APPLICATION PROFILE

PETROCHEMICAL PUMPING SOLUTIONS

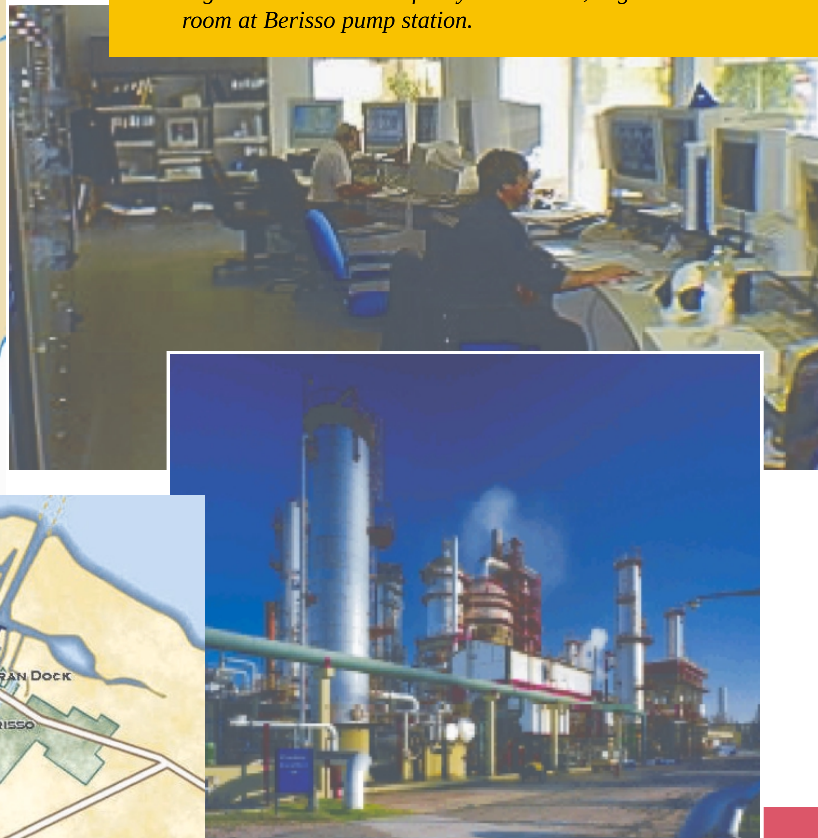
PETROCHEMICAL GIANT SELECTS VARIABLE FREQUENCY DRIVES TO OPTIMIZE EFFICIENCY AND ENERGY SAVINGS

Figure 1 : The price of YPF oil could be as cheap as $1.95 per barrel to produce by 2002, by cutting operation costs at their refineries.

The operational requirements and duty ratings for large volume petrochemical applications can vary greatly in proportion to demand and the physical properties of the products being conveyed. The pumping systems that convey product from refineries to distribution facilities are fundamental components in connecting a company's upstream operations to its downstream facilities. The efficiency of these processes in terms of power consumption and flow delivery is crucial to the overall profitability of an operation. This paper discloses the events that took place during a modernisation project at Repsol-YPF's pumping station at Berisso, in Buenos Aires province, Argentina. In addition, it discusses the design criteria project engineers were required to consider, the conventional technologies that were available to them and the chosen solutions that lead to their success.
A detailed comparison is included that discloses the data recorded during the course of retrofitting their existing system. After careful consideration of all the design criteria and careful selection of automation solutions, a 23% improvement in power utilization was achieved with a total cost reduction of 21%.

Early in 1999, YPF undertook to satisify major objectives as part of its ATP project(Actualizacion Tecnologica de Plantas) to modernize and update electrical, control and operational systems in order to achieve a measurable reduction in energy consumption, simplify maintenance procedures and reduce operating costs (See Figure 1). The facility in question was a pumping station at Berisso, Argentina approximately 75 km south of Buenos Aires. The station receives refined chemical and petroleum products via pipeline from a refinery in La Plata at a rate of approximately 1700m^3/hr and stores it (See Figure 2). It is then conveyed on demand to plants in Matanza and Darsena Sud harbour. As part of their ATP, project engineers at YPF undertook a major analysis of their existing facilities on which to base a feasibility study of their proposed upgrades and to determine the success of the completed upgrade in terms of delivered and not potential results. With a large scale takeover in the works by Spain's petroleum giant Repsol, incentives were very high to reduce operation costs in order to satisfy management directives. The plants delivery rate would vary accordingly with their supply from La Plata and the demand from their downstream operations. The redundant pumping system at Berisso maintained a continuous flow rate necessary to pressurize their pipelines. The use of throttling valves to vary this rate of flow delivery was determined by their analysis to be costly and inefficient.

Figure 2 : YPF' s oil refinery at La Plata, Argentina and control room at Berisso pump station.



