Abstract
A team forms to address the challenge of low cost, low maintenance gas compression that can be quickly ramped up to meet peak demands. The Natural Gas Industry recognizes the importance of efficient, flexible compression equipment for the transmission of gas. In the early 1900s the Gas Industry met its compression objectives with many small reciprocating compressor units. As competition increased, Gas Companies began employing more cost effective larger units 3.7 MW (5,000 bhp) and eventually gas turbines 11+ MW (15,000+ bhp) became the prime mover of choice. While gas fired engine driven compressors are convenient for gas companies; they are becoming increasingly difficult to install. Environmental restrictions have tightened making permitting difficult. The larger gas turbine units seemed a solution because they were the low capital cost prime mover and clean burning. However, gas turbines have not yet achieved the high degree of flexibility and fuel efficiency gas transporters hoped. Flexibility has become an increasingly important issue because of the new “Peaking Power Plants” that are coming online. Gas companies are trying to solve the problem of low cost, low maintenance compression that can be quickly ramped up to meet peak demands. The idea of using electric motors to drive compressors to minimize the environmental, regulatory, and maintenance issues is not new. The idea of installing an electrically powered, highly flexible, efficient, low maintenance compressor unit directly into the pipeline feeding the load, possibly underground where it won’t be seen or heard, is a new and viable way for the gas and electric industries to do business together.

This paper examines the application of totally enclosed, variable speed electric motor driven gas compressors to applications requiring completely automated, low maintenance, quick response gas pressure boosters. In this paper we will describe how a natural gas transporter, compressor manufacturer, motor manufacturer, and power company have teamed up to design the world’s first gas compressor that can be installed directly in the pipeline. We will discuss methodologies for installing the proposed compressor, the environmental benefits –no emissions, a small footprint, minimal noise—and the benefit of being able to install compression exactly where it is needed to meet the peaking requirements of today's new loads.

Introduction
At some point in their career, everyone has looked at the functioning of the system they work with and asked, "Is there a better way?" This paper discusses the idea of transporting natural gas with a new type of compressor from four very different perspectives: the operator, the electric drive manufacturer, the compressor manufacturer, and the power supplier. The paper begins with an overview of the natural gas transmission industry, and then examines the equipment necessary to move natural gas to market and what lead the idea of an inline electric motor driven gas compressor. The body discusses how the four teams approached the development of the new compressor.

History of Natural Gas Transmission
The 1930s, '40s and '50s were remarkable times for the natural gas industry. Hundreds of miles of pipeline were placed in service each year. Compressor stations were built every 70 – 150 kilometers (40 – 80 miles) along the pipelines to compress the gas and keep it moving to market. Equipment manufacturers such as Cooper, Clark, Ingersoll Rand, and Worthington developed new types of large slow speed reciprocating engines to push the gas through the pipelines. In the 1960's the industry saw a new entrant, the gas turbine driving a centrifugal compressor. The gas turbine offered ease of automation and a small footprint. The 1970s and early 1980s saw a few electric motor driven compressors installed. The emergence and attention to electric motor driven compression was primarily driven by new environmental constraints, and the need to replace 40 year-old gas fired compression equipment. The first electric motor driven compressor sets were basically the same compressors that had been used for the last 30 years with motors connected to them.

Technology continued to improve and in the late 1980s a new breed of gas compression equipment appeared, the MOPICO [2]. The MOPICO was revolutionary in that it had magnetic bearings, a gas cooled motor, a variable speed drive controller, and could be switched from series to parallel operation, giving it the advantage of a broad operating range. One aspect of gas compression seems to have remained constant. Generally, mainline transmission gas compressors are installed in a compressor station building that is located within a few hundred feet of the pipeline. In spite of the new technology gas still had to travel through numerous fittings and tens if not hundreds of feet of station piping to get to the building housing the gas compressors and then back to the pipeline.

