Variable Speed Drives for Car Wash Vacuum Systems

ET 08.15 Report

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ABBREVIATIONS AND ACRONYMS

CZ	Climate Zone
CT	Current Transformers
DEER	Database for Energy Efficient Resources
ET	Emerging Technology
FLA	Full Load Amps
HP	Horse Power
Hz	Hertz
inHg	Inches of Mercury
kW	Kilowatt
kWh	Kilowatt Hour
PI	Proportional Integral
PLL	Phase Locked Loops
RPM	Rotations Per Minute
SCE	Southern California Edison
V	Volt
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

FIGURES

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EQUATIONS

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EXECUTIVE SUMMARY

This field evaluation accesses the viability of the variable speed drive (VSD) technology and measures the potential and incremental energy savings and demand reduction when compared to conventional type constant speed vacuum pump motors in the car wash industry. This field evaluation further demonstrates the difference in the operation of a VSD compared to the baseline/constant speed vacuum pump motor. The vacuum system is a significant component of a car wash and is used to vacuum the interior of a car when a customer purchases a car wash service. Typically, these vacuum pumps operate by a conventional constant speed motor that is turned “ON” when a facility opens for business and runs constantly at full-speed until the end of each business day. As a result, a car wash uses the same amount of energy regardless of the number of cars actually serviced.

VSDs can be retrofitted on an existing vacuum pump and piping system to realize energy savings when the system is idle or running at a very low load. VSD is a system that controls the amount of rotations per minute (RPM) of a motor by modulating load-side power frequency in response to the pressure feedback signal provided by the feedback loop transducer. This helps in maintaining a constant vacuum pressure in the main duct to which the hose drops are connected. The VSD evaluated in this project is a three-phase drive connected to a conventional motor that supplies vacuum pressure to the hose drops where cars are vacuumed.

Test sites were selected in order to include various size car washes (small, medium and large) and to analyze the impact and savings potential of a VSD. Site 1 had two vacuum pump motors each rated at 20HP (total 40HP); site 2 had one 20HP vacuum pump motor and; site 3 had one 10 HP vacuum pump motor. Measurements taken in the field verify the energy savings and demand reduction of a VSD compared to the baseline. Additionally, spot measurements for change in vacuum pressure were recorded with the corresponding change in motor speed. Pressure changes were recorded in order to observe the affect of VSDs on the mechanical performance of a vacuum pump motor.

Site 1 was not included in peak demand and annual energy savings calculations due to the improper controls of VSD implemented at this site. The first VSD was controlled by the pressure feedback signal and the second VSD was control by the frequency output of the first VSD. This type of control for the second VSD eliminated the feedback control provided by the pressure transducer. Therefore, the two VSDs are operating with different settings. This set up does not provide a direct comparison to the normal

operation of conventional constant speed vacuum pump motors. Due to this reason, this site was abandoned. Since the control methodology for two VSDs performing similar function was not comparable this site was abandoned. At Site 2 maximum power demand seen during the VSD test was approximately 11 kilowatts (kW) and the peak demand reduction was 39%; and at site 3 maximum demand seen during VSD tests was close to 2 kW and peak demand reduction was approximately 18%.

The average demand reductions and energy savings revealed during these field evaluations are listed in Table 1.

TABLE 1. AVERAGE KWH PER CAR PER HP FOR ALL TEST SITES

SITE NAME	SIZE OF TEST SITE	ANNUAL ENERGY SAVINGS (KILOWATT HOUR (KWH)/YR.)	PEAK DEMAND REDUCTION (KW)	% ANNUAL ENERGY SAVINGS	% PEAK DEMAND REDUCTION
Site 2	Medium	10,793	4.23	38.71%	24.8%
Site 3	Small	2,259	0.42	17.73%	22.04%

These savings are an estimate based on the 1 month field monitoring performed at each test site and all testing sessions started with clean filter bags.

Spot pressure readings were also recorded in order to determine any variation in vacuum pressure at the hose drops when the VSD settings were implemented. On average, pressure remained very close to the optimal pressure of 4 inches of mercury (in Hg) that is required to perform an adequate job while operating a VSD. On the other hand, pressure recorded at the minimum load condition during constant speed settings was higher than the optimal pressure. This high pressure required additional effort from the employees to vacuum the cars and also resulted in higher power demand when fewer cars were serviced.

In addition to these tests the Kilowatt-Hour (kWh) per car per horsepower (HP) at each site was also calculated in order to provide a benchmark for savings of a VSD over a conventional constant speed motor. These calculations provide a savings estimate that may be seen at a car wash depending on the size of the motor installed and the average number of cars serviced by the facility. Results from the test sites are listed in Table 2.

TABLE 2. AVERAGE KWH PER CAR PER HP

Test Site	Installed HP	Average Number of Cars per day	Average kWh		Average kWh per Car		Average kWh per Car per HP		Energy Savings (kWh/Car/HP)
			VSD Test	Baseline/ Constant Speed Test	VSD Test	Baseline/ Constant Speed Test	VSD Test	Baseline/ Constant Speed Test	
Site 2	20	186	89.64	119	0.48	0.64	0.024	0.032	0.008
Site 3	10	72	21.88	28	0.30	0.38	0.03	0.038	0.008

Error analysis of the data collected during this field evaluation resulted in a less than 1% average error at all test sites. These results provide high confidence in the data collected and the results presented in this report.

It can be concluded that a VSD is a viable replacement for constant speed motor control of a vacuum pump in a commercial setting. The recommendation is that the size of the motor drive system and correct implementation of the program settings of the VSD be considered in order to realize the potential savings, otherwise a VSD can cause higher demand and diminish any prospective energy savings.

INTRODUCTION

BACKGROUND

A vacuum system is a significant component of the electrical load of a car wash and typically includes a vacuum pump motor, piping system, vacuum filter bags, and end-use hose drops. Hose drops are used to vacuum the interior of a car when a customer purchases a car wash service.

Historically, these vacuum pump motors run at a constant speed during the hours of operation regardless of the number of cars serviced, resulting in high power demand and energy consumption. Furthermore, running vacuum pumps at a constant speed increases vacuum pressure at the hose drops even when it may not be necessary (typically 4 (inHg) inches of mercury); this means the same amount of power is used to vacuum one car as is used to vacuum 10 cars. With the addition of variable speed drives (VSDs) this pressure can be controlled.

A VSD is a system that controls the rotations per minute (RPM) of a motor by modulating the load side power frequency. This is achieved by using a feedback control that detects the vacuum pressure near the hose drops where cars are being vacuumed. This feedback pressure is then compared to a setpoint pressure pre-selected by the car wash owner. Any difference in setpoint and feedback pressures triggers the VSD to automatically adjust the load frequency of the motor to provide optimal pressure at the hose drops.

Using this approach, demand is automatically adjusted as the load fluctuates (e.g., the number of cars vacuumed at a given point in time). When a car wash gets less busy or idle, VSDs detect high pressure at the hose drops through the feedback signal and triggers the vacuum pump motor to slow down by reducing the load frequency and the RPM of the motor. When this process is continually repeated throughout the day, both energy consumption and operational costs are reduced. Conversely, as the car wash gets busier, VSDs allow the vacuum pump motor to ramp up in order to provide optimal pressure at the hose drops servicing the cars. Change in speed is achieved by the modulation of load frequency going into the motor; lower line frequency forces the motor to run at a lower RPM and vice versa. The VSDs tested in this project have a similar pressure feedback loop. This process optimized demand and energy consumption at the car wash test sites.

Within the Southern California Edison (SCE) service territory there are 1,179 car washes with the potential to consume approximately 61,000 kilowatt hour (kWh) per car wash per year and a total of 71,919,000 kWh per year. Therefore, the VSDs are a viable option to reduce demand and increase annual energy savings.

ASSESSMENT OBJECTIVES

The primary objectives of this emerging technology (ET) assessment of the VSD applications for car washes are to:

- Evaluate the energy savings, if any, after installing a VSD on the vacuum pump of a car wash.
- Evaluate the peak demand savings during the field test, if any, after installing a VSD.
- Estimate the annual energy savings and peak demand reduction.

This field evaluation also addresses customer concerns. Due attention was paid to the comfort of employees when the constant speed motor was switched to a VSD and the pressure at the hose drops changed.

In order to meet the primary objectives of this evaluation, the following steps were taken.

1. Installed monitoring equipment on the service panel of the tested vacuum pump motors.
2. Performed baseline tests in order to quantify constant speed performance.
3. Compared recorded data with the motor manufacturer's specifications to verify the recorded data.
4. Programmed the VSD to replicate a conventional constant speed motor. Monitored this operation using the data acquisition equipment.
5. Recorded energy consumption of the motor and compared with it and without a VSD.
6. The pressure changes were quantified and any loss or deviations in optimal pressure were accounted for as a result of installing a VSD.

In conclusion, this project provides the assessment results needed to confirm the electrical energy savings and peak demand reduction potential to SCE and for reducing future utility system peak power demand and long-term energy consumption.

TECHNOLOGY DESCRIPTION

BASELINE TECHNOLOGY

The baseline for this field evaluation is a constant speed motor controlled by an across-the-line starter with a simple "ON" and "OFF" operation. A typical car wash facility has a constant speed motor that is turned "ON" when the facility opens and runs at a constant speed throughout the day regardless of the number of cars vacuumed. The worst case scenario is when no cars are washed or vacuumed and the vacuum pump motor still runs at full speed.

Since VSDs were already installed at each test site, their settings were modified to mimic a constant speed motor operation. There was some loss associated with the settings, which are accounted for in the savings calculations.

