

Variable Frequency Drive (VFD) Controlled Irrigation Pumps – Analysis of Potential Rebate

Well pumps, booster pumps, and a combination of the two are used throughout the agricultural sector to provide water for on-farm irrigation. However, the pump discharge pressures for the majority of irrigation systems are excessive (Burt, 2009), waiving considerable monetary and power consumption savings. This report analyzes the numerous potential benefits of integrating a variable frequency drive (VFD) to irrigation supply systems and modifying system design philosophies.

Bottom line – Pump discharge pressures can be reduced with appropriate design procedures and the integration of a VFD on well pumps.

In 2002, ITRC (Burt and Howes, 2002) surveyed five California irrigation districts regarding the integration of VFD controllers to supply pumps. The results were positive across the board including substantial reductions in energy costs, reduced peak load demand, and other savings related to less vehicular travel and manpower. Annual paybacks were in the 2-4 year range.

For on-farm irrigation, VFDs will not provide as many secondary benefits to the owner as for irrigation districts, because their operations are not similar. Nevertheless, substantial benefits can be achieved on-farm.

Table 1 summarizes the results that are discussed in this Appendix. Key assumptions for **Table 1** are:

Location = West side of the San Joaquin Valley, Kern County

Price of power = \$0.16/kWh

Table 1: Estimated annual kWh savings in western Kern County if VFDs are installed on pressurized field irrigation systems of 160 acres.

Crop Type	Annual kWh savings with VFD	
	Category 1 – Booster pump only.	Category 2 – Well pump plus booster or well pump only supplies pressure to drip/sprinkler irrigation system.
Deciduous Trees	21,078	64,176
Grape Vines	13,672	41,667
Tape on Produce Crops	13,672	41,667

Variable Frequency Drive (VFD) Controlled Pumps

Pressure Reduction with VFDs

VFD controllers for irrigation pump motors may have the greatest potential for immediate power savings. There are numerous reasons to promote VFDs on both well pumps and booster pumps. The two most significant reasons are:

1. Designers must always over-design pumps. Farmers do not complain if they have too much pressure; but they definitely complain if they do not have enough. The uncertainties with pump design are:
 - a. Designers always include a “safety factor” of at least 5 psi in a design – whether needed or not.
 - b. Published pump curves often do not exactly match what goes into a field.
 - c. The pressures from irrigation district pipeline turnouts vary over time, and may not even be known by the designer.
 - d. Well water levels vary from year-to-year, and from Spring to Fall. These variations can easily be 50 feet.
2. Irrigation systems do not require a constant pressure. In general, irrigation systems incorporate sequences of multiple blocks. These blocks have varying elevations and sizes, each with unique pressure requirements.

Given the two items above, VFDs allow designers to over-design the pump to meet uncertainties and occasional extreme conditions, without having continuous power wastage due to an over-designed pump.

The power savings that are obtained from a VFD will depend upon the specific installation. In the case of well pumps for which the lift from the pumping water level to the ground surface is substantial, the power savings are not properly predicted using the affinity law equation:

$$(\text{New kW}/\text{Old kW}) = (\text{New RPM}/\text{Old RPM})^3$$

The equation above assumes that the flow rate varies proportionally as the RPM changes. In irrigation, the RPM of the pump is changed in the case of fluctuating water levels, to maintain a constant GPM. In the case of irrigation block sizes that have variable elevations and GPM requirements, the relationship is more complex.