The Challenge

It became obvious to the project engineers at YPF that a solution was required to vary the operation of their pump motors to better synchronize it to the frequently fluctuating demand. This would make their system more efficient in terms of flow rate delivery. Less hydraulic power would be wasted and less electrical power would be consumed. However, frequently stopping and starting the motors in accordance with the demand would have a serious negative impact on their 30-year old motors. Full voltage (across-the-line) starting of their motors would generate mechanical and thermal stresses that would seriously shorten their lifespan and/or increase the requirement for maintenance and repair. In many applications where motors of higher voltage ratings are used on weaker power supplies, the full voltage starts can cause serious noticeable disruptions for other recipients of the line supply. These "brown-outs", as they are called, can cause undesirable interruptions in computer equipment, lighting systems and other industrial processes to other facilities on the same power grid. The main issue for the Berisso facility, however, was efficiency and savings in energy and, more importantly, money. The system needed to be upgraded without any excessive capital expenditure, that would be incurred by redesigning their entire pump station or procuring new motors.

The Berisso facility used 2 - 800HP motors and 2 - 500 HP induction motors to draw refined petroleum and petroleum-based products from large storage tanks and direct it to one of two pipelines (See Figure 3). Depending on the viscosity of the product being conveyed, more or less horsepower is required to supply the pipeline. The project engineers needed to maximize the systems m^3 per horsepower ratio and in manner that accomodated the variances in viscosity of different products. Refined crude oil for example will have a much higher viscosity rating than a

Figure 3 : Berisso Storage, Pump and Throttling Valve

product such as methanol and require higher pump output. The viscosity of product will also require a higher starting torque due to the increased load inertia.

The project engineers began to examine existing technologies in pumping systems with respect to AC motor control. The resulting solution would no doubt be an electrical one rather than mechanical. Use of fluid coupling (See Figure 4), as a hydrokinetic linkage between motors and driven loads to reduce mechanical stress and reduce the frequency of repair, is fairly common to industrial processes where solid materials are being conveyed or milled. Fluid couplings are prohibitively expensive to retrofit, design intensive, require a great deal of maintenance and are generally considered "over-kill" in pump applications like Berisso, where high inertial loads are not an issue.

Electrical solutions were too numerous to mention and involved careful consideration with respect to both starting duty and continuous motor operation. Devices such as a Solid-State Reduced Voltage ("Soft") Starter, Autotransformer or Reactor would all provide starting solutions with torque control, but lacked the capability to independantly overcome line harmonic, cable length and thermal limitation issues.

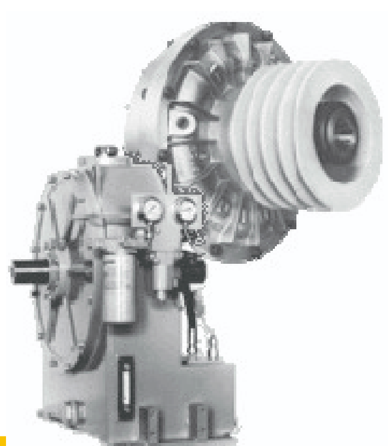
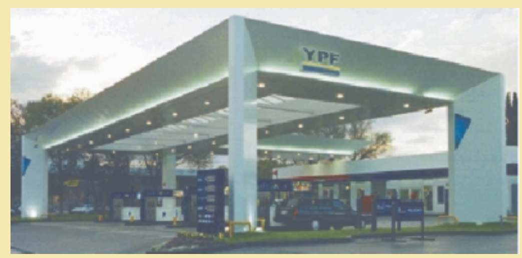


Figure 4 : Examples of Fluid Couplings

Company Profile

YPF (Yacimientos Petroliferos Fiscales) was the largest industrial company in Argentina before Spanish petroleum giant Repsol acquired 97.5% of YPF S.A., worth $13 billion (US), in June of 1999. Repsol, being Spain's largest petroleum company, often taunted as being the oil company with no oil, sought to expand into more upstream business and acquire reserves. Although the initial proposal was seen as a hostile takeover, YPF was quick to recognize the market potential and recommended approval of the deal to its share holders. YPF's extensive reserves upstream combined with Repsol's downstream management and know-how would rapidly catapult them to being the 5^{th} largest oil and gas company in the world.

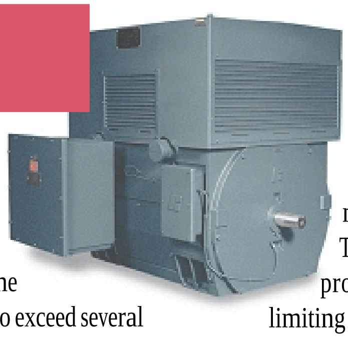
YPF grew slowly from its beginnings at its refinery in La Plata. that was inaugurated in 1925. YPF was the first state-owned oil company outside of the Soviet Union. YPF continuously lost money right up until its privitisation in the early '90's. However, after extensive downsizing, extensive layoffs and expanding exploration efforts, the company gradually started to show a regular substantial growth every year up until the takeover. In the year 2001, Repsol-YPF is a leading international oil and gas company engaged in all activities of the petroleum business; exploration and production, refining and marketing, chemicals, gas and power generation. Although extraction, refining and marketing of crude oil accounted for 70% of its revenues in 1999, Respol-YPF was also rapidly becoming a world leader in natural gas production, 21 billion cm^3 for that year. Other petrochemical products they manufacture or distribute include propane, butane, propylene, butylene, isobutylene, linear alkyl benzene, benzene, cyclohexane, toluene, o- and p-xylene, mixed xylene, asphalt, lubricants, pentane, hexane, solvents, methanol, alcohols, and n-heptanes, to name a few.



