DEID VFD STUDY

Delano-Earlimart Irrigation District

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Variable Frequency Drive Study

REPORT

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BACKGROUND

This report was conducted to study the pump station operation at Delano-Earlimart Irrigation District (DEID) after the installation of a variable frequency drive (VFD) control. The district is currently involved with the California Energy Commission's low-interest loan program for the installation of VFD units on their pump stations near Delano, California.

Delano-Earlimart Irrigation District is a special water district organized under Division 11 of the California Water Code and encompasses 56,500 acres in Southern Tulare County and Northern Kern County. DEID has 18 individual pumping stations. DEID installed VFDs on key pumps at three different plants (D-3, D-12, and D-14). See Figure 1 for a description of the project location.

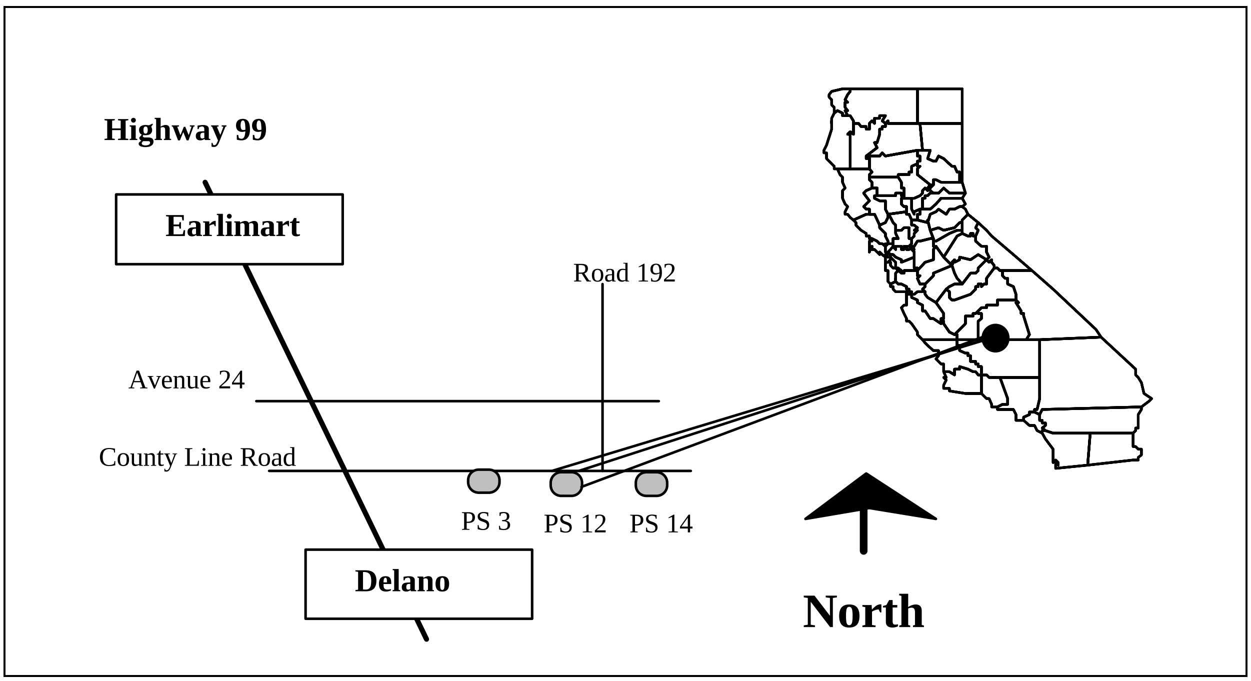

Figure 1. Delano-Earlimart Irrigation District - CEC Project location map.

Project Objectives

In order to develop specific recommendations on the operation and use of the VFDs, a detailed evaluation was performed on Pump Station 12. This project had the following specific objectives:

- Estimate 1991-1993 energy savings and payback period for going to VFD based on ideal pump sequencing and historical (actual) pump sequencing.
- Collect data regarding existing pump operation at Station D-12.
- Examine current VFD performance and compare it to single speed hydraulic tests conducted by Southern California Edison.
- Develop guidelines for pump sequencing and choosing which pump to automate with VFD.

Variable Frequency Drive (VFD) Concept

Variable frequency drives (VFDs) were incorporated into key pumps at pumping stations and were intended to be capable of varying the flow of a pump. The objective is to minimize wasted energy at the pumping station associated with pumping water to meet customer water demand.

The VFD system used at Station D-12 consists of four basic components:

- Pump and motor set
- Variable frequency drive
- Process controller
- Level sensor

Figure 2 shows how each of the components are connected and used. The desired set point is established and is typically lower than the historical operation level for the TDH. The value is lower because the water is not required to spill as was done historically.

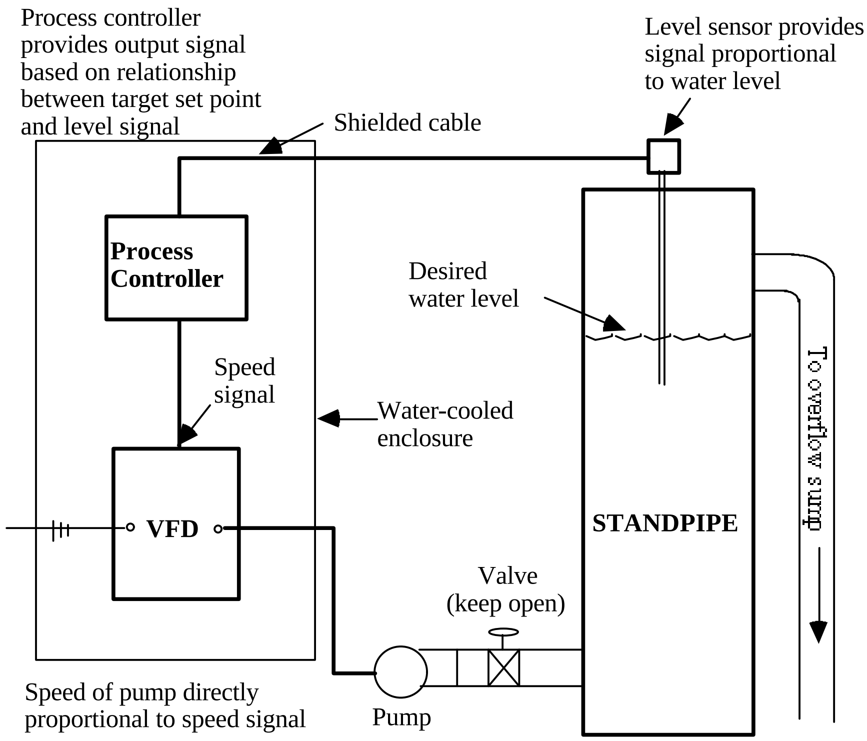

Figure 2. Diagram of VFD concept.

The VFD system automatically maintained a desired water level in the discharge standpipe. The lower set point has the potential to lower the energy consumption of the pumping station slightly. Maintenance of the set point was accomplished by mounting a water level sensor inside the standpipe that works in conjunction with a process controller. The process controller generates a signal that controls the output of the VFD on one of the pumps. Because the speed of the pump can be varied, this VFD pump may also be referred to as an adjustable speed drive (ASD) pump. This pump, used by itself or in conjunction with any other pump, provides full flow variability up to the capacity of the plant. With this control, the objective of reducing wasted energy consumption can be met.

Benefits of VFDs

Using the VFD has the following benefits:

- Conserves energy by reducing pump speed to produce lower flow.
- Eliminates the need for the flow control valve at the pump station; thus, generates reductions in amount of energy used by the pump.