The objective of compressor station design is to devise a facility that is safe, reliable, efficient, and minimizes piping pressure losses. A conventional compressor station with 13,000 hp (10MW), generally costs USD$ 13 - 19 million to install. The stations are generally 40 to 80 miles apart because that distance represents the low cost solution when considering the cost of adding pipe and compression to increase capacity. If the compressor units were less expensive they would be installed closer together, reducing the overall pipeline cost. Installing compression at shorter distances enables the pipeline to operate at a higher average pressure, which translates to lower fuel consumption for equivalent deliveries of gas.
Figure 1. Elevation view of an inline electric motor driven compressor, fan option, installed below grade with isolation block valves and an upstream vertical scrubber. Pipeline growth is arrested by the concrete anchor blocks.

Today a single turbine might be installed in a compressor station because of its low emissions and ease of automation. However, air quality and noise standards continue to tighten and the cost of complying with the tightened standards is becoming increasingly difficult to manage. The cost of the turbine and compressor accounts for less than 50 percent of the project cost. Buildings, fittings, piping, construction, engineering, noise abatement, air permitting, and emissions testing can add millions of dollars to the cost of a typical project. The environmental constraints are not the only changing aspects of the gas industry.

The late '90s saw the power infrastructure changing to accommodate and incorporate gas fired power plants. The deregulation of the gas and now the power industry is changing the way gas pipelines operate. Once the flows were fairly predictable. Units could be scheduled for maintenance in the summer months. However, the early hot summers of 1999 changed the maintenance practices of the gas and electric industries. Today the gas transmission companies need gas compressor units that require little or no maintenance. The units need to be capable of starting and stopping several times per week, or even several times per day. The installed equipment costs must be lowered and outages must be greatly reduced to meet customer requirements. The need of the conventional compressor building comes into question. Hence the authors asked themselves:

- What if an electric motor driven compressor could be installed directly into the pipeline?
- If the unit were reliable, automated and modular, is a building necessary?

Local emissions would no longer be an issue. Construction costs would be significantly reduced. The piping pressure loss could also be reduced. Conventional buildings might not be required. Noise impact could be significantly reduced.

IEMDC – Concept Formation

It was the recognition of the need for a gas compressor that was environmentally friendly, and relatively easy and economical to install, that lead to the formation of a multi-disciplinary team consisting of a pipeline operator, an electric drive manufacturer, a compressor manufacturer, and an electric company.

An Inline Electric Motor Driven Compressor (IEMDC) can be a below-ground compressor unit that uses an inline electric motor driven compressor to transport gas through the pipeline. The motor is cooled by the gas flowing around it as it compresses the gas. Using a variable frequency drive (VFD) the IEMDC not only has the broad operating range but also has the potential to generate electricity when not required as a compressor, making the pipeline one of the world’s largest batteries. The following diagrams illustrate the concept of placing a motor inside the flowing gas stream. The compressor wheel, shown in Figure 2, is press-fit onto the motor shaft, eliminating the need for a conventional coupling between the compressor and motor.
Comparisons
In theory the IEMDC compressor could replace older large reciprocating compressor stations that were installed at eighty-mile intervals. The IEMDC cannot compete one-on-one with a single compressor; the IEMDC is a system solution. Two IEMDCs might be located in series halving the distance between a conventional single large compressor station.

An IEMDC installed package cost is predicted to be roughly 70 percent that of a conventional compressor package, if there is a reliable high voltage power source within a few a miles. The IEMDC compressor permits the pipeline controller to pack more gas into the pipe than could be achieved with a conventional station and to turn it off when system capacity has been reached, cycling several times per day if necessary with relatively minor impact on unit life.

Advantages of Inline Electric Motor Driven Compressors
In theory IEMDCs offer a few major advantages over conventional types of compression [3]. The IEMDC is less sensitive to stops and starts than other types of compression equipment, which means the operator can run the unit only when required and the shut it down without the worry of significantly shortening the life of the unit. Pricing strategies such as operating at higher loads in the evening when power prices drop off adds value.