Repsol-YPF operates in 27 countries, with a major presence in Spain and Argentina. It owns more than 4,500 million barrels of oil equivalent in reserves, and produces over one million barrels per day. With a refining capacity of 1.2 million barrels per day, the company has a service station network of over 7,200 outlets throughout the world of which 2500 are operated by YPF.

Besides Argentina's rich domestic reserves such as the developments at Neuquén's Loma de La Lota and Sierra Barrosa oilfields, Repsol-YPF is also undertaking offshore activites in Campana Basin and expanding foreign assets into Chile, Brazil and even the Texas Panhandle in the United States. Respol-YPF's foreign developments have take them as far abroad as having a stake in a phosphate fertilizer mine in Kapuskasing, Ontario and oil and gas exploration holdings in Azerbaijan and Kazakhstan. More recently Repsol-YPF has divested many of its less promising holdings in Epypt, Indonesia and the Eastern Mediterranean to concentrate on more profitable ventures such as an offer by Petrobras to further exploit oil and gas fields in the Campos Basin, a major discovery off the coast of Guyana and major gas finds in Trinidad and Tobago.

Figure 5 : Many electromechanical starting methods require new motors of special design



As an example, a Soft-Starter would be thermally limited to a certain number of starts per hour and Autotransformer, even fewer. Line harmonics are generally not an issue when discussing motor starting options, except when the duration of acceleration to full-load speed begins to exceed several seconds, at which point, the integrity of the motor would be the major concern. These options require precise design and application of motor data. Invariably the motor data determines whether or not one of these options could be successful or even applicable. In addition, these options often require new motors of special configuration supplied with precise nameplate data (See Figure 5). Establishing accurate motor data on a thirty year old motor could not be done easily or cost-effectively. Exact calculations are required when considering applying a Soft-Starter to an older induction motor. The relationship between torque and current with regards to reduced voltage starting of an induction motor is a considerable design requirement. When starting an induction motor under reduced voltage, one also reduces the available torque to driven load by the square of the voltage (See Figure 6). Such a condition would dictate that the total system inertia be limited to a minimal initial torque requirement and marginal inertial load. Some devices are limited to motor starting duty only and provide no deceleration control. Soft-Starters are only capable of starting loads gently and limiting the amount of inrush current to the motor. They lack the inherent variable load-speed control that Variable Frequency Drives (VFDs) were designed for and do not possess the capability of precision torque/speed rate control. These are very important considerations when attempting to optimize any pump application. Precise torque/speed rate control is achieved with self-powered gate-driven controllers (SMCs) which can be programmed with various starting and stopping profiles (See Figure 7) and can be very effective in avoiding pressure surges and the "water-hammer" effect that is common in many pump applications. These devices can deliver up to 600% full load current, 180% of full load torque with a stepless transition start-up of a motor - more than ample for starting high inertia loads. These devices, under pump applications, can provide soft start without sacrificing torque by limiting current rather than utilizing reduced voltage. However, they do not provide the flexibility of infinite control across the entire torque and speed spectrums, with the added degree of motor protection, that VFDs do. Although a device capable of soft-starting the pumps would be an enhancement, it was not the primary concern.

$T \propto V^2$

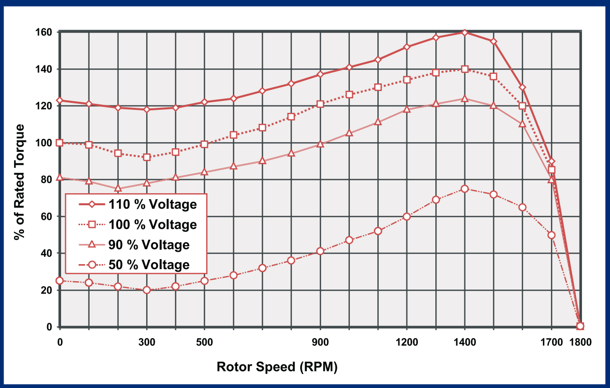


Figure 6 : Torque/Speed Relationship to Reduced Voltage Starting

Due to the requirement for variable control of the pumps to vary the overall system flow delivery and in turn reduce energy consumption, this eliminated solutions that only addressed starting duty criteria. In addition, the stations pumps and motors did not operate under conditions considered to be high inertial loads. Once the motors were started they achieved break away torque rather quickly and did not experience any serious fluctuations in performance. All four pumps used in the system were rated at 2300 VAC. Although it was possible to supply variable frequency control from a low voltage source by use of a step-up transformer, a low voltage controller would generate poor waveforms that would be amplified by the transformer and cause high dv/dt thermal stresses on the motors. This option was not recommended for use with their 30 year-old motors. This narrowed the search for a solution to equipment of a medium voltage rating. The requirement to retain the existing motors and attached mechanical equipment would lead the project engineers to conclude that a medium voltage AC drive was the only solution that could meet all of their requirements. The decisions as to what configuration of drive would best suit their needs and what system supplier would be chosen still remained to be determined. To further complicate their selection, the ideal system (See Figure 8) would be capable of starting one motor, accelerating it to full-load speed and then starting and accelerating a second motor without losing control of the first – a process called Synchronous Transfer. Procuring a drive for each pump motor was not economically viable for YPF.

