BROWN AND CALDWELL

SEATTLE REGIONAL OFFICE
SEATTLE, WASHINGTON

TECHNICAL MEMORANDUM 24616.108

DATE: March 10, 2004

TO: Eric Johnson, P.E., City of Tacoma

FROM: Gary L. Anderson, P.E.

SUBJECT: Medium Voltage VFD Evaluation

Background and Introduction

The City of Tacoma will be upgrading and expanding its Central Wastewater Treatment Plant (CTP) to provide new treatment process(es) for peak wet weather flow, expand the plant's hydraulic and treatment capacity, and repair / rehabilitate certain existing features and structures at the plant (collectively referred to as "the Project").

The City has elected to develop the Project using an alternative delivery design-build process under RCW 39.10, and is currently in the process of defining Project technical requirements. R.W. Beck is advising and assisting the City on the design-build procurement process. Brown and Caldwell, as a sub-consultant to R.W. Beck, is providing technical support to help better define Project requirements.

The City has an approved Facilities Plan from the Washington State Department of Ecology. While the Facilities Plan addresses many aspects of the Project, the City has identified certain changes from the Facilities Plan that it wishes to incorporate into the Project. Examples of such changes include: replacing the chlorine disinfection system with a hypochlorite system, including several repair / rehabilitation activities in the Project scope, and deferring work on the outfall until a later phase. In addition, the City has decided, wherever practical, to define Project requirements in terms of performance specifications and basis of design requirements, rather than specific design concepts, in order to provide proposing firms with the opportunity to innovate. The scope of the Project includes expanded influent and effluent pumping capacity.

The CTP's existing influent pump station consists of three 400 hp pumps with a rated capacity of 39 mgd per pump. The capacity of the existing influent pump station with all pumps online is limited to approximately 103 mgd, due to flow restrictions in the former comminutor channel immediately downstream of the pump station. The existing influent pumps are equipped with eddy current type drives.

The existing effluent pump station consists of three 450 hp pumps producing total station flows ranging from 75 mgd to 86 mgd, depending upon tidal levels. The existing effluent pumps are equipped with variable frequency drives (VFDs). These drives are susceptible to utility "bumps" or excursions.

The Facilities Plan encompassed the following concepts for upgrading the CTP's influent and effluent pumping capacity:

- Two new influent pumps rated for 45 mgd at 55 feet of head with 600 hp VFDs installed in a new wet well constructed as an extension of the existing influent pump station wet well;

- Replacement of the three existing effluent pumps with three new 40 mgd pumps, at 75 feet of head, with 800 hp VFDs; and

- Installation of five new 37.5 mgd effluent pumps, at 165 feet of head, with 1,500 hp VFDs, at a new effluent pump station.

Subsequent to the Facilities Plan, the City determined that some flexibility in meeting the expanded pumping requirements could be provided to teams proposing on the design-build Project but that certain minimum Project requirements would be established in the Project technical requirements. In part, these are likely to include:

- Influent pumping capacity will need to be at least 150 mgd with the largest pump off-line and will need to accommodate flows as low as 8 mgd. The capacity of the influent pump station with all pumps online will be approximately 200 mgd.

- Redundancy for influent pumping will determined by meeting Ecology Orange Book requirements.

- Proposers will be allowed to select the number and types of influent pumping units provided that: influent pumping system meets the minimum and maximum flow requirements; pumps operate in a rpm range that results in reduced noise and equipment wear on the pump and motor; pumps selected would most frequently be operating in the more efficient area of their operating curves; and other requirements in the pump technical specifications are met.

- Effluent pumping capacity will need to be 150 mgd with the largest pump off-line. The capacity of the effluent pump station with all pumps online will be approximately 200 mgd. It is possible that the City may elect to provide an initial installation capacity somewhat less than 200 mgd (with all pumps online) and provide space for future pumps to provide the peak expansion capacity of 200 mgd following outfall improvements (determination yet to be made by the City).

- Redundancy for effluent pumping will be determined by meeting Ecology Orange Book requirements.

