

CASE STUDY ON DESIGN AND CONSTRUCTION OF A REGULATING RESERVOIR PUMPING STATION

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ABSTRACT

The case study is on the recently constructed pumping station on the Government Highline Canal, Grand Valley Project, Grand Junction, Colorado. The pumping station is part of a canal modernization project that includes new canal check structures, local automation, and a SCADA system. The pumping station design and construction process involved four areas: pumps, hydraulic structures, power distribution, and automation. The pump aspect included determining the needed pumping capacity, operational sequencing, pump selection, specifying and purchasing pumps. Hydraulic facilities work included the design of the intake structure, isolation gate, trash rack/fish screen, pump control house, pump discharge piping, and canal delivery structure. Power distribution work included extension of 3 phase power service 1.5 miles, selection of variable frequency drives and soft starts compatible with the power distribution system, connection of power to the pump control house, development of pump control strategy, and implementation of that strategy in the automation system. This pumping station is not necessarily a model for other projects, but rather a documentation of this project's requirements and the lessons learned.

INTRODUCTION

Grand Valley Project, Government Highline Canal

The Government Highline Canal was constructed in the first part of the 20th century. Water is diverted from the Colorado River into the Highline Canal, which flows 55 miles and serves 24,000 irrigated acres in the Grand Valley Water Users' Association (GVWUA) project area. Most of the earth laterals were converted to pipe in the 1980's as part of the Colorado River Salinity Control Program. The resulting elimination of lateral tail-water increased the volatility of flows in the Highline Canal. A canal modernization study was initiated and included the U.S. Bureau of Reclamation (Reclamation), the Irrigation Training and Research Center (ITRC), and the GVWUA. The Study evaluated the

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potential to reduce diversion from the Colorado River while enhancing fish flows in the historical low-flow fall season. The study analyzed three years of daily canal delivery data using the Canal-CAD hydrodynamic computer model. From this study, a recommendation was made to incorporate a regulating reservoir and pump station at Highline Lake as part of the modernization package. The project was funded with non-federal endangered fish recovery money.

The Highline Canal has a major administrative spillway structure from the canal into Highline Lake. The lake is located six miles from the end of the canal, and is upstream of 6,000 acres of irrigated project land (the “West End”). The sole water supply for the lake is spill from the Highline Canal. When full, the lake has a surface area of 140 acres, and there is a 38-foot static lift to the canal’s normal water surfaces. The Highline Canal upstream of the lake is operated with an upstream control logic, which passes any mismatch in supply or demand to the next downstream pool. Therefore, the plan was to have all flow mismatches accumulate at the Highline Lake spill. Any surplus water would be spilled and stored in Highline Lake and supply shortages would be supplemented by pumping from the lake..

PUMPS

Determining Needed Pumping Capacity

The spillway and pumping plant re-regulate the last six miles of the canal, which is now operated in downstream control mode. When supply exceeds demand, water is spilled into Highline Lake. Spilling water into the lake has been the historical operating method. By operating the canal with a smaller spill margin, there are times when demand temporally exceeds the available supply in the canal and water is pumped from Highline Lake to makeup the shortfall. The ITRC modeled the pumping requirements using historical daily demands with an added level of random errors to determine the maximum required pumping capacity. They determined that 75 cubic feet per second (cfs) would be sufficient to meet the largest historical daily demand change. The canal design flow at the start of the West End (the last 6 miles of the canal) is 160 cfs. The dynamic nature of flow in canals and the changing water demands can create shortages and spills in a variety of flows and durations. The pumping station responds incrementally to these supply shortages.

Operational Sequencing

To match the variability and unpredictability in canal flow shortages, a flexible pumping response is required. Three pumps were chosen to achieve the desired flexibility. The lead pump (Pump One) was slightly larger pumping capacity than the other two pumps and is driven by a motor coupled to a variable frequency

drive (VFD). Pump Two is one of the smaller capacity pumps and also has a motor with a VFD. Pump Three is a fixed speed pump with motor and soft-start.

The operational strategy developed by the ITRC was that the large pump is the first pump to start and the last pump stop in responding to a canal flow shortage. The minimum flow for the VFD pumps is 4 cfs and the maximum flow for the large pump is 29 cfs, with a maximum flow for the smaller pumps of 25 cfs each. The first pump operates in the flow range of 4-29 cfs. Although it is possible to operate the pumps below 4 cfs, due to prevalent manufacturers recommendations and operational need, a 4 cfs minimum was selected. Pumps one and two operate in the flow range of 29-54 cfs, and pump three is used in the rare situation of a flow shortages above 54 cfs, or as a spare pump in case of a pump failure. The important concept in this arrangement is that the large pump overlaps the maximum flow rate of the smaller pumps, so that there is no flow jump in changing from one pump, to two pumps, to three pumps. In other words, a flow rate of 29 cfs can be accommodated by pump one operating at full speed, or pump one operating at 4 cfs and pump two operating at 25 cfs without any discontinuity in flow.