- Provides cost-saving benefits, such as reduced electrical and mechanical maintenance.
- Improves reliability and pump-control strategies.

Pump Station D-12 Configuration

Pumping Station D-12 consists of two sets of pumps. One set of pumps supplies water to the lateral pipeline system for the water users, and pumps conveying water to another reservoir. This study is based on data at Station D-12 for which DEID retrofitted the panel for Pump 3 at Station D-12 for VFD control (see Fig. 3). The overall pumping plant efficiencies were provided by Southern California Edison (SCE) from single speed hydraulic tests.

The station under evaluation consists of four pumps connected in parallel with a common output manifold hooked to a standpipe, approximately 30 feet tall. This standpipe has an overflow pipe which returns excess water to a common sump. By turning on a combination of pumps to fill this standpipe to overflow level, a variable and uninterrupted flow of water to the pipeline system for the customer is attained.

For example, water demand for a specific day might be 8.7 cubic feet per second (cfs):

> This demand would be met by turning on the 6.1 cfs pump and the 2.9 cfs pump, thereby producing 9.0 cfs. The standpipe fills to overflow height and the excess 0.3 cfs is returned to the sump. Energy is wasted by pumping excess water to the overflow.

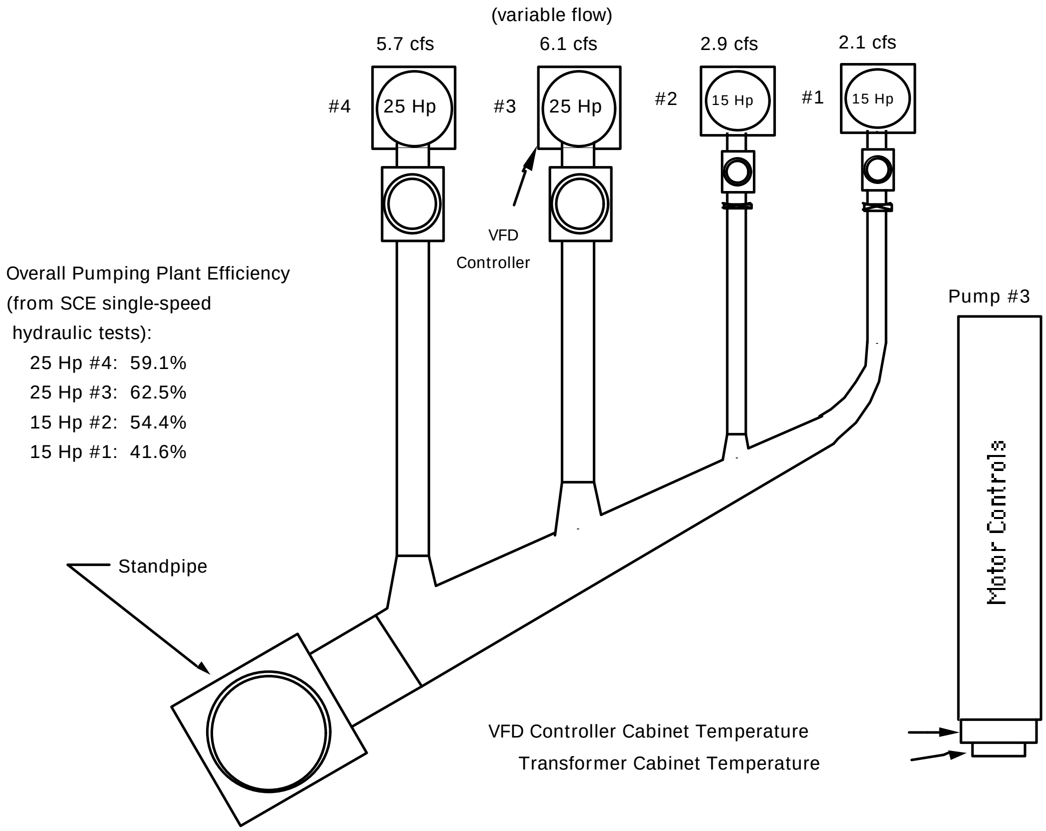

Figure 3. Pumping station layout.

Theoretical Energy Savings

Estimates were made by ITRC for Stations D-3, D-12, and D-14 based on water demand and pumping hours from 9/1/91 to 8/31/93. The following focuses only on the savings at Station D-12. Table 1 illustrates two methods of payback analysis.

Table 1. Comparison of payback analysis (based on 9/1/91-8/31/93 data).

	IDEAL SEQUENCING		HISTORICAL SEQUENCING	
CFS Used	CFS Demand		CFS Demand	
kW Consumed	kW/pump based on an ideal pump seq. to fulfill CFS Pumps 1-4 are sequenced so that the CFS capacity per pump (SCE) is then totaled to meet CFS demand.		kW/pump rating directly from SCE	
Overspill?	some overspill		unknown	
Pumping Hours	24 hrs/day basis		actual recorded pumping hrs	
	EXISTING PUMP	NEW PUMP	EXISTING PUMP	NEW PUMP
Annual kWH without VFD	128,802	128,802	115,415	115,415
Annual kWH with VFD	109,698	93,377	104,764	96,095
Annual kWH Savings	19,104	35,425	10,651	19,320
Annual Savings ($.114/kWH)	$ 2,177	$ 4,038	$ 1,214	$ 2,203
VFD Cost + pump (if applicable)	$18,342	$ 23,342	$18,342	$ 23,342
Simple Payback (years)	8.4	5.9	15.1	10.6

Table 1 indicates that the actual pumping hours (historical) were significantly less than the ideal situation that should have occurred to achieve a predetermined flow rate. This was based on the lower annual kWH without the VFD. This means that the CFS demand was not met, and the customer received less water than the recorded CFS deliveries. Thus, Table 1 shows that savings are highly sensitive to how the pumps are sequenced.

Table 2. Table summary of kWH consumed based on ideal and historical sequencing from 9/1/91 to 8/31/93.

PUMPING STATION: D-12 (Pumps 1-4)

		kWH				Monthly Average kWH/AF			
		Ideal			Historical	Ideal			Historical
		With VFD		Without VFD	Without VFD	With VFD		Without VFD	Without VFD
Date	AF Demand	Existing Pump	New Pump			Existing Pump	New Pump		
Sep-91	267	9,758	7,227	12,931	11,782	27.1	27.1	48.5	44.2
Oct-91	287	10,540	7,724	13,927	13,362	26.9	26.9	48.5	46.5
Nov-91	355	12,871	8,920	16,277	14,214	25.1	25.1	45.9	40.0
Dec-91	0	0	0	0	0	0.0	0.0	0.0	0.0
Jan-92	0	0	0	0	0	0.0	0.0	0.0	0.0
Feb-92	20	1,146	1,181	1,181	1,033	58.7	58.7	58.7	51.3
Mar-92	7	498	590	590	517	80.7	80.7	80.7	70.6
Apr-92	448	16,061	14,034	18,494	16,625	31.3	31.3	41.3	37.1
May-92	525	17,641	15,924	19,790	16,451	30.3	30.3	37.7	31.3
Jun-92	597	21,708	18,917	23,916	17,798	31.7	31.7	40.1	29.8
Jul-92	365	13,381	10,948	15,643	14,697	30.0	30.0	42.9	40.3
Aug-92	188	7,734	6,606	9,586	8,331	35.2	35.2	51.1	44.4
Subtotals Ave.	3,059	111,338	92,072	132,336	114,810	36.4	30.1	43.3	37.5
Sep-92	124	5,551	5,067	7,584	5,873	44.9	41.0	61.4	47.6
Oct-92	75	3,939	4,249	5,201	4,759	31.9	34.4	42.1	38.5
Nov-92	42	1,867	1,877	2,606	659	15.1	15.2	21.1	5.3
Dec-92	0	0	0	0	0	0.0	0.0	0.0	0.0
Jan-93	0	0	0	0	0	0.0	0.0	0.0	0.0
Feb-93	21	1,161	1,181	1,181	517	9.4	9.6	9.6	4.2
Mar-93	44	2,254	2,165	2,518	1,841	18.3	17.5	20.4	14.9
Apr-93	304	11,220	10,222	13,330	12,867	90.9	82.8	107.9	104.2
May-93	549	19,631	16,811	22,646	22,405	159.0	136.1	183.4	181.4
Jun-93	695	24,727	21,421	27,024	26,539	200.2	173.4	218.8	214.9
Jul-93	765	27,657	24,200	30,233	28,278	223.9	196.0	244.8	229.0
Aug-93	280	10,050	7,490	12,945	12,281	81.4	60.6	104.8	99.4
Subtotals Ave.	2900	108,057	94,681	125,268	116,020	37.3	32.6	43.2	40.0
2 Yr Totals	5959	219,395	186,753	257,604	230,830				
Yrly Ave	**2980**	**109,698**	**93,377**	**128,802**	**115,415**	**36.8**	**31.3**	**43.2**	**38.7**

