

**Analysis For Updating An Irrigation Pumping Station
With Variable Frequency Drives**

By

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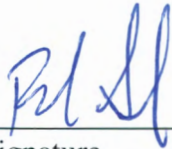
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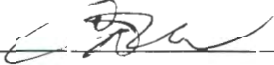
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ABSTRACT

The goal of this project is to analyze one of Teixeira and Sons irrigation pumping stations in their water transportation system in order to update it with variable frequency drive “VFD” capability. The pump station’s operating costs will be analyzed to see if updating with VFDs could become more profitable and cost effective. The outcome of the evaluation and specification proposal helped in making decisions on pump restorations, energy use revisions and future capital investments regarding additional canal automation. At the conclusion of this project Teixeira and Sons have decided to update their first pumping station, out of three stations within the system, with variable frequency drives due to the power savings that will be obtained. This step is a first towards automating the entire water transportation system with more restorations to come.

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INTRODUCTION

Background

Teixeira and Sons Farming is a privately owned farming company located in California's central San Joaquin Valley. Teixeira and Sons has been established for more than 40 years. They currently farm over 5,000 acres, which includes primarily row crops and some almond orchards. Teixeira and Sons is continually looking for new and improved ways to become more efficient and profitable throughout their company. When taking efficiency and profitability into consideration Teixeira and Sons had identified an issue within one of their irrigation pumping stations that needed improvement.

These improvements deal with their water transportation system within their Los Banos ranch. This water transportation system is comprised of a series of three lift stations and three canal waterways. The purpose of this water transportation system is to move water from the lower section of the ranch out of the Delta Mendota Canal, to the upper section of the ranch about three miles away.

The main reason Teixeira and Sons is concerned with the efficiency of this system relates to the enormous cost to power these pumping stations and the liability in operating them. Currently only the third pumping station out of the three is equipped with Variable Frequency Drives (VFDs). One of the main expenses farmers encounter is energy cost. Specifically for Teixeira and Sons, electricity is the power source that keeps their pumps running. VFDs have been proven in an agricultural setting to lower energy costs and aid in increase the efficiency of water transportation systems. This is why this senior project will consider VFD integration.

Justification

In order for Teixeira and Sons to remain as an efficient farming operation they will need to maintain maximum efficiency and reliability at their pumping stations. To do this, Teixeira and Sons needs to maximize their pumping plant efficiencies and power use for their three lift stations in the water transportation system. This Senior project evaluated the pump efficiency test results for the first pump station to determine if the pumps need to be refurbished or updated with VFDs in order to make the pumps operate most efficiently. Having an efficient and automated pumping system could result in decreased energy and labor costs and save Teixeira and Sons money, while decreasing liability in the long run.

Objectives

The objective of this senior project was to perform an evaluation of Teixeira and Sons number one lift station in their water transportation system. The goal of this senior project was to analyze the benefit of updating the lift station with VFD controlled units. The results from these modernizations could aid in decreased labor, decreased energy consumption, increased efficiency and safety. This initial modification will be a first step towards modernizing Teixeira and Sons entire water transportation system in the future.

LITERATURE REVIEW

Water Delivery Systems

The Western United States, farmers, specifically in California, depend on surface water storage and water transfers for agricultural irrigation practices. These intertwined storage and delivery systems keep California's agriculture industry alive. California has seen its fair share of droughts and water delivery system restrictions in the past.

The environmental pressures and governmental shortcomings in understanding California's water related issues has made it hard for California farmers to carry out their farming practices without tightening up their water conveyance systems and usage. According to the Bureau of Reclamation "the increasing demands placed on the finite supply of water in the west make improved water management and water-use efficiency ever more important"(TSC 2014). With decreased surface water supply as a result of the drought and environmental regulations, the price of water to grow crops in some areas has risen depending on the district. Central California Irrigation Districts base allocation fee went from \$7.00 per acre-foot to \$17.00 per acre-foot from 2013 to 2014. This is almost a three-fold increase, but when compared to San Luis Water District, their supplemental water supply went from \$450.00 to \$875.00 (Teixeira 2014). As you can see, based on the district you are in there could be some hefty water prices for your crops. With farmers paying more for water they need to find out other areas to save money, and become more efficient in their operations to offset these increased water prices.

Energy Selection For Motors

The fuel source that powers pumps is a large expense for the growers, so maximizing the efficiency is important. There are roughly five different fuel sources for pumping; electricity, diesel, gasoline, propane, and natural gas. Each of these different fuel sources has their benefits and drawbacks. Some potential advantages when using electricity is, ease of operation, very low maintenance, very long life, can incorporate the use of solar-PV cells to fully or partly power the system. Some disadvantages of using electricity, may be expensive to install, requires 3-phase power lines, only runs at a single speed without a variable frequency drive (VFD).

Using gasoline, natural gas or propane to operate pumps is not normally recommended because of the fire hazard danger and noise pollution. On the other hand in regards to natural gas it is relatively inexpensive. However, using diesel does have some advantages. For example, diesel provides the ability to vary speed, fuel is easily obtainable, and they are more efficient than a spark ignition engine. Some disadvantages with using diesel are the noise pollution, fire hazard, continual maintenance required.

Pumps

Pumps are mechanical devices that impart energy to a fluid. Irrigation pumps lift water from one elevation to a higher level. Pumps have to be able to impart enough energy on the water to overcome friction losses during conveyance in order to provide pressure for irrigation systems or any other operations in which they are needed. Irrigation pumps use mechanical energy, usually from electric and diesel powered motors but may also use gasoline, liquid petroleum gas, or natural gas to power motors. Pump may be classified as positive displacement pumps or centrifugal pumps.

Positive Displacement Pumps. According to an advisor from Pumpsout.com, positive displacement pumps also known as PD pumps, move a liquid and pressurize it to allow it to pass through the system by drawing the liquid into a chamber, then contracting the chamber to force the liquid out of the pump at the necessary pressure to move through the piping system. PD pumps do not have impellers, but rather rely on rotating or reciprocating parts to directly push the liquid in an enclosed movable volume, until enough pressure is built up to move the liquid into the discharge system.

Because it doesn't rely on increasing the velocity of the fluid as the centrifugal pump does by moving the liquid through the impeller, the fluid velocity inside a PD pump is much lower than a centrifugal pump. This is often a desirable feature for certain applications such as pumping fragile solids.

Centrifugal Pumps. According to an advisor from Pumpsout.com, centrifugal pumps are the most common type of pump, with dozen of different configurations available including: fire pumps, end suction pumps, chopper pumps, grinder pumps, magnetic drive pumps well pumps. Centrifugal pumps use one or more impellers, which attach to and rotate with the shaft, providing the energy that moves liquid through the pump and pressurizes the liquid to move it through the piping system.

Centrifugal pumps are usually the best choice for lower viscosity (thin) liquids and high flow rates. They are also used in many residential, commercial, industrial, and municipal applications. Multi-stage centrifugal pumps have more than one impeller, and are used for applications that require higher pressure or head.

Impeller Designs

There are many different impeller designs for different pumping needs. Impellers used in water pumping operations typically have three different structural designs, open, closed, and semi-open impellers. Each style has its specific primary uses and operation environment.

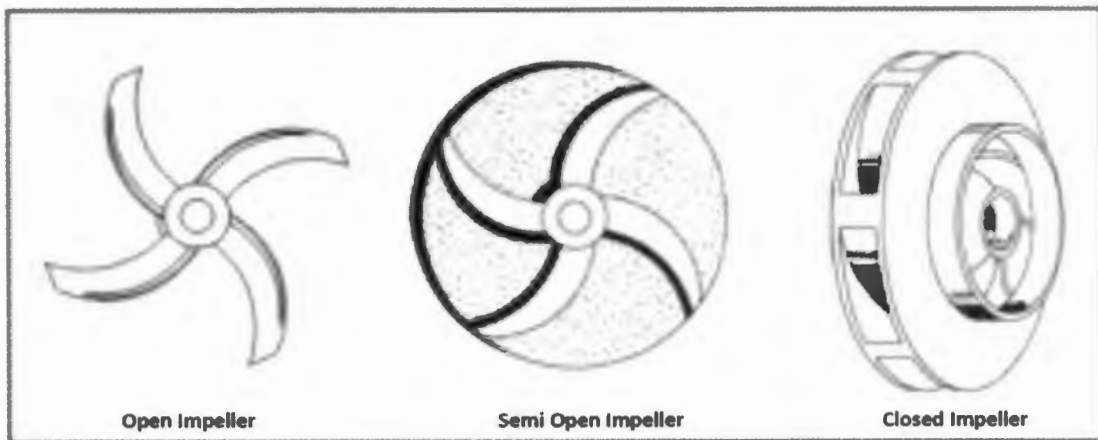


Figure. 1 Impeller Designs. Credit. Tech Transfer

Open Impellers. Open Impellers are used to move high volumes of water easily in an environment of minimal pressure. One drawback is that these impellers see a higher rate of wear on the vanes requiring increased service (GlobalSpec 2014).

Closed Impellers. Closed impellers, also called enclosed impellers have a shroud and a hub surfaced attached. Having this enclosed area minimizes leakage losses across the vanes, provides strength and stability to the vane allowing the vane thickness to be reduced and increasing the flow area through the impeller. One would choose to use a closed impeller in a situation that needs to generate a lot of pressure. One disadvantage of this impeller is that it can become clogged with debris and must be disassembled to clean (GlobalSpec 2014).

Semi-Open impellers. Semi open impellers have some of the advantage characteristics from each of the other style impellers. Allowing one side of the impeller to be open minimizes the occurrence of impeller clogging and allows more flow to be passed through. Only having one shroud causes this type of impeller to become easily unbalanced causing problems in pumping operations (GlobalSpec 2014).

Impellers can be designed to impart various flow characteristics. Impeller flow designs can take on three distinct types: axial, radial, and mixed. Because centrifugal pumps are also classified in this manner, the impeller selection depends upon matching the pump's flow characteristic to that of the impeller.

- Axial flow impellers move media parallel to the impeller.
- Radial flow impellers move media at right angles to the impeller itself.
- Mixed flow impellers have characteristics of both axial and radial flow. They may move media at an angle, which is different from right angle radial flow.

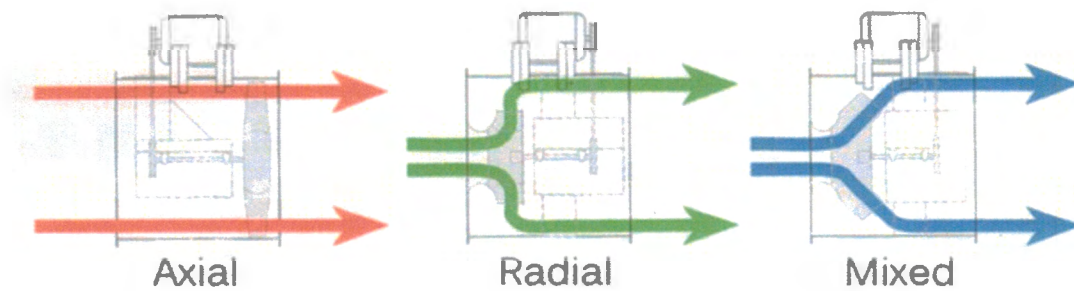


Figure. 2 Flow Characteristics Credit: Tech Transfer

Efficiency

The general definition of efficiency in pumps is the ratio of the output to the input expressed as a percent.

$$\text{Efficiency (\%)} = \frac{\text{Output}}{\text{Input}} \times 100 \quad (1)$$

When we are evaluating pumps the main components we are interested in are the driver (motor or engine) efficiency, the impeller efficiency, and the overall pumping plant efficiency.

Driver Efficiency (E_m)

The driver efficiency is the percent ratio of the power output of the driver to its input power.

$$E_m = \frac{\text{Shaft output power of the driver}}{\text{power consumption}} \times 100$$

$$= \frac{\text{Motor output HP}}{\text{Input HP}} \quad (2)$$

Approximately 80% of all pumps in California driven by motors, although most hand-move sprinkler booster pumps and many large well pumps are driven by engines (Burt 2014). The following table acquired from the book title "Pumps" edited by Dr. Charles Burt, represents the efficiencies of different sizes of standard 3-phase electric motors and vertical induction motors operating at 460 volts.

