**Work Paper PGECOAGR121**

**VFD (Enhanced Specifications) on Agricultural Pumps**

**Revision 1**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**Variable Frequency Drives (Enhanced Specifications) on Agricultural Pumps**

**Measure Codes: IR020 to IR023 (Tier 2)**

**IR024 to IR027 (Tier3)**

6/3/2019

# At-A-Glance Summary Table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Applicable Measure Codes:** | **IR020 (Tier 2)**  **IR024 (Tier 3)** | **IR022 (Tier 2)**  **IR026 (Tier 3)** | **IR021 (Tier 2)**  **IR025 (Tier 3)** | **IR023 (Tier 2)**  **IR027 (Tier 3)** |
| Measure Description: | VFD ON AG WELL PUMPS (<=75HP)  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 (<=75HP)  This measure involves installing a variable frequency drive (VFD) on an agricultural booster pump used for irrigation purposes in place of throttling the flow. | VFD ON AG WELL PUMPS (>75 to <=600HP)  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 (>75 to <=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 | per rated pump HP | per rated pump HP |
| Base Case Description: | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD controls (Most pumps have throttle valves) | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD controls (Most pumps have throttle valves) | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD controls (Most have throttle valves & soft starters) | Source: CEC-500-2011-049.  Majority of pumps do not operate with VFD controls (Most have throttle valves & soft starters) |
| Base Case Energy Consumption: | 1,752 kWh/hp and  0.740 kW/hp | 1,752 kWh/hp and  0.740 kW/hp | 1,767 kWh/hp and  0.747 kW/hp | 1,772 kWh/hp and  0.748 kW/hp |
| Measure Energy Consumption: | 1,468 kWh/hp and  0.620 kW/hp | 1,515 kWh/hp and  0.640 kW/hp | 1,491 kWh/hp and  0.630 kW/hp | 1,515 kWh/hp and  0.640 kW/hp |
| Energy Savings (Base Case – Measure) | 284 kWh/hp and  0.120 kW/hp | 237 kWh/hp and  0.100 kW/hp | 276 kWh/hp and  0.177 kW/hp | 257 kWh/hp and  0.108 kW/hp |
| Costs Common Units: | Cost per HP | Cost per HP | Cost per HP | Cost per HP |
| Base Case Equipment Cost ($/hp): | $4 per hp | $4 per hp | $15 per hp | $17 per hp |
| Measure Equipment Cost ($/hp): | $227/hp (Tier 2)  $308/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report | $227/hp (Tier 2)  $308/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report | $128/hp (Tier 2)  $192/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report | $133/hp (Tier 2)  $230/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report |
| Measure Incremental Cost ($/hp): | $223/hp (Tier 2)  $304/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report, and PGECOAGR119R3 | $223/hp (Tier 2)  $304/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report, and PGECOAGR119R3 | $113/hp (Tier 2)  $178/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report, and PGECOAGR119R3 | $116/hp (Tier 2)  $213/hp (Tier 3)  Source: “VFD Specifications for Ag Irrigation Pumping” Report, and PGECOAGR119R3 |
| Effective Useful Life (years): | EUL\_ID: Agr-VSDWellPmp:10 years  Source: DEER2016 | EUL\_ID: Agr-VSDWellPmp:10 years  Source: DEER2016 | EUL\_ID: Agr-VSDWellPmp:10 years  Source: DEER2016 | EUL\_ID: Agr-VSDWellPmp:10 years  Source: DEER2016 |
|  |  |  |  |
| Program Type: | New Construction (NC) | New Construction (NC) | , New Construction (NC) | New Construction (NC) |
| Net-to-Gross (NTG) Ratio: | Agric-Default>2yrs: 0.6  Source: DEER2016 | Agric-Default>2yrs: 0.6  Source: DEER2016 | Agric-Default>2yrs: 0.6  Source: DEER2016 | Agric-Default>2yrs: 0.6  Source: DEER2016 |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| Revision # | Date | Section by Section Description of Revisions | Author (Company) |
| Revision 0 | 10/30/2017 | Original Work:  PGECOAGR121 R0.docx  Enhanced Specifications Variable Frequency Drives on Agricultural Pumps | Randy Kwok (PG&E) |
| Revision 1 | 6/3/2019 | - Renamed Enhanced Specifications VFD  as Tier 3 VFD system  - Added Mid-tier Specifications VFD as Tier 2  VFD system.  - Cost Update | Randy Kwok (PG&E) |

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# Section 1: General Measure & Baseline

## 1.1 Background

Electrical demand from irrigated agricultural fields is expected to increase in the future due to increasing demand for pumped irrigation water. The conversion from surface to pressurized irrigation systems is ongoing in the western United States and is expected to continue. Additionally, new irrigation wells continue to be developed throughout California.