VARIABLE SPEED DRIVE SYSTEMS

Each car wash site has a VSD system already installed on their vacuum pump motors. The VSD systems have various hardware components including:

- **Vacuum Producer:** Produces the suction pressure required at the hose drops to vacuum cars. There are two types of vacuum producers available:

FIGURE 1. CENTRIFUGAL VACUUM PRODUCER

  - **DIRECT DRIVE:** A compact industrial vacuum producer that includes impellers, an extended shaft, and varied intake and exhaust openings used to optimize the suction pressure at the load.
  - **CENTRIFUGAL VACUUM PRODUCER:** A multi-stage exhauster that uses a rotating impeller to produce pressure and increase flow rate.
- **Filter Separator:** Combines the vacuum pressure and a cyclonic action to separate debris and dirt from air and guide it to the bottom of the filter separator. There are two types of filter separators available for the different VSD applications:
  - **PRIMARY SEPARATOR:** In this separator, air is pulled through vacuum hoses and the piping that contains dirt passes around a baffle. Debris and dirt drop into a waste container while air and any remaining particles move into the filter separator. The primary separator can be used in heavy flow conditions and underground piping systems. Other applications can use only the filter separator.

FIGURE 2. PRIMARY SEPARATOR

- **FILTER SEPARATOR:** This separator combines centrifugal action with the dust-trapping capability of filter bags. As the vacuum producer creates suction it pulls air, dirt, and debris through the vacuum hose into the lower half of the filter separator. The debris is guided downward into a waste container using a cyclonic action. The air then passes through a series of filter bags contained in the upper portion of the filter separator.

FIGURE 3. FILTER SEPARATOR

- **Piping Kit:** A piping kit delivers suction to the point of use via a piping system installed at the facility, and then carries air and debris through a filtration device, and back to the vacuum producer. A piping kit is referred to as hose drops in this report.

FIGURE 4. PIPING KIT

- **Variable Frequency Drive (VFD):** A VFD is an electronic motor control designed for motor-driven centrifugal vacuums and pump systems that automatically adjusts motor speed to a changing load requirement system that manages vacuum motors. It includes a VFD and customized software.

FIGURE 5. VARIABLE SPEED DRIVE WITH A KEYPAD MOUNTED ON FRONT

- **Pressure Sensors:** Pressure sensors provide a feedback signal to the VSD that guides the vacuum producer to increase or decrease the amount of pressure sent into the piping system. This pressure fluctuation is based on the number of cars being serviced at a specific point in time at the facility.
- **Keypad:** The keypad provides a user interface to program or modify the programmed settings of the VSD, when required. The keypad is attached to the VSD and can be detached and operated via a network cable for easy access.

PARAMETER CONFIGURATION

Besides the sizing of a VSD (dictated by the size of the motor), parameter configuration also has an influence on the amount of savings that can be achieved on a motor using a VSD. However, parameters need to be configured according to the facility and its typical loading conditions. Settings that are successful at one car wash do not guarantee energy savings at another car wash that uses the same program settings.

The VSD systems installed and tested at all three test sites are from the same manufacturer and use various parameters to influence the frequency and speed change of the motor. Key parameters that influence the motor speed include:

- **Minimum Pump Frequency:** This frequency sets the lower limit of the operating limits of a vacuum pump motor. The VSD does not allow the motor to run below this setpoint and hence saves the motor from running at an extremely low frequency that can adversely affect the life of a motor (0-100 Hertz (Hz) on a 60 Hz base system).
- **Motor Rated Full Load Current:** This parameter is also known as full load amps (FLA) and defines the current rating of the drive.
- **Proportional Integral (PI) Setpoint:** This setpoint is the preset speed at which the motor runs during full load conditions. When setpoint values are near 100% (e.g., 60 Hz), the motor starts behaving as a conventional constant speed motor. This setting may result in higher demand and lower cost savings. This parameter typically ranges from 0-100% where 0% represents 0 Hz and 100% represents 60 Hz. For variable speed settings, the PI setpoint is usually set below 50%.

- **Stopping Method:** The stopping method is usually determined by the application for which the VSD is used. For example, at the test sites in this evaluation, the “Coast to Stop” setting is used to decrease the impact on the motor when it stops.

EQUIPMENT COST

The cost of a VSD system is dependent on the size of the motor. Typically, a 20 HP VSD system costs approximately $6,500 and a 10HP system costs approximately $4,500. This includes installation and drives cost as provided by the owner. However, the price point varies for smaller or larger motors depending on their horsepower and the site condition.

TEST METHODOLOGY

To evaluate field performance and to demonstrate how a VSD reduces energy costs, each test site's vacuum pump energy and demand use was monitored.

VSD MONITORING PERIOD

After the test sites were selected, the system configuration was recorded. Circuit breaker service panel ratings and motor name plate ratings were also identified for the vacuum pump motor. This information was used to finalize the selection of instrumentation used to monitor electrical and mechanical parameters.

The VSD evaluation was conducted for a period of two weeks when the vacuum pump motor was running at variable speed settings. Since VSD systems were already installed at the test sites, monitoring and recording equipment was installed to monitor and record the VSD demand data. Instrumentation installed at all test sites was allowed to monitor for 24 hours after the initial installation. Data recorded during this period was downloaded and analyzed to ensure proper installation and functioning of the monitoring equipment. If any deviations were detected the connections were checked to correct any errors in installation or programming of the monitoring equipment. Spot real-time readings of a Fluke® meter (Fluke 43B) were compared with the real-time data of monitoring equipment to ensure accuracy of the installation. After proper installation was verified, data monitoring and acquisition equipment were left at the test site for a period of two weeks to establish an average profile of a car wash during weekdays and weekends. Data was downloaded periodically to minimize any data loss. However, one of the meters stopped recording data during a portion of the monitoring sessions for unknown reasons. Eventually the meter was replaced to avoid further data loss. Testing duration was extended accordingly in order to recover the time lost.

VSD SETTINGS ADJUSTMENT

After monitoring of the vacuum pumps with VSD settings was concluded, the drives were programmed to run the vacuum pump motors at a 100% PI setpoint value (60 Hz constant speed operation). Baseline monitoring and data acquisition was conducted using these settings. Any losses introduced in the recorded data due to these VSD settings during the base lining period are accounted for in the data analysis.

BASELINE/CONSTANT SPEED MONITORING PERIOD

The baseline evaluation was conducted for a period of two weeks when the vacuum pump motor was running at a constant speed with a simple ON/OFF operation. Typically, motors were turned "ON" when the car wash opened for business and turned "OFF" at the end of operating hours. During the time of operation, vacuum pump motors were allowed to run at a constant speed regardless of the number of cars passing through the car wash.

After the VSD was switched to run at a constant speed, the data quality was checked as was done for the VSD evaluation period. Loggers were allowed to record data for 24 hours and data was evaluated to ensure proper functioning of the system.

PRESSURE MEASUREMENTS- MINIMUM- AND FULL-LOAD TEST

In addition to power monitoring, another set of tests were performed to observe the change in pressure at the hose drops when the facility was running at full load and all of the hose drops were used, and again when the facility was running at minimum load and only one hose drop was used. These tests were performed with the VSD and constant speed settings on the vacuum pump motor. The objective of this test is to observe the mechanical performance of the VSDs under the best and worst conditions. (The best condition is the minimum load and the worst condition is the full load.) The results of the VSD were compared to baseline/constant speed test results.

Ideally, during minimum load conditions pressure should be approximately 4 inches of mercury (inHg) in a vacuum across all of the hose drops. At full load pressure when all of the hose drops are used, a vacuum pump motor should be able to maintain that pressure. Overall, a vacuum pump should be able to maintain fairly constant pressure across all of the hose drops under any condition in order to do a satisfactory job.

These tests were performed every time power data was downloaded. Tests were performed using an analog hand-held pressure gauge.

Each testing session started with the clean filters at all test sites. Power data was recorded at an interval of one minute at every test site. A high sampling rate (256 times per wave cycle) was used in order to achieve high accuracy and resolution. This also aided in capturing small transients and harmonic distortion that occurred due to the VSDs.

MONITORING EQUIPMENT

The field evaluation used the Dranetz BMI PowerXplorer PX5 to monitor power. This device has four independent differential channels for voltage measurements and uses current transformers (CT) to record the amperage readings. Voltage and current readings fed to the PX5 are used to calculate demand and energy consumption at the test site.

The PX5 samples each wave cycle of amperes and volts on each channel 256 times. This means that the voltage and current are sampled continuously. It also administers phase locked loops (PLLs) that automatically adjust the sampling rate according to the line frequency. This allows the PX5 to capture the smallest power variations with the change in frequency of VSDs. The PX5 also has the capability to capture high speed transient and harmonic measurements but analyzing these variables is beyond the scope of this field evaluation.

MONITORING EQUIPMENT SETUP AND PROGRAMMING

The data acquisition equipment, PX5, used in this field evaluation is a touch screen programmable device and is capable of monitoring the following circuit types:

- Three-phase delta
- Three-phase wye
- 2 1/2 element
- Split single-phase
- Single-phase
- Generic

Test sites were set up as three-phase wye circuit monitoring with the exception of one test site where two three-phase wye circuits were monitored using a generic configuration. Figure 6 shows a sample of a typical PX5 configuration for a test site.

