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# An overview of turbomachinery project in Malaysian oil and gas industry

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**Abstract.** Being the most demanding, challenging and exciting engineering and technological advances has provided escalated interests amongst the engineers at large to venture into the oil and gas (O&G) industry. Although claimed as the most expensive industry in the world via the utilisation of critical equipments, the O&G industry is still recording notorious failures in its project management especially due to turbomachinery issues, the heart equipment of any O&G project. Therefore, it is important for this paper to review turbomachinery project as one of the long lead items during project executions that is also proven to be the most costly and expensive equipment. This paper therefore discusses the gaps in turbomachinery studies via literature review in highlighting its application in O&G projects. It is found that the main components of turbomachinery are driver and driven equipment, which are applied for mechanical equipment, Electric Power Generation and heat generation for Combined Cycled Configuration. Important variables for turbomachinery selection include: (1) process requirement; (2) site location; (3) driver selection; (4) equipment sparing philosophy; (5) efficiency and reliability; (6) operability and maintainability; and (7) cost. It is hoped that this paper would lead to the successful project management of turbomachinery in the O&G industry.

**Keywords:** Turbomachinery; Malaysia; oil and gas industry; overview.

## 1. Introduction

Oil and gas (O&G) industry contributes to Malaysian economic as one of the most important sectors. The country's O&G industry has developed from mere production of crude for export involving the front-end engineering design (FEED) of oil production facilities to the design and construction of chemical plants [1]. Therefore, there are opportunities of the expansion of local engineering positions in the market.

Due to its unique requirement, the O&G industry in Malaysia has developed standards and practices almost at par with the high standards of requirements of foreign countries, for instance the United States of America (USA) and the United Kingdom (UK). Nevertheless, looking at the Malaysian O&G practices, which are split into upstream and downstream sectors, the upstream is observed as the most critical sector [2] to be improved via these standards given that the upstream sector is the first ever sector traditionally developed in the industry [3]. However, for both sectors, turbomachinery is observed as the heart of this sector project management as the success and failure of the sectors operation is eventually determined by the turbomachinery delivery.

This is due to the fact that although major turbomachinery service provider or Original Equipment Manufacturer (OEM) in Malaysia are recognised internationally and based worldwide, major issues



related to turbomachinery project management are still being recorded. These have eventually led to the additional cost incurred and loss of business opportunity to the client side [4] as well as failed the O&G facilities project in Malaysia as a whole.

Hence, based on turbomachinery that is proven to be the most costly/expensive equipment [5], there is a significant need to review the management of turbomachinery project in Malaysia, whilst at the same time are capable of driving the O&G project towards success. These reviews, integrating with the project management of various stakeholders of multi-disciplinary (including contractors) throughout the project life cycle, ranging from procurement, engineering, construction and commissioning stages [6] will be able to properly manage the turbomachinery projects in the O&G industry.

## **2. Gaps in turbomachinery project research**

With a larger demand for gas and new technologies, which has made the oil and gas (O&G) industry becoming financially attractive, O&G project industry has become the focus of many studies around the globe, for instance [7] who investigate the relational study of supply chain agility, competitiveness and business performance in the oil and gas industry, [8] who identifies the economics, execution and management of complex offshore projects and [9] who determines the list of criteria for success in O&G industry. However, literature review focusing on the turbomachinery project execution, the most critical equipment in any O&G facilities project [10] is missing.

Even though as mentioned beforehand that turbomachinery is the heart of any O&G facilities project, no academic study has been carried out pertaining to its application [11]. Most of the studies available around the globe focus on the overall O&G project execution, namely platform design and construction with no interest to turbomachinery.