Most new well and booster pumps will be driven by induction AC electric motors due to increasing regulations on internal combustion engines. Variable frequency drives (VFDs) are sometimes installed on irrigation pumps to enable adjustment of the pump speed. Adjustment of the pump speed can provide energy savings as well as additional benefits to the farmer and power utility. The use of VFDs is being promoted by irrigation dealers and incentivized by power utilities through rebate programs.

The combination of improved product quality and utility incentives helps to accelerate the adoption of VFDs in the agricultural irrigation sector.

In early 2017, PG&E contracted with the Irrigation Training & Research Center (ITRC) at California Polytechnic State University (Cal Poly), San Luis Obispo to develop the technical specifications requirement for a new enhanced VFD rebate offering. The specifications requirement was completed and submitted to PG&E in August 2017 in a report titled “VFD (Variable Frequency Drive) Specifications for On-Farm Pumps” (ITRC Report No. R 2019-006).

* The report can be found at <http://www.itrc.org/reports/vfdspecs19b.htm>
* The specifications document can be found at [www.itrc.org/VFD/](https://urldefense.proofpoint.com/v2/url?u=http-3A__www.itrc.org_VFD_&d=DwMFAg&c=Oo_p3A70ldcR7Q3zeyon7Q&r=29_qY9qhfVJ3hp0HSihAQg&m=TCDfuYKZke2tasrBUgDCAFkLChmspSTwe8rQFFG-ugE&s=vQCzKVry4xYlWzK1G0MnkzpUafkjCTCcswy_VY9m9e8&e=)

According to the authors of the report, there are very few VFDs in pre-existing operations at the time the specifications were created, but the number of VFD systems installation is increasing and areas for improvement still remain. Most importantly, a specific agricultural VFD system performance standard has not been historically available. While various standards and codes related to VFDs exist, in general, the codes and standards can be described as:

* Piecemeal, individually designed to cover narrow aspects of a VFD installation
* Not publicly available, and most of them are relatively expensive
* Unenforced, especially if the installation is not inspected by an authority

The authors also cited that without specifications requirements and special design attention, the basic VFD installations can be the source of power quality and radio interference issues that affect can affect other customers. Other problems caused by poor VFD system design that can affect VFD system owners are: Frequent nuisance tripping (automatic resetting or shutdowns) or even preventing the pump motor from starting. Without standards, mitigating or avoiding these issues for new VFD installations is optional, rather than obligatory.

PG&E currently offers rebate programs for agricultural pumping VFD installations. However, the agricultural VFD installation rebates have no minimum performance standards requirement. As such, PG&E does not have the ability to filter out sub-optimal VFD installations that participate in the existing rebate programs.

The primary goal of the specifications requirement is to improve PG&E’s agricultural VFD rebate program for low voltage (≤480 VAC) well pumps (600HP or less) and booster pumps (150HP or less) by setting minimum requirements for high quality VFD installations. It was anticipated that detailed VFD specifications will directly benefit new rebate participants and PG&E by helping to:

* Increase energy efficiency, VFD life expectancies, and reliability
* Minimize power quality issues

## 1.2 Product Measure Description

This work paper documents the rationale for the 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** |
| IR020 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps <=75hp |
| IR021 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to <=600hp |
| IR022 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps <=75hp |
| IR023 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to <=150hp |
| IR024 | Tier 3 Enhanced Specification VFD on Ag Well Pumps <=75hp |
| IR025 | Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to <=600hp |
| IR026 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps <=75hp |
| IR027 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to <=150hp |

***Program Requirements 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 increase the size of the motor serving 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 VFD system 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.
* For increased loads application, pumping system must currently have the means of varying the pressure/flow (i.e. throttling valve, control valve, etc.).
* Minimum operation of 1,000 hours per year.
* *Tier 3* installed VFD systems must conform to the requirements outlined in the “Agricultural

