More than Energy Saved

Des Moines WRA Improves Reliability with Medium Voltage Drives

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Abstract: The Des Moines, IA WRA uses six centrifugal pumps in the headworks to lift the plant influent flow from the influent wet well to the plant. They have historically used variable speed pumping to optimize the pump system. For several years the reliability of the existing VFDs was poor, and in recent years the maintenance cost of the pump system and drives has been unacceptable. By replacing the existing VFDs with state-of-the-art medium voltage drives the plant staff has achieved reliability and operator confidence that exceeded their expectations.

Keywords: variable speed pumping, variable frequency drives, medium voltage drives, pump reliability, VFD maintenance

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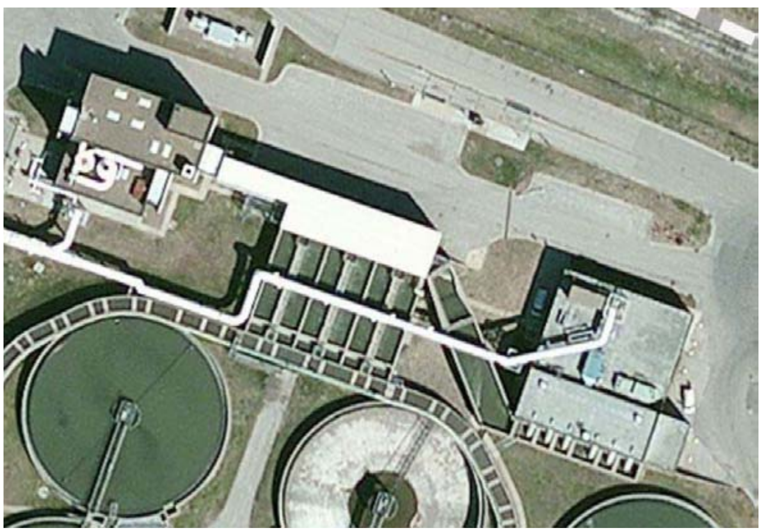
Introduction: The Des Moines, Iowa Metropolitan Wastewater Reclamation Authority (WRA) serves 17 area municipalities, counties and sewer districts. The central wastewater treatment facility provides BOD (Biochemical Oxygen Demand) removal and nitrification for these communities prior to discharging treated water into the Des Moines River. The plant has a design hydraulic capacity of 200 mgd (million gallons per day), with current average dry weather flows ranging between 40 and 60 mgd. Three shifts of operators are on duty to keep the plant running smoothly.

The 125 mile long conveyance system terminates at the plant headworks. After passing through bar screens the wastewater enters the influent wet well. From there the raw wastewater pumping system raises the wastewater 54 feet. The flow then passes by gravity through the grit removal system and the rest of the treatment processes. Plug flow activated sludge is used for secondary treatment. Anaerobic digestion provides sludge reduction and generates methane, which is used for digester heating.



Aerial View of Headworks

The WRA includes sustainability and energy conservation in their core values. With electricity consumption of nearly 80,000 kWh per day energy is an economic consideration as well. The WRA has won recognition for its conservation efforts. WRA's conservation programs have also resulted in a variety of grants and financial incentives from government agencies and their electric utility, MidAmerican Energy.

Background: The influent pump station follows a common design pattern. The raw wastewater wet well level is monitored by a level transmitter connected to the plant PCS (Programmable Control System) and connected to a central SCADA (Supervisory Control and Data Acquisition) system. The PCS uses programmable logic controllers (PLCs) for I/O and logic.

Six (6) 700 hp centrifugal pumps are installed in the raw wastewater pump station. Each pump is rated for 60 mgd (4,100 gpm). The pumps are installed in a dry well, and extended shafts raise the motors several stories above the pumps. The motors are 4160 VAC, 514 rpm, with WP1 enclosures. The motors

View of the Pump Gallery

are rated "adjustable speed duty" for compatibility with VFDs. During dry weather conditions only one pump is needed. During rain events and spring snow melt up to five pumps have been required to operate in parallel for short duration peak flows.

A separate VFD is provided for each pump, located several stories above the motors. Two separate power buses provide medium voltage to the variable frequency drives (VFDs). This allows removal of half of the drives from the medium voltage power for service without disrupting pumping ability. The PCS maintains constant wet well level by varying the pump speed and flow. As with most municipal facilities there is typically a 2:1 variation daily between peak and average flow rate.

The VFDs were designed to provide two principal benefits for the influent pumping system. First, by allowing the pump flow to match the flow rate from the conveyance system continuous wastewater flow is provided to the preliminary treatment system. This eliminates frequent starting of the pumps and results in more uniform hydraulic loading to the grit removal and other downstream processes. The performance of these processes benefits from continuous hydraulic loads.