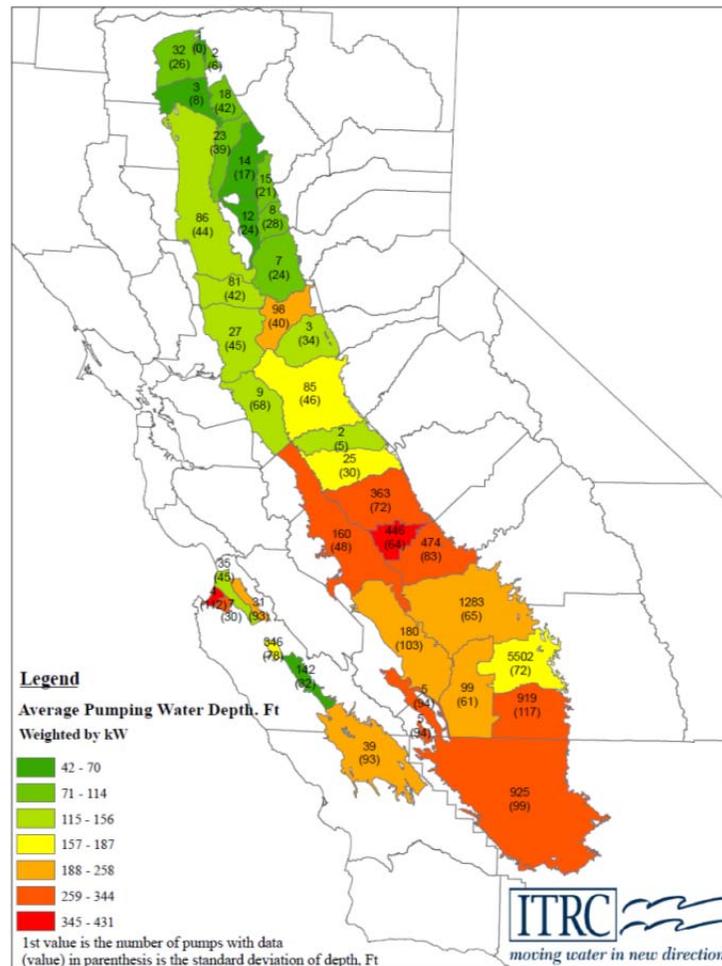
Readily attainable pressure savings estimates for a well pump are shown in the following table. These values are based on design experience of ITRC staff, and are therefore somewhat subjective.

Table 2: Readily attainable pressure savings.

Pressure savings category	Estimate of pressure savings (ft)
Over-design for fluctuating water table	10% of the average pumping water level in the area
Over-design for unknown factors in system design	10
Variations in block sizes and locations	6
Total pressure savings, unadjusted	Depends on the average pumping water level in the area

As described in **Table 2**, the magnitude of pressure savings will be proportional to the average pumping water level in the area. **Figure 1** displays average pumping water levels of the pumps sampled, weighted by kW, for California’s various groundwater basins. This white paper utilizes data from a reference region in western Kern County.

Figure 1: Weighted pumping water depths from surveyed pumps (ft)



Three additional benefits derived from the use of VFDs are also substantial, although they do not in themselves reduce electricity consumption (kWh). These benefits are:

1. Water hammer and subsequent damage to the pump and irrigation system are reduced because of the slow start and slow stop capabilities of VFD-equipped pumps.
2. Farmers are much more likely to adopt time-of-use pumping practices with well pumps. This is because the slow starting of well pumps, as opposed to 100% speed starting (with subsequent very high flow rates), can have a drastic impact on the life of wells. Many farmers will not start or stop well pumps during the irrigation season because they are afraid the starts and stops will damage their wells.
3. The slow start minimizes large but temporary current loads on the electric utility grid.

Baseline Data

Table 3 describes data obtained from the ITRC website (ITRC, 2003) for the reference area, specifically in California Department of Water Resources ETo Zone 16. In this case, ET of irrigation water is assumed to equal the applied water - making the assumption that farmers irrigate to the average condition of their fields and have both over- and under-irrigation on orchards and vines, but have slight over-irrigation on taped fields.

Table 3: Estimated annual applied irrigation water for three crop categories in the southern SJV.

Crop Category	Applied Irrigation Water (AF/Acre/Year)
Deciduous Orchards	3.7
Vines	2.4
Row Crops (Tape)	2.4

Table 4 reflects the average pumping data of the pumps sampled during the research completed for **Figure 1** in the Kern County groundwater basin.

