



AGRICULTURE
ENHANCED VFD ON IRRIGATION PUMP
SWWP005-01

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MEASURE NAME

Enhanced VFD on Irrigation Pump

STATEWIDE MEASURE ID

SWWP005-01

TECHNOLOGY SUMMARY

Electrical demand from irrigated agricultural fields is expected to increase in the future. 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.

Variations and uncertainties in irrigation systems leads designers to frequently over-design irrigation pumps (by at least 10%) to meet the worst-case hydraulic conditions, since it is favorable to have too much pressure rather than too little pressure. considering the following factors:

- 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.
- For drip/micro-irrigation systems, designers typically include a “safety factor” of at least 5 psi to the design pump discharge pressure requirement.
- The pressures available from district pipeline turnouts are variable over time and depend on the instantaneous irrigation flow rate.
- Published hydraulic performance data from pumps, pressure regulating valves, filters, and emitters are not always accurate, or even available.
- Pumping water levels vary with changes in hydrology and well efficiency; 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.
- Automatically cleaned filters require temporary increases in pump flow rate during the cleaning cycle.
- Pumps wear out over time.

Variable frequency drives (VFDs) are sometimes installed on irrigation pumps to enable adjustment of the pump speed. Adding a VFD system to an over-designed pump will provide sufficient capacity in worst-case conditions as well as the capability of reducing the pump speed most of the time to avoid developing excess pressure and consuming excess electricity.

Note, however, that 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 significantly reduce the pump efficiency and 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 due to the parasitic load of the VFD.

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.

PG&E has incentivized “Tier 1 basic VFD systems.” However, the Tier 1 rebates do not have any minimum performance standards requirement. Thus, in early 2017, Pacific Gas & Electric Company (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 requirements for an enhanced VFD measure offering.¹ The specifications requirement was included in a subsequent ITRC report, VFD (Variable Frequency Drive) Specifications for On-Farm Pumps.² The ITRC analysis revealed VFDs in pre-existing operations are rare and, although the number of VFD system installations is increasing, areas for improvement still exist. Most importantly, a specific agricultural VFD system performance standard has not been available, historically.

The ITRC analysis confirmed that without specifications requirements and special design attention, the Tier 1 basic VFD installations can be the source of power quality and radio interference issues. Notably, poor VFD system design can cause frequent nuisance tripping (automatic resetting or shutdowns) and may prevent the pump motor from starting. Without standards, mitigating or avoiding these issues for new VFD installations is optional, rather than obligatory.

The primary goal of the specifications requirements is to improve agricultural VFD installations for low voltage (≤ 480 VAC) well pumps (≤ 600 hp) and booster pumps (≤ 150 hp) by setting minimum requirements for high quality VFD installations. Detailed VFD specifications will increase energy efficiency, VFD life expectancy and reliability, and will decrease power quality issues.

Since the rollout of the ITRC technical specifications requirement for the enhanced VFD system, PG&E has received numerous requests from the industry to offer rebates for a lower-cost VFD system without sacrificing power quality. In response, a “Tier 2 mid-tier VFD system” was created, is now referred to as the “Tier 3 enhanced VFD system.” See Measure Case Description.

MEASURE CASE DESCRIPTION

This measure is defined as a variable frequency drive (VFD) added to a clean water agriculture pump to adjust the water flow/pressure to meet the facility irrigation needs.

The measure offerings are defined by pump type (well or booster) and the pump horsepower range, as specified below.

¹ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*. Prepared for Pacific Gas and Electric (PG&E).

² Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2019. *Variable Frequency drive (VFD) Specifications for On-Farm Pumps*. ITRC Report No. R 19-006. Updated March 2019.

Measure Case Specification Summary

Measure Offering	Horsepower (hp)
Advanced VFDs on Well Pump	≤ 75
	75 < hp ≤ 600
Advanced VFDs on Booster Pump	≤ 75
	75 < hp ≤ 150

Measure Case Specification – Measure Offerings

Statewide Measure Offering ID	Measure Offering Description
SWWP005A	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Well Pumps ≤75hp
SWWP005B	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to ≤600hp
SWWP005C	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Booster Pumps ≤75hp
SWWP005D	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to ≤150hp
SWWP005E	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Well Pumps ≤75hp
SWWP005F	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to ≤600hp
SWWP005G	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Booster Pumps ≤75hp
SWWP005H	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to ≤150hp
SWWP005I	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Well Pumps ≤75hp
SWWP005J	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Well Pumps >75hp to ≤600hp
SWWP005K	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Booster Pumps ≤75hp
SWWP005L	FarmIrrig-IrrifSys-Tier 2 Mid-tier Specification VFD on Ag Booster Pumps >75hp to ≤150hp
SWWP005M	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Well Pumps ≤75hp
SWWP005N	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Well Pumps >75hp to ≤600hp
SWWP005O	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Booster Pumps ≤75hp
SWWP005P	FarmIrrig-IrrifSys-Tier 3 Enhanced Specification VFD on Ag Booster Pumps >75hp to ≤150hp

BASE CASE DESCRIPTION

The base case for this measure is a constant speed well or booster agricultural pump controlled to operate by throttling the flow based on irrigation needs.

