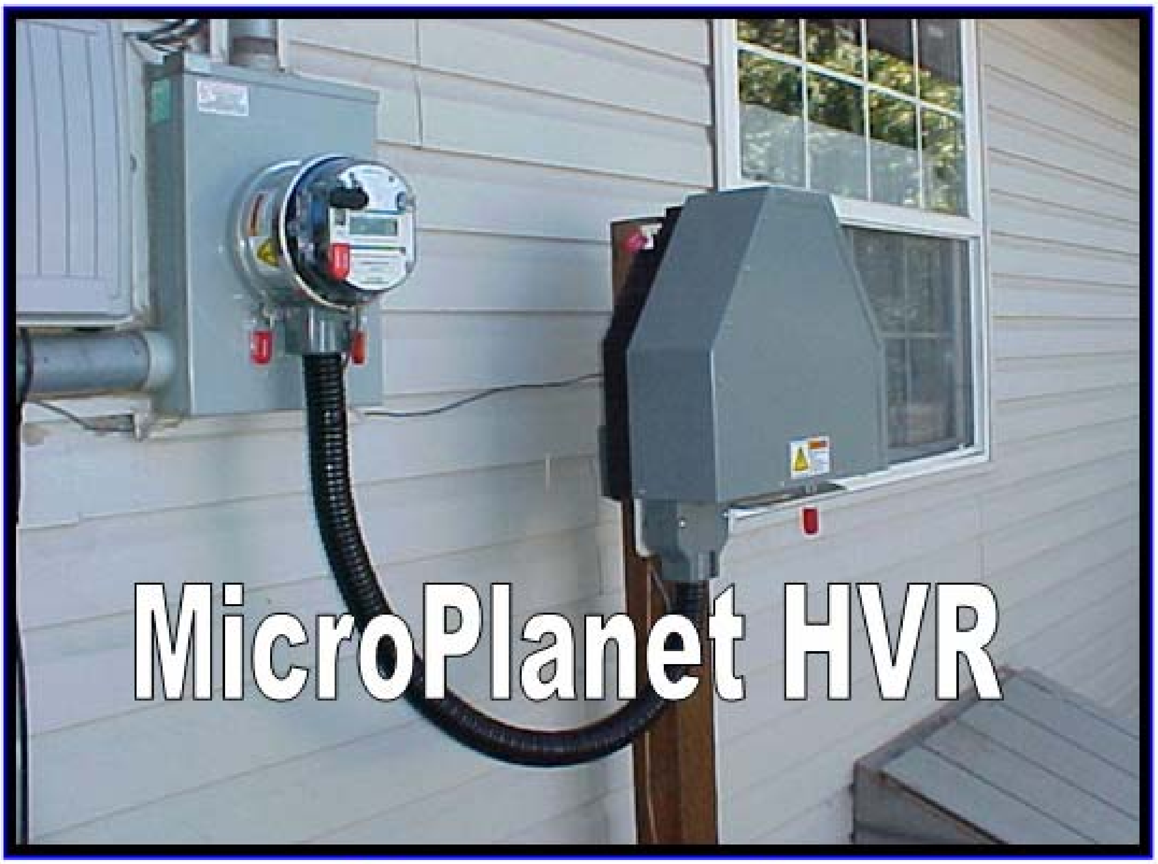
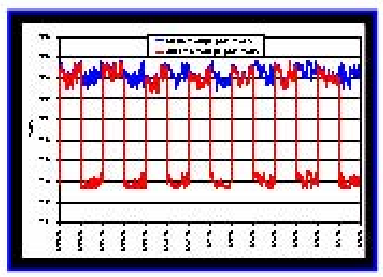
Customer Advanced Technologies Program
Technology Evaluation Report





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Contents

About the Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or under utilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), residential building shell construction, geothermal heat pumps, indirect/direct evaporative cooling, non-chemical water treatment systems and a wide variety of other technologies.

For more information, please visit: http://www.smud.org/education/cat/index.html

Introduction

Electric utilities strive to provide their customers with power at 'acceptable voltage levels' at all times (e.g. nominal voltage plus or minus 5%). Practically speaking this means that some customers receive voltage at the higher end, while others receive voltage at the lower end of the spectrum. Theoretically, customers receiving higher voltages are overdriving their equipment and wasting energy. However, if the supply voltage is too low, electrical equipment may be severely damaged.

In 2004 SMUD ran a series of tests on MicroPlanet Ltd.'s High Voltage Regulator (HVR) at its photovoltaic test laboratory at Rancho Seco. Using a dedicated transformer, a load bank, a welder and a photovoltaic inverter, the HVR was tested for resistive loads, reactive loads, and inverter compatibility. The results of the tests indicated that the HVR was capable of boosting and bucking (reducing) the voltage in accordance with manufacturer claims, as well as improving power factor.