- Proposers will be allowed to select the number and types of effluent pumping units provided that: effluent pumping system meets the minimum and maximum flow requirements; pumps operate in a rpm range that results in reduced noise and equipment wear on the pump and motor; pumps selected would most frequently be operating in the more efficient area of their operating curves; and other requirements in the pump technical specifications are met.

The existing influent drives are eddy current type drives that are approximately 20 years old. However, because of their durability they are likely to remain in service for many more years if provided with new controls. Given new controls, we believe that there would only be a moderate and reasonable risk associated with the re-use of the existing eddy current drives. Therefore, due to the longevity of eddy current drives, we also recommend leaving the selection of influent pump station drives (ie: VFD or eddy current) to the Proposers based on their influent pump station design strategy. If the existing pumps and motors are reused and the drives replaced with VFDs, consideration must be given to the fact that the existing motors are not VFD rated. (Additional information and discussion of these issues is included under the Eddy Current Drive Replacement Issues section of this memorandum.) Due to past failures of the existing effluent VFDs, they should be replaced as part of the DB Project, although the existing motors could be reused.

For low voltage applications, the City of Tacoma's Pumping Station Design Standards Manual identifies Robicon VFDs as the drive of choice for 480 volt installations. The City of Tacoma has confirmed that Robicon drives are the drive of choice for 480 volt applications under this Project. Though Robicon drives have been selected for 480 volt applications, there has not been a definitive choice of drives for medium voltage applications. Motors larger than approximately 600 hp are considered candidates for medium voltage service. It is likely that the DB Project's technical requirements will allow for or require medium voltage VFDs. Depending upon the pump station design and the electrical service selected by the Proposers, new VFDs installed on the existing effluent pumps may or may not be medium voltage VFDs.

Technical Memorandum Purpose and Objectives

The overall purpose of this Technical Memorandum (TM) is to define Project technical requirements and other constraints related to medium voltage VFDs. Specific questions this TM is intended to answer include:

- Who are the major manufacturers of medium voltage VFDs?
- What has been the experience of wastewater treatment plant operators and other end users with medium voltage VFDs from various manufacturers?
- Can the RFP effectively define performance criteria for the VFDs or should other requirements (i.e. allowing only certain makes / models or disallowing certain makes / models) be included?
- Should requirements for other related equipment, such as motors, also be specified and should these other requirements also be applied to the re-use of existing pumps?
- What should the performance specifications for the VFDs encompass?

To answer these questions, Brown and Caldwell conducted the following investigations / analyses:

- Reviewed manufacturer's literature and met with manufacturer's representatives for 4 of the 5 leading medium voltage VFD manufacturers.
- Conducted telephone interviews with plants or facilities where drives under consideration have been installed.
- Summarized findings relating to drive reliability, access to service and replacement parts, and medium voltage VFD performance and operations for the manufacturers under consideration.
- Conducted research to determine the type of VFDs that are installed in water and wastewater plants along the west coast and in other parts of the country.

Manufacturer and Facility Contacts

Brown and Caldwell collected information and held discussions with four of the five leading medium voltage VFD manufacturers. The manufacturers were Toshiba/General Electric (Toshiba/GE), Asea Brown Boveri (ABB), Allen Bradley (AB), and Robicon.

Technical information, drive reliability, and access to service and replacement parts were reviewed and discussed. Siemens was also contacted, but Brown and Caldwell did not receive information from Siemens during the time period of this technical review.

The four responding VFD manufacturers were asked to provide wastewater client references where their latest medium voltage VFD technology was installed. Brown and Caldwell was able to speak with some of the Operations and Maintenance Plant Managers, included as references, regarding their medium voltage drive performance and operation.

In addition, Brown and Caldwell held discussions with senior wastewater operating staff from King County's Westpoint and Renton Plants, and attempted to contact other west coast installations. Because of the high motor horsepower associated with medium voltage VFDs, there are relatively few water and wastewater treatment plant installations in the U.S. where medium voltage VFDs are installed. Information obtained regarding various medium voltage drive installations is summarized in Table 1. Table 1 reflects information obtained from medium voltage drive installation locations within the scope of this memorandum's time frame. Additional 150 plus MGD plants in southern California and other parts of the country were contacted but they did not return multiple telephone calls requesting information.