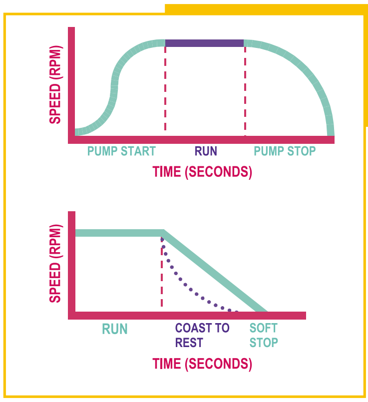


Figure 7 : Starting and Stopping Profiles of a Solid-State Starter

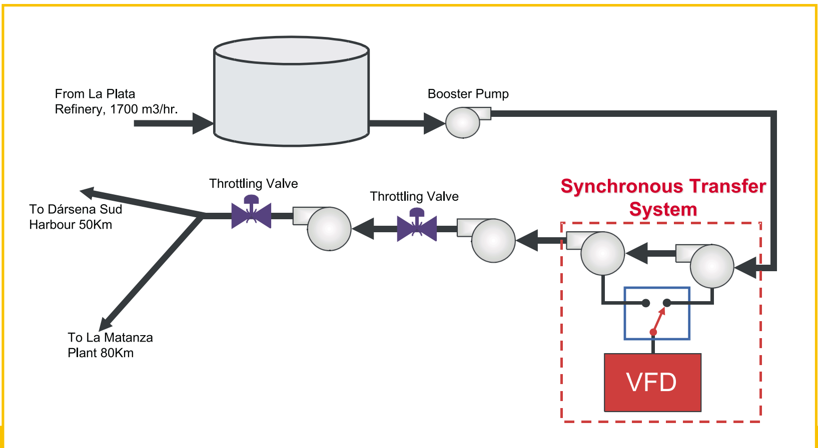
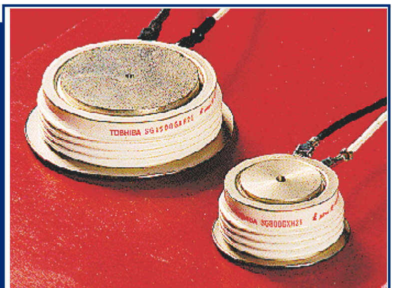


Figure 8 :The Berisso pumping system layout with Synchronous Transfer System

Medium Voltage Drives

Medium Voltage AC drives operate by supplying a rectifier with three-phase fixed main system AC voltage to convert it to fixed DC voltage. An identical DC voltage pattern is induced into a three-phase inverter opposite the rectifier and is used to reconstruct the AC waveform by means of the high speed switching of high current semiconductors (See Figure 9) called silicon controlled rectifiers (SCRs – sometimes called "thyristors") and gate turn-off thyristors (GTOs). This high speed switching effectively emulates the rotor-induced bipolar switching of magnetic fields that generate alternating current. The three-phase inverter generates these AC waveforms at frequencies between 5-70 cycles per second (Hz). Some drive system inverters, like the Voltage Source Inverter (VSI), are capable of frequencies of 200Hz. The inverter then converts the DC voltage back into variable three-phase AC where it can then be supplied to the pump or motor. There are two main topologies available in medium voltage drives that vary mainly in the manner in which the DC voltage is conveyed to the inverter and the way the inverter converts the DC voltage back into a reconstructed variable AC waveform. The two common topologies to medium voltage drives are the Voltage Source Inverter (VSI) and Current Source Inverter (CSI). These topologies are also available in 6, 12 and Pulse Width Modulation (PWM) configurations. Both drive topologies have their inherent advantages and disadvantages which are important to consider when applying a medium voltage drive to any given motor application. For simplicity sake, the more sophisticated and efficient PWM configurations will be discussed.

Figure 9 : Silicon controlled rectifier(left) and gate turn-off thyristor (right)



The VSI - PWM topology (See Figure 10) utilizes a rectifier and inverter section that incorporates a large capacitor between them and an inverter device known as an Integrated Gate Bi-polar Thyristor (IGBT). This arrangement enables a high switching frequency that enables the capacitor to quickly supply instantaneous currents to the inverter, with very little impedance, when rapid changes in motor performance are detected. The inverter output response time of the VSI-PWM is 3-5 times (greater than 30 radians per second) that of the CSI-PWM. The VSI-PWM drive does, however, require exact matching of the motor to the inverter. Due to the difficulty in determining nameplate data on existing motors and anticipating the motor performance under certain conditions for derating, procurement of new motors is usually recommended when selecting the VSI-PWM for a drive system. The requirement to retain existing motors, due to their prohibitive cost and extraordinarily long lead times, usually rules out VSI as an option. As for the actual motor performance, the VSI-PWM generates fairly high dv/dt thermal stresses and total harmonic distortion conditions which can seriously affect the performance and longevity of the motor without the aid of some additional line filtering equipment. The waveforms generated by the VSI-PWM are however considerably more friendly than any low voltage drive topology like the Variable Voltage Inverter (VVI). The VSI topology can be very advantageous in industrial processes that convey, crush or separate solid raw materials, where instantaneous response from the inverter can be required due to variances in consistency, weight and/or