The motor maintains a high efficiency, above 94 percent from 50-100 percent of rated load so the unit can be part loaded and still provide excellent fuel economy. This is unlike a turbine, which has a limited minimum operating range, shown in Figure 4. The motor option can operate in regions typically not shown in OEM compressor maps enabling greater turndown. Each project is of course unique and the end-user must weigh the benefits of turndown against low ambient power gains of the gas turbine.
Maintenance and Operations

The unit is designed for a common dimension between flange faces which means a failed unit can be quickly removed and replaced with a spare or a spool of pipe. Pipeline companies will be able to choose compressors from a number of vendors. Currently, each turbine or reciprocating compressor has a footprint that is unique to its vendor. When a unit fails, the pipeline operator must scrap everything, modify the plant piping, or install like equipment. Using the IEMDC, the pipeline operator will have the option of swapping out equipment or inserting a spool if the unit isn’t installed in a by-pass configuration.

Figure 4. Compressor map - motor minimum load
The IEMDC, built to run with no emissions is environmental advantageous. The unit will not have any rotating seals exposed to the outside environment. There will be no oil to spill because the bearings are magnetic. The amount of surface area that will have to be disturbed will be halved. If the unit is installed in the ground there will be significantly less noise to abate. The old saying "out of sight out of mind" has meaningful benefits for companies building near populated areas. Since the motor will be in a 100 percent pressurized gas atmosphere the chance of fire is almost nil, as combustion without oxygen is not possible.

Pressure losses associated with the piping could be reduced by as much as 30 percent. Savings up to USD$ 60K per year can be expected for a 10MW station, assuming a USD$ 2.00/MMBTU the cost of gas. The elimination of more than half of the bends and fittings will decrease the installed costs (USD$ 200K - $500K less than conventional stations) because fewer fittings and less welding are required. The pipeline system improvements could approach 20 percent as the average pressure increases with multiple unit installations.

Future Possibilities for the IEMDC

Where inexpensive power is available, the inline gas compressor may provide gas companies with an opportunity to increase their system capacity and throughput in an environmentally friendly manner. The future applications of IEMDCs include opportunities for electricity arbitrage where the pipeline companies install the IEMDCs in parallel with existing compression equipment.

A new pipeline using only IEMDCs could blur the line between power companies and gas transmission companies revolutionizing the energy service market. In theory the pipeline operators could overpack sections of the pipeline at night and allow the gas to expand through downstream IEMDCs during peak daytime hours to produce electricity. The flow of gas through the compressor impeller could be reversed. In the axial configuration, the blades could be rotated 180 degrees such that the motor becomes a generator back feeding electricity through the same power lines that normally supply electric power to the motor.

Challenges to the IEMDC Project

The number one issue for an electrically powered compressor is the cost of electricity. Power costs are just beginning to approach self-generated power costs. Given the ever-improving efficiencies of the turbine and reciprocating engines currently available, it is still less expensive to burn fuel gas and produce power on site when in a remote location. Electric transmission lines can cost up to $600K per mile making electrification of remote sites very costly. Installing a compressor unit in the ground is too unconventional for some pipeline people, especially when you consider using electric motors instead of gas engines. The whole industry concept of repairing units in place would have to undergo a major transformation. Magnetic bearings have only recently proven cost effective, reliable, and readily available. There are many challenges that can only be successfully met by a team of dedicated and highly knowledgeable individuals working together.

THE ELECTRIC HIGH-SPEED DRIVE

Background

Electric high-speed drives have been realized with both, synchronous and induction motors. Synchronous motors have designs similar to large turbogenerators used for power generation. They are mainly used for larger units due to higher cost than induction motors and limited rotational speed. Limitation of the rotational speed for large synchronous motors is around 7000 rpm due to mechanical integrity of the exciter diode bridge. Induction motors are inherently less complex, have a smaller number of components and are therefore more cost efficient than synchronous motors. They are mainly used up to 20,000 hp (15 MW) power. Induction motors do not have a need for separate rotor excitation and therefore allow higher rotational speed.

Until about the mid 80s load commutated inverters (LCI) were the only viable option for medium voltage high power electric adjustable speed drives. Thus, in the beginning synchronous motors that naturally match for LCI were the main solutions for large high-speed applications. Due to progress in power switches, output filters, and controller technologies medium voltage power converters for induction motors became available for high power and have been used for a decade. On-going progress in power electronics has made power converters for high power available and cost attractive. As a result adjustable
speed drives have become common in many applications. Recent developments have made power converters very reliable, easy to use and to maintain, and even more cost efficient.