Table 1. Medium Voltage VFD Facility Information

Location	Drive Type	Quantity/ Hp	Voltage	Pulse	Age	Comments
City of Phoenix Union Hills WTP Finished Water Reservoir	Robicon - Harmony	4 - 600	4160	18	4 yrs	No operations personnel were reached. Drive information provided by BC offices.
City of Des Moines, Iowa, WRA Raw Sewage Pump Station	Robicon	6 – 700	4160	18	3 yrs	No operations personnel were reached. Drive information provided by BC offices.
Irondequoit Bay South Central Pure Waters District in Rochester, NY	Allen-Bradley PowerFLEX 7000	2 - 1250	4160	n/a	New	No operations personnel were reached. Drive information provided by BC offices.
Oklahoma City The Draper Plant	ABB	2 -2500	4160	18	3 yrs	Plant staff going to sole source ABB for low and medium voltage installations.
Oklahoma City The Hefner Plant	ABB	2 - 2000	4160	18	2 yrs	Plant staff going to sole source ABB for low and medium voltage installations.
City of Nashville Brown's Creek Pumping Station	Robicon - Harmony	2 – 1250	4160	18	1 yr	Plant Manager says "perfect fit" and that "Robicon is the best in the industry".
King County West Point	Anfodo Roshill	7-2000	4160	12	5 yr	Company no longer in business and now Robicon servicing the drives.

Table 1. Medium Voltage VFD Facility Information						
Location	**Drive Type**	**Quantity/ Hp**	**Voltage**	**Pulse**	**Age**	**Comments**
King County South Plant (Renton)	Anfodo Roshill	4-5000	4160	12	4 yr	Company no longer in business and now Robicon servicing the drives.
King County South Plant (Renton)	Anfodo Roshill	4-650	4160	6	16 yr	Company no longer in business and now Robicon servicing the drives.
Region of Waterloo, Waterloo, Canada	Allen-Bradley	2-900 1-1750	4160	n/a	6 mos	The 1750 hp drive took AB 5 weeks to solve trips that would happen every 2-3 days. The drives have been operating continuously and flawlessly since June 03.
Ashgrove Cement	Toshiba/GE	1-1750	4160	24	2 yr	Parties did not return BC calls.
Wheelabrator	Toshiba/GE	6-350	4160	24	1yr	Parties did not return BC calls.
City of Lethbridge, Alberta, Canada	Allen-Bradley	1-1000 1-2250	4160	n/a	6 mos	AB's active front end on VFD had an appeal to owner. A proposed ten week delivery after drawing submittal review was a big factor in selection The drives went in perfectly and ran right from the moment they were energized. "Impressive machines."
Olivenhain Pump Station San Diego, CA.	Allen-Bradley	3-2500	4160	n/a	6 mos	Tuning the drives to the process was the biggest issue. However, the field support was good and the drives are working well.
City of Detroit	ABB	8 > 1500	4160	18	2 to 10 yrs	"Very Good Drives", "Maintenance very happy."
City of Detroit	ABB	2 - 700	4160	18		"Very Good Drives", "Maintenance very happy."
City of Detroit	Robicon	2 - 2000	4160	18	6 yrs	"We are currently installing more Robicon drives."
City of Detroit	Robicon	2 - 1200	4160	18	3 yr	"We are currently installing more Robicon drives."

Based on our review of available manufacturer's literature, discussions with manufacturer's representatives, and conversations with wastewater reference installations, it appears that ABB, Robicon, and AB all make excellent equipment. Toshiba/GE may also make a drive of equivalent quality, but Brown and Caldwell did not receive feedback regarding Toshiba/GE installations during the time period of this technical review. There are many elements of a drive system and some manufacturers offer some of those elements as standard equipment while other manufacturers offer the same elements as optional items. It would best serve the City of Tacoma to set forth performance based design requirements in the RFP documents.

Customer service is another factor that should be considered in addition to quality equipment design. Customer service after the sale is often critical to plant operational staff. It was ABB's "Quality and Service" that "sold" the manager from the City of Oklahoma City. Robicon, Allen Bradley, and Toshiba/GE all have local representatives in western Washington. The nearest ABB factory product sales representative is located in California with their west coast service and repair experts are based out of Oregon. ABB promotes immediate action to resolve any issue by flying out an expert within 24 hours.