Table. 1 Approximate motor efficiencies

Full Load HP Rating	* Standard 460 V 3- Phase Effic. (%)	** Vert Induct 460 V 3- Phase Effic. (%)	Full Load HP Rating	Standard 460 V 3- Phase Effic. (%)	Vert Induct 460 V 3- Phase Effic. (%)
1	78.5	-	60	91	91
2	82.5	-	75	91.7	91.5
3	78.5	81	100	93.6	92
5	85.5	81	125	93.6	92.5
7.5	85.5	83.5	150	94.1	92.5
10	86.5	85	200	95	92.5
15	88.5	87	250	95	92.5
20	88.5	88	300	-	92.5
25	89.5	89	350	-	92.5
30	90.2	89.5	400	-	92.7
40	90.2	90	450	-	93
50	90.2	90.5	500	-	93
* Marathon Electric Motors			** General Electric Motors		

Impeller and Bowl Assembly Efficiencies (E_i). As shown in **Table 1** above, motors are not 100% efficient, as they do not convert all the input energy into mechanical energy. Likewise, pump impellers do not convert all mechanical energy into hydraulic energy. This results in a pumping plant efficiency well below 100%. Also we can see in the table above, as the motor size increases so does the efficiency rating. The impeller and bowl assembly efficiency (expressed as the percent ratio of the water horsepower (WHP) to the brake horsepower (BHP)) is affected by the following pump characteristics and flow conditions:

- Impeller design
- Bowl design
- Flow rate
- Wear on impeller and bowl assembly
- Impeller trim
- Number of stages in series, and inlet conditions

The equation for impeller efficiency is as follows:

$$E_i = \frac{\text{Water Horsepower}}{\text{Horsepower delivered by the shaft to the impellers}} \times 100 \quad (3)$$

Also written as:

$$= \frac{WHP}{BHP} \times 100$$

Overall Pumping Plant Efficiency (E_{pp}). The overall pumping plant efficiency is the ratio of the power exerted into the water to the input power to the driver. This efficiency is sometime called the wire-to-water efficiency (Burt 2014), when motor drivers are used.

$$\text{Overall pumping plant efficiency } (E_{pp}) = \frac{\text{Water horsepower (WHP)}}{\text{Input horsepower (IHP)}} \quad (4)$$

* Pump testers for the electric utilities in California calculate the overall plant efficiency as (CEE 2011):

$$\text{Overall plant efficiency} = \frac{\text{Water pumped (GPM)} \times \text{Total lift (Feet)}}{\text{The horsepower input to motor}} \quad (5)$$

The electric utility tested overall plant efficiencies are classified as good, fair, or poor according to motor size as shown in **Table 2**: In most cases, having a pumping plant efficiency of 60% or better is considered good to very good.

Table. 2 Overall Plant Efficiency

Overall Plant efficiency classifications				
Motor Hp	Low	Fair	Good	Very Good
5 - 7.5	47.9 or less	48 - 50.9	51 - 54.9	55 or above
10	47.9 or less	50 - 52.9	53 - 57.9	58 or above
15	50.9 or less	51 - 53.9	54 - 58.9	59 or above
20 - 25	51.9 or less	52 - 56.9	57 - 61.9	62 or above
30 - 50	54.9 or less	55 - 59.9	60 - 64.9	65 or above
60 - 75	56.9 or less	57 - 61.9	62 - 66.9	67 or above
100	58.9 or less	59 - 63.9	64 - 69.9	70 or above
125 - 250	59.9 or less	60 - 64.9	65 - 70.9	71 or above
300	59.9 or less	60 - 65.9	66 - 71.9	72 or above

Pump Testing

Pump efficiency testing is very important in determining the efficiency of a pumping plant and monitoring the energy usage to minimize the pumping costs. Periodic pump testing is necessary to monitor performance and is an accurate way of understanding how the system is being operated. Having the ability to anticipate which pumps will need maintenance instead of waiting for a complete pump failure is very beneficial. Pump efficiency testing is relatively simple and most of the time cost effective.

What Is A Pump Efficiency Test. A pump test measures important aspects of the pump's operation including "flow, discharge pressure, well lift (if applicable) and power use. The end result of a pump test is an estimate of the overall efficiency of the pump and the cost of running it under the conditions of the test" (CEE 2011). In analyzing the results from a pump test an individual can evaluate if they need to revamp their pump or motor based on the condition and see if the modifications will make economical sense in the long run to yield lower energy and service costs.

Pump Testers. Pump testing is available from (Rain For Rent 2014):

- Public utilities – using their own employees or contract testers.
- Pump dealers – using their own employees or contract testers.
- Independent pump test companies – many of these testers have a public utility background.

Pump Tester Measurements. The tester measures at least four variables within a pump test (Rain For Rent 2014):

1. Water flow rate.
2. Pumping lift for a well or inlet pressure for a booster pump.
3. Pump discharge pressure.
4. Energy input to the pumping plant.

Calculations are performed for low lift pumps with components including flow; lift and discharge pressure measurements and then results are compared to the energy input to the pumping plant.

Understanding Pump Curves

A pump curve is a descriptive diagram that shows a pump's ability to produce specific flows against a specific pressure/head. Pump curves are usually oriented with the Total Dynamic Head (TDH) on the "Y" axis and Gallons Per Minute (GPM) on the "X" axis.

Pump Curve Terminology. Before we delve into the components and structure of pump curves individuals should know some basic terminology associated with pump performance curves. The National Environmental Service Center (NESC) outlines the important terms needed to understand through one of their published Tech Briefings. The terms are as follows:

Impeller—the moving element in a pump that drives the liquid.

Static Head— The vertical height from the center of the impeller to the center of the discharge outlet.

Total Dynamic Head—the total height a fluid needs to be pumped considering friction losses within the pipe.

Flow Rate—the rate of liquid flow that can be carried, typically measured in gallons per minute (gpm).

Net Positive Suction Head—how much suction lift a pump can achieve by creating a partial vacuum. Atmospheric pressure then pushes liquid into pump. A method of calculating if the pump will work or not.

Cavitation—cavities or voids in liquid. Bubbles take up space leading to a drop in pump capacity. Collapsing bubbles can damage the impeller and volute, making cavitation a problem for both the pump and the mechanical seal.

Friction Loss—the amount of pressure / head required to force liquid through pipes and fittings.

Pump Efficiency—the ratio of energy delivered by the pump to the energy supplied to the pump shaft. Some pump curves will show you the percent of efficiency at the best efficiency point.

Best Efficiency Point—the point of highest efficiency of the pump.

Brake Horsepower (BHP)— (horsepower required at the pump shaft). The brake horsepower curves run across the bottom of the pump performance curve usually sloping upward from left to right. These lines correspond to the performance curves above them (the top performance curve corresponds to the top BHP line and so on). Like the head-capacity curve, there is a brake horsepower curve for each different impeller trim.

Affinity Laws— Are associated with the rotational speed or rpm of a centrifugal pump is that if the speed or impeller diameter of a pump change, we can calculate the resulting performance change using:

1. The flow changes proportionally to speed: double the speed / double the flow.
2. The pressure changes by the square of the difference: double the speed/multiply the pressure by four.
3. The power changes by the cube of the difference: double the speed/multiply the power by eight.

Pump Curve Example. The example below is a simple pump curve example representing one pump with selected operation points marked for reference.

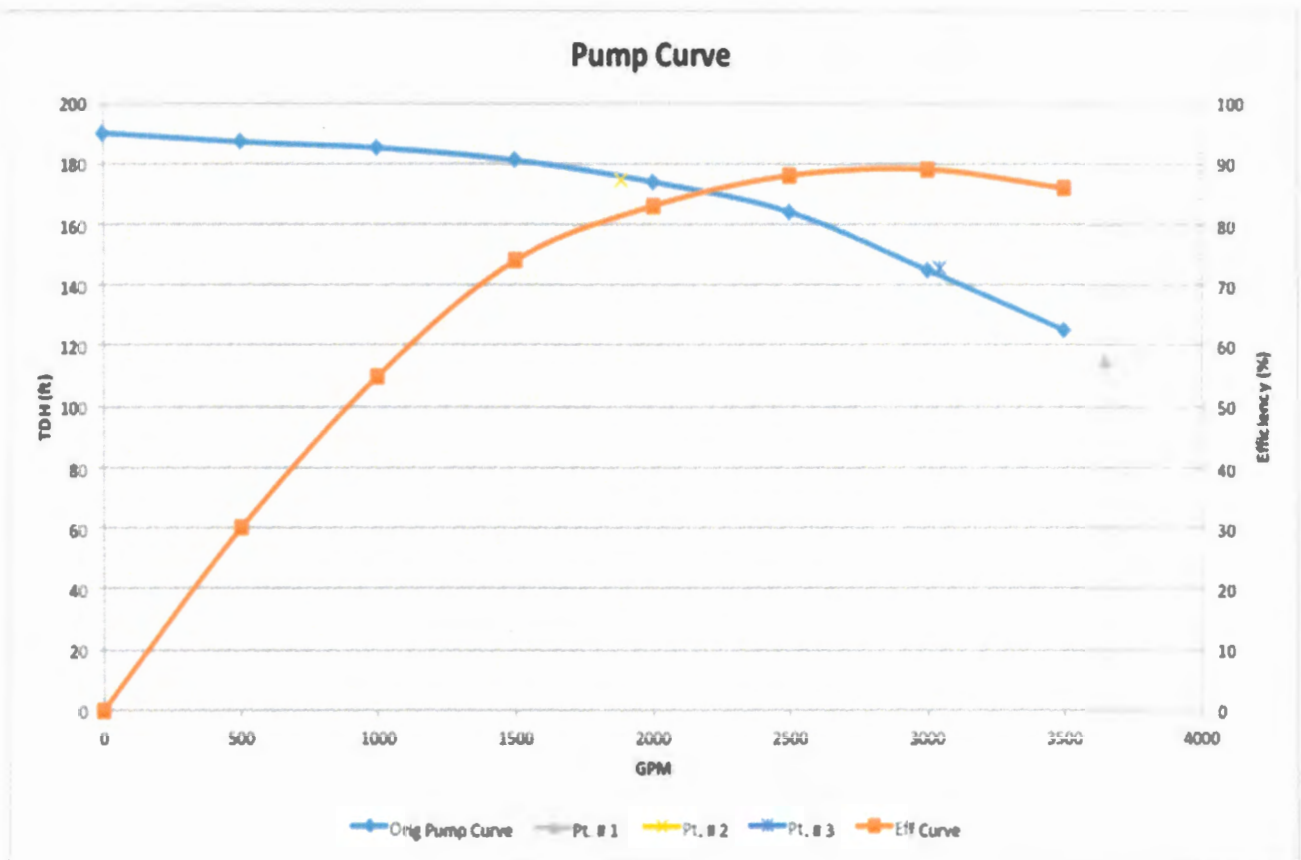


Figure. 3 Example Pump Performance Curve

The blue line represents the pump curve in relation to its operation with TDH Vs. GPM. The Orange line is the impeller efficiency curve for the specific pump impeller. The three other points on the pump curve represent operation points for this pump and checking how efficient it will be. The graph is displayed with the TDH on the left side, GPM on the bottom and the efficiency on the right side.

Direct Current (DC) And Alternating Current (AC)

Electrical power is usually generated from a power plant in remote locations where most people don't see. Electrical energy coming from a power plant starts out from some type of spinning electrical generator, whether it is from a hydroelectric dam, a diesel engine or a gas turbine. In most cases the thing spinning the generator is a steam turbine. No matter what it is that spins the generator, commercial electric generators generate what is called 3-phase AC power. Nikola Tesla discovered AC power after Thomas Edison's push for the widespread use of DC power in the 1880's. The problem with the DC power is that it is inefficient in long distance distribution and much more dangerous to work with. The advantage that alternating current provides for the power grid is the fact that it is relatively easy to change the voltage of the power, using a device called a transformer (Lantero, Allison 2014).

Variable Frequency Drives

Variable frequency drives (VFDs) controls the speed of an ac motor, which provides flexibility to the process since speed can be changed easily for process optimization. "It takes the fixed power supplied to it and converts it into a variable frequency and variable voltage source which then feeds a motor. This allows the drive to control the speed and torque the motor produces"(Siemens 2011).

Common VFD Terms. Variable Frequency Drives (VFD) use power electronics to vary the frequency of input power to the motor, thereby controlling motor speed. Variable Speed Drive (VSD), is a more generic term, which applies to devices that control the speed of either the motor or the equipment driven by the motor (fan, pump, compressor, etc.). This device can be either electronic or mechanical. Adjustable Speed Drive (ASD), again a more generic term applying to both mechanical and electrical means of controlling speed.

Variable Frequency Drive (VFD). This senior project focuses on VFDs because they are most commonly used for irrigation applications. According to VariableFrequencyDrives.com a VFD is, a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Other names for a VFD are, adjustable frequency drive, AC drive, microdrive, and inverter.

Frequency, which is the rate of oscillations of the electrical current transmission measured in hertz, is directly related to the motor's speed RPMs (Siemens, Stephen 2011). In other words, the faster the frequency, the faster the RPMs go. If an application does not require an electric motor to run at full speed, the VFD can be used to ramp down the frequency and voltage to meet the requirements of the electric motor's load. "As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement" (Yin Tang 2014).

According to the U.S. Department of Energy, motor-driven equipment accounts for 64 percent of the electricity consumed by U.S. industry. As businesses come under

increasing pressure to reduce energy use and operating costs, VFDs are emerging as a popular solution (Focusonenergy 2009). Focusonenergy, a Wisconsin energy efficiency and renewable resource program explains in a energy awareness article that, over the last 10 years, FVDs have become an efficient and reliable means of controlling motor speeds. Facilities that install VFDs use less energy, cut operating costs and even improve precision.

Focusonenergy explains why VFDs are such a good investment. VFDs eliminate the need for expensive and energy-wasting throttling mechanisms such as control valves and outlet dampers. In addition to lowering electricity costs, VFDs reduce wear and tear on motors and related components decreasing maintenance costs and prolonging equipment life. A motor without a VFD operates at a constant speed. When full power isn't needed, the motor can cycle on and off frequently in an attempt to match the load. This creates unnecessary wear and reduces equipment life. A major benefit of VFDs is their "soft-start" capability that gradually ramps up a motor's operating speed at startup and greatly reduces the stress on components. On typical startup, a constant-speed motor is subject to high torque and electrical surges that can reach up to 10 times the full current load (Focusonenergy 2009).