CODE REQUIREMENTS

This measure is not governed by either state or federal codes and standards.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards	None.	n/a

NORMALIZING UNIT

Rated horsepower (hp)

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
New construction	DnDeemed	Ag
New construction	DnDeemDI	Ag
New construction	DnDeemed	Com
New construction	DnDeemDI	Com
Add-on equipment	DnDeemed	Ag
Add-on equipment	DnDeemDI	Ag
Add-on equipment	DnDeemed	Com
Add-on equipment	DnDeemDI	Com

Eligible Products

The customer must install a VFD system on an existing electrically operated agricultural booster or well pump motor installed on site or install VFDs on new pumps or existing pumps where the horsepower of the serving motor is increased (added load).

The customer must install a VFD system on the pump motor.

The pumping application must be able to vary the flow/pressure of the pump (i.e. throttle valve, control valve, etc.) and the VFD must be used to adjust operation of pump to meet flow/pressure requirements, not simply as a soft starter, or for cavitation control.

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

The pumping application must operate for a minimum of 1,000 hours per year.

Tier 3 installed VFD systems must conform to the specifications outlined in the *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*.³

Tier 2 installed VFD systems must conform to the requirements outlined in the *Variable Frequency drive (VFD) Specifications for On-Farm Pumps*,⁴ except for the requirement specified in item 3.E.7c in section “3.E.7 Cooling” of the Design Specifications.

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.

Eligible Building Types and Vintages

This measure is applicable to agricultural pumps that rely on electric pumping to irrigate crops.

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

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)

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

³ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*.

⁴ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2019. *Variable Frequency drive (VFD) Specifications for On-Farm Pumps*. ITRC Report No. R 19-006. Updated March 2019.

USE CATEGORY

Water pumping & irrigation

ELECTRIC SAVINGS (kWh)

Scope

The analysis focuses on potential energy savings that could be expected from a VFD system installation on a typical field with pressurized irrigation. 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

Category 2 installations can result in higher energy savings. However, 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 installations are excluded from this analysis.*

Comparison of Potential Energy Savings of 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 the table below. Some values reported are referenced from the ITRC Report No. R 11-005,⁵ while others are readily available in accepted design literature.

⁵ Burt, C. (Irrigation Training & Research Center, ITRC). 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.

Potential Pressure Savings (feet) for Each Pump Type with VFD systems⁶

Pressure savings category	Potential pressure savings (ft) 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

Unit Energy Savings Calculation

The unit energy savings (UES) was calculated for two pump types:

1. Booster pump supplying micro/drip system
2. Well pump supplying a booster with a micro/drip system downstream

Assumptions used for the computations are specified in the tables below.

Assumed Values for Computations⁷

Assumption	Value	Source
Well pumping level, San Joaquin Valley (feet)	300	Burt, C. 2011. <i>Variable Frequency Drive (VFD) Controlled Irrigation Pumps – Analysis of Potential Rebate</i> . San Luis Obispo (CA): Irrigation Training and Research Center, California Polytechnic State University. ITRC Report No. R 11-005.
Minimum well pump TDH (feet)	321	Burt, C. 2011. <i>Variable Frequency Drive (VFD) Controlled Irrigation Pumps – Analysis of Potential Rebate</i> . San Luis Obispo (CA): Irrigation Training and Research Center, California Polytechnic State University. ITRC Report No. R 11-005.
Minimum booster pump TDH (feet)	120	
Annual operating hours, deciduous orchard (hours)	2,368	

⁶ Burt, C. (Irrigation Training & Research Center, ITRC). 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.

Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*. Prepared for Pacific Gas and Electric (PG&E). Table 3-5.

⁷ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*. Prepared for Pacific Gas and Electric (PG&E). Table 3-3.

Assumed Values for New Pump Plants on Horsepower Basis ⁸

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		

** TDH values were adjusted up slightly from the minimum values reported above 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 specified above to determine if there was a difference on a per-horsepower basis.

Using the equation below, the initial overall pumping plant efficiency (OPPE) was calculated as the product of the motor efficiency and impeller efficiency values.

