LNG PROCESS USES AERODERIVATIVE GAS TURBINES AND TANDEM COMPRESSORS

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ABSTRACT

This paper describes a LNG process which uses as a central feature, a single aeroderivative gas turbine driving two centrifugal refrigerant compressors, one for propane and one for mixed refrigerant (MR), in a unique tandem configuration.

In this case study, this compact configuration has the following features:

- Pre-cooling of the feed natural gas with propane in a direct injected, plate-fin exchanger followed by liquefaction and production of LNG using a mixed refrigerant (MR) in a coil wound heat exchanger,
- Liquefaction at moderate pressure to facilitate simple heavy hydrocarbon removal,
- Water cooling (although air cooling is also an option but is not as compact).

This design is flexible in allowing use of many different, commercially available aeroderivative gas turbines ranging in size from low to high horsepower. The LNG production rates will therefore range from those required for small scale LNG plants to those typical of medium to large base load plants. LNG production rates will be proportional to the total installed power generated by these gas turbine drivers in single or multiple sets.

One GE LM 6000 PF gas turbine driving two tandem refrigerant compressors sets using this process at 20 °C ambient can produce about 0.9 million metric tons per annum (MTPA) of LNG. Two parallel GE LM 6000 PF sets can produce 1.8 MTPA and 4 sets, 3.6 MTPA. Each additional set will add 0.9 MTPA. Use of Rolls Royce Trent 60 gas turbines, as refrigerant compressor drivers, could increase all of these production levels by up to 20% because of the higher horsepower capabilities of those gas turbines.

A LNG plant using this process (a) will have a specific power rate of approximately 0.3 MWh/ton (megawatt hour per metric ton), (b) will not need large electric motor starter/helpers, (c) will not need to depressurize the suction sides of the refrigerant compressors on startup (d) will not release refrigerants to atmosphere on plant shutdown, (e) will eliminate flaring during normal operations by recycling excess boil off gases for reliquefaction, (f) will have minimum complexity, (g) will be easy to automate, operate and maintain, (h) will have low operating and capital costs and (i) will have wide turndown capabilities. Depending on the feed gas composition and some other constraints, this process can use molecular sieves for both water removal and CO_2 removal (thus eliminating expensive, AGRU circulating amine plants).

INTRODUCTION

Recently built onshore, base load LNG liquefaction plants are often complex facilities that employ multiple numbers of air coolers, heat exchanger chillers, coil wound mixed refrigerant exchangers, gas heaters, fractionation towers, gas turbines, compressors and pumps, as well as significant quantities of piping, valves and instrumentation. These plants also often require relatively large tracts of land. The process described below was designed to reduce the overall complexity and plot plan requirements of typical LNG plants.

The LNG process described below employs one LNG unit with three modules – a gas turbine-compressor module, a pre-cooling module and a liquefaction module. The gas turbine-compressor module uses thermally efficient and fully automated aeroderivative gas turbines that drive tandem-coupled refrigerant compressors. One of the compressors is a three-stage propane compressor while the other is a single casing, mixed refrigerant compressor.

The pre-cooling module uses a plate-fin exchanger for the three stages of propane cooling. These exchangers pre-cool the feed gas and the mixed refrigerant using only the liquid phases of propane evaporating at three pressure levels. Propane liquid is separated from propane vapor before being delivered to the pre-cooling exchangers. Propane vapor from the separators and vapor from the pre-cooling exchangers are mixed and then returned directly to the suction sides of the propane compressor for recompression and recycling.

The liquefaction module employs coil wound heat exchangers to liquefy the mixed refrigerant and the feed gas to LNG

UNIQUE DESIGN FEATURES

The gas turbine-compressor module is shown in Fig. 1. In this process, an aeroderivative gas turbine drives both a propane pre-cooling refrigerant compressor and a MR compressor in a tandem configuration on a single shaft. Multiple sets of these gas turbine–compressor modules can be used in parallel in a plant as well as different sizes of gas turbines and compressors to yield larger or smaller annual LNG production capacities.

In this work, GE LM 6000 PF gas turbine drivers were studied in detail but many other gas turbine drivers, such as the larger Rolls Royce Trent 60, could also be used depending on the LNG production targets for the plant.

This process uses two closed refrigeration loops in series. The first is a pre-cooling loop that uses propane and the second is a liquefaction loop that uses a mixed refrigerant. The propane pre-cooling loop uses 3-stage propane compressors instead of 4-stage conventional designs. This permits a more compact and lower cost plant design.