Recommended Vendor, Quality, and Warranty Requirements

Based on the analysis of medium voltage VFD manufacturers, Brown and Caldwell recommends the following general provisions be included in the specifications for VFDs:

- The VFD manufacturers reviewed as part of this memorandum all appear to make a high quality medium voltage VFD product. Due to the feedback and our research Brown and Caldwell recommends that the City consider specifying ABB, Allen Bradley, or Robicon in the RFP.

- The VFD manufacturer must participate in overall Project start-up and commissioning. VFD training should be one element of the structured training that City personnel will receive on the Project. To be most valuable, multiple comprehensive VFD training sessions, including hands on training and training in troubleshooting techniques, should be provided. Job site training should be a coordinated training course with certified manufacturer's factory staff providing training to City personnel on variable frequency drives.

- The RFP's 2-year warranty requirements should extend to VFDs. However, a more robust warranty is recommended for VFDs. History has shown that some manufacturers produce a VFD model only to have the model obsolete and unsupported within 30 months. Therefore, it is recommended that the City request, from the Proposers, an extended warranty cost to provide a 5 year warranty. A 7 year warranty would further ensure that a VFD manufacturer is committed to their product line.

- The RFP should require Proposers to discuss the types of emergency service, repair service, maintenance, and trouble-shooting service that would be provided by VFD manufacturers.

Recommendations for Other Project Technical Requirements Related to Variable Frequency Drives

The following discussions address a number of related technical issues. Items presented below were discussed with City personnel to verify City concurrence with various recommendations.

Motor Starting Options
One of the inherent properties of VFDs, besides speed control, is their ability to reduce the severe starting currents placed on the electrical distribution system caused by the VFD's respective motor. By starting the motor at a low frequency the motor turns slower and the required motor starting current can be reduced by 80% or more. However, depending on the Proposer's pumping design strategy, not all large horsepower pumps may require VFDs. Tacoma Power has related that they can not support "across-the-line" starting of 600 hp motors and larger due to the resulting voltage disturbances caused by the high starting currents. In addition, it is believed that this starting current may also result in other Plant loads being adversely affected by the ensuing voltage sag on the Plant's distribution system. In those cases where the horsepower of a pump motor is 400 hp and greater and the designed pumping strategy does not require VFD installation, a "soft-start" pump motor starting method should be installed. Consideration and evaluation of the effects of across-the-line starting of 250 hp motors and greater on other Plant loads and distribution systems should be required.

VFD Maintenance By-Pass
Whenever a drive breaks down, the drive's respective motor can not be used. In addition, maintenance tasks must be accomplished on the VFD periodically to ensure long life and reliability. To perform maintenance, the VFD and motor must be taken off line. The Project is building redundancy into the influent and effluent pumping scheme that will resolve this problem during non-peak flow times. If a VFD must be taken offline for maintenance or fails, the redundant pumping unit can be brought online. However, during peak flow rates, when all pumps are online, the loss of a VFD could spell disaster. Therefore, it is recommended that soft start maintenance by-pass VFDs be installed on all new influent pump motors (if VFDs are installed) and effluent pump motors.

VFD and Motor Interface
In addition to protecting the motor from harmonics, common mode voltages, electrically induced pulsating torque, and damaging voltage waveforms, the VFD must provide motor overload protection. The leading four manufacturers that submitted information to Brown and Caldwell state that installation of their VFDs should not compromise or be compromised by the use of standard induction motors. Specifically, they affirmed that they can meet the following requirement:

> *The VFD system shall provide an output waveform that will allow utilization of a standard squirrel cage induction motor without de-rating or requiring additional service factor. Life expectancy should not be compromised in any way by being powered from the VFD.*

Nonetheless, Brown and Caldwell believes it is important to consider the consequences of a failure to meet this requirement over the life of the VFD, and to consider whether the added benefit of requiring a more robust system (i.e. also requiring a motor designed for VFD operation) outweighs the added cost for the premium motor. Based on Brown and Caldwell's conversations with motor suppliers, requesting a premium motor would add approximately 10 percent to the cost of a standard motor.

