Solar Jack Emerging Technologies Technical Assessment

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LEGAL NOTICE

ABBREVIATIONS AND ACRONYMS

BFPD	Barrels of Fluid Per Day
CES	Customer Energy Solutions
CT	Current Transformer
CV	Coefficient of Variation
DC	Direct Current
DOGGR	Division of Oil, Gas, and Geothermal resources
ET	Emerging Technologies
Hp	Horsepower
IGBT	Insulated-Gate Bipolar Transistor
ISP	Industry Standard Practice
kW	Kilo Watts
kWh	Kilo Watt Hour
M&V	Monitoring and Verification
NEM	Net Energy Metering
PF	Power Factor
PG&E	Pacific Gas and Electric
POC	Pump-off Controller
PS	PowerSight
RCM	Regen Capacitive Module
PV	PhotoVoltaic
SD	Secure Digital
VSD/ VFD	Variable Speed Drive/ Variable Frequency Drive

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EXECUTIVE SUMMARY

This report presents the findings of technical assessment to evaluate energy efficiency potential of the Solar Jack Energy Management System (also referred as "Solar Jack"). PG&E's Emerging Technologies (ET) Group within the Customer Energy Solutions (CES) organization has funded this assessment. Lincus, Inc. an energy efficiency consulting firm was commissioned to perform this assessment.

PROJECT GOALS

The goals of this assessment are to:

- Research existing information about the Solar Jack technology from published materials, field experts and manufacturers.
- Develop Measurement and Verification (M&V) procedures for determining Solar Jack energy savings potential, perform M&V, analyze data, and calculate the DEER peak kW and annual kWh energy savings potential over the existing/industry standard baseline.
- Determine the energy savings contribution from each of the (3) three components in the Solar Jack system which includes regenerative component, Variable Frequency Drive (VFD), and Solar Photovoltaic (PV) panel.
- Discuss PG&E Customized Incentive Program eligibility and utilization of the findings for future projects.

PROJECT DESCRIPTION

Solar Jack is installed on a rod beam pump as add-on equipment. Solar Jack is a combination of the following (3) energy saving sub-components:

- VFD is controlled by the customer's existing monitoring system to match motor rpm with well output.
- Regeneration Component –Solar Jack has a capacitor bank to store regenerative power during down-stroke and reuse it without exporting to the grid. Without this component, the regenerative power is either wasted as heat or exported to the grid as poor quality (low Power Factor) power.
- Solar PV – A solar PV system is installed to provide auxiliary power to the rod beam pump. A properly sized Solar PV system in combination with the above components may allow the pumping system to operate off-grid.

To assess the energy savings potential of Solar Jack, it was installed on three wells with rod beam pumping system at three different customer sites, designated as Host Site #1, Host Site #2 and Host Site #3. During the course of the assessment, Host Site #3 dropped out of the study for reasons explained later in the report. Host Site #2 and Host Site #1 rod beam pumps are driven by a 15HP and 30HP motor, respectively, with continuous operation and no controls. The installed Solar Jack system at each site had appropriately-sized VFD, regen capacitor bank, and Solar PV rated for 2.12 kW DC output. The performance of each pumping system was measured before and after the installation of the Solar Jack system.

PROJECT FINDINGS/RESULTS

Table 1 summarizes the total annual energy savings and DEER peak demand reduction at each test site, and Table 2 provides component level savings values. It is important to note that at Host Site #2 there were two post installation monitoring periods, once when the pump was running at full speed and the other when the VFD on the pump's motor was modulated to a reduced speed.

TABLE 1: TOTAL ENERGY SAVINGS AND PEAK DEMAND REDUCTION

	Host Site #1	*Host Site #2 (VFD at full speed)*	*Host Site #2 (VFD at reduced speed)*	*Units*
Annual Baseline Energy Usage (Grid)	188,200.0	44,177.6	44,177.6	kWh
Annual Post-installation Energy Usage (Grid)	156,848.7	34,456.2	21,330.0	kWh
Annual Energy Savings	31,351.4	9,721.4	22,847.6	kWh
Energy Savings as % of Baseline	16.7%	22.0%	51.7%	
DEER Peak Demand Reduction	3.58	1.11	2.61	kW

TABLE 2: SAVINGS CONTRIBUTED BY EACH COMPONENT

Component	*Host Site #1*	*Host Site #2 (VFD at full speed)*	*Host Site #2 (VFD at reduced speed)*	*Units*
Variable Frequency Drive	21,411.70 [68%]	-1,043.4 [-11%]	8,071.9 [35%]	kWh [% of total]
Regeneration Energy Recovery	6,791.98 [22%]	7,767.59 [80%]	11,696.29 [51%]	kWh [% of total]
Solar Panel	3,147.68 [10%]	2,997.24 [31%]	3,079.36 [13%]	kWh [% of total]

While the study concludes that each component of the Solar Jack system has the potential to save energy, it is observed that savings magnitude is dependent on several factors such as well characteristics, well stimulation technique, well balancing, motor/pump sizing, etc. Solar Jack resulted in about 16.7% reduction in annual energy consumption at the Host Site #1, 22% reduction at Host Site #2 at 100% VFD speed, and 51.7% reduction at reduced a VFD speed. As can be seen, savings vary significantly between each test site and operational characteristics; hence, project team is of the opinion that PG&E's Customized Incentive Program which evaluates each project independently is the most appropriate program for incentivizing this technology/measure.

PROJECT RECOMMENDATIONS

The Solar Jack system demonstrated energy savings potential at both test sites. However, application of these results from this study to a wider population is not recommended due to variations in equipment and operation at each site. The M&V plan and a calculation methodology developed in this study can be used for estimating energy savings from future Solar Jack installations. Once the system is installed on more pumping systems and additional M&V data is available, a more generalized savings approach (deemed/ prescriptive) can be developed to reduce the project level M&V costs and effort.

INTRODUCTION

Energy required for extracting oil and gas from wells is continuously increasing due to conventional source depletion (Brandt 2011). Between 1990 and 2009, as reported by the U.S. Energy Information Administration (EIA) data on the Petroleum Industry, output of crude oil production per well in the United States has dropped from 12.2 barrels to 10.1 barrels per day while the average well depth has increased from 4,602 to 6,084 feet (EIA 2009). Energy Return on Investment (EROI), the ratio of energy delivered to energy cost, increased from 100:1 in 1930 to 20:1 in 2005 for oil extraction (Cleveland 2005). Investment in more efficient energy technologies is often the most cost-effective way of improving the EROI especially when the crude oil prices have decreased substantially in last few years. Solar Jack Energy Management System is touted as one such technology by its manufacturer, Solar Jack, LLC.

This ET study was conducted to evaluate energy savings potential of Solar Jack. Solar Jack provides an innovative solution to efficiently operate a rod beam artificial lift pump (also called "sucker rod pump" or "Jack pump"). The impact of this technology can be widespread because more than 80% of oil production wells operating in the Western U.S. and California use a rod beam pump system.

The Solar Jack system comprises of a solar photovoltaic system, a variable speed drive, and a capacitor bank. Solar Jack lowers the energy usage by capturing and temporarily storing the energy from the system's solar array along with the regenerative energy from the down stroke of the pump jack (primarily through capacitor banks), and uses this energy to help power the upstroke of the pump jack. Variable Speed Drive provides additional energy savings by matching the motor/pump speed to the oil well production rate.

The project team conducted preliminary research, developed and implemented the M&V plan, analyzed the M&V data, and developed this report. The M&V was conducted on two oil wells owned by different companies. Both companies are independent minor oil producers in San Joaquin Valley, CA. Minor oil producers were selected in part due to constant speed baseline as per the current Industry Standard Practice. Other factors considered in the selection were control mechanism, well/pump/motor age, well stimulation technique, customer willingness to participate, etc.

The M&V results indicate savings potential from each of the Solar Jack components. It is observed that savings is dependent on many factors such as well characteristics, well stimulation technique, well balancing, motor/pump sizing, etc. The M&V plan and the calculation methodology developed as part of this project can be utilized for assessing future projects/installations if PG&E decides to include this technology in their Energy Efficiency (EE) portfolio.

BACKGROUND

A rod beam pump is used to mechanically lift oil out of the well if there is not enough bottom-hole pressure for the liquid to flow all the way to the surface. The pumping unit has an electric or a gas motor which powers a positive displacement pump to force underground emulsion (oil + water mixture) into a pump barrel. The ram lifts the weight of the sucker rod and emulsion. When the ram reaches the top of the pump stroke, the emulsion is released into a fluid reservoir and the pump is ready for the down-stroke. Some of the potential energy during the down-stroke is captured by the counterbalance weight (fly-wheel) with the remaining energy wasted as heat.

Rod beam pumps are the most commonly-used pumps for existing and new wells in California oil fields. Lincus' quick review of the California Division of Oil, Gas, and Geothermal Resources (DOGGR) database, which includes all oil production wells in California, showed that more than 80% of wells are using the rod beam pumping system for artificial/ mechanical lift. The efficiency of a rod beam pumping system is in the range of mid 40% (McCoy 1997). In spite of their prevalence due to simplicity and lower initial costs compared to other artificial lift technologies, rod beam pumping systems have several drawbacks as described below.