The second benefit of the VFDs is a "soft start" for the pumps, with the intent being to reduce torsional shocks and torque loads during acceleration. Limiting damage from short cycling of the pumps and motors is another benefit of continuous operation.

The VFDs provide some energy cost reduction, primarily by minimizing demand charges ($5.85 per kW). Actual energy consumption benefits are limited, since the pump head is almost entirely static lift with minimal friction losses in the discharge piping. As is to be expected with this type of pump load the operating speed range is limited – between 81% and 100% speed (49 and 60 Hz). The limited speed range and small friction component result in minimal total energy savings from variable speed.

Several protective functions were included in the pump control system. Motor protection relays were provided to monitor motor winding RTDs. The pump and motor bearings were also fitted with RTDs for temperature monitoring. The pump shafts were monitored for vibration as well. The pump bearing monitors are connected to a Bentley Nevada protection system.

Original VFD Problems: The original medium voltage VFDs were installed in 1996. The VFDs were a so-called "clean power" design, with the intent being to minimize line side harmonics. Each VFD had an autotransformer on the line side to provide "18-pulse" waveform and minimize harmonics. That aspect of the VFDs performed per expectations.

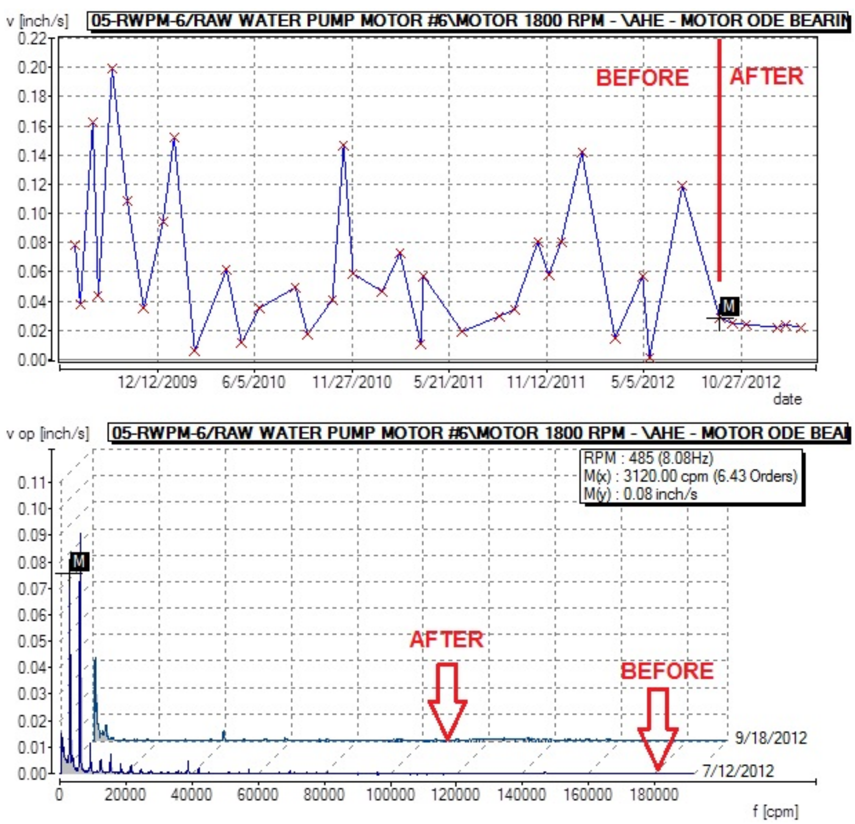
Unfortunately, the system was plagued with reliability issues and high maintenance expenses. Some of these expenses were directly related to the VFDs themselves. The VFDs were also implicated in multiple mechanical concerns associated with the pumps and motors.

One serious problem with the VFDs was frequent and chronic failures of the IGBT (integrated gate bi-polar transistor) cells. These failed at an alarming rate, with as many as seven cells failing in a single week. This was of great concern because keeping the influent lift station operational was absolutely essential to providing treatment for the communities relying on the WRA. At one point it was necessary to keep one of the six VFDs offline and use it as a "parts machine" – scavenging components from it to keep the other five VFDs operational. The expense of replacement cells was also a concern. In addition to the labor and time required for the plant electricians to change out the defective cells replacement IGBT cells cost over $3 thousand each!

Factory and local help from the VFD supplier was minimal at best. The plant staff first suspected that power quality problems from the utility were causing transients and damaging the VFDs, but investigation proved that that was not the case. After an arduous program of testing and component replacement the plant electricians determined that defective capacitors in the VFD were causing the IGBT cell failures. By replacing the capacitors the epidemic of IGBT cell failures was eliminated.