In consideration of the importance of the new effluent and influent motors in question, a premium motor, designed for operation with a VFD, provides prudent insurance and is recommended. In discussion with City of Tacoma staff on this topic, premium VFD motors have been requested whenever new motors are installed in conjunction with VFDs.

The motors on the existing effluent pumps are not VFD rated. However, these motors have been operating without major incident since installation and the cost to replace the motors with new VFD rated motors is substantial. If the motors do not require replacement as part of the hydraulic capacity upgrade, it is recommended that the new VFDs be equipped with output filters when installed on the existing motors and that the motors be replaced with VFD rated motors when the existing motors require replacement.

Front End Transformation

A shielded or drive isolation transformer is recommended if line voltage needs to be stepped down to the required VFD medium voltage level. Transformation is expected as the Plant's electrical distribution operates at 13,800 volts and a standard medium voltage VFD is 4160 volts. Besides stepping down the voltage, the transformer could provide surge protection by preventing capacitance coupling of the transformer's coils and thus prevent upstream high frequency utility excursions from damaging the VFD components. The shielding would also reduce common mode voltages, a source of motor insulation damage.

A drive isolation transformer would reduce high primary surges getting through the transformer. In addition, they take into account the coil heating that can result from harmonic and offset currents from the VFD.

Only rectifier grade K-factor step down transformers would be recommended as the drives will have front end rectifiers. It is recommended that the Proposers be responsible for reducing the potential damage to the drive units from utility or other remote excursions by the addition of shielded or drive isolation transformers and that VFD front end filtering or VFD performance will be provided to meet the design criteria.

Cooling
All of the VFD manufacturers utilize air-cooling for their equipment. It is recommended that the VFD be provided with an alarm to notify an operator of the fan system failure. City staff confirmed that the VFDs shall be equipped with alarm contacts for fan failures. All openings in the VFD enclosure will require filters being installed. All alarms shall be connected to the DCS.

Monitoring
Metering is recommended on the VFD system to continuously monitor and display input and output power quality. This will allow easy operator verification of the performance of the VFD system. The information gathered needs to be relayed to the Plant's DCS system. The Proposer must coordinate the selection of the monitoring equipment with the DCS system to ensure that the protocols and hardware are in place for the interface. The monitoring of the following parameters is recommended. All of the manufacturers reviewed as part of the memorandum are capable of providing the data listed below.

- Input voltage (rms value)
- Input current (individual phase rms values and average rms value)
- Input frequency
- Power factor
- Input kW, kVAR
- Input kWHR
- Input current THD (average of three phases)
- Input voltage harmonic distortion
- Motor voltage (rms)
- Motor current (rms)
- Motor speed (in RPM or %)
- Motor torque (%)
- Drive output power (kW)
- Output kWHR

Elapsed time running meter should also be provided.

Diagnostics and Fault Recording
A fault log data device is recommended. In discussions with manufacturers, the device could be incorporated into the drive for an additional 3 to 5 percent of the drive's cost. The device should be provided with memory stored in non-volatile memory, or be supported by a UPS sized to provide a minimum of 48 hours of data retention.

The VFD fault log data device should include a comprehensive microprocessor based digital diagnostic system, which monitors its own control functions and displays faults and operating conditions.

To facilitate troubleshooting the device should include a fault log that should record, store, display and print or download upon demand, the following for at least the last 30 events: The more event storage capability the better the diagnostic ability during a trip or fault condition. The following parameters should be included in a fault log.

- VFD mode (Auto/Manual)
- Date and time of day
- Type of fault
- Reset mode (Auto/Manual)

An expanded feature would be to require another log that would also record, store, display and print or download upon demand. This data log could be used during daily operations or to review the past operating parameters after a system change has been incorporated. For an additional 2 to 3 percent of the drive cost, the following control variables could be recorded following a VFD drive trip.

- VFD mode (manual/auto/tripped/etc. This status has further detail.)
- Speed demand
- VFD output frequency
- Demand (output) Amps
- Feedback (motor) Amps
- VFD output volts
- Type of fault

The City has requested that each of these variables be included in the VFD fault data logging for the Project.