Background of VFDs and Payback

Perceived or actual improved energy efficiency is undoubtedly the greatest stimulus towards the use of VFDs, but it is not the only one. It is the connection between energy efficiency and better process control which often fuels the interest in VFDs (Process Engineering, 1994). The VFD controller can be used to modify an existing, single speed motor operation, as at DEID.

Performing an Economic Analysis. Variable speed systems have the potential to save energy in many installations. However, they do not necessarily save money. The total cost of equipment and life cycle should always be analyzed for applications. The estimates of energy savings must account for the hours of operation of various speeds, the pump TDH and flow rate at those speeds, and the total pumping plant efficiency at those speeds. In general, the pump impeller and motor efficiencies are considerable lower at low RPMs than at higher RPMs. This drop in efficiency will reduce the payback efficiency.

As part of the work done at DEID for the CEC, the ITRC developed two sets of guidelines for new installations. One is related to the selection of the proper pump to automate with a VFD; the other guideline relates to the computation of annual savings in power. These are included in a subsequent section of this report.

Key Definitions. The following are the key definitions for this report:

Affinity laws. These are the relationships between speed ratios, pressure ratios, and horsepower ratios for centrifugal pump applications:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}\ ; \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 ; \qquad \frac{hp_1}{hp_2} = \left(\frac{N_1}{N_2}\right)^3 \tag{1}$$

$Q = flow\,(GPM), \quad N = speed\,(RPM); \quad H = head\,(ft); \quad hp = horsepower$

** It should be noted that the affinity laws are only used to develop a new pump curve for different RPMs. The actual HP used by the pump when changing RPMs will depend on where the system curve intersects the pump curve. In determining power savings, the system curve must be taken into account.

Pump curve. A graph showing the relationship between TDH (total dynamic head) and flow rate at a single RPM. The efficiency of the impeller is also shown at key flow rates. In general, as the flow rate increases, the TDH delivered by the pump decreases. The curve will be different at each RPM.

System curve. A graph showing the relationship between the TDH required by an irrigation system and the flow rate through the system. As the flow rate through the system increases, the TDH required increases. For most cases, the pump curve will only intersect the system curve at one point (this assumes one RPM of the pump).

Head. This refers to pressure given in units of feet of water column or pounds per square inch (PSI).

Static head**.** The static head is the elevation change between the source water level and the discharge point. The pump must deliver a TDH greater than the static head before water will begin to flow.

Friction. The friction is the pressure loss due to the friction of the water moving against the pipe and fittings.

Drawdown. The drop in the source water level once pumping starts.

Discharge pressure. The pressure (head) at the discharge point. For example, a sprinkler may have a discharge pressure of 50-60 psi. An open pipe has a discharge pressure of 0 psi.

Total Dynamic Head (TDH). The TDH is the pressure that the system will impose on the pump at a particular flow rate. This is simply a sum of the static head, the friction, drawdown, and the discharge pressure. On the type of pump stations analyzed at DEID, the TDH remains relatively constant through the range of flow rates. This is because the static head is the greatest component in the TDH. The piping system is of a large diameter and short in length, so there is very little friction loss. Also, there is no drawdown. In other words, the system curve is fairly flat (horizontal).

Pumping plant efficiency. This is the efficiency of the complete pumping plant, including the VFD panel, the motor, and the impeller/bowl assembly. It is computed as:

$$PPE = \frac{\text{Water Horsepower}}{\text{Input Horsepower}} \times 100$$

where

$$\text{Water Horsepower} = \frac{\text{GPM} * \text{TDH}}{3960}$$

with TDH measured in feet of pressure, and

Input Horsepower = measured at the meter

Maximum GPM. The maximum actual flow rate (gallons per minute) developed by the pump. This was obtained from SCE (Southern California Edison) single speed pump tests.

Operating scenario. This is the percent time at a certain flow rate.

SITE INVESTIGATIONS

The examination of the DEID VFD applications concentrated around one site - D12. An initial meeting was held with DEID personnel, employees from Turnipseed Electric of Delano (which installed the equipment), and SCE energy specialists. At that time, several items of interest were defined:

- Since the efficiency of the pump itself had not been considered, it was determined that more information about the pump characteristics was needed.
- The actual payback of the unit was a primary concern of DEID.
- This project provided SCE with an opportunity to examine the details of operation of a VFD for a whole irrigation season.

After that meeting, the pumps were evaluated for flow rate, TDH, and efficiency. SCE also arranged for the installation of a complete data collection and remote monitoring system at plant D12. SCE contracted with Severson Company, Inc. for the installation of equipment and software. The ITRC specified what equipment was needed, and the required accuracy of that equipment. The ITRC also participated in the installation of the equipment. SCE arranged for the ITRC to obtain the data from Severson. Table 3 is a listing of the primary components of the data collection system. Data was recorded in 15 minute intervals. Operations for 3 months (6/2/94-10/26/94) were used in this study.

Table 3. Sensor inventory used in data acquisition.

DATA COLLECTION		UNITS	EQUIPMENT/NOTES
Data logger			Campbell Scientific Model 21 XL with Modem and Cellular Phone Interface Sample Rate: for this project, 1 per second
Flow	Pump 3 (VFD)	GPM	Flow meter Model: LP-3 Serial: 934923 Size: 12" Pulse: 10pps @ 3000 GPM Pipe size calibration: 11.938" Calibration ratio: $\text{Ratio} = \frac{\text{New pipe Area}}{\text{Calibration Area}} = \frac{144.1\ in^2}{11.9\ in^2}$ = 1.287:1 Therefore: Pulse 10 pps @ 3000 x 1.287 GPM = 10 pps @ 3861 GPM
Motor Speed	Pump 3	RPM	Pulse
Power	Pumps 1 - 4	kW	Error in Pump 3 (VFD): 1.5% (1.6 % Efficiency offset)
Pump Pressure	Pump 3	ft	Pressure Transducer Omega Model: PX 615 Serial: 413292 Range: 30 psi Error: 1% Current Loop Installation Input: 10-30v Output: 4-20 Ma
Temperature	Into Pump 3 Out of Pump 3 VFD Transformer	^oC	Type "T" Thermocouple
Water Level	Above Transducer	ft	Pressure Transducer IP-DC Model: 5PSI6 Differential PTX 165-0857

Figure 4 shows the location of the data collection components used for this study. The critical dimensions of the measurement points are also shown.