VFD Operation. The United States Department Of Agriculture and the Natural Resource Conservation Service developed a technical article discussing the modernization of agricultural pumping with the use of VFDs. They discuss many great aspects in this technical report included in the following about motor efficiencies and pump speed operation. If the purpose of installing a VFD is power savings, several factors need to be considered including motor efficiency and motor loading.

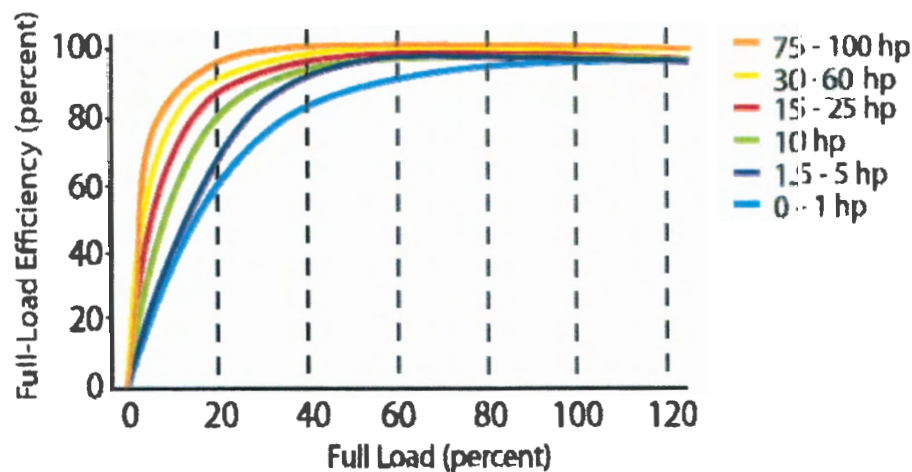


Figure 4 Induction motor efficiency as a function of load
Credit: USDA

To prevent operating the motor in its inefficient range, a good rule of design is to avoid operating a motor at less than 50% of full load. If the motor is operated at less than 50% load, adjustments in motor and system efficiencies may need to be made in system analysis.

In **Figure 4** above depicts the situation where different horsepower motors operate at different percent speeds and the efficiency that comes by this. We can see that between the 60% and 120% of full load range a majority of the motors will be operating efficiently. To obtain the results shown in **Figure 4**, a VFD “converts AC to DC then pulses DC to emulate an AC wave form. This process is not 100% efficient. Heat is generated and this is an energy loss. A suggested efficiency range for VFD’s is 95-98%. The pulsed nature of the current may also cause harmonic losses in the motor for another drop of about 1% efficiency. For design purposes, an appropriate estimate of efficiency for VFD’s is 97%” (USDA 2010).

Understanding the basic principles behind VFD operation requires understanding the three basic sections of the VFD: the **rectifier**, **dc bus**, and **inverter**.

Carrier Corporation explains the technical operations of a VFD system in their “Operation and application of variable frequency drive technology report”. The voltage on an alternating current (ac) power supply rises and falls in the pattern of a sine wave, see **Figure 5**. “When the voltage is positive, current flows in one direction; when the voltage is negative, the current flows in the opposite direction. This type of power system enables large amounts of energy to be efficiently transmitted over great distances” (Carrier 2005).

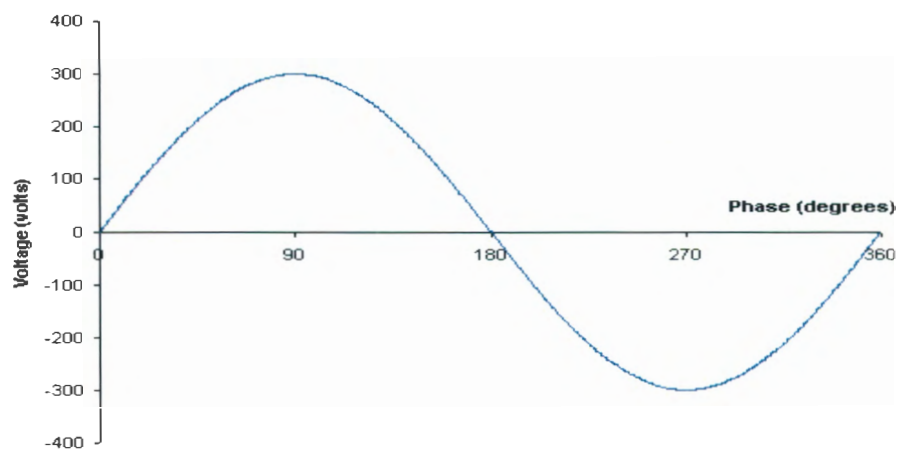


Figure. 5 AC Sine Wave Credit: Carrier Corp 2005

According to Carrier Corporation the **rectifier** in a VFD is used to convert incoming ac power into direct current (dc) power. One rectifier will allow power to pass through only when the voltage is positive. A second rectifier will allow power to pass through only when the voltage is negative. Two rectifiers are required for each phase of power. Since most large power supplies are three phase, there will be a minimum of 6 rectifiers used see **Figure 6** below (Carrier 2005).

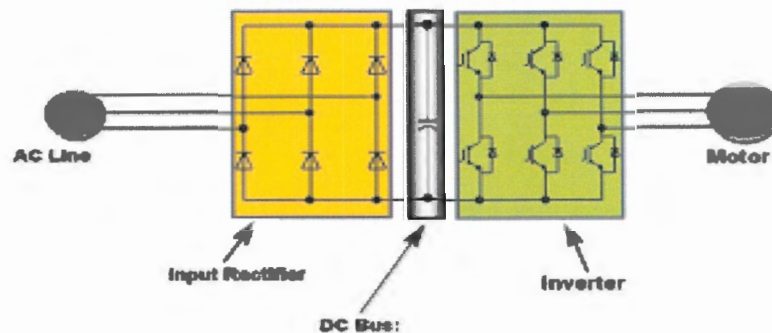


Figure. 6 Internal VFD Setup. Credit: Carrier Corp 2005

Appropriately, the term 6 pulse, is used to describe a drive with 6 rectifiers. A VFD may have multiple rectifier sections, with 6 rectifiers per section, enabling a VFD to be 12 pulse, 18 pulse, or 24 pulse. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power. Diodes are the simplest device and allow power to flow any time voltage is of the proper polarity. Silicon controlled rectifiers include a gate circuit that enables a microprocessor to control when the power may begin to flow, making this type of rectifier useful for solid-state starters as well. Transistors include a gate circuit that enables a microprocessor to open or close at any time, making the transistor the most useful device of the three (Carrier 2005).

After the power flows through the rectifiers it is stored on a **dc bus**. The dc bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The dc bus may also contain inductors, dc links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the dc bus. The final section of the VFD is referred to as an **inverter**. The inverter contains transistors that deliver power to the motor. The Insulated Gate Bipolar Transistor, (IGBT) is a common choice in modern VFDs. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named pulse width modulation (PWM) to simulate a current sine wave at the desired frequency to the motor (Carrier 2005). In **Figure 7** below you can see how the pulse width modulation (PWM) restructures the sine wave to send a strong continual surge of power to the motor.

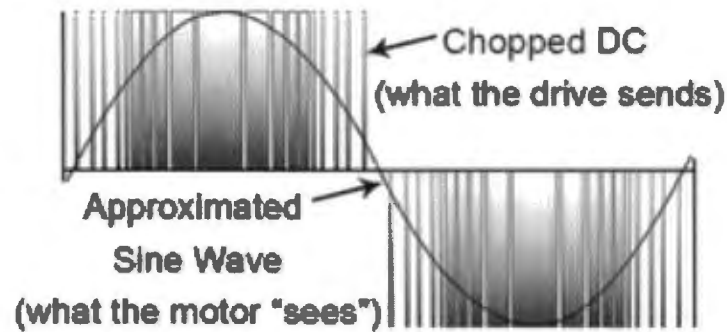


Figure. 7 Post Width Modulation Signal Compared to a sinusoidal.
Photo Credit: Carrier 2005

Motor speed (rpm) is dependent upon frequency. Varying the frequency output of the VFD controls motor speed:

$$\text{Speed (rpm)} = \text{frequency (hertz)} \times (120 / \text{no. of poles}) \quad (6)$$

Example:

2-pole motor at different frequencies

$$60 \text{ hertz} \times 120 / 2 = 3600 \text{ rpm}$$

$$50 \text{ hertz} \times 120 / 2 = 3000 \text{ rpm}$$

$$40 \text{ hertz} \times 120 / 2 = 2400 \text{ rpm}$$

Power Factor. Seeing that we are dealing with power transmission and ultimately efficiencies, power factor is an important topic to discuss. Power factor is a characteristic of alternating circuits (AC) and has to do with how efficient a system receives power from a utility company. The power factor is a dimensionless value between (0.0) and (1.0), the higher the number the greater/better the power factor.

Utilities may impose penalties on customers who do not have good power factors. Watts, or real power, is what a customer pays for. VARS is extra “power” transmitted to compensate for a power factor less than 1.0. The combination of the two is called “apparent” power (VA or Volt-amperes). The bottom line is that a relatively high power factor is good for both the customer (in terms of smaller wire size and power quality) and for the utility (in terms of smaller generation capacity needed, and smaller transmission lines) (Burt 2014).

Efficiencies and benefits of VFD’s. Before VFD’s, people could basically obtain the same outcome of reducing flow by adding a throttling valve (having a valve partially closed downstream of the pump head to reduce flow) to their system. There is one problem with this, the pump would still be running at full speed thus becoming very

inefficient for this application. Adding a VFD in the proper application to your pumps allows you to vary the flow by reducing motor and pump RPMs, reducing the inefficiencies incorporated with the use of a throttling valve.

VFDs deliver the following benefits to the industry (Gozuk, 2014):

1. Overall electricity savings
2. Control of startup and shutdown procedures
3. Reduces motor burn outs
4. Prevents shaft breaks, attributed to rapid starts and stops
5. Reduces water hammer in pipelines due to controlled acceleration/deceleration
6. Reduces voltage draw down on power lines at start up
7. Excludes need for pump control valves in many instances
8. Controls pump to deliver precise flows or continuous pressures
9. Gives the ability to remotely control the pump and obtain pressure variation notifications
10. Added safety feature to shut down pump in emergencies
11. Can lower the power needs in peak charging periods

Reasons to Consider Using VFDs. VFDs may be used in many different types of situations within irrigation applications. The Irrigation Training And Research Center (ITRC) at Cal Poly San Luis Obispo discussed 5 reasons why a VFD system should be considered within a paper entitled “Pump Operation With VFD Controlled Motors” (Burt, 2010). His findings are as follows;

1. Pumps are for the most part oversized and can produce more pressure than needed in most cases.
 - a. Pumps will wear and become more and more inefficient over time
 - b. Pumps are rarely operating exactly on their certified performance, the pump curves are only accurate within plus/minus range.
 - c. Pressure loss within a system design is common but rarely exactly known.
 - d. Source water levels change over time, thus there is no correct lift value; the designer must design for the maximum condition.
2. Flow rate requirements may change with time depending on how any systems the operation is set up to handle. When this happens and the flow needs to be decreased, without a VFD you have to bypass extra or dissipate the extra pressure to develop the desired lower flow rate. In doing this there is obviously more power consumption used making this a very inefficient system within the lower flow conditions. In this case, a VFD-controlled pump can often save energy during periods of low flow.
3. If a pump is filling a reservoir or waterway that needs to maintain a specific water level and require specific flow rates VFDs can provide that capability. If VFDs were not implemented the situation may require the pump to start and stop multiple times per hour thus causing intense wear on the motor.
4. Minimization of water hammer can be attributed to VFD use. The slow start and stop capability helps to minimize hammer when flow begins or ends.
5. Increasing the longevity of well life. Without a VFD a single speed well pump

starts with a very high flow rate because the total dynamic head (TDH) during startup is low. This causes rapid drawdown within the well casing- exceeding the drawdown rate outside the well casing. The difference in pressure weakens old pipes quickly, and incidentally tends to draw out a lot of sand on start up.

The three biggest problems Burt (2010) has noticed with VFD applications are:

1. The proper understanding of VFD cabinet air conditioning is not utilized or is ignored. Good VFD controllers are very efficient- 98% to 99% efficient. But for a 100kw panel, this is equivalent to a 1-2 KW heater operating inside the cabinet. Heat is the death on VFD controller electronics.
2. VFD controllers are sometimes undersized. A rule of thumb is to upsize the controller by one size above the motor rating. A motor may be 90 – 94% efficient, and often motors are over- loaded. It's simple math – with a 5% overload on a 100 HP motor that's 94% efficient, the VFD controller needs to supply $100 \text{ HP} / .94 / .95 = 112 \text{ HP}$. A 100 HP VFD controller can't do it. Although VFD controllers are rated in terms of volts and amps, think "125 HP controller for a 100 HP motor".
3. Using lower quality cheaper VFD controllers can get you in trouble with low efficiency, noise, dirty power quality, and having limited cable lengths from the controller to the motor.

Another common error that was found in the article Burt (2010), is thinking that the affinity laws are easy to use for predicting power savings. "The affinity laws for pumps that relate power, head, and flow are only useful for drawing new pump curves at various RPMs. The curves cannot be used by itself to estimate power savings. To estimate power savings, one must overlay the system curve on the family of pump curves" (Burt 2010).

Burt go's on to explain, "low lift installations that use mixed and axial flow pumps, one must always examine the pump curve all the way to zero GPM. Most pump suppliers will only supply curves that show the upper 50% of the flow range. With a system for which the majority of the pressure requirement is elevation lift rather than friction, there can be problems if the pump curve has a dip. If the pump and system curves do not have one unique point of intersection, the flow rate can suddenly shift and damage the system"(Burt 2010).