Table 4: Typical well pump data in the Kern County groundwater basin, from Appendix 3C.

Kwh/AF	Input Kw	TDH (ft)	Pumping Water Level (ft)
555	127	321	300

Energy Savings

The next section will highlight the substantial energy and monetary savings possible though the points previously discussed using collected data from the southern San Joaquin Valley (SJV) specifically in ETo Zone 16 for reference (western Kern County). To differentiate pressure savings from the complex variety of irrigation supply systems, the calculations are divided into two categories.

Base Unit:

A well pump that supplies a booster pump for pressurized irrigation systems.

For this analysis, the “typical well pump data” in **Table 4** are used to compute the following:

- *GPM of this pump = 1365 (assuming a 65% pumping plant efficiency)*
- *Hours necessary to pump 1 AF = 4 hours*
- *This size of a pump would typically irrigate about 160 acres of drip*

The new total dynamic head (TDH) (a.k.a., pressure) for the well pump is computed as:

$$\text{Eq. 1: } \text{New TDH} = \text{Old TDH} - (\text{PWL} \times 0.1) - 16'$$

Where,

- Old TDH = Old TDH from **Table 4** (321 ft)
 PWL = pumping water level (ft); in other words, the static water level (SWL) plus drawdown, from **Table 4** (300 ft)
 0.1 = Assumes 10% overdesign of TDH due to possible water table fluctuations
 16' = Factors from **Table 2**, related to unknown variables that must be included in a pump design

$$\text{New TDH} = 321' - 300' \times 0.1 - 16' = 275'$$

Assuming a constant flow rate requirement, power savings can be computed as:

$$\text{Eq. 2: } \text{New kW} = \left(\frac{\text{New TDH}}{\text{Old TDH}} \right) \times \text{Old kW}$$

Where,

Old kW = energy used to pump water, in kilowatts, from **Table 4**

$$\text{New kW} = \left(\frac{275'}{321'} \right) \times 127 \text{ kW} = 108.8 \text{ kW}$$

Power Savings = Old kW - New kW

$$= 127 \text{ kW} - 108.8 \text{ kW} = 18.2 \text{ kW}$$

The annual monetary saving per Category 1 pump is then computed as:

$$\text{Eq. 3: } \frac{\text{Dollars}}{\text{year}} = \Delta \text{ kW} \times \frac{\text{Hrs}}{\text{yr}} \times \frac{\text{dollars}}{\text{kWh}}$$

Where,

$\Delta \text{ kW}$ = kW savings calculated previously; (Old kW - New kW)

$\frac{\text{Hrs}}{\text{yr}}$ = typical hours of operation per year, which depends upon the crop and the area of the field served.

Table 5: Hours of operation for the example well pump on 160 acres.

Crop	Annual applied, AF/Acre	Hours/year
Deciduous trees	3.7	2368
Vineyard	2.4	1536
Tape on row crop produce	2.4	1536

$\frac{\text{dollars}}{\text{kWh}}$ = typical cost per kWh. Assume \$0.16/kWh.

For the deciduous trees,

$$\Delta \frac{\text{kWh}}{\text{yr}} = 18.2 \text{ kW} \times 2368 \frac{\text{hours}}{\text{yr}} = 43,098 \frac{\text{kWh}}{\text{yr}} \text{ for 160 acres}$$

$$\frac{\text{Dollars}}{\text{year}} = 43,098 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.16}{\text{kWh}}$$

= \$ 6896/yr for the well pump, only on 160 acres.

Table 6: Well pump only VFD savings on a per crop basis – 160 acres.

VFD on Well Pump Only – Western Kern Co.		
Crop Category	Hours/yr	Δ kWh/Year
Deciduous Orchards	2368	43,098
Vines	1536	27,995
Tape on Produce Crops	1536	27,995

Booster Pump Only

A system that receives water from a canal or irrigation district, without any pressure.