**Range**
The main disadvantage of existing electric high-speed drives so far has been their high cost when compared with electric low-speed drives. The main reasons for this are special motor designs, prototype development instead of a range development, complex cooling systems and very high cost for magnetic bearings.

ABB’s high-speed drives overcome the cost disadvantage with a highly pre-engineered design [1]. These high-speed induction drives are designed to cover a large speed-power range. The drives have the necessary flexibility and can be adjusted to customer needs. An electric high-speed drive system consists of a motor, a power converter and a transformer. Such drive systems are pre-engineered and can easily be tailored to specific applications. This cost efficient solution has required a new, modular concept for the motor and the power converter. With a system approach the high-speed drive has been optimized both technically and cost-wise.

The efficiency of an electric high-speed drive is above 94 percent with efficiencies above 96.5 percent for the motor, 98.5 percent for the power converter and 99 percent for the transformer. For an inline motor the efficiency is reduced due to higher windage losses.

The electric drive for the enclosed inline compressor is a spin-off of the pre-engineered electric high-speed drive. Whereas transformer and power converter can be used without any changes, the motor design needs slightly to be modified.

**Electric motor**
When the design process for a high-speed motor is started, the diameter of the active part should be as large as possible. The limit is the mechanical strength of the material (mechanical integrity and lifetime). Standard motor designs have circumferential speeds of up to 200 m/s and for high-speed motors with rotor bars designs with circumferential speeds up to 300 m/s are used. The large diameter helps to minimize the motor active part length and thus the bearing span. With higher power and the resulting longer active part rotordynamics of the motor may limit the design. For inline electric motors the circumferential speed needs to be limited not due to the material strength but due to high windage losses at the motor surface. These windage losses increase linearly with the pressure. At pressure levels of e.g. 6000 kPa (60 bar) they need to be minimized as far as possible without compromising rotordynamic behavior too much. A reasonable approach has been found with circumferential speeds of about 200 m/s. Due to the modular range concept of the high-speed motor such a design could be chosen from the pre-engineered range.

A key decision for the design of high-speed motors is whether lamination sheets should be used, as for low-speed motors or whether a solid rotor design should be used. The concept for the developed high-speed motors uses solid rotor disks that are bolted together. This concept is similar to many aeroderivative gas turbine designs and combines the advantages of a solid rotor with a high degree of modularity and reduced manufacturing cost. Delivery time is rather short due to the modular concept and the similar manufacturing process for different motors. The inline motor uses the stand-alone high-speed motor as a basic design. Design modifications are only done where necessary but the electric design and the manufacturing are identical. This approach helps to limit development effort and reduces manufacturing cost for the inline motor.

The high-speed drives use magnetic bearings allowing a dry, oil-free rotor string. Such an oil-free system is simpler, safer and more reliable than other drives. Magnetic bearings suspend a rotor contact-free with magnetic forces. Thus, they do not have any wear, do not require any lubricants and do not require any maintenance. This allows very high rotational speeds and leads to significantly lower losses compared with other bearings. The stiffness and damping properties of magnetic bearings can be chosen by controller design. Magnetic bearings have been successfully used for compressors and gas expanders for more than a decade. These installations have demonstrated the technical feasibility and that the technical advantages of magnetic bearings can lead to economical advantages for some applications. The main disadvantage of magnetic bearings so far has been high cost due to a prototype approach with special custom-made solutions. The high-speed drive range concept has been focussed on an optimized system design with a robust, cost efficient magnetic bearing design. The main rotordynamic differences between inline and stand-alone high-speed motor are the overhang impeller at one end of the shaft and the impeller forces that need to be taken into account. Although the rotordynamics of the integral electric motor compressor drive is different to a stand-alone high-speed drive, the concepts and achievements for the magnetic bearing can be transferred.

The inline motor operates in a high-pressure natural gas environment where the gas is used as cooling medium. At high-pressure heat transfer and thus cooling is very efficient and therefore the cooling concept of an inline motor can be realized in a simpler way than for a stand-alone high-speed motor. The high-speed motors are designed for temperature class H (usage temperature class B) and for hazardous area temperature class 3. Due to very efficient cooling at high pressure, temperatures in the motor are very low. The motor operates in a different environment than usual and thus the insulation materials have been checked for the high-pressure environment and the different medium, i.e. natural gas. All evaluations and tests so far have shown that the different environment will not cause any problems.