Pre-cooling of the feed gases is accomplished using plate-fin heat exchangers that are fed with a controlled quantity of liquid propane rather than the large circulating volumes used in other plant designs. This feature aids in reducing the sizes of the plate-fin exchangers and also the piping and valves used in these circuits. The inventory of liquid propane in the plate-fins is minimized.

Liquefaction of the pre-cooled feed gases with a mixed refrigerant is achieved in a coil wound heat exchanger. Due to the robust nature of their design, these exchangers are more easily able to handle stresses that may be caused by uncontrolled temperature swings during rapid start ups and emergency shutdown situations.

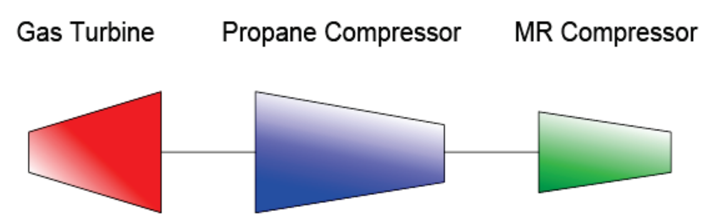

Fig. 1 Gas Turbine / Compressor Module

PROCESS DESCRIPTION

The simplified block flow diagram for this process is shown in Fig. 2. After passing through the gas treating units where water, carbon dioxide and mercury are removed, the treated feed gas is mixed with any recycled excess boil off gas that cannot be burned in the fuel gas system and passed into the pre-cooling plate-fin exchanger. The latter is located inside the pre-cooling module illustrated in more detail in Fig.3.

If the feed gas contain less than 0.2 mole % CO_2 and the size of the LNG plant module is about 1 MTPA, the CO_2 can be removed by molecular sieve system without the mole sieve vessels becoming unreasonably large. If the feed gas contains more than 0.2 mol% CO_2 then conventional acid gas removal systems such as mDEA units will have to be considered.

A molecular sieve system upstream of the CO_2 removal molecular sieve system is also used to remove water from the feed gas. Regeneration gas consisting of BOG and end flash gas is heated by a gas-fired furnace. This gas is first used to regenerate the CO_2 mole sieves and secondly, to regenerate the dehydration mole sieves. The CO_2 in the regeneration gas released from the regenerated CO_2 molecular sieve vessels will not adhere to the dehydration molecular sieves during their regeneration because of the high temperature of the regeneration gas and the presence of water. After condensed water is removed from the regeneration gas, it is returned to the fuel gas system where all the CO_2 and most of the nitrogen (in the feed gas) are released to the atmosphere after passing through the gas turbines.

In this work, the treated feed gas was assumed to be a typical natural gas mixture of methane, ethane and propane with small amounts of nitrogen, CO_2 and some heavy hydrocarbons.

The pre-cooling exchanger shown in Fig. 3 is a single unit, plate-fin type divided into three sections. The top three sections of this exchanger cool the feed gas and MR refrigerant progressively from ambient to temperatures near that of the normal boiling point of propane using three stages of liquid propane refrigerant operating at three different pressure levels, namely high pressure, medium pressure and low pressure.

Three stages of propane pre-cooling were used in order to reduce the size of the propane compressor so it could then be more easily placed on the same shaft as the MR compressor. This design was also adopted to reduce the complexity and number of vessels, piping and valves required by the process as well as to reduce the size and complexity of the plate-fin exchanger. While three stages of propane pre-cooling were used in this work, the use of four stages of propane refrigerant is a possible alternative arrangement that could be studied in the future.

The heavy hydrocarbon separator downstream of the pre-cooling exchanger removes C5+ (pentanes plus higher hydrocarbons) from the feed gas to prevent their passing forward to the coil wound exchanger where they could freeze. This separator may also remove some ethane and propane which can be sent to a fractionation section of the plant for production of makeup refrigerants. Stripped feed gas from the heavy hydrocarbon separator is delivered to the coil wound exchanger in the liquefaction module (see figure 3). In this exchanger, the feed gas is liquefied and cooled using a mixed refrigerant (MR). The MR is composed of nitrogen, methane, ethane, propane and n-butane. After leaving the liquefaction exchanger, the MR is sent to a JT (Joule Thompson) valve where it drops in temperature by undergoing isenthalpic expansion. It then returns to the coil wound exchanger where if provides the low temperature coolant necessary to liquefy both the MR and feed gas. The LNG exits the liquefaction module and after depressurizing and flashing in the end flash vessel, it is delivered to LNG tanks for storage. End flash vapors are compressed and then mixed with boil off gases (BOG) prior to being sent to the fuel gas system. The MR exiting the liquefaction coil wound exchanger passes through a suction drum separator and then is delivered to the suction of the MR compressor where it is compressed to complete its closed loop cycle.