Irrigation Pump Variable Frequency Drive (VFD) Enhanced Specifications”. The specification

document can be found at [www.itrc.org/VFD/](https://urldefense.proofpoint.com/v2/url?u=http-3A__www.itrc.org_VFD_&d=DwMFAg&c=Oo_p3A70ldcR7Q3zeyon7Q&r=29_qY9qhfVJ3hp0HSihAQg&m=TCDfuYKZke2tasrBUgDCAFkLChmspSTwe8rQFFG-ugE&s=vQCzKVry4xYlWzK1G0MnkzpUafkjCTCcswy_VY9m9e8&e=)

* *Tier 2* installed VFD systems must conform to the requirements outlined in the “Agricultural

Irrigation Pump Variable Frequency Drive (VFD) Enhanced Specifications”, except for the

requirement specified in item 3.E.7c in section “3.E.7 Cooling” of the Design Specifications.

***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 installing VFDs on new pumps or existing pumps where the horsepower of the serving motor is increased (added load).
* 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.

* Additional required documentation as stated in the VFD specification which can be found at

[www.itrc.org/VFD/](https://urldefense.proofpoint.com/v2/url?u=http-3A__www.itrc.org_VFD_&d=DwMFAg&c=Oo_p3A70ldcR7Q3zeyon7Q&r=29_qY9qhfVJ3hp0HSihAQg&m=TCDfuYKZke2tasrBUgDCAFkLChmspSTwe8rQFFG-ugE&s=vQCzKVry4xYlWzK1G0MnkzpUafkjCTCcswy_VY9m9e8&e=)

***Market Applicability:***

This measure is applicable to agricultural pumps in the PG&E service territory that rely on electric pumping to irrigate 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.

## 1.3 Product Technical Description

This measure encourages agricultural customers to install quality VFD systems 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)

Vertical turbine pumps are commonly installed in wells and used to pump groundwater to be used for irrigation either directly (provides lift and pressurization) 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 frequently 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 typically 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 the report authors had with experts in the field, designers commonly can over-design by at least 10% (very conservative estimate)[[1]](#endnote-1). Thus, VFDs 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 also it can increase the radial load on the impeller and cause early failure of bearings. Operating a pump at close to 100% of design capacity with a VFD will consume more energy than one without a VFD due to the parasitic load of the VFD.

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 typically vary from around 1000 hours to over 3000 hours based on the project data received for analyses in this work paper.

## 1.4 Measure Application Type

Table 2 Measure Application Type

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| NC | New Construction | Single baseline (above code/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. Pump systems of less than or equal to 75hp assume a base case of a throttle valve only, while systems of higher horsepower assume a soft starter. The Measure Case is considered to be a pump that will use a VFD system 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 (<=600HP): NC
* Agricultural Booster Pumps (<=150HP): NC

## 1.5 Product Base Case and Measure Case Data

### 1.5.1 DEER Base Case and Measure Case Information

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 3 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 4 DEER2017 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 5 Net-to-Gross Ratio

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| ET-Default | Emerging Technologies approved by ED through work paper review | Ag | Any | Any | 0.85 |

### 1.5.2 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.

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

This work paper used the report titled “Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping” by the Irrigation Training & Research Center (ITRC) at California Polytechnic State University (Cal Poly) San Luis Obispo.

* Type of pump
  + *Booster pump supplying micro/drip system*
  + *Well pump supplying a booster with a micro/drip system downstream*
* Pump horsepower
* Pump annual electrical energy consumption
* Whether pump efficiencies were checked annually
* Average pumping efficiency
* Whether VFDs were installed on the pumps

Throughout the process of developing the VFD system specifications, a variety of external entities participated in discussions and review of the proposed specifications:

* Technical staff from five (x5) major VFD manufacturers
* Two major AC motor manufacturers
* Two large VFD vendors
* Multiple, independent registered electrical engineers
* PG&E Power Quality Group and other staff

Additionally, cost data was collected from a variety of sources:

* Two large VFD vendors
* Four irrigation and pump dealers

The pre-existing datasets of the authors of the report

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

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

This work paper used no other sources than the ITRC report cited previously.

