



AGRICULTURE
VFD ON WELL PUMP
SWWP002-01

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MEASURE NAME

VFD on Well Pump

STATEWIDE MEASURE ID

SWWP002-01

TECHNOLOGY SUMMARY

The most common pumps used in agricultural irrigation systems are *well pumps* (usually either vertical turbine or submersible) and *booster pumps* (often vertical turbine, with some inline centrifugal). Turbine pumps are commonly installed in wells and used to pump groundwater for irrigation either directly or just pumping well water to the ground level. Booster pumps are ordinarily used to pressurize water for irrigation systems.

Variations and uncertainties in irrigation systems lead designers to over-design irrigation pumps since it is favorable to have too much pressure rather than too little pressure. Variations and/or uncertainties include (but are not limited to):

- For drip/micro-irrigation systems, designers always include a safety factor of at least five-pound force per square inch (psi).
- The pressure from irrigation pipelines turnouts vary over time.
- Well water levels vary year to year, and seasonally 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.

Operating the pumps at low capacities can overheat the water caused by friction between the water and impeller, which can damage the pump. Additionally, operating at capacities less than 30% of the design capacity will significantly reduce the pump efficiency and can increase the radial load on the impeller, which will cause early failure of the bearings. In contrast, operating the pump at near 100% of design capacity will require more energy than prior to VFD installation.

A conservative estimate by experts is that designers over-design by at least 10%.¹ A variable frequency drive (VFD) on an agricultural well pump controls the motor speed of a pump so that the pump operates more efficiently. VFDs for agricultural irrigation pumps have the potential for significant energy savings by adjusting the pump speed to produce the desired flow and/or pressure for the irrigation system.

MEASURE CASE DESCRIPTION

The measure case is defined as a pump for which a variable frequency drive (VFD) will adjust the flow/pressure to meet facility irrigation needs. The measure offerings are defined by pump type and horsepower rating, as indicated below:

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

1. Installation of a VFD on agriculture well pumps (≤ 300 hp) used for irrigation purposes in place of throttling the flow.
2. Installation of a VFD on agriculture booster pumps (≤ 150 hp) used for irrigation purposes in place of throttling the flow.

BASE CASE DESCRIPTION

The base case is defined as a constant speed well or booster agricultural pump that is controlled by throttling the flow based on irrigation needs. The Agricultural Water Energy Efficiency study,² conducted by Irrigation Training and Research Center (ITRC) through the Public Interest Energy Research (PIER) Program, characterized the industry standard practice for agricultural irrigation pumps. The study included basic pump data gathered through an irrigation district energy survey from 30 irrigation districts. The data included the following:

- 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 (VFDs) were installed on the pumps

A total of 2,045 pumps were represented in the survey data, only 60 of which ($< 3\%$) had VFDs incorporated into the pumping systems. The study revealed that VFDs are not commonly used in the industry and constant speed pumps are industrial standard practice. A study published by the Lawrence Berkeley National Lab (LBNL) confirmed this result.³

CODE REQUIREMENTS

There are no applicable state or federal codes that apply to this measure.

NORMALIZING UNIT

The normalizing unit is per horsepower (hp).

² Burt, C., D. Howes, and B. Freeman (Irrigation Training and Research Center). 2011. *Agricultural Water Energy Efficiency*. Public Interest Energy Research (PIER) Program Final Project Report. California Energy Commission. CEC-500-2011-049.

³ Marks, G. and E. Wilcox, (iP Solutions Corp), D. Olsen and S. Goli (Lawrence Berkeley National Laboratory). 2013. *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*. Ernest Orlando Lawrence Berkeley National Laboratory. LBNL-6108E.