Another operating strategy considered, but abandoned, was putting a VFD on a small pump and ramping it up and down while switching larger pumps on and off incrementally as the flow demand increases. This strategy requires a lot of pump sequencing and did not seem to offer the greatest flexibility and redundancy.

Pump Selection

Pump selection started by calculating the Total Dynamic Head (TDH) using the flow range for each pump. The static head is 38 feet and the dynamic head at maximum flow rate is calculated at 7 feet, for a TDH of 45 feet. This results in a flat system curve where over 80 percent of the TDH is from static head.

Based upon the assumption that slower turning motors and pumps would last longer, and that single stage pumps would be more simple and less expensive to maintain, only single stage pumps designed for 900 RPM or less were considered. Searching the single stage vertical turbine pump curves with a TDH of 45 feet at 29 cfs yields a group of pumps with a bowl diameter of 26-30 inches and a motor speed of 900 rpm.

Generally on VFD applications with a flat system curve, the full speed operating point is to the right of the pump's Best Efficiency Point (BEP) on the curve and as the pump rpm decreases, the operating point moves through the BEP. The next requirement is that the pump curve has a moderate slope and no inflection over the intended operating range. Figure one shows the selected pump curve for various pump speeds and the system curve. Not that at full speed, the system curve is to the right of the BEP. As the pump slows down, efficiency actually

increases for an operational range before efficiency starts to decrease. This was done because due to the staging of the pumps it is more likely that the pumps will be operating at less than full speed more often than they will operate at peak output.

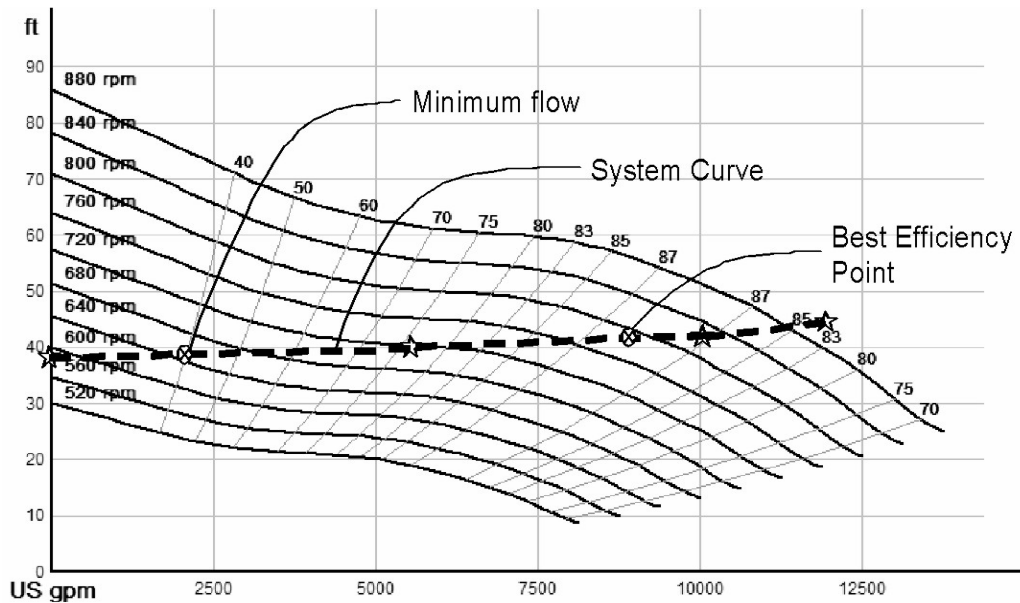


Figure 1. Selected pump curve with system curve.

Again, in the interest of simplifying maintenance, three identical pumps were selected. To achieve a higher flow, Pump One has a full size impeller and requires a 200 hp motor which will be driven by a VFD. Pumps Two and Three have trimmed (reduced diameter) impellers and require 150 hp motors. Pump Two has a VFD and Pump Three has a soft-start.

The engineering departments of the pump manufacturers having pumps with promising pump curves were contacted to ask for help in determining if the pump is well suited for the intended application and what other recommendation they have to offer. Once it was determined that a particular pump was a good fit, the next step was to ask for a recommendation of a supplier who is focused on the installation and maintenance of the type of pump being considered.

