, or determined empirically by varying capacitance and measuring results. In any case, if done correctly, a desirable shift in power factor and some degree of cost savings should result.

Respectfully Submitted,

SMT Engineering, LLC