FIXED SPEED COMPRESSORS OPERATION IN OFFSHORE PRODUCTION PLATFORMS

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ABSTRACT

This paper discusses the use of centrifugal compressors with fixed speed in offshore production units using as reference the experience of the Petrobras' Rio de Janeiro Operational Unit. The operational and maintenance records of two of its' major production platforms are used to discuss technical aspects on the specification and acceptance during testing of fixed-speed compressors. From this discussion, recommendations are formulated to prevent repetition of the main problems faced by the Operational Unit in the operation and maintenance of such equipment.

INTRODUCTION

The first production platforms in Rio de Janeiro Operational Unit used variable-speed drivers for their main gas compressors: gas turbines in one platform and electric motors with variable frequency drivers (VFDs) on the other three platforms. The usage of fixed speed electric motor to drive the main compressors began to be used in upstream projects from 2002, with the first two platforms starting production in 2008 and 2009.This new configuration of the main compression system brought new challenges and a new philosophy for its operation and control, along with a simplification of the compression module.

The problems faced in the first years of operation on these two units led to this work. Traditional the three compression stages train, in two casings, were powered by a single driver. In this new configuration for the main compressor system, the previous single three-stage train is divided into two compressors trains, each driven by its own electric motor, allowing greater operational flexibility: a low pressure compressor can be operated paired with any of the high pressure compressors.

This simplification and increased flexibility of the main compression has taken their toll. The fixed speed compressors and the suction throttling capacity control don't have the same operational flexibility that variable speed compressors do. The equipment limits, either in available head or available power, are more easily achieved with changing operational conditions in comparison to the design conditions. These deviations are quite common and have a wide range of causes, from operational necessity to reservoir uncertainties in the design phase.

This paper will show that the successful use of fixed speed electric motor as compressor drivers in new projects depends largely on the reduction of reservoir uncertainties, a better assessment on the sizing of the driver during the design phase and new control strategies, such as the implementation of a control loop for electric motor current.

HISTORY

The selection of the technology used for the compressor-driver pair takes into account various technical and economic factors. Some technical factors typically taken into account are the type of vessel where the compression system will be installed (floating production storage and offloading units or semisubmersible platforms), the operational envelope, the required compression power, the associated control strategy, the weight and occupied area of the equipments and arrangement of the electrical system. The economic factors include the investment costs (CAPEX) and operational costs (OPEX). Operational costs account for spendings in the entire life cycle of the unit (typically 25 to 30 years of operation), including energy, consumables, maintenance costs and, with greater importance, the availability of equipment. Each arrangement alternative will give the compression system a different reliability and availability.

For the compressor, from a technical standpoint, the flow rates and discharge pressures typically demanded for production gas movement in offshore units typically leads to the selection of multi-stage centrifugal compressors with interstage cooling, liquid knockout between stages and contaminants (such as CO_2, H_2S and water) removal plants. The driver selection, taking into account the above parameters, can be categorize according to the associated control strategy, divided in two major groups: variable speed compressors and fixed speed compressors.

Variable speed compressors

For the compressor, speed variation is the most efficient control strategy from both the energy consumption and operational flexibility points of view. From the driver viewpoint, however, the speed variation becomes a complicating factor, due to the amount of required power and the size of the equipments involved, demanding more elaborate devices to vary the speed in a fast, reliable and controlled fashion. Typical devices used for this purpose in offshore gas compressors are gas turbines, variable frequency drivers and hydraulic variable speed drivers.

Gas turbine driven compressors

This configuration was historically used in the Campos Basin projects prior to 2002. Gas turbines are well proven technology in the offshore environment and have an inherent capacity for speed variation within the range required by centrifugal compressors. Typically, light industrial or aeroderivative gas turbines are used.

As advantages of this driver, we have electric power being used only for relatively small auxiliary loads, leading to a significantly reduced power generation system and associated electrical panels. A wide range of gas turbines with rated power up to 30MW ISO is available with extensive operational experience.

As disadvantages, these devices are heavy and take up greater area when the auxiliaries systems are taken into account. They also present performance and integrity degradation over time, requiring periodic interventions for preventive maintenance and have a significant influence from ambient conditions, leading to the need of oversizing the driver.

