**Work Paper PGECOAGR119**

**VFD on Agricultural Pumps**

**Revision 3**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**Variable Frequency Drives on Agricultural Pumps**

**Measure Codes: IR006, IR007**

4/1/2017

# At-A-Glance Summary Table

|  |  |  |
| --- | --- | --- |
| **Applicable Measure Codes:** | **IR006** | **IR007** |
| Measure Description: | VFD ON AG WELL PUMPS (<=300HP)  This measure involves installing a variable frequency drive (VFD) on an agricultural well pump used for irrigation purposes in place of throttling the flow. | VFD ON AG BOOSTER PUMPS (<=150HP)  This measure involves installing a variable frequency drive (VFD) on an agricultural booster pump used for irrigation purposes in place of throttling the flow. |
| Energy Impact Common Units: | per rated pump hp | per rated pump hp |
| Base Case Description: | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD control. | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD control. |
| Base Case Energy Consumption: | 1,490.25 kWh/hp and 0.7019 kW/hp | 1,300.74 kWh/hp and 0.6563 kW/hp |
| Measure Energy Consumption: | 1,233.65 kWh/hp and 0.5812 kW/hp | 1,073.62 kWh/hp and 0.5343 kW/hp |
| Energy Savings (Base Case – Measure) | 256.60 kWh/hp and 0.1207 kW/hp | 226.65 kWh/hp and 0.1220 kW/hp |
| Costs Common Units: | Cost per hp | Cost per hp |
| Base Case Equipment Cost ($/unit): | Existing equipment.  $0.0 | Existing equipment.  $0.0 |
| Measure Equipment Cost ($/unit): | $189/hp  Source: 2014 Means Mechanical Cost Data Guide. | $201/hp  Source: 2014 Means Mechanical Cost Data Guide. |
| Measure Incremental Cost ($/unit): | $189/hp  Source: 2014 Means Mechanical Cost Data Guide. | $201/hp  Source: 2014 Means Mechanical Cost Data Guide. |
| Effective Useful Life (years): | 10 years | 10 years |
|
| Program Type: | Retrofit Add-On (REA), New Construction (NC) | Retrofit Add-On (REA), New Construction (NC) |
| Net-to-Gross (NTG) Ratio: | Source: DEER 2014:  Agric-Default>2yrs: 0.6 | Source: DEER 2014:  Agric-Default>2yrs: 0.6 |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| Revision # | Date | Section by Section Description of Revisions | Author (Company) |
| Revision 0 | 7/29/2014 | Original Work:  PGECOAGR113 R0.docx  Variable Frequency Drives on Agricultural Pumps | Sandra Chow (BASE Energy, Inc)  Ahmad Ganji (BASE Energy, Inc) |
| Revision 1 | 3/10/2015 | Added new measure code to include Replace On Burnout (ROB) and New Construction (NC) for Agricultural Booster Pumps <=150HP and for Well Pumps <=300HP | Steve Fok (PG&E)  Sandra Chow (BASE Energy, Inc) |
| Revision 2 | 4/15/2016 | Updated to the latest ex ante format. Removed ROB measures. | Linda Wan (PG&E) |
| Revision 3 | 4/1/2017 | Retired measure codes IR008 and IR009 effective 4/1/2017. Added NC for IR007 and IR006. | Linda Wan (PG&E) |

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# Section 1. General Measure & Baseline Data

## 1.1 Product Measure Description & Background

Variable Frequency Drives on Agricultural Pumps

This work paper documents the rationale for the “variable frequency drive (VFD) on agricultural pumps” measure as listed in the PG&E Agricultural and Food Processing Rebate Catalog, part of Pacific Gas and Electric Company’s Customer Energy Efficiency Program. PG&E offers incentives to non-residential customers for installing qualifying lighting, refrigeration, air-conditioning, food service, and agricultural equipment.

The following table provides a brief overview of the measures included in this work paper.