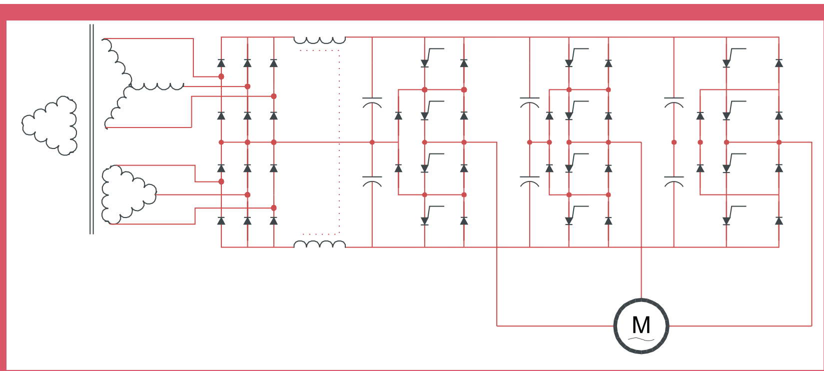


Figure 10 : Schematic representation of a Typical VSI-PWM

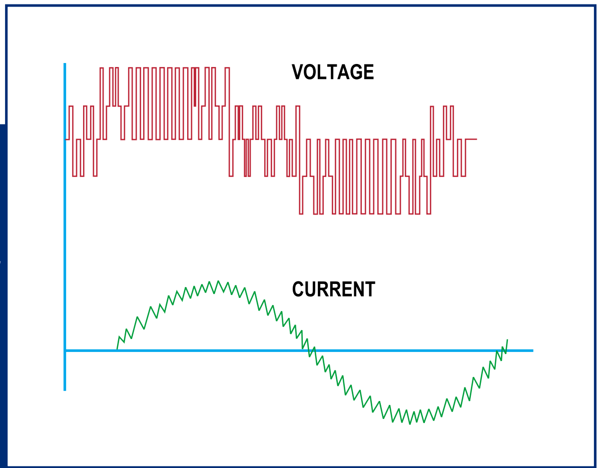


Figure 11: High frequency switching in the output waveform of a VSI PWM.

density and where cable length between the motor and drive is not excessive. Due to the high-speed switching nature of the inverter IGBTs (See Figure 11) and closed-loop sensoring of the VSI, excessive oscillations can occur at motor startup, especially when cable length and resulting power losses become excessive enough to interfere with inverter response time. For this reason a more continuous, smoother inverter operation for a pumping system is preferred.

The CSI-PWM topology offers a list of features to a medium voltage drive system that make it the ultimate system for productivity, flexibility and motor protection. This topology (See Figure 12) incorporates an inverter that demands all current required through a large DC link reactor. This places a high impedance on the circuit between the inverter and the rectifier and results in a decreased response time to that of the VSI-PWM. The inverter converts the DC link current back into variable frequency alternating current that is supplied to the pump or motor. The switching of the GTOs transfer the DC link current to the AC output terminals in an output waveform that is dependant on the timing of the switching. The CSI provides tighter, smoother control over fluctuations in motor performance where quick responses are not an issue, such as fan or pump applications. The CSI-PWM is a less complicated and less expensive alternative. The CSI-PWM generates motor-friendly output waveforms at all loads and speeds, because it operates at frequencies closer to that of the actual motor specifications and because it requires using a motor filter capacitor and inductive components of the motor load cables and stator windings. This arrangement efficiently converts variable duty-width square pulses into pulses that are virtually sinusoidal (See Figure 13) and that exhibit a Total Harmonic Distortion (THD) of less than 5%.

In terms of the overall system features, the CSI-PWM brings to medium voltage drive technology inherent over-current protection, regeneration capability, fuseless power structure, low component count and the capability of operating motors on cable lengths of up to 15 km with only marginal power losses when tuned correctly to a given motor rating. The CSI in its 6-pulse, 12-pulse and PWM configurations have all been proven to reduce operating costs and mechanical failures, while extending motor longevity. With the additional use of an isolation transformer at the drive output, the CSI-PWM can be used on existing motors without the added requirement of modifying them or replacing windings. In applications where new drive installations must comply with strict regulatory guidelines regarding line harmonics, an isolation transformer will provide cancellation of the principle 5th, 7th, 11th and 13th harmonics by using phase-shifting of the secondary voltages.

One major feature that makes the CSI-PWM drive ideal for the pumping station at Berisso is its capability to perform Synchronous transfer. Synchronous transfer enables two pump motors, each with their own controllers, to be operated independantly from a single drive. To further enhance the attributes of the CSI-PWM drive, all of these features are applicable to both induction and synchronous motors, old or new.