VFD driven compressors

This technology gained strength with developments in power electronics devices and has different architectures depending on model and manufacturer. Despite their differences, these devices have similar basic working principle: speed variation of the electric motor by variation on the frequency of the voltage available to the motor. This is achieved by the use of power electronic devices, generically called thyristors, which function as switches controlling the rate of voltage pulses delayed from the original alternating-current source by a transformer.

This device has no moving mechanical parts to wear and show good controllability, acting directly on the motor. Additionally, it presents present smoothed start up, reducing the impact of starting currents on the electrical system.

However, this arrangement requires much electric power, heavily impacting the size of the electrical system and leading to a centralized power generation. Due to the size of the equipment, it requires greater sheltered area, ventilated or refrigerated for panels and transformers, resulting in great difficulty when the movement of components such as coils and transformers for maintenance is needed. Depending on the configuration it still requires harmonic filters and has a history of unforeseen failures to critical components (thyristors, cells, coils, and transformers) during operation.

Compressor with fixed speed electric motors and hydraulic variable speed drives

This technology, although not new, has no history of application in offshore units in Brazil and will be used in the first platforms of the Pre-salt area development. This device, which replaces the gearbox, is approximately 30% bigger than a traditional gearbox and uses a induction electric motor with fixed speed. It varies the compressor speed changing the degree of hydraulic coupling in a torque converter, similar to torque converters in automotive hydraulic transmission.

As advantages, this system achieves reduced starting torques by reducing the hydraulic coupling, helping to reduce the motor starting time and its impact on electrical system and it has the lowest total area requirement among the variable speed options. It has a high reliability and availability, in onshore applications, and, despite using moving mechanical parts, has low maintenance and operation costs.

Besides having no historical data in offshore applications, this arrangement also has the disadvantage of requiring a large centralized power generation system.

Adopting fixed speed electric motor driven compressors

The adoption of fixed speed electric motors as drivers for large gas compressors implies in a simplification of the compression system, with the replacement of variable speed drivers (GTs, VFDs or HSDs) by suction throttling valves as the capacity control strategy. This change has brought a great increase in the system reliability, due to the failure history with long periods of repair of VFDs and their transformers, along with significant reduction in the area and weight required by the compression system. This change also brought some disadvantages and the need of special attention to some details, especially in the design phase, which will be discussed below.

The use of electric motors with fixed speed led to doubts regarding its impact on the platform electrical system. Typically, platforms in the Rio de Janeiro Operational Unit use compressors with two casings and nominal compression ratio and flow of 25:1 and 2×10^6 Nm^3/day, which leads to a power of compression in the range of 10 to 12MW (and up to 16.7MW in one unit using 3×10^6 Nm^3/d compressors). These two casings may be driven by a single or by two separate electric motors.

The adoption of compressor trains driven by a single direct starting electric motor leads to special care being needed with respect to the electrical system of the platform, such as the selection of motors with low starting current to prevent big drops in the electrical system voltage and the need for the operation of four 25MW gas turbine generator sets for the electric motor start-up. Because of the uncertainties with respect to these points, meaning, whether or not to perform direct starts in electric motors of this size in an isolated electrical system, in the first platforms with fixed speed compressors adopted a division in the compression system in two modules with the use of an intermediate header and one electric motor for each compressor casing. As a further disadvantage, the adoption of a single electric motor to drive all the compressor casings leads to the selection of a large electric motor, making it extremely difficult to be moved for repair in the event of a failure.

Some recent projects kept the two modules arrangement, but, rather than an having an intermediate header, process plants such as dehydrating (glycol) and CO_2 removal (amine) lies between them. On another unit, compression train arrangement with a single direct starting driver for all casings was selected, in this case with a 15.8MW electric motor. These units described above are not yet in operation.

The split of the compression modules in two has advantages such as increasing the reliability of the system, by allowing operation of the low pressure and high pressure compressors in any arrangement (for example, operating LP-A with HP-C), and the usage of smaller motors, easing the movement of these equipment during any maintenance.

