Utilizing Pressure to Put the Logic Back in Variable-Frequency Drive Controls

Martin (Tim) MacVittie

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In the coastal community of Hampton Roads, Va., sanitary sewer pump stations are often connected to large manifold force main systems. These systems can experience large pressure fluctuations due to the many pumps connected to the system. The programming logic for variable-frequency drive (VFD) controllers used to control sanitary sewer pumps in these areas has historically relied upon wet well levels to control pump speed settings. This condition can lead to sanitary sewer pumps operating in an area of the pump curve with reduced efficiency and increasing operation and maintenance (O&M) costs. This article discusses an improved control logic, improved efficiency, preferred operating conditions, and reduced O&M costs for sanitary sewer pumps operating in this condition. In addition, the results of a recent pilot project will be discussed.

Background

Hampton Roads is a large metropolitan region located in southeast Virginia, consisting of 10 cities and six counties, with a combined population of over 1.6 million. A map showing the extents of Hampton Roads can be seen in Figure 1.

The majority of the sewage generated within this region is treated by Hampton Roads Sanitation District (HRSD), a political subdivision of the Commonwealth of Virginia. The sewage is treated by 13 different wastewater treatment plants, with a combined treatment capacity of approximately 249 mil gal per day (mgd). Since the topography within this region is relatively flat, HRSD utilizes a large interceptor force main system to convey the sewage to the treatment plants. Additionally, each locality within this region utilizes a large number of pump stations in order to convey its sewage to the HRSD interceptor force main system. For example, the City of Virginia Beach owns and operates over 400 sanitary sewer pump stations. With such a high number of pump stations within the region, municipalities prefer duplex station configurations, with pumps sized for wet weather flow rates in order to minimize their associated installation costs. Due to the large number of pump stations pumping into the HRSD system, large pressure fluctuations can occur, especially when a station is far from a treatment plant.

Designing pump stations to account for these large pressure fluctuations can be challenging. Within the Hampton Roads region, VFD controllers have typically been utilized to overcome these pressure fluctuations. This is accomplished by varying the speed of the pumps based on wet well level set points. If the wet well level rises, the pump speed subsequently speeds up; if the wet well level falls, the pump speed subsequently slows down.

The HRSD issues pressure letters for connection points to its interceptor force main with modeled dry weather and wet weather pressures to allow municipalities to design their pumping systems appropriately. A sample of HRSD's pressure letter for the case study that will be discussed is illustrated in Figure 2. The dry weather pressure fluctuation for this letter is 34 ft and the difference between the minimum dry weather pressure and the wet weather pressure is 77 ft.

In order to minimize O&M costs, it is important to operate pumps within their preferred operating region (POR), as defined by the Hydraulic Institute standard ANSI/HI 9.6.3. Operation outside of this region generates unfavorable pump operation and higher O&M costs. The POR typically extends from 70 to 120 percent of flow at the best efficiency point (BEP), but it can be narrower depending on the pump. The POR is a much narrower region when compared to the pump manufacturer's allowable op-

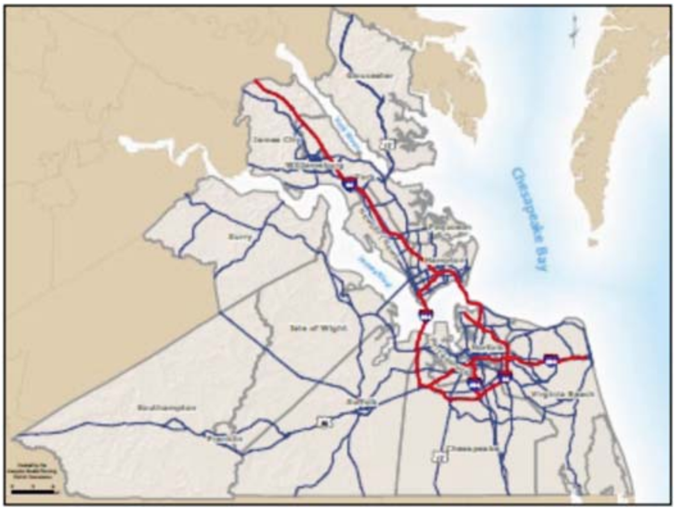
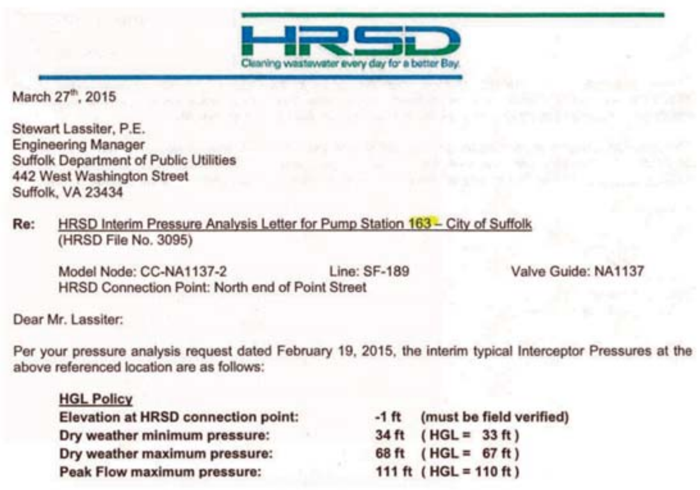