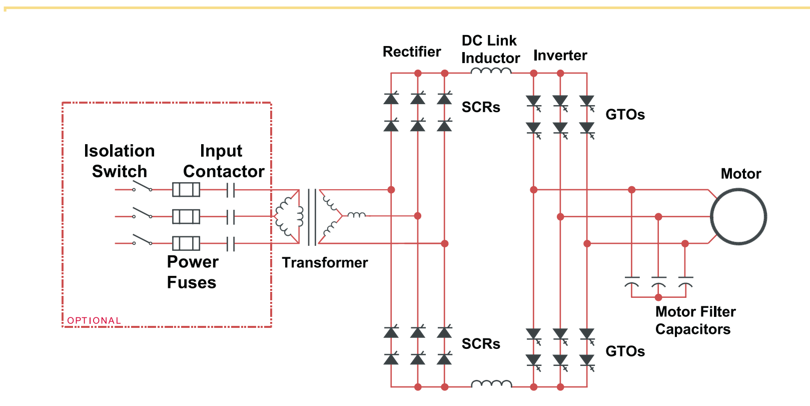


Figure 12 : Schematic representation of a Typical CSI-PWM

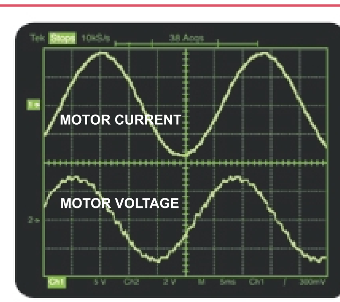


Figure 13 : Sinusoidal Output waveform of a Typical CSI-PWM

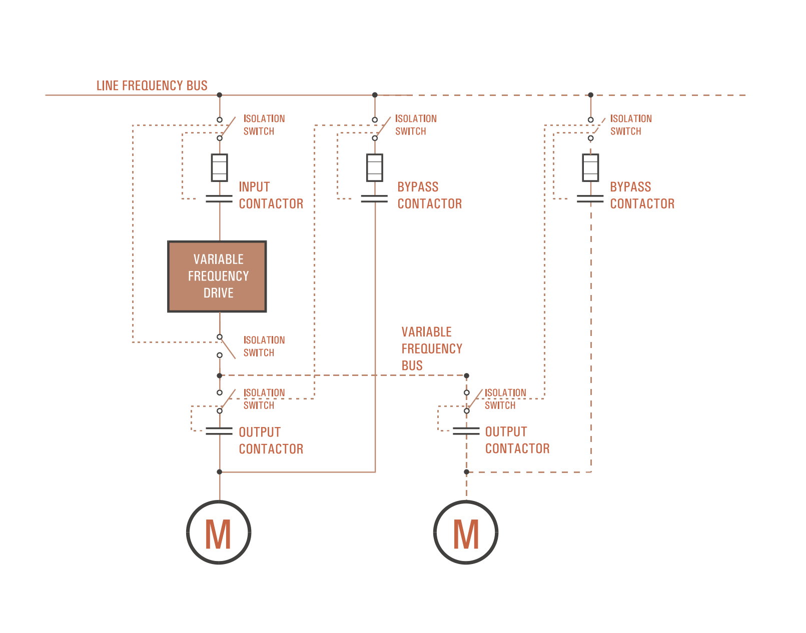


Figure 14 : Schematic of Typical Synchronous Transfer Layout

Synchronous Transfer

The capability of Synchronous transfer (See Figure 14) requires that each motor be provided with its own two-section controller. Each controller must share common line frequency (drive input) and variable frequency (drive output) busses. The first section is an E2 class controller that is equipped with an isolation switch, power fuses and vacuum contactor. Its function is to transfer the motor from the drive to the line supply via the line frequency bus while remaining in control of the drive, as well as providing protection of the motor when running in bypass mode. The second section houses an isolation switch and vaccuum contactor that isolates/connects the drive output from the motor via the variable frequency bus. With the isolation switches in both sections ganged together, the drive can be totally isolated from the machine and line sides of the system. This enables the motors to be run across-the-line in bypass mode while maintenance is performed on the drive. With each controller independantly isolated from their respective motors, it is possible to start one motor, accelerate it to full-load speed and then transfer it to line. After which, the second motor can be started, accelerated and transferred to line without losing control of the first motor. The overall synchronous transfer operation can be controlled with a programmable logic controller that can be interfaced with motor control centers, wireless SCADA monitoring and distributed I/O plant control.

Figure 15 : Control room with controllers and AC drive system

Figure 16 : Pump Station at Berisso

The Solution

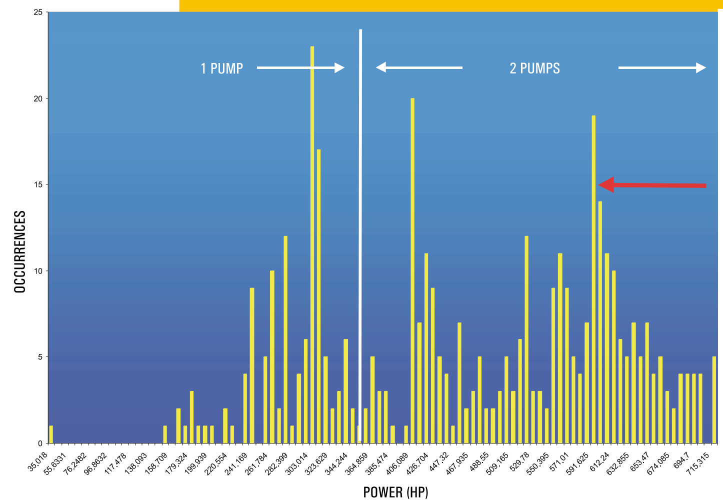
After careful consideration of all the technologies and options open to them, the project engineers at YPF made the decision on what equipment would be used to retrofit their pump system and who would be the supplier. The project would be awarded to Rockwell Automation who had extensive experience in providing added value to complete automation solutions for a multitude of applications in a broad range of industrial processes and who had examined the challenges and had devised cost-effective, easy-to-use solutions for each of them. By July 1999, the pumping station at Berisso would be up and running with CSI-PWM Variable Frequency Drives (See Figure 15) for their 2300VAC main pumps (See Figure 16), Low voltage Motor Control Centers for electrical control, Controllers and Distributed I/O for plant control. Two appropriately rated drives would independantly control their 2 - 500 HP pumps. One drive would control their 2- 800 HP pumps via synchronous transfer using a two-section controller for each pump and an SLC 500 programmable logic controller to interface the system with the newly acquired motor control centers. The results of the retrofit would become apparent almost immediately following a final flow analysis and savings calculation that would begin in September of 1999.