As with any utility power system there were occasional Voltage sags in the VFD power source. This resulted in the VFDs dropping out because of limited ride through capability. The plant would have to wait for the pumps to coast down to a stop and then restart them. This in turn resulted in surges in the hydraulic loading of the grit tanks and preliminary treatment system.

The problems traceable to the VFDS didn't end there, unfortunately. The pumps exhibited extreme vibration during starting. This was originally attributed to cavitation, but it is more likely that internal recirculation in the pump during acceleration caused the phenomenon. Until a pump reaches a speed where it can provide sufficient head to overcome the static pressure, flow cannot occur. During this time the water circulates inside the pump case and can result in vibration, overheating, and eventual mechanical damage to the pump.



Motor Vibration Trend & Spectrum Before & After VFD Replacement

There were even more significant vibration and mechanical issues. Bearing failures were a common occurrence with the pumps and motors. The assistance of Pros, Inc., rotating machinery specialists, was enlisted to diagnose the problems. Brinelling and grooves in the races of the bearings were observed. This was initially attributed to bearing fluting from current discharges from the rotor to ground through the bearings. Grounding brushes were added to the motors, but the problem persisted. Bearing repairs for the pumps and motors reached a total of $90,000 – clearly unacceptable. A program of diagnostic vibration testing was implemented as part of the plant preventive maintenance. This was able to avoid catastrophic failure by predicting impending bearing issues, but the cause of the short bearing life could not be immediately identified.

Some of the pumps also exhibited disturbing levels of vibration during normal operation – to the point that the lift station floor would shake. Pump #6 was particularly prone to this experience. The Pros, Inc. analysis established that this was not related to the bearings. The VFD manufacturer was unable to identify or resolve the problem.

VFD Replacement: By 2012 the replacement of the VFDs was the only viable option. The concerns over reliability, ongoing operational issues, and the high cost of maintenance could no longer be tolerated. The staff investigated alternate VFDs and initiated a project to replace the existing drives.

Through the Baldwin Automation & Controls, the local ABB distributor, with assistance from ABB factory application engineers, ACS-2000 medium voltage VFDs manufactured in New Berlin, Wisconsin by ABB Inc. were selected. These drives feature direct to line connection, eliminating the need for isolation transformers. The active front end (AFE) provides "clean power" compliance with IEEE 519 specifications on the line side of the VFDs. The active front end in the ABB design is very efficient and achieves harmonics compliance with minimal losses, providing a substantial improvement over the transformers used in 18-pulse and 24-pulse systems.

On the motor side of the drive several ACS-2000 features were important to the Des Moines application. The IGBT switching and built-in dV/dt filtering insured compatibility with the existing pump motors and eliminated concerns regarding insulation life. The output provides sinusoidal waveforms for both voltage and current. The advanced design provides high efficiency (96.5% at full load) and near unity power factor throughout the operating range.

Three of the Six New ABB Medium Voltage VFDs

The new ACS-2000 VFDs feature a much smaller footprint than the existing drives. This was important, since access to the existing location was limited. The new VFDs had to enter through existing personnel doors, creating a challenge for the contractor. It was an extremely tight fit, but the compact design made it possible. Once the new drives were installed the small footprint provided 360° access which was important for both improved cooling and future maintenance. The ambient temperature rating of 104°F (40°C) further alleviated staff concerns about reliable operation in the demanding Iowa climate.

Because of the unsuccessful performance of the original VFDs the reliability and maintainability of the new units were high on the list of concerns for the plant staff. The Midwest location of the ABB factory, extensive spare parts inventory, and available local support influenced the plant's selection of ABB. The ACS-2000, with advanced components and a low part count is inherently more reliable than older designs and has an outstanding mean time between failure (MTBF). Furthermore the modular design, extended use of standardized components throughout the drive, and front access design simplify maintenance if it is required. Advanced thermal management techniques provide reliable cooling of all components. This eliminates internal heat, which is the most common cause of component failure. Additional gains in reliability are achieved in the ACS-200 by eliminating the electrolytic capacitors of the previous VFDS's. ABB's design utilizes reliable oil filled film capacitors, similar to the power factor correction capacitors used by electric utilities.

A separate 480 VAC 3-Phase power supply is provided to the drives for pre-charging the DC bus and powering control circuitry. This allows immediate availability of the pumps without providing continuous 4160 VAC power to idle components. The result is enhanced reliability and reduced heat rejection to the pump building. When the drive is called, a pre-charge cycle of a few seconds duration is initiated. When the cycle is complete the drive provides a ready status, and the PCS initiates pump startup and acceleration.

The ACS-2000 has direct torque control (DTC) which provides more precise speed control than the conventional Volts/Hz control employed in many designs. This control is obtained without encoders or tachometers on the motors.

Although the ACS-2000 proved very easy to configure using the front panel keypad ABB provided factory technicians to assist in commissioning. Training in operation and maintenance by factory engineers was also included with the system. The plant feels that the installation and start up were remarkably trouble free.