# Section 2: Calculation Methods

## 2.1 Electric Energy Savings Estimation Methodologies

It is common, and considered good design practice, to over-design irrigation pumps to meet the worst-case hydraulic conditions, considering:

1. Estimated individual irrigation flow rate and pressure demands can vary at the head of each block (portions of a field irrigated when a single valve is opened). Farmers irrigate one or multiple blocks at a time. Each combination of blocks irrigating simultaneously requires a unique pump discharge pressure and flow rate. Sometimes farmers must decrease the number of blocks normally operated at one time in response to water supply constraints.
2. Good designers typically include a “safety factor” of at least 5 psi to the design pump discharge pressure requirement.
3. The pressures available from district pipeline turnouts are variable over time and depend on the instantaneous irrigation flow rate.
4. Published hydraulic performance data from pumps, pressure regulating valves, filters, and emitters are not always accurate, or even available.
5. Pumping water levels vary with changes in hydrology and well efficiency.
6. Automatically cleaned filters require temporary increases in pump flow rate during the cleaning cycle.
7. Pumps do wear out over time.

Given the factors above, reasonably over-designed pumps will continue to be installed. Adding a VFD system to an over-designed pump not only provides sufficient capacity in worst-case conditions, but also the capability of reducing the pump speed most of the time to avoid:

1. Developing excess pressure
2. Consuming excess electricity

There are two categories of VFD system implementations.

**Category 1:** Enhanced VFD system, capable of manually adjusting motor speed based on a target set point (in units such as percent of full speed, Hertz or RPM)

**Category 2:** More complex installations with automatic control and instrumentation

As shown in Table 6, Category 2 installations are capable of providing more energy savings. While Category 2 has the potential of achieving more savings, the additional hardware and automatic VFD control included in Category 2 installations are considered optional and not universally applicable. Moreover, the potential additional savings would be difficult to quantify. Therefore Category 2 installation is excluded from this analysis.

Table 6 Comparing potential energy savings between enhanced and more complex VFD system installations

|  |  |  |  |
| --- | --- | --- | --- |
| **Energy savings component** | **Achievable interval for pump speed adjustments after conditions change** | **Achievable Energy Savings Component, by VFD System Installation Category** | |
| **Category 1 (enhanced) – follows the proposed specifications** | **Category 2 (complex) – requires automatic control and sensors** |
| 5 psi safety factor | n/a | X | X |
| Inaccurate design data from pumps, filters, emitters, etc. | n/a | X | X |
| Changes to district pipeline pressure | n/a |  |  |
| Minute-to-minute |  | X |
| Changes to pumping water level, pump wear, and well efficiency | Annual to monthly | X |  |
| Minute-to-minute |  | X |
| Unknown pressure from district pipeline turnout | n/a | X | X |
| Temporary boost of pump speed during filter cleaning cycles | Minute-to-minute |  | X |

The analysis focuses on potential energy savings that could be expected from a Category 1 VFD system installation on a typical field with pressurized irrigation. Values were allocated to each of the potential energy savings components as listed in Table 7. Some values reported are referenced from ITRC Report No. R 2019-006, while others are readily available in accepted design literature.

Table 7 Potential pressure savings (feet) for each pump type with VFD systems

|  |  |  |
| --- | --- | --- |
| **Pressure savings category** | **Potential pressure savings (feet) for each pump type** | |
| **Booster Pumps** | **Well Pumps** |
| General 5 psi safety factor | 11.5 | 11.5 |
| Pressure requirements when irrigating different blocks | 6 | 6 |
| 10% of pumping water level for groundwater variability (ft) | n/a | 32.1 |
| Future pump wear | 5 | 5 |
| Loss of well efficiency | n/a | 5 |
| **Total potential baseline TDH savings** | **22.5** | **64.5** |

**Computations**

The energy savings analysis for this project focused on two scenarios:

*Scenario 1: Booster pump supplying micro/drip system*

*Scenario 2: Well pump supplying a booster with a micro/drip system downstream*

Assumptions used for the computations are listed in Table 8 and Table 9.