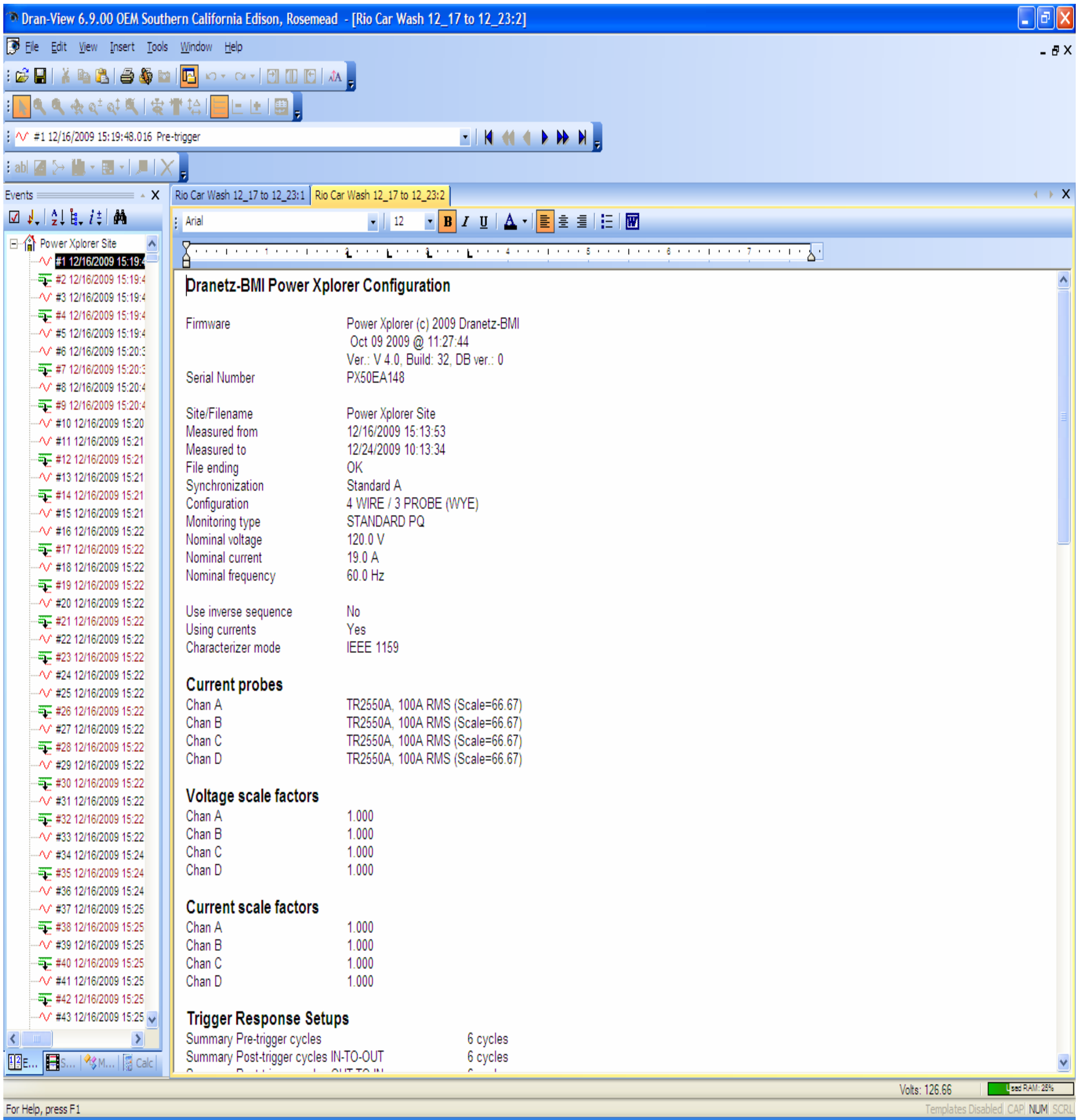

FIGURE 6. SETUP PROGRAM USED AT TEST SITES

Dranetz BMI's PX5, CT model# TR 2550A and voltage leads were installed on the electrical circuit breaker panel at each test site. Output of the CTs and voltage leads fed into the PX5 data acquisition equipment. Data monitoring and acquisition setup display in Figure 7.

FIGURE 7. FIELD MONITORING EQUIPMENT SETUP

Data was sampled every one minute to achieve higher accuracy. The measurements included sampling for voltage, current, power factor, demand, and energy consumption. Harmonic and transients were captured every five minutes in order to see the effect of VSDs on wave shapes of voltage and current.

ACCURACY OF THE MONITORING EQUIPMENT

Electrical service for each vacuum pump at all test sites was either 480 volt (V) delta or 208Y/120V circuits. To monitor the 480/208V circuits, a PX5 was used and CTs were sized according to the amperage rating of the respective circuit being monitored. In regards to voltage readings, PX5 has an accuracy of 0.1% of the reading + 0.05% of the full scale up to the 51st harmonic and transients. For current readings PX5 has an accuracy of a 0.1% reading + accuracy of the CTs. CTs used in this study were TR2550A; these have an accuracy of ± 1% over the full-scale readings. Cumulative accuracy for current readings during this field evaluation totaled to ± 1.1% of the reading.

CALIBRATION OF MONITORING EQUIPMENT

All instrumentation used during monitoring of this field evaluation was purchased solely for the purpose of this project. PX5s used in this field evaluation were factory calibrated on 11/11/2009 and the calibration is valid for 12 months. The TR2550 current transformers were also factory calibrated on 11/12/2009 and the calibration is valid for a period of 18 months. Calibration certificates for the equipment used in this field evaluation can be found in Appendix 1.

TEST SITE DESCRIPTION

Test sites selected for this field evaluation are located in Rancho Cucamonga, Temecula, and Lake Elsinore and referred to as Site 1, Site 2, and Site 3, respectively. These test sites were chosen in an effort to cover different sizes of car washes ranging from a large-scale car wash to a small-scale car wash. All facilities have standard 208Y/120V three-phase service panels feeding a vacuum pump motor. Two of the three test sites have one vacuum pump motor each with a VSD installed on a 20 HP and 10 HP motor, respectively. The third test site has two 20 HP vacuum pump motors and two VSDs with each controlling an individual vacuum pump motor. The size of motors and drives were dictated by the number of hose drops or vacuum stations at each test site. The higher the number of hose drops or vacuum stations the higher the rating of the vacuum pump motor installed at the site.

SITE #1

Site 1 is a large car wash with 15 end-use hose drops and two 20 HP vacuum pump motors that maintain optimal vacuum pressure at each hose drop. The cumulative horsepower rating of this site is 40 HP with a 208Y/120V three-phase configuration. This site has the capacity to service eight cars at full load. During the evaluation each VSD was used to control an individual vacuum pump motor to realize energy savings. Two VSDs were identified as the primary and secondary drives.

The control methodology implemented at this site was also unique. The primary VSD was controlled by the pressure feedback signal provided by the pressure transducer and the secondary VSD was controlled by the frequency output of the first VSD such that; Control settings allowed the primary VSD to ramp up and down based on the pressure in the main duct. When the pressure dropped in the main duct, the RPM and the operating frequency of primary VSD increased accordingly. When the operating frequency of the primary VSD reached full load, the secondary VSD was turned on to offset the load of the primary VSD and to provide optimal pressure at the hose drops/main duct. This type of control for the secondary VSD eliminated the pressure feedback control loop and the pressure transducer. Therefore, the two VSDs are operating with different settings. This set up does not provide a direct comparison to the normal operation of conventional constant speed vacuum pump motors. Due to this reason, this site was abandoned. Since the control methodology for two VSDs performing similar function was not comparable this site was abandoned and the results from this site have not been included in peak demand and annual energy savings calculations.

SITE #2

Site 2 is a medium sized car wash with a 20 HP vacuum pump motor and uses 10 hose drops to vacuum cars. This facility also has a 208Y/120V three-phase configuration on which demand and energy consumption readings were monitored and recorded for the purposes of this field evaluation. At this site cars are vacuumed before entering the washing tunnel, hence all cars are vacuumed regardless of the type of car wash purchased. Another unique feature of this test site is that it provides a quick oil lube service before washing the car, making vacuuming an intermediate step of the process. The posted hours of operation at this site are 8:00 A.M. – 6:00 P.M. Monday through Saturday and 8:00 A.M. - 5:00 P.M. on Sunday during the summer; however, during the winter operating hours change from 8:00 A.M. to dusk every day.

This site also has only one vacuum pump motor and only one VSD was installed in order to reduce energy consumption.

SITE #3

Site 3 is a relatively small car wash facility with a 10 HP vacuum pump motor and six hose drops. This site has the capability to service two to four cars at full load and is served by a 208Y/120V three-phase configuration on which the demand and energy measurements were recorded for purposes of this field evaluation. At this facility cars are vacuumed before entering the washing tunnel regardless of the type of car wash the customer purchases.

Since this site has only one vacuum pump motor, only one VSD was installed. Hence, there were no differences in the work practices during both test periods.

Data monitoring was conducted for a total of 30 days at each test site. This period was equally divided into constant speed monitoring and VSD monitoring in order to obtain a weekly profile and to study the pattern at each test site. Results of the monitoring sessions are discussed in the Evaluation section of this report.

EVALUATION

ERROR ANALYSIS

Error analysis was conducted on the recorded data in order to establish confidence in the data before savings calculations were done. For this, the rated accuracy of the data monitoring and acquisition devices were collected and the actual error in kW and kW percent was calculated. Power variation due to dynamic frequency change of the VSDs was also a contributing factor in introducing uncertainty to the field data. These values were used to deduce the standard deviation of the recorded data from the actual power consumption at the test sites.

An average car wash operates for approximately eight hours each day. For the rest of the day all electronic and electrical devices at the facility are turned off. Error analysis only accounts for the operational hours at the facility for accurate analysis. Voltage and current error are used to calculate power error (kW and %kW) using Equation 1, Equation 2, and Equation 3.