- High Start-up Demand
- Low Power Factor
- Wasted Power
- Violent Motor Starts
- Inefficient Speed Adjustments Process

Installing a VFD can address some of the drawbacks identified above by providing soft start and reducing the strokes per minute to match well production. By the nature of rod beam pump operation; there is a regeneration phase during the down stroke where the motor is able to generate power. The traditional VFDs do not have the capability of observing the balance of pump jack, and any power generated during the down-stroke operation of the pump jack is either wasted as heat through brake resistors or returned to the grid without customer being paid for the generated power. Since the power returned to the grid has a low power factor, some utilities charge customers penalties for the power going back to the grid. Solar Jack system harness the power during the down stoke, recycles, improves the power quality, and reuses it within the pumping system without exporting to the grid.

EXISTING CONTROL MECHANISM

Itron, on behalf of the California Public Utility Commission, published an Industry Standard Practice (ISP) Study in February 2013 which provided control technologies for various types of artificial lift in oil field systems including rod beam pumping systems.

According to this study, among the major oil producing companies, the large majority of rod beam pumps are controlled with Pump-off Controllers (POCs). Minor oil producers largely operate rod beam pumps without any controls on new oil wells. Continuous operation without control accounts for approximately 83% of existing rod beam pumps, and most of the remaining 17% are in the upper end of production levels within the minor producer category. Some rod beam pumps also utilize timers to control pump operation. Major oil producers are those accounting for 90% of the oil produced in California.

In summary, POCs were determined to be an ISP for the major producers and constant speed/no control for the minor producers. Also, VFDs were determined to be not an ISP for either major or minor producers. This is important because Solar Jack systems utilize a VFD to optimize the pump speed. Both the customers selected for this project are minor independent producers and had no control mechanism on test wells.

EMERGING TECHNOLOGY/PRODUCT

The Solar Jack systems studied in this project comprise a system for supplementing the electrical energy required by a rod beam pump motor, hence reducing the electricity purchased from the utility (PG&E). In this embodiment, Solar Jack consists of a solar PV system, a capacitor bank to restore the regenerated power from the electric motor, and a VFD. The unique feature of the Solar Jack system is the sequestration of the regenerative power which is available by the nature of the rod beam pump operation. Without the Solar Jack system, this power which is typically low quality power is either wasted as heat or exported to the grid.

The Solar Jack system allows for a balanced connection between the power from a utility grid and a solar PV system through the DC bus of a VFD. Initially, the required power of the rod beam pump motor is provided by the solar PV system and by the energy from the regeneration process stored in the capacitor bank. Additional energy required by the pump motor is supplied from the utility grid. By increasing the capacity of the Solar PV system with storage banks, if desired, the pumping systems can be operated fully off-grid. Both the test systems are connected to the grid.

The VFD in the system is appropriately sized for the motor load and modulates the speed of the motor which in turn modulates the strokes per minute of the rod beam pump. The VFD can be either controlled manually or automatically. Manual control is a reduction in speed based on the operator judgement which is typically the case in most of the sites operated by minor producers. Automatic control of the VFD is based on the down-hole monitoring and communication to the VFD panel. The VFD also plays the role of an inverter for the Solar PV power and regenerative power from the Solar Jack capacitor bank.

The capacitor bank consists of nickel oxide hydroxide high amperage capacitors. The VFD acts as gateway for the flow of the regenerative power from the motor to the capacitor bank and back to the motor. The grid power is the source of energy to make up the difference. The installed capacitors are appropriately sized and governed; this being a key and proprietary technology in the Solar Jack system, the manufacturer would not disclose their specifications. Please refer to Figure 1 for the electrical single line diagram of the Solar Jack System. Figure 2 shows a photograph of the Solar Jack panel without the PV system at the Host Site #2.

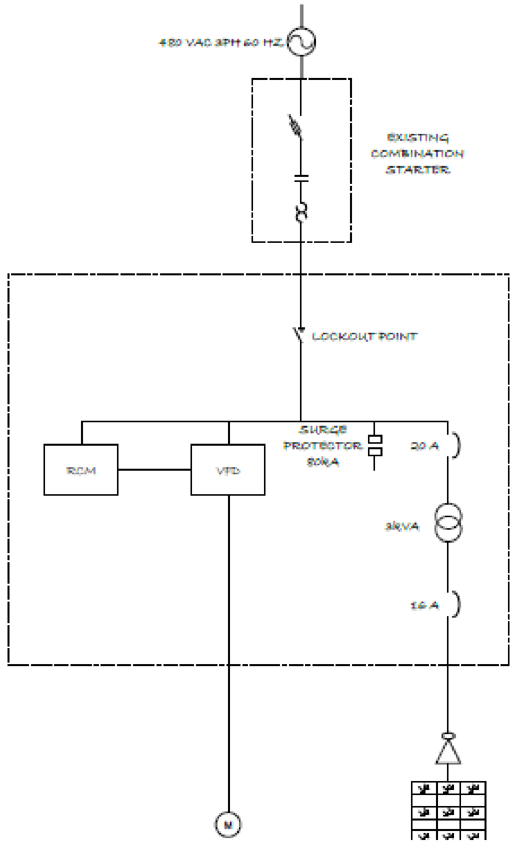

FIGURE 1: SOLAR JACK SINGLE LINE DIAGRAM

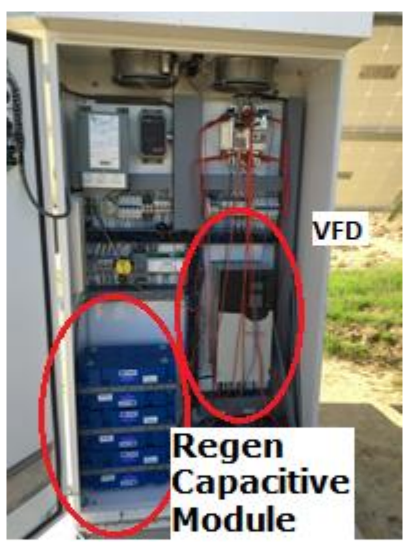

FIGURE 2: SOLAR JACK SYSTEM APPARATUS

As stated in the previous sections, continuous operation without any controls is the ISP among minor producers and POCs among major producers. The energy savings from Solar Jack is expected to be lower on rod beam pumps which are already equipped with timers, POCs, or VFDs.

In addition to energy savings, the Solar Jack system also improves the overall power factor by eliminating the low quality power input on the grid and using the VFD with Insulated-Gate Bipolar Transistor (IGBT) for the power sourced from the grid. By eliminating the wasted energy in the form of heat, the system also reduces the maintenance down-time and extends the life of the pumping system.

The savings contribution from the VFD is eligible for Custom/ Deemed Energy Efficiency Incentive program. The savings contribution from Solar PV does not qualify as energy efficiency; however, they could qualify for incentives under other renewable energy or self-generative incentives programs. The regen component existed before the Solar Jack system but in the form of low quality power exported to the grid. The customer was neither credited nor penalized for this. With the Solar Jack system, the regen component is recycled and reused within the pumping system without exporting to the grid. This reduces the electric consumption and cost for the customer without any impact on the grid because the uncredited export is now used by the customer. Since there are no savings realized at the grid level from the regen component, the corresponding customer savings may not be eligible for energy efficiency program incentives.

ASSESSMENT OBJECTIVES

The goal of this assessment is to verify the energy savings potential and contribution of individual components using empirical methods. Additional goals are to develop calculation methodology, M&V plan, and evaluate Energy Efficiency incentive eligibility.

TECHNOLOGY/PRODUCT EVALUATION

For each well, the pre installation (existing) system is a rod beam pumping system without any controls. The regen power generated during the down stroke is being sent to the grid. The post installation systems include Solar Jack as an add-on component to the existing system.

The technology assessments were done in the oil field due to the nature of the process and technology. A field assessment was the best option since many parameters affect the results which could be hard, if not impossible to replicate in a lab environment.

Three rod beam pump test sites with no existing controls and operated by "Minor" producers were chosen for this study. Minor oil producers have an established ISP of no controls which means they are eligible to claim savings from VFD. Customer's availability, location, stimulation technique, well/pump/motor age, and willingness to implement the technology were also considered in selecting the test sites. Table 3 provides information about all three sites.

TABLE 3: BASIC INFORMATION OF SELECTED WELLS

Oil Well System	**Host Site #1**	**Host Site #3**	**Host Site #2**
Producing From	October, 2007	August, 2013	May, 2014
Av. BFPD (Customer)	361.1	144.0	30.7
Av. BFPD (DOGGR)	470.2	146.5	65.3
Av. BOPD (Customer)	8.6	3.7	2.9
Av. BOPD (DOGGR)	10.4	4.4	0.7
Strokes Per Minute (SPM)	9.3	7	7.5
Min. Turn-down Ratio	54%	71%	67%
Pump off Controller	Yes, but bypassed or not operational	No	No
Rated Motor HP	30	30	15
Rated Motor Efficiency	93%	86%	NA
Regenerative Power	Export to the grid	Export to the grid	Export to the grid
Well Stimulation	No stimulation was performed in the recent history of the well. However, after the post-installation data monitoring, the customer steamed the well and not necessarily because of the data gathered during the study.	None	Hot water stimulation to loosen the accumulation of the fluid downhole and performed once in few weeks as deemed reasonable.