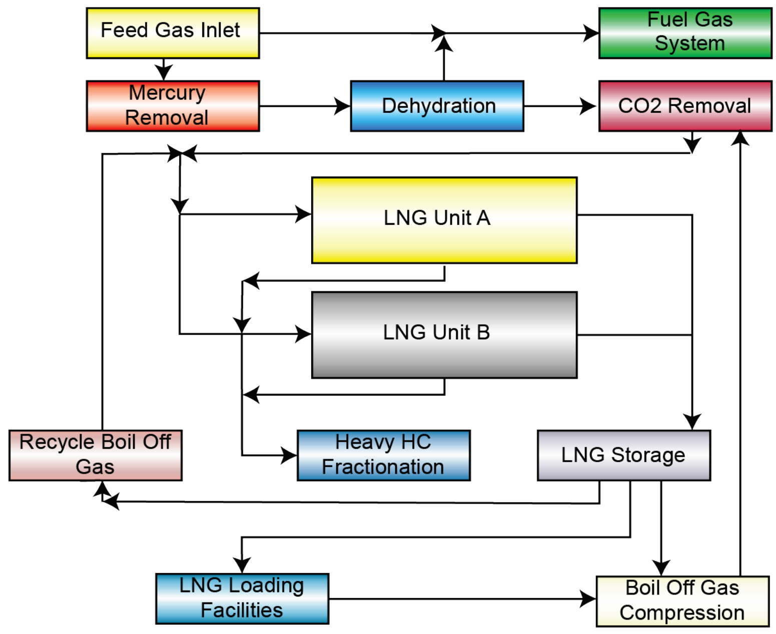

Fig. 2 Simplified Block Flow Diagram

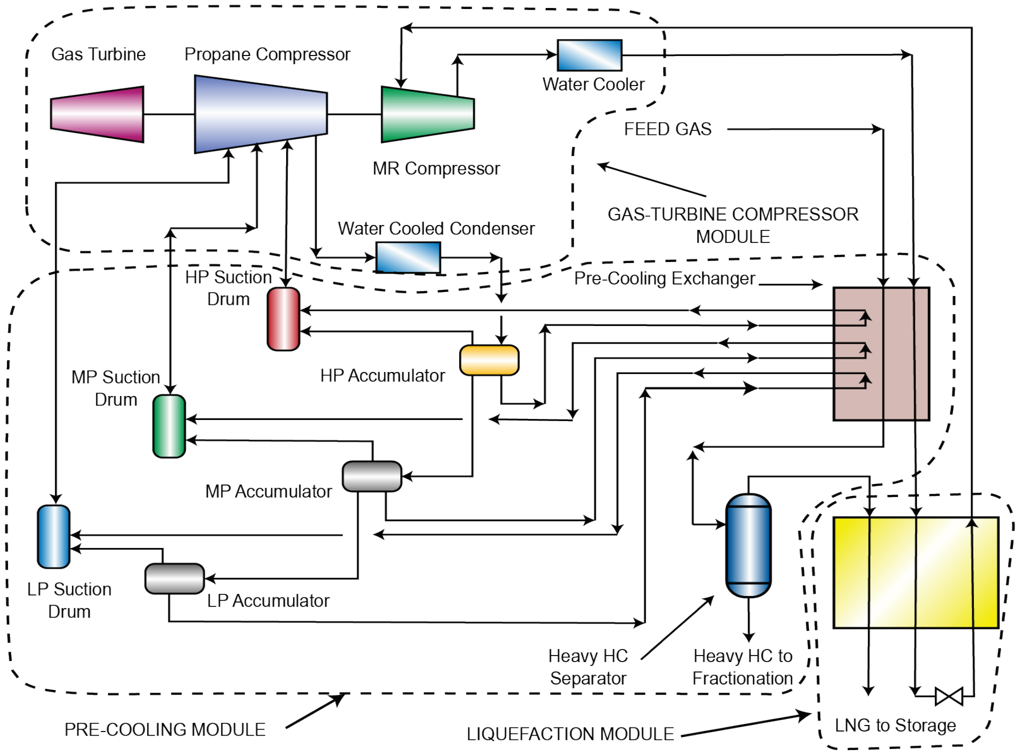

Fig. 3 LNG Unit A (or B)