EQUATION 1. CURRENT ERROR

$$\sigma_{A} = 0.1\% \times reading + CT\ Error$$

Where CT Error = 1% of reading

Therefore, $\sigma_{A} = 1.1\% \times reading$

EQUATION 2. VOLTAGE ERROR

$$\sigma_{v} = 0.1\% \times reading + 0.05\% \times Full\ Scale$$

Where, Full Scale = 120V/208Y

EQUATION 3. POWER ERROR

Power= Voltage x Current

Partial Differential of Power equation: $\sigma_P = \left(\frac{\partial P}{\partial I}\right) \times \sigma_I{}^2 + \left(\frac{\partial P}{\partial V}\right) \times \sigma_V{}^2$

$$\sigma_P{}^2 = V^2 \sigma_I{}^2 + I^2 \sigma_V{}^2$$

Power Error per Phase: $\sigma_{PPhase} = \sqrt{V^2 \sigma_I{}^2 + I^2 \sigma_V{}^2}$

Total 3-Phase Power Error: $\sigma_{PTotal} = \sigma_{PhaseA} + \sigma_{PhaseB} + \sigma_{PhaseC}$

An example of how the power error was calculated is shown in Table 3. These are results from one of the test sites during weekend working hours. Although data was sampled every minute, Table 3 and Table 4 illustrate calculations per hour only.

It is important to note that losses due to constant speed operation of VSDs were incorporated in the average power results shown in Table 4.

TABLE 3. EXAMPLE OF VSD POWER ERROR CALCULATION METHODOLOGY

Time	Average Three-Phase Voltage (Volts)	Average Three-Phase Current (Amps)	Average Power (kW)	Average Voltage Error (Volts)	Average Current Error (Amps)	Average Power Error (kW)	% Power Error
8:00:00 A.M.	120.17	41.39	8.82	0.12	0.46	0.05	0.62
9:00:00 A.M.	119.89	31.73	6.36	0.12	0.35	0.04	0.66
10:00:00 A.M.	118.90	35.17	7.39	0.12	0.39	0.05	0.63
11:00:00 A.M.	118.81	25.30	4.89	0.12	0.28	0.03	0.68
12:00:00 P.M.	118.29	30.30	6.04	0.12	0.33	0.04	0.66
1:00:00 P.M.	118.50	25.44	4.99	0.12	0.28	0.03	0.67
2:00:00 P.M.	119.40	39.51	8.46	0.12	0.43	0.05	0.62
3:00:00 P.M.	119.05	28.98	5.64	0.12	0.32	0.04	0.68
4:00:00 P.M.	118.16	2.75	0.30	0.12	0.03	0.00	1.21

TABLE 4. EXAMPLE OF CONSTANT SPEED POWER ERROR CALCULATION METHODOLOGY

Time	Average Three-Phase Voltage (Volts)	Average Three-Phase Current (Amps)	Average Power (kW)	Average Voltage Error (Volts)	Average Current Error (Amps)	Average Power Error (kW)	% Power Error
8:00:00 A.M.	120.24	48.34	10.36	0.18	0.53	0.06	0.60
9:00:00 A.M.	119.21	51.04	11.18	0.18	0.56	0.07	0.58
10:00:00 A.M.	119.30	50.28	11.79	0.18	0.55	0.07	0.54
11:00:00 A.M.	119.66	46.47	9.92	0.18	0.51	0.06	0.60
12:00:00 P.M.	119.17	45.95	10.23	0.18	0.51	0.06	0.57
1:00:00 P.M.	119.79	48.74	10.60	0.18	0.54	0.06	0.59
2:00:00 P.M.	118.08	54.76	11.90	0.18	0.60	0.07	0.58
3:00:00 P.M.	119.85	46.19	9.87	0.18	0.51	0.06	0.60
4:00:00 P.M.	119.73	51.25	12.21	0.18	0.56	0.07	0.54

As shown in the above tables, the percent power error remained well below 1% of the standard deviation for this particular site. Similar results were also revealed at other test sites for the VSD and for the baseline/constant speed test periods. Results for each test site during both test periods are listed in Table 5 and Table 6.

TABLE 5. AVERAGE ERROR DURING THE VSD TESTING PERIOD

	VSD			
TIME STAMP	AVERAGE VOLTAGE ERROR (VOLTS)	AVERAGE CURRENT ERROR (AMPS)	AVERAGE POWER ERROR (KW)	POWER % ERROR
Site 2	0.18	0.35	0.04	0.63%
Site 3	0.18	0.13	0.02	0.81%

TABLE 6. AVERAGE ERROR DURING THE BASELINE/CONSTANT SPEED TEST PERIOD

	CONSTANT SPEED			
TIME STAMP	AVERAGE VOLTAGE ERROR (VOLTS)	AVERAGE CURRENT ERROR (AMPS)	AVERAGE POWER ERROR (KW)	POWER % ERROR
Site 2	0.18	0.54	0.07	0.59%
Site 3	0.18	0.16	0.02	0.90%

The average current error and the average voltage error remained true to the rated accuracy range for all test sites. However, error decreased when a 24-hour profile was evaluated and compared to the error calculated during operational hours. On average, the error remained within one standard deviation of the readings which provides high confidence in the recorded data.

DEMAND REDUCTION AND ENERGY SAVINGS CALCULATION METHODOLOGY

At the conclusion of the testing and monitoring period, data was analyzed. Energy and demand consumption of the VSD system was compared to the baseline case demand and energy consumption. Average demand reduction was calculated using Equation 4.

EQUATION 4. AVERAGE DEMAND REDUCTION

$$Percent\ Average\ kW\ Reduction = \frac{Baseline_{Average\ kW} - VSD_{Average\ kW}}{Baseline_{Average\ kW}} \times 100$$

The posted hours of operation at these sites are 8:00 A.M. to 5:00 P.M. on weekdays and 8:00 A.M. to 4:00 P.M. on weekends; however actual hours of operation of the vacuum pump motors deviated from the posted hours and the test sites turned those motors "OFF" when they did not expect more business for the day. Therefore, the actual hours of operation of the vacuum pump motors were established from the recorded demand data since power draw occurred only when the vacuum pump motor was in operation.

Daily average energy consumption was calculated using daily average power demand (kW) and multiplying it with the number of operating hours at each test site. Adjustments were made to the energy savings estimate for any deviation from the average monthly energy consumption based on the monthly billing history of the previous two years. Adjustments were also made for any variation in the number of cars serviced and in the number of hours of operation during the baseline monitoring period compared to the VSD monitoring periods.

Additional losses due to the constant operation of the VSD during base lining were also considered. The average daily energy consumption was multiplied by the total number of days in the year in order to calculate the annual energy consumption. Rainy days and national holidays were subtracted from the count of the number of days in a year in order to project the most accurate annual energy consumption values. On average 15 days of the year were assumed as non-working days on the premise of rain or holidays. The annual energy savings were calculated using Equation 5.

EQUATION 5. ANNUAL ENERGY SAVINGS

$$Percent\ Average\ kWh\ Reduction = \frac{Baseline_{Average\ kWh} - VSD_{Average\ kWh}}{Baseline_{Average\ kWh}} \times 100$$

The kWh per car per HP for each testing day was also calculated for comparison using Equation 6.

EQUATION 6. DAILY KWH PER CAR PER HP

$$kWh\ per\ Car\ per\ HP = \frac{Estimated\ kWh}{HP \times Number\ of\ cars}$$

This kWh per car per HP was used to calculate the average kWh per car per HP at each test site. The resulting average value can be used as a benchmark to estimate the energy savings per unit at such facilities. The number of cars serviced per day was provided by the car wash owner.

RESULTS

WEEKLY DEMAND ANALYSIS

All test sites had a pattern of demand that depicts the busiest days of the week for a car wash. On average all of the sites revealed that the weekend days, Friday, Saturday, and Sunday are the busiest days for business. Demand increases during evening hours on Friday and starts to slow down on Sunday afternoon. Figure 8 shows this pattern.