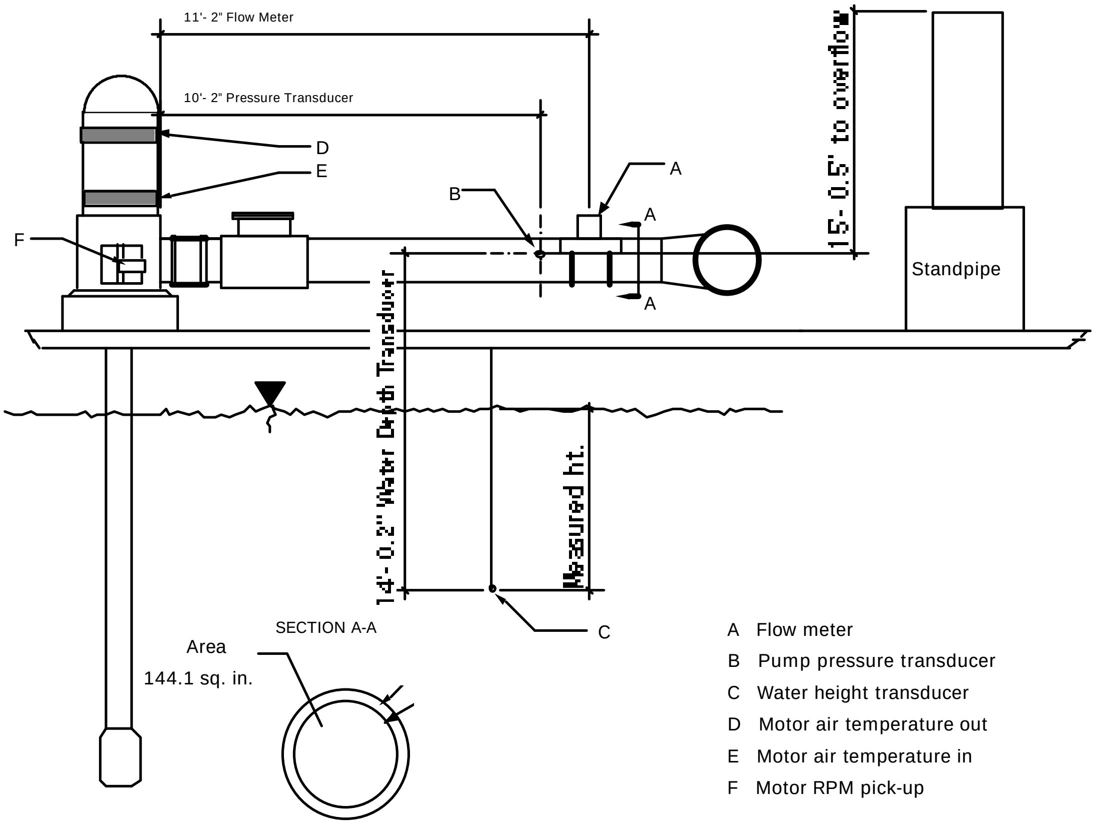

Figure 4. Key measurement points at Station D-12 Pump #3.

The purpose of collecting data is to evaluate VFD pump operation and performance. VFD performance and its comparison to values generated from SCE single speed pump tests are represented in the form of graphs:

- Discharge head and Total Dynamic Head (TDH) vs. GPM.
- kW to motor vs. GPM.
- kWH/AF vs. GPM.
- VFD panel efficiency vs. kW to motor.
- Pumping Plant Efficiency (PPE) vs. GPM.
- Pumping Plant Efficiency (PPE) vs. RPM.

To compare the VFD pump operation and performance to that of the constant speed drive pumps, values generated from SCE single-speed pump tests were designated as data points on the Pump #3 curves.

Data Evaluation Procedure

The following information regarding Station D-12 was gathered:

1. Water delivery records and hours of pump operation from DEID:
   a. Historical (9/1/91-8/31/93)
   b. With VFD (current)

2. Data from data logger:
   a. Pumping hours and kilowatts (kW) consumed for each pump.
   b. Pump #3 (VFD)
      - Flow rate (GPM)
      - Speed (RPM).
      - Water pressure (ft).
      - kW into VFD panel, kW into motor.
      - Temperatures

3. Single speed pump hydraulic tests from Southern California Edison (SCE).

4. Estimated cost of VFD conversion from contractor.

Observations and Results were represented by:

1. Estimated 1991-1993 energy savings based on:
   a. Ideal pump sequencing
   b. Historical (recorded) pump sequencing

2. Actual operation of the chosen VFD Pump (#3) is represented by:
   a. Graphs of GPM, RPM, and water pressure versus time. (6/2/94-10/2/94)
   b. Average operating flow rate, pumping plant efficiency, and kWH/AF.

3. Comparison of VFD performance to that of SCE single speed pump tests:
   a. Pumping Plant Efficiency (PPE) vs. GPM.
   b. PPE vs. RPM.
   c. VFD panel efficiency vs. kW to motor.
   d. kW to motor vs. GPM.
   e. Discharge head and TDH vs. GPM.
   f. kWH/AF vs. GPM.

Highlights of the Monitoring

Attachment B includes current operation of Station D-12 from 6/02/94 to 10/26/94 (see Table B.1). Key factors to look at regarding the VFD pump (#3) were flow rate (GPM), speed (RPM), and water pressure (P1) (see Figs. B.1-B.21).

DEID selected the proper pump for VFD conversion based upon the following summary:

Table 4. Comparison of variable to constant speed drive pump at D-12 Pump #3.

	Constant Speed Drive SCE test (8/10/93)	**Variable Frequency Drive** existing operation (6/02/94-10/26/94) Average	Range
Discharge Head, ft	16.4	15.3	11.0 - 15.8
Total Dynamic Head, ft	20.5	21.8	18.8 - 34.2
% of Maximum GPM	100	72	25 - 100
Flow Rate, GPM	2735	1994	675 - 2725
Speed, RPM	1184	1046	780 - 1183
kW input to motor	16.9	11.2	6.6 - 16.2
kW input to VFD Panel	--	11.3	6.9 - 16.6
kW per Acre-Ft	34	34.9	30.1 - 57.9
VFD Panel Efficiency %	--	98	94 - 99
Overall Pumping Plant Efficiency (PPE) %	62.5	62.0	35.0 - 71.0

One of the questions regarding a VFD operation related to what the average flow rate would be. At D-12, the average operating flow rate was 72% of the maximum capacity.

The following figures represent current VFD pump performance. SCE test values for Pump 1 through 4 are designated with an "X" and labeled as P-1, P-2, P-3, and P-4. The ITRC included some additional factors in the computation of the VFD, such as column friction.

The discharge head of the VFD pump should remain fairly constant if the pump is operated properly. In this piping system, there is very little difference in friction with flow rate changes, since the pipes have a large diameter and are short in length. In Figure 5, the discharge head can be seen to remain fairly constant, but suddenly drops off near 2,600 GPM. This occurs because the pump is at 100% RPM, and the flow rate leaving the standpipe is greater than the pump capacity -- the water level in the stand drops (i.e., the discharge pressure of the pump drops). Another example of this is seen in Figure B.4 (Attachment B) where the pump was at maximum flow rate while the pressure continued to drop.