Please refer to Figure 3 and Figure 4 for the pumping system and motor nameplate at Host Site #2 and Figure 5 for the motor nameplate at Host Site #1. During the M&V process, Host Site #3 dropped from the list due to the reasons explained later in the report.

FIGURE 3: HOST SITE #2 ROD BEAM PUMP

FIGURE 4: HOST SITE #2 ROD BEAM PUMP MOTOR NAMEPLATE

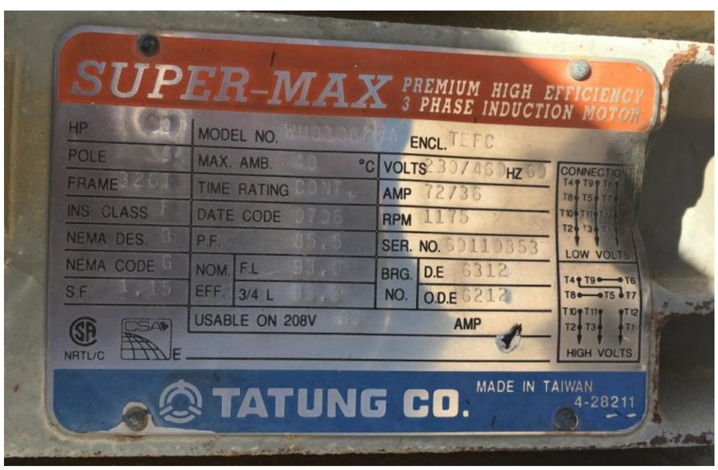

FIGURE 5: HOST SITE #1 ROD BEAM PUMP MOTOR NAMEPLATE

The project team, Lincus and PG&E have extensive experience with oil production sites and M&V activities. The test sites were chosen by Lincus, PG&E Field Engineer (Terry Kloth), and PG&E Project Manager (Phil Broaddus). In the pre-installation and post-installation phases, under the supervision of Lincus, data loggers were installed by technicians from Solar Jack.

TECHNICAL APPROACH/TEST METHODOLOGY

The selected International Performance Measurement and Verification Protocol (IPMVP) option for this project is *Option B – Retrofit Isolation: All Parameter Measurement*. For this option, savings are determined by measurement of all performance parameters which define the energy use of the measure's affected system.

Due to the nature of the pumping process and the fact that pumping units were operating at several strokes per minute, Lincus and PG&E agreed to use PowerSight 4500 (PS4500) data loggers to perform the logging at one second intervals. This logger has the capability of adding a Secure Digital (SD) card to increase its data storage capacity

In the baseline monitoring phase (also known as "pre-installation M&V"), (1) PS4500 data logger was installed in the motor panel serving the pumping system to monitor the net true power and net apparent power (Power import and export). Simultaneously to the power monitoring, production data was also monitored. Please refer to the Table 4 for details regarding the pre-installation M&V parameters, equipment, time interval, and duration.

After installation of the Solar Jack system (also known as "post-installation M&V"), (2) PS4500 data loggers were used: one to monitor apparent and true power sourced from the grid and the other to monitor regen power; (1) DENT Elite Pro SP logger was used to monitor the Solar PV output. Please refer to the Table 5 details regarding the post-installation M&V parameters, equipment, time interval, and duration.

TABLE 4: PRE-INSTALLATION M&V PLAN

Data Points	List of Parameters	Metering Equipment	Interval & Duration
Min, Max, Average	Voltage, Current, Apparent Power, True Power, Frequency, Power Factor	PowerSight 4500 to monitor the net power	Interval: 1 second Duration: 2 weeks
Average	Flow Rate (BFPD/BOPD)	Customer's bucket and centrifuge method	1 test during 2 weeks period

TABLE 5: POST-INSTALLATION M&V PLAN

Data Points	List of Parameters	Metering Equipment	Interval & Duration
Min, Max, Average	Voltage, Current, Apparent Power, True Power, Frequency, Power Factor	3 data loggers each well: 2 x PowerSight 4500 one each for power from grid and regen power 1 x Dent Elite Pro SP for the solar PV	Interval: 1 second Duration: 4weeks
Average	Flow Rate (BFPD/BOPD)	Customer's ball trap test	2 tests during 4 week period

MONITORING AND TEST PROCESS

A pre-field meeting was conducted to assign roles and responsibilities to implement the M&V plan. Table 6 lists the project team members and their respective roles.

TABLE 6: LIST OF PROJECT TEAM MEMBERS

Company Name	Role
PG&E	Investor-Owned Utility sponsoring the assessment
Lincus Inc.	Consultant contracted for conducting the study
Host Site #1	(3) Customer locations selected for test sites
Host Site #2	
Host Site #3	
Solar Jack	Manufacturer of the Solar Jack System
KSi	Electrical contractor hired by Solar Jack to perform the installation of the data loggers and Solar Jack system
GexPro	Distributor of Solar Jack System and project management team hired by Solar Jack to supervise the installation and coordinate the study

The project team evaluated various power data loggers available in the market and decided to use PS4500 for the following reasons:

- Storage capacity can be increased by adding a SD card. With additional storage, data can be monitored at one-second interval.
- Multiple modes of monitoring.
    - Net Average: PS4500 monitors the power in the direction of Current Transformers (CTs) as positive and against as negative. The average of the readings over the time interval is recorded. This is called "Negatives Allowed" mode.
    - Absolute Average: PS4500 assumes that all the power going through the CTs is positive. Hence, the sign of the negative power changes to positive. The average of the readings over the time interval is recorded. This is called as "Always Positive" mode.

Except for one of the PS4500s, all others were rented from Summit Technologies, who is also the manufacturer of PowerSight meters. One PS4500 was rented from the Pacific Energy Center. Calibration of the loggers was ensured by the owners. Table 7 lists the parameters, ranges, and accuracy measured by PS4500. Please refer to Attachment#2 for the manufacturer specifications of PowerSight 4500.

TABLE 7: RANGES AND ACCURACY OF MONITORED PARAMETERS

Parameter	Range	Accuracy
Voltage	1-600 Vrms	± 0.1% of reading ±0.3 Vrms
Current Probe	10-3000A	Accuracy: ±1% (± 2% for varying position around the conductor)
Current	10-3000A	± 0.1% of reading plus accuracy of probe
Power	Not Available	± 0.5% plus accuracy of current probe

BASELINE/ PRE-MONITORING

Baseline monitoring was performed by installing the PS4500 data logger on the starter panel serving the pumping system to monitor the net power. Net power is defined as the difference between the power being imported from the grid and regen power exported to the grid. Table 8 lists the start date and end date of the monitoring period for each test site.

TABLE 8: BASELINE MONITORING TIMELINE

Test Site	Baseline Power Monitoring		Baseline Production collected dates
	Start Date	End Date	
Host Site #1	12/14/2015	12/28/2015	12/17/2015 12/21/2015
Host Site #2	12/30/2015	01/14/2016	12/29/2015
Host Site #3	12/14/2015	12/28/2015	Not Available

At Host Site #1, the baseline power data was successfully recorded and monitored at one-second intervals for a 2-week period. At Host Site #2, data was only recorded for few hours due to issues with the external SD card. However, because of constant baseline operation and no changes in strokes per minute, it was observed that there is very minimal variation in the power consumption at both sites. Hence, the few hours of data collected provide a good representation of the baseline operations. At Host Site #3, DENT Elite Pro SP was installed on 01/15/2016 to monitor the baseline net true power at 15 minute intervals due to similar issues with the PS4500 data logger. For the reasons explained later in the report, Host Site #3 was dropped out from the study. The production data for the sites is based on the customers' production tests identified in Table 4 and 5. Please refer to the following files for the raw baseline data.

- Attachment #3: Baseline production data.zip
- Attachment #4: Host Site #1 Baseline Raw Data.zip
- Attachment #5: Host Site #2 Baseline Raw Data.zip
- Attachment #6: Host Site #3 Baseline Raw Data.zip

POST MONITORING

Individual data loggers were used to monitor the power consumption of the (3) components of the Solar Jack System. Solar Jack system uses the following naming format on the device for the flow of the power; and the way post data loggers are set up, is explained below.

Line – Data loggers were installed on the line to monitor the power imported from the grid, which is the power consumed by the pumping system with a VFD. This is the power in addition to the regen power and the Solar PV power. Since there is no export of power to the grid with Solar Jack system, there is only unidirectional power through this cable. PS4500 was installed with the CTs facing the direction of the power to record "Always Positive" Power. If the direction of CTs is properly set, the modes of PS4500 "Always Positive" or "Negative Allowed" should not matter.

Load – Data loggers were installed on the Load side to monitor/calculate the regen power. There are multiple powers going through the load cable and in different directions.

- Line Power going to the motor.
- Solar PV power going to the motor.
- Regen power coming from the motor and going into capacitor bank through VFD. (Power Generated during down stoke)
- Regen power going to the motor from the capacitor bank through VFD.

Figure 6 shows the arrangement of the installed loggers at post-installation monitoring stage.