MAIN TECHNICAL FEATURES OF THE PROCESS CONFIGURATION

- Minimizes plot space,
- Minimizes complexity
- Has high turndown capability
- Maximizes capabilities for easy expansion
- Uses plate-fin cold boxes for propane pre-cooling
- Uses coil wound exchangers for mixed refrigerant cooling and condensing of feed gas
- Uses a three-stage propane compressor to simplify process equipment and reduce costs
- Propane compressor and MR compressor are arranged on a single shaft in a tandem configuration
- Low capital and operating costs – aeroderivative gas turbine have high thermal efficiencies
- Permits use of many different commercially available aeroderivative gas turbine drivers, such as the GE LM 6000, RR Trent 60, or RB 211,
- Low specific power consumption, 0.3 MWh/ton
- Eliminate flaring of excess boil off gases during holding and loading operations by recycling to the inlet of the plant
- No flaring of refrigerants before or during startups or shutdowns,
- Fast start up and shutdown times
- High availability by employing a multiple liquefaction module concept – if one shuts down, the others keep running
- Eliminate the need for large electric helper/starter motors,

MECHANICAL DESIGN FEATURES OF THIS PROCESS

Choice of Gas Turbine Driver

The choice of gas turbine driver was based on the following criteria:

- Power output
- High efficiency
- Low weight to improve constructability and maintainability
- Suitability for mechanical drive, based on experience or validation tests
- High reliability and availability
- Turbine output speed to be preferably suitable for direct drive for refrigerant compressor

The following is a partial list of aero-derivative gas turbines that were potential candidates for this process along with their major characteristics.

MODEL	ISO RATING MW	EFFICIENCY %	TURBINE SPEED RPM	MECH. DRIVE EXPERIENCE
GE PGT25+	31.4	41.1	6100	Yes
RR RB211-GT61	33.0	40.4	4850	Yes
GE PGT25+G4	34.3	41.2	6100	Yes
GE LM6000PF	43.9	43	3600	Validated
RR Trent 60 DLE	52.5	42.9	3400	Yes

The aero-derivative type gas turbines satisfied all of the above criteria. The target power output of 40 MW was selected to suit the size of LNG plant contemplated. The model that satisfied all the above criteria and selected for this work was the GE LM6000PF. The Rolls-Royce Trent 60DLE, with about 20 % higher power output was also acceptable, but for a plant of a larger size.

The GE LM6000PF is a 2-shaft gas turbine engine derived from the core of the CF6-80C2 aircraft engine. The LM6000-PF DLE gas turbine is capable of achieving 15 ppm NOx when using natural gas fuel which is an advantage, compared to the 25 ppm NO_X emission level of other gas turbines.

The main characteristics of the LM6000-PF are:

- 43 percent simple cycle thermal efficiency
- 44 MW (ISO rating)
- Allows full speed range capability from 50-105% of the rated speed of 3600 RPM.
- High part-power efficiency that improves system-operating economics.
- Cycling capability without impacting maintenance intervals
- Zero to 100 percent load in 10 minutes
- Variable speed for mechanical drive
- Lightweight, compact, modular design

Aero-dynamic considerations in the impeller selection for the propane compressor favor a low operating speed, whereas an economic selection of the MR compressor favored a higher speed. The optimum speed, that was acceptable for both services, required the use of a speed increasing gear.

