The notion of using Variable Speed Drives (VSDs) and Programmable Logic Controllers (PLCs) in oil and gas facilities and pipeline pumping station applications is hardly new. Besides giving pipeline operators a better range of choices in controlling flow rates and pressures, VSD and PLCs give the operators the ability to effectively control their power usage. With the electrical utility deregulation causing wide swings in regional power rates and the exposure of many to market demand prices, facility and pipeline owners are watching their power usage more closely. Many oil and gas companies are applying Variable Frequency Drives (VFDs) as the VSD of choice for pipeline pumping and facilities applications for two reasons:

- Enhanced VFD/PLC based motor control with energy savings
- Enhanced VFD/PLC based motor transfer control with soft-starting

In the first case, variation of the VFD output frequency causes proportional variation of the motor and pump speed, giving energy savings over conventional pump stations. In the second case, since the frequency output is set by the drive, it can be used to soft-start and synchronously transfer (or sync-transfer) motors between fixed speed operation at 60 Hz and variable frequency operation from 0 to 60 Hz.

In order to understand these benefits let us look at the following associated topics:

- Medium Voltage VFD Technology Update
- Oil and Gas Facilities Operation and Energy Savings Basics
- VFD/PLC Synchronous Transfer Basics
- Typical VFD Project Experiences

Medium Voltage (MV) VFD Technology Update

Developments in microprocessor based control systems have made possible many technological changes and consequent cost savings in the oil and gas business. VFDs have also seen the same significant improvements.

Over the last ten years, driven by these control technology improvements, there has been a slow migration from 6 and 12 pulse inverter control systems to PWM based inverter systems. Also the two following VFD inverter topologies have become popular with VFD systems designers, namely:

- Current-Source Inverters [See diagram 1A]
- Voltage-Source Inverters [See diagram 1B]
Semiconductor Device Improvements – VFDs With Conventional MV Bridges
The switching characteristics of thyristors have substantially improved allowing GTO (Gate Turn-Off) thyristors and their recent cousin the Integrated Gated Commutated Thyristors (IGCT) to be used to enhance the performance of conventional MV bridge based VFDs. These semiconductor devices have made possible such design improvements as active front-ends, smaller harmonic filters, and the use of more sophisticated Pulse Width Modulation (PWM) control techniques. These device improvements have resulted in improved input and output power quality[1] albeit with more complex control circuits. [See diagram 2: Details of MV Bridge Based VFDs]

Advantages Of Multiple Power Cell Designs Over MV Bridge Based VFDs
As mentioned above, prior to the availability of medium voltage, power cell based, modular VFDs, medium voltage bridge designs were the topology of choice.
With the medium voltage bridge arrangement, in order to overcome the individual device voltage and current rating limitations, the thyristors were connected in series to extend the range of the bridge configuration. Both current and voltage balancing networks were necessary to ensure device voltage and current sharing and compensate for the manufacturing variations in the semiconductors.
A significant factor in the development of the more technologically advanced power cell based VFD systems, was the coordination of the power semiconductors control circuits over multiple power cells. The improved performance of the new power cell based VFDs, over those with a conventional MV bridges, has resulted in a dramatic increase in their use, especially in remote pipeline and similar oil and gas installations.
The uptime advantages of power cell based VFDs are:
• VFD maintenance allows for a cell repair-by-replacement method rather than requiring the immediate replacement of individual semiconductor devices.
• In many drives where higher availability is desired, additional

Diagram 2

Semiconductor Device Improvements – VFDs With Multiple Power Cells
The switching characteristics of IGBT’s (Integrated Gate Bi-polar Transistors) have substantially improved, allowing the IGBT to be used to enhance the performance of conventional MV bridge based VFDs as well as multiple power cell drive topologies. These semiconductor devices have made possible design improvements that have led to the complete elimination of the harmonic filters with incremental improvements in input and output power quality[1] over the conventional MV bridge designs. [See diagram 3: Details of Multiple Power Cell Based VFDs]
More recently higher voltage and current rated IGBT’s, used extensively in low voltage drives, were made available for use in medium voltage VFD systems. The use of IGBTs in medium voltage VFDs brought out the best in switching characteristics along with the simpler control circuits associated with the device. These systems are being applied today with terrific power quality improvements[1].
cells can be added to the VFD system so that if any cell fails, the coordinated power cell control can bypass the faulty cell and keep the VFD in service. This gives the drive configuration a level of redundancy in the event of a device or component failure.

- Some new drives can even change the coordinated PWM control to all cells, thereby effectively shifting the drive output neutral point to maintain phase balance. This clever technique permits the removal of only the failed cell and leaves the other cells able to contribute power to the drive’s output.