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Add-on equipment	DnDeemDI	Ag
Add-on equipment	DnDeemed	Ag
Add-on equipment	DnDeemDI	Com
Add-on equipment	DnDeemed	Com
New construction	DnDeemDI	Ag
New construction	DnDeemed	Ag
New construction	DnDeemDI	Com
New construction	DnDeemed	Com

To substantiate conformance with program requirements, the customer must supply an invoice or other supporting documentation that includes the following:

- Quantity of VFDs
- Type (well and/or booster)
- Horsepower rating of motor(s) and VFD(s)
- Area map showing physical location of pumps
- Manufacturer make/models of each VFD installed

Eligible Products

The variable frequency drive (VFD) must be used to adjust operation of a pump to meet flow/pressure requirements and not be used simply as a soft starter or for cavitation control.

The pumping application must currently have the means to vary the pressure/flow (i.e. throttle valve, control valve, etc.).

The VFD must be installed on the pump motor with a minimum operation of 1,000 hours per year.

The VFD must be installed on a pressurized irrigation system (no flood irrigation).

The VFD is recommended to meet requirements as specified by IEEE Standard 519™-2014.⁴

The customer must have an existing electrically operated agricultural booster or well pump installed on site or plans to install a new agricultural booster or well pump.

Eligible Building Types

This measure is applicable for all existing and new commercial and agriculture facilities.

Eligible Climate Zones

The measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

This measure cannot be used for the following pumping applications:

- A well pump used to fill a reservoir,
- A well pump discharging directly into a canal, and/or
- A mixed flow pump (high volume, low head).

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

USE CATEGORY

Water pumping & irrigation

ELECTRIC SAVINGS (kWh)

Based upon a standard hydraulic horsepower equation, the electric unit energy savings (UES) of the installation of a VFD on an agricultural irrigation pump is calculated as the following:

$$UES = \sum [(Q_i \times TDH_i \times OH_i / EFF_{pi} \times EFF_m) \times C_1 / C_2]_{throttle} - \sum [(Q_i \times TDH_i \times OH_i / EFF_{pi} \times EFF_{vfd} \times EFF_m) \times C_1 / C_2]_{vfd}$$

$UES =$	<i>Electric unit energy savings (kWh)</i>
$Q_i =$	<i>Flow for each period (gpm)</i>
$TDH_i =$	<i>Total head for each period (ft)</i>
$OH_i =$	<i>Operating hour for each period (hr/yr)</i>
$EFF_{pi} =$	<i>Pump efficiency under each operating condition (no units)</i>
$EFF_m =$	<i>Motor efficiency (no units)</i>

⁴ Institute of Electrical and Electronics Engineers (IEEE) Standards Association. 2014. *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*. IEEE Std. 519™-2014. New York (NY): IEEE.

EFF_{vfd} = Efficiency of variable frequency drive (no units)
 C_1 = conversion constant, 0.746 kW/hp
 C_2 = conversion constant, 3,956 ft-gal/hp-min
 $throttle$ = Throttled condition (baseline)
 vfd = VFD control (proposed)

Data to calculate the UES was drawn from Pacific Gas and Electric (PG&E) projects for which VFDs were installed on agricultural pumps to determine the range in energy savings, demand reduction, implementation cost, and incentives. In particular, the PG&E provided data on the installation of VFDs on agricultural irrigation pumps included data from 81 Non-Residential Retrofit (NRR) projects and over 300 Customized New Construction (CNC) projects. These data were analyzed and cleaned to develop final database for estimating the savings for VFDs on agricultural pumps. The projects retained for the overall analysis had sufficient data using similar calculation methodologies and aligned with the basic engineering methodology for such applications. The final VFD agriculture pump database⁵ included the following:

- Well Pumps: 197 projects (combination of NRR and CNC projects) representing a total of 197 well pumps.
- Booster Pumps: 99 projects (combination of NRR and CNC projects), representing a total of 99 booster pumps.