LM6000 Gas Turbine

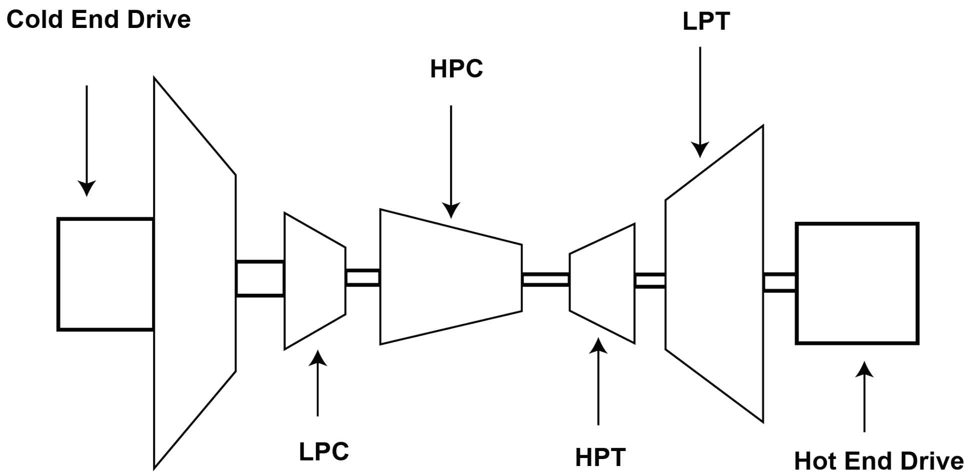

Fig. 4 LM6000

The LM6000 uses a two-shaft rotor in a spool configuration. This differs from the conventional gas generator + power turbine configuration of other aero-derivative gas turbines. The LM6000 has no separate power turbine, and results in a more compact arrangement. Driven equipment can be coupled at either the cold end, or at the hot end. For safety reasons, hydrocarbon compressors are coupled at the hot end. Gas emissions from the compressor will then have a lower chance of migrating into the air inlet of the gas turbine.

The LM6000 starting motor acts on the HP rotor and accelerates the HPC compressor + HPT turbine to a speed when the firing temperature is reached. After firing, the HP rotor is further accelerated and the additional mass flow creates a torque on the LPT rotor. Once a break-away torque is developed, the LPT rotor along with the driven equipment, in this case, the compressors, also start to rotate. This starting sequence ensures that the gas turbine can be started up by a relatively small sized motor, even when coupled to a large compressor train.

Trent 60 Gas Turbine

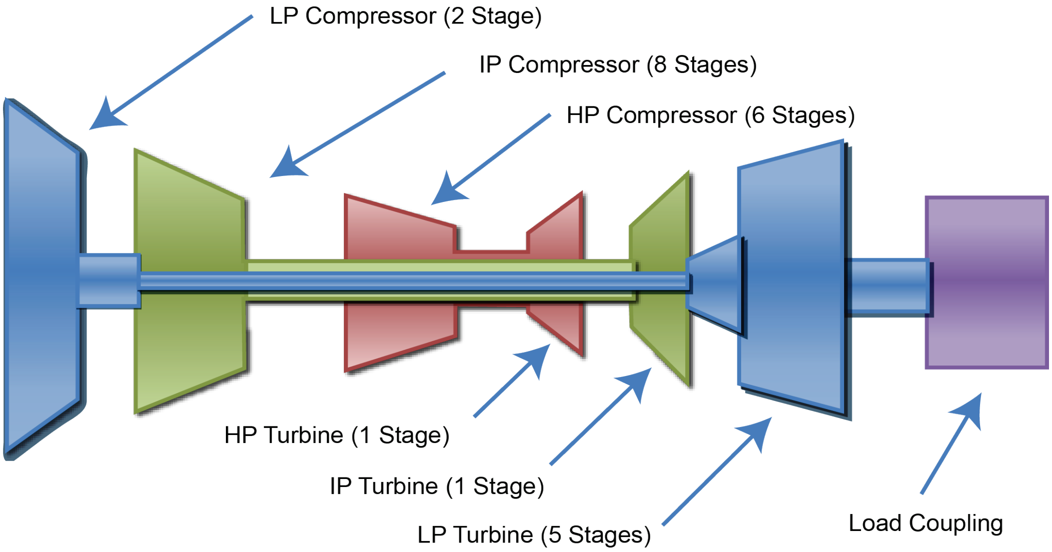

Fig. 5 Trent 60 - 3 Spool Rotor Arrangement

The Trent 60 DLE has a three-rotor spool configuration and utilizes a starting strategy similar to the LM6000. In this case, the starter mechanism engages the intermediate pressure (IP) rotor. Unlike the LM6000, the Trent 60 power output is available only at the hot end.

Gas Turbine Validation through Testing

In the turbo-machinery industry, it is a generally accepted practice to look for "proven experience" as demonstrated in operating plants before the machinery is considered acceptable for a new application. In this work, the application of a LM6000 gas turbine falls in un-chartered territory as far as experience in using aero-derivative gas turbines for mechanical drivers in LNG plants are considered. There are no LM6000 gas turbines currently in mechanical drive operation. This gas turbine however, has been recently selected for a major new LNG application and is now under manufacturing and testing. There are, however, no demonstrated experiences yet.