Initial Overall Pump Plant Efficiency

$$\text{Initial OPPE} \left(\frac{\%}{100} \right) = \text{New Motor Efficiency} \times \text{New Impeller Efficiency}$$

The estimated water horsepower (WHP) requirement is calculated as:

Estimated Water Horsepower Requirement

$$\text{Initial Water Horsepower (WHP)} = \frac{\text{Initial Input HP}}{\text{Initial OPPE}}$$

$$\text{Input HP} = \text{Initial input hp (see above)}$$

$$\text{Initial OPPE} = \text{Computed, see above (\%/100)}$$

⁸ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center, ITRC). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*. Prepared for Pacific Gas and Electric (PG&E). Table 3-4.

To separate the flow and pressure total dynamic head (TDH) demand, the initial pump flow rate was estimated as a function of the WHP and initial pump TDH.

Initial Pump Flow Rate

$$\text{Initial Pump } Q \left(\frac{\text{gal}}{\text{min}} \right) = \frac{\text{WHP} \times 3960}{\text{Initial Pump TDH}}$$

$$\text{WHP} = \text{Computed (see above) (hp)}$$

$$\text{Initial Pump TDH} = \text{Initial pump total dynamic head (TDH) (feet)}$$

Initial Input kW

$$\text{Initial Input kW (kilo - watts)} = \text{Input HP} \times 0.746 \frac{\text{kW}}{\text{HP}}$$

Compute the new pump TDH with a category 1 enhanced VFD (no automation).

New Pump TDH

$$\text{New Pump TDH (feet)} = \text{Initial Pump TDH} - \text{Total Potential TDH Savings}$$

$$\text{Initial Pump TDH} = \text{Initial pump total dynamic head (TDH) (feet)}$$

$$\text{Total Potential TDH Savings} = \text{See above (feet)}$$

New Input kW

$$\text{New Input kW} = \text{Initial Input kW} \times \frac{\text{New TDH}}{\text{Initial Pump TDH}}$$

$$\text{Initial Input kW} = \text{Computed, see above (kW)}$$

$$\text{New Pump TDH} = \text{Computed, see above (feet)}$$

$$\text{Initial Pump TDH} = \text{See above}$$

The average demand reduction is the difference between the baseline (initial) and measure case (new) input demand. Annual unit energy savings (UES) is calculated as the average demand reduction multiplied by the estimated annual hours of operation.

Average Demand Reduction

$$\text{Demand Reduction, kW} = \text{Initial Input kW} - \text{New Input kW}$$

$$\text{Initial Input kW} = \text{See above (kW)}$$

$$\text{New Input kW} = \text{Computed, see above (kW)}$$

Annual Unit Energy Savings

$$\text{Annual UES, kW} = \text{Demand Reduction} \times \text{HOURS}$$

$$\begin{aligned} \text{UES} &= \text{Annual unit energy savings (kW)} \\ \text{HOURS} &= \text{Annual Operating Hours (hours)} \end{aligned}$$

The energy savings and demand impacts of each measure offering were analyzed and the weighted averages were calculated based on the number of pump motors in each horsepower bin.

- Well pumps > 600-hp and booster pumps > 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 UES were first calculated for each of the twelve pump horsepower bins, then the average kW and kWh impacts per horsepower was calculated. See table above for the horsepower bins and the pump data.
- For booster pump VFD, the UES were calculated for each of the three pump horsepower bins, then the average kW and kWh impact per horsepower savings was then calculated. See table above for the horsepower bins and the pump data.

PEAK ELECTRIC DEMAND REDUCTION (kW)

The average demand reduction is the difference between the baseline (initial) and measure case (new) input demand. Annual unit energy savings (UES) is calculated as the average demand reduction multiplied by the estimated annual hours of operation.

Average Demand Reduction

$$\text{Demand Reduction, kW} = \text{Initial Input kW} - \text{New Input kW}$$

$$\begin{aligned} \text{Initial Input kW} &= \text{See Electric Savings (kW)} \\ \text{New Input kW} &= \text{Computed, see Electric Savings (kW)} \end{aligned}$$

The flow that the pump is providing during the peak period, 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)

There are no gas savings associated with this measure.