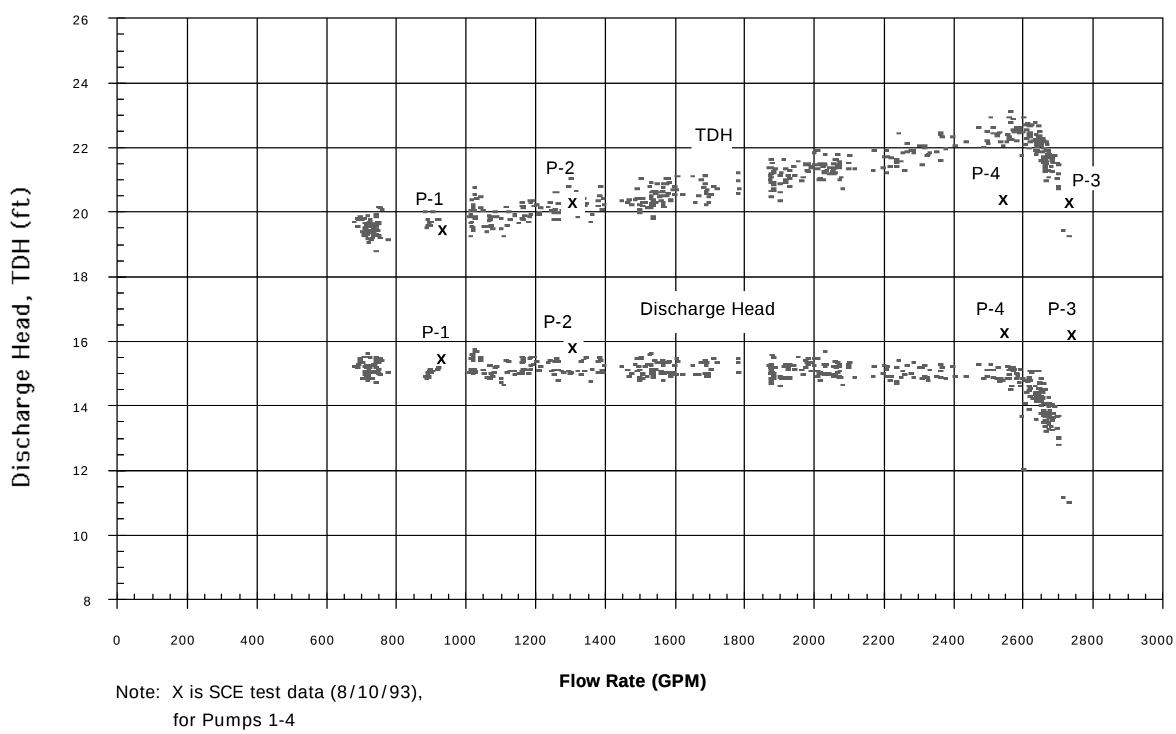

Figure 5. Discharge head and TDH versus GPM for D-12 Pump 3 (6/02/94-10/26/94).

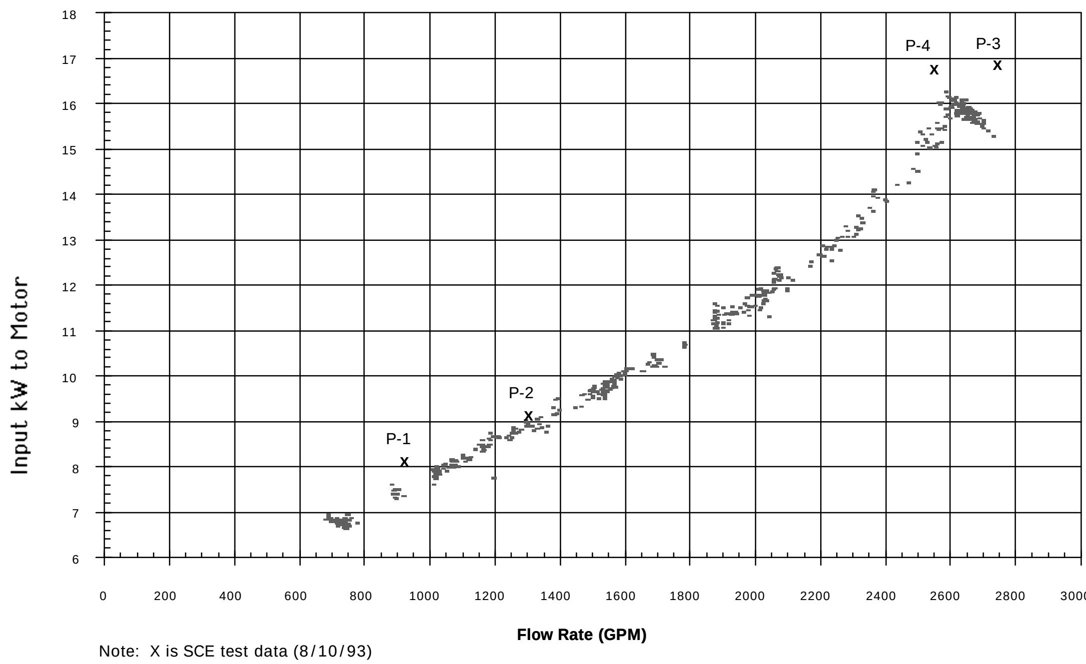

Figure 6. Input kW to motor versus GPM for D-12 Pump 3 (6/02/94-10/26/94).

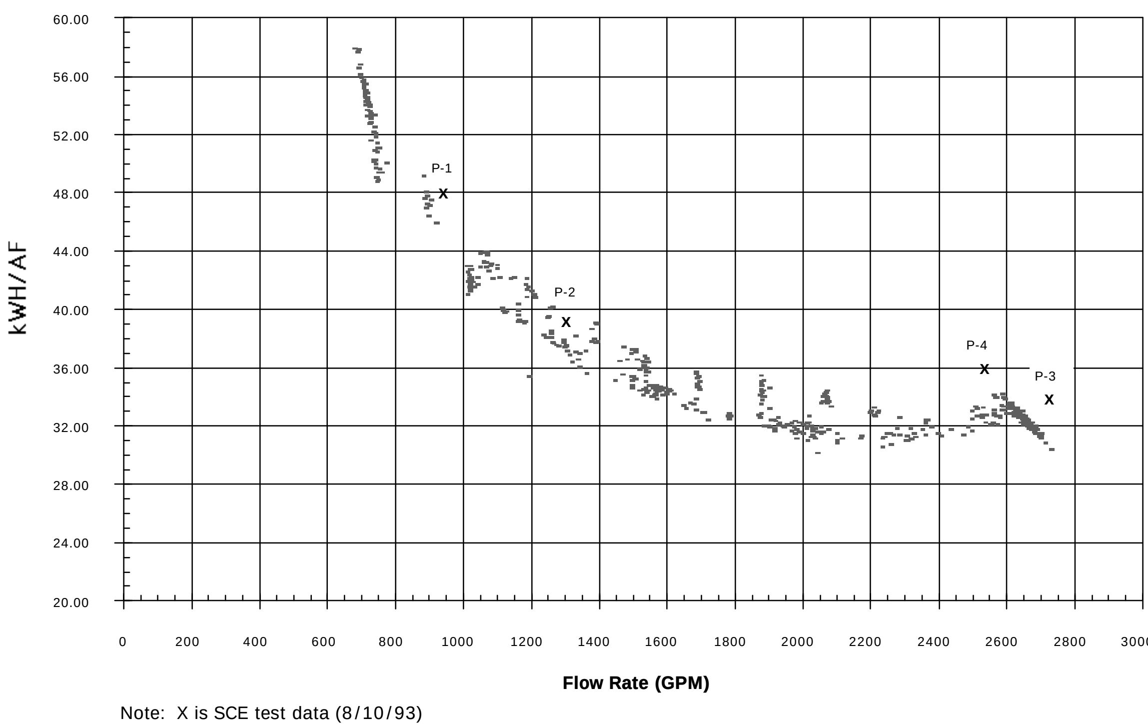

Figure 7. kW/AF versus GPM for D-12 Pump 3 (6/02/94-10/26/94).