The adoption of an arrangement with an intermediary header results, however, in a dilemma with respect to the arrangement of the various compression stages on the different modules. On all platforms in the Rio de Janeiro Operational Unit, as well as many others in Campos Basin, three compression stages (sections) are used, being usual for the first casing to contain two compression stages in back-to-back arrangement and another straight-through casing to contain the third stage. This arrangement, when compared with the arrangement in which the first casing as a single section straight-through configuration and the last two stages are in another back-to-back casing, minimizes internal leakages between stages (because of the smaller pressure difference between the units), increasing the efficiency of the compressor. However, the best balance of power requirements between the two casings is achieved by the second arrangement, allowing the selection of identical and interchangeable motors as drivers for each casing.

The use of identical electric motors has proved extremely valuable when it was needed to carry out a recall on all electric motors on one of the platforms. In this case it was possible to repair the motors in sequence while keeping only one LP compressor (with capacity slightly larger than the HP compressor) unavailable, thus minimizing the compression capacity loss.

On the other hand, the adoption of a straight-through casing for the first compression stage and a back-to-back casing for the last two stages results in higher suction pressures in the second and third stages. Depending on the concentration of CO_2 in the compressed gas, this higher pressure may lead to or aggravate corrosion of carbon steel (function of the CO_2 partial pressure and gas flow velocity), as occurred in another platform. In these cases, special care is needed in the design phase concerning the materials selection, especially for the suction region of each compression stage.

ISSUES AND LIMITATIONS WITH THE FIXED SPEED CONFIGURATION

The fixed speed electric motor driven compressors, when compared with GT or VFD driven compressors, is a configuration option that is less adaptable to deviations in the operating conditions originally specified in the compressors selection phase.

Despite the gains by system simplification, the successful application of this driver option depends on the reduction of the uncertainties on the design parameters, especially the composition of the gas to be moved and pressures required.

Electric motor overload

In the Rio de Janeiro Operational Unit, a major challenge faced by the first two units operating with fixed speed electric motors was the recurring events of compressor electric motor overload, which occurred largely due to the significant difference between the design conditions of the compressor and the it's operating condition, as required by the production plant.

The compressors in the first three platforms operating fixed speed compressors were specified from a single operational point. The choice of this rated point, for each unit, was made based in the foreseen maximum discharge pressure requirement to ensure gas lift and gas export throughout the life of the platform. The selection criteria of the driver, as stated in the API 617 standard (2002), ensures that the selected electric motor has an additional power margin of at least 10% over the highest required power among the specified conditions, in order to accommodate possible variations in process conditions and in the compressed gas composition. However, the operating conditions established for these projects does not match the point of maximum power demand in the compressor operational range. In practice, it was observed that the actual required discharge pressure to perform gas lift and gas exportation was lower than the design case, resulting in a different operating condition than originally provided (see Figure 1).

In general, centrifugal compressors tend to demand more power with higher flow rates and with lower pressure ratios required by the process. In this case of increased power demand, the power margin in the electric motor is reduced to less than 10%, being often insufficient to accommodate operational situations such as variation in the produced gas composition, variation in the three-phase (gas, oil and water) separation pressure and the equipment natural performance degradation.