During the development of this process, an independent validation procedure was undertaken by GE, the manufacturer, to determine if this gas turbine was acceptable for the proposed task. Prior to offering the LM6000 to the market as a mechanical drive, GE had already carried out an extensive test campaign to demonstrate the ability of the gas turbine to perform mechanical drive duties especially those found in an LNG plant. Two features of utmost importance in a mechanical drive scenario were established by reviewing manufacturer's development program, in-house test results and by holding discussions with the manufacturer:

1. Starting torque capability
   An actual gas turbine was subjected to high starting torque by applying an external restraining load. Torque developed by the turbine was measured. Other mechanical performance characteristics such as nearly steady torque over a certain range close to rated speed, high torque at low speed, acceleration with load and capability to quickly ride through critical speeds of driven equipment, were also established. It is the high starting torque capability that is expected to enable starting the compressor train without de-pressurizing the compressors and thereby avoid loss of refrigerant. Further analytical work and testing will have to be carried out during an actual project to confirm ability of the driver to start the selected compressors from settle-out pressures.

2. Variable speed capability
   Stable operation was studied over a wide speed range while delivering power along a cubic power curve that is typical of a centrifugal compressor application. The variable speed capability improves the operational flexibility of the train and helps to vary the discharge pressure of the propane compressor based on ambient conditions.

Reliability and Availability

The Trent 60 has also undergone similar tests to those performed on the LM6000. Six machines have been in mechanical drive operation since 2007 in a pipe line application in the Middle East. Another six joined the mechanical drive fleet for pipeline operation in Russia. Three more have been ordered by the original customer. The Trent 60 gas turbines have not been used for LNG mechanical drive applications yet.

Even though LM6000 is yet to be used in mechanical drive application, there are a large number of generator drive machines installed all over the world. The generator drive fleet has recorded 99.7 % reliability. The overall fleet of Trent 60 which includes both the generator drive and mechanical drive applications has recorded 99.31 % reliability.

Maintainability of Aeroderivative Gas Turbine

It is recognized that the downtime for scheduled maintenance of the gas turbines, especially for major overhauls is a major factor in the availability of LNG plants. Due to the light weight nature of the aero-derivative gas turbine, the various maintenance schedules that are performed on-site take less time compared to those for a heavy duty frame machine. The engines require a major overhaul every 50,000 hours of operation. Major overhaul is performed in an off-site maintenance depot of the manufacturer. Either a spare engine or a lease engine can be installed and the plant re-started in three or four days. Different maintenance contract options are offered by the manufacturers. Typical maintenance schedules for the LM6000 and Trent 60, using natural gas as fuel, are given below:

GE LM 6000 TYPICAL MAINTENANCE SCHEDULE		
Hours	**Maintenance Action**	**Outage Time**
4,000	Inspection (Every 4,000 hours) Note (1)	12-16 hours
25,000	On-site Hot Section Replacement	3 days
50,000	Spare or lease Engine Installed during Refurbishment	2-3 days
75,000	On-site Hot Section Replacement	3 days
100,000	Spare or lease Engine Installed during Refurbishment	2-3 days
125,000	On-site Hot Section Replacement	3 days

Note: (1) At 12,500 hours, concurrent with every 3^{rd} borescope, the LM600 compressor bushings are replaced – including both borescope and bushing change, outage can be 24 hours.

RR Trent 60 TYPICAL MAINTENANCE SCHEDULE		
Hours	**Maintenance Action**	**Outage Time**
(1)	Borescope Inspection - Hot End	1 day
8,000	Function and safety checks, borescope inspection	2 days
25,000	HP/IP Core Refurbishment Note (2)	3-4 days
50,000	Full engine overhaul Note (3)	3-4 days

Note: (1) Less than 2000 hours

Note (2) Inspection of hot end and replacement or refurbishment of worn parts; re-coating of gas washed parts as required

Note (3) Total engine strip and refurbishment of all parts for a further lifecycle; utilize exchange engine for higher availability

Process Simulation

Based on a process simulation using two LM6000 gas turbines working in parallel, each driving in tandem one pre-cooling propane compressor and one mixed refrigerant compressor, the LNG production rate into the storage tanks was 2 MTPA. Assuming an availability of 0.93, typical of plants of this size and complexity, an annual LNG production rate of 1.8 MTPA was achieved.