Retrofitting VFDs to Existing Motors. When updating a pump with a VFD one must make sure the motor is capable of working with the upgrade. In general if the motor is relatively new and the windings are in good condition it will be ok. VFDs are more demanding on the motor because of the electrical distortion they cause. According the ITRC at Cal Poly San Luis Obispo the quick and simple way to determine if a motor is appropriate for a VFD retrofit is through the process of a Meggar test.

A Meggar test measures the resistance between the motor windings and ground. This resistance is a measure of the condition of the motor winding insulation. If the resistance

is over about 300,000 ohms and the installation was properly performed, then the motor is probably ok for the VFD retrofit. If the resistance is less than 300,000 ohms then the motor should be “dipped and baked” to renew the winding insulation. One cautionary note – if the motor has been idle for a long time – several weeks or more – then the motor should be run long enough to bring it up to operating temperature and kept there for an hour or more before conducting the Meggar test. This is because dust and moisture can collect in the windings during idle periods. Running the motor dries off the moisture and “blows” loose dust from the windings. Moisture and dust in the windings will provide false low values when performing a Meggar test (Burt 2009).

Pump Affinity Laws. Another very important aspect one should look at in retrofitting a pump with a VFD is applying the use of affinity laws to the pump situation to evaluate the retrofitted outcome. The pump affinity laws can be used to predict the performance of a centrifugal pump as two variables change, the pump shaft rotational speed and the pump impeller diameter. They are useful particularly for the modification of existing pumps to meet a new service or to evaluate where a pump could be operating at in the addition of a VFD application. These relationships are approximate and rely on the assumption that the pump efficiency is equal at both speed/diameters. The prediction of performance based on impeller design changes also relies on the assumption that the impellers are geometrically similar. This section covers the equations that relates to holding a constant impeller size with changing shaft rotational speed.

Pump operation at varying speed (with a constant impeller diameter) is defined by the affinity laws as follows (Burt 2014):

For Flow Rate:

$$\frac{Q_1}{Q_2} = \frac{RPM_1}{RPM_2} \quad (7)$$

For Head:

$$\frac{H_1}{H_2} = \left(\frac{RPM_1}{RPM_2} \right)^2 \quad (8)$$

For Power:

$$\frac{P_1}{P_2} = \left(\frac{RPM_1}{RPM_2} \right)^3 \quad (9)$$

** Equation Legend*

Q = Volumetric flow rate

RPM = Rotations Per Minuet

$H = \text{Head or Pressure Developed}$

$P = \text{Power}$

These equations demonstrate that the flow rate changes as the ratio of the RPM, the head changes as the square of the ratio of the RPM, and the power changes as the cube of the ratio of the RPM.

The affinity laws are not applied directly to a particular flow condition to estimate power savings. This is because of the interaction of the irrigation system curve with the pump curve. If the flow rate is reduced by reducing the speed of the motor the operating point changes, but the operating point must be on the system curve. This means the required system head and water horsepower (WHP) change along the system curve as the flow changes, and the affinity laws by themselves, do not give any information about irrigation system curve (Burt 2014).

Using Affinity Laws. The proper way to apply the affinity laws is to use the laws to develop a whole set of pump curves (each at a different RPM) for a given pump (Burt 2014). This is done as follows:

1. From the pump curve that is provided by the manufacture at the maximum RPM, select 10 or so points (flow rate and pressure) along the complete span of the curve.
2. Using the affinity laws, determine the corresponding 10 (flow rate and pressure) points for a different RPM. This provides a second pump curve.
3. Repeat this for several RPMs.

VFD Design Considerations.

The following design considerations have been established by the United States Department of Agriculture (2010) and should be taken into consideration when evaluating VFD upgrades for an agricultural pumping situation.

Sizing. In the design process, it is not unusual for a VFD to be rated for more horsepower than the nameplate horsepower of motor being driven. Because of the service factor, it is not uncommon for a motor to use 15% or more horsepower than its nameplate rating. Also, the rating of the VFD should include the factor of its operating efficiency. For example, a 100 HP (rated) VFD at 97% efficiency will output 97 HP (USDA 2010). However, if the system is adequately analyzed, the rating of the VFD will be no more than the electric motor rated HP. Another reason drives are oversized is to minimize, voltage distortion and interference with other electrical equipment. Care should also be taken to not select a VFD too large as the VFD output might exceed motor specifications and cause motor failure (USDA 2010).

Line Filters. “Because incoming power may have irregularities the VFD should not be connected directly to the line voltage”(USDA 2010). An isolation motor contactor should be used. This will also provide a method of bypassing the VFD in emergency situations. Line filters may be required for VFD's. The line filters regulate the voltage of the different legs of a three-phase supply and control the voltage of all legs to equal the lowest voltage in any one leg. Imbalance in voltage generates more heat and loss of efficiency in the VFD, motor, and line filters (USDA 2010).

Environmental Control. Most agricultural applications can be considered outdoor installations. Dust, rodent damage, and heat are the leading causes of VFD failure. VFD's also generate significant heat that must be dissipated. Cool, clean electrical components last longer and perform better. VFD's are rated for a specific amperage and voltage at a specified temperature. An increase in temperature will see a dramatic drop in VFD efficiency and may require installation of a cooling mechanism. Ambient air temperature must be between 32° F. and 104° F (USDA 2010). Several types of cooling methods exist, such as external heat sinks, fans, and water-cooled air conditioning. Dust is an enemy in VFD panels and it is essential that the VFD controls are monitored regularly and kept dust free and maintain a cool air temperature for a smooth operating environment.

Water Level Sensors

An input is required for the VFD to maintain a target or set point. Typically, water level sensors are used because the grower desires a constant water level in a canal pool. That is the case for this senior project. The water level in the canal downstream of the pump station needs to be monitored in real-time so that the VFD can maintain that level.

The four different types of water level sensors that are generally used today in agriculture settings are ultrasonic sensors, float sensors, submersible pressure sensors, and bubbler sensors. The one thing these four different types of sensors have in common is that they are all trying to obtain an accurate measurement of water depth, or are connected to devices that want to maintain a specific water level margin.

Ultrasonic Sensors. Ultrasonic sensors are used in the irrigation industry and many others to provide accurate readings of a water depth using sound waves. “Ultrasonic sensors rapidly transmit a pulse of high frequency sound (typically 42 kHz), which travel away from the sensor, hit the surface of the liquid and return to the sensor. Within the ultrasonic sensors, electronics measure the time it takes from transmitted sound to return of echo. With reference to the speed of sound in air, the exact distance of the liquid surface from the sensor can be calculated with high accuracy”(Greyline Inst 2014).

The sensor should be positioned so that it has a clear view of the liquid surface and away from ladders, pipes or other obstructions. The recommended settings are “1 foot from sidewall for every 10 feet of depth. Heat and humidity can affect the accuracy of these ultrasonic signals but a majority of these new sensors have secondary sensors and programming to compensate for these variables” (Greyline Inst 2014). Also foam and water turbulence are other factors that can skew data and needs to be taken into

consideration when installing these sensors. To help avoid turbulence and to keep a flat water level, stilling wells may be put in place to help maintain accurate measurements. Another important characteristic of this sensor is that it is completely out of the water. This aids in the fact that this sensor can be used with many different qualities of water without affecting the longevity of the system. Also having this sensor elevated from the water accommodates easy service when attention is required. A diagram of how an Ultrasonic sensor works can be seen in **Figure 8**.

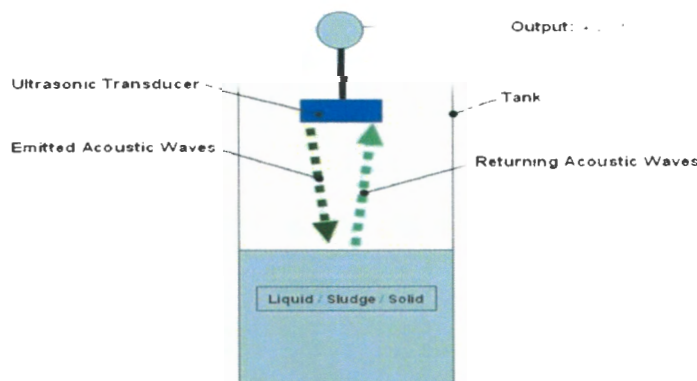


Figure. 8 How An Ultrasonic Sensor Works Credit: Suvo 2010

Some general advantages of using a ultrasonic sensor is that they are, not affected by fluctuating water temperatures, they are easy to calibrate, low maintenance and can withstand freezing temperatures. But unfortunately there are some disadvantages to ultrasonic sensor as well such as, they may reflect off floating foam or debris, they must be aligned precisely, they may be affected by turbulent water (A stilling well may be required). And if the echo is lost it may display a misleading reading.

Float Sensors. The (ITRC 2014) describes the two basic styles of float sensors as follows, one involves a pulley and counterweight (**Figure. 9**) and one that utilizes a spring (**Figure. 10**) to produce an upward force on the float cable. In the pulley and counterweight version, a counterweight provides tension to a beaded cable. Notches in the pulley mesh with cable beads, forcing the pulley to turn as the water level rises or lowers and the float goes up or down. This version of the float sensor is the more difficult to install and calibrate. The pulley has a “travel stop” for both the clockwise and counterclockwise directions.

In the second style, the cable wraps and unwraps around a spring-loaded shaft inside the sensor. Turns of the pulley or spring-loaded shaft change the resistance of a potentiometer within the sensor housing, changing the output electrical voltage or current. Though the electronics are less complex than in an ultrasonic sensor, they still

must be mounted directly over the water (Burt 2014). If the water level fluctuates around a certain level for an extended period of time the potentiometer may wear out quickly. Having a stilling well is essential when using a float sensor to ensure that you have accurate readings. The sensors can be seen in the images below with general advantages and disadvantages described from the ITRC.

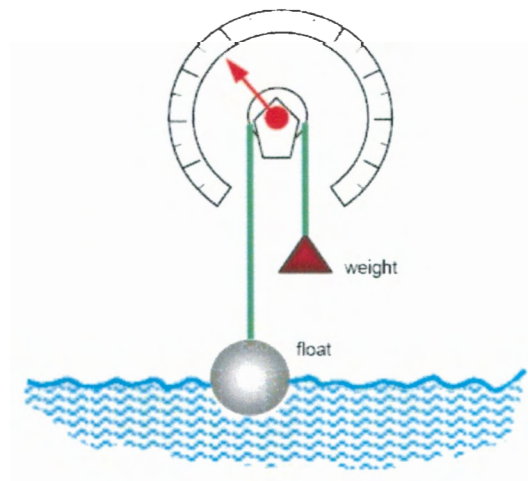


Figure. 9 Pulley and Counterweight Float sensor Credit: Joy, 2012

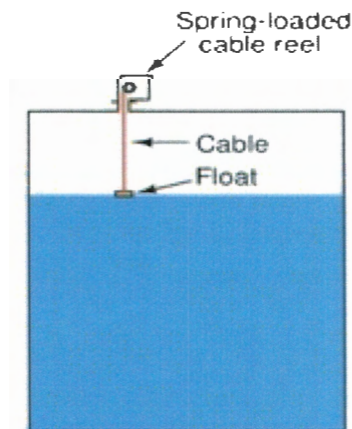


Figure. 10 Spring Operated Float sensor Credit: Tony 2012

Some general advantages of these float sensors are that they are not affected by dirty water, not affected by water temperature, not affected by foam, they have a low affect of changing air temperatures, they have relatively low maintenance, and are inexpensive. Some disadvantages is that they require a stilling well, the cable may slip (Pulley and

counterweight type only), they may wear if water level remains at one position for extended periods, and salt build-up may freeze the pulley and cause problems.

Submersible Pressure Sensors. Submersible pressure sensors perform liquid measurements by having the sensor submerged at a fixed level under the water surface. “The pressure sensor measures the equivalent hydrostatic pressure of the water above the sensor diaphragm, using this to calculate for total liquid depth water pressure. At any point in time at any level liquid and gasses exert an equal pressure in all directions. Water level increases linearly with depth of submergence. For every 2.31 feet of water the pressure increases by 1 Pounds per Square Inch (PSI) (Burt 2010). These sensors require a stilling well to minimize turbulence factors. **Figure. 11** below depict some styles of submersible pressure sensors.



Figure. 11 Submersible Pressure Sensor Credit: Sensortechinics 2013

Some general advantages are, easy installation, electronics are hidden from view, they have a low power requirement, they are not usually affected by air temperature fluctuations, they are not affected by foam and have almost no time lag. Some disadvantages in relation to the submersible pressure sensors are they can get damaged by ice, they can clog in dirty water, they are susceptible to malfunction if often allowed to dry, may hang up debris they are adversely affected by water temperature fluctuations, the range is not adjustable, stilling wells are often required and they sensor can be damaged if submerged too deep.

Bubbler Sensors. A Bubbler sensor system is relatively simple to operate, it consists of a constant low flow of clean air passing through a tube by a filter-regulator. Lesman

products describe their bubbler sensor as follows “A pressure transducer or transmitter monitors the tube’s backpressure, which is representative of the level head pressure. Any change in the liquid’s level corresponds to an equivalent change in the backpressure inside the tube. Digital pressure transmitters can also serve to provide local level indication” (Lesman Air Bubbler 2014). The following figure indicates how a bubbler sensor works.