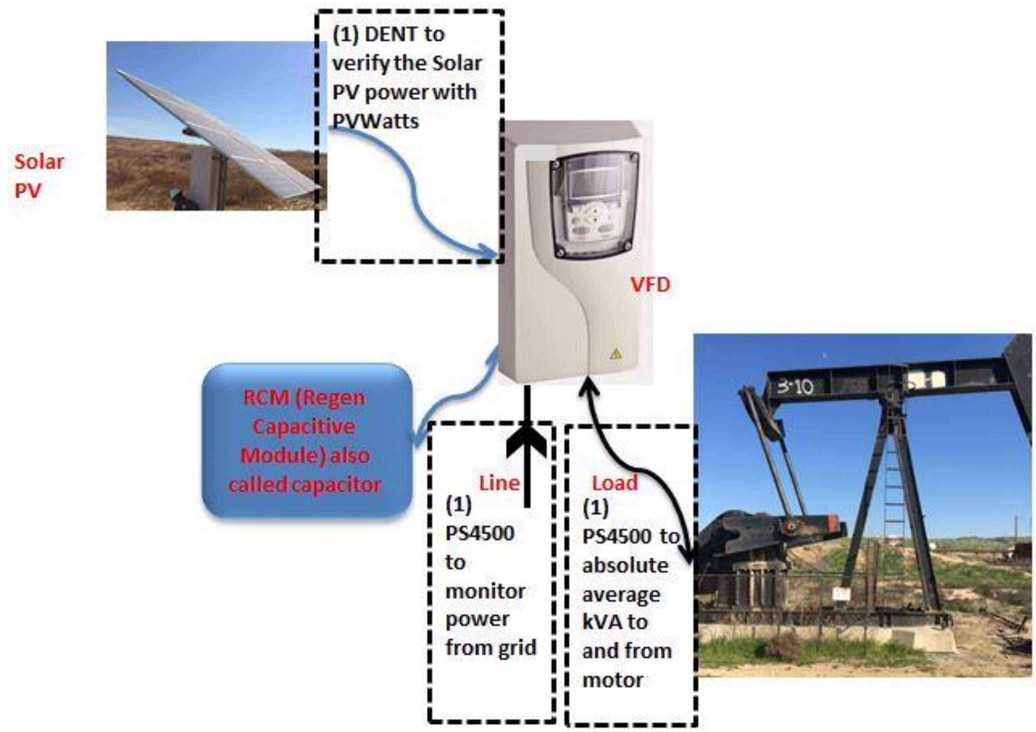

FIGURE 6: ARRANGEMENT OF INSTALLED LOGGERS

Table 9 lists the start date and end date of the post monitoring period for the power and production measurements. During the Solar Jack start-up test at Host Site #3, it was found that there is an overvoltage fault on the VFD drive causing concerns for the safe operation of the system. Due to this, Solar Jack team decided to not install the system and hence, this test site is dropped from the study. (2) PS4500 data loggers were installed at each well site: one to monitor the power sourced from grid and the other to monitor the regen power. Additionally, (1) DENT logger was also installed at each site to monitor the Solar PV power output. The production data for the sites is based on the customer's production tests identified in Table 4 and 5.

TABLE 9: POST-INSTALLATION MONITORING TIMELINE

Well Site	Post Install Power Monitoring		Post Production collected dates
	Start Date	End Date	
Host Site #2	01/14/2016	02/15/2016	1/15/2016 1/23/2016 1/26/2016 1/28/2016
Host Site #1	01/19/2016	02/15/2016	1/27/2016 2/5/2016
Host Site #3	Dropped from the study		

During the post-installation period, both the pumps were observed to operate at 100% VFD speed. It was determined that fear of a negative impact on production capacity was the main reason for customers' reluctance to reduce the VFD speed.

At the time of the removing the post-install data loggers, the project team discussed with operators the benefits of the VFDs and suggested to try lower speeds for a few days and switch to original full speed operations if the production was reduced. Both sites agreed to reduce the speed and only Host Site #2 was monitored.

Additional post data logging (from 04/04/2016 to 04/12/2016) was performed on Host Site #2 test to determine the energy savings impact by reducing the VFD frequency to 33 Hz. Table 10 summarizes the start date and end date of the additional power and production monitoring.

TABLE 10: ADDITIONAL POST-INSTALLATION MONITORING TIMELINE

Well Site	Post Install Power Monitoring		Post Production collected dates
	Start Date	End Date	
Host Site #2	04/04/2016	04/12/2016	04/06/2016 04/08/2016
Host Site #1	No Additional Monitoring		
Host Site #3	Dropped from the study		

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EVALUATIONS

The data analysis was performed using engineering spreadsheet calculations. The one-second interval was converted to hourly intervals using Equation 1.

EQUATION 1. AVERAGE PUMP KW

$$Hourly\ Average\ Power\ (kW_{avg}) = \frac{\sum_{n=1}^{3600} kW_n}{3600}$$

The hourly average was further organized into hourly bins for the specific hours using Equation 2.

EQUATION 2. AVERAGE PUMP KW FOR SPECIFIC HOUR

$$kW_{i=1,2,\ldots 24} = \frac{\sum_{j=1}^{n} kW_{avg\ ij}}{n}$$

Where *n* is the number of average kWs for the particular hour. Hourly average data is included in the Attachments labelled as "summary" spreadsheets. Solar PV power output, which was collected at 30 seconds interval, was also converted to hourly average.

BASELINE MONITORING ANALYSIS

The PS4500 used in the baseline monitoring was set to the "Negative Allowed" mode to record the net power. Since PS4500 could not separate the positive and negative power, the power consumed by the pump was calculated by adding the "estimated" regen power to the monitored net power. Since no changes were made to the motor balancing, the regen power was assumed to be the same in the pre and post monitoring after normalizing for the production rate. Equation 3 shows the baseline power consumed by the pumping system.

EQUATION 3. AVERAGE BASELINE POWER CONSUMED

Baseline Power (kW) = Logged Net Power (kW) + Calculated Regen Power @ Post Stage x Baseline Production Rate (BFPD) / Post Production Rate (BFPD)

This was organized into hourly bins using Equation 3. It was observed that there is less than 4% variation (Coefficient of Variation (CV)) in the hourly average baseline kW values. Baseline energy metric was calculated using the Equation 4. In this equation, the baseline production rate has the unit of Barrel of Fluid per Day (BFPD).

EQUATION 4. BASELINE ENERGY METRICS

Baseline Energy Metric (kWh/BFPD) = Average Baseline Energy (kW) x 24 (hours/day) / Baseline Production Rate (BFPD)

POST MONITORING ANALYSIS

In the post-installation operation, there are multiple cycles of two directional power going through the cable connecting the motor and the VFD within each second with varying power factors. Per Summit technologies (manufacturer of PS4500), the true power is misleading in cases of multiple two directional power flows within the time interval. Hence, on the "Load", the data loggers were installed in "Always Positive" mode. Using the apparent power readings and reasonably "assumed" power factors, the true regenerative power is isolated using Equation 3 through Equation 7.

EQUATION 5. POST APPARENT POWER

$$kVA_{Load} = kVA_{Line} + kVA_{Solar} + kVA_{Regen1} + kVA_{Regen2}$$

Where

kVA_{Load} = Apparent power recorded on the "Load"

kVA_{Line} = Apparent power recorded on the "Line"

kVA_{Solar} = Apparent power from the solar panel which is same as the true power recorded by the DENT logger

kVA_{Regen1} = Apparent regen power to motor from the capacitor bank via VFD (regen power consumed after conditioning and storage in the capacitor bank)

kVA_{Regen2} = Apparent regen power from motor to the capacitor bank via VFD (regen power generated during down-stroke)

Regen power (kW_{Regen}), kVA_{Regen1} and kVA_{Regen2} are replaced according to the following formulas:

EQUATION 6. APPARENT REGEN POWERS

$$kVA_{Regen1} = kW_{Regen} / PF_{VFD\text{-}motor}$$

$$kVA_{Regen2} = kW_{Regen} / PF_{motor\text{-}VFD}$$

Where

$PF_{VFD\text{-}motor}$ = Power Factor during the motor consumption mode.

$PF_{motor\text{-}VFD}$ = Power Factor during the motor generation mode.

Note: Since no changes were made to the motor with the installation of Solar Jack system, the baseline and post PFs are assumed to be the same.

kW_{Regen} was calculated using Equation 7:

Equation 7. Regen true power

$$kW_{Regen} = (kVA_{Load} - kVA_{Line} - kW_{Solar}) \times [(PF_{VFD\text{-}motor} \times PF_{motor\text{-}VFD}) / (PF_{VFD\text{-}motor} + PF_{motor\text{-}VFD})$$

The DENT logger measuring solar PV output showed a bias of 0.02 kW (measurement recorded during night); hence all measured solar output kW was adjusted by subtracting 0.02 kW. This data was further organized into average hourly bins and compared with the hourly output from the National Renewable Energy Laboratories' PVWatts® calculator[1]. It is observed that the monitored kW and the kW from PVWatts is within ± 8%. Hence, it is reasonably concluded that PVWatts can be used to estimate the Solar PV output for the entire year. The annual average Solar PV kW was calculated using Equation 8.

Equation 8. Average Solar Power

$$kW_{solar} = kWh \text{ per year from PVWatts} / 8760$$

Equation 9 was used to find the energy draw from the grid (grid power) required for the production of each barrel of fluid.

Equation 9. Grid energy metric

$$\text{Grid Energy Metric (kWh/bbl)} = kW_{Line} \times 24 \text{ (hours/day)} / \text{Post Production rate (BFPD)}$$

Equation 10 was used to find the solar *energy* required for the production of each barrel of fluid.