Table 8 Assumed values for computations

|  |  |  |
| --- | --- | --- |
| **Assumption** | **Value** | **Unit** |
| Well pumping level (San Joaquin Valley) | 300 | feet |
| Minimum well pump TDH | 321 | feet |
| Minimum booster pump TDH | 120 | feet |
| Annual operating hours (deciduous orchard) | 2368 | hour |
| $ / kW-hr | 0.17 | 0.17 |

Table 9 Assumed values for new pumping plants on a horsepower basis

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Electrical Input HP** | **New Motor Efficiency (%/100)** | **New Impeller Efficiency** | **Initial Booster Pump TDH (ft)\*\*** | **Initial Well Pump TDH (ft)\*\*** | **Reduction in new OPPE due to VFD (%/100)** | **Reduction in new OPPE due to decreased impeller efficiency at different operating points (%/100)** |
| 50 | 0.9 | 0.7 | 120 | 321 | 0.965 | 0.99 |
| 100 | 0.91 | 0.77 | 122 | 325 |
| 150 | 0.92 | 0.8 | 124 | 327 |
| 200 | 0.92 | 0.81 | 126 | 329 |
| 250 | 0.92 | 0.81 | 128 | 331 |
| 300 | 0.92 | 0.84 | 130 | 332 |
| 350 | 0.92 | 0.84 | 131 | 335 |
| 400 | 0.92 | 0.84 | 132 | 335 |
| 450 | 0.92 | 0.84 | 132 | 335 |
| 500 | 0.92 | 0.84 | 132 | 336 |
| 550 | 0.92 | 0.84 | 132 | 336 |
| 600 | 0.92 | 0.84 | 132 | 336 |

*\*\*As shown in Table 10, the TDH values were adjusted up slightly from the minimum values reported in*

*Table 9 to represent an increasing field size with additional mainline friction losses.*

The calculations outlined below follow the procedure used to solve for a single input horsepower. The process was repeated for the arbitrary range of input horsepower listed in Table 10 to determine if there was a difference on a per horsepower basis.

First, solve for the Initial Overall Pumping Plant Efficiency (OPPE), starting with one set of horsepower-specific values reported in Table 10:

**Eq. 1:**

With the Initial OPPE, compute the estimated water horsepower requirement. Use values shown in Table 10.

**Eq. 2:**

Where,

*Input HP* = selected from Table 10

*Initial OPPE* = computed using **Eq. 1** (%/100)

In order to separate the flow and pressure (TDH) demand, estimate the initial pump flow rate from the WHP:

**Eq. 3:**

Where,

*WHP* = Computed using **Eq. 2** (HP)

*Initial Pump TDH* = Values from Table 10 (feet)

Compute the Initial Input kW:

**Eq. 4:**

Compute the new pump TDH with a Category 1 VFD (enhanced no automation):

**Eq. 5:**

Where,

*Initial Pump TDH* = Value from Table 10 (feet) used in **Eq. 3**

*Total Potential TDH Savings* = Values from Table 8 (feet)

Solve for the new input kW:

**Eq. 6:**

*Initial Input kW* = Computed using **Eq. 4** (kW)

*New Pump TDH*  = Computed using **Eq. 5** (feet)

*Initial Pump TDH*  = same value used in **Eq. 3 & 5** (feet)

Solve for the average energy savings:

**Eq. 7:**

*Initial Input kW* = Used in **Eq. 6** (kW)

*New Input kW*  = Computed using **Eq. 6** (kW)

Solve for the average annual energy savings:

**Eq. 8:**

*Energy Savings* = Computed using **Eq. 7** (kW)

*Annual Operating Hours* = Value shown in Table 8 (hours)

Solve for the average annual dollar savings:

**Eq. 9:**

*Annual Energy Savings* = Computed using **Eq. 7** (kW-hours)

Cost per kW-hour = Listed in Table 9

The computation results are listed in Table 10 and Table 11. Table 10 summarizes energy savings for VFD system installations on well pumps supplying a booster pump for drip/micro irrigation, with a VFD system on the well pump only.