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 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.”⁹ This approach provides a “reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.”¹⁰ Further, as per Resolution E-4807, the California Public Utilities Commission (CPUC) revised add-on equipment measures so that the EUL of the measure is equal to the lower of the RUL of the modified system or equipment or the EUL of the add-on component.”¹¹

The EUL and RUL specified for VFDs on agriculture pumps are specified below. For add-on equipment installations, the host equipment is the pump motor.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) – VFD	10.0	The source for this data/information is unknown.
EUL (yrs) – host pump motor	15.0	California Public Utilities Commission (CPUC). 2008. “EUL_Summary_10-1-08.xls.”
RUL (yrs) -	3.3	

BASE CASE MATERIAL COST (\$/UNIT)

For the *add-on equipment*, the base case material cost is equal to \$0 because there are no modifications to the existing equipment. The customer’s alternative is to make no changes to their existing irrigation pumping system.

For *new construction* installations, the base case material cost is the cost of the throttling valves and soft starters (pumps >75-hp).

Base case material costs were derived using the 2015 RSMeans Mechanical Cost Data.¹²

MEASURE CASE MATERIAL COST (\$/UNIT)

For all installation types, measure case material costs were derived from cost data obtained and analyzed by the Irrigation Training & Research Center (ITRC) from VFD vendors and irrigation and pump dealers.¹³

⁹ California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

¹⁰ KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

¹¹ California Public Utilities Commission (CPUC). 2016. Resolution E-4807. December 16. Page 13.

¹² RSMeans Engineering Department. 2015. *RSMeans Mechanical Cost Data 2015*. 38th Annual Edition. Page 257. Section 23 05 23.30 Valves, Iron Body, Butterfly, lug type, gear operated, sizes 3" to 5".

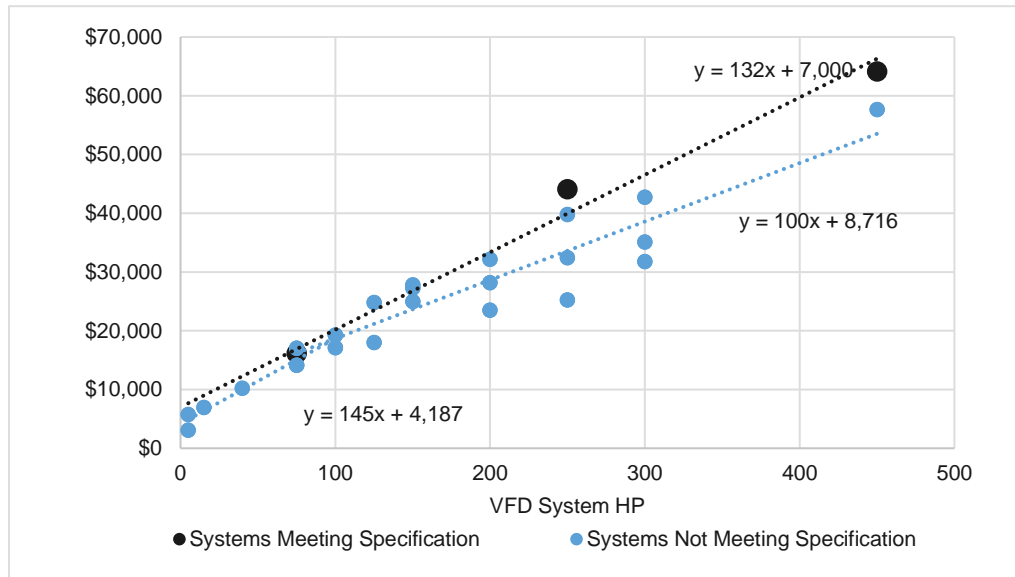
Pacific Gas & Electric Company (PG&E). 2019. "SWWP005-01 Cost Calc.xlsx."

¹³ Burt, C., K. Feist, and G. Wilson. (Irrigation Training & Research Center). 2017. *Variable Frequency Drive (VFD) Specifications for Agricultural Irrigation Pumping*. Prepared for Pacific Gas and Electric (PG&E).

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

The installed VFD system cost (including materials, labor and tax) dataset is plotted in the figure below. Only three of the 24 invoices met the specifications; the VFD systems that did not meet the specifications are considered “typical”. The total installed cost for pumps in the eligible horsepower bins were averaged to calculate the average cost per horsepower rating.