Equation 10. Solar energy metric

$$\text{Solar Power Metric (kWh/bbl)} = kW_{Solar} \times 24 \text{ (hours/day)} / \text{Post Production rate (BFPD)}$$

Equation 11 was used to find the contribution of regen power in the production of each barrel of fluid.

Equation 11. Regen energy metric

$$\text{Regen Energy Metric (kWh/bbl)} = kW_{Regen} \times 24 \text{ (hours/day)} / \text{Post Production rate (BFPD)}$$

---

[1] https://developer.nrel.gov/docs/solar/pvwatts-v5/

Equation 12 was used to calculate the overall energy required for the production of each barrel of fluid.

EQUATION 12. POST ENERGY METRIC

$$Post\ Energy\ Metric\ (kWh/bbl) = Grid\ Energy\ Metric + Solar\ Energy\ Metrics + Regen\ Energy\ Metrics$$

For more details about the calculation methodology, please refer to the following attachments:

- Attachment #11: Host Site #1 Post summary.xlsx
- Attachment #12: Host Site #2 Post summary.xlsx
- Attachment #13: Host Site #2 Reduced-speed Post Summary.xlsx

ENERGY SAVINGS CALCULATIONS

The following assumptions were made for calculating the annual energy savings and DEER peak demand reduction:

- The well pumps are down 2% of the time annually for maintenance.
- The production/energy consumption is uniform throughout the year.
- The annual production used in the calculations was obtained from the DOGGR database.
- The annual production will remain the same as in 2015.

The formulas below were used to find the annual energy savings and peak demand reduction:

EQUATION 13. BASELINE ENERGY USAGE

$$Baseline\ energy\ usage\ (kWh) = Baseline\ Energy\ Metrics\ (kWh/bbl) \times 2015\ Annual\ Production\ (bbl/year) \times (100\% - 2\%)$$

EQUATION 14. POST ENERGY USAGE

$$Post\ energy\ usage\ (kWh) = Baseline\ Energy\ Metrics\ (kWh/\ bbl) \times 2015\ Annual\ Production\ (bbl/year) \times (100\% - 2\%)$$

EQUATION 15. ANNUAL ENERGY SAVINGS

Annual energy savings (kWh) = Baseline energy usage - Post energy usage

EQUATION 16. PEAK DEMAND REDUCTION

Peak demand reduction = Annual energy savings (kWh) / 8760 (hours/year)

For more information about the 2015 annual production data, please refer to the following attachments:

- Attachment #14: Host Site #1 Production Data (DOGGR).xlsx
- Attachment #15: Host Site #2 Production Data (DOGGR).xlsx

RESULTS

The two rod beam pumping systems considered in the assessment are not identical; they have different flow and heads and are powered by different capacity motors in addition to geological differences. Hence, the results are presented separately for each system.

The baseline data collected at one second intervals was graphed for a sample minute and presented in Figure 7 and Figure 8 for Host Site #1 and Host Site #2, respectively. As expected, the power has sine wave format and the number of repeated patterns in each minute matches the number of strokes per minute for each pump. In addition, it is important to note that in each cycle, the true power becomes negative during down-stroke which is the regen power exported to electric grid.

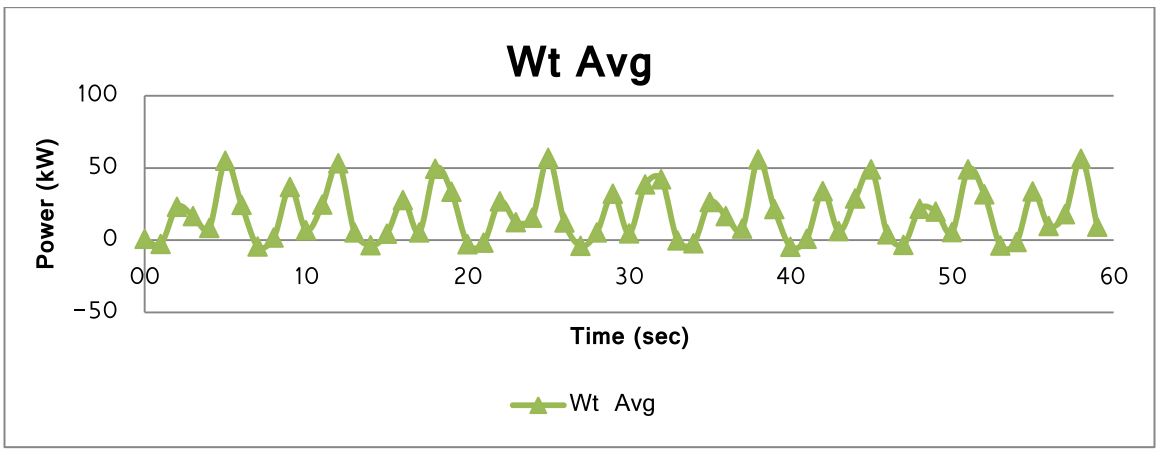

FIGURE 7: AVERAGE SYSTEM WATTAGES AT HOST SITE #1 DURING ONE SAMPLE MINUTE IN BASELINE (5:20 PM ON 12/14/2015)

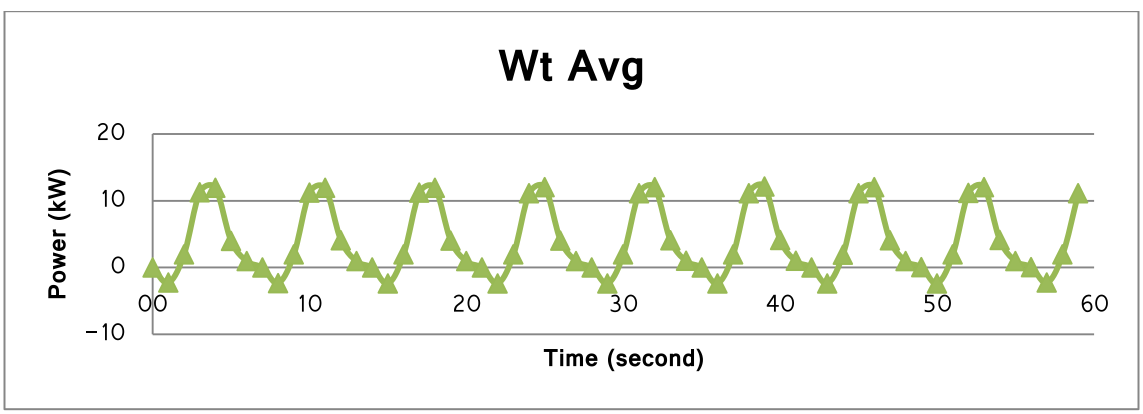

FIGURE 8: AVERAGE SYSTEM WATTAGES AT HOST SITE #2 DURING ONE SAMPLE MINUTE IN BASELINE (6:10 AM ON 12/30/2015).

Figure 9 shows the power factor during the consumption and generation mode for Host Site #2 and Host Site #1 sites. It is observed that the power factor of the regen power is very low.

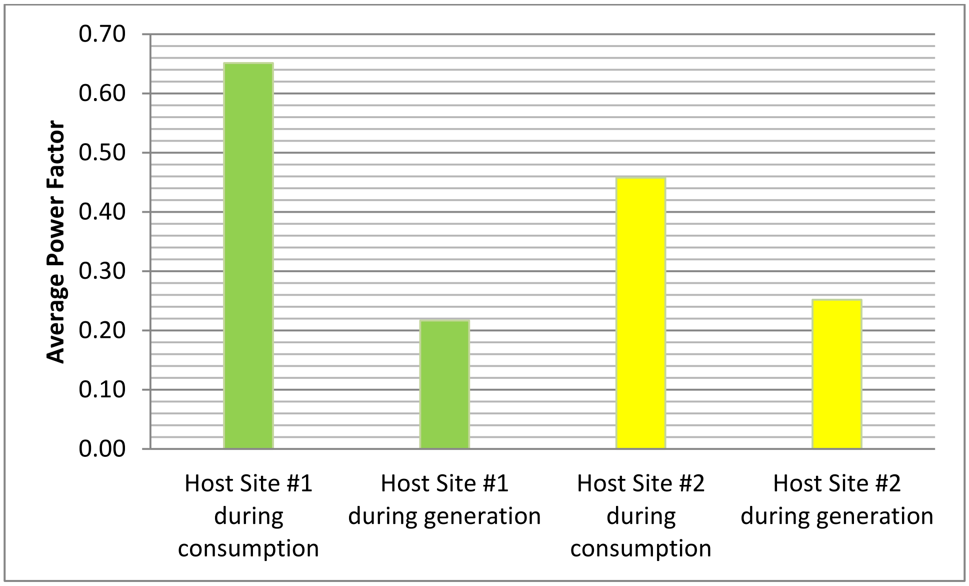

FIGURE 9: POWER FACTOR DURING CONSUMPTION AND GENERATION MODE OF ENTIRE MONITORING PERIOD

Table 11 and Table 12 summarizes the average energy metric (kWh/ barrel) calculated using the Equation 4.