Since the majority of SMUD's summer peak electrical demand is due to residential air conditioning systems, we were interested in assessing claims that residential vapor-compression air conditioning systems could operate more efficiently at lower voltages. In 2005, SMUD obtained a research grant from the American Public Power Association's Demonstration of Energy-Efficient Developments (DEED) program to evaluate the HVR's effects upon air conditioner performance. Project scope and objectives included:

- Conduct laboratory testing to determine the impact of voltage levels upon a 3.5-ton and a 5-ton conventional (vapor-compression) air conditioner.

Figure 1: MicroPlanet HVR
Source: www.microplanetltd.com

- Field testing a HVR on a small office building to assess impacts upon various loads including lighting, air conditioning systems and office equipment. Specific metrics included energy consumption, illumination levels, reliability and power quality.

To accomplish the project objectives, SMUD hired the Davis Energy Group to perform the laboratory testing. The field tests were completed by ADM Associates, Inc. as well as SMUD's power quality technician. Although the tests were limited to a laboratory and one test site, the results provided some interesting insights on the benefits and challenges associated with conservation voltage regulation.

Technology Overview

MicroPlanet Inc. currently offers products for voltage regulation for both residential and small commercial applications. Their voltage regulators are designed to maintain a desired voltage level by reducing or boosting incoming line voltage by ± 8.33 %. SMUD and other electric utilities strive to provide nominal voltage levels within a range of ± 5% – which translates to 114 to 126 volts for a standard 120 volt service. All of these devices have the ability to improve power factor, and their 3-phase product, 3P, also can correct voltage phase imbalances of up to 8%. According to the manufacturer's web site, (http://www.microplanetltd.com), main components and features include:

- Proprietary AC to AC power converter.
- Control board with a microprocessor for measuring the input and output voltage and controlling the AC-to-AC converter to precisely maintain a fixed level set by the customer.
- Patented, advanced pulse-width modulation technology to regulate voltage without creating harmonics.
- Thyristor board for short-circuit current fault protection.
- Metal Oxide Varistors (MOVs) for voltage transients.
- A torridal transformer that reduces the losses in the transformer by decreasing the excitation current.

Figure 2: MicroPlanet HVR shown with the cover removed. Source: www.microplanetltd.com

- An integral automatic bypass feature that allows uninterrupted electrical service to the customer in the event of a malfunction or electrical event that exceeds the operating limits of the device.

MicroPlanet HVRs weigh approximately 90 pounds and can be installed on the utility poles, on the side of buildings or on a dedicated pole. The regulators are fairly easy to install and can be ordered with a pre-wired harness and meter adapter ring (Figure 2). Technical specifications and detailed installation instructions for the HVR (residential product) and the 3P (commercial product) are available from MicroPlanet.

Energy Savings

The energy savings from this technology is based upon a strategy known as 'Conservation Voltage Regulation' (CVR). The main concept is that customers receiving voltage at the higher levels are overdriving their equipment and wasting energy. Although most electrical equipment is designed to operate at nominal voltage levels plus or minus 10%, there is often a definite "sweet spot" or optimal voltage. According to MicroPlanet, most equipment rated for 120 volts operates most efficiently at 114 volts. By lowering the voltage to 'optimal levels' customers may be able to reduce energy consumption by five to ten percent (depending on the original incoming voltage levels and the type of load).

Conservation Voltage Regulation is not new; from 1977 to 1985 the California Public Utilities Commission (CPUC) implemented this strategy (at the utility distribution circuit level) and issued a series of reports. A cover letter written by the Commission on February 20, 1986 contained the following statement: "Since its inception in 1977, the California CVR program has saved 20 billion kWh (cumulative total) at an average of 2.5 mils per kWh, making it an extremely cost-effective program."[1] The key difference between the Commission's program and MicroPlanet's approach is the point of regulation. The Commission's efforts focused on utility electrical distribution circuits while

[1] Source: California Public Utilities Commission File number S-2490, 199-2, 40010, CVR, 1985

MicroPlanet products are designed to be installed at the customer's electric panel. Installing the regulators at the customer site provides much more precise voltage regulation and hence the opportunity for greater savings..

Although CVR definitely saves energy, it is important to note that simply lowering the supply voltage level does not necessarily improve the **efficiency** of motors, lighting systems or any other connected load. When supply voltage levels are reduced, some of these systems will produce less work. For example, when the voltage at our test site was reduced 8%, the metal halide lamps lost an average of 22% of their light output. To help gain a better understanding of the potential energy savings and effects upon different types of equipment, SMUD employed a combination of laboratory and field tests.

Laboratory Testing

<u>Background Information</u>

SMUD hired the Davis Energy Group to conduct laboratory testing to:

1. Gather steady-state performance data on how different voltage levels affect an air conditioner's efficiency, cooling capacity, and power consumption.