Results: The new ABB medium voltage drives have completely met the plant's objectives for performance and reliability. The new system has even provided a number of unexpected benefits.

The authority was able to obtain financial incentives from the US Department of Energy and from their electric utility as part of their standard variable speed pumping programs. This made justifying the expenditure easier, but for plant staff the need to achieve reliable performance overwhelmed all other considerations. Wastewater treatment plants must be able to provide 24/7 performance, without exception.

According to Brent Arntzen, Maintenance Coordinator for the WRA, “There have been no problems with the ABB drives.” This is a welcome relief from the ongoing struggle to keep the old system operational.

The plant expected the new drives to be reliable, but there have been a variety of additional and unexpected benefits. The most important of these are related to the mechanical operation of the pumps.

The first thing that the staff noticed was the absence of the pump vibrations during starting. The pumps quietly and smoothly accelerated and established flow. The disturbing vibrations that previously shook the entire building during pump starting were simply gone.

The next thing the plant realized was that pump #6 now operated as smoothly as the other units. The mechanism causing the original vibration on this pump, and the reason it disappeared with the ABB drives, are not fully understood. Nonetheless, the fact remains that the problem is gone, and #6 can be operated in turn with the other five pumps.

The staff found that they were no longer experiencing the bearing failures that had previously plagued the pumps and motors. The preventive maintenance testing by Pros confirmed this benefit. Again, the mechanism for the problem and its elimination isn’t fully understood, but the vibration spectrum analysis confirms it.

The superior ride through capability of the new VFDs has eliminated most of the nuisance trips associated with momentary power sags and voltage dips at the utility connection.

The noise level in the VFD room has noticeably decreased. The old VFDs were powered up at the full 4160 Volts continuously and the cooling fans for all six VFDs had to run continuously. Because the new ABB units only power the low voltage section in standby mode the cooling fans aren’t required until the pumps are started, improving operator comfort.

The low heat generation of the ABB drives in standby mode resulted in an unexpected reduction in operating cost. The original system required continuous operation of two air conditioning (A/C) units to maintain the VFD room at an acceptable temperature during the summer. One A/C unit was rated 20 tons (240 thBTU/hr, 70 kW) and the other was rated 25 tons (300 thBTU/hr, 88 kW). Both units were required even when only one pump was running to meet dry weather flow. With the ABB drives one A/C unit is expected to be sufficient to maintain acceptable VFD room temperature. This will represent a significant reduction in A/C power consumption. If the efficiency of the A/C unit is estimated at 80% then the reduction in summertime power demand is between 88 kW and 110 kW. The plant is investigating an available option from ABB that would provide ducts for the VFD cooling air flow. This would allow the heat to be vented outside the pump building, further reducing the summertime air conditioning load.

The pump start/stop commands are hardwired to dry contacts in the PCS system PLC in the pump building. The speed reference is a 4-20 mA signal hardwired between the PLC and the drives. Each ABB drive also includes a Modbus serial communications port. The plant personnel connected them to a communications port in the PCS local PLC and programmed the PLC for data collection from the VFD. This has greatly expanded the information that is available to the SCADA system. The data collected includes multiple status and alarm bits that could not be conveniently hardwired. The communications link provides enhanced diagnostics capabilities for the operators.

Conclusions: VFD applications are commonly thought of as energy conservation measures. Certainly in a great many cases this is true, and the reduction in energy consumption and power costs can be impressive. It is important to remember, however, that energy is not the only factor that influences VFD selection. The Des Moines influent pumping system is a case in point.

In wastewater treatment the requirement to remove pollutants continuously and reliably is absolutely the first priority. Once this is accomplished the secondary objective of cost optimization can be considered.

Treatment plant operators are dedicated professionals, and they take their responsibility to the public and the environment very seriously. Wastewater treatment is a technically demanding field, and multi-disciplinary skills are mandatory to maintaining process performance. Operators can’t be experts in all of these disciplines, and they occasionally need support from specialists provided by manufacturers and suppliers. Failure to get this support can create a crisis that goes beyond economic considerations.

The Des Moines WRA could not tolerate the high failure rate and poor reliability of their original VFDs. These issues were aggravated by poor support from the original supplier. Replacement with a system the operators could rely on was mandatory.

The answer was to use high quality medium voltage VFDs from ABB – the ACS 2000. Immediately after these were installed the plant was able to reliably and consistently meet the performance requirements of raw wastewater pumping. A high confidence level has been established in the ABB VFDs. The plant knows that the drives themselves will continue to operate reliably, and they are comfortable knowing that secondary failures in the pumps and motors have been eliminated.

Energy cost is always a concern, of course. Sometimes, however, selecting the right drive and engineering the right application is about much more than the energy saved.

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