TABLE 11: SUMMARY OF HOST SITE #1 BASELINE MONITORED DATA

Pre-installation M&V		
Nominal Motor hp	30	hp
NEMA Motor Efficiency	93%	
Pump kW	20.18	kW
Load Factor	83.9%	
Power Factor	0.57	
VFD Frequency	59.96	Hz
Av. BFPD	316.58	BPD
Energy Metric	1.530	kWh/Barrel of Fluid

TABLE 12: SUMMARY OF HOST SITE #2 BASELINE MONITORED DATA

Pre-installation M&V		
Nominal Motor hp	15	Hp
NEMA Motor Efficiency	85%	
Pump kW	4.46	kW
Load Factor	33.8%	
Power Factor	0.42	
VFD Frequency	59.13	Hz
Av. BFPD	57.00	BPD
Energy Metric	1.876	kWh/Barrel of Fluid

For the post-installation case, the power sourced from the grid (through the line cable), regen power, and Solar PV output were calculated using the methodology presented in the section "Post Monitoring Analysis". Table 13, Table 14, and Table 16 summarize the average post-installation M&V results for Host Site #1, full VFD speed, and reduced VFD speed monitoring at Host Site #2 sites, respectively. It is observed that the coefficient of variation (CV) of the hourly averages of total power is less than 3%. Since the VFD speed was not modulated during the monitored period, this trend is expected. The difference between the baseline and post total power is that some of the power requirements in the post case are met by the regen component and by the Solar PV system.

TABLE 13: SUMMARY OF HOST SITE #1 POST-INSTALLATION MONITORING DATA

Post-installation M&V		
Annual kWh Solar Generation	3,484	kWh
Average Grid Power	19.82	kW
Average Regen Power	0.86	kW
Average Solar Power	0.40	kW
Average Total Power	20.99	kW
Average Power Factor of System	0.83	
Average Apparent Power of Motor	22.44	kVA
Average Apparent Power of Regen	28.35	kVA
Frequency (Motor)	59.88	Hz
Frequency (Regen)	59.55	Hz
Av. BFPD (Customer)	372.99	BPD
Annual Production	5,508	bbl
Grid Energy Metric	1.275	kWh/Barrel of Fluid
Regen Energy Metric	0.055	kWh/Barrel of Fluid
Solar Energy Metric	0.026	kWh/Barrel of Fluid
Total Energy Metric	1.351	kWh/Barrel of Fluid

TABLE 14: SUMMARY OF HOST SITE #2 POST-INSTALLATION WITH VFD AT FULL SPEED

Post-installation M&V		
Annual Solar Energy Generation	3,484	kWh
Average Grid Power	4.57	kW
Average Regen Power	1.03	kW
Average Solar Power	0.40	kW
Average Total Power	6.00	kW
Average Power Factor of Motor	0.72	
Average Apparent Power of Motor	5.32	kVA
Average Apparent Power of Regen	10.42	kVA
Frequency (Motor)	59.15	Hz
Frequency (Regen)	58.91	Hz
Av. BFPD	75.00	BPD
Annual Production	24,031	bbl
Grid Energy Metric	1.463	kWh/Barrel of Fluid
Regen Energy Metric	0.330	kWh/Barrel of Fluid
Solar Energy Metric	0.127	kWh/Barrel of Fluid
Total Energy Metric	1.920	kWh/Barrel of Fluid

TABLE 15: SUMMARY OF HOST SITE #2 POST-INSTALLATION WITH VFD AT REDUCED SPEED

Post-installation M&V		
Annual Solar Energy Generation	3,484	kWh
Average Grid Power	2.75	kW
Average Regen Power	1.51	kW
Average Solar Power	0.40	kW
Average Total Power	4.66	kW
Average Power Factor of Motor	0.67	
Average Apparent Power of Motor	3.68	kVA
Average Apparent Power of Regen	11.04	kVA
Frequency (Motor)	33	Hz
Frequency (Regen)	33	Hz
Av. BFPD	73.00	BPD
Annual Production	24,031	bbl
Grid Energy Metric	0.906	kWh/Barrel of Fluid
Regen Energy Metric	0.497	kWh/Barrel of Fluid
Solar Energy Metric	0.131	kWh/Barrel of Fluid
Total Energy Metric	1.533	kWh/Barrel of Fluid

Figure 10, Figure 11, and Figure 12 compares the baseline and post energy metrics for Host Site #1, Host Site #2 (full speed), and Host Site #2 (reduced speed). The reduction in energy metric in the post case is due to energy savings from the VFD, regen, and solar PV components.

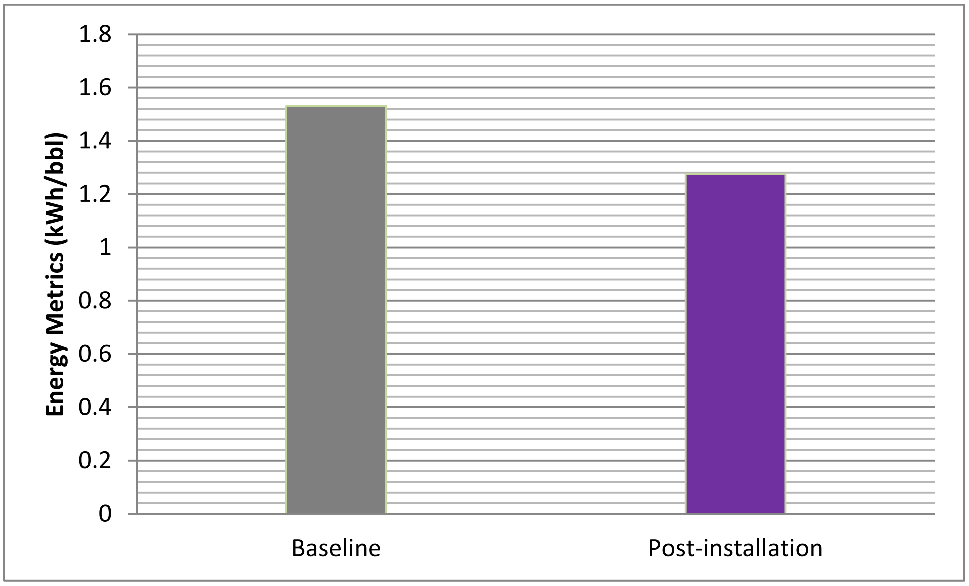

FIGURE 10: PRODUCTION ENERGY METRICS AT HOST SITE #1

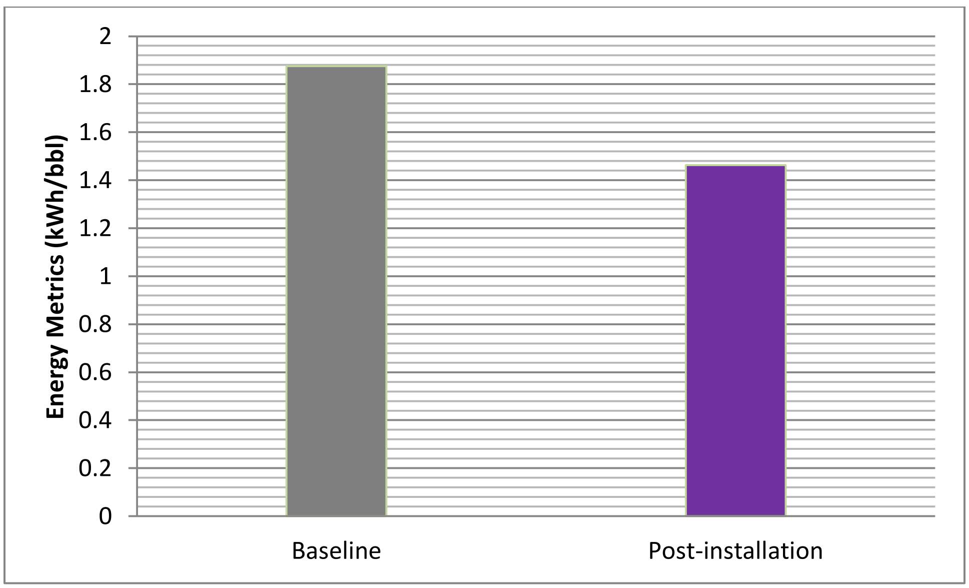

FIGURE 11: PRODUCTION ENERGY METRICS AT HOST SITE #2

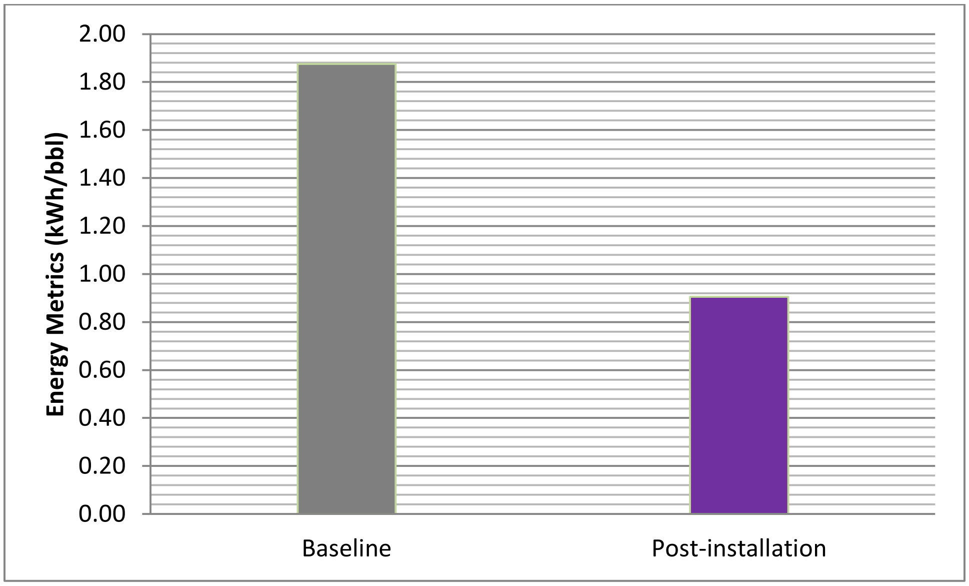

FIGURE 12: PRODUCTION ENERGY METRICS AT HOST SITE #2 (REDUCED-SPEED MONITORING)

As stated earlier, the Solar Jack system also helps in improving the power factor due to two reasons:

1) The low quality regen power is no longer exported to the grid but reused within the pumping system, and

2) The IGBTs in the VFD increases the power quality of the grid power input to the VFD.