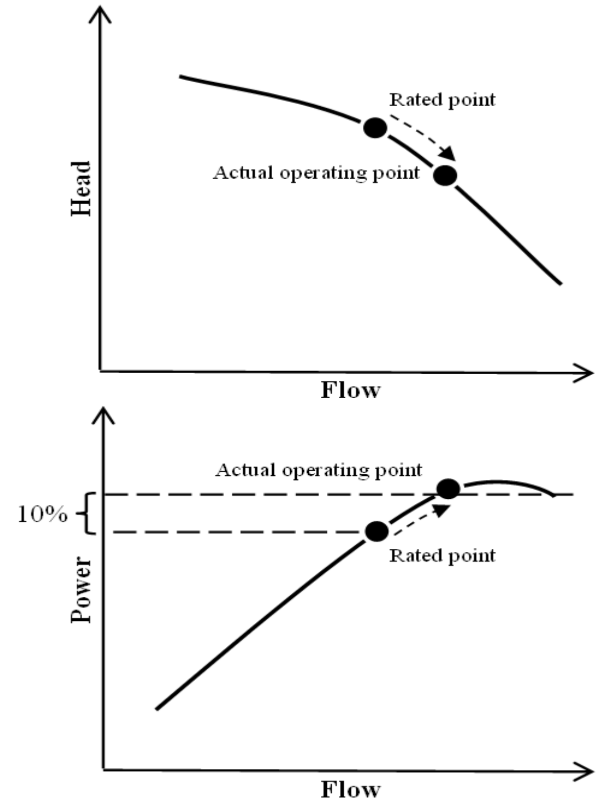

Figure 1. Schematics on how an operating point different from rated point can lead to a power demand above the electric driver rated power, causing overload.

To solve this issue it was necessary to review togheter with the electric motor manufacture the project of its cooling system to identify any design margins that could be used to increase the motor rated power. However, as there is no guarantee that this type of solution can be adopted in all cases, it is recommended to select the driver with a 10% power margin to the highest demanded power point in the compressor curve, instead of the specified points. This selection criterion may impact the power generation system design, In such situations it may be needed to reduce the driver power margin to avoid oversizing the power generation. Even in such cases, the electric driver selection margin shall reference the highest demanded power point in the compressor curve, with a minimum of 4% margin.

Reservoir uncertainties

The type of the gas to be handled impacts heavily on the selection of the compressors. For upstream units, the gas composition adopted as design parameter for the compressor is achieved by simulation and fluids analysis results obtained in the exploration phase of the reservoir. Frequently, the samples are taken from few exploratory wells, while the operating unit compresses a blend of gas from several wells. This process brings a great level of uncertainty to the estimated compressed gas composition.

In one platform, the molecular weight difference between the gas composition used as design parameter and the composition achieved in operation exceeded 10%. While the specified gas predicted a molecular weight of 21.7 kg/kmol at the compressor suction, the actual gas was as light as 19.0 kg/kmol. This difference resulted in up to 40% reduced flow capacity (Figure 2). The main reasons for this divergence were the three-phase separation temperature reduction and the production of the reservoir's gas cap during the first year of the unit. The wells connection campaign to the platform lasted for about two years and during this period the capacity of the compressors was severely reduced (the final gas blend have a molecular weight similar to the design one). It is noteworthy that the gas composition of the reservoir's gas layer is not known in advance, unlike the composition of its oil and associated gas, which can be estimated from samples taken in the exploration phase.

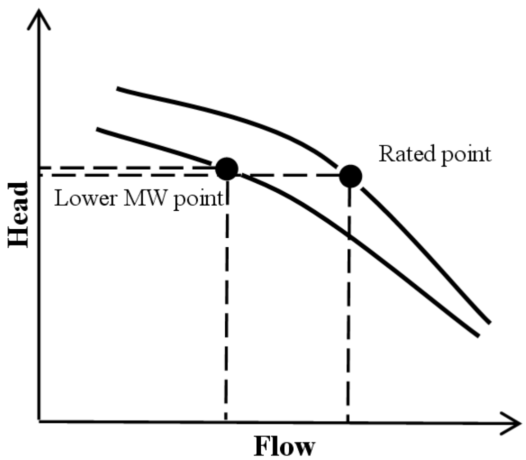

Figure 2. Schematics on how the change of the compressed gas molecular weight affects the compressor capacity.

Some of the uncertainties in the design parameters for a project may not be reduced in a feasible way. A possible alternative to accommodate large variations in operating condition, therefore reducing the risks associated with the gas composition uncertainties, is to specify some other operational conditions in the design phase. This could be from information taken from other exploratory wells or similar reservoirs, or even by extrapolating the predicted composition to more extreme scenarios. Importantly, this alternative would result in a slight increase in investment cost, from extra engineering hours and maybe even the design or manufacture of a second gear set with different output speed, but would certainly reduce production losses, a far greater cost, due to these uncertainties during operation. For most projects, a different output speed should be sufficient accommodate the different gas composition scenario. For a wider gas composition range, a second set of compressor internals or speed variation should be evaluated.