2. Determine how changes in supply voltage affect power factor and total harmonic distortion.

During this project, three different vapor compression-cooling systems were tested under a range of nominal voltages ranging from 210 to 252 Volts (although the actual voltage varied slightly depending on the line voltage supplying the HVR). Tested equipment included:

- Prototype Davis Energy Group air conditioner.
- 3.5-ton York air conditioner (13 SEER).
- 5-ton York air conditioner (13 SEER).

The units were tested in an environmental testing chamber that provided the consistent cooling load needed to facilitate steady-state testing. Test 1 was used to simulate hot weather conditions (105°F) while Test 2 conditions are close to Air-Conditioning and Refrigeration Institute's (ARI) Energy Efficiency Ratio (EER) test (Figure 3).

During these tests the following parameters were monitored to determine the performance of the air conditioners at each of the test voltages.

- Air flow.
- Return air temperatures and humidity.
- Supply air temperatures and humidity.
- Air handler kW.
- Condensing unit kW.
- Refrigerant suction pressure at A-coil.

Outdoor Conditions	Return Air Condition	Nominal Voltage Condition
Start-up test conditions		
105°F	75°F dry bulb, 61.5°F wet bulb	240V
Test 1		
105°F	75°F dry bulb, 61.5°F wet bulb	252V
"	"	244V
"	"	238V
"	"	232V
"	"	226V
"	"	220V
Test 2		
95°F	80°F dry bulb, 67°F wet bulb	252V
"	"	244V
"	"	238V
"	"	232V
"	"	226V
"	"	220V
"	"	210V*

Figure 3: Test matrix showing the temperature conditions used during laboratory testing.

- Refrigerant condensing pressure.
- True Flow pressure differential (for airflow correlation).
- Pressure differential (Delta P) across air handler/furnace.
- Supply plenum pressure (with reference to ambient).
- Discharge pressure at condenser unit.
- Condensate collected in graduated cylinder (for calculating latent cooling).

The collected data was then used to calculate sensible cooling, latent cooling, total cooling and EER at both test conditions.

Performance Test Results

The results of the laboratory testing indicate that the two York units operated at a higher efficiency and a lower power demand as the voltage was decreased. Result trends were fairly consistent between the 3.5-ton and 5-ton unit and are summarized in the tables and graphs below. The results for the DEG prototype unit were inconclusive.

Performance Summary for 5-ton York (ARI Test 2 conditions)

Nominal Voltage	Actual Voltage	Power (kW)	Total Cooling Delivered (Btu/hour)	EER (Btu/Watt-hr)
252	246.6	4.82	38,980	8.61
244	244.2	4.76	38,770	8.66
238	237.4	4.70	38,630	8.76
232	231.6	4.60	38,950	8.99
226	225.2	4.55	38,870	9.03
220	219.3	4.41	39,060	9.31
210	211.5	4.47	38,890	9.22

Performance Summary for 3.5-Ton York (ARI Test 2 conditions)

Nominal Voltage	Actual Voltage	Power (kW)	Total Cooling Delivered (Btu/hour)	EER (Btu/Watt-hr)
252	253.8	3.96	33,930	8.56
244	246.3	3.84	33,090	8.62
238	239.1	3.73	32,870	8.81
232	232.8	3.63	33,060	9.10
226	226.8	3.68	33,620	9.13
220	220.8	n/a	n/a	n/a
210	211.8	3.55	33,190	9.36

[2] The HVR is capable of bucking or boosting voltage by 8.33% of the incoming voltage levels. In some tests the unit was unable to achieve the target voltage because of the incoming voltage level.

Figure 4: Results of performance tests for ARI Test 2 conditions.

The system Energy Efficiency Ratios were calculated using the total capacity values derived from the enthalpy calculation. Looking at these tables and charts, the following observations can be made:

- EER values for the 5-ton system increased 7.1% between 256.6 and 211.5 Volts.

- EER values for the 3.5-ton system increased 9.3% between 253.8 and 211.8 Volts. Unfortunately, the data for the 3.5-ton unit at 220 volts was compromised and is therefore not reported.