Table 10 Energy savings for VFD system installations on well pumps only

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Arbitrary Input HP** | **Assumed Motor Efficiency** | **Assumed Impeller Efficiency** | **Overall Pumping Plant Efficiency, OPPE (%/100)** | **Old Well Pump Total Dynamic Head (feet)** | **Water Horsepower (WHP)** | **Computed Pump Flow Rate (GPM)** | **Computed Old Input Power (kW)** | **Computed New Pump TDH (ft)** | **Reduction Factor For New OPPE Due To VFD System (%/100)** | **Reduction Factor For Variable Impeller Efficiencies At New Operating Points (%/100)** | **Computed New Input kW** | **Computed New kW Savings** | **Computed New Annual kWh savings** | **Estimated Total Installed VFD System Cost Plus Tax ($)** | **Annual Savings ($) Due To New VFD System** |
| 50 | 0.9 | 0.7 | 0.63 | 321 | 31.5 | 389 | 37 | 256.5 | 0.965 | 0.99 | 31 | 6.1 | 14,449 | 13,600 | 2,456 |
| 100 | 0.91 | 0.77 | 0.70 | 325 | 70.1 | 854 | 75 | 260.5 | 0.965 | 0.99 | 63 | 12.0 | 28,441 | 20,200 | 4,835 |
| 150 | 0.92 | 0.8 | 0.74 | 327 | 110.4 | 1337 | 112 | 262.5 | 0.965 | 0.99 | 94 | 17.9 | 42,325 | 26,800 | 7,195 |
| 200 | 0.92 | 0.81 | 0.75 | 329 | 149.0 | 1794 | 149 | 264.5 | 0.965 | 0.99 | 126 | 23.6 | 55,990 | 33,400 | 9,518 |
| 250 | 0.92 | 0.81 | 0.75 | 331 | 186.3 | 2229 | 187 | 266.5 | 0.965 | 0.99 | 157 | 29.3 | 69,440 | 40,000 | 11,805 |
| 300 | 0.92 | 0.84 | 0.77 | 332 | 231.8 | 2765 | 224 | 267.5 | 0.965 | 0.99 | 189 | 35.1 | 83,002 | 46,600 | 14,110 |
| 350 | 0.92 | 0.84 | 0.77 | 335 | 270.5 | 3197 | 261 | 270.5 | 0.965 | 0.99 | 221 | 40.4 | 95,710 | 53,200 | 16,271 |
| 400 | 0.92 | 0.84 | 0.77 | 335 | 309.1 | 3654 | 298 | 270.5 | 0.965 | 0.99 | 252 | 46.2 | 109,383 | 59,800 | 18,595 |
| 450 | 0.92 | 0.84 | 0.77 | 335 | 347.8 | 4111 | 336 | 270.5 | 0.965 | 0.99 | 284 | 52.0 | 123,056 | 66,400 | 20,919 |
| 500 | 0.92 | 0.84 | 0.77 | 336 | 386.4 | 4554 | 373 | 271.5 | 0.965 | 0.99 | 315 | 57.5 | 136,199 | 73,000 | 23,154 |
| 550 | 0.92 | 0.84 | 0.77 | 336 | 425.0 | 5009 | 410 | 271.5 | 0.965 | 0.99 | 347 | 63.3 | 149,819 | 79,600 | 25,469 |
| 600 | 0.92 | 0.84 | 0.77 | 336 | 463.7 | 5465 | 448 | 271.5 | 0.965 | 0.99 | 379 | 69.0 | 163,438 | 86,200 | 27,785 |

Table 11 Estimated energy savings for booster pumps supplying drip/micro irrigation

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Arbitrary Input HP** | **Assumed Motor Efficiency** | **Assumed Impeller Efficiency** | **Computed Overall Pumping Plant Efficiency, OPPE (%/100)** | **Old Well Pump Total Dynamic Head (feet)** | **Water Horsepower (WHP)** | **Computed Pump Flow Rate (GPM)** | **Computed Old Input Power (kW)** | **Computed New Pump TDH (ft)** | **Reduction Factor For New OPPE Due To VFD System (%/100)** | **Reduction Factor For Variable Impeller Efficiencies At New Operating Points (%/100)** | **Computed New Input kW** | | **Computed New kW Savings** | **Computed New Annual kWh savings** | **Estimated Total Installed VFD System Cost Plus Tax ($)** | **Annual Savings ($) Due To New VFD System** |
| 50 | 0.9 | 0.7 | 0.63 | 120 | 31.5 | 1040 | 37 | 97.5 | 0.965 | 0.99 | | 32 | 5.6 | 13,207 | 13,600 | 2,245 |
| 100 | 0.91 | 0.75 | 0.68 | 122 | 68.3 | 2215 | 75 | 99.5 | 0.965 | 0.99 | | 64 | 10.9 | 25,846 | 20,200 | 4,394 |
| 150 | 0.92 | 0.76 | 0.70 | 124 | 104.9 | 3349 | 112 | 101.5 | 0.965 | 0.99 | | 96 | 16.0 | 37,944 | 26,800 | 6,450 |