Figure 13 show the average power factor of the power sourced from the grid before and after the Solar Jack system for Host Site #1 and Host Site #2 (full speed), and Host Site #2 (reduced speed) sites.

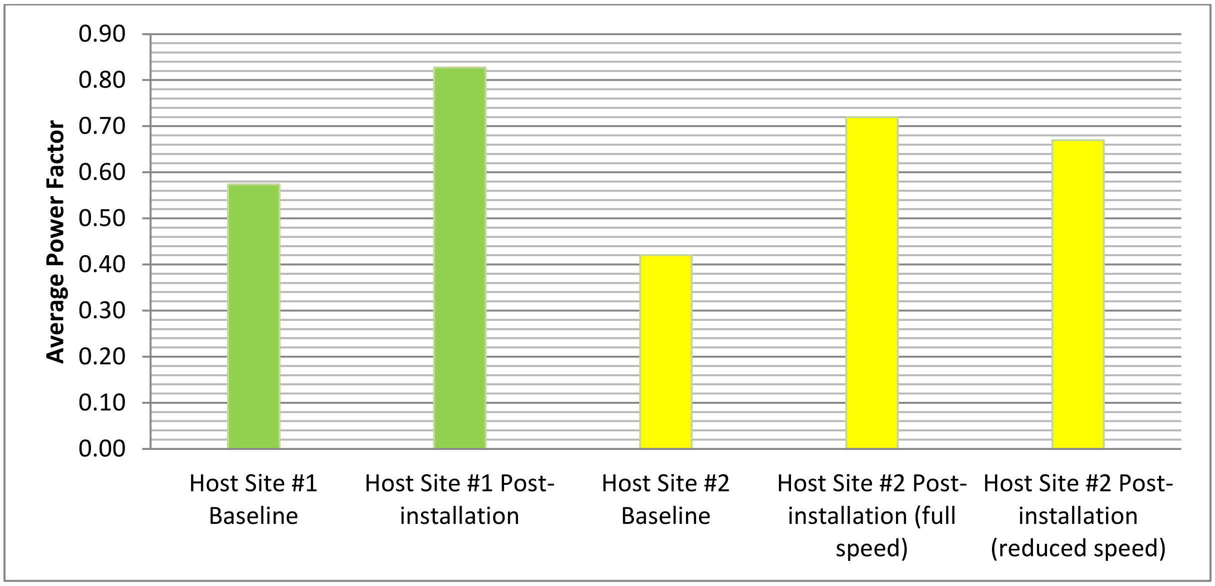

FIGURE 13: POST-INSTALLATION POWER FACTORS

Table 16 and Table 17 summarizes the hourly average kW during the monitored period for Host Site #1 and Host Site #2 (full speed), and Host Site #2 (reduced speed) sites, respectively.

TABLE 16: HOURLY AVERAGE OF THE POST INSTALLATION MONITORED DATA AT HOST SITE #1

Hour	Grid Power (kW)	Grid Apparent Power (kVA)	Load Apparent (kVA)	Calculated Regen Power (kW)	Grid Power Factor	Solar Power (kW)	Total Power (kW)
0	20.23	22.82	28.59	0.90	0.84	0.00	21.13
1	20.24	22.78	28.62	0.91	0.84	0.00	21.15
2	20.26	22.85	28.65	0.91	0.84	0.00	21.17
3	20.28	22.85	28.64	0.91	0.84	0.00	21.18
4	20.29	22.90	28.63	0.90	0.84	0.00	21.19
5	20.30	22.90	28.63	0.90	0.84	0.00	21.19
6	20.31	22.92	28.64	0.89	0.84	0.00	21.21
7	20.32	22.93	28.50	0.86	0.84	0.09	21.27
8	20.28	22.82	27.71	0.70	0.84	0.39	21.37
9	20.16	21.92	27.53	0.77	0.83	0.70	21.63
10	19.25	21.51	27.13	0.73	0.81	0.96	20.94
11	18.20	21.02	27.82	0.90	0.80	1.04	20.14
12	18.57	21.48	28.52	0.93	0.80	1.11	20.61
13	18.99	21.94	28.51	0.84	0.79	1.18	21.01
14	18.95	21.94	28.41	0.86	0.79	1.00	20.81
15	19.09	21.95	28.32	0.88	0.80	0.73	20.70
16	19.31	22.13	28.29	0.91	0.81	0.36	20.58
17	19.72	22.40	28.31	0.92	0.83	0.02	20.66
18	20.07	22.63	28.39	0.90	0.84	0.00	20.97
19	20.11	22.69	28.45	0.90	0.84	0.00	21.01
20	20.14	22.72	28.49	0.90	0.84	0.00	21.04
21	20.16	22.76	28.51	0.90	0.84	0.00	21.06
22	20.19	22.78	28.54	0.90	0.84	0.00	21.09
23	20.21	22.80	28.56	0.90	0.84	0.00	21.11

TABLE 17: HOURLY AVERAGE OF THE POST INSTALLATION MONITORED DATA AT HOST SITE #2

Hour	Grid Power (kW)	Grid Apparent Power (kVA)	Load Apparent Power (kVA)	Calculated Regen Power (kW)	Grid Power Factor	Solar Power (kW)	Total Power (kW)
0	4.80	5.49	10.64	1.13	0.73	0.00	5.93
1	4.81	5.50	10.67	1.13	0.73	0.00	5.95
2	4.82	5.50	10.66	1.13	0.73	0.00	5.95
3	4.83	5.53	10.66	1.12	0.73	0.00	5.95
4	4.83	5.51	10.65	1.12	0.73	0.00	5.95
5	4.84	5.53	10.60	1.11	0.73	0.00	5.95
6	4.83	5.54	10.57	1.10	0.73	0.00	5.93
7	4.55	5.24	10.11	1.04	0.72	0.10	5.69
8	4.28	5.04	9.99	0.99	0.69	0.40	5.68
9	4.12	4.95	9.96	0.94	0.70	0.69	5.75
10	4.08	4.96	9.93	0.89	0.70	0.89	5.86
11	4.07	4.98	9.96	0.87	0.70	1.02	5.95
12	4.11	5.03	9.94	0.84	0.71	1.05	6.01
13	4.17	5.14	10.14	0.85	0.69	1.11	6.14
14	4.41	5.33	10.56	0.95	0.69	0.89	6.25
15	4.38	5.20	10.55	1.03	0.68	0.62	6.03
16	4.59	5.29	10.55	1.11	0.71	0.20	5.90
17	4.67	5.34	10.52	1.13	0.73	0.01	5.81
18	4.70	5.36	10.52	1.13	0.73	0.00	5.83
19	4.73	5.40	10.55	1.13	0.73	0.00	5.86
20	4.75	5.42	10.57	1.13	0.73	0.00	5.88
21	4.76	5.43	10.58	1.13	0.74	0.00	5.89
22	4.78	5.46	10.60	1.12	0.73	0.00	5.91
23	4.80	5.48	10.63	1.12	0.73	0.00	5.92

Evaluation of Energy Savings

Host Site #1

Table 18 outlines the baseline and post energy usages along with the energy savings and peak demand reduction at the Host Site #1 test site.

TABLE 18: ENERGY SAVINGS AND PEAK DEMAND REDUCTION AT HOST SITE #1

Customer energy savings and peak demand reduction		
Baseline Grid Energy Usage	188,200.0	kWh
Post-installation Grid Energy Usage	156,848.7	kWh
Energy Savings	31,351.4	kWh
Energy Savings as Percent of Baseline	16.7%	
DEER Peak Demand Reduction	3.58	kW

Table 19 and Figure 14 present the contribution of each Solar Jack component to the energy savings of the project.