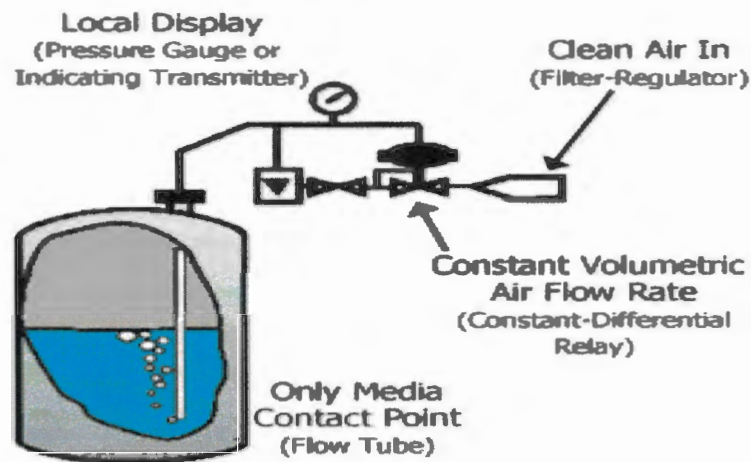


Figure. 12 Bubbler Sensor Credit: Lesmen 2012

Some general advantages of using a bubbler sensor is that they are easy to install and calibrate, only inexpensive bubbler tubing contacts the water, not significantly affected by air or water temperature fluctuations, they are not affected by foam and they are not easily clogged by dirty water. Some general disadvantages of using a bubbler sensor is that it may hang up debris, they require either a large nitrogen tank, which must be periodically refilled or a power-hungry air compressor also these sensors have a relatively high list price.

PROCEDURES AND METHODS

Preliminary Evaluation Procedure

The first steps that need to be taken for this project are the analysis to the current pumping station with the review of Teixeira and Sons current operating cost of for this station. Documentation of what pumps are present, analyze the electrical setup that powers the station, review of their most recent pump testing documents, and analyze their pumping operations procedures and pump controls.

Current Pumping Station Analysis. The pumping station that is being evaluated is located in Los Banos California off Highway 165. This pumping station contains two water lubricated parallel oriented slant pumps pumping out of the Delta Mendota canal (**Figures 13 and 14**). These pump lead into one common pipeline that empties into the first canal in a series of three that feeds Teixeira's water delivery systems to irrigate their farmland. This pump station is responsible for providing water to 1,750 acres of Teixeira and Sons 5000+ acre ranch consisting of row crops and Almond orchards.

The age of these two pumps are not exactly known but are estimated to be over 20 years old. "Pump A" is a 40 horsepower lift pump operating at 4,000 Gallons per minuet (GPM) and "Pump B" is a 75 HP lift pump operating at 7960 GPM. These two pumps are somewhat automated, they are set up with a remote signal system relaying to a upstream float switch telling the pumps when to kick on and off based on the water level needed. The purpose for the two different size pumps at this pumping station is to deliver the optimum quantity of water needed to irrigate the ever-changing demand for the crops throughout the year.

The minimum demand needed at any one time is about 2000 GPM and the maximum is as much as both pumps can supply which is about 12,000 GPM. These pumps are not equipped with VFD or soft starts so when they are on they are running at maximum flow. If the water level drops, Pump B will turn on first. If the water level is not rising in the canal pool fast enough Pump A, will turn on to increase the flow.



Figure. 13 Teixeira and Sons Lift Station # 1



Figure. 14 Lift Station # 1 Pumps

Current Power Supply & Automation. The pumping station receives power for both pumps from PG&E fed through a 50 kVa (kilovolt-amps) or 67 HP transformer (1 HP = .746 kVa) as shown in **Figure 15**. Seeing that there is a 75 HP pump and a 40 HP pump it can be determined that this transformer is maxed out passed its capacity thus may be restricting the ability of this pumping station. Adding a VFD could help in reducing strain on the transformer.



Figure. 15 Lift Station Transformer

These pumps are automated with upstream control float switches regulating the on and off cycles for these pumps (see **Figure 16 and 17**). This is an easy system to rely on so a worker doesn't have to be standing at the canal all day and monitoring the water level and continually start and stop the pumps by hand.

This system has some drawbacks as well, when it is desired to maintain a tight water level this may require the pumps to be turning on and off multiple times per hour. This is very inefficient due to the fact that every time these pumps start up they draw a large energy load to ramp up the pumps to their operating point, thus building up more of an expense with the energy companies. Also having a pump turn on and off more than five to six times per hour could result in overheating and faster wear of the motor windings requiring unnecessary rehabilitation and wasted time and money (Burt 2014).



Wireless Communication Receiver

Figure. 16 Electrical Panels and Wireless Receivers



Figure. 17 Float Control Switches and Wireless Transmitters

Pump Test Analysis. Both pumps and motors have been refurbished within the last 10 years. The most recent pump test was performed in February 2013. The results of each individual pump test are explained in the following Tables:

Pump Test Results For Pump A (40 HP). Anderson Pump Company conducted this pump test on February 18th 2013.

Table 3 Pump A (40 HP) Pump Test Results

<u>Pump A (40 HP)</u>	
Test Date: 2/18/2013	
Pump Test Categories :	Measured Pump Condition
<u>1. Overall Pumping Efficiency</u>	<u>59%</u>
2. Nameplate Horsepower	40 Hp
3. Motor Efficiency	90%
4. Actual Motor Input Horsepower	36 HP
5. Motor Loaded At	81%
6. Flow Rate (Gpm)	4,100 Gpm
7. Inlet Water Level (Ft)	4 Ft
8. Discharge Pressure (Psi)	5 Psi
9. Total Dynamic Head (Ft)	21 Ft
10. Acre-Feet Pumped/Year	1,200 af/yr
11. Average Cost Per kWh	\$ 0.15/ kWh
12. Estimated Total kWh Per Year	26,869 kWh/yr
13. Hours Of Operation Per Year	1000 hr/yr
14. Kilowatt-hours Per Acre Foot	36 kWh/af
15. Average Cost Per Acre-Foot	\$5.34 /af
16. Estimated Total Power Cost Per Year	\$4,030.35

As shown in **Table 3**, the overall pumping plant efficiency for Pump A is 59%, which is not bad but could be a little better considering it was refurbished within the last few years. This pump is only putting out 4,100 GPM with an input of 36 HP from the motor. Also after looking through all the info it is apparent that just to operate this pump for 1 year it will cost about \$ 4,000 in energy. These prices are estimates, the actual energy cost is relatively higher then this. This is a slightly large number probably due to the fact of frequent start-ups per hour or day.

Pump Test Results For Pump B (75 HP). Anderson Pump Company conducted this pump test on February 18th 2013.

Table 4 Pump B (75 HP) Pump Test Results

<u>Pump B (75 HP)</u>	
Test Date: 2/18/2013	
Pump Test Categories :	Measured Pump Condition
<u>1. Overall Pumping Efficiency</u>	<u>68%</u>
2. Nameplate Horsepower	75 Hp
3. Motor Efficiency	91%
4. Actual Motor Input Horsepower	61.1 HP
5. Motor Loaded At	74%
6. Flow Rate (Gpm)	7,960 Gpm
7. Inlet Water Level (Ft)	4 Ft
8. Discharge Pressure (Psi)	5 Psi
9. Total Dynamic Head (Ft)	21 Ft
10. Acre-Feet Pumped/Year	2,200 af/yr
11. Average Cost Per kWh	\$ 0.15/ kWh
12. Estimated Total kWh Per Year	45,607 kWh/yr
13. Hours Of Operation Per Year	1000 hr/yr
14. Kilowatt-hours Per Acre Foot	31 kWh/af
15. Average Cost Per Acre-Foot	\$4.67 /af
16. Estimated Total Power Cost Per Year	\$6,841.05

When reviewing Pump B from **Table 4**, the overall pumping efficiency is 68%, this is considered good for this size pump in reference to **Table 2** of this report. It also has a higher motor efficiency then Pump A and cost less to pump and an acre-foot of water. The overall energy cost to operate this pump for the year comes in around \$6,842. These prices are estimates, the actual energy cost is relatively higher then this due to the fact that these numbers are based off of the testing representation at that specific time and 1000 hours of operation per year, which could be more or less depending on the demand.

Pump Curves. Seeing that there are two different size pumps operating in parallel there will be many different operating points for these pumps that will be seen on the pump curves. There is a need to analyze the system curve as well as with the incorporation of the affinity laws to develop new pump curves to see where these pumps will be operating at in the case of a VFD retrofit. The information below is in regards to the actual pumps at the pump station and was provided by Anderson Pump Company who recently performed some maintenance on these pumps and had the pump information handy.

The key details for Pump A (40 HP) are as follows:

- Name: Peerless
- Size: 16 HH
- RPM: 1170
- Flow: 4,100 GPM
- TDH: 21 Feet

Pump Curve:

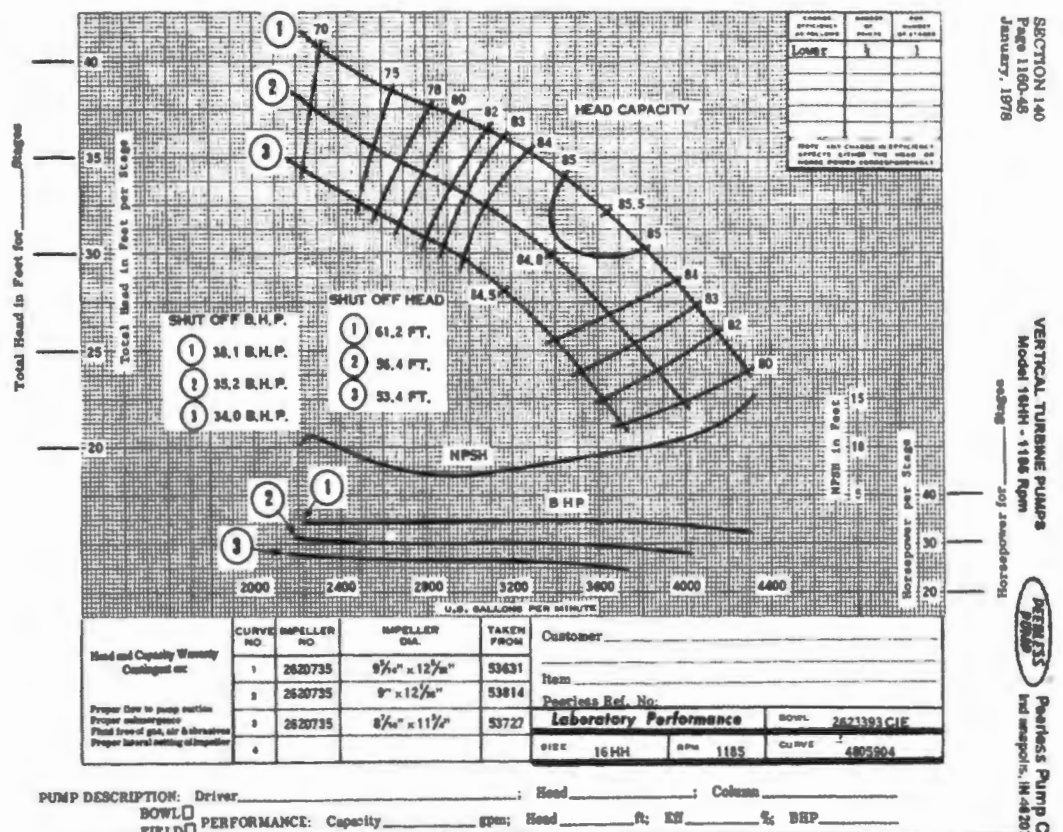


Figure. 18 Peerless 40 HP Pump Curve Credit: Peerless Pumps

The key details for Pump B (75 HP) are as follows:

- Name: Peerless
- Size: 18 MF
- RPM: 1190
- Flow: 7,960 GPM
- TDH: 21 Feet

Pump Curve:

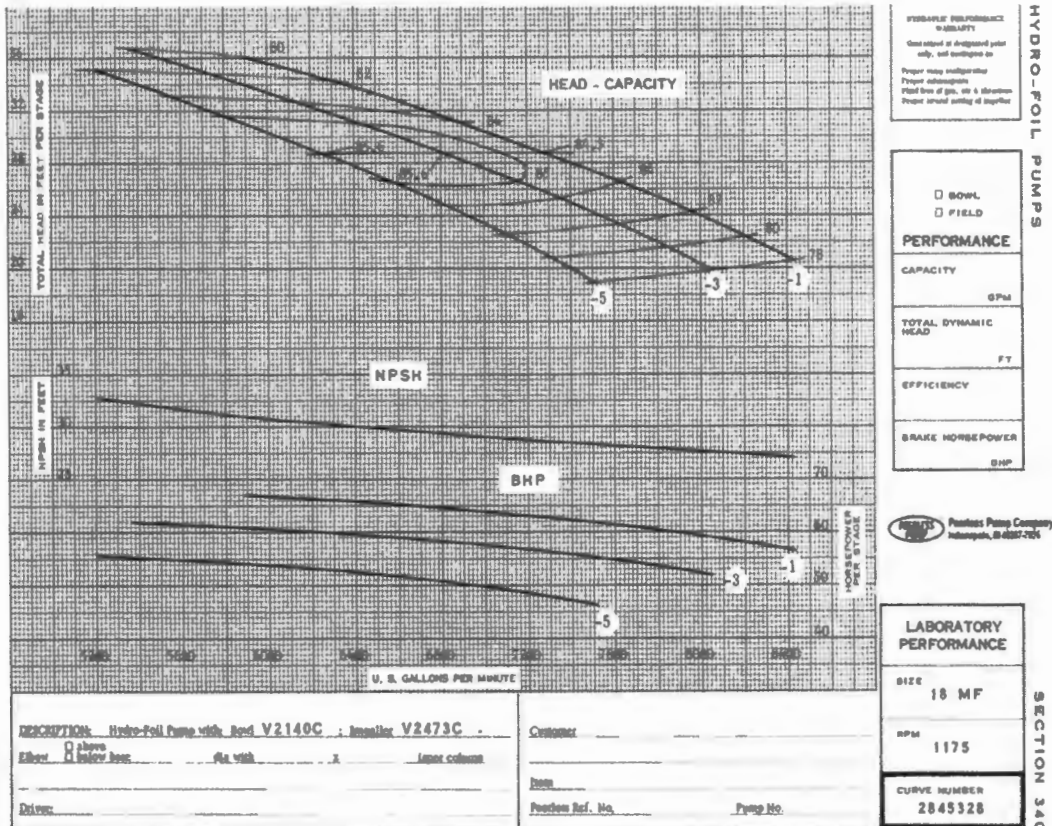


Figure. 19 Peerless 75 HP Pump Curve Credit: Peerless Pumps

Using this information, the operating points on the curve need to be evaluated and incorporated with the use of the affinity laws to develop the new operation curves for VFD integration. One of the main issues that came about is that in order to accurately portray the new pump curves at different operating speeds there is a need for a fully expanded pump curve from zero GPM to max GPM, looking back at the pump curves we were provided with it is evident these curves are not fully expanded thus making it hard to accurately analyze the pumping situation.