## 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 update of this work paper.

## 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 600-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.

For well pump VFD - The unit energy savings were first calculated for each of the twelve pump horsepower bins, then the average kW and kWh per horsepower savings was then calculated from that. See table 11 for the horsepower bins and the pump data.

For booster pump VFD - The unit energy savings were first calculated for each of the three pump horsepower bins (one bin for <=75hp for both pump types, one bin for >75hp to <=600hp for well pumps, and one bin for >75hp to <=150hp for booster pumps), then the average kW and kWh per horsepower savings was then calculated from that. See table 11 for the horsepower bins and the pump data.

Table 12 below shows the result of the unit energy savings per horsepower calculations:

Table 12 Savings Estimates

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Code** | **Measure name** | **Average kWh/hp** | **Average kW/hp** |
| IR020 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps <=75hp | 284 | 0.120 |
| IR021 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to <=600hp | 276 | 0.177 |
| IR022 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps <=75hp | 237 | 0.100 |
| IR023 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to <=150hp | 257 | 0.108 |
| IR024 | Tier 3 Enhanced Specification VFD on Ag Well Pumps <=75hp | 284 | 0.120 |
| IR025 | Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to <=600hp | 276 | 0.177 |
| IR026 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps <=75hp | 237 | 0.100 |
| IR027 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to <=150hp | 257 | 0.108 |

# 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 13 below for the measure Load Shape. Please refer to Attachment A for reference regarding the load shapes for this measure.

Table 13 Load Shapes

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

# Section 4: Base Case & Measure Costs

The authors of the ITRC report sent out requests for cost data to over 10 VFD vendors and irrigation dealers with the latest VFD specifications attached. The information request was designed so that the VFD vendors and irrigation dealers would:

* Submit three (x3) previous invoices for previously sold and/or installed VFD systems with a range of VFD horsepower, rather than develop new cost estimates for the project
* Indicate which of the VFD system specifications were met by the VFD system
* Provide a cost estimate for any additional equipment needed to meet the specifications
* Subtract the cost of any equipment that was originally provided, but would be replaced by equipment required to meet the specifications

Multiple submissions were received from:

* Two VFD vendors
* Four irrigation and pump dealers

In order to increase confidence in the returned data, a pre-existing VFD system cost dataset was incorporated in this analysis. Some cost adjustments were made in order to compare equivalent values (e.g., adding sales tax where missing from the invoice or quote).

The installed VFD system cost (including materials, labor and tax) dataset is plotted in

Figure 1. Only three of the 24 invoices met the specifications. The VFD systems that did not meet the specifications are considered “typical”.

Figure 1 Comparison of “typical” and specification-compliant VFD system installed costs (materials and labor)

The data indicate that:

1. Most of the VFD system costs were missing one of, or any combination of, the following features:
   * Harmonic mitigation
   * Surge suppression
   * Acceptable cooling (without outside air circulation across electronics)
2. Some of the “typical” VFD system costs are more expensive, but cannot meet the specified performance standards.
3. On average, it is more expensive to comply with the specifications. The additional cost to meet the specifications are listed below:
   * Less than or equal to 75 VFD HP – the cost premium is about $2,000

*Note: While they exist, differences in premium costs required to meet the specifications for “typical” VFD systems less than or equal to 75 HP are relatively small. Therefore, the flat rate premium of $2,000 is used as a simplification.*

* + Greater than 75 VFD HP – the cost premium is about $27 per VFD HP

1. “Typical” VFD system costs are highly variable.

The most common technologies for harmonic mitigation for the quotes received were either:

* + Passive harmonic filters, or
  + Input line reactors

Passive harmonic filters are capable of providing harmonic mitigation that meet the specifications for VFD systems over 75 HP. A range of approximate consumer costs for adding passive harmonic filters is listed in Table 14.