Figure 1. Map of Hampton Roads Region in Southeast Virginia



HRSD
Cleaning wastewater every day for a better Bay.

March 27th, 2015

Stewart Lassiter, P.E.
Engineering Manager
Suffolk Department of Public Utilities
442 West Washington Street
Suffolk, VA 23434

Re: HRSD Interim Pressure Analysis Letter for Pump Station 163 – City of Suffolk
(HRSD File No. 3095)

Model Node: CC-NA1137-2 Line: SF-189 Valve Guide: NA1137
HRSD Connection Point: North end of Point Street

Dear Mr. Lassiter:

Per your pressure analysis request dated February 19, 2015, the interim typical Interceptor Pressures at the above referenced location are as follows:

HGL Policy		
Elevation at HRSD connection point:	**-1 ft**	**(must be field verified)**
Dry weather minimum pressure:	**34 ft**	**(HGL = 33 ft)**
Dry weather maximum pressure:	**68 ft**	**(HGL = 67 ft)**
Peak Flow maximum pressure:	**111 ft**	**(HGL = 110 ft)**

Figure 2. Hampton Roads Sanitation District Pressure Letter

erating region (AOR). The AOR is also defined by ANSI/HI 9.6.3 and extends from the manufacturer's minimum safe flow for a pump all the way to the tail end of the pump curve.

Operating VFDs based on wet well level set points in areas with large interceptor force main pressure fluctuations can lead to operation outside of the POR. This is mainly due to the fact that the VFDs, in this instance, are being installed to overcome the system pressure fluctuations, but are being controlled by a variable that indirectly relates to system pressure. The only condition that causes the pump speed to increase is when the influent flow rate is higher than the discharge flow rate, as this condition will cause the wet well level to rise. With the pumps sized for wet weather flow rates, the operating point can move far to the left on the pump curve before it creates a condition where the wet well level will rise. This can occur during dry weather conditions, coupled with HRSD dry weather pressure fluctuations. This can generate pump operations far outside of the POR and sometimes even outside the AOR.

Operating outside of the POR increases radial thrust on the pump impeller, which increases the forces acting on the pump bearings and seals, causing them to fail prematurely; additionally, pump ragging increases due to an increase in pump recirculation. Pump efficiency also decreases the further operation that occurs from the best efficiency point, thereby driving up electrical consumption costs; additionally, vibration also increases further as the operation drifts away from the POR. All of these items drive up the costs associated with operating and maintaining pump stations.

However, if a system variable that directly correlates to system pressure, such as station discharge flow rate or force main pressure, is utilized with wet well level, the control logic can be optimized. This optimization will help minimize the O&M costs associated with each pump station by maintaining operation within the POR.