VFD Integrated Pump Curves. The images below depict the affinity laws incorporated pump curve with the system curve that was generated with the limited information taken from the actual peerless pump curves in **Figure 18** and **19**. The curves represent the flows (GPM) and TDH (Ft) at varying RPMs.

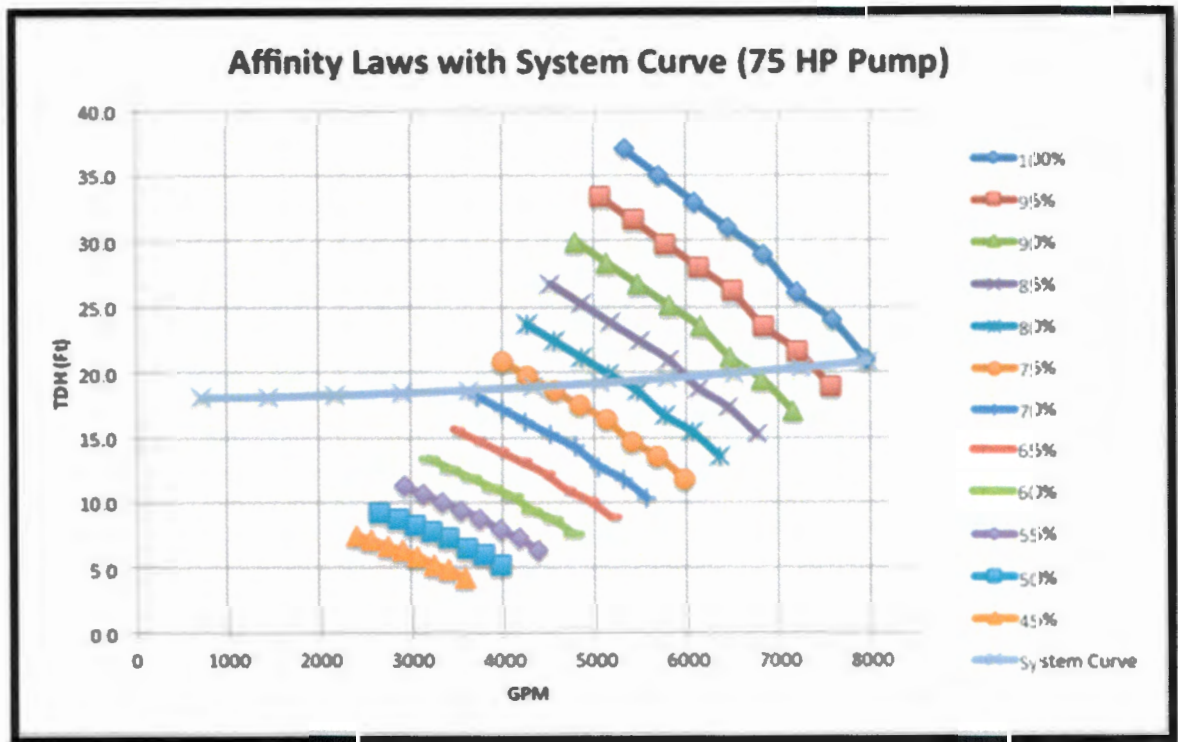


Figure. 20 75 HP Affinity Law Pump Curve

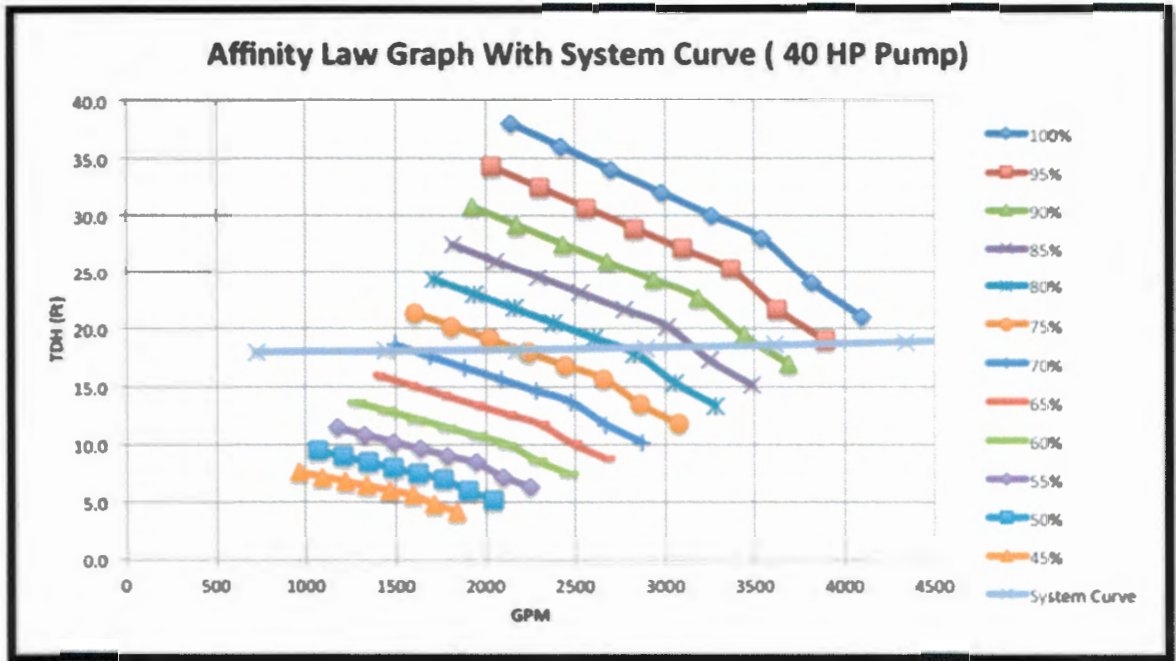


Figure. 21 40 HP Affinity Law Pump Curve

As shown above, there are gaps on the left side of both newly generated pump curves, this is due to the unexpanded pump curves provided by Anderson Pump.

To make estimates of what the curve might look like on the lower end, an online pump software was used called ePrism, This is a Goulds pump software program that only uses Gould pumps to formulate the pump curves not the Peerless pumps that are currently in place at the pump station. However, this software gives the potential shape of the curve at lower flows, which is better than assuming it is linear. Finding a pump that most accurately matches the current system was not very difficult and it is believed to be about right. Using the ePrism software, the following Affinity Law chart was created (**Figure 22**).

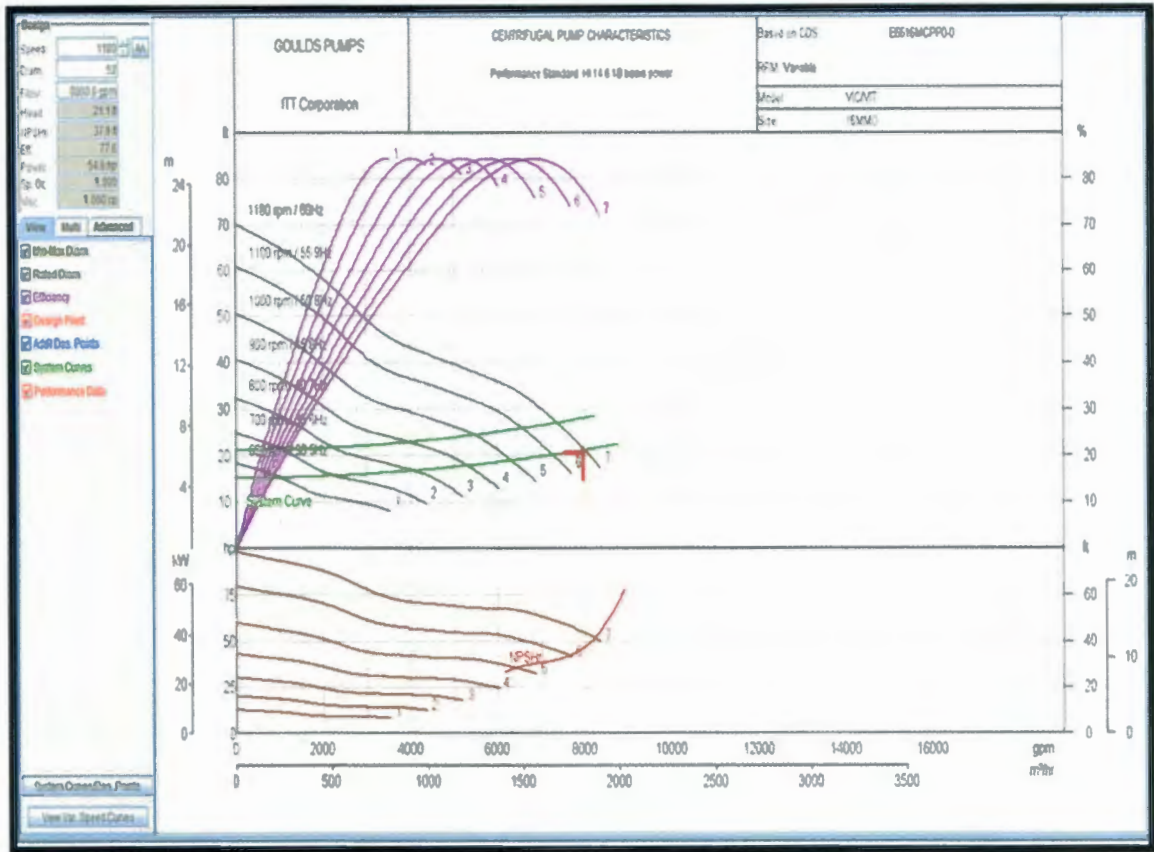


Figure. 22 Goulds ePrism Pump Curve

Figure 22 portrays a Goulds pump that was selected to match the current 75HP peerless pump at the pump station. There were seven different RPMs chosen to develop these pump curves from 1,180 RPM to 600 RPM. Specifically looking at the top part of the graph, the figure displays two system curves (Green) the first lower curve is the system curve for the 75 HP pump and the upper curve represents the max operation points for the 75 HP pump and 40 HP pump operating together. The points between these two curves are the operation ranges for any mix and match flows and TDH that these pumps could possibly generate. The purple arched lines are the operating efficiency where these pumps could be running at. The Red "L" shaped marker represents where the single 75 HP pump was chosen to operate at 100%.

Cost Analysis for VFD Upgrade

This section covers the cost breakdown of this pumping station, which includes labor costs and energy costs. This section will also breakdown the total retrofit quote obtained for IDC and review the return on investment and potential annual savings for considering the full retrofit.

Pump Station Energy Costs. Teixeira and Sons were able to provide the energy usage and cost sheets for the 2013 and current 2014 year. This information is helpful to analyze the current energy usage and total power cost to operate this one pumping station. The data that was provided can be seen below in **Table 5**.

Table 5 Lift Station #1 Power Use and Energy Costs

Lift Station #1. 2013-2014 Monthly Power Used & Energy Cost				
	2013 kWh	2013 Energy Cost	2014 kWh	2014 Energy Cost
January	-	\$45.54	-	\$45.54
February	-	\$41.40	-	\$44.16
March	-	\$44.16	-	\$721.52
April	28,783.00	\$2,546.42	9,506.00	\$1,184.60
May	20,397.00	\$1,947.35	14,090.00	\$2,248.23
June	32,823.00	\$3,586.76	-	\$23.46
July	35,408.00	\$5,025.06	12,193.00	\$4,552.74
August	-	\$-	12,922.00	\$3,140.31
September	30,133.00	\$4,494.86	25,114.00	\$3,140.31
October	10,736.00	\$2,500.55	30,130.00	\$2,045.41
November	1,464.00	\$1,872.51	NA	NA
December	18,298.00	\$45.54	NA	NA
Totals =	178,042.00	\$ 22,150.15	103,955.00	\$ 17,146.28

Table 5 shows that between the last two years, with the acceptance of the remaining months in 2014, the average kWh used was well over 100,000 for the pumping station, which is including both pumps. The annual energy cost to operate this lift station is above \$20,000. This is a significant amount of money to be spending on pumping costs alone, this doesn't include labor to operate and monitor this station or even maintenance factors.