Table 14 Approximate unit costs for integrated passive harmonic filters

|  |  |  |
| --- | --- | --- |
| VFD HP | Integrated passive harmonic filter unit costs ($) | Approximate dollars per VFD HP |
| 75 | 1848 | $25 |
| 250 | 3629 | $15 |
| 450 | 20714 | $$46 |

3% input line reactors are one of many prescribed harmonic mitigation measures for VFD systems 75 HP or less. Line reactors can serve dual functions: harmonic mitigation and some degree of transient voltage protection. The consumer costs for adding 3% line reactors is approximately $5 per VFD HP as shown in Figure 2.

Figure 2 Approximate unit costs for input line reactors, plus tax

Because line reactors operate with a voltage drop, AC line reactors may not be appropriate for certain installations that:

* + Experience frequent utility sag events. The additional line reactor voltage drop could cause more frequent nuisance tripping and possibly damage internal VFD components as the voltage sag normalizes.
  + Long cable runs will compound the voltage drop caused by the line reactors and can increase current requirements above expected levels to produce the same brake horsepower at the motor.

One of many VFD system cooling methods that comply with the specifications is a panel-mounted HVAC unit. HVAC units are usually more expensive than other acceptable cooling methods, but it is relatively easy to incorporate HVAC units into a VFD system design. The approximate costs for adding an HVAC unit for VFD system cooling listed in Table 15.

Table 15 Approximate unit costs for VFD cooling unit

|  |  |  |
| --- | --- | --- |
| VFD HP | Nominal HVAC (ton) | Installed cooling unit cost plus tax($) |
| 50 | 0.5 | 1850 |
| 100 | 1 | 2100 |
| 200 | 2 | 2550 |
| 400 | 3 | 3050 |
| 600 | 5 | 4000 |

## 4.1 Base Case(s) Costs

For NC measure categories, the base case cost is assumed to be the cost of the throttling valves of a new well pumping system. For pumps greater 75-hp the cost of soft starters are also included.

## 4.2 Measure Case Costs

The measure cost for measure type NC is the incremental cost, which is the specification-compliant VFD system cost minus the base case cost of the throttling valves and soft starters (pumps >75-hp). Costs for pumps in the eligible horsepower bins were averaged and the resulting cost for each ach pump type is given in Tables 16 and 17 below.

Table 16 Total Measure Cost

|  |  |  |  |
| --- | --- | --- | --- |
| **Pump Type** | **Measure Code** | **Measure** | **Total Measure Cost/hp** |
| Ag Well | IR020 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps <=75hp | $278/hp |
| Ag Well | IR021 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to <=600hp | $134/hp |
| Ag Booster | IR022 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps <=75hp | $278/hp |
| Ag Booster | IR023 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to <=150hp | $147/hp |
| Ag Well | IR024 | Tier 3 Enhanced Specification VFD on Ag Well Pumps <=75hp | $360/hp |
| Ag Well | IR025 | Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to <=600hp | $198/hp |
| Ag Booster | IR026 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps <=75hp | $360/hp |
| Ag Booster | IR027 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to <=150hp | $244/hp |

## 4.3 Incremental Measure Costs

Table 17 Incremental and Full Measure Costs

|  |  |  |  |
| --- | --- | --- | --- |
| **Pump Type** | **Measure Code** | **Measure** | **Incremental Measure Cost/hp** |
| Ag Well | IR020 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps <=75hp | $223/hp |
| Ag Well | IR021 | Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to <=600hp | $113/hp |
| Ag Booster | IR022 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps <=75hp | $223/hp |
| Ag Booster | IR023 | Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to <=150hp | $116/hp |
| Ag Well | IR024 | Tier 3 Enhanced Specification VFD on Ag Well Pumps <=75hp | $304/hp |
| Ag Well | IR025 | Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to <=600hp | $178/hp |
| Ag Booster | IR026 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps <=75hp | $304/hp |  |
| Ag Booster | IR027 | Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to <=150hp | $213/hp |

# References

# See references in the ITRC Report No. R 2019-006 at <http://www.itrc.org/reports/vfdspecs19b.htm>

1. [↑](#endnote-ref-1)