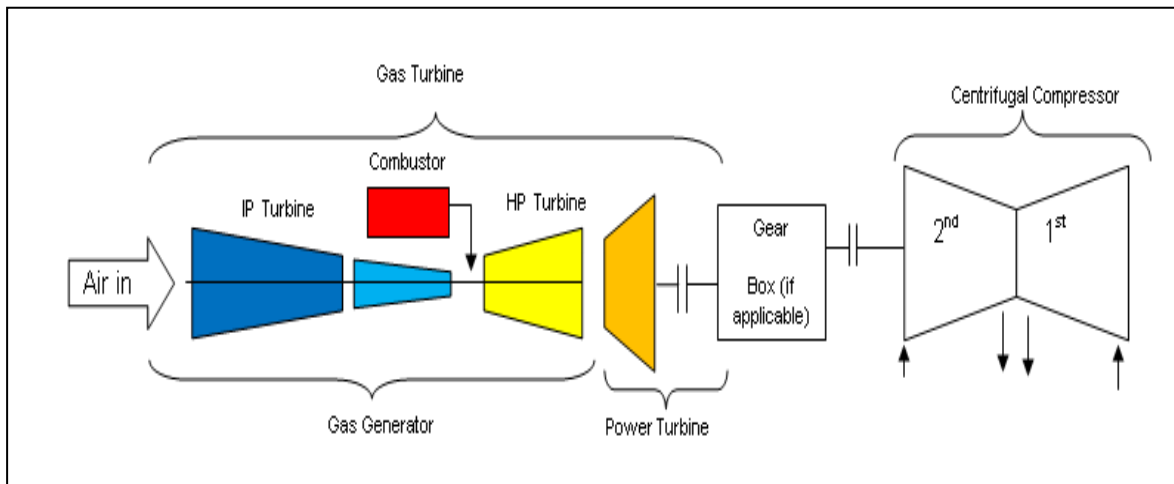
Therefore, it is seen by this study that Malaysia, and in particular PETRONAS, would need to develop a support base that can effectively and efficiently manage the turbomachinery project in O&G industry. This is because a lot of project challenges are faced by PETRONAS while managing the turbomachinery during the conceptual phase (Original Equipment Manufacturer (OEM) selection), front-end engineering design (FEED) and detailed design (technical specification, procurement, vendor data engineering review and incorporation, interface with disciplines, namely process, electrical, instrument, piping, structural, safety, equipment inspection and critical testing), construction (installation, pre-commissioning and commissioning) and finally the operation and maintenance of the turbomachinery [12].

## **3. Turbomachinery application in oil and gas projects**

The non-existence of the turbomachinery leads to the impossibility of the facilities to function and eventually fail the operation. Apart from that, the turbomachinery, which consists of compressors, generators and turbine units, are identified as critical packages by [13] due to its complexity. As highlighted by [14], the design, procurement, manufacture, test and documentation of a turbomachinery system itself becomes a unique project within the larger overall project.

The main component of turbomachinery can be divided into two, namely the driver and driven equipment. For turbomachinery, the selected driver, or also known as the prime mover, will be a turbine (steam or gas turbine), as other drivers, such as electric motor and internal combustion engine, are not classified as turbomachinery. The most commonly used for O&G facilities project is gas turbine. According to [15], gas turbine is divided into five groups: (1) frame type heavy duty gas turbine; (2) aeroderivative gas turbine; (3) industrial type gas turbine; (4) small gas turbine; and (5) micro turbine.

For the driven equipment, it depends on the application of the turbomachinery itself. It can vary from centrifugal compressor, electric generator and pump. A typical schematic of turbomachinery package is shown in Figure 1 Depending on the operating speed of the driver and driven equipment, a gearbox might be required in between to ensure smooth operation.



**Figure 1.** A typical schematic of turbomachinery package [11].

### 3.1. Typical turbomachinery application

It is noteworthy to underpin that the turbomachinery involves in each of the aforementioned phases. First of all is mechanical drive. The turbomachinery configuration is selected to drive the main mechanical equipment, such as centrifugal compressors and pumps, to be used for oil and gas (O&G) facilities process requirement. This varies from gas compression system, gas re-injection system, gas lifting system, refrigeration system, liquid pumping system and various process requirements. There are also increasing demands of turbomachinery application for Carbon Capture and Storage (CCS), Enhanced Oil Recovery (EOR), Coal Gasification and offshore high pressure Carbon Dioxide (CO<sub>2</sub>) Compression [16].