**Table 1 Measure Names**

|  |  |
| --- | --- |
| **Measure Code** | **Measure name** |
| IR006 | VFD ON AG WELL PUMPS (<=300HP) |
| IR007 | VFD ON AG BOOSTER PUMPS (<=150HP) |

***Program Restrictions and Guidelines***

* Customer must have electricity distributed by PG&E to the installation address.
* Customer must be under a PG&E agricultural rate schedule.
* Customer must have an existing electrically operated agricultural booster or well pump installed on site or customer is planning on installing a new agricultural booster or well pump.
* Customer must install a variable frequency drive (VFD) on the pump motor.
* VFD must be installed on a pressurized irrigation system (no flood irrigation).
* VFD must be used for controlling the flow/pressure of the pump.
* VFD is recommended to meet qualify requirements as specified by IEEE Standard 519-2014, Recommended Practices and Requirements for Harmonic Control in Electrical Systems.
* Pumping application must currently have the means of varying the pressure/flow (i.e. throttle valve, control valve, etc.).
* Minimum operation of 1,000 hours per year.

***Terms and Conditions:***

* VFD must be used to adjust operation of pump to meet flow/pressure requirements and not simply as a soft starter, or for cavitation control.
* The VFD must NOT be used for the following pumping applications:
  + A well pump used to fill a reservoir
  + A well pump discharging directly into a canal
  + A mixed flow pump (high volume, low head)
* These rebates are provided to directly installed VFDs on new or existing pumps.
* The customer must supply an invoice or other supporting documentation that includes the quantity of VFDs, type (well and/or booster), horsepower rating of motor(s) and VFD(s), area map showing physical location of pumps, and the manufacturer make/models of the VFDs installed.

***Market Applicability:***

This measure is applicable to agricultural pumps in the PG&E service territory that rely on electric pumping to water crops in the downstream and direct install delivery channels. Pumps with horsepower outside of allowable ranges must be considered under the customized retrofit or new construction programs, as applicable. Pumps that do not meet the other restrictions outlined above may also be considered under the customized retrofit or new construction programs.

## 1.2 Product Technical Description

This measure encourages agricultural customers to install variable frequency drives in lieu of throttling control on their irrigation pumping systems.

The most common pumps used in agricultural irrigation systems are:

* Well Pumps (typically either vertical turbine or submersible)
* Booster Pumps (typically vertical turbine, with some inline centrifugal)

Turbine pumps are commonly installed in wells and used to pump groundwater to be used for irrigation either directly or just pumping well water to the ground level.

Booster pumps are typically used to pressurize water for irrigation systems.

Variations and uncertainties in irrigation systems lead designers to always over-design irrigation pumps since it is favorable to have too much pressure rather than too little pressure. Some of the variations or uncertainties include, but are not limited to:

* For drip/micro-irrigation systems, designers always include a safety factor of at least 5 psi
* Pressure from irrigation pipelines turnouts vary over time
* Well water levels vary year to year, and from Spring to Fall
* Pumps may serve more than one type of irrigation system (i.e. drip and sprinkler)
* Pumps may serve multiple fields at different elevations and/or acreage

Based on conversations with experts in the field, designers over-design by at least 10% (very conservative estimate)[[1]](#endnote-1). Thus, variable frequency drives for irrigation pumps have great potential for energy savings by adjusting the pump speed to produce the desired flow and/or pressure for the irrigation system.

Operating the pumps at very low capacities should be avoided. If the capacity is too low, overheating of water caused by friction between water and impeller can damage the pump. Also operating at capacities less than 30% of the design capacity will not only significantly reduce the pump efficiency but it can increase the radial load on the impeller and cause early failure of bearings. Operating at near 100% of design capacity will consume more energy than prior to VFD installation.

Irrigation pump operating hours vary widely depending on the type of crop. Additionally farms may provide irrigation to more than one crop type. Operating hours typical vary from around 1000 hours to over 3000 hours based on the project data received for analyses in this work paper.