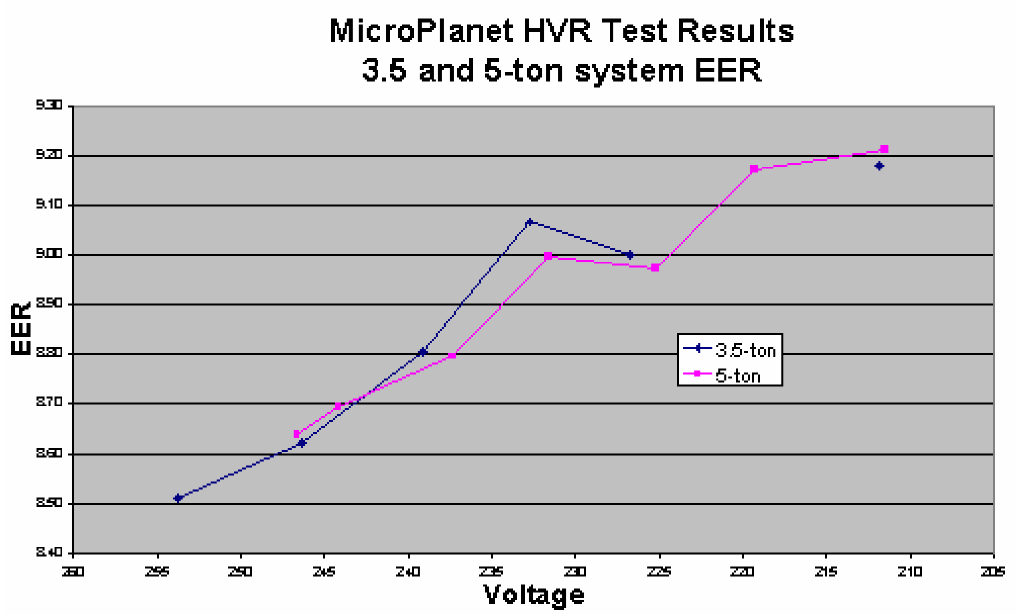


Figure 5: Results of performance tests for ARI Test 2 conditions.

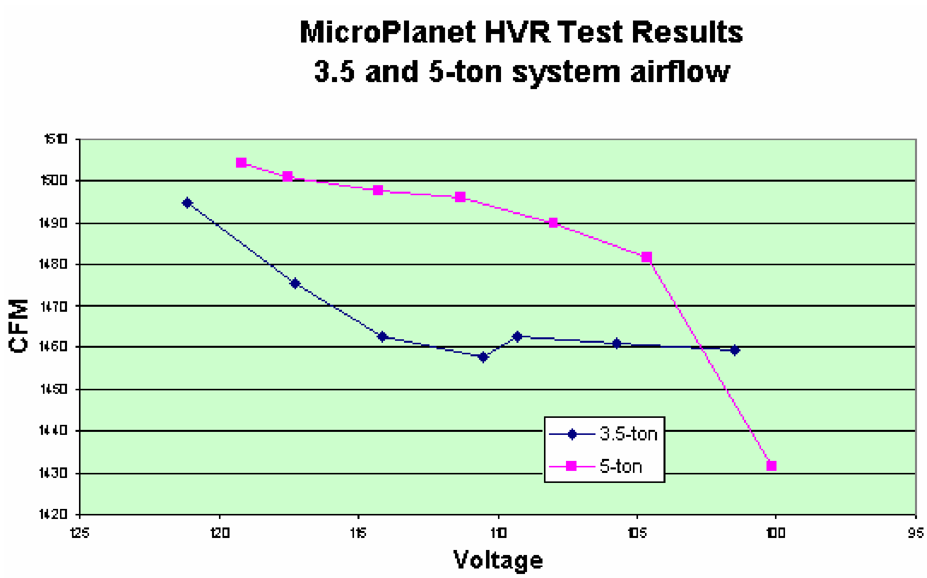


Figure 6: Measured changes in air flow delivered by the air handling unit.

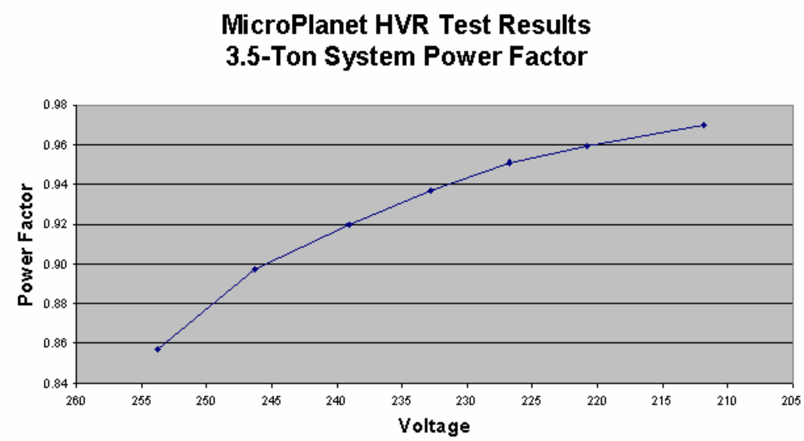
- Although at first glance, Figure 6 appears to show significant changes in airflow, the actual airflow deviations across the voltage ranges are relatively small - especially considering the improvements in EER shown earlier. The system airflow for the 5-ton unit was reduced by 5.1% across the range of voltages, while the 3.5-ton system, airflow was reduced 2.5% (note that the voltage is presented as the single-phase voltage at the air handler blower).