Next is the application for Electric Power Generation. In this application, the turbomachinery main function is to generate power for internal O&G facilities consumption or even for external by exporting the electricity via national power grid. The most common equipment identified for the power generation is the turbogenerator or gas turbine generator. A multi-train configuration consists of aero-derivative gas turbines is commonly considered compared to industrial type gas turbines due to the advantage of weight reduction, space requirement and maintenance logistic reasons [17].

Finally is the Combined Cycled Configuration, which means that the exhaust heat is being recycled by adding additional equipment on the exhaust system. As explained by [15], the combined cycled configuration generates up to 70 per cents of heat efficiency compared to the simple cycle which can only provide between 30 per cents to 40 per cents of heat efficiency. The exhaust can be utilised to generate steam or heat other heat transfer medium by adding a heat recovery steam generator and waste heat recovery unit at the exhaust system of the driver equipment.

### 3.2. Turbomachinery selection

There are various variables need to be taken into consideration while selecting turbomachinery in any oil and gas (O&G) platform project execution. As described by [11], these variables consist of: (1) process requirement; (2) site location; (3) driver selection; (4) equipment sparing philosophy; (5) efficiency and reliability; (6) operability and maintainability; and (7) cost. These variables are substantially discussed in the following subsections.

**3.2.1 Process requirement.** Process requirement is basically the main technical requirement that determines whether the turbomachinery meets the technical criteria or not. Under process requirement, the first requirement is to identify the type of services/application. Each project needs to determine the main function of the turbomachinery, whether to be used for mechanical drive and/or electrical power generation. Each service will have a different production profile of the process requirement. Depending on the application, some services require a constant production profile and some of the applications require a dynamic/broad production profiles, which will change according to time.

Next requirement is about the oil and gas (O&G) field production profile. As highlighted by [18], the trend for a production oil and gas facilities generally foresees a peak production within the initial production years, where the gas production profile will decrease subsequently. Changes of production characteristic, such as gas properties and lowering of production inlet pressure in the process system in order to maintain the production at an acceptable level and/or introduction of new field development within the area, will result in changes in production profile with various operating cases. Therefore, it is critical to optimise the driven equipment design to cover at least majority of the operating cases, if not all cases.

Despite traditional approach of utilising reciprocating compression system to handle high carbon dioxide (CO<sub>2</sub>) application, according to [19], centrifugal compressors have been favoured due to capacity of most CO<sub>2</sub> recovery system exceeds the reciprocating compressor operating range, maintenance intensive of reciprocating compressors, CO<sub>2</sub> high density which may lead to reciprocating compressor high velocities problems at the valves and require high strength foundation, which lead to high capital and operating expenditure. Centrifugal compressor, which usually can match the high speed driver and combine under turbomachinery, provides superior efficiency, offer higher capacity/operating range and maintenance wise it has an acceptable extended interval between overhauls.

There is also an option to pre-engineer for future compressor bundle/impeller design to cover the balance of future operating cases. According to [20], due to depleted gas reservoir after operating for few years, the facility production will decline well below the design flow rate of the centrifugal compressor. Therefore, the most effective approach would be to increase the production by reducing the well backpressure and raising the centrifugal compressor polytropic head capacity. This can be undertaken by performing the retrofit of the compressor aero bundle. By performing this, usually the gas turbine driver and auxiliaries system will remain the same. This enables to lower down the overall life cycle cost.

At this stage, it is very important not to oversize the turbomachinery equipment as it will lead to the unnecessary increase of energy consumption, operation and maintenance cost. According to [21], the application of excessive safety margin in the equipment sizing to accommodate unforeseen system changes is equivalent to an expensive insurance policy, which leads to oversized equipment.

Next criteria is to check the Criticality of Equipment/Service. If the equipment is out of service and resulted in reduction or loss of oil and gas facilities production, the service is deemed critical. Therefore, it will impact the selection by introducing equipment sparing during the selection. The same goes for power generation application, where it might result in loss of production if the turbomachinery is unavailable due to the scheduled or unscheduled maintenance. Hence, an adequate power margin and equipment sparing is necessary to mitigate the issue.