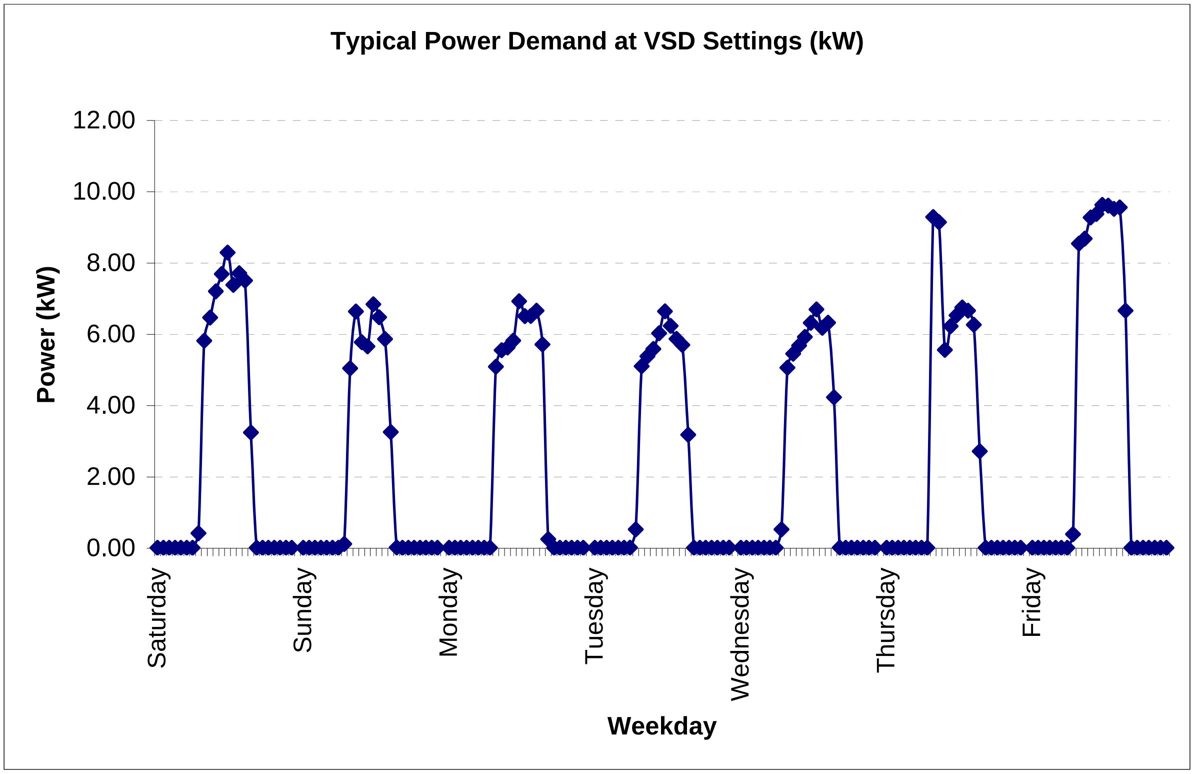

FIGURE 8. AVERAGE WEEKLY PROFILE AT A TEST SITE WITH VSD SETTINGS

Figure 8 is a sample of average weekly profile seen at one of the test site 2 that participated in the field evaluation. As illustrated, demand varies throughout the week with a significant peak on Friday and continuing through Sunday. Similar patterns were seen on other test sites as well. Comparison of these results with the constant speed settings on the same test site shows a fixed demand throughout the week and during the weekend as shown in Figure 9.

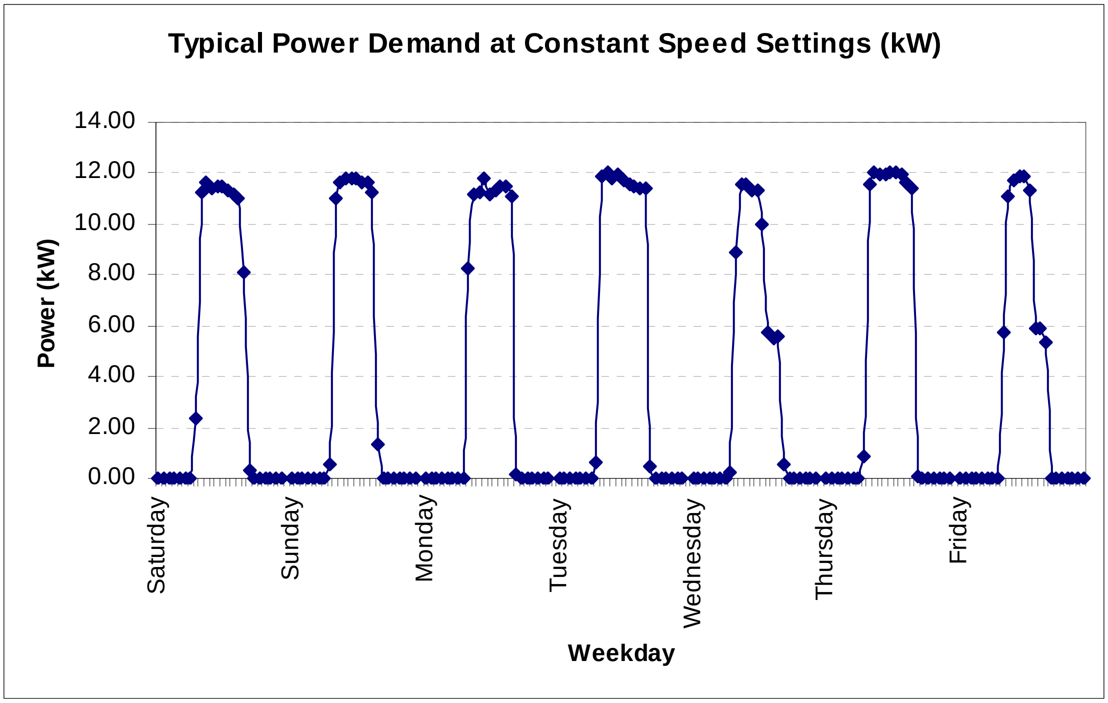

FIGURE 9. AVERAGE WEEKLY PROFILE AT A TEST SITE WITH BASELINE/CONSTANT SPEED SETTINGS

Figure 9 illustrates a typical weekly power demand at a car wash using constant speed settings. It represents a demand of approximately 12 kW throughout the week but when compared to typical demand at VSD settings, it can be seen that the demand fluctuates from 7 kW to 10 kW. The highest demand of 10 kW represents a typical weekend and 7 kW represents weekdays. This test site shows a demand reduction of at least 2 kW in VSD settings during a weekend and a higher reduction during weekdays. Similar results were seen at other test sites that had a drive installed on its premises. This indicates that VSDs have the potential to produce savings over a constant speed motor when implemented correctly.

PEAK DEMAND REDUCTION

Average peak demand as defined by the Database for Energy Efficient Resources (DEER) is:

".. The average grid level impact for a measure between 2:00 P.M. and 5:00 P.M. during three consecutive weekday periods containing the weekday temperature with the hottest temperature of the year."

All test sites are located in climate zone (CZ) 10 and the peak demand days for this CZ are July 8-10. Since the testing period did not fall during the peak demand days for this CZ, a representative annual profile was simulated using the seven day profile from the recorded data. Demand during the peak demand period was calculated using the 9 hour average kW usage during the three-day data for the baseline and VSD testing periods. Site 2 revealed a peak demand reduction of approximately 39%. Peak demand results are illustrated in

FIGURE 10. VSD PEAK DEMAND AT SITE 2

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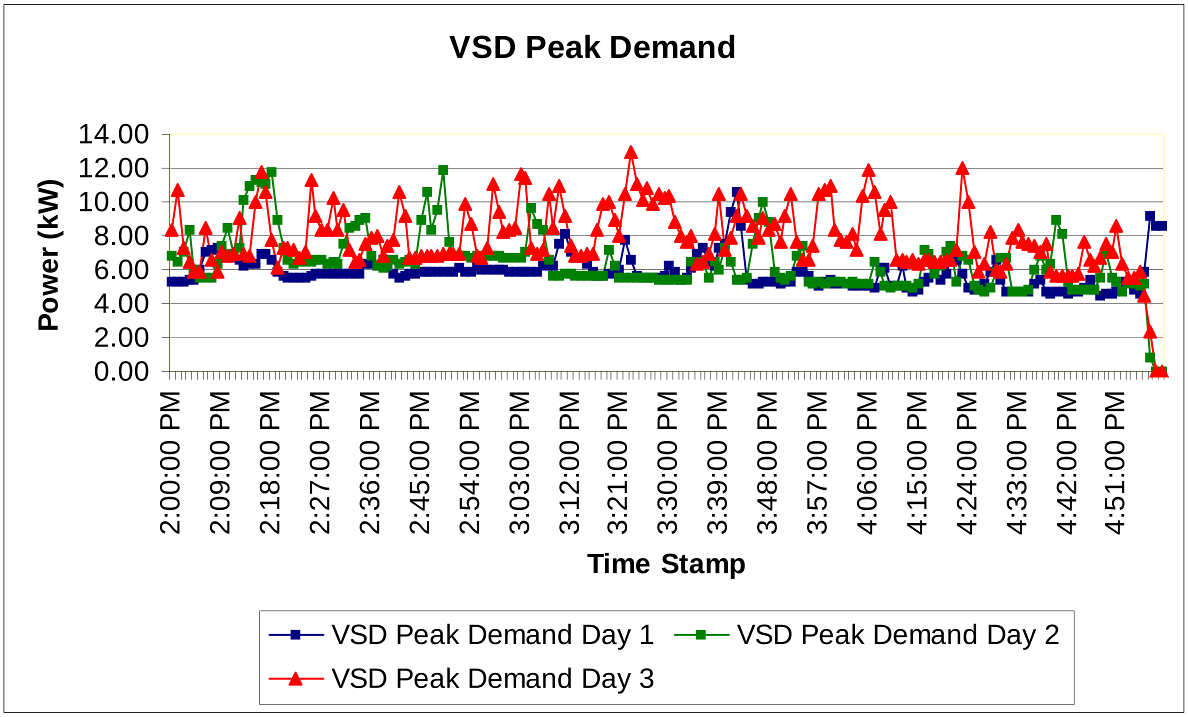