- For a 220 volt service, 253 volts represents an over-voltage condition of 15%. It is unlikely that many customers actually receive voltages at this level--especially at the air conditioner itself since voltage drops between the electrical service panel and the air conditioner may be quite common.

- MicroPlanet voltage regulators are limited to ± 8.33% of the incoming voltage. Therefore if the incoming voltage was 253 volts, the HVR would be able to lower it to only 232 volts.

Power Factor

Power factor for both the 3.5 and 5 ton units improved considerably as the voltage was lowered (please refer to Figure 7). The power factor increased 10.3% over the range of voltages for the 5-ton unit and 13.2% for the 3.5-ton unit. This increase in power quality represents a significant improvement due to the HVR. However, since the HVR is limited to bucking or boosting incoming voltage by ±8.33% of the current incoming voltage level, the voltages for the two tests shown below varies slightly.



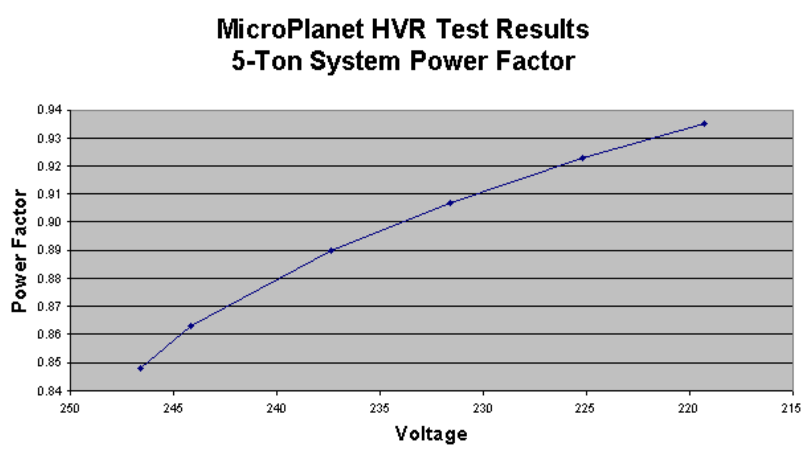


Figure 7: Power factor trends for the 3.5-ton and 5-ton units at 80F dry bulb and 51% RH return air.

Conclusions from Laboratory Testing

Tests conducted by the Davis Energy Group indicate that two HVAC units operated at a higher efficiency and a lower power demand as the voltage was decreased. Results for the 3.5-ton and 5-ton York units are summarized in Figure 8.

HVR Performance Summary

Unit	Voltage Range (V)	Demand (kW)	Capacity (Btu/hour)	EER (Btu/W-hr)	Airflow (cfm)	Power Factor
5 ton	246.6 to 211.5	-7.3%	-0.2%	7.1%	-5.1%	10.3%
3.5 ton	253.8 to 211.8	-10.4%	-2.2%	9.3%	-2.5%	13.2%

Figure 8: Summary of Davis Energy Group's performance testing.

Field Testing

Background Information

SMUD chose to test the HVR at a produce packaging plant that was experiencing voltage fluctuations during their busiest time of the year. The HVR was installed on the single phase, 200-amp electrical panel that serves the plant office, a storage room and an area used to pack carrots (total area of approximately 2,010 ft^2).

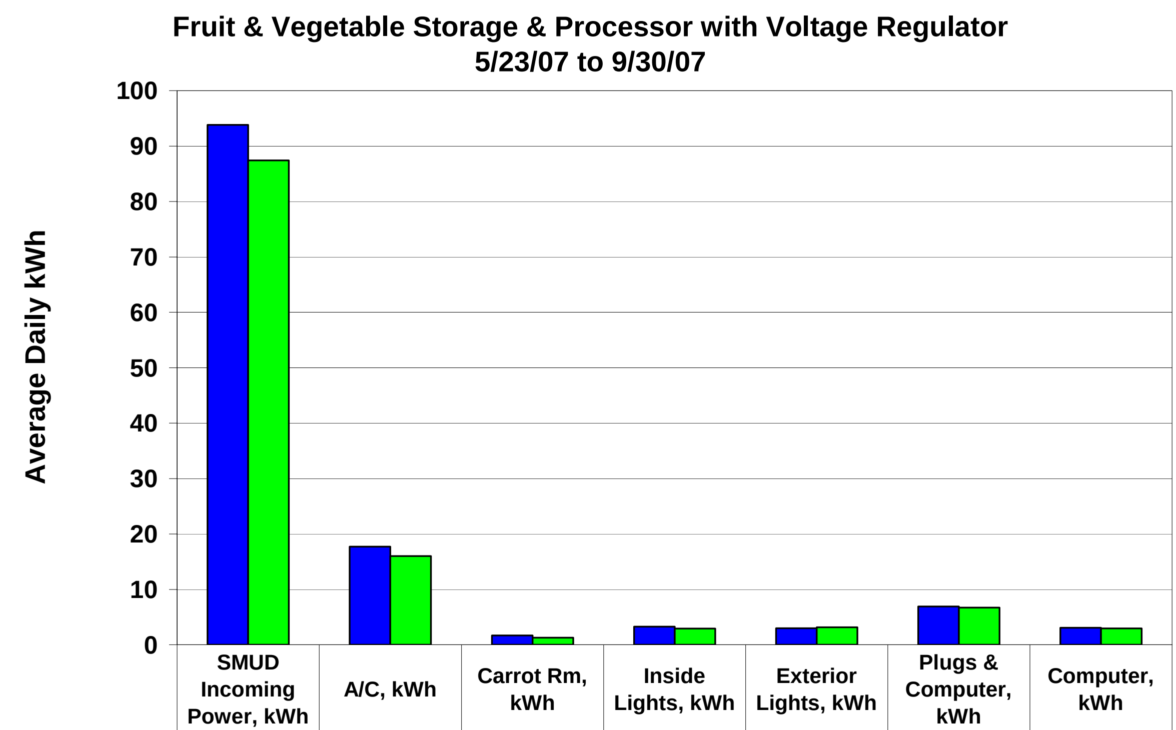
During the summer of 2006, SMUD's power quality technicians conducted monitoring. Unfortunately, when the data was downloaded and carefully analyzed, we discovered that the HVR had operated in somewhat of an erratic fashion. Since the cause of this problem was never determined, MicroPlanet requested additional testing with a newer version of the HVR and provided the new unit at no cost. Unfortunately, since the electrical load at the produce packaging plant is seasonal and varies considerably, the monitoring was discontinued until the summer of 2007.