**Power converter**
The development of cost efficient power converters for high power did not only lead to an increase of the adjustable speed market (new installations as well as retro-fits) but opened the market for high-speed drives. The on-going progress in the area of power electronics helps to realize power converters for higher frequencies at lower cost than in the past. With power converters available for high-speed and high power development of high-speed motors has become an opportunity for motor manufacturers in order to be able to offer such a solution. In the power range up to 20,000 hp (15 MW) frequencies of the power converter up to 340 Hz and therefore rotational speeds up to 20,000 rpm are already available.

The power converters for the high-speed drives are based on ABB’s pre-engineered medium voltage ACS 6000 power converters. The high-speed power converters use optimized control software for high frequencies and are used in a new, twin configuration. This configuration has the big advantage that it leads to excellent voltage and current waveforms and hence to very low torque pulsation. This leads to a compact, efficient, and cost effective power converter for high-speed drives. The drive and the motor design have been optimized together in order to find a solution that is cost efficient and technically sufficient. This coordinated approach also helps to reduce harmonics into the electric grid (IEEE 519).
The reliability and availability of electric adjustable speed drives is dominated by the power electronics. Today’s power converters achieve a mean time between failure (MTBF) of 6 years and more. Furthermore, these power converters are designed modular for easy maintenance and repair. E.g. if an electronic part of the converter fails, the printed circuit board or the power electronic element (Integrated Gate Commutated Thyristors IGCTs) can be exchanged in a short time. Typically, the mean time to repair (MTTR) is less than 4 hours. These values have been proven with several hundred installations of adjustable speed drives over the last years. Thus, electric drives achieve an availability as high as 99 percent and above. This is much higher than typical figures for gas turbines where reliability is about 99 percent and availability is in the range of 96 to 98 percent.

**Advantages**

Comparisons between electric and mechanical drives show that electric drives are nowadays very competitive and offer significant advantages against gas turbines. The main advantages are lower capital cost, higher efficiency, higher availability and lower maintenance cost. Due to their simplicity electric drives are easier to operate and demand less service and maintenance. Therefore, they are much better suited for remote control and unmanned operation. The start-up procedure is much easier than for gas turbines and thus electric drives are much more flexible to use.

Maintenance cost of a drive depends on its complexity, the necessary service and on the number of wearing parts and auxiliary systems. Thus, it is obvious that an electric drive with its relatively simple design requires less maintenance than gas turbines and gas engines that have many hot gas parts and wearing parts. Besides technical and commercial benefits, electric drives are beneficial from an environmental point of view. High efficiency, oil-free operation and no emissions make electric high-speed drives the most environmental friendly compressor drive. Electric drives have no emissions on-site and total emissions are reduced as well. Thus electric drives help pipeline companies to comply with the 1990 Clean Air Act Amendments (CAAA). It is easier to get permissions and therefore permitting time is shorter. Nevertheless, the benefits of emission reduction are site specific. The lower noise level compared with gas turbines make electric drives very attractive for urban areas.

The Centrifugal Pipeline Compressor

When Dresser-Rand was first approached by El Paso Energy to investigate the feasibility of what was then known as the "inline underground pipeline booster," the idea instantly appeared to have many advantages. Having supplied several pipeline boosters utilizing magnetic bearings in the past, as well as several multistage compressors driven by variable speed electric motors, El Paso Energy’s concept was a unique blending that was intuitively feasible. From a compressor design standpoint the primary advantages are:

- No rotating shaft seals are required to contain the gas
- There is no seal system required
- There is no discharge volute with attendant asymmetrical force distribution
- There is no lube oil system required due to the magnetic bearings
- The high motor speed capability permits optimization of the compressor selection and allows many applications to be done in a smaller case size and/or with fewer impellers as compared to what is possible with lower speed direct connected gas turbine drivers
- Assembly and dis-assembly for maintenance are greatly simplified compared to conventional pipeline booster compressors due to the modular nature of the unit.