Total Annual Operating Costs. The operating costs are not limited to just the energy cost for this lift station. This station is only partially automated, there is still a great need

for human interaction to monitor and maintain the water transportation system including this lift station. Teixeira and Sons has explained that it will take one employee at the wage rate of \$12.00 per hour, two hours per day, 60 hours a month for nine months for the irrigation season totaling 540 hours to monitor and maintain this water transportation system which includes the lift station #1. The total labor cost for one individual to maintain this system for the nine months of operation is around \$6,480.00 and with a 28% payroll burden for that labor, the total cost comes out to be \$8,294.00. **Figure 23** portrays the operating costs for this lift station between the energy costs and labor to manage it. The energy is a major expense for this lift station but the labor is nearly 30% of the total cost. The labor could ne greatly reduced with the use of a VFD.

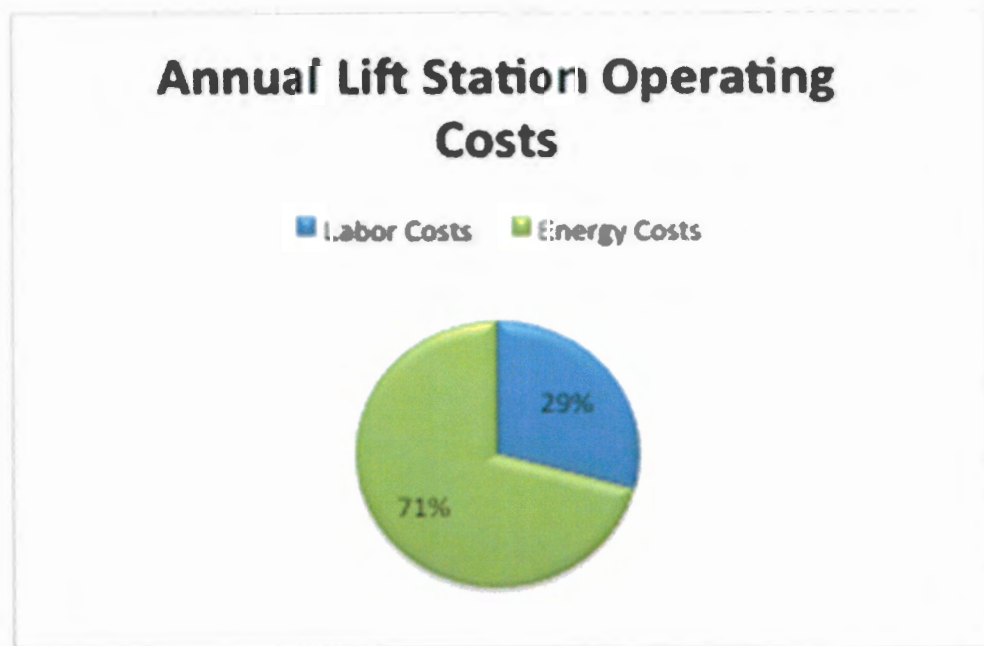


Figure. 23 Annual Lift Station Operating Costs

VFD Quote. Irrigation Design and Construction (IDC), a local irrigation supply and installation company located in Dos Palos CA, was contacted to develop a cost estimate for the entire retrofit of this project. After the revision of the current pumping station they developed a cost estimate for each VFD upgrade of the two lift pumps including labor, wire and fittings and miscellaneous extras. IDC is quoting the full retrofit to cost around, \$17,000. These prices include \$5,300 for a 40 HP Dar. Foss or Fiji VFD, \$6,100 for a 75 HP Dan Foss or Fiji VFD, conduit, wire, fittings to complete the retrofit comes in at \$1,554 and the total labor on the project was estimated to cost \$4,000. At the current time this is the only company that has been contacted to develop a cost estimate for this project. **Figure 24** compares the monetary weights of the components for the upgrade.

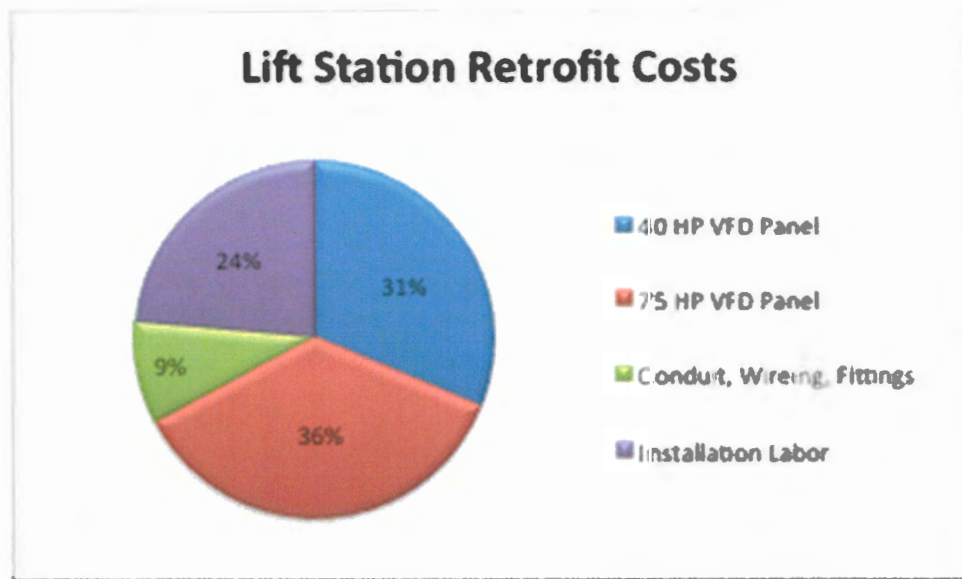


Figure. 24 Lift Station Retrofit Cost Chart

VFD Upgrade Economics. Referring back to **Figure 23**, displaying the annual lift station operating costs, we can see that on average the annual cost to operate that station is around \$20,000 in energy costs and \$8,294 in labor costs, totaling around \$ 28,294 per year. The next step is to obtain the total savings that a VFD will save.

According to an article released at the Irrigation Association Technical conference in Anaheim CA developed by the ITRC, it is impossible to say without knowing the details of the specifics on the pumping station and irrigation system. There is an inherent extra 6% or so power requirement for VFD controllers (inefficiency plus air conditioning), so the savings have to be greater than 6% to break even. But "experience" seems to indicate that 10-15% overall savings are commonplace (Burt 2008). **Table 6** demonstrates the return on investment and the savings that will benefit from the VFD retrofit.

Table 6 Lift Station Retrofit Cost Analysis

Lift Station Upgrade Cost Analysis		
First Year	Cost	Savings
Retrofit	-\$17,000.00	
Energy		\$3,000.00
Labor		\$8,294.00
Totals	\$17,000.00	\$11,294.00
Total Net Savings End of Year 1	-\$5,706.00	
Second Year		
Forward Net Savings From Year 1	-\$5,706.00	
Retrofit	\$0.00	
Energy		\$3,000.00
Labor		\$8,294.00
Totals	-\$5,706.00	\$11,294.00
Total Net Savings End of Year 2		\$5,588.00
Third Year		
Forward Net Savings From Year 2		\$5,588.00
Retrofit	\$0.00	
Energy		\$3,000.00
Labor		\$8,294.00
Totals	\$0.00	\$16,882.00
Total Net Savings End Of Year 3		\$16,882.00

As we can see from **Table 6** above, the retrofit will be costly in the first year leading into negative savings towards the beginning of the second year. The important concept to grasp is that by the end of the second year the total retrofit costs will be paid off in full and the money savings will begin. The second years total net savings ends with a savings of \$5,588.00 and only increases in the years to follow. This calculation is an estimate due to the fact that every year water requirements may slightly change, causing a change in the operation time, as well as the energy costs for pumping may change and the efficiencies of the pumps could increase or decrease.

Figure 25 below shows a more visual representation of the lift station operating costs after the VFD integration. After the lift station upgrade with the VFDs there is a potential for an annual 40% savings in operating costs which includes 29% savings in labor and 11% savings in energy.

Annual Lift Station Operating Costs, Post VFD integration

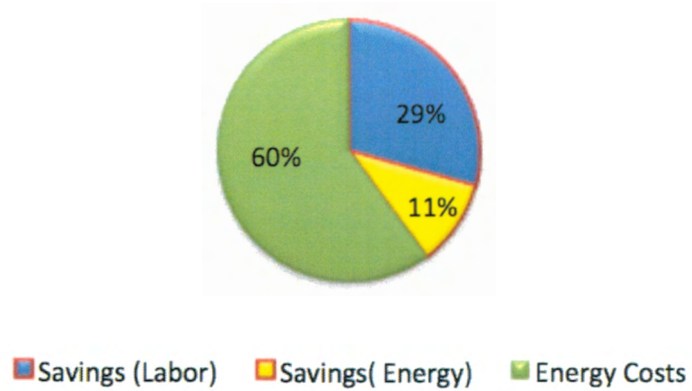


Figure. 25 Lift Station Operating Cost Post VFD Integration

RESULTS AND DISCUSSION

After thorough evaluation of Teixeira and Sons water transportation system specifically focused on the efficiency and capability of their first lift station, some important decisions were made about the next steps in improving the efficiency of their overall system. As the scope for this project, Teixeira and Sons have chosen to update both pumps in their first lift station with Variable Frequency Drives in a prodigious step to supersede their determination in maximizing productivity and efficiency. This section will go over the findings of the system analysis and discuss the results of the VFD retrofit and cost analysis.

Pump Curves

Some complications came about in developing the new pump curves for the VFD integration. To avert this issue Goulds ePrism pump selection software was utilized to develop a pump curve representing where the two pumps would operate with VFD upgrades. Referring back to **Figure 22**, notice that the efficiency curves correlating with the seven different operation speeds. These can be viewed in comparison with the system curves to determine the most efficient operating points for the individual 75 HP pump or both pumps operating together.

When looking back at **Figure 22**, the efficiency for the 75 HP pump operating at 100% will be is around 75% efficient. When we have both operating at full capacity the efficiency gets a little better but not by much. The VFD setup will be to turn on the 75 HP pump first and once the system exceeds the demand of that pump the 40 HP pump will turn on and ramp up to aid in higher flow. In analyzing the ePrism generated pump curves, the 75 HP pump must be operating at or above 4000 GPM or the pump will risk of operating out of its effective range. If the system requires a lower flow the 75 HP pump will ramp down while the 40 HP pump delivers the lower flow requirement.

When analyzing these curves we want to make sure that we are staying within their optimum range. The seven different pump curves generated have a slight dip in them from left to right. In order to obtain the optimum efficiency it is essential to make sure the operations points are on the right side of this dip along the pump curve.

Efficiency Review

When referring back to the evaluated power usage before any VFD retrofitting has taken place, Teixeira and Sons is spending over \$20,000 a year on power costs just on this first lift station alone this is a large number to move water 1,500 feet through a pipe into an open canal and up to the next lift station.

The three lift stations and canal waterways together span about 2.4 linear miles and with a total elevation change of around 75 feet. The third lift station was recently retrofitted with VFDs, which helped make the system more efficient, but the first and second lift stations are not updated. With the first two lift stations under similar conditions and

incorporating the increased efficiency of the third pumping station, it would cost a total of \$60,000 in energy costs alone to transport their water for a nine-month period. This is a cost that should be lower and with this first step of retrofitting the first lift station, the second lift station will not be far behind.

Another inefficient aspect of the first lift station is the float sensor automation that is currently in place. The float sensors, as depicted in **Figure 17** have a tendency to get stuck thus causing the pumps to run and if not attentively monitored could overtop the canal and flood the adjacent highway. In order to counteract the problem Teixeira and Sons has chosen to do away with the float sensors and install pressure sensors within the pipeline to aid in the automation of their pumps. Doing away with the float sensors and adding pressure sensor automation is a safer way for these pumps to operate due to the fact that there is no moving parts to get stuck, less chance of malfunction and the pressure sensors are more suitable and can be protected within the discharge pipeline.

Cost Analysis Review

After the system was evaluated and the cost analysis was developed for the incorporation of the VFDs Teixeira and Sons was very pleased and eager to proceed with the VFD retrofit. The first year the company will be in the red due to the sizeable investment for the VFDs and the installation. But what was very appealing to Teixeira and Sons was the fact that by the end of the second year they will have already paid off the VFD investments and will begin their savings adding to \$5,588 in savings at the end of the second year and \$16,882 at the end of the third year.

The overall savings accumulate from the yearly savings in energy costs and labor cost that were a large burden before. Note that the calculation for the savings from the energy costs for the VFD upgrade used a conservative 15% savings value, which in actuality could be much greater. Also looking back at **Figure 25** (lift station operating cost, post VFD integration) with the VFD update, Teixeira and Sons will be saving approximately 40% on the operation cost of the first lift station for each year after it has been paid off. This is very appealing and when the whole three lift stations within the water transportation system are updated it will be that much more savings in operation costs. By doing this Teixeira and Sons are not only saving energy on this project, but by alleviating the demand for an employee to supervise this water system they can put that employee to work in a more productive area to produce more of a return for the company becoming more efficient and profitable, not saying that this pumping station will never need service but it will be very minimal compared to labor requirement it had before.