In 2007, SMUD hired ADM Associates, Inc. to monitor the electrical consumption of the various loads within the office and storage area to determine the energy impacts of the HVR. ADM was also asked to measure illumination levels and motor speeds to determine the effects of lower voltage levels upon the performance of these systems. The monitoring period was from May 23, 2007 to September 30, 2007. Monitored systems included:

- Electrical energy consumption for the entire office.
- Fluorescent lights.
- Metal halide lights.
- One 4-ton air conditioner.
- Conveyor belt motors (carrot packing room).
- Office and computer equipment.

Energy Savings

The HVR was set up to regulate on alternate days during the monitoring period. The energy consumption data was collected for approximately four months and then organized into average daily kWh values for periods when the HVR was actively regulating the voltage as well as when it was inactive. The results are shown in Figure 9 below.



	SMUD Incoming Power, kWh	A/C, kWh	Carrot Rm, kWh	Inside Lights, kWh	Exterior Lights, kWh	Plugs & Computer, kWh	Computer, kWh
VR Not Active	93.83	17.69	1.68	3.26	2.99	6.92	3.08
VR Active	87.41	16.00	1.25	2.94	3.14	6.73	2.95

Figure 9: Average daily kWh values for various loads regulated by the MicroPlanet HVR.

Using the above data and assuming the HVR was in constant operation (instead of only every other day), the energy savings during the monitoring period may be calculated by multiplying the average daily kWh savings by the number of days in the entire monitoring period (131 days). Using this formula for the individual loads and the total panel yields the following results:

Air conditioner	221 kWh	9.5% reduction in daily kWh
Carrot Room	56 kWh	25.6 % reduction in daily kWh
Inside lights	42 kWh	9.8% reduction in daily kWh
Exterior lights	0	no savings
Plugs & computer	25 kWh	2.7% reduction in daily kWh
Computer	17 kWh	4.2% reduction in daily kWh
Total load*	841 kWh	6.8% reduction in daily kWh

* **Note:** not all of the loads on this panel were individually monitored. This is why the savings for the total load is greater than the sum of the listed individual loads.

Taking the next step, we may use the monitoring data to calculate a rough estimate of the annual energy savings at this site. Keeping in mind that the air conditioner and carrot room motors are used only during the summer months, and assuming that the monitoring data reflects the schedule, a rough estimate of the annual energy savings may be calculated as follows:

Total kWh saved /day x 131 days / year
+ (Total kWh saved/day – AC & carrot room kWh/day) x (365 -131 days)
Estimated annual kWh savings

6.42 kWh /day x 131 days / year
+ (6.42kWh/day – 2.115 kWh /day) x 234 days/year)
Estimated annual kWh savings

841 kWh
+ 1,007 kWh
1,848 kWh / year

Figure 10: Carrot packing room

Financial Summary

Assuming an energy rate of $0.10 per kWh, the annual cost savings for this small office would be approximately $184. Since the installed cost for the HVR was $2,523, the simple payback for this particular site would be: $2,523 ÷ $184 /year = 13.7 years. Although this is indeed a long payback, it is **very important** to note the following:

- The building served by this account was rather small and much of the equipment was operated only on a seasonal basis. In fact the average electrical load for this panel was only 34 amps - only 1/5 of the HVR's capability. Using this same HVR on a facility with a higher electrical load would have undoubtedly resulted in much higher savings and a shorter payback period.