**Oil and Gas Facilities Operation**

**And Energy Savings Basics**

For many applications equipment sharing, such as VFDs or PCVs (Pressure Control Valves), makes perfect sense. This is true in most pumping stations with multiple series connected pumps. Most pump stations are operated by simply starting one pump, then the next, and so forth, until there is sufficient head developed. Such stations also use a PCV to trim the total pump unit pressure to the desired station discharge pressure set point, the latter station discharge pressure set point being set by an operator based upon the desired pipeline flow requirements. Throttling using a PCV is a necessary evil, in that it provides a desired outlet pressure but at a great energy cost.

In the traditional PCV based station the total head is the addition of one or more units plus a half-head unit. In the case of the VFD based station, the half-head unit is replaced by
varying the speed of one or more of the full head units. Utilizing a VFD, instead of a PCV, improves the flexibility of a half-head pumping unit without having to buy the energy for the entire unit. It does this by varying the speed of a single full-head or half-head unit rather than throttling. Thus with the VFD no energy is lost due to the elimination of pressure drop across the PCV.

**VFD/PLC Synchronous Transfer Basics**

There have been many pipeline pumping station installations with sync-transfer VFD systems. Even though much station and pumping unit design has been done and much of this previous design is applicable, there is a need for an appropriate amount of engineering for each project. This is usually necessary because of the site to site variations in the electrical power supply and the hydraulic pumping systems.

Note - the purpose of a pumping station is to deliver the energy into the hydraulic system. Often the power involved in the movement of fluid is large. If the system controlling such large amounts of power is improperly configured, pressure shock waves in the liquids pipeline can result and literally cause a pipeline rupture. Similarly an improperly controlled closed circuit, sync transfer of two high power motor circuits can cause a similar and spectacular energy release.

**PLC Based System Types & Requirements**

Control systems that implement both VFD sync-transfer controls and station controls sometimes are combined into one PLC system. Alternatively, in the case where the “station controls” are developed by a different control specialist than the “sync-transfer controls”, a separate VFD-PLC system is used to reduce the programming coordination required.

Because station operation procedures vary from company to company and sometimes between sites, safety limits and unit lockouts must be defined before the PLC programming is started. Also a rigorous commissioning procedure must be used to ensure the closed circuit sync transfer controls operate correctly.

**VFD/PLC Based Synchronous Transfer Control**

In any system where one VFD controls multiple motors, the problem becomes “How do we efficiently move pumping units from the 60Hz utility bus to the VFD output or variable frequency bus and vice-versa”? VFD/PLC based sync-transfer controls have the following components:

- VFD per system
- PLC per system
- VFD contactor per motor
- Bypass contactor per motor

During synchronous transfer control system operation it is common to set the VFD output frequency to match the 60 Hz operation of the electrical utility. This allows paralleling of the utility 60 Hz bus and the VFD output bus by closing both the VFD and bypass contactors. Once the output frequency
matches the utility’s operating frequency (with equal voltage magnitude and phase angle), the latter motor bypass and VFD output contactors may be simultaneously operated to quickly transfer the motor from the VFD output to the 60 Hz utility bus and vice-versa. This process allows the VFD to sequentially control multiple motors using the closed circuit, sync-transfer operation. The latter is the basis of “VFD/PLC based sync-transfer control” where one VFD controls many motors.

The VFD and associated PLC based control system is programmed to implement the synchronous transfer control process by the use of two basic commands:

**UP Transfer** - transfers the motor from the VFD to the Utility bus.

**DOWN Transfer** - transfers the motor from the Utility bus to the VFD.

**UP Transfer Command Process**

[See figures 1 through 5]

The PLC based control system UP transfer command involves the following operations - assuming all motors are stopped on receipt of an operator command the PLC and VFD operate as follows:

1. PLC closes motor1 VFD contactor
2. VFD accelerates motor1 to the operator set point
3. PLC receives a start motor2 command
4. PLC sends the UP transfer request for motor1 to the VFD
5. VFD accelerates motor 1 to 60 Hz and confirms synchronization OK
6. PLC closes motor1 bypass contactor transferring motor1 to the 60 Hz bus
7. PLC opens motor1 VFD contactor and closes motor2 VFD contactor
8. VFD ramps its output and accelerates motor2 to the operator set point

Note: This process continues until all requested motors are operating.

**DOWN Transfer Command Process**

The PLC based control system DOWN transfer command involves the following operations - assuming at least two motors are operating on receipt of an operator command the PLC and VFD operate as follows:

1. PLC receives stop motor2 command from the operator
2. PLC requests VFD to decelerate motor2 to minimum speed
3. PLC opens VFD contactor
4. PLC sends DOWN transfer request for motor1 to VFD
5. VFD accelerates to 60 Hz and confirms synchronization OK
6. PLC closes motor1 VFD contactor and opens motor1 bypass contactor
7. VFD decelerates motor1 to the operator set point

Note: This process continues until only one motor is operating on the VFD.