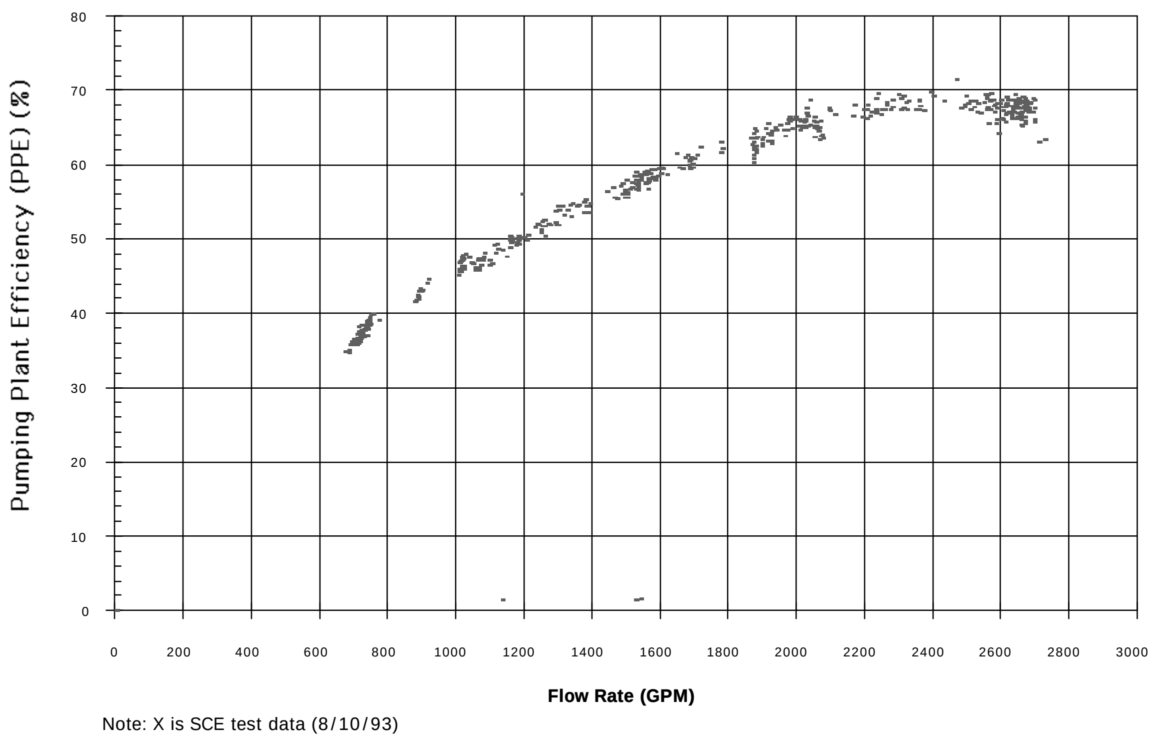

Figure 8. Pumping plant efficiency versus flow rate for D-12 Pump 3 (6/02/94-10/26/94).

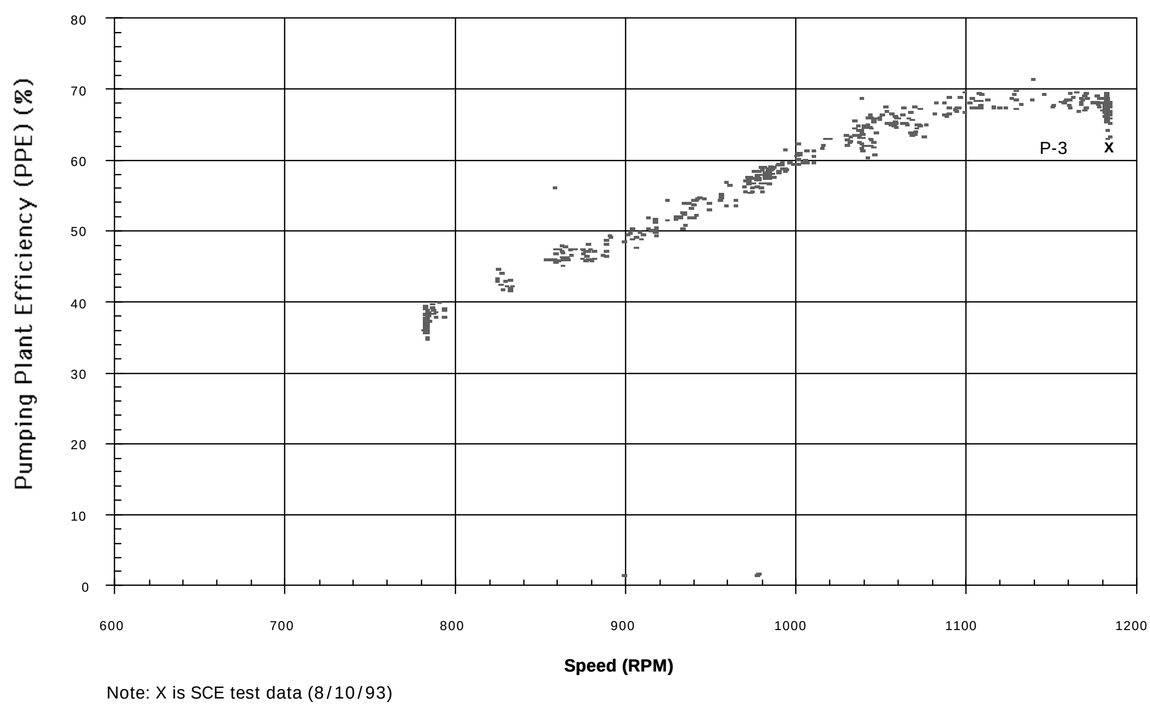

Figure 9. Pumping plant efficiency versus RPM for D-12 Pump 3 (6/02/94-10/26/94).

DISCUSSION

The following observations were made.

Actual Acre-Ft Pumped and Historical Water Deliveries

The acre-ft pumped and recorded by the data logger (Tables C.1.1-C.2.2) closely matched DEID historical daily water deliveries (Tables A.1.1-A.1.2) for the months of June and July 1994.. This supports the reliability of using the collected data values for determining current pump performance and estimating energy savings.

Managing the VFD Operation

In several cases the data shows that the VFD pump reached its maximum capacity at 1,184 rpm, and the water level in the stand continued to drop significantly. For example, in Fig. B.4 (Attachment B), Pump #3 is operated at the maximum RPM of 1,183 RPM from 6/29/94 to 7/2/94. That problem can be solved if another pump is turned on to supplement the VFD flow rate. Remote monitoring and/or automation of all of the pumps at the station provide a simple remedy.

From 8/22/94 - 10/26/94 (Figs. B.12 - B.21), there were no significant fluctuations in water pressure. The VFD pump covered a wide range of operating flow rates from 700 GPM to 2725 GPM.

The pump chosen for VFD was the proper pump to automate. It was the correct size (see Guideline #1 in the next section), and it had a reasonably good efficiency (62%).

DEVELOPMENT OF GENERALIZED RECOMMENDATIONS FOR VFD INSTALLATIONS

As a result of the work at DEID, three sets of guidelines were developed for the CEC so that it can assist others with the proper selection of VFD pumps.

Guideline #1 - An explanation of which pump should be controlled by a VFD if more than 1 pump exists at a site, and what characteristics that pump should have (see Attachment F)

Guideline #2 - The recommended procedure for estimating the annual cost (payback) which will occur if a VFD is to be installed (see Attachment G).

Guideline #3 - The proper hardware that should be used in a new installation (see Attachment H).