Specifying and Purchasing Pumps

The pump suppliers, who were recommended by the pump manufactures, were helpful in finding a solution to the pumping application. Established suppliers should have the field experience to achieve a good installation. The suppliers prepared a factory pump specification for selecting their pump. Factory specifications include features that tend to exclude the competitors' pumps. Comparing factory specifications between reputable pump competitors, was

helpful in distilling a more generic specification that was specific about the needed pump features for the project, but open enough to encourage competition among pump suppliers with pumps of acceptable quality. Included in the specifications were requirements for installation and start-up to be preformed by the supplier. The bids were ranked by their conformance to the specifications. Unacceptable bids were eliminated. Two things that were helpful in the bid processes were: there was a select list of bidders with known capabilities, and the low bid was not automatically awarded the contract.

Even with the above criteria, there were some interesting lessons in the processes. The low bidder (a friend of a friend who should not have been invited to bid) was 20 percent below the other proposals. They ignored the details in the specifications, sent in some cut-sheets, and stated that they met the specification (prove that we did not). They wanted to protest that they were not selected as the low bidder when their bid was eliminated. The high bidder (a local supplier) did not like the specifications and felt that they could deliver a better product if they were sole sourced as the pump supplier for the project. A very competitive and competent bidder wanted to redesign the large pump using a 34 inch bowl and slower turning motor (the pump structure would not accommodate this pump). The bid processes prevailed and good pumps were purchased from a good supplier.

HYDRAULIC FACILITIES

Intake structure

The principles of redundancy and simplicity guided the design of this pump station. The pumps share a common structure, but have individual pump bays. The intake structure is a monolithic reinforced concrete structure. The design is based on guidelines from the Hydraulic Institute and the book *Pump Station Design*. The design incorporates three parallel pump bays with the dimensions that are a function of the pump's bell diameter. The structure was designed around a 30 inch diameter pump bell. Ultimately a 26 inch pump was selected for the project. The structure design and the start of construction preceded the final pump selection, without determining whether or not over-sizing the structure by 15 percent is going to be a problem. Had the pump selection been made before the structure was designed, the structure would have been smaller.

The deck of the structure is designed to be 2 feet above the spillway elevation of the dam. Highline Lake was under a 5 foot water surface restriction in the 1990's due to excessive seepage through the dam. The leak has been repaired and the restriction removed. To protect the operation from similar limitations in the future, the pumping structure is designed with additional 5 feet of submergence over the pumps.

A construction contractor was selected based on their excellent performance on a previous bid for canal check structures, and the pumping structure was built on a cost plus basis. The greatest unknown in constructing the pump structure was the condition of the foundation material. The structure is located on a finger of the lake, normal to the centerline of the canal spillway. The plunge pool for the spill has been under water since the lake was constructed. The underlying material is shale with occasional gypsum lenses. This material decomposes rapidly when exposed to air and water and, is not a good foundation. Consequently, the sub-base for the foundation was over-excavated and back-filled with 177 yards of concrete before the structural foundation was formed on top of the concrete back-fill. The plunge pool for the canal spill now has a 5-foot thick concrete floor.

Isolation gate and trash rack/fish screen

Highline Lake is stocked with non-native sport fish for recreational fishing. These fish are predators of the native endangered fish that are being re-established in the Colorado River. To prevent fish escapement from the lake, into the canal, and possibly into the Colorado River, two 8-foot wide combination trash rake/fish screens were installed in front of the pump fore-bays. The 1/4-inch slotted screens serve as the pump intake screen and a fish barrier. A Langemann gate is installed in front of the fish screens to isolate the pump structure from the lake and prevent debris from canal spill from accumulating in front of the screen during non-pumping periods. An unanticipated problem was the high silt load that accompanies the spring runoff that is spilled into the lake in front of the pumping structure. Silt migrates into the structure despite the fact that the pumps are not operated and the isolation gate is closed. A periodic silt flushing routine is incorporated into the pump operations.

Pump Control House

The control house contains the electrical equipment that powers the pump station. The requirements for the control house are that it shields the electrical equipment from the environment and vandalism. The control house also includes two air conditioners to control the temperature inside the building. The power distribution requirements are: 480 volt 3 phase power for the pumps; 480 volt 3 phase power for the two power trash rakes; 240 volt single phase power for the two air conditioners; and 120 volt power to run the Langemann gate and the building lights. An additional requirement is to locate the VFDs reasonably close to the pumps to prevent harmonics from developing in the power cables between the pumps and the VFDs. The control house is located 5 feet above the pump-deck over the pump discharge piping. The house has a cast-in-place concrete deck supported by a steel frame. The walls of the house are constructed split-face masonry blocks. The roof is cast-in-place light concrete decking. The building is made of steel and concrete and is essentially fireproof.