Not quite so apparent at the time, were some of the technical challenges that were involved. Some of these appear below:

- Cooling a motor and magnetic bearings mounted inside of a pressurized compressor case
- Developing power and control cable transits through the pressure containing case wall
- Developing a cylindrical aero flowpath from the radial diffuser exit to the discharge flange
- Allowing for expansion of the connected piping

The initial idea from El Paso was quickly turned into a conceptual design shown in Figures 6 and 7 below.
Figure 6. Conceptual model of the In-Line Electric Motor Driven Compressor, “IEMDC”.

Figure 7. Conceptual model showing impeller mounting and casing “shear ring” closure.
The basic heart of the compressor, the impeller, is borrowed directly from the existing Dresser-Rand "PDI" pipeline booster compressors. These impellers have been used extensively in gas transmission applications over the past twenty years. The basic performance expectation was therefore based upon a solid foundation of experience. The only aerodynamic development was in the design of the cylindrical diffuser flowpath around the outer diameter of the motor. The major concern was determination the pressure loss coefficients associated with the cylindrical diffuser. The loss coefficients were estimated using 3-D CFD (computational fluid dynamics) analysis, and will be verified during shop tests.

The analysis also indicates that the flow is remarkably well behaved. Some of the outputs of this analysis are shown in Figures 8 and 9 below.
The basic configuration of the IEMDC is very straightforward. A single impeller is mounted on the motor shaft. The impeller mounting utilizes conventional hydraulic expansion methods typical of existing direct inlet pipeline booster units. The motor is mounted inside a barrel type centrifugal compressor casing, similar in design to the existing Dresser-Rand DATUM multistage centrifugal compressor product line. Installing the motor into the casing is made easy by roller bearings mounted to the underside of the motor, again borrowing from Dresser-Rand DATUM compressor technology. The end covers (heads) at each end of the case are held in place by Dresser-Rand style shear ring closures. The end covers also contain bolted-on inlet and discharge nozzles. See the Figure 10 below.
The IEMDC design is scalable, and will eventually be available in three frame sizes matched to the most common pipeline sizes. The initial design, a mid-size unit utilizes 24-inch diameter 600-pound rating ANSI flanges on the inlet and discharge nozzles. The casing design rating is 10,342 kPa (1500 psig). The design operating condition is based upon a flowrate is 3.78 ACMS (500mmscf), and utilizes a 610 mm diameter impeller. The design point speed and power are approximately 9000 rpm and 5.5 MW respectively.

The motor cooling system consists of a simple mechanism to bleed-back gas at discharge pressure and distribute it through the motor stator and rotor before admitting it back to the inlet of the compressor. The gas transmission application is ideal for this type of approach, since the gas composition is relatively stable, and clean. The gas temperature inside the pipeline is typically at an ambient of 16 degrees C (60 F). The heat of compression adds anywhere from 10 to 20 degrees (C) of temperature depending upon the compression ratio of the application. However, 40 to 50 degrees C (110 to 120 F) gas is still more than sufficient to provide adequate cooling. In fact, the increased pressure and density of the pressurized gas greatly enhances the heat transfer coefficients.

The increased gas density does have an adverse effect on motor efficiency due to higher windage losses in the gap between the rotor and stator. However, this is accounted for in the design and rating of the motor.

The electric motor utilized in the IEMDC is a variant of the "stand-alone" high-speed motor family developed by ABB. The primary differences between the IEMDC motor and the ABB high-speed motor are in the cooling systems, the extended shaft for impeller mounting, the round cylindrical casing, and the addition of a magnetic thrust bearing to compensate for any residual thrust.

Although the first generation of IEMDC compressors are designed solely for compression services, future generations are planned for development that will be able to "windmill" in the generation mode. In other words, the compressor impeller will act as a radial turbine wheel and drive the motor as an electric generator to produce power for the grid or local network use. Additional enhancements in the planning stages include variable inlet guide vanes and variable diffuser vanes, which are expected to enhance the efficiency and operating range in both the compression mode and power generation mode. And of course, as new impellers are developed for pipeline booster applications, they will be immediately made available for the IEMDC as well.