ENHANCEMENT OF THE PRESENT VFD OPERATION

The following recommendations have been given to DEID regarding the VFD installation at D-12:

1. Renovate the existing VFD pump with a new impeller/bowl assembly. The ITRC has worked with DEID and various pump manufacturers to locate a suitable pump. This included the development of written pump specifications by the ITRC. DEID is presently in the process of locating a suitable pump. DEID has found that care must be taken with some pump company employees - in spite of written specifications, they may recommend the incorrect pump for an installation, and may be unfamiliar with their own products and how they can be applied in VFD installations.

2. Install remote monitoring of the location. This will enable district staff to know the status of water deliveries and pump operation without having to physically visit the site. It will enhance the district's ability to provide more flexible deliveries (see next item).

3. Allow farmers to personally operate their turnouts. They should be required to request water deliveries in advance, so that the district can determine if there will be sufficient capacity. However, an automated and remotely monitored installation will allow them to shut off without giving advance notice. This concept was explained by the ITRC and the DEID manager to the board members at an informal meeting.

4. Automate the three other pumps at the D-12 overflow stand. They would be constant speed, but a Programmable Logic Controller, PLC (the same one as is presently used to control the VFD), can be used to automatically turn the pumps on and off as the flow rate demand from the VFD approaches the maximum or minimum limits. This is a standard type of operation for most municipal systems.

CONCLUSIONS

The following are the main conclusions or results from this project:

1. The payback period is longer than was anticipated in the loan application. The computations on the original loan application did not account for the irrigation system curve. VFD controller specialists may not be familiar with pump and irrigation system characteristics, which are key items in estimating payback periods.

2. In order for a VFD installation to minimize the payback period, it is important to consider the pump and motor efficiencies. In the D-12 case, a different pump will reduce energy consumption and also improve the payback period. Care must be taken when working with pump suppliers, as many are unfamiliar with VFD requirements.

3. As a result of experiences on this projects, specifications were developed for the proper initial estimate of payback periods, and for required VFD equipment.

4. The VFD application is capable of providing the district with significant secondary energy savings (not quantified in this report) related to less travel by operations staff and improved on-farm irrigation efficiency through better flexibility in turning water on and off at the farm level.

5. Having a VFD control can guarantee a stable water level at the discharge as long as (i) the controller has the correct logic, (ii) the pump curve is not intersected by the system curve in more than one point, and (iii) the flow rate being withdrawn from the stand does not exceed the flow rate capacity of the pumps which are activated. Regarding the last point, it is apparent that it is very valuable to automate all of the pumps at a station, and to have remote monitoring.

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Attachment A

DEID and SCE Data

Attachment B

Actual Pump Operation, TDH Calculation

Attachment C

Data Logger Summary (Hrs, kWH, AF/day)

Attachment D

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Historical Pump Sequencing, Savings Calculation

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Figure I.6. Overflow stand at Station D12 to which the VFD was attached. The VFD maintains a constant water level in the stand, below the overflow pipe seen on the right hand side.

Attachment F

Pump Selection Criteria

1. The pump to automate with a VFD (in a location with multiple pumps supplying the same pipeline) is the smallest which will meet both of the following criteria:

   a. (Flow Rate of the VFD pump

      + Sum of the flow rates of all the smaller pumps)

      must be greater than or equal to

      (The flow rate of the next bigger pump)

      i.e., $(Q_{VFD} + [\text{sum of all } Q_{\text{smaller pumps}}]) >= Q_{\text{Next bigger pump}}$

   b. No larger pump flow can exceed the combined flow of all pumps which are smaller than it (including the VFD at full speed).

2. There is generally little or no energy savings associated with converting to VFD control for more than one pump at an installation.

Attachment G

Estimating the Payback

for an

Electrical VFD (Variable Frequency Drive) Application

in a Pumping Plant Which Presently Spills Excess Pumpage

1. Estimating the maximum potential savings.

An estimate of savings requires an estimate of the historical amounts of spilled water. If, for example, the spilled water is 5% of the total pumped water, then the maximum KW-Hr savings can be:

Max. KW-Hr savings = .05 x Annual KW-Hr

If pumping amounts vary significantly from year to year, an average of three years of data should be used.

The savings may be somewhat less than this (if the VFD operation puts the pump into a less efficient operating range) or somewhat more than this (if the new controlled water level is lower than the previous spill level). An examination of pump efficiencies may show the greatest savings possible can be obtained by simply improving the efficiencies of existing pumps.

a. The following information is necessary in most cases:

- Monthly power bills or pump test data providing KW-Hr per Acre-Foot (AF) pumped for each pump

- Monthly hours of operation per pump

- Monthly water deliveries (as opposed to pumped amounts)

- Pump test data, providing Acre-Feet (AF) pumped per hour of operation for each pump

b. Compute AF pumped per month for each pump

$$AF = \frac{AF}{hour} \text{ x Hours of operation}$$

c. From district delivery records, determine the total AF delivered to users (plus seepage and conveyance losses) supplied by the pumping station, by month

d. Sum the monthly totals

e. For each water year, find the % spilled

$$\%\ \text{Spilled} = \frac{\text{AF Pumped - AF Delivered}}{\text{AF Pumped}} \text{ x } 100$$

f. Compute the total KW-Hr savings possible

$$\text{Annual KW-Hr savings possible} = \frac{\%\ \text{Spilled}}{100} \text{ x (Ann. KW-Hr consumed)}$$

2. Estimating KW-Hr which would have been consumed if one of the pumps had been converted to VFD.

This second step should serve as a check on the first step, in which the "possible" savings were computed. By doing this computation, the effect of the overall pump efficiency of the selected VFD-controlled pump is accounted for.

Again, use historical data to make these "what-if" computations.

a. Estimate the AF which will be pumped by the VFD unit

$$AF = \frac{\text{(Hours) x GPM}}{5428}$$

where

Hours = The total hours per year that water is delivered from the pump station (the VFD will operate continuously)

GPM = 67% of the maximum GPM of the pump with the VFD controller (the actual percentage can be determined with a detailed analysis, but it is probably not warranted. The 67% provides a weighted average for a typical condition, accounting for the KW-Hr consumed at various flow rates)

b. Estimate the annual KW-Hrs which would be used by the VFD

$$\text{Kw-Hrs}_{VFD} = \frac{\text{GPM x TDH x 0.0188 x Hours}}{\text{Efficiency/100}}$$

where

TDH = The total dynamic head of the pump, in feet.

Efficiency = The total efficiency of the pump (generally in the range of 40 - 70), which depends upon:

Panel Efficiency (Panel) -about 97

Motor Efficiency (Motor) - depends upon motor size and model; typically somewhere between 85 - 93

Impeller Efficiency (Impeller) - the efficiency of the impeller and bowls. The Impeller Efficiency to use will occur at a flow rate of about 67% of the maximum flow rate

Losses (Losses) - a measure of the losses which occur due to bearings; typically about 98 on a short lift.

$$\text{Efficiency} = \frac{\text{Panel x Motor x Impeller x Losses}}{10^6}$$

c. Estimate the annual KW-Hrs used by the other pumps at the station.

1. Estimate the AF delivered by the other pumps

AF_{other} = (Total AF delivered to users plus conv. losses) - AF_{VFD}

2. Compute the average pump efficiency (Eff_{other}) for the other (non-VFD) pumps.

The information from individual pumps will come from a pump test. Ideally, the average efficiency should be determined by taking a weighted average after considering the KW and the Hours of each pump, as anticipated after the VFD is installed. In practice, a simple average may be sufficient because the pumps with the lowest KW will be cycled on and off more often than the larger pumps, so they will have more hours of operation than the larger KW pumps.