Compressor internal corrosion

As described above, in the first projects to adopt fixed speed electric motors as compressor drivers, it was opted to have identical electric motors driving both low and high pressure compressors. Consequently, the low pressure compressor was arranged in a single section straight-through casing and the high pressure compressor was arranged in a two sections in back-to-back casing. This configuration results in a significantly higher suction pressure for the third section (Figure 3).

In units in which the compressed gas contains non-negligible fraction of CO_2 (typically above 0,1%), the conditions at the suction of the final stages of compression, saturated gas at high pressure, can have a severe corrosion potential (API, 1999) for carbon steel components, such as pipes, vessels and the compressor itself. This phenomenon was quite evident in one of the first three platforms to used fixed speed electric motors, where the compressors suffered severe internal corrosion in the casing and in the first diaphragm of third section (both carbon steel), while the pipes and the scrubber (manufactured in stainless steel) in the suction of the compressor were unaffected.

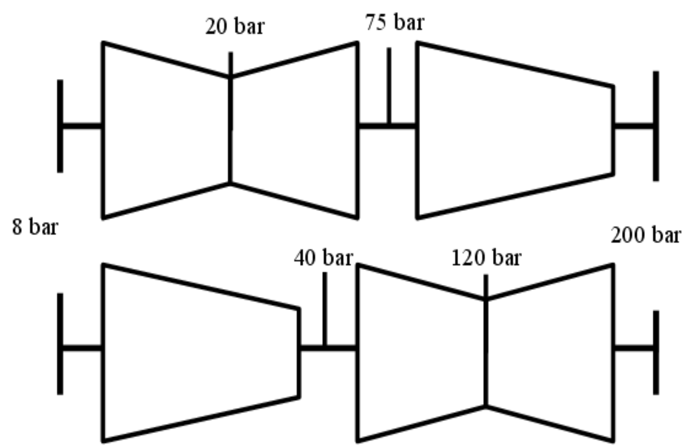

Figure 3. Typical compressor trains arrangements showing their influence on interstage pressures.

In a later project, where a higher fraction of CO_2 was predicted, the material selection by the compressor manufacturer foresaw the corrosive potential on carbon steel components, opting to use stainless steel cladding in the casing internal surface and to manufacture the diaphragm entirely in stainless steel.

For the unit suffering from CO_2 corrosion, a similar solution was adopted: coating the casing internal area and the first diaphragms with electroless nickel platting. This case, and the difficulty in applying this coating in compressors already operating in offshore units, lead to a revision in the internal technical requirements for offshore gas compressors, resulting in corrosion-resistant materials being adopted from the design phase.

CONCLUSIONS AND RECOMENDATIONS

It is the authors' opinion that the adoption of fixed speed electric motors as main compressors drivers drive brought a great simplification and robustness to the compression systems in the Rio de Janeiro Operational Unit platforms, being a good option for future projects, especially for those without a large variation or uncertainty in the gas to be compressed. The problems described in this paper can be avoided with some adjustments in the technical specifications for gas compressors.

To avoid electric motor overload events two strategies are recommended. The first is the extension of the 10% power margin requirement for the electric motor selection from the compressor rated point to the maximum compression power point in the compressor operational envelope. In some cases, this criterion may need to be adjusted to avoid power generation oversizing. The second is the implementation of an electric power (or current) limiter control loop in the compressor capacity controller, acting on the suction throttle valve. For such limit loop to work, the throttle valve must be installed inside the compressor recycle loop, eliminating the need of the sometimes used starting valve.

To minimize the risks associated with reservoir uncertainties concerning compressed gas composition, it is recommended that the design includes alternative scenarios, with both lighter and heavier gas compositions. As a way to add flexibility to the compression plant, the project can include a second gear set design with a different output speed to accommodate some of these scenarios.

Finally, although the compressor internal corrosion issues are not caused by its fixed speed driver, this exacerbated a fragility in recent projects with significant CO_2 content by increasing the last section suction pressure. With a careful analysis of both materials and coatings to be used in the compressor's internal components, especially on the higher pressure ones, this corrosion-related failures can be avoided.

The usage of fixed speed electric motors as gas compressor drivers is a simple solution and, with the above adaptations in our technical specifications, should prove to be even more robust and reliable.

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