The final criterion identified under process requirement is the material selection. The material selected must be suitable for each application selected for the turbomachinery equipment. The compressed medium composition is vital in determining the material selected for the mechanical drive section of the turbomachinery. Factor that leads to the selection of super alloy materials is due-creation of corrosive environment, such as high carbon dioxide content, chloride content and traces of mercury.

For the driver equipment, continuous research and development by gas turbine manufacturer leads to the evolution of new material in order to achieve a higher combustion firing temperature, thus increasing the overall power output of the turbomachinery. As mentioned by [22], one of the main active areas in research and development of the gas turbine is the material itself; covering the superalloys, coatings and ceramic.

*3.2.2 Site location.* The site location of the oil and gas (O&G) facilities plays a significant role during conceptual engineering in order to decide the type of turbomachinery to be selected for each particular project. The main factor would be whether the facility is based at onshore or offshore as well as site rating. For offshore application, it is very unlikely that the frame type heavy duty gas turbine can be applied due to the space concerns and weight limitation.

Due to site specific geographical location for each O&G fields, different site ambient temperature and site elevation will result in changes in the driver power output, especially gas turbine. Therefore, site rating is very important to ensure that correct prime mover is selected.

A prime mover is rated at the International Organisation for Standardisation (ISO) standard condition, which is equivalent to ambient temperature 15 degree Celcius, 1 Bar and 60 per cents relative humidity. As each O&G facilities are located at a different site condition, the prime mover needs to be leveraged according to the site rating to reflect the actual condition. With reference to Petroliam Nasional Berhad (PETRONAS) Technical Standard PTS 20.180L, the gas turbine will be de-rated at 0.8 per cents for every 1 degree Celcius increment above the ISO condition, 4 per cents for fouling and wear; and finally another four percents due to the intake and exhaust losses [22].

*3.2.3 Driver selection.* In general, there are multiple choices for driver selection, ranging from gas turbine, steam turbine, electric motor and even internal combustion engine. This study focuses more on gas turbine selected as the prime mover, where the reason behind this selection is discussed in the later part. According to [23], the main advantages of selecting gas turbine compared to steam turbine are as the following: (1) gas turbine application provides a smaller footprint or space required compared to a steam turbine application at the same power requirement, thus lesser weight; (2) gas turbine application provides a better purchase cost per unit of power; and (3) gas turbine overall project installation is generally involved faster and quicker delivery.

*3.2.4 Equipment sparing philosophy.* In reference with Petroliam Nasional Berhad (PETRONAS) Technical Standard PTS 20.180L, all critical equipments are required to have a N+1 philosophy, with N is the total number of trains required to have a total of 100 per cents production [22]. This sparing philosophy needs to be adjusted according to the availability of prime mover in the market. For example, take a case of 2 x 100 percent configuration, where one unit operates at 100 percent capacity, whilst another one unit is a spare. If the process requirement resulted with one unit requires a total power of 45 MW, whereas the current prime mover model is not able to provide the power required; it is not feasible to select the 2 x 100 percent philosophy. The project needs to explore for other configuration such as 3 x 50 percent, 4 x 33 percent or more. This exercise needs to be balanced between the overall project cost as well as the available prime mover model in the market.

*3.2.5 Efficiency and reliability.* An efficient turbomachinery leads to lower fuel consumption and in a long run, resulted in lower total cost of ownership. In order to increase the overall efficiency, an option that can be taken is to go for dual cycle configuration. Another point to ponder is the capability for fuel flexibility. This is vital especially during first or black start up scenario, where the main fuel might not be available yet. Instead of utilisation of hydrocarbon gas as the main fuel, some gas turbines can also accept dual fuel capability by having a backup fuel such as diesel or heavy oil.

High carbon dioxide (CO<sub>2</sub>) gas is also a challenge [24][25], which needs to be considered in the selection of an appropriate turbomachinery. Since the technology becomes more mature, the turbomachinery original equipment manufacturer (OEM) is able to adapt their machines to accept these high CO<sub>2</sub> gases as the main fuel source without jeopardising the power and ability to start up the machine. However, to ensure high reliability during start up, the option of having a dual fuel capability need to be considered and balanced with the overall project cost.