The Electric Industry Perspective

The electric power generation market has adopted the latest gas turbine technology to power the vast majority of all new generation. Evidence of this is that 94-96% of all new generation capacity in North America is scheduled to be gas turbine. Low capital cost, lower emissions, smaller land and water requirements, energy efficiency, and ease of permitting and site approval all contribute to this recent shift in the industry. Many of the gas turbines are planned as peaking units since they are relatively easy to start and stop on a daily basis. The impact to the gas pipelines of the world is an increased variance in the daily demand for natural gas during times of high electricity use. This volatility in demand places increased stress on the pipelines and their associated compression and gas storage systems. To supply the increasing gas markets in this manner, competitive pipeline companies will have to employ sophisticated gas control systems and increasingly flexible compressor technology. This must be done in a way which, also decreases costs to remain competitive in their markets. The pipelines that do this will win by having more of the new power generation connected to their systems.

Many countries have already begun the transition to a privatized electric power industry and/or competitive generation markets. Examples include: The UK, Australia, Hungary, Poland, Sweden, Norway, New Zealand, Chile, Pakistan, the Philippines, USA, and Canada. It is expected that others will follow over time. Generally speaking, the electric power industry views the challenge of meeting the needs of the changing gas industry as an opportunity. Transitions to a more market based power industry as opposed to a regulated or state owned monopoly should further improve the power industry's motivation to meet pipeline industry needs. Many varied and more flexible electric energy pricing structures are evolving in those privatized power industries and where competitive generation markets exist, there is market pressure for both lower cost and technological innovation.

Now what does this mean for the pipelines of the world? Most gas compression technology is based upon either piston engine drivers or small gas turbine technology. While both offer somewhat flexible speed and flow capacity control, this often is at the price of fuel efficiency and higher maintenance costs. High capital cost and both exhaust and noise emissions restrictions are making it more difficult to site this type of compression technology. The electric motor drive gas compressor is viewed as a lower capital cost, lower maintenance alternative to the typical industry solution. The energy costs associated with electric compression may or may not be lower than the engine drive and turbine drive alternatives. This will vary with specific regions of the world and the current state of those markets. The inherent fixed speed nature of a standard (non-IEMDC) electric motor driven compressor is one of the limitations facing the prospective pipeline user. Others obstacles include, widely different prices and pricing structure for electric power delivery, proximity of suitable high voltage power transmission lines and right-of-way approval from land owners for the extension of high voltage lines to the gas compressor sites. The voltage levels required for the local power grid for transmission of this power varies from site to site. The size of the wires transmission companies in deregulated markets can only be determined on a case by case basis. The larger electric motors can in some cases create disturbances to the nearby power customers. A reduced voltage star can help this situation but will do nothing for the gas flow control, since the compressor will still be a fixed speed device. Various flow capacity control devices can be applied to the compressor to vary the output of the unit, but these typically will reduce the efficiency of the machine at some point to the detriment of the pipeline's cost of operation.

The electric power interconnection can be an obstacle in some cases. The very large size 3 MW to 7.5 MW and larger (4,000-10,000 hp) of many electric motor driven compressors makes operation from lower voltage distribution lines difficult. Both the power capacity requirements as well as the price and reliability needs of the pipeline most often drive the prospective electric compressor user to seek high voltage sub-transmission (34 to 69-kV) or transmission service at higher voltages. In most regulated power markets the local utility is normally quite willing to extend the high voltage lines a distance of as much as 4-8 miles and in some cases up to 12 miles at little or no cost to the pipeline. Such action represents an investment of up to a few million dollars in some cases. This is true since electric gas compressors represent a very attractive new business opportunity and the regulated environment insures a return over the life of the investment. In those countries where deregulation is now a reality, the power grid is still normally a regulated monopoly or a nationally owned asset. While generation is priced in an open competitive manner the wires transmission companies in deregulated markets can only earn income from regulated wheeling fees. This substantially reduces the level of investment judged to be prudent and attractive by the electric power utility in each case. The implications to pipeline companies are that there could be a required payment in aid to construction for the necessary power line extension. This will limit electric compression to sites where adequate power facilities are relatively close to the compressor sites. In North America this
amounts to about 20-25% of the total compressor sites today.