Pump Piping and Canal Structure

Each pump has an individual pipeline, check valve and dissipater that discharge water into the canal. The size of the pump column and discharge head is 24-inch diameter pipe. To isolate the pump from the pipeline there is a rubber coupling and short spool connect the pump discharge head to a 24-inch check valve. The check valve is a massive spring loaded 45-degree swing-gate type valve. The valve can be serviced through a top port, without removing the valve body from the pipeline. The valve is anchored to the pump structure deck and serves as a thrust block as well as checking the 1,100 cubic feet of water in each pipeline between the pump station and the canal. Each of the three conveyance pipes are 300 feet of 27 inch, SDR-51 Plastic Irrigation Pipe, with fabricated steel elbows. The canal discharge structure is a three-compartment box, one for each pump, which dissipates the velocity head before spilling water into the canal. There are drain valves on both ends of the check valves, and there are no isolation valves required to service either the pumps or the check valves.

Using three conveyance pipelines, rather than one that requires for a manifold with a single pipeline, allows each pump to have an individual system curve. It would be very difficult to manage two VFD pumps and a fixed speed pump in parallel with high efficiency in a single pipeline conveyance.

ELECTRICAL POWER

Power Utility

The electrical utility company is a relatively small power company serving the rural areas of the Grand Valley. The closest three-phase power was a mile and a half from the pump station. The utility company was contracted to extend the three-phase power lines to the pump station and supply a 750 KVA transformer and service. The electric utility requirements were that the pump motors be “soft-started” at no more than 65 percent reduced voltage, and that any harmonics back-feed from the VFDs into their distribution system meet IEEE 519 section 1.06 standards. The reduced voltage pump start is necessary, because of power distribution limitations.

At this point in the program an electrical engineering consultant with an extensive background in power and VFDs was hired. The consultant task was to analyze the installation, write VFD specifications, prepare a bidders list, analyze the bid proposals, and make recommendations. To confirm performance of the VFD's and establish a baseline, the consultant will measure the harmonic levels feed-back to the distribution lines.

Selection of Variable Frequency Drives

The process of specifying the VFD, the electrical consultant marries the pump motor to the utility service. The pump motors were specified for VFD service at 5,000 feet elevation. The utility service was evaluated by calculating the three phase symmetrical fault current, which is 12,000 amps, with an $x/r = 1.15$ (inductance/resistance). These calculations were provided by the power utility company and were included in the VFD specifications. The electrical consultant found that the power distribution system has a high impedance source, which is referred to as “soft power”. Therefore, the VFD has to run the pumps, operate on “soft power” provided on the tail-end of a rural service line, and create a limited amount of harmonic feed-back to the service lines.

To provide some redundancy, two 200 hp VFDs were purchased. One will be on the 200 hp pump and the other will be on the 150 hp pump. Even though purchasing a 200 hp VFD for the 150 hp pump was more expensive, it was possible to purchase one spare parts package for both VFDs, thus overall this was a reduction in costs. A VFD on each pump is expensive and considered over-kill. Based on the field conditions, the consultant’s recommendation was an 18 pulse VFD. The specification was loosened up to include 6 pulse VFD with a front end filter to control the feed-back harmonics. A 200 hp VFD can drive a 150 hp motor, but the front end filters must match the horsepower rating of the motors. The supplier with the 18 pulse drive had the best proposal, but 8 weeks after being notified as the selected bidder they had not ordered the VFDs and would not be able to meet the delivery schedule. The second best proposal, a 6 pulse drive was given the contract. Even hiring a professional does not guarantee the process will go smoothly.

Compatibility

To assure system electrical compatibility it may be necessary to evaluate the power supply system, the supply transformer, the VFD, the harmonic filters and the pump motor. The need for this type of analysis increases as the pumping horsepower increases.

CONTROL STRATEGY

Pump Control Strategy

The pump control algorithm Proportional Integral Filtered (PIF) that the ITRC uses for canal gate control was used to control the pumps. The pump station control PIF constants were tuned as part of the Highline Canal Canal-CAD model by the ITRC. The strategy for control is a bit complicated, because it was decided to use the adjacent canal pool storage to minimize the number of pump starts. There are canal turnouts on the adjacent pool, and because the downstream check

structure is automated for downstream control, minimal variations in the pool water surface elevation are required to prevent water delivery service problems. The pumps are activated when the canal water surface drops one foot below the spill elevation. The pumps then attempt to maintain the water at that level. An operating rule to keep it simple is that only one VFD speed is changed per time step.

CONCLUSIONS

An appropriate conclusion might be a list of lessons learned:

- You do not know everything about everything; ask for help. If you really don't know what you know, hire an expert.
- Keep it simple and make it redundant.
- Put the VFD on the large pump and insure there is sufficient overlap between pumps.
- The pump-curve needs some slope when the system curve is flat.
- Get help from the pump manufacturers in putting the pump specification together.
- Select the pump size before completing the pump structure design.
- Silt Happens!
- Each pump has a separate isolated discharge pipeline if possible.
- The electrical power considerations include both the supply and the demand.
- The VFD is not the entire solution.
- Control strategy is everything; think hardware last.

REFERENCES

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