The following variables in the final VFD pump database were analyzed to quantify the UES resulting from installation of VFDs on well pumps and booster pumps:

- Pump type
- Number of pumps and pump size (hp)
- Annual operating hours
- Flow and pressure profiles
- Pump efficiency

The type of crop that the irrigation pumps served 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 initially separated to two categories: deciduous and non-deciduous. The analysis of segregated data revealed similar averages as combining the data of both crop types together. Since facilities may irrigate both crop types, it was determined that combining the data of 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 UES and demand reduction for each measure offering were calculated then the weighted averages were calculated based on the number of pump motors in each horsepower bin. Results were plotted to show pump horsepower versus kWh/hp to identify outliers (i.e., project(s) that were significantly off the linear curve.) The projects with significant variations (roughly 10% of the samples used) were removed from the analysis to ensure the distribution was representative of average conditions.

⁵ Pacific Gas & Electric. 2017. "Attachment A_PGECOAGR119 R2 VFD on Agricultural PumpsSavings.xlsx."

PEAK ELECTRIC DEMAND REDUCTION (kW)

The average demand reduction for this measure was calculated as the following:

$$DemandReduction_{avg} = UES / HOURS$$

$$DemandReduction_{avg} = \text{Average demand reduction (kW)}$$

$$UES = \text{Annual electric unit energy savings (kWh/yr)}$$

$$HOURS = \text{Annual operating hours (hr/yr)}$$

The flow that the pump provides during the peak period of 4 p.m. to 9 p.m., as well as the associated pump head and pump efficiency are difficult to estimate. Thus, the peak demand reduction is assumed to equal the average demand reduction of the pump.

GAS SAVINGS (THERMS)

Not applicable.

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration. The RUL is only applicable to the first baseline period for a retrofit measure with an applicable code baseline.

As per Resolution E-4807, the California Public Utilities Commission (CPUC) defined the EUL of an add-on equipment as the minimum of the EUL of the measure itself and the RUL of the host equipment.⁶ The methodology to calculate the RUL conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends "one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values." This approach provides a "reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced."⁷

⁶ California Public Utilities Commission (CPUC). 2016. *Resolution E-4807*. December 16. Page 13.

⁷ KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

The EUL and RUL specified for this measure are specified below. A pump motor is specified as the host equipment for which the EUL is based upon several retention studies conducted by the California investor-owned utilities.⁸

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs)	10.0	California Public Utilities Commission (CPUC). 2014. "DEER2014-EUL-table-update_2014-02-05.xlsx."
RUL (yrs)	3.3	California Public Utilities Commission (CPUC), Energy Division. 2020. <i>Energy Efficiency Policy Manual, Version 6</i> .

BASE CASE MATERIAL COST (\$/UNIT)

The base case cost for an *add-on equipment installation* is equal to \$0 because these are no modifications to the existing equipment. The customer has the option to make no changes to their existing irrigation pumping system.

The base case cost of a *new construction* installation is assumed to equal the cost of a pump motor equipped with a soft starter. Cost data for soft starters was obtained from the 2020 RSMeans Mechanical Cost Data.⁹ The unit cost (per hp) is the average cost of the pump sizes with soft starters within the eligible horsepower range.¹⁰

MEASURE CASE MATERIAL COST (\$/UNIT)

The measure case material cost for *all installation types* was derived from the 2020 RSMeans Mechanical Cost Data 2020.¹¹ The costs for VFDs on pumps in the eligible horsepower ranges were averaged to calculate the cost for each pump type designated for this measure.¹²

⁸ San Diego Gas & Electric (SDG&E), Marketing Programs & Planning. 2004. *1994 & 1995 Commercial Energy Efficiency Incentives Ninth Year Retention Evaluation*. Study ID Nos. 925 & 961.

ADM Associates, Inc. 2003. *Southern California Edison Commercial/Industrial/Agricultural Energy Efficiency Incentives Program Retention Study*. Prepared for Southern California Edison Company.

San Diego Gas & Electric (SDG&E). 2003. *1996 & 1997 Agricultural Energy Efficiency Incentives Sixth Year Retention Evaluation*. Study ID Nos. 1000 & 1024.