After successful completion of the ATP project , a complete assessment would be done that would involve incorporating data from three different evaluations of their operations at Berisso. These three evaluations would chronologically represent the effects before, during and after the retrofit on their operations. As part of their first evaluation, traditional calculation methods were undertaken from which their project feasibility study was generated back in early 1999.

The projects second evaluation would involve the collection of hydraulic system data, taken over a 40 day period starting in September of 1999. This data included hourly readings of system suction, discharge pressure, flow rates and pipeline pressures that were stored and made available for future system control. This data made it possible for project engineers to analyze the overall system, increase their understanding of how the pumping system behaved under certain conditions and to help them identify and correct certain inefficiencies. It became possible at this point to compare full voltage (across-the-line) operation of their existing pump and throttling valve systems with that of a system that was now operating via Variable Frequency Drive.

Using data collected for pump numbers 3 and 4 to illustrate (See Figure 17), it can be seen that both pumps provided an average hydraulic output of 360 HP +/- 20 HP each when operating at a fixed speed. Both pumps are required when the system requires an output between 360 and 720 HP. However, when the requirement for hydraulic power drops below 360 HP, the demand can be satisfied with only one pump. The systems existing design did not accommodate the varying requirement to start a second motor, when additional horse power was required, or stop a motor to conserve energy, when it wasn't required. Running both pumps continuously at a fixed speed, 24 hours a day, with their flow delivery governed only by the throttling valves was calculated to constitute an overall power loss of 22% (See Figure18). Although Argentina's cost of electrical power supplies are relatively inexpensive when compared with other global utilities, this amounted to substantial expense in lost power – a gross inefficiency.

The third evaluation involved the analysis of electrical and flow delivery measurements taken from January to September of 1999, from the time of inception of the ATP to after the installation and operation of the drive systems. This resulted in a comparison of the full-voltage (across-the-line) operation of their existing pump and throttling valve systems with the same system now operating under the control of VFDs. Using the records of plant electrical power consumption in total



	# OF SAMPLES	% of TOTAL
TOTAL POWER USED IN 40 DAYS		
404113.4509	860	
TOTAL POWER LOSS IN THROTTLING WHEN 1 PUMP IS IN USE		
17750.0732	234	5%
TOTAL POWER LOSS IN THROTTLING WHEN 2 PUMPS ARE IN USE		
113187.0115	624	27%
TOTAL POWER LOSS		22%

Figure 17 : Horsepower output for pump numbers 3 and 4 and calculation of overall power loss

...23% improvement in efficiency... amounting to a 20.6% savings in electrical power.

Figure 18 : Calculation of savings using VFDs

Month	KWh	Pumped M3	Avg. HP/Hr use	M3/HP	Avg	SAVINGS	$/KWh	Total Cost	$/KM3	Avg	SAVINGS
Jan-99	861.490	293221	1552,77	188,84	179,95	23,00%	0,04	34.459,60	117,52	120,15	20,6%
Feb-99	754.610	246281	1505,85	163,55			0,04	30.184,40	122,56		
Mar-99	821.697	274205	1481,04	185,14			0,04	32.867,88	119,87		
Apr-99	739.151	237146	1376,67	172,26			0,04	29.566,04	124,67		
May-99	766.705	264863	1381,92	191,66			0,04	30.668,20	115,79		
Jun-99	643.173	213531	1197,91	178,25			0,04	25.726,92	120,48		
Jul-99	687.014	251301	1238,29	202,94	221,33		0,04	27.480,56	109,35	99,60	
Aug-99	650.480	276002	1172,44	235,41			0,04	26.019,20	94,27		
Sep-99	613.750	257934	1143,11	225,64			0,04	24.550,00	95,18		