The computations assume the following savings with a VFD on a booster pump:

Table 7: Savings with a VFD on a booster pump.

Pressure Savings category	Estimate of pressure savings, ft.
Over-design for "safety factor"	11.5
Likely overdesign of pump or lack of trimming impellers	5
Adjustment due to kW impact caused by flow adjustment	6
Total pressure savings	22.5 ft

Assuming the same system as the previous well pump example, with a flow rate of 1365 GPM on 160 acres, with 65% pumping plant efficiency:

For deciduous orchards:

$$kW \text{ savings} = 22.5 \text{ ft} \times \frac{1365 \text{ GPM}}{3960 \times .65} \times .746 \frac{kW}{HP} = 8.9 \text{ kW}$$

Using the same hours per year as with the well pump:

$$kWh \text{ savings/yr on deciduous trees} = 8.9 \text{ kW} \times 2368 \text{ hours/yr} = 21,078 \text{ kWh/yr saving}$$

Table 8: Booster pump VFD savings on a per crop basis – 160 acres.

VFD on Booster Pump Only – Western Kern Co.		
Crop Category	Hours/yr	Δ kWh/Year
Deciduous Orchards	2368	21,078
Vines	1536	13,672
Tape on Produce Crops	1536	13,672

Summary of kWh Savings

There are two general categories of pumps for pressurized on-farm systems (drip and sprinkler):

- **Category 1** – Booster only. Water is supplied from an irrigation district turnout, and a booster pump is needed to provide the pressure for the drip system. Even if the irrigation district supplies pressurized water, that pressure can vary over time so the designer must design the pump for the worst situation (lowest pressure from the turnout).
- **Category 2** – A well pump provides water directly to the drip system under pressure, or is directly linked to the drip system booster pump. For this case, the savings of the well pump only, plus the booster pump, are added.

The estimated annual power savings will depend upon the crop type and acreage. Well pump savings will depend upon the depth to standing water level as well. The table below has been developed for the western side of Kern County.

Table 9: Estimated annual kWh savings in western Kern County if VFDs are installed on pressurized field irrigation systems of 160 acres.

Crop Type	Annual kWh savings with VFD	
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Rebate Programs for VFD and Pump Selection

Given that VFD controllers can provide substantial energy-related benefits with agricultural irrigation pumps, any rebate program for VFDs should contain minimum requirements for the purchase of VFD controllers, covering the following features:

1. Efficiency. Inefficient VFDs create excess heat, which requires significant air conditioning power to dissipate.
2. Temperature rating.
3. Power quality.
4. Form of the simulated sine wave.
5. Audible noise.
6. Length of power cords that can be used. Some low quality VFD units can only have a cable of about 20 feet long between them and the motor.
7. Means of cooling the VFD.
8. Allowable voltage variation between legs.
9. Allowable average voltage variation.

A rebate program should have a different scale for well pumps versus booster pumps. This is because there are additional benefits to using VFDs on well pumps, which include:

- The slow startup will enable farmers to take advantage of off-peak power programs that they might not otherwise utilize.
- The slow startup introduces less dirt into the irrigation system, which requires less filtration and less water used for backflushing of filters.

However, a rebate program designed primarily for kWh reduction, rather than load shedding, would not include well pumps that discharge into canals or pipelines that supply surface irrigation (furrow or border strip) fields. This is because the farmers easily adapt to the changing groundwater levels by managing their irrigation systems for less or more flow (as the groundwater levels fluctuate over time). In other words, the irrigation system adapts to the well flow rate.

In contrast, the flows from wells that supply drip or sprinkler systems must adapt to the constant or changing demands of the irrigation system. Therefore, VFD control of well pumps is desirable, and will save power, on such systems. These are the systems that must have over-designed pumps to provide enough pressure and flow in the worst condition – meaning excess pressure is supplied at all other times.

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