## 1.3 Measure Application Type

Table Measure Application Type

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| REA | Retrofit Add On | Single baseline (above pre-existing), full measure costs required |
| NC | New Construction | Single baseline (above industry standard), incremental measure costs required |

The Base Case assumes a constant speed well or booster agricultural pump controlled to operate by throttling the flow based on irrigation needs. The Measure Case is considered to be a pump that will use a VFD for adjusting the flow/pressure to the facility’s irrigation needs. The measure application types considered for this work paper are as follows:

* Agricultural Well Pumps (<=300HP): REA, NC
* Agricultural Booster Pumps (<=150HP): REA, NC

## 1.4 Product Base Case and Measure Case Data

## 1.4.1 DEER Base Case and Measure Case Information

Table DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Difference Summary Table** | |
| Modified DEER Methodology | No |
| Scaled DEER Measure | No |
| DEER Building Prototypes Used | No |
| Deviation from DEER | No |
| DEER Version | DEER 2016, READI v2.3.0 |
| DEER Run ID and Measure Name (Sample) | IR006, IR007 |

The IR values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in the table below:

Table Installation Rate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Def-GSIA | Default GSIA values | Any | Any | Any | 1 |

Spillage rates are not tracked in work papers; they are tracked in an external document which will be supplied to the Commission Staff.

The EUL and RUL values were obtained using the DEER READI tool. DEER defines the RUL as 1/3 of the EUL value. The RUL value is only applicable to the first baseline period for an RET measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are in the table below:

Table DEER2016 EUL and RUL

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| Agr-VSDWellPmp | Well Pump Variable Speed Drive | Ag | Irrigate | 10 | 3.3 |

The NTG value was obtained using the DEER READI tool. The relevant NTG value for the measures in this work paper is in the table below:

Table Net-to-Gross Ratio

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| Agric-Default>2 | All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | Ag | Any | Any | 0.6 |

## 1.4.2 Codes & Standards Requirements Base Case and Measure Information

***Title 20:*** These measures do not fall under Title 20 of the California Energy Regulations.

***Title 24:*** These measures do not fall under Title 24 of the California Energy Regulations.

***Federal Standards:*** These measures do not fall under Federal DOE or EPA Energy Regulations.

## 1.4.3 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

The Agricultural Water Energy Efficiency (CEC-500-200-049) report2, prepared by Irrigation Training and Research Center for the California Energy Commission as a part of the Public Interest Energy Research (PIER) Program addresses the industry standard practice for agricultural irrigation pumps. The report included an irrigation district energy survey that surveyed whether variable frequency drives were installed on agricultural irrigation pumps. Basic pump data was gathered from 30 irrigation districts which included:

* Type of pump
  + deep well pumps
  + surface supply pumps (includes lift and booster pumps)
  + surface drain pumps
* Pump horsepower
* Pump annual electrical energy consumption
* Whether pump efficiencies were checked annually
* Average pumping efficiency
* Whether variable frequency drives were installed on the pumps

A total of 2,045 pumps were reported in the survey and of these pumps only 60 pumps (less that 3% of the total number of pumps) had VFDs incorporated into their pumping operations. The study shows that VFDs are not commonly used in the industry and constant speed pumps are industrial standard practice. This is also confirmed in LBNL’s study that VFDs are not common in agricultural irrigation3. It has been assumed that for New Construction projects, new pumps would be equipped with soft starters to avoid sudden spikes when the pump turns on.

There were no EM&V studies identified that addressed the potential energy savings associated with installing variable frequency drives on agricultural pumps.

## 1.4.4 Assumptions and Calculations from other sources – Base and Measure Cases

This work paper used no other sources.