⁹ RSMeans Engineering Department. 2020. *RSMeans Mechanical Cost Data 2014*. 37th Annual Edition. Section 26 29 23.10 Variable Frequency Drives/Adj. Frequency Drives.

¹⁰ Pacific Gas and Electric (PG&E). 2020. "VFD and Soft Starter Cost Data per hp.xlsx"

¹¹ RSMeans Engineering Department. 2020. *RSMeans Mechanical Cost Data 2020*. 37th Annual Edition. Section 26 29 23.10 Variable Frequency Drives/Adj. Frequency Drives.

¹² Pacific Gas and Electric (PG&E). 2020. "VFD and Soft Starter Cost Data per hp.xlsx"

BASE CASE LABOR COST (\$/UNIT)

The base case labor cost for an *add-on equipment installation* is equal to \$0 because these are no modifications to the existing equipment. The customer has the option to make no changes to their existing irrigation pumping system.

The base case labor cost of the *normal replacement* and *new construction* installations is assumed to equal the cost to install a standard pump motor equipped with a soft starter. Cost data for soft starters was obtained from the 2020 RSMeans Mechanical Cost Data.¹³ The unit labor cost (per hp) is the average cost of installation within the eligible horsepower range.¹⁴

MEASURE CASE LABOR COST (\$/UNIT)

The measure case labor cost for *all installation types* and pump types designated for this measure was derived the 2020 RSMeans Mechanical Cost Data.¹⁵ The unit cost (per hp) is the average cost of the pump sizes with soft starters within the eligible horsepower range.¹⁶

NET-TO-GROSS

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. These NTG values are based upon the recommended rates by CPUC's Resolution E-5082 and were derived from the Small/Medium Commercial Sector EM&VPY2018. These sector average NTGs ("default NTGs") are applicable to all energy efficiency measures that have been offered through agriculture and commercial sector programs for more than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
NTG – agriculture	0.60	CPUC's Resolution E-5082 and the <i>Small/Medium Commercial Sector EM&VPY2018</i>
NTG – commercial	0.60	

GSIA

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor

¹³ RSMeans Engineering Department. 2020. *RSMeans Mechanical Cost Data 2014*. 37th Annual Edition. Section 26 29 23.10 Variable Frequency Drives/Adj. Frequency Drives.

¹⁴ Pacific Gas and Electric (PG&E). 2020. "VFD and Soft Starter Cost Data per hp.xlsx".

¹⁵ RSMeans Engineering Department. 2020. *RSMeans Mechanical Cost Data 2014*. 37th Annual Edition. Section 26 29 23.10 Variable Frequency Drives/Adj. Frequency Drives.

¹⁶ Pacific Gas and Electric (PG&E). 2020. "VFD and Soft Starter Cost Data per hp.xlsx"

varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current “default” rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustments

Parameter	Value	Source
GSIA	1.0	California Public Utilities Commission (CPUC), Energy Division. 2020. <i>Energy Efficiency Policy Manual Version 6.</i>

NON-ENERGY IMPACTS

Non-energy impacts for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Building Prototypes Used	No
DEER Version	DEER 2020, READi v2.5.1
DEER Run ID	IR006, IR007
NTG	Source: DEER 2014. The NTG of 0.60 is associated with NTG ID: <i>Com-Default>2yrs, Agric-Default>2yrs</i>
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: <i>Def-GSIA</i>
EUL/RUL	Source: DEER 2014. The value of 10 years is associated with EUL ID: <i>Agr-VSDWellPmp.</i>

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	03/31/2018	Jennifer Holmes Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: Workpaper PGECOAGR119 Revision 3 (April 1, 2017) Consensus reached among Cal TF members.
			Revisions for submittal of version 01.
	01/29/2021	Adan Rosillo PG&E	Adopted AOE measures per 3P requirements. No measure savings or costs were altered.