Comparison of Typical and Specification-compliant VFD System Installed Costs (including materials, labor, and tax)



The cost data indicate the following:

- Most of the VFD system costs were missing one of, or any combination of, the following features: harmonic mitigation, surge suppression, and/or acceptable cooling (without outside air circulation across electronics)
- Some of the “typical” VFD system costs are more expensive but cannot meet the specified performance standards.
- On average, it is more expensive to meet 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
- “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

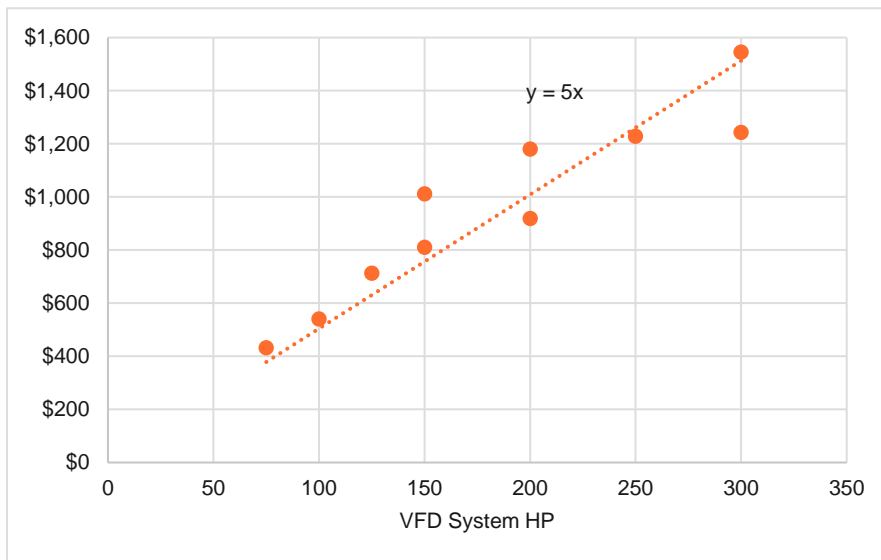
Passive harmonic filters can provide harmonic mitigation that meet the specifications for VFD systems > 75 hp. A range of approximate consumer costs for adding passive harmonic filters is provided below.

Approximate Unit Costs for Integrated Passive Harmonic Filters

VFD hp	Integrated passive harmonic filter unit costs, plus tax (\$)	Approximate \$/hp
75	\$1,848	\$25
250	\$3,629	\$15
450	\$20,714	\$46

A 3% input line reactor is one of many prescribed harmonic mitigation measures for a VFD system ≤ 75 hp. Line reactors can serve dual functions: harmonic mitigation and some degree of transient voltage protection. The consumer cost to add 3% line reactors is approximately \$5 per VFD hp as shown below.

Approximate Unit Cost for Input Line Reactors (+ tax)



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

- 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 are listed below.

Approximate Unit Costs for VFD Cooling Unit

VFD hp	Nominal HVAC (ton)	Installed Cooling Unit Cost (+ tax) (\$)
50	0.5	\$1,850
100	1.0	\$2,100
200	2.0	\$2,550
400	3.0	\$3,050
600	5.0	\$4,000

BASE CASE LABOR COST (\$/UNIT)

For the *add-on equipment*, the base case labor cost is equal to \$0 because no modifications are to the existing equipment. The customer's alternative is to make no changes to their existing irrigation pumping system.

For *new construction* the base case labor cost is included in the material costs, as described for the Measure Case Material Cost.

MEASURE CASE LABOR COST (\$/UNIT)

Labor costs are included in the material cost; see Measure Case Material Cost.

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. The NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 commercial and agriculture programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. This sector average NTG ("default NTGs") is applicable to all energy efficiency measures that have been offered through commercial and agriculture sector programs for less than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
NTG – Commercial	0.60	Itron, Inc. 2011. <i>DEER Database 2011 Update Documentation</i> . Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.
NTG – Agriculture	0.60	

GROSS SAVINGS INSTALLATION ADJUSTMENT (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 varies by end use, sector, technology, application, and delivery method. This GSIA is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment

Parameter	GSIA	Source
GSIA – Default	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. <i>Energy Efficiency Policy Manual Version 5</i> . Page 31

NON-ENERGY BENEFITS

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
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	n/a
Reason for Deviation from DEER	This measure is not included in DEER.
DEER Measure IDs Used	n/a
NTG	The NTG of 0.60 is associated with NTG ID: <i>Agric-Default>2yrs, Com-Default>2yrs</i>
GSIA	The GSIA of 1.0 is associated with GSIA ID: Def-GSIA
EUL/RUL	The value of 10 years is associated with EUL ID: <i>Agr-VSDWellPmp</i> . RUL is 1/3 of the value based upon EUL ID of host pump motor: <i>Motors-Pump</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: PGECOAGR121, Revision 0 (November 1, 2017) Consensus reached among Cal TF members.
	06/07/2019	Randy Kwok, PG&E Jennifer Holmes, Cal TF Staff	Revisions for submittal of version 01.
	01/29/2021	Adan Rosillo PG&E	Adopted AOE measures per 3P program requirements. No measure savings or costs were altered.