Other Recommended Specification Requirements for VFDs

The following issues relate to specific performance and technical requirements that Brown and Caldwell recommends including in the Project Technical Requirements for medium voltage VFDs.

- The VFD controller needs to communicate with the remote monitoring devices and their respective operators. Each vendor examined has the ability to communicate over a variety of means. The specific communication type required for this project was discussed with City staff. The Plant utilizes Ethernet and the system is to remain during this Project. Therefore, the drives will need to interface with the existing Ethernet system.

- Mechanical key interlocks are recommended on all doors. Interlocking should be fully coordinated to prevent access to all high voltage compartments, including transformers, and filters when line power is applied to the VFD system. Mechanical interlocks provide positive lock-out prevention and safety. Electrical interlock switches alone should not be considered acceptable, due to the possibility of inadvertent shutdown and the ease with which such switches could be bypassed.

- The full load rating of the VFD shall be a minimum of 110% of the respective motor rating. For variable torque applications the overload capacity should be identified at 110% of rated current for 1 minute repeated every 10 minutes. For constant torque applications the overload capacity should be 150% of rated current for 1 minute repeated every 10 minutes.

- In wastewater applications, the VFD needs to be able to catch and take control of a spinning load, if started while rotating equipment is already spinning. Northwest utilities are well known for power bumps that take a device off line only to have the power come back with a motor programmed for an auto re-start command. Appropriate safeguards need to be included in VFD specifications to prevent damaging torque(s), voltages or currents from impacting any of the equipment. The VFDs shall include an auto restart feature. The specifications should include a setup that allows CTP operators to have the option of employing the auto restart feature or disabling it depending on the application.

- In wastewater applications, the VFD needs be capable of continuous operation ("ride-through") in the event of a power loss. It is recommended that the specifications include a minimum ride-through of 1 second. Another recommendation is that the VFD should be able to safely operate, without tripping, with up to 30% voltage sag on the input voltage.

- The specifications should require 18-pulse drives, or an equivalent architecture, above 200 horsepower. "Equivalent" is used here because one of the manufacturers (AB) uses an active front end that modulates the pulse time of the front diodes and; therefore, does not specifically match to an 18 pulse rate.

- The providing utility, Tacoma Power, assesses a monetary power factor penalty for service power factor below 0.95. In regard to VFD input power factor, it is recommended that the specifications require an input power factor at > 0.95 for the load range of 20 to 100%. Where necessary, the VFD manufacturer should provide power factor correction filters if the VFD does not meet this requirement. To prevent the possible compromise of upstream utility relay protection or jeopardize the safety of the utility's operating crews, reactive power should not be exported to the utility.

Therefore, it is also recommended that the specifications state that the VFD including power factor correction and/or harmonic filter should never have a leading power factor.

- It is recommended that the VFD design eliminate the effects of Common Mode voltages (by the addition of an output reactor or other means) at the VFD's output to the motor to prevent elevated voltages and motor insulation degrading.

- Long cable distances, typically over 50 feet, between a motor and its respective VFD have always elevated concern for cable insulation damage due to VFD voltage reflection. Because of the potential cable damage, VFDs are typically installed close their respective motors. However, as part of this Project all VFDs will be installed within a controlled environment, either within their own room or other suitable controlled space. Therefore, the VFDs may not reside next to their respective motors. It is recommended that the VFD design eliminate motor cable voltage reflections from the drive to the motor. In addition, to prevent wear on motor and pump bearings, as well as the shaft keyed connections, the drive should not induce greater than 1% torque pulsations to the shaft of the driven system.

- Indoor VFD enclosures with a NEMA 12 Ventilated rating are recommended, unless installed within an area where a NEMA 3R Ventilated rating would be required. An example where a NEMA 3R enclosure may be required is in a basement environment below grade, where water could drip from above, yet still within a controlled space. Outdoor installations are not recommended. It is not recommended that VFDs be installed within any environment where NEMA 4 is considered.

- The internal VFD components should require front access only for service, maintenance, and removal. Any other arrangement could prevent future service and maintenance, or limit where the equipment could be located within a room.