**Soft Start Advantage Of Synchronous Transfer Control**

A great benefit of the VFD is the ability to avoid across the line starts by ramping the unit motors from zero speed to the minimum speed over several seconds. The soft start advantage of VFDs allows large motors to be sequentially started while maintaining compliance with the local utility flicker limits and minimizing the mechanical strain on the electric motors. [see figure 6]

**VFD Project Examples**

Like many great ideas, the “real world” implementation requires a significant amount of attention to the control of the system in order to realize these benefits. However the capital cost savings can be compelling with large VFD equipment costs sometimes over a million dollars per drive.

In the early 1990s, notable pipeline companies like Enbridge (then IPL) and BP (then Amoco) invested in the application of VFDs for improvements in their pipelines. In 1994, Enbridge deployed nine 3700 HP, Ansaldo Ross-Hill VFDs on their new Line 13 pipeline running from Hardisty, Alberta to Clearbrook, Minnesota. The new pumping stations were in configurations of one, two or three pumping units depending on their location on the pipeline. The deployment and operation of these new systems brought about a new set of “real world” problems. New
controls for the operators meant new operations procedures and training. New power utilization characteristics meant changes to the pipeline energy model and new rate agreements with the utilities. The introduction of VFD generated harmonics meant the need for harmonic filters and the associated electrical system strains for any unfiltered harmonics. Electrical maintenance personnel needed new maintenance procedures and training. Even the warehousing of spares added new complications. On the mechanical side, the pumps were now operating in new speed ranges so the pump performance curves were different. In some cases fluid resonance in the pump casing became a factor at certain operating speeds. Even with these new factors in their business, the value of VFDs at the pumping station to Enbridge and other pipeline companies was sufficient to call for the deployment of more VFDs in pumping stations in the years to follow.

I Want A New Pumping Station; And I Want It Now!

In a marketplace that demands “Faster, Better, Cheaper” the application of sync-transfer can make an impossible project possible. On March 17, 1997, a Husky Oil management team called for the design, procurement and construction of a new pumping station located between Lloydminster and Wainwright, Alberta. [2] Because of an increase in shipping oil nominations, they needed the station in service by the end of June 1997, (approximately 100 days later), otherwise they would be trucking it. The station needed to be about 5000 HP of new pumping capacity. Because of the station’s location on the electrical grid, the transmission lines would not take an across the line start. So a VFD or soft-start would have to be used. With two pumping units, a VFD for each unit was cost prohibitive and made the equipment procurement timing twice as difficult. The application of the sync-transfer VFD configuration in this case lowered the equipment cost close to that of using soft-starts.

The primary issue in this situation, as in most situations, is the need to assess the application requirements in context with the end user’s primary business. Sadly, even the customers themselves sometimes get caught up in a project side issue and overlook important business issues. In the case of this pumping station, the long and short of the customer’s business was to ship oil cost effectively. Side issues of a very short project execution time and the weak connection point on the electrical utility grid overshadowed the more fundamental issues of pipeline flow requirements, pump characteristics and pipeline operating pressure constraints.

An evaluation with Husky to assess their basic business needs, then defining schedules, then the electrical requirements led to an aggressive, but attainable business solution. An able project team was assembled. A Robicon Harmony 3500 HP VFD was procured and engineering was done to include the sync-transfer contactors and controls. In the end these project objectives were met and the pumping station is in service today, taking advantage of the VFD and the enhanced controls.

Conclusion

In Canada and United States there are hundreds if not thousands of multiple unit pumping stations that are prospective VFD sync-transfer opportunities. These sites could also reap the benefits of improved pipeline control and energy cost savings like the applications discussed. (In many cases the energy savings alone could pay for the implementation of the VFD and associated PLC control system.) The number of viable opportunities has increased appreciably since there have been so many technological improvements in the VFDs, VFD control and associated application.

Roy Spencer is the Canadian Sales Manager for ASI-Robicon and is on the Board of Directors of JTG Technology. Roy has his Bachelors Degree in Electrical Engineering from Trent University and his Masters Degree in Electrical Engineering from the University of Alberta.

Jon Blois is a Senior Engineer at Hinz Automation Inc. Jon is a Registered Professional Electrical Engineer in California, and he also teaches in the Electrical Engineering department of the University of Alberta.

References

[1] “Power Quality” is defined by the IEEE 519 industry accepted standard.