Example Case Study

The City of Suffolk, Va., recently asked Brown and Caldwell to design a new pump station to service the Cedar Hill area of the city. A pressure letter was issued by HRSD (Figure 2) for this station's connection point to its interceptor force main system. Additionally, this station had a metered average daily flow rate of 341 gallons per minute (gpm) and an existing modeled 10-year wet weather flow rate of 3,860 gpm. Because of the large pressure and flow

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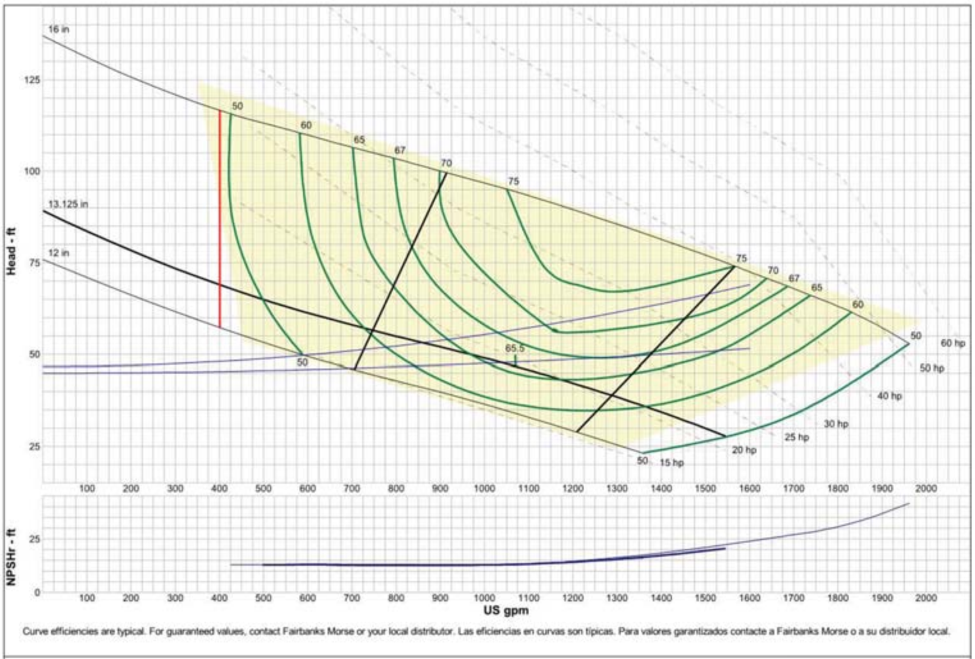


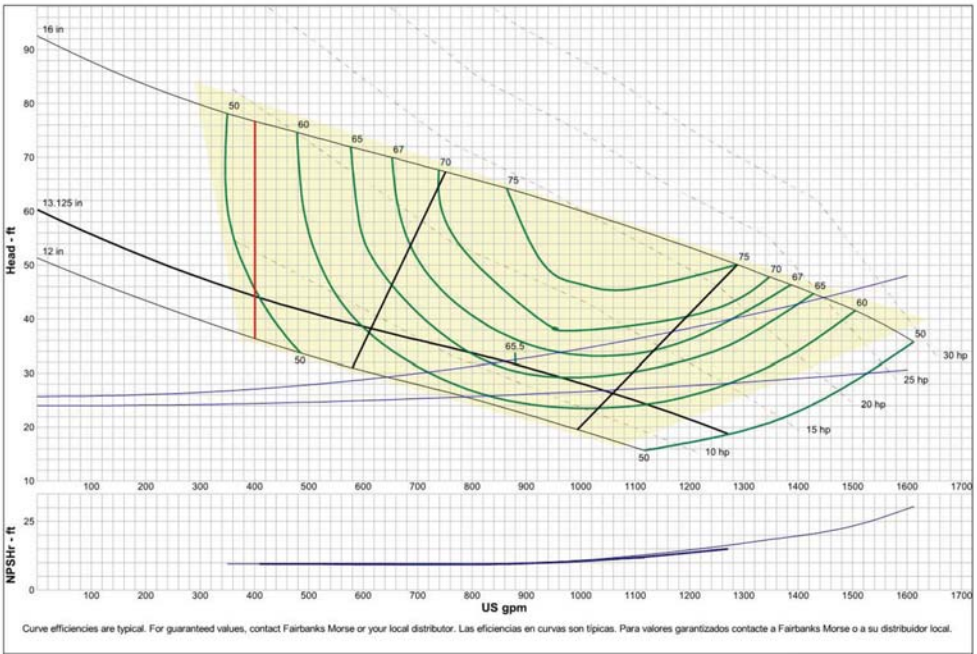
Curve efficiencies are typical. For guaranteed values, contact Fairbanks Morse or your local distributor. Las eficiencias en curvas son típicas. Para valores garantizados contacte a Fairbanks Morse o a su distribuidor local.