FIGURE 10. VSD PEAK DEMAND AT SITE 2

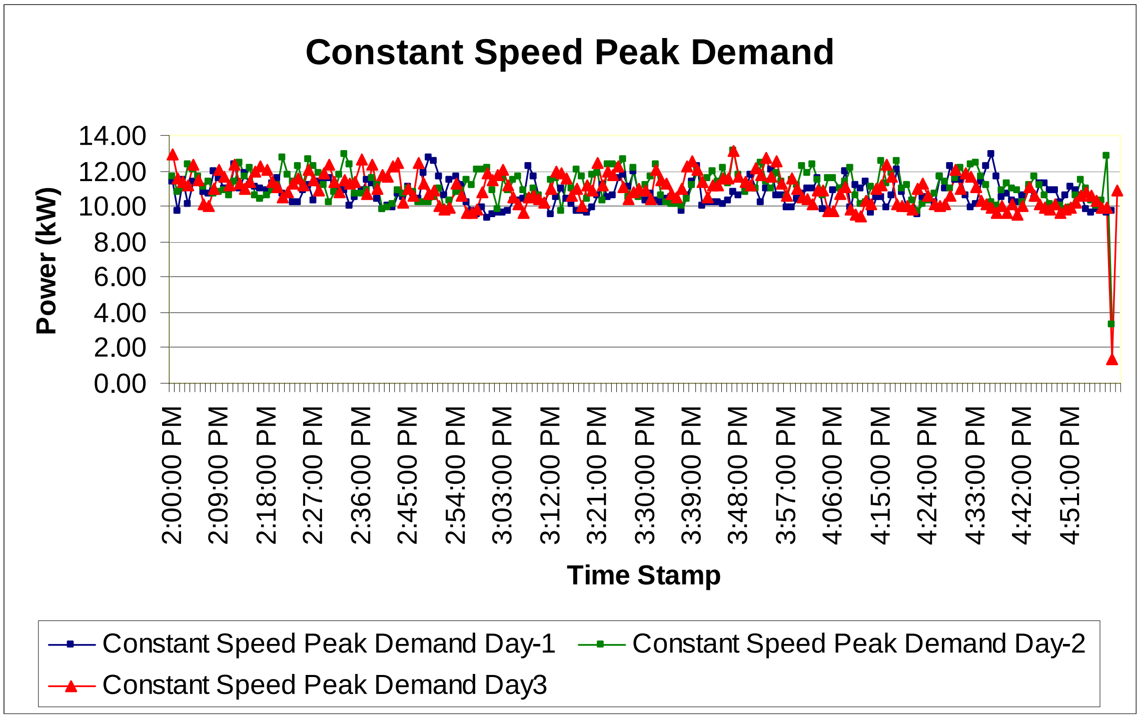

FIGURE 11. CONSTANT SPEED PEAK DEMAND AT SITE 2

Site 3 revealed an approximate demand reduction of 18%. Results seen during VSD and constant speed operation are shown in Figure 12

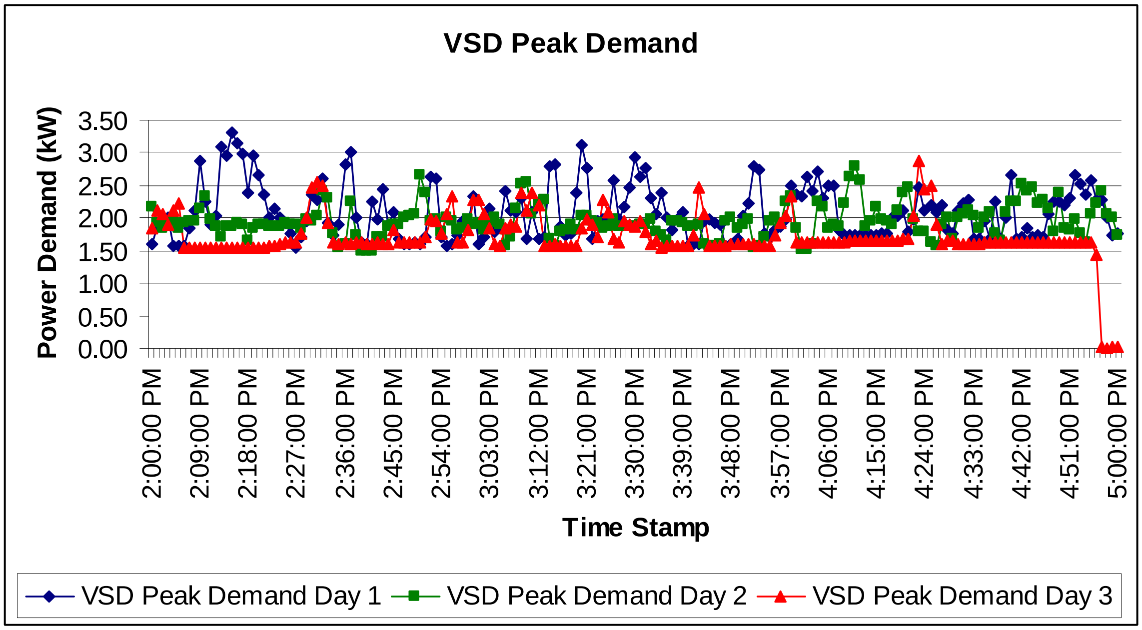

FIGURE 12. VSD PEAK DEMAND AT SITE 3

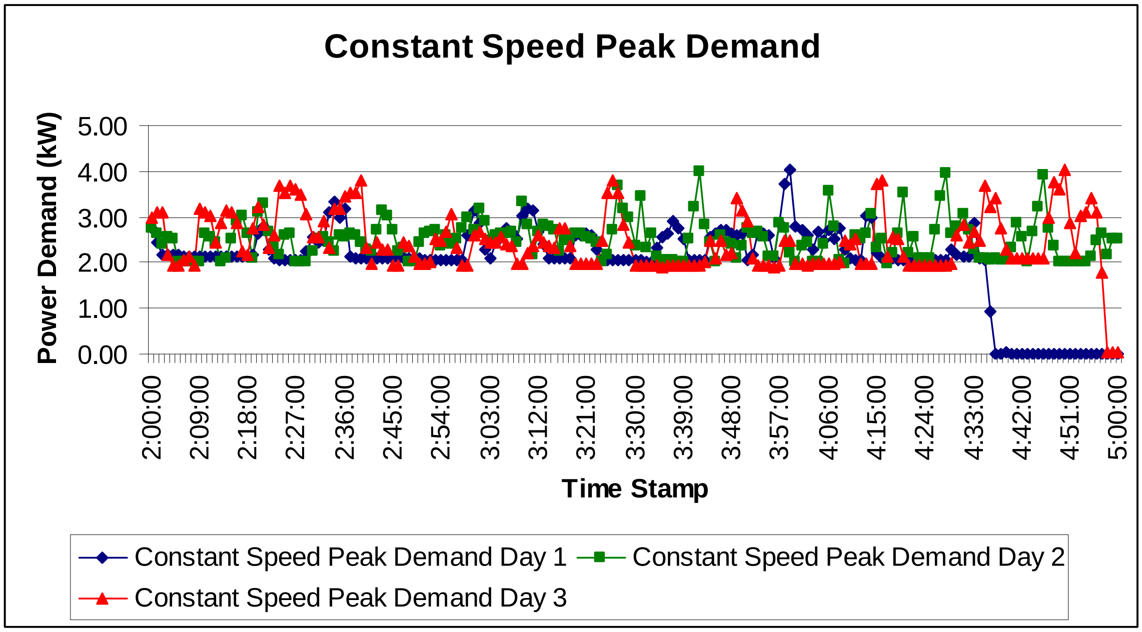

FIGURE 13. CONSTANT SPEED PEAK DEMAND AT SITE 3

Table 7 tabulates the results of site 2 and site 3:

TABLE 7. PEAK DEMAND REDUCTION RESULTS

TEST SITES	BASELINE/CONSTANT SPEED AVERAGE PEAK DEMAND (KW)	VSD AVERAGE PEAK DEMAND (KW)	% AVERAGE PEAK DEMAND REDUCTION
Site 2	10.93	6.70	38.71%
Site 3	2.33	1.91	17.73%

The demand values of each test site were used to simulate a yearly profile at each test site. Since the testing period did not fall during the peak demand days for CZ 10, simulated values were used to create a yearly demand profile for each test site. Results for each site are discussed in the following section of this report with a corresponding demand simulation.

SITE 2 DISCUSSION

Site 2 revealed a fairly constant demand during operating hours of the facility, as shown in Figure 14. Two dips were observed on the demand graph between 10:00 A.M. - 11:00 A.M. and demand increased during lunch hours, and then dipped again at approximately 1:00 P.M., and recovered at approximately 2:00 P.M. On the Tuesday during the week of the evaluation, the facility turned off the vacuum pump at 4:00

P.M., indicating that the facility is usually less busy than other weekdays (Wednesday, Thursday, and Monday).

The yellow region in peak demand simulation results shown in Figure 14 and Figure 11 illustrates the DEER defined peak demand hours for the CZ of this test site. The graph in Figure 14 indicates that the true peak demand hours for this type of commercial business may not necessarily coincide with DEER-defined peak demand hours.