On top of high CO<sub>2</sub> fuel gas, listed down several challenges for upcoming offshore CO<sub>2</sub> compression system such as space restriction, high reliability, very high compression pressure which relates to high density and high molecule weight of CO<sub>2</sub> and turbomachinery rotordynamic behaviour [16].

*3.2.6 Operability and maintainability.* For mechanical drive, [27] has stated that the centrifugal compressor can be controlled via few methods, including variable speed control of the driver, adjustable inlet guide vane, suction or discharge valve throttling as well as flow recycling. The main purpose is to ensure the operational flexibility in case of production upsets or even unscheduled shutdown.

The turbomachinery equipment design must incorporate the maintainability of this turbomachinery equipment by having a modular configuration, having a quick replacement of parts and allowing a one-to-one replacement in order to reduce the equipment downtime or production loss. For upstream oil and gas (O&G) facilities, the direct impact of production loss would be the loss of revenue. Apart from that, there might be additional penalties imposed by the buyer which lead to damage of reputation to the company. Additional utilities system required to support the operability of the turbomachinery needs to be considered during the design stage, as the requirement will have a significant impact on other equipment and also overall cost.

*3.2.7 Cost.* Apart from the technical aspect, the most important and influential decision during the final selection of the turbomachinery for each project is the cost. Material and equipment cost accounts for a notable portion from the overall cost profile of an oil and gas (O&G) company [28]. As highlighted by [29][21], the overall or Life-Cycle Cost (LCC) shall be considered by including the capital expenditure (CAPEX) and operating cost (OPEX). Traditionally, some equipment procurements are still based on capital expenditure (CAPEX) instead of LCC, which is according to [30], this was due to the precisely known price of the CAPEX, whereas the LCC is based on theoretical cost. Another main reason is due to the deeply rooted practice by certain company, which is solely based on CAPEX. Therefore, the cultural resistance is identified as an obstacle in order to adopt the LCC [30], which obviously provides a wider perspective to the end user and provides a broader view of overall cost expenditure.

According to [27], CAPEX for a project covers the initial cost and installation cost of the newly purchased equipment. The initial cost shall not only cover the cost of the turbomachinery equipment, but also the auxiliaries system required to ensure the successful operation of the equipment. This includes, for example the structural platform to house the turbomachinery, separators, interconnecting piping, control system, coolers and other associated equipment.

[28] also suggested that LCC to be calculated based on different contributing factors, such as initial equipment purchase, installation, operation, maintenance, inventory and training. On top of that, the LCC calculation must also take the Net Present Value (NPV) at a chosen interest, for example PETROBRAS has established 15 per cents per year for their feasibility study [28]. Thus, the NPV interest might vary according to each company.

According to [31], the major compressor and gas turbines manufacturers are also experiencing the same issue of cost incremental. It was recorded that between 2006 and 2007 alone, the machinery cost jumped between 8 percent to 20 percent and 15 percent to 25 percent, respectively.

#### **4. Conclusion**

This paper provides an overview of turbomachinery project in the oil and gas (O&G) industry in Malaysia. The findings show that turbomachinery is the critical equipment of any O&G facilities. Even so, there is a huge gap in terms of literature review related to the management of turbomachinery in O&G projects that eventually lead to many unsuccessful turbomachinery project execution. The main components of turbomachinery are driver, which is commonly used for gas turbine, and driven equipment, which can vary from centrifugal compressor, electric generator and pump. Generally, turbomachinery is applied for main mechanical equipment, Electric Power Generation and heat generation for Combined Cycled Configuration. In addition, turbomachinery selection is very critical in any O&G project, thus seven variables need to be focused on during its selection: (1) process requirement; (2) site location; (3) driver selection; (4) equipment sparing philosophy; (5) efficiency and reliability; (6) operability and maintainability; and (7) cost. It is hoped that the discussion would lead to the successful project management of turbomachinery in the O&G industry.

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