- MicroPlanet's next generation HVR (also a 200A unit) will go into production in early 2008. As manufacturing volume ramps up, MicroPlanet expects the pricing to fall substantially below $2,000 in 2008 and be below $1,000 within the next few years.

- The energy rate for this customer is well below that of many commercial customers in California. Customers with higher energy rates should experience greater financial savings.

Performance Test Results

As mentioned earlier in this report, when the MicroPlanet HVR regulates voltage it also improves power factor. This may be important for customers with poor power factors or utilities with overloaded distribution lines. Figure 11 shows average values for kW, kVA and KVAR from the test site. Note the table

	Regulated	Unregulated	% Difference	CVR Factor
Average kW	3.66	3.95	7.4%	0.94
Average kVA	3.80	4.14	8.4%	1.07
Average kVAR	1.00	1.24	19.6%	2.49
Average Voltage	113.9	123.6	7.9%	n/a

Figure 11: Average electrical values during monitoring period

includes a column for "CVR Factor." CVR or Conservation Voltage Reduction Factor (CVR) is simply a metric used to show the mathematical relationship between voltage and other parameters. For example: at this test site, kVAR was reduced 2.49% for every 1% in voltage reduction. CVR will vary for different sites depending on the types of electrical equipment within the facility.

The chart shown at the right (Figure 12) shows the voltage levels for a 120-volt circuit. The effect of the HVR when it is engaged clearly can be seen. Note how tightly the voltage level is controlled when the HVR is active.

Figure 13 shows energy consumption trends for the air conditioner at the demonstration site. Note the reduction in kWh during periods when the outside air temperature exceeded 90°F. This trend would seem to confirm the results of the laboratory tests discussed earlier in this report.

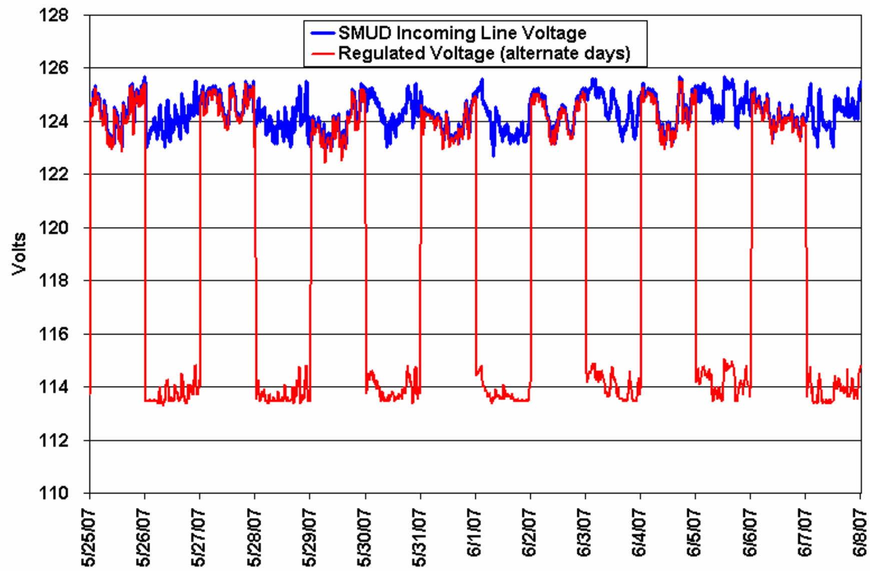


Figure 12: Measured voltages levels for a 120-volt circuit.