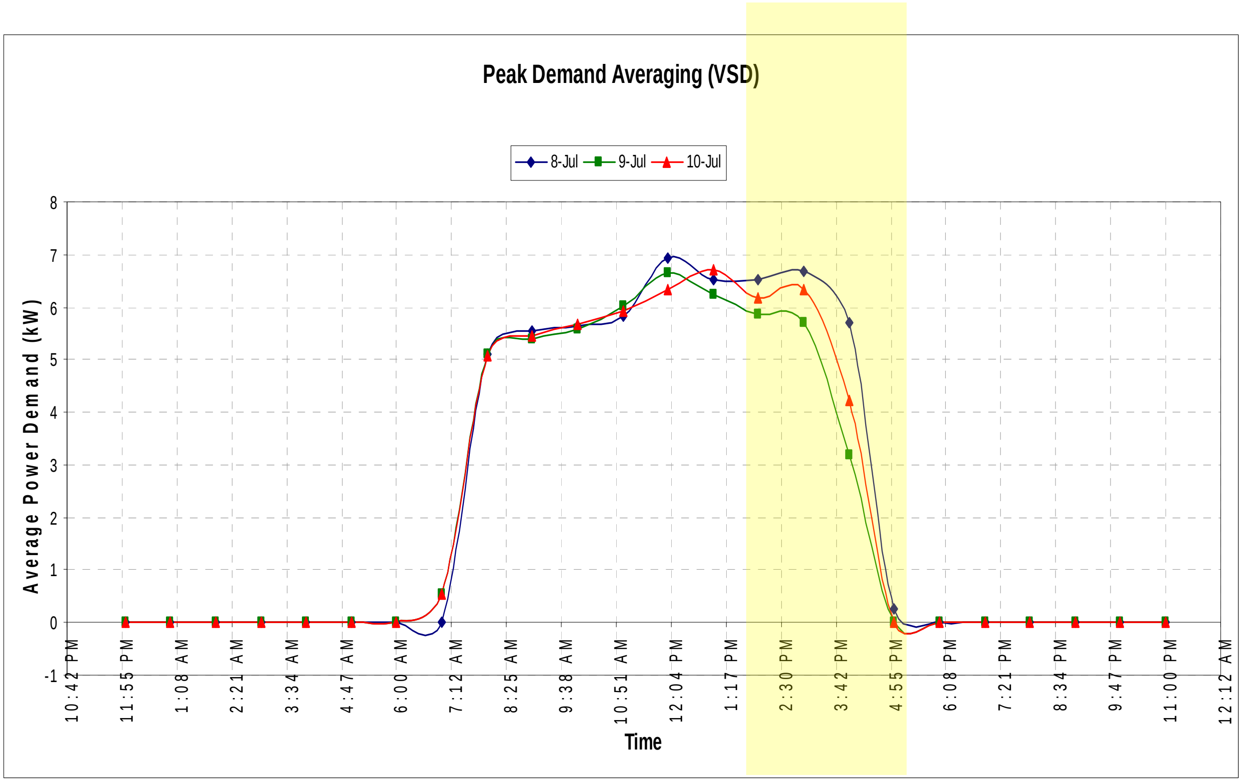

FIGURE 14. AVERAGE DEMAND SIMULATION RESULTS FOR SITE 2 DURING DEER DEFINED PEAK DEMAND DAYS

SITE 3 DISCUSSION

The results of Site 3 are similar to the demand reduction results of Site 2 as shown in Figure 15. The highest demand was seen at approximately 9:00 A.M. and remained fairly constant until 4:00 P.M. This pattern is indicated by the increase from 0 kW - 2 kW and the decrease at 4:00 P.M. from 2 kW-0 kW, when the vacuum pump motor is operating with a VSD. Thursday was an exception since the demand decreased after 2:00 P.M. This may be a result of fewer cars on that particular day.

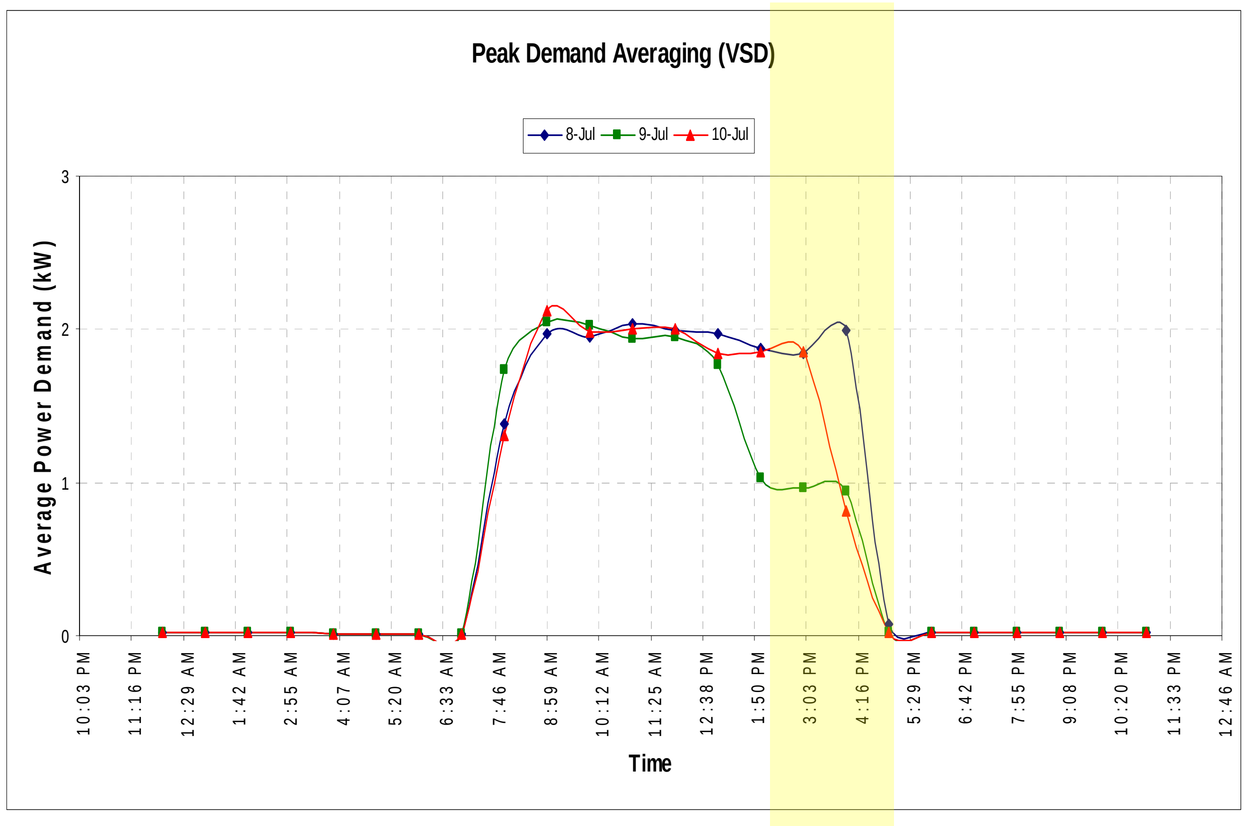

FIGURE 15. AVERAGE DEMAND SIMULATION RESULTS FOR SITE 3 DURING DEER DEFINED PEAK DEMAND DAYS

The results revealed at both sites illustrated in Figure 14, and Figure 15 vary according to the demographics of the areas in which they are located. This establishes the fact that the peak demand for such commercial facilities may or may not coincide with the DEER defined peak demand hours.

PRESSURE MEASUREMENTS - MINIMUM- AND FULL-LOAD TEST RESULTS

Results of the minimum and full load tests performed at each site are listed in Table 8 and illustrates a comparison of performance between both the VSDs and constant speed settings on a vacuum pump motor.

TABLE 8. PRESSURE COMPARISON OF THE VSD AND BASELINE/CONSTANT SPEED SETTINGS

		VSD SETTINGS		BASELINE/CONSTANT SPEED SETTINGS	
COLUMN TITLES	HOSE DROP	MIN. LOAD	FULL LOAD	MIN. LOAD	FULL LOAD
Site 2	First Drop Pressure (inHg)	3.5	3.5	4.1	3.0
	Last Drop Pressure (inHg)	3.0	3.0	3.5	2.5
Site 3	First Drop Pressure (inHg)	3.5	3.0	3.5	3.0
	Last Drop Pressure (inHg)	3.0	2.5	3.0	2.5

The vacuum pressure remained fairly constant at the VSD settings during both minimum load and full load conditions. At both test sites, VSDs were able to maintain close to optimal vacuum pressure at minimum and at full load. However, a steep drop in the pressure was seen during the baseline/constant speed tests. During baseline period, pressure varied from 4.1 inHg to as low as 3.0 inHg at the hose drop closest to the vacuum pump (minimum pressure loss). Lowest pressure of 2.5 inHg was recorded at the last hose drop (drop farthest from the vacuum motor, has maximum pressure loss) at full load.

The comparison of the power demand and pressure at the VSD and constant speed settings suggests that VSDs are able to provide satisfactory performance in terms of providing optimal pressure to the hose drops. The constant speed motor settings provided higher pressure when not required and caused discomfort to the car wash employees. Constant speed settings also resulted in higher demand at full load and minimum load. Whereas, the VSD settings revealed demand savings while providing optimal performance.

ANNUAL ENERGY SAVINGS

Daily energy consumption at each test site was calculated using the recorded demand data over the daily operational hours. The average annual energy consumption was estimated by multiplying the average daily energy consumption by the number of days in a year. The following adjustments were made to the recorded data in order to increase the accuracy of the results:

- Adjustments were made for the variations in the annual energy consumption based on the data from previous years. The average monthly energy consumption was calculated using the figures on the utility bills provided by the car wash owners. This value was compared to the recorded monthly energy consumption during the test period. Any difference in the historical consumption and recorded consumption was offset by applying the adjustment for a percent difference in the two values.

- Adjustments were made for the variation in the number of cars serviced during the VSD test and baseline/constant speed test. The percent difference in the number of cars during both test periods was calculated using the data provided by the car wash owners. If the number of cars were less during the baseline/constant speed test than during the VSD test period, the energy consumption during this test period was increased to match the VSD test period results by applying the percent difference to the average annual energy consumption of the baseline/constant speed test or vice versa.
- Since the baseline/constant speed tests were performed by setting the VSDs to run at 100% at all times during the baseline/constant speed test period, loss introduced due to VSDs was also accounted for when calculating the peak demand reduction and annual energy savings. Based on the vendors recommendation an approximate 4% loss was assumed during the VSD constant operation for the purposes of this field evaluation.