3. Make the final KW-Hr computation for the other pumps

$$\text{KW-Hr}_{other} = \frac{\text{TDH x 102 x AF}_{other}}{\text{Eff}_{other}}$$

d. Find the total annual KW-Hrs to be used by all pumps

Total KW-Hr = KW-Hr_{other} + Kw-Hrs_{VFD}

e. Compute the total KW-Hr savings possible

Annual KW-Hr savings possible = (KW-Hr actually consumed - Total KW-Hr)

Attachment H

Requirements for AC VFD (Variable Frequency Drive) Installations

Nov. 1994

Farm Energy Assistance Program

California Energy Commission

The installer shall supply the VFD controller, and also be responsible for the turn-key installation and all other electronics related to the sensor, motor, and controls.

NEMA Standards Publication No. ICS 7 shall be adhered to. All electrical codes must be met or exceeded.

The features listed below are required for the CEC loan program because their absence in VFD installations has contributed to problems or failures. They are complimentary to many standard protective features; they shall not replace more stringent or protective features which are required by various codes, standards, and specifications.

Features required for the VFD panel

- Space heater for winter to prevent condensation
- Weatherproof and dust/insect-proof enclosure
- Fluorescent light (external mounting)
- Water cooling heat exchanger for the panel, with a water filter having automatic flushing

- GFI receptacle (external mounting)
- Speed potentiometer and starter for manual control
- Remote Terminal Unit (RTU) containing a PID process controller, with communication port for either radio or phone. Radio or phone must be specified.
- Message Display of Operational Parameters and System Faults.
- HOA switch(es).
- Shading of the panel from direct sunlight.

Automation

- **The RTU must automate both the VFD and the other pumps which operate in parallel with the VFD**.

Conditioning of incoming power.

- A self-contained control power transformer must be supplied to feed the GFI, controls, and light. The RTU must have an isolated, conditioned power supply and battery backup.
- Harmonic filters must be provided for each leg of incoming power of the VFD.
- If the VFD is to be installed on an ungrounded Delta system, then a 3 phase, Delta to WYE isolation transformer, electrostatically shielded, should be installed before the VFD with the WYE grounded with an individual grounding rod.
- The contractor shall specify in the bid (1) the maximum overvoltage and undervoltage prior to trip, (2) maximum overcurrent capacity prior to trip, and (3) maximum transient protection.

Lightning Protection

Recommendations of the NEMA Standard No. ICS7 shall be followed.

Voltage and Current Distortion back to the line.

The performance specified in IEEE 519 shall be met or exceeded. The contractor must specify the degree of harmonic control provided, after consultation with the local electrical utility. Performance must be verified after installation by an independent instrumentation contractor or the local utility. Such performance verification must be arranged by the contractor.

Sensors

The water level sensor shall be calibrated to within 0.2' of the water level in a stand, and shall have an accuracy better than plus or minus 0.1 feet.

Control

Water levels must be controlled within plus or minus 0.5 feet of the target depth.

Other

Radio frequency interference filters shall be provided.

Warranty

The installation shall have a two year warranty on all parts and labor, beginning on the date of satisfactory operation.

Attachment I

Site Photos

Figure I.1. Station D12. Pumps for the detailed study.

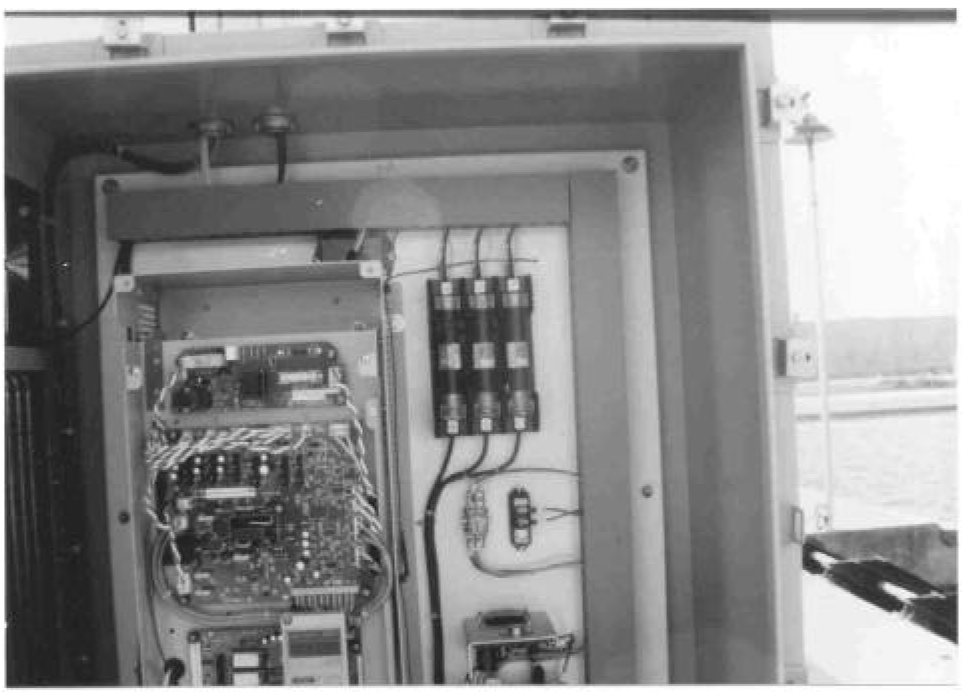
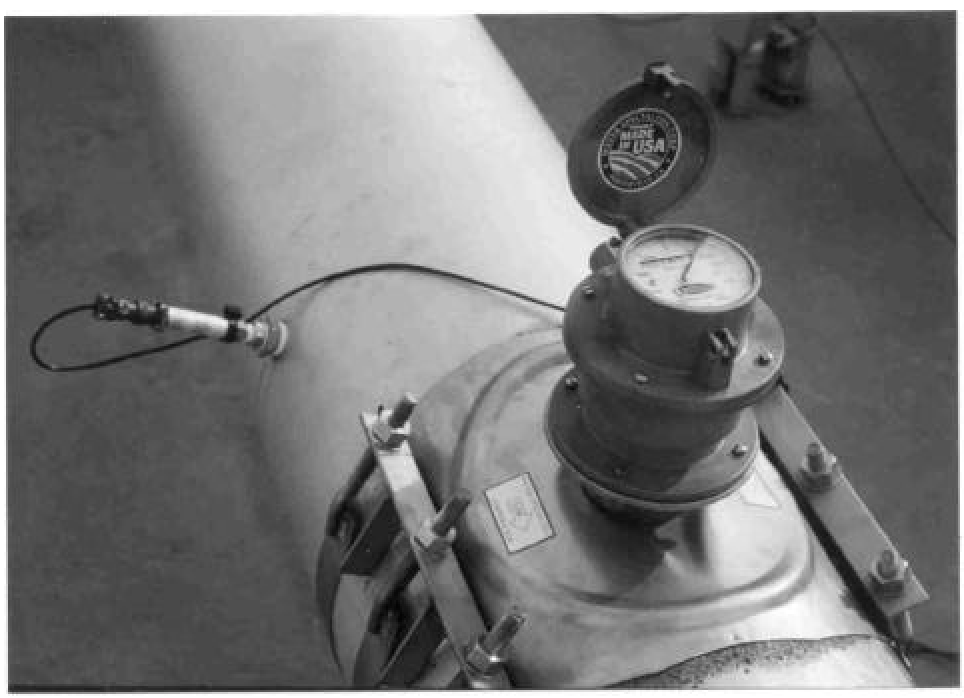


Figure I.2. Control panel for VFD at Station D12.

Figure I.3. Datalogger provided by SCE for data acquisition at Station D12.



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