Company: Brown and Caldwell
Name: Martin MacVittie
4/4/2016
Small Pump ADF.ufs

Fairbanks Morse Pump, 60 Hz
Catalog: Fairbanks Morse Submersible.60, Vers 3
5430BLADELESS - 1200
Design Point: 853 US gpm, 49.3 ft

Size: 6"5434MK&WK
Speed: 1180 rpm
Dia: 13.125 in
Curve: 340606A
Impeller: T6D1A

Figure 3. Maximum Daily Pressure System Curve and Full-Speed Pump Curve



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Company: Brown and Caldwell
Name: Martin MacVittie
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Small Pump ADF.ufs

Fairbanks Morse Pump, 60 Hz
Catalog: Fairbanks Morse Submersible.60, Vers 3
5430BLADELESS - 1200
Design Point: 853 US gpm, 49.3 ft

Size: 6"5434MK&WK
Speed: 970 rpm
Dia: 13.125 in
Curve: 340606A
Impeller: T6D1A

Figure 4. Minimum Daily Pressure System Curve and Minimum-Speed Pump Curve

Continued from page 33

rate fluctuations, Brown and Caldwell recommended two dry weather pumps and two wet weather pumps. The remaining discussion will be focused on the sizing and control of the dry weather pumps.

System curves were developed for the pumping station and a dry weather pump was selected for the anticipated daily pressure fluctuations. Additionally, the firm pumping capacity for the dry weather pumps was set at 853 gpm in order to bridge the gap between dry weather and the modeled 10-year wet weather event. Figure 3 depicts the dry weather pumps operating at full speed against the maximum daily pressure system curve, and Figure 4 depicts the dry weather pumps at minimum speed operating against the minimum daily pressure system curves.

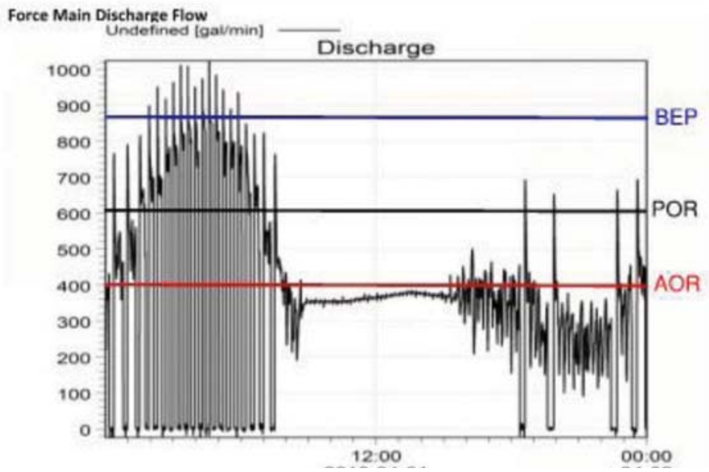

Figure 5. Pump Model Results (Discharge Versus Time of Day)

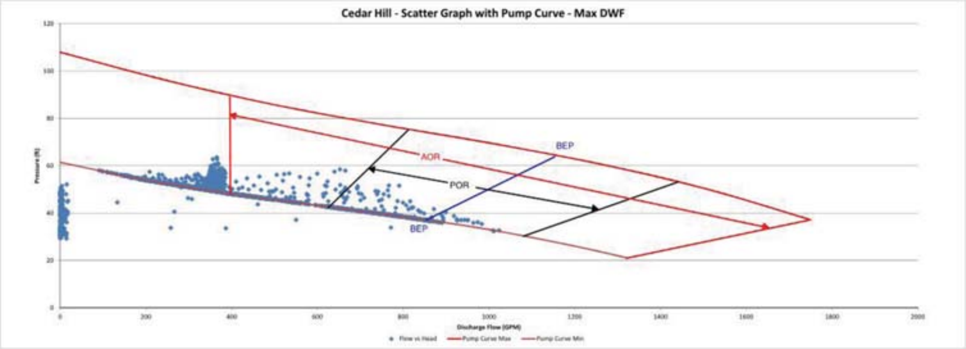

Figure 6. Pump Model Scatter Graph Results (Pressure Versus Discharge Flow)