The results of the estimated annual energy savings for each test site are shown in Table 9, and Table 10. Site 2 and Site 3 revealed an annual energy savings of 10,793 kWh and 2,259 kWh, respectively. This translates into a 25% savings for Site 2 and 22% for Site 3.

TABLE 9. ESTIMATED ANNUAL ENERGY SAVINGS FOR SITE 2

	VSD TEST	BASELINE/ CONSTANT SPEED TEST	RESULTS
Adjusted kWh/day	89.64	119	
Annual Energy Consumption (kWh)	32,717	43,510	
Annual Energy Savings (kWh)			10,793
% Annual Energy Savings			24.8%

TABLE 10. ESTIMATED ANNUAL ENERGY SAVINGS FOR SITE 3

	VSD TEST	BASELINE/ CONSTANT SPEED TEST	RESULTS
Adjusted kWh/day	21.88	28	
Annual Energy Consumption (kWh)	7,987.87	10,247	
Annual Energy Savings (kWh)			2,258.84
% Annual Energy Savings			22.04%

SCE has 1,179 car washes in its service territory with an estimated average energy consumption of 61,000 kWh per year per car wash. If the savings seen at both Site 2 and Site 3 are realized for the entire SCE service territory, then significant energy savings can be realized. The results from Sites 2 and 3 are listed in Table 9 and Table 10.

In addition to the annual energy savings and peak demand reduction, calculations were done to calculate the kWh per car and the kWh per car per HP installed at each test site. The number of cars per day was provided by the site owners. The average kWh per day during the test period was calculated using the field monitoring data. This average kWh was then divided by the average number of cars per day each test site services. Further division by the horse power rating of the vacuum pump motor installed at each facility resulted in the average kWh per car per HP. These calculations were performed in order to provide a benchmark savings due to the VSD over the conventional constant speed motor. This calculation provides a savings estimate that may be seen at a car wash according to the size of motor installed and the average number of cars serviced by the facility. Results for each test site are shown in Table 11.

TABLE 11. AVERAGE KWH PER CAR PER HP FOR ALL TEST SITES

			AVERAGE KWH		AVERAGE KWH PER CAR		AVERAGE KWH PER CAR PER HP		ENERGY SAVINGS (KWH/CAR/ HP)
TEST SITE	INSTALLED HP	AVERAGE NUMBER OF CARS PER DAY	VSD TEST	BASELINE/ CONSTANT SPEED TEST	VSD TEST	BASELINE/ CONSTANT SPEED TEST	VSD TEST	BASELINE/ CONSTANT SPEED TEST	
Site 2	20	186	89.64	119	0.48	0.64	0.024	0.032	0.008
Site 3	10	72	21.88	28	0.30	0.38	0.03	0.038	0.008

CONCLUSIONS AND RECOMMENDATIONS

Overall, VSD systems have some advantages over the constant speed motor controls in terms of energy savings. To realize the full advantage of VSDs requires matching the size of the drive to the size of the facility as well as evaluating other variables including the peak load of the facility (e.g., the maximum number of cars the facility has seen historically and the number of employees). The number of employees at a facility also helps in determining the maximum number of cars that can be potentially vacuumed at any given time. Therefore, such factors should be considered and the VSDs should be sized, implemented, and programmed accordingly.

Vacuum pressure at the hose drops is a straightforward comparison although a constant speed motor control provides higher pressure at minimum load conditions. This pressure is higher than the optimal pressure required to perform a satisfactory job and hence this extra pressure is not necessary as it requires extra effort by the employees when vacuuming a car. Moreover, at full load the vacuum pressure at the last nozzle drops down to a level that is comparable to the vacuum pressure when the VSD settings are used. Therefore, having the extra pressure at minimum load does not provide any advantages to constant speed motors over VSDs. The optimal pressure required to vacuum a car can be provided by a VSD while saving energy and operating cost to the owner.

The power tests verify savings at two car washes where the annual energy savings ranges from 22% to 25% and the peak demand reduction is approximately 18% and 39%. Overall, VSD systems are a viable option for commercial operations where the vacuum pump motors are used and do not have a consistent volume of load during the hours of operation. However, the programming of the VSD should not be overlooked and the filter bags of the vacuum pump should be cleaned on a regular basis in order to gain maximum savings when using these systems.

APPENDICES

APPENDIX 1 CALIBRATION CERTIFICATES FOR PX5S USED IN FIELD

Sales Order or RMA# 86981

DRANETZ BMI

CERTIFICATE OF CALIBRATION

GLOBAL POWER TECHNOLOGIES

1000 New Durham Road, P.O. Box 4019, Edison, New Jersey 08818-4019

INSTRUMENT PX5-XFAST SERIAL NO. PX50EA147

PROPERTY OF SOUTHERN EDISON CALIFORNIA PURCHASE ORDER # JUAN MENENDEZ

The above instrument has been checked and calibrated against our working standards, which are traceable to the United States National Institute of Standards and Technology (NIST). All specifications were found to meet those set forth by the manufacturer. The metrology procedures utilized conform to and satisfy the requirements set forth in ANSI/NCSL Z540-1.

CALIBRATION PERFORMED BY: B. VEGA

CALIBRATION DATE: 11/11/09

Valid for 12 Months

TEST EQUIPMENT USED FOR CALIBRATION

MFG	MODEL	SERIAL NUMBER	DATE DUE
FLUKE	6100A	860948282	6/30/2010
VALHALLA	2701C	26-1101	5/31/2010

Calibration Technician/Quality Assurance

Temperature 22.6 °C Humidity 35.9 %

Form: 4_10.03C Rev. E

Sales Order or RMA# 86981

DRANETZ
BMI

CERTIFICATE OF CALIBRATION

GLOBAL POWER TECHNOLOGIES

1000 New Durham Road, P.O. Box 4019, Edison, New Jersey 08818-4019

INSTRUMENT PX5-XFAST SERIAL NO. PX50EA149

PROPERTY OF SOUTHERN CALIFORNIA EDISON PURCHASE ORDER # JUAN MENENDEZ

The above instrument has been checked and calibrated against our working standards, which are traceable to the United States National Institute of Standards and Technology (NIST). All specifications were found to meet those set forth by the manufacturer. The metrology procedures utilized conform to and satisfy the requirements set forth in ANSI/NCSL Z540-1.

CALIBRATION PERFORMED BY: B. VEGA

CALIBRATION DATE: 11/11/09

Valid for 12 Months

TEST EQUIPMENT USED FOR CALIBRATION

MFG	MODEL	SERIAL NUMBER	DATE DUE
FLUKE	6100A	860948282	6/30/2010
VALHALLA	2701C	26-1101	5/31/2010

Calibration Technician/Quality Assurance

Temperature 22.6 °C Humidity 35.9 %

Form: 4_10.03C Rev. E

Sales Order or RMA# 86981

DRANETZ BMI

CERTIFICATE OF CALIBRATION

GLOBAL POWER TECHNOLOGIES

1000 New Durham Road, P.O. Box 4019, Edison, New Jersey 08818-4019

INSTRUMENT PX5-XFAST SERIAL NO. PX50EA148

PROPERTY OF SOUTHERN EDISON CALIFORNIA PURCHASE ORDER # JUAN MENENDEZ

The above instrument has been checked and calibrated against our working standards, which are traceable to the United States National Institute of Standards and Technology (NIST). All specifications were found to meet those set forth by the manufacturer. The metrology procedures utilized conform to and satisfy the requirements set forth in ANSI/NCSL Z540-1.

CALIBRATION PERFORMED BY: B. VEGA

CALIBRATION DATE: 11/11/09

Valid for 12 Months

TEST EQUIPMENT USED FOR CALIBRATION

MFG	MODEL	SERIAL NUMBER	DATE DUE
FLUKE	6100A	860948282	6/30/2010
VALHALLA	2701C	26-1101	5/31/2010

Temperature 22.6 °C Humidity 35.9 %

Calibration Technician/Quality Assurance

Form: 4_10.03C Rev. E

CALIBRATION CERTIFICATES FOR CTS USED IN THE FIELD

A sample calibration certificate for CTs used in field testing is shown below. All CTs were calibrated on 11/12/09 and the calibration is valid for 18 months.

Sales Order or RMA# 86981

DRANETZ BMI

CERTIFICATE OF CALIBRATION

GLOBAL POWER TECHNOLOGIES

1000 New Durham Road, P.O. Box 4019, Edison, New Jersey 08818-4019

INSTRUMENT TR-2550A SERIAL NO. 091103038

PROPERTY OF SOUTHERN CALIFORNIA EDISON PURCHASE ORDER # JUAN MENENDEZ

The above instrument has been checked and calibrated against our working standards, which are traceable to the United States National Institute of Standards and Technology (NIST). All specifications were found to meet those set forth by the manufacturer. The metrology procedures utilized conform to and satisfy the requirements set forth in ANSI/NCSL Z540-1.

CALIBRATION PERFORMED BY: R.P.

CALIBRATION DATE: 11/12/09

Valid for 18 Months

TEST EQUIPMENT USED FOR CALIBRATION

MFG	MODEL	SERIAL NUMBER	DATE DUE
DRANETZ	3105	843105425	5/31/2010
DRANETZ	TR-2004	86	7/31/2010

Temperature 22.6 °C Humidity 27.7 %

Calibration Technician/Quality Assurance

Form: 4_10.03C Rev. E

ATTACHMENTS

The following calculation spreadsheets are attached to this report:

- Peak Demand Reduction Calculations Spreadsheet

  2_week_cw_data with Normal kWh

- Annual Energy Savings Calculations Spreadsheet:

  Site 2 - RH

  Site 3 - RIO