# Section 2. Calculation Methods

## 2.1 Electric Energy Savings Estimation Methodologies

Pacific Gas and Electric (PG&E) Company’s database was used to obtain records for projects where variable frequency drives were installed on agricultural pumps to determine the range in energy savings, demand savings, implementation cost and incentives. PG&E provided the following projects for data in regards to installation of variable frequency drives on agricultural irrigation pumps:

* 81 Non-Residential Retrofit (NRR) projects
* 300+ Customized New Construction (CNC) projects

Data for the above projects were reviewed to determine which projects had sufficient data for the purpose of estimating the energy savings for this work paper. In reviewing the above projects, only projects that with sufficient data using similar calculation methodologies as outlined in this work paper in agreement with basic engineering methodology for such applications were included in the overall analyses. Projects which included the necessary information for analyses was compiled into a spreadsheet and used for analyses. After a thorough review of the NRR and CNC projects, the following number of pump data was used in the analyses for this work paper:

* Well Pumps: 197 projects (combination of NRR and CNC projects)
* Booster Pumps: 99 projects (combination of NRR and CNC projects)

The following variables were utilized to quantify the energy savings resulting from installation of VFDs on the two pump types above:

* Pump Type
* Number of Pumps and Pump Size (hp)
* Annual Operating Hours
* Flow and Pressure Profiles
* Pump Efficiency (as presented in pumps’ performance curves)

The type of crop that the irrigation pumps serve was not available for the projects evaluated, only the annual operating hours. With a huge variation in operating hours and fields that served more than one type of crop, data was originally separated to 2 categories: deciduous vs. non-deciduous. After an evaluation of segregating the data into these two categories versus combining them together, it was found that the averages for combining both crop types together yielded a similar result as separating them. As facilities may irrigate both crop types, it was determined that combining both crop types together for well pumps and for booster pumps would make it easier for the customer to apply for their rebate for this measure.

The following methodology was used to calculate the electrical energy savings (EES) due to installing a variable frequency drive on an agricultural irrigation pump:

EES = ∑ [(Qi × TDHi × OHi/EFFpi × EFFm) × C1 / C2]throttle

- ∑ [(Qi × TDHi × OHi/EFFpi × EFFvfd × EFFm) × C1 / C2]vfd

Where the terms are:

Qi = flow for each period, gpm

TDHi = total head for each period, ft

OHi = operating hour for each period, hr/yr

EFFpi = pump efficiency under each operating condition, no units

EFFm = motor efficiency, no units

EFFvfd = efficiency of variable frequency drive, no units

C1 = conversion constant, 0.746 kW/hp

C2 = conversion constant, 3956 ft-gal/hp-min

throttle = throttled condition (baseline)

vfd = VFD control (proposed)

## 2.2 Demand Reduction Estimation Methodologies

The average demand savings (DS) for this measure can be estimated as follows:

DS = EES/ OHtotal

Where,

EES = electrical energy savings, kWh/yr

OHtotal = total operating hours, hr/yr

The Peak demand reduction depends on the climate zone of the agricultural pump, the flow that the pump is providing during the Peak period as well as the associated pump head and pump efficiency. This varies significantly and would be difficult to estimate. Thus, the Peak demand reduction is assumed to be the average demand of the pump.

Please note that due to a Memorandum dated December 28, 2015 from the CPUC for custom Project No. NC0128786 (X493) subject titled “EAR Final Findings Memo,” the kW peak demand savings is under consideration, and PG&E is conducting due diligence of the peak demand operation brought forward in the memo. The discoveries and analyses will be shared with the CPUC and reflected in the next submission of this work paper in the next quarter with the effective date of January 1, 2016.

## 2.3. Gas Energy Savings Estimation Methodologies

There will not be any natural gas savings for this measure.

## 2.4. Categorized Energy Savings Estimation Methodologies

The energy savings and demand savings for each measure in this work paper were analyzed then the weighted averages were calculated based on the number of pump motors in each horsepower bin.

Well pumps larger than 300-hp and booster pumps larger than 150-hp are recommended to go through Customized Retrofit Incentives or New Construction, as applicable, as this was the range of pumps that most projects have seen come through these programs.

Results were plotted on a graph showing pump horsepower versus kWh/hp to determine whether there were project(s) that were significantly off the linear curve. The projects with significant variations (roughly 10% of the samples used) were removed to make the distribution more representative of average conditions.