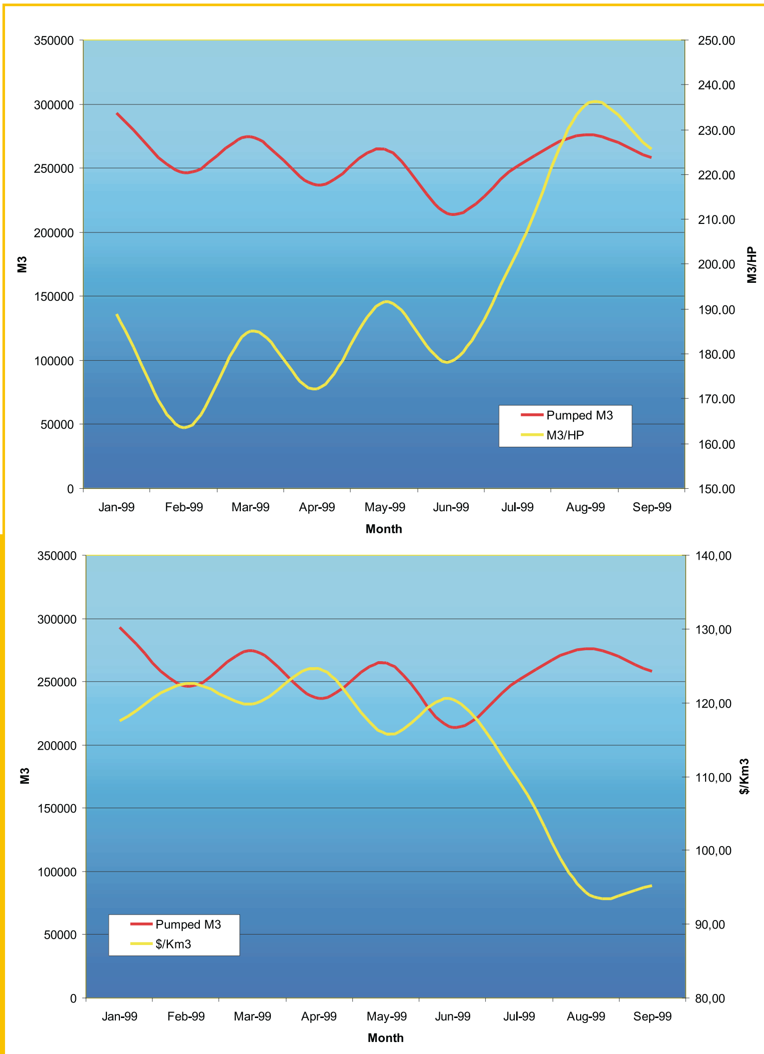


Figure 19 : Analysis of the effects of the Berisso pump station retrofit

kilowatt/hours (kW/h) and figures for the overall volume pumped for each period of time, the average m^3 per HP used and the average cost ($US) per thousand m^3 (or km^3) pumped can be calculated to determine any improvement in efficiency (m^3/HP) and expense ($/$km^3$).

The results of these calculations were most illuminating. The results showed a 23% improvement in efficiency of hydraulic power and flow delivery utilized, amounting to a 20.6% savings in electrical power. This savings amounted to an annualized figure of $60,000 (US). This figure would increase dramatically, as it was based on an initial operating period of only three months. The rapid improvement over the course of that time is remarkably apparent in the charts shown in Figure 19. Under these figures, taking into account the equipment cost and cost of downtime during installation, the drive system would pay for itself within a period of 3.5 - 4 years. This figure would be substantially reduced as the personnel at Berisso became accustomed to the equipment, improved their planning skills, increased their output and further reduced their operating costs. This was facilitated by the control flexibility that is inherent with the MV technology. The interface capabilities of the MV drive system installed at Berisso permit the operator to optimize the performance of each pump (See Figure 20), improve the efficiency of the overall system flow delivery, as well as make the compilation of process control, duty cycle and machine performance data much easier to manage. This in turn enables effective service and maintenance scheduling. Incidences of downtime are very costly. Under the system monitoring and control of MV technology, system downtime can be greatly reduced, if not eliminated.

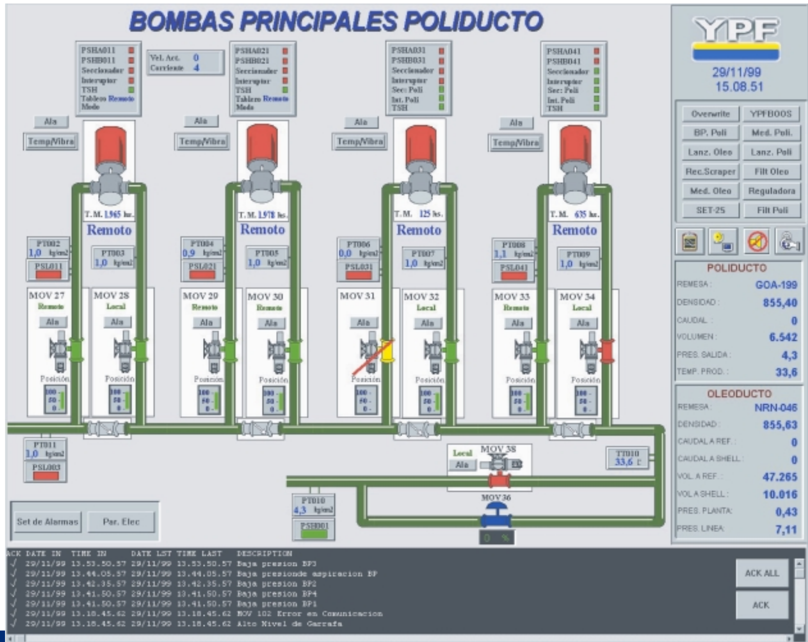


Figure 20: Example of Berisso SCADA system monitoring user interface

Worldwide Support

Allen-Bradley drives are backed by a global network of trained service engineers who are ready to respond to customer needs anytime of the day or night. Whether it's help with a start up, fine tuning the operation, or system maintenance, Rockwell Automation Global Technical Services (GTS) personnel are always close by to provide help.

For more information on Allen-Bradley medium voltage drives, or to discuss how it can help enhance your new and/or existing applications, contact your local Rockwell Automation sales office.
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