TABLE 19: ENERGY SAVINGS OF SOLAR JACK COMPONENTS AT HOST SITE #1

Energy savings of Solar Jack components			
Component	**Energy Savings**		**Percent of total Savings**
Variable Frequency Drive	21,411.7	kWh	68.3%
Regeneration Energy	6,792.0	kWh	21.7%
Solar PV	3,147.7	kWh	10.0%

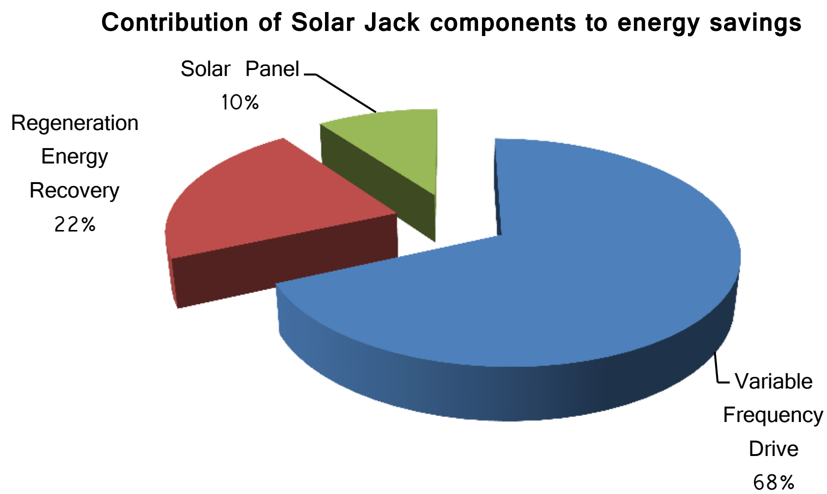

FIGURE 14: CONTRIBUTION OF SOLAR JACK COMPONENTS TO ENERGY SAVINGS AT HOST SITE #1

HOST SITE #2 (VFD AT FULL SPEED)

Table 20 outlines the baseline and post energy usages along with the energy savings and peak demand reduction at Host Site #2.

TABLE 20: ENERGY SAVINGS AND PEAK DEMAND REDUCTION AT HOST SITE #2 AT FULL SPEED

Customer energy savings and peak demand reduction		
Baseline Energy Usage (Grid)	44,177.6	kWh
Post-installation Grid Energy Usage	34,456.2	kWh
Energy Savings	9,721.4	kWh
Energy Savings as Percent of Baseline	22.0%	
DEER Peak Demand Reduction	1.11	kW

Table 21 presents the contribution of Solar Jack components to the energy savings of the project.

TABLE 21: ENERGY SAVINGS OF SOLAR JACK COMPONENTS AT HOST SITE #2 AT FULL SPEED

Energy Savings of Solar Jack components			
Component	**Energy Savings**		**Percent of total Savings**
Variable Frequency Drive	-1,043.4	kWh	-10.7%
Regeneration Energy Recovery	7,767.6	kWh	79.9%
Solar Panel	2,997.2	kWh	30.8%

HOST SITE #2 (VFD AT REDUCED SPEED)

Table 22 outlines the baseline and post energy usages along with the energy savings and peak demand reduction at Host Site #2.

TABLE 22: ENERGY SAVINGS AND PEAK DEMAND REDUCTION AT HOST SITE #2 AT REDUCED SPEED

Customer energy savings and peak demand reduction		
Baseline Grid Energy Usage	44,177.6	kWh
Post-installation Grid Energy Usage	21,330.0	kWh
Energy Savings	22,847.6	kWh
Energy Savings as Percent of Baseline	51.7%	
DEER Peak Demand Reduction	2.61	kW

Table 23 and Figure 15 present the contribution of Solar Jack components to the energy savings of the project at the Host Site #2 test site.

TABLE 23: ENERGY SAVINGS OF SOLAR JACK COMPONENTS AT HOST SITE #2 AT REDUCED SPEED

Energy Savings of Solar Jack and its components			
Component	**Energy Savings**		**Percent of total Savings**
Variable Frequency Drive	8,071.9	kWh	35.3%
Regeneration Energy Recovery	11,696.3	kWh	51.2%
Solar Panel	3,079.4	kWh	13.5%

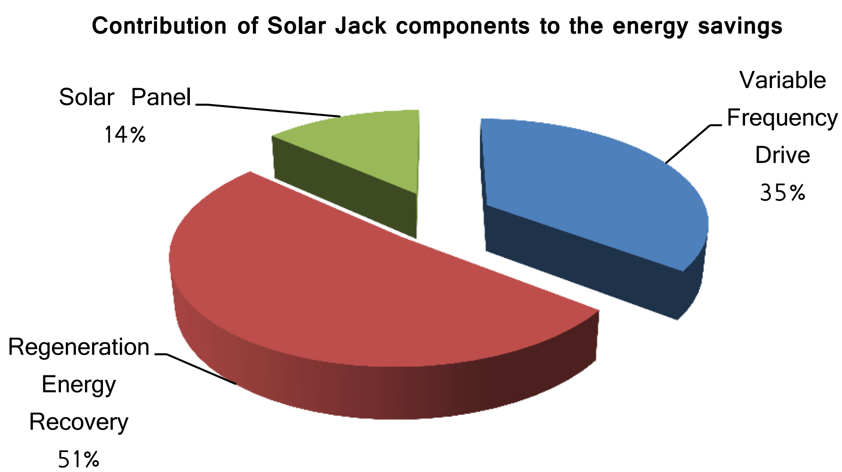

FIGURE 15: CONTRIBUTION OF SOLAR JACK COMPONENTS TO ENERGY SAVINGS AT HOST SITE #2

The total energy savings at each test site and percent contribution of each of the three components are also outlined in Table 24.

TABLE 24: OVERALL ENERGY SAVINGS AT EACH TEST SITE

Component	Host Site #1	Host Site #2 (VFD at full speed)	Host Site #2 (VFD at reduced speed)	
Overall energy savings	31,351.4	9,721.4	22,847.6	kWh
Variable Frequency Drive	68.3%	-10.7%	35.3%	
Regeneration Energy Recovery	21.7%	79.9%	51.2%	
Solar PV	10.0%	30.8%	13.5%	

At both the sites, it is observed that the production increased during the post-installation monitoring period. This may be from the well geology and not necessarily directly attributed to the Solar Jack installation. If the customer is operating the VFD at full speed, typically there should not be any savings but a penalty from the losses in VFD. However, from the post monitored data at Host Site #1 where the VFD was operating at 100%, it is observed that production increased by 18% but the energy usage increased by only 4%; resulting in savings even at full speed conditions. This results in an interpretation that there are other geological factors like the fluid levels, well replenish rate, etc. that cannot be easily monitored but impact the energy consumption. Even with the VFD operating at less than full speeds, from the monitored data it is observed that energy usage is not linearly proportional to production.

RECOMMENDATIONS

The technology assessment of Solar Jack Energy Management system at two test sites concludes that there is savings potential from each of the three components i.e. VFD, Regen capacitor bank, and Solar PV. Test results from both sites showed that savings range between 16.7% to 51.7% of the baseline energy consumption. Due to the variations in geological and operational characteristics of each oil well and pumping equipment, it is not unexpected to see this wide variation. The percent contribution from the VFD varies from -10.7% to 68.3%; Regen capacitor bank varies from 21.7% to 80%; and Solar PV varies from 10% to 30%.

It is important to note that these results are based on evaluation of two host sites and preliminary energy analysis, from which many lessons have been learned that may inform future measurement and verification of this category of equipment. However, application of these results to a wider population is not recommended due to variations in equipment and operation at each site. This means providing a deemed EE offering for this technology is also not recommended until a statistically significant number of well sites are evaluated and energy savings can be projected as a function of certain equipment and/or operational parameters (e.g. motor size, flow rate, etc.). After this system is installed on a number of wells that would achieve statistically defensible confidence levels, a work paper could be developed to determine average savings impact per motor hp or other related parameters.

PG&E's customized incentive EE program could be used to offer incentives for the VFD component of this technology. The M&V plan and the calculation methodology incorporated in this report could be used to determine customer and incentive eligible savings amounts. At the time of writing this report, PG&E's customized incentive program provides incentives for measures that result in coincident reductions in consumption of PG&E-supplied energy from the grid/system. Also, onsite generation is not eligible for receiving program incentives. As discussed earlier in the report, the regen capacitor bank results in reduction in energy consumption for the customer bill but does not impact the net grid supply. Therefore, both regen capacitor bank and Solar PV savings contributions are not eligible for program incentives. Only the contribution from the VFD component is eligible for the program incentives.

During the course of the assessment, some challenges have been identified, including:

a. Selecting the appropriate portable data logger for monitoring the regenerative power. Since there are no data loggers available in the market to isolate and record the two directional flow of AC power with-in one second interval, future evaluations could consider either the approach identified in this study wherein the apparent power with conservative estimates of power factor are used to calculate the regen power, or could explore alternatives like installing data loggers that could monitor DC power and isolate the two-way DC power between the capacitor bank and the VFD.

b. Lack of information about the capacitor bank due to its proprietary design. If the size and type of the capacitor bank could impact the performance of the system, it would require more understanding of the system.

c. The VFD is manually modulated unless the customer has an existing automation system. The operators may not have enough data and training to modulate the VFD speed and tend to set the speeds to maintain the stokes per minute the pump has been operating in the past.

The future scope of evaluating this technology could include rod beam pumps with existing controls like POCs, VFDs with or without regenerative capacity. Research could be conducted to review and compare performance of Solar Jack systems with other VFDs with regenerative capability and how they work with POCs, which may be standard practice at some producers. Additionally, the rationale for sizing the capacitor bank, type of the capacitor bank and their impact on the savings potential, could be part of the future scope. Future analysis could also include financial analysis which may also be complicated given the variable performance due to variation in geologic factors and conditions, and possible variability in savings persistence.

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