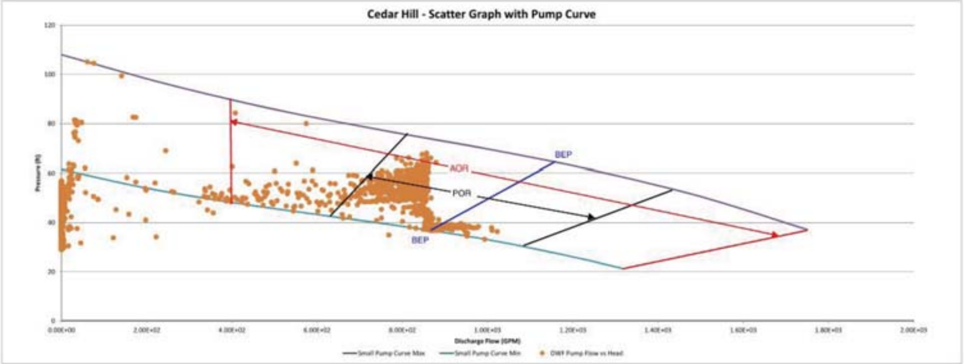

Figure 7. Modified Model Scatter Graph Results

Notice that the intersection of both system curves occurs within the POR for both the maximum and minimum HRSD pressure system curves; therefore, there is a way to control the pumps that places their operation within the POR. The City of Suffolk asked its modeling consultant to model these pumps utilizing a hydraulic model of the HRSD force main system to simulate the pump operation using the city's standard control logic. The model accounts for the daily fluctuations in both influent flow rates, as well as HRSD pressures. A graph illustrating the results from these model runs is displayed in Figures 5 and 6.

Although the pump selection appears to be acceptable, as indicated by the operating points shown in Figures 3 and 4, the control logic was preventing the pump from operating as intended. The model results indicated that the pumps were operating almost 60 percent of the day outside the pump manufacturer's AOR (Figure 5).

Based on the modeling results, Brown and Caldwell recommended that the model controls be modified, such that pump speed would be adjusted in order to target a discharge flow rate; the wet well level readings were only used to start and stop the pumps. The modeling results based on the modified control logic are illustrated in Figure 7.

As shown in Figure 7, the pump operation improved significantly when a variable directly related to system pressures was utilized. It is worthy to note that the points on the far left of the scatter graphs were taken as the pump was just starting in the model and are not an indication of sustained operation in that location.

As a result of the modeling, the City of Suffolk requested that Brown and Caldwell test the logic on an existing city pumping station prior to its implementation elsewhere in its system. Brown and Caldwell worked with the city's instrumentation and control engineering consultant to develop and implement the logic. Since the city does not have any existing discharge flow meters in its system, it requested that the logic be based off of discharge pressure readings.

Pump Control Logic

The implemented control logic utilizes force main pressure readings prior to pump start to calculate the pump total dynamic head (TDH). In order to account for the system pressure increases due to pump start and operation, two separate TDHs are calculated. The first one, called "Pump Start TDH," is utilized just for the start-up speed selection and incor-

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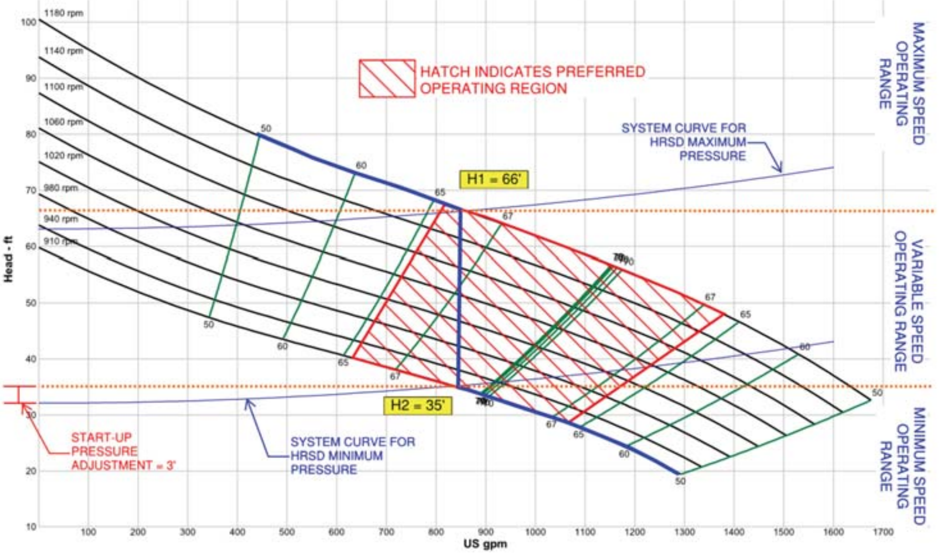