To maximize the benefit of the electric motor option the logical choice is to use variable frequency drive (VFD) coupled to a high speed motor driving a suitable gas compressor. This will provide power grid friendly motor starting characteristics, true variable output capacity control, with very small effects on unit efficiency. Significant energy savings can be realized during partial capacity operation using the latest VFD technology. AEP Pro Serv has applied a number of VFD’s to many variable power plant processes with outstanding, positive results. In some cases the energy savings have been over 30%. Similar results have been achieved in some cases using standard speed motors in the gas compression industry. A major benefit of electric motor drive is the ability to start, ramp to full load and stop repeatedly on an hourly and daily basis reliably with no detrimental affect on the compressor driver system. The small footprint, low noise and zero exhaust emissions make the electric gas compressor an environmentally friendly solution to the gas pipeline’s operational challenges. This allows the pipeline to react to the changing needs of the gas markets in a responsive manner. The IEMDC and the separable HiSpin motor system offer one of the best electric motor drive compressor packages. There is no need for a building to house the machine. There is no lubrication oil system and the magnetic bearings used have less total losses than a bearing in oil alternative. The broad operational speed and flow envelope offers to be one of the most flexible compressors on the market. All this in a package that promises to cost less then the best competitive alternative.

Installation Methodologies & Concepts
The IEMDC is the integral version of the HiSpin electric motor driven compressor. The original concept was for a simple high-speed machine using no lubricants to leak and few moving parts to wear out or fail. This is all coupled to a centrifugal compressor and is integrated into a single housing and installed “In-Line” to the pipeline. Since the unit is sealed, it could even be direct buried or sealed in a vault below grade. Capable of being fully automated, the IEMDC also contains only one moving part, namely the motor/compressor rotor & shaft assembly. There is both little to adjust or maintain and very little to wear out. While initial installations would most likely be in existing compressor stations, the concept includes unmanned installations at intermediate sites between the existing compressor locations. This has the potential to boost pipeline throughput capacity by about 20% based on El Paso Energy analysis. Since the design requires very little land and has very low noise emissions, it is less likely to face opposition from neighboring landowners. The IEMDC has output ratings of up to 13,400 hp (10,000 kW) and operates at up to 12,000 rpm. This is a good match with the current centrifugal compressors in use today with gas turbine drives. Since the speed of the motor exceeds the synchronous speed of either the 50 or 60-Hertz utility power supply, all IEMDC units will be supplied with an adjustable speed drive (ASD). Larger and smaller units will be available, as the market demands them.

The normal installation scenario for the installation of the IEMDC or the HiSpin units will be above ground, outdoor installation with the VFD system housed in cabinets nearby. A properly sized high voltage electric substation will be built beside the unit and in many cases will transform high voltage transmission service directly to the VFD input voltage. AEP Pro Serv, Inc. has developed a patent pending compact substation design called the Unitized Base Substation or (UBS), which complements the low profile, small land use concept of the IEMDC. The UBS is a low cost, low profile, small footprint design capable of up to 20 MVA at up to 138-kV. The design requires less field installation labor, which translates into faster set-up at a more predictable cost. The UBS substation can be installed with an optional station automation package, which includes full supervisory control of all systems. Land requirements for the station alone are only about 70’x70’.

Operational Concepts
The expected normal operational mode of the IEMDC will depend at least in part to the market price of electricity as compared to the alternative options at each site. However, the flexible operational envelope of this product will make it attractive to run as the compressor of first choice during times of low power prices and as a peaking compressor at other times. The unit can be started and stopped multiple times during the day and will be ideal for increasing line pack during off-peak periods of the pipeline. An added value concept that is being designed into the IEMDC is the ability to pack the pipeline at night, while taking advantage of the off-peak power prices. The next day the IEMDC can be reversed and operated as a generator driven by the flow of natural gas in the pipeline. This in effect allows the unit to run as a low cost source of peaking power. Since peaking generators typically run only 7-10% of the time this will not appreciably impact the use of the IMEDC as a gas compressor and in fact will provide a high value cash flow option for the pipeline compressor owner.

References

Refer questions to: Contact D-R