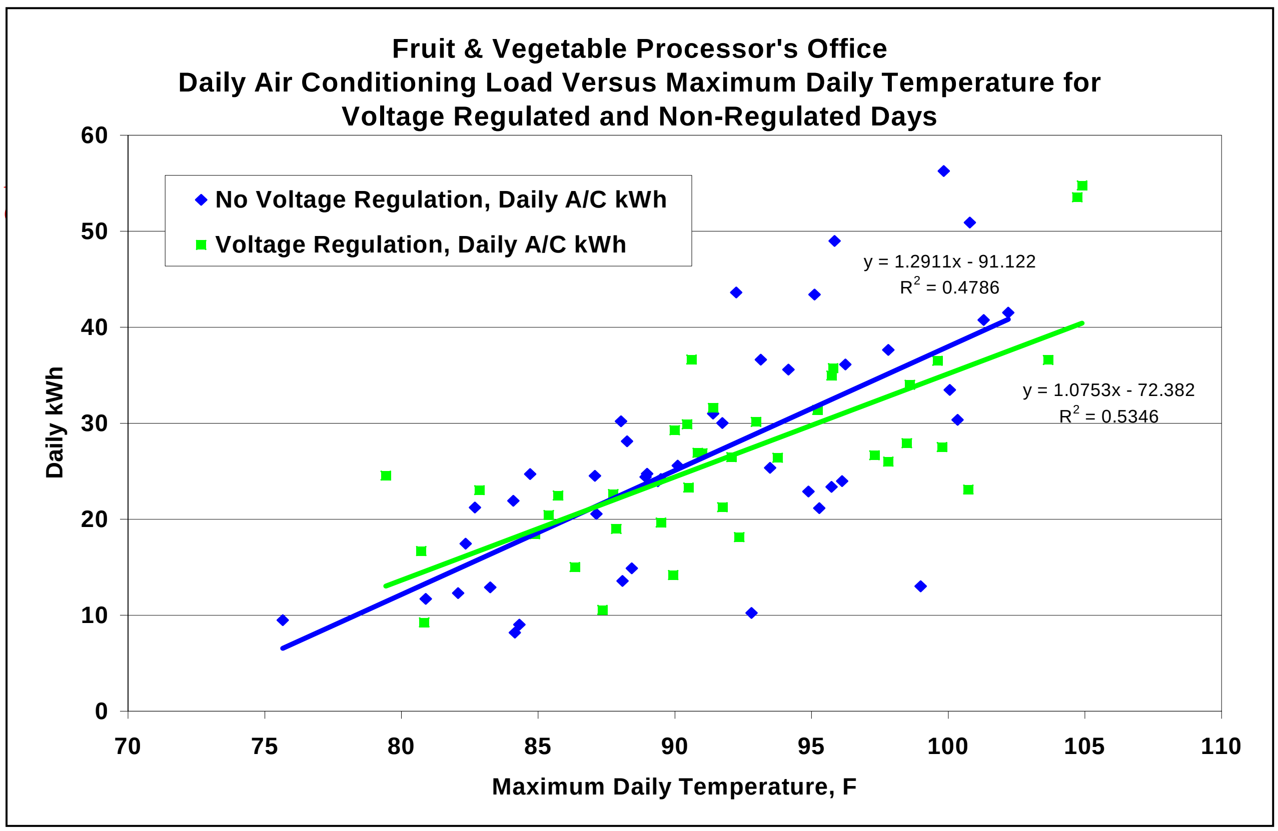


Figure 13: Daily kWh values for the air conditioner shows significant savings during hotter weather.

The lighting systems for the office areas include T8 fluorescent lamps and electronic ballasts while the carrot room uses 70-Watt metal-halide fixtures. When the MicroPlanet HVR was in operation, illumination levels were relatively unchanged for the fluorescent systems. However, the light output of the metal halide fixtures was reduced by 22% while the energy consumption dropped by 25.6%.

ADM also measured the speed of the conveyor belt motors. The HVR had a negligible affect upon the speed of the motors - a reduction of only 1%.

Conclusions

Summary

Although the scope of this project was limited to laboratory tests and one test site, the results suggest the following applications could possibly merit the use of a HVR:

- Reducing line voltage where it is consistently high to improve cooling system efficiency and save energy. **The overall energy savings for this demonstration site was 6.8%**.
- Boosting line voltage up where it is low to meet minimum requirements.
- Mitigating voltage flicker and improving power factor--especially where power available from the utility is "dirty" due to neighbors using highly reactive power loads.

Some Important Considerations

Customers thinking about using a HVR need to consider:

- Cost effectiveness: Is the MicroPlanet HVR cost-effective based solely upon energy savings? Since voltage levels are affected by many factors – storms, load conditions, traffic and construction accidents (to name just a few) accurately estimating energy savings could be a daunting task. The voltage at our test site was 124 volts, so the HVR was able to produce significant savings. However, is 124 Volts typical of other sites? Fortunately several other agencies are conducting much broader tests and pilot programs to help answer this question and quantify potential savings for different applications. For more information about these efforts, please contact MicroPlanet at (206) 625-0851 or www.microplanet.com.
- Application: Voltage drops between the electrical service panel and electrical equipment such as air conditioners may be quite common. Care must be taken when choosing a set point to ensure electrical equipment receives the proper voltage. Fortunately, unlike fixed tap transformers, the MicroPlanet HVR has an adjustable setpoint (within ± 8.33%) and actively adjusts the voltage levels.

Technology Transfer

The results of this project have been forwarded to SMUD's Efficiency Program Planners for consideration for inclusion into SMUD's energy efficiency rebate programs.

Acknowledgements

We gratefully acknowledge the contributions made by:

1. American Public Power Association (APPA) for providing a grant to support this research project through the Demonstration of Energy-Efficient Developments (DEED) program.

2. Davis Energy Group Inc., Davis CA. www.davisenergy.com.

3. MicroPlanet Inc., Seattle, www.microplanet.com.

4. ADM Associates, Inc. www.adm-energy.com.