Figure 8. Discharge Pressure Control Logic

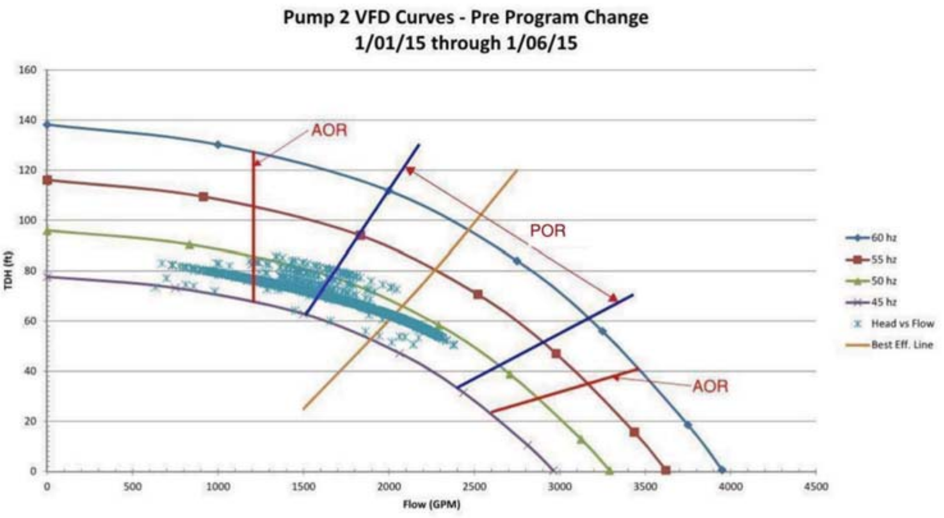

Figure 9. Existing Control Logic Pump Operation

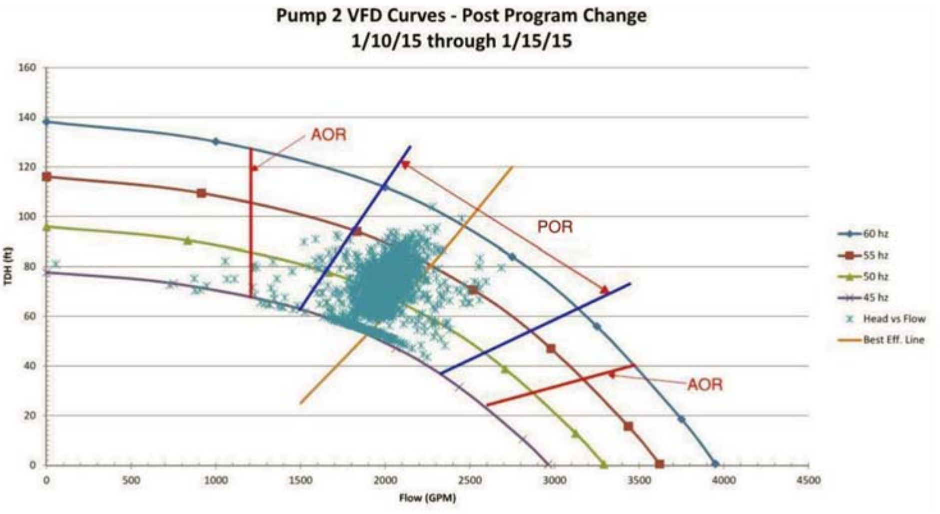

Figure 10. Changed Control Logic Pump Operation

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porates a constant that accounts for the pressure increase caused by the pump operation. The "Pump Start TDH" is calculated by the following equation:

Pump Start TDH = $(P + F_{PTP} + Z + I) - (WW_L - F_{WWP})$

P = *Average of the pressure readings over the last 10 seconds*
F_{PTP} = *Constant equal to the estimate of the friction loses between the pump and the pressure transducer*
Z = *Vertical distance between the pump volute and pressure transducer*
I = *Constant equal to the increase in system pressure due to pump operation/start-up*
WW_L = *Current wet well level*
F_{WWP} = *Constant equal to the estimate of the friction loses in the suction piping*

The second TDH, called "Pump Run TDH," is utilized for speed adjustments after the pump has already started. These adjustments do not occur until 30 seconds after the pump has started in order to prevent the controls from reacting to system surge pressures. The "Pump Run TDH" is calculated by the following equation:

Pump Run TDH = $(P + F_{PTP} + Z) - (WW_L - F_{WWP})$

P = *Average of the pressure readings over the last 10 seconds*
F_{PTP} = *Constant equal to the estimate of the friction loses between the pump and the pressure transducer*
Z = *Vertical distance between the pump volute and pressure transducer*
WW_L = *Current wet well level*
F_{WWP} = *Constant equal to the estimate of the friction loses in the suction piping*

Figure 8 illustrates the methodology utilized to select the pump speed based on the calculated TDHs. If the calculated TDH is above "H1" then the pump goes to full speed; if the calculated TDH is below "H2" then the pump goes to minimum speed. If the calculated TDH is between H1 and H2 the speed is interpolated accordingly.

Scatter graphs from supervisory control and data acquisition (SCADA) data show the pump operation before and after the control logic modifications were generated to substantiate the benefits of this logic change. These scatter graphs are shown in Figures 9 and 10, respectively.

Figure 10 depicts the improved pump operation that occurs based upon the improved pump control logic.

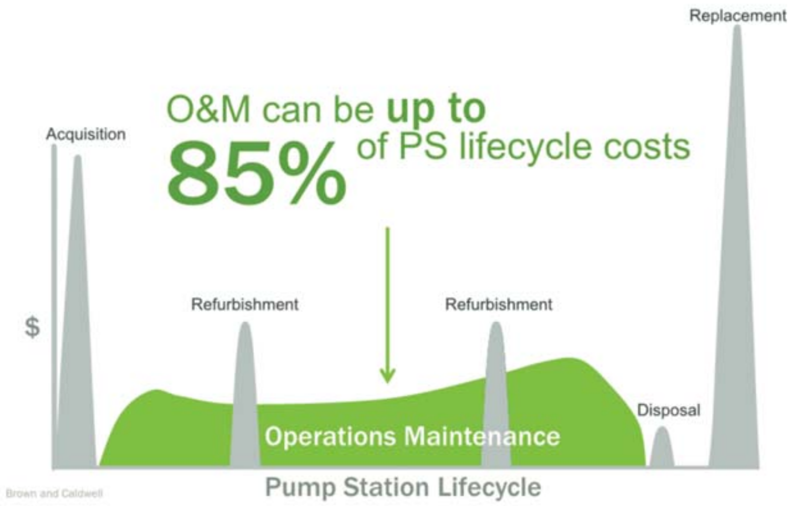

Figure 11. Pump Station Life Cycle Costs

Conclusion

When analyzing the life cycle costs of owning a pump station, it has been determined that up to 85 percent of the cost can be associated with station O&M. It is important to focus on minimizing these costs during the design stage of these facilities.

Minimizing these costs requires focus on three critical elements of station design: the stations hydraulic configuration (wet well geometry and piping configuration), pump selection, and controls. This discussion only focused on the control optimization for pump stations that experience large pressure fluctuations downstream. The benefits from optimizing the controls can be negated by failing to focus on and optimize the hydraulic configuration and pump selection. The effectiveness of this control logic also relies on obtaining accurate pressure readings from the system. Therefore, the pressure transmitters should be isolated from the process fluids through the use of a diaphragm seal or full-body ring seal, and calibrated and tested on a regular frequency. Using this modified control logic in areas with large force main pressure fluctuations, coupled with proper pump selection and station hydraulic configuration, can help to ensure that pump operation occurs within the POR and reduce the O&M costs associated with the following:

- Electrical Usage
- Seal and Bearing Replacements
- Shaft Replacements
- Pump Deragging
- Impeller and Case Wear
- Excessive Vibration