- Because VFDs are noisy devices, they are sometimes installed within their own controlled space. It is recommended that the combined VFD and fan noise level should be less than 75 dB(A) at 3 feet distance from the drive. This limit is based on an operator having to stand in front of the VFD to set parameters or operate the VFD locally.

Eddy Current Drive Replacement Issues

Depending upon the Proposer's influent and effluent pump station design strategies, the existing influent pump station eddy current drives, motors, and pumps may be left in place or may be replaced. There are operational issues that must be considered if the eddy current drives are to be replaced. As indicated below, full flow may not be possible if the drives are simply replaced without also replacing the existing influent pump station pumps and motors. A system head/flow/horsepower analysis must be performed to address this concern if replacement of the drives is considered to be an option by the Proposer.

Eddy current drives control pump speed via variable slip couplings. This means that there is slip between the motor's shaft speed and the pump's shaft speed such that they do not spin at the same speed. The more slip induced by the eddy current drive, the slower the pump will turn for the same constant motor speed. Variable slip couplings, whether eddy current or permanent magnet type, always have some added slip between the motor and the driven equipment. When the original systems were designed the output pump flow curves were calculated based on this additional slip between the full speed of the motor and the maximum, but slower, speed of the pump. On centrifugal pumps, the horsepower required varies with the cube of the speed.

If the eddy current drive is replaced with a VFD, the adjustable coupling must be removed and the pump and motor are direct coupled in preparation for VFD installation. When the adjustable coupling is removed from the system and a VFD is used to vary the speed of the resulting direct driven load, full pump flow may not be possible. With a variable slip coupling the motor always runs at full speed and, therefore, can always produce full horsepower. A VFD/motor combination results in a variable horsepower system. While the torque output can be constant, the motor's horsepower is a product of that torque times its present RPM. As a result, if the driven load was designed for 100 percent horsepower at the slip coupling's maximum output speed at 100 percent motor speed, (i.e. maximum pump speed is 1650 RPM for an 1800 RPM motor) and now the pump is connected directly to the motor fed by a VFD, the 100 percent horsepower point for the system would still be expected at 1650 RPM, but the 100 percent HP for the motor VFD combination is at 1800 RPM. The system would require a horsepower that the drive could not produce at that pump speed, and the VFD will be dragged down and full pump flow would not be reached.

If the pump/motor is operated under this configuration (new VFD on existing motor), the motor will be overloaded at the maximum pump flow and will likely fail over time. Operating in the high flow range will also cause stress to the VFD at that frequency. Solutions include restrictor valves or orifice plates to prevent high flows in the range that will stress the motor and VFD, installing new rotors on the existing motors, or installing increased HP motors and VFDs on the same pump. A new system head/flow/horsepower analysis should always be done on these retrofit applications.

Information Regarding Existing Conditions Required by Proposers

There are certain pieces of information that a prospective contractor and vendor will require before they can properly bid on a medium voltage VFD installation. The following specific information would be necessary to size various VFD elements, filters, etc.

- The available short-circuit power at the point of common connection to the CTP's distribution system. This will be necessary for the drive manufacturer's to ensure their equipment will be rated for the available fault energy. Some manufacturers have standard equipment with a 350 MVA rating while others have a 250 MVA rating as standard. Fusing and brace work can be added to increase the rating.

- The VFD should comply with the harmonic and current distortion limit level requirements of the latest edition of IEEE 519 at the point of drive connection to the CTP's distribution system. Brown and Caldwell recommends that pre-installation calculations and post installation measurements be required as submittals.

Summary and Conclusions

Based on information obtained during our medium voltage VFD evaluation, it appears that the leading four medium voltage VFD manufacturers all make excellent equipment. Based on feed back received and our research, Brown and Caldwell recommends that the City consider specifying ABB, Allen Bradley, or Robicon in the RFP. Specific key drive elements described above should be required in the RFP to maximize drive reliability and performance. If new VFDs are to be installed on the existing influent pumps, system components must be installed to prevent motor and VFD stress and a system head/flow/horsepower analysis must be performed to evaluate the impact of the VFD on the maximum pump performance.

Environmental Engineering And Consulting

SUITE 1200, 701 PIKE STREET, SEATTLE, WASHINGTON 98101
TEL: (206) 624-0100 FAX: (206) 749-2200