Update With VFDs

The reason that Teixeira and Sons only considered the update with VFD integration compared to soft starts is because with the VFDs the soft start component is already built in not to mention the VFDs can operate at different rates minimizing the potential of rapidly overflowing the canal. Seeing that the system demands in farming change frequently depending on the time of year or what is in season they need more flexibility on their water delivery and with the VFDs, they would benefit when they need to reduce or increase the pumping demands. And thus, for a little more money initially they will be glad to have that flexibility and the higher energy savings that comes with it.

RECOMMENDATIONS

The first recommendation would be to perform an updated pump test so the data is recent with no discrepancies. If the data is older then three to five years you accuracy may be a little off. It would be advisable to perform more invasive testing such as performing a Meggar test on the pump motor to see if it is compatible for retrofit.

This project contained more of a visual inspection to conclude if the motor was suitable for the retrofit. Another recommendation that would be highly advised is to get two or three quotes on the price of the VFDs and installation. While the evaluation of this individual pump station was beneficial for its increase in efficiency it would be recommended to evaluate every pump station in the system at the same time so you can prioritize and plan out the investment plan for the update of the whole system.

Another important discovery that was brought to light later in this project and should be utilized is the benefit of the PG&E rebate programs. PG&E strives to promote their customers to become as efficient as possible and relieve the stress on the power grid. One major way in doing this is updating pumps with variable frequency drives to reduce high startup loads for non VFD integrated pumps. The information found on PG&Es website explains that there is a \$40.00 per horsepower rebate when updating with VFDs. The **Figure 26** below displays the rebate codes and criteria.

Rebate Code	Description	Rebate/ Unit Measure
IR006	Well Pumps—Variable Frequency Drive (<300hp)	\$40/hp
IR007	Booster Pumps—Variable Frequency Drive (<150hp)	\$40/hp

Figure. 26 PG&E Rebate Information Credit: PG&E

When reviewing the pumping situation there is a total of 115 horsepower available for VFD update. Using the chart above that would be a savings of \$4,600. This rebate would basically pay for the total cost of installation and then some decreasing our initial investment from \$17,000 to \$12,400 and thus decreasing the time to pay off the investment in full and time to start saving money to just over one year as described in the **Table 7** below. A full description of the PG&E rebate can be found in appendix B of this report.

Table. 7 Lift Station Cost Analysis With PG&E Rebate

Lift Station Upgrade Cost Analysis With PG&E Rebate		
First Year	Cost	Savings
Retrofit	-\$17,000.00	
Energy		\$3,000.00
Labor		\$8,294.00
PG&E Rebate		\$4,600.00
Totals	-\$17,000.00	\$15,894.00
Total Net Savings End of Year 1	-\$1,106.00	
Second Year		
Forward Net Savings From Year 1	-\$1,106.00	
Retrofit	\$0.00	
Energy		\$3,000.00
Labor		\$8,294.00
Totals	-\$1,106.00	\$11,294.00
Total Net Savings End of Year 2		\$10,188.00
Third Year		
Forward Net Savings From Year 2		\$10,188.00
Retrofit	\$0.00	
Energy		\$3,000.00
Labor		\$8,294.00
Totals	\$0.00	\$21,482.00
Total Net Savings End Of Year 3		\$21,482.00

REFERENCES

1. "AC Waveforms." *All About Circuits Forum RSS*. N.p., n.d. Web. Sept. 2014.
2. Agriculture, United States Department Of. Natural Resources Conservation Service. Engineering Technical Note No. Mt-14, and January 2010. *Variable Speed Drive (VSD) for Irrigation Pumping* (n.d.): n. pag. Web.
3. Air Bubbler Systems for Liquid Level Measurement. *Lesman Air Bubbler Level Measurement Systems for Liquids in Sumps, Reservoirs, Vented Tanks, and Air Washers*. Web. 20 May 2014.
4. Lantero, Allison. "The War of the Currents: AC vs. DC Power." *Energy.gov*. N.p., 18 Nov. 2014. Web.
5. Battery and DC Supply Powered Ultrasonic Level Sensors. *BrightHub Engineering*. N.p., n.d. Web. 23 Oct. 2014.
6. *Benefits of VFD Drives in Irrigation Pumping*. Shenzhen Gozuk, 2014. Web.
7. Burt, Dr. Charles M., and Herve L. Plusquellec. *Water Delivery Control*. San Luis Obispo: Irrigation Training and Research Center, 1989. Print.
8. Burt, Charles M., Dr. *PUMP OPERATION WITH VFD CONTROLLED MOTORS*. Tech. no. 10-007. San Luis Obispo: Cal Poly Irrigation Training and Research Center, 2010. Print.
9. Burt, Charles M., Dr. *Pumps*. Spring ed. Vol. 2014. San Luis Obispo: ITRC, 2014. 28-30. Print.
10. Burt, Charles M., Dr. *Pumps*. Spring ed. Vol. 2014. San Luis Obispo: ITRC, 2014. G-1. Print.
11. Burt, Charles M., Dr. *Improving Pump Performance*. N.p.: n.p., n.d. Nov. 2008. Web.
12. California Water Prices. Telephone interview. Tom Teixeira. 10 Dec. 2014.
13. Centrifugal Pumps. *PumpScout*. N.p., n.d. Web. 10 June 2014.
14. (CEE) Customer Energy Efficiency, Technical, and Advisory. *Pump Efficiency Tests from the Advanced Pumping Efficiency Program* (n.d.): n. pag. 1 June 2011. Web.

15. Carrier, New York Syracuse, and October 2005. *VARIABLE FREQUENCY DRIVE* (n.d.): n. pag. Web.
16. Focusonenergy.com. *Control Your Energy Costs with Variable-frequency Drives* (n.d.): n. pag. Jan. 2009. Web.
17. *EPrism*. Computer software. *Goulds Pumps EPrism*. N.p., n.d. Web. 24 Nov. 2014.
18. Impeller Designs. *Holland Applied Technologies*. N.p., n.d. Web. 23 Oct. 2014.
19. Impellers Information. *On GlobalSpec*. N.p., n.d. Web. 12 June 2014.
20. Instrumentation and Controls. *Specializing in Instrumentation & Control System Design as Part of a VFD*. N.p., n.d. Web. Mar. 2014.
21. Joy, Sijo. "INSTRUPEDIA." *Level Measurement : Direct Methods -*. N.p., 28 Feb. 2012. Web.
22. Lesmen. "Are Bubbler Systems." N.p., 2012. Web.
23. National Environmental Services Center (NESA). *Reading Centrifugal Pump Curves* (n.d.): n. pag. *Tech Brief*. Zane Satterfield, P. E. Web.
24. Pulse Width Modulation Used for Motor Control. *Basic Electronics Tutorials*. N.p., n.d. Web. Apr. 2014.
25. Pump Training. - *Rain for Rent*. N.p., n.d. Web. 05 Sept. 2014.
26. Rebates for Your Business. *By Equipment*. PG&E N.p., n.d. Web. 02 Dec. 2014.
27. Siemens, Stephen P. "Understanding Variable Frequency Drives." N.p., 8 Apr. 2011. Web.
28. Sensortechnics. "Custom Submersible Level Sensors." N.p., May 2013. Web.
29. Suvo. "How an Ultrasonic Level Sensor Works." *Brighthubengineering*. N.p., 2010. Web.
30. Tony. "Level Calculation." *Globalspec*. N.p., 26 Feb. 2012. Web.
31. TSC *Water Delivery and Operations, Operation and Maintenance, Technical Service Center, Bureau of Reclamation, U.S. Department of the Interior*. N.p., n.d. Web. 14 May 2014.
32. Ultrasonic Level. *Greyline Instruments*. Web. 19 May 2014.
33. Understanding Positive Displacement Pumps, *PumpScout*. N.p., n.d. Web. 10 June 2014.

34. (UVFD) Understanding Variable Frequency Drives. *Plant Engineering*. N.p., n.d. Web.
35. Yin Tang VFDs.com. *VFD, Inverters, & AC Drives*. N.p., n.d. Web. 19 Oct. 2014.
36. Variable Frequency Drives – Planning Your Syst, and Charles Burt, Dr. *ITRC Report No. R 02-009 EMERGING TECHNOLOGIES* (n.d.): n. pag. 2009. Web.

COST ESTIMATE

Page 1 of 1
California Contractor's
License #: 838980



IDC SUPPLY, INC.

P.O. BOX 1412
PATTERSON, CA 95363

Date November 3, 2014

Estimate Submitted To:

Name Tetxeira & Sons

AddressCity, State, Zip Los Banos, Ca

Phone Number

Work To Be Performed At :

Address/Field # Lift Station 1, Mercey Springs

City, State Los Banos, Ca

Design Number

[illegible]

1. PRICES QUOTED ARE SUBJECT TO CHANGE.
2. ACCOUNT APPLICATION IS REQUIRED FOR MOST TRANSACTIONS.
3. PLEASE REVIEW TERMS AND CONDITIONS LISTED ON REVERSE.
4. UNAUTHORIZED USE OF DRAWINGS, DESIGN INFORMATION OR MATERIAL LISTS IS STRICTLY PROHIBITED. DESIGNS AND MATERIAL LISTS ARE THE PROPERTY OF IDC Supply, Inc. AND PROTECTED BY COPYRIGHT.

IDC Supply, Inc. is a licensed California General Engineering Contractor (Lic. No. 839980). Our designers are subject to certification by the Irrigation Association.

SUBTOTAL	
FREIGHT	
DELIVERY	
LABOR	
TAX	
TOTAL	\$16,954.00

APPENDIX B

PG&E Rebate Requirements For VFD Pumps

Agricultural Irrigation Pump Variable Frequency Drive (VFD)



Adding a variable frequency drive to irrigation pumps may enable you to reduce your irrigation system's operating pressure, thus reducing energy consumed by pumps. Adding a VFD also enables you to vary the flow of water as needed for your irrigation schedules, while providing additional benefits such as soft start capability and enhanced performance of equipment.

Note: A VFD can save energy in cases where pumps and irrigation equipment are oversized or in situations with variable water supply or irrigation flow conditions but are not recommended in all situations. Consult a PG&E expert or an irrigation system engineer for more information.

Product must be purchased on or after August 1, 2014.

Requirements:

- VFDs must be installed as a retrofit of an existing single-speed pump and irrigation system on a productive field, replacing an existing booster or well pump.
- VFDs must be used for control in place of a throttle valve used for controlling the flow/pressure of the pump.
- The allowable horsepower ratings of the well pump motor must be less than 300 hp per motor, and the booster pump motor must be less than 150 hp per motor.
- Applicable to pressurized irrigation system types including sprinklers, microsprinklers, and drip, but excluding flood irrigation.
- VFD must meet quality requirements as specified by IEEE Standard 519-1992, Recommended Practices and Requirements for Harmonic Control in Electrical Systems.
- Pumping application must currently require throttling below full flow to meet irrigation requirements.
- Minimum operation of 1,000 hours per year.
- Installation address must have an agricultural electric account with PG&E

Exclusions:

- Variable frequency drive 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 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)
- Not applicable to new plantings of vineyards, orchards, or other field crops, or installations of new wells.
- Not applicable to industrial or commercial pumps; only agricultural irrigation pumps are eligible.
- Not eligible in combination with A272 or A273 (Low-Pressure Sprinkler Nozzles Hand Move or Permanent) incentive.

Application process:

- To qualify for this rebate, customer must supply an invoice that includes the quantity of VFD's, type (well and/or booster), horsepower rating, area map with physical location of pumps, and the manufacturer make/models of the VFD's installed.
- Must include copy of manufacturer's specification sheet of VFD's installed and a statement that the VFD complies with IEEE Standard 519-1992.

Rebate Code	Description	Rebate/ Unit Measure
IR006	Well Pumps—Variable Frequency Drive (<300hp)	\$40/hp
IR007	Booster Pumps—Variable Frequency Drive (<150hp)	\$40/hp



2014 Business Rebate List

Product offerings and rebate amount are subject to change.
Business Rebate Catalogs are available at www.pge.com/businessrebates.

Agriculture

Greenhouses		
Rebate Code	Description	Rebate/Unit Measure
A10	Greenhouse Heat Curtain	\$0.20/sq. ft.
A102	Infrared Film for Greenhouses	\$0.05/sq. ft.
Irrigation		
Rebate Code	Description	Rebate/Unit Measure
A272	Low-Pressure Sprinkler Nozzles Hand Move	\$1.15/nozzle
A273	Low-Pressure Sprinkler Nozzles Permanent (Solid Set)	\$1.15/nozzle
A266	Sprinkler to Drip Irrigation Field Vegetable	\$44/acre
A268	Sprinkler to Drip Irrigation Deciduous Tree	\$44/acre
A269	Sprinkler to Drip Irrigation Vineyard	\$44/acre
IR001	Submersible Well Pump System Overhaul (≤ 25 hp)	\$75/hp
IR002	Submersible Booster Pump System Overhaul (≤ 25 hp)	\$75/hp
IR003	Centrifugal Booster Pump System Overhaul (≤ 25 hp)	\$75/hp
IR004	Turbine Booster Pump System Overhaul (≤ 25 hp)	\$75/hp
IR005	Turbine Well Pump System Overhaul (≤ 25 hp)	\$75/hp
IR006	Well Pumps—Variable Frequency Drive (< 300 hp)	\$40/hp
IR007	Booster Pumps—Variable Frequency Drive (< 150 hp)	\$40/hp