Table 8 below shows the result of the analyses of the selected PG&E retrofit and new construction projects:

**Table 8 Savings Estimates**

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Code** | **Measure name** | **Average kWh/hp** | **Average kW/hp** |
| IR006 | VFD ON AG WELL PUMPS (<=300HP) | 256.60 | 0.1207 |
| IR007 | VFD ON AG BOOSTER PUMPS (<=150HP) | 226.65 | 0.122 |

\* Calculated based on using $0.08/kW and $150/kW reduction

# Section 3. Load Shapes

This section of the work paper explains the measure’s load shape, which indicates what fraction of annual energy usage and savings occurs in each time period of the year.

The difference between the base case load shape and the measure load shape would be the most appropriate load shape; however, only end-use profiles are available. Therefore, the closest load shape chosen for this measure is the Agricultural load shape based on E3 calculators. See table below for the measure Load Shape. Please refer to Attachment A for reference regarding the load shapes for this measure.

Table 9 Load Shapes

|  |  |  |
| --- | --- | --- |
| **E3 Target Sector** | **Load Shape** | **Code** |
| Agricultural | 14 = Agricultural | PGE:AGRICULTURAL:14 = Agricultural |

# Section 4. Base Case & Measure Costs

## 4.1 Base Case(s) Costs

For the REA measure category, the base case cost is assumed to be zero because these are no modifications to the customer’s existing equipment. The customer’s alternative is to make no changes to their existing irrigation pumping system.

For NC measure categories, the base case cost is assumed to be the cost of a pump motor equipped with a soft starter. Cost data for soft starters was obtained from RS Means Mechanical Cost Data Guide 2014. The cost of a soft starter is approximately $64/hp. The labor cost is the same as the labor cost in Section 4.2 Measure Case Costs.

## 4.2 Measure Case Costs

For this deemed measure, cost data was obtained from RS Means Mechanical Cost Data Guide 2014. The costs for VFDs on pumps in the eligible horsepower ranges shown in Table-1 were averaged and the resulting cost for each pump type is given in Table 10 below.

Table 10 Gross Measure Cost

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Market** | **Pump Type** | **Measure Code** | **Measure** | **Material Cost/hp** | **Labor Cost/hp** | **Gross Measure Cost/hp** |
| AG | Well | IR006 | VFD ON AG WELL PUMPS (<=300HP) | $163/hp | $26/hp | $189/hp |
| AG | Booster | IR007 | VFD ON AG BOOSTER PUMPS (<=150HP) | $171/hp | $30/hp | $201/hp |

## 4.3 Incremental & Full Measure Costs

Table 11 Full and Incremental Measure Cost Equations

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| ROB | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |
| NEW/NC |
| RET/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |
| REF | (MEC + MLC) – (BEC + BLC) | MEC + MLC | N/A |
| REA | MEC + MLC | MEC + MLC | N/A |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

The costs for pumps in the eligible horsepower ranges shown in Table-1 were averaged and the resulting cost for each pump type is given in Table 11 on the following page.

Table 11 Incremental and Full Measure Costs

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Market** | **Pump Type** | **Measure Code** | **Measure** | **Base Cost/hp** | **Material Cost/hp** | **Labor Cost/hp** | **Incremental/ Full Measure Cost/hp** |
| AG | Well | IR006 | VFD ON AG WELL PUMPS (<=300HP) | $0/hp  $64/hp | $163/hp | $26/hp | $99/hp  $189/hp |
| AG | Booster | IR007 | VFD ON AG BOOSTER PUMPS (<=150HP) | $0/hp  $64/hp | $171/hp | $30/hp | $107/hp $201/hp |

# References

1 Burt, C.M., Variable Frequency Drive (VFD) Controlled Irrigation Pumps – Analysis of Potential Rebate (ITRC Report No. R 11-005, Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, 2011.

2 Burt, C.B., Howes, D.J., Freeman, B., Agricultural Water Energy Efficiency (CEC-500-2011-049), California Energy Commission, December 2011.

3 Marks, G. and Wilcox, E. Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study, Ernest Orlando Lawrence Berkeley National Laboratory, January 2013.

# Attachments

[A] PGECOAGR119 R3 VFD on Agricultural Pumps Savings.xlsm

1. [↑](#endnote-ref-1)