In this work, the shaft power required for one gas turbine driving in tandem one pre-cooling propane compressor and one mixed refrigerant compressor was 33 MW or 66 MW for two sets in parallel. One LM6000 PF gas turbine (44 MW ISO rating), de- rated for operation at 20 °C, inlet and outlet losses, air compressor fouling, turbine aging and 4% API compressor power margin, is expected to have a power availability of at least 35.5 MW, well within the requirements of the gas turbines used in this process.

LNG Liquefaction Module Controls

LNG plants always operate in environmental conditions where ambient air temperatures, humidity and barometric pressures regularly change. While humidity and barometric air pressure changes do impact gas turbines in LNG plants, their sensitivities to these parameters are relatively low and can often be ignored. Ambient air temperature changes, on the other hand, can have large impacts on gas turbine performances (especially aeroderivative gas turbines). Cooling water temperatures will affect the discharge pressures, and hence the power requirements, of the propane compressors. Rules of thumb vary, but in this work, figures from 0.7% to 1% decrease in plant production rate per degree C increase in temperature were used.

In this process, which uses aeroderivative gas turbine drivers, an increase in operating speed of the turbine-compressor set is possible. The GE LM6000 is a variable speed turbine and therefore compensation for a higher discharge pressure of the propane compressor (and hence power requirement) as the cooling water temperature increases can be accomplished by increasing the speed of the turbine. This assumes however that some gas turbine reserve power still remains if the ambient temperature also increases. This capability of a speed increase of the turbine affords an advantage for this process relative to other LNG plants that use fixed speed gas turbine drivers. This process could therefore permit slightly higher daily or annual LNG production rates in climates where distributions of ambient temperatures may be skewed towards higher values compared to mean average temperatures.

Being on the same shaft, the propane and mixed refrigerant compressors will spin at the same speed. Control of the propane compressor will be conceptually by speed variation while control of the mixed refrigerant compressor will be either by inlet guide vanes or by suction throttling.

Refrigerant Compressors

Each of the two parallel compressor trains described in this process consists of:

Gas Turbine Driver + Speed Increasing Gear + Propane Compressor + M R Compressor

Two compressor vendors who have experience in designing and manufacturing compressors for LNG plants of comparable size, were provided with the details of the process described in this paper and were then solicited for compressor proposals. The following major objectives for selection of the compressors were specified:

- Establish feasibility of operating both the compressors at the same speed
- Establish feasibility of using a single casing, three-section propane compressor;
- Establish the feasibility of a single casing for the MR compressor and advantages and disadvantages of eliminating an inter-cooler;
- Establish a power balance, and confirm that a margin was available on the gas turbine site rated power, under design conditions to account for short and long term deterioration of the gas turbine, API margin and process margin;
- Establish operability of the train when the maximum site ambient temperature was reached with a corresponding reduction in the gas turbine power output;
- Establish experience in use of the selected impellers with the help of appropriate scatter plots for aero-dynamic characteristics of the impellers; and
- Identify viable control options.

The salient points that resulted from the evaluation by the compressor vendors were the following:

- Both compressors could be driven at a common speed, but higher than the speed of the gas turbine. Therefore, a speed increasing gear was found to be necessary;
- An intercooler in the MR compression would not save much power and could add costs by way of an additional compressor casing. A single barrel type casing for the MR compressor was therefore found to be feasible. It had to be located on the outboard end of the train, for reasons of maintainability;
- Normal discharge temperature of the MR compressor was found to be acceptable. But, in the event of a full recycle operation, the recycle gas would have to be chilled down to an inlet temperature below ambient. This requirement could be accommodated within the process;
- The propane compressor, with two side-streams had to have a horizontally split casing. This could to be located at the inboard side. Even though this compressor consumed less power, its shaft and bearings had to be sized to be suitable for the full power delivered by the gas turbine, and with appropriate margins;
- Efficiency of the selected compressors was found acceptable and the required power margin was confirmed;
- The compressor manufacturers could provide scatter plots that confirmed experience of the selected impellers, especially in the regime of relative inlet mach number of the propane impellers;
- Rotor design acceptability was validated by preliminary rotor dynamic analysis;
- The two compressors would have to be separately controlled. As a first approach, the propane compressor could be controlled by speed control and the MR compressor could be controlled by suction throttling.

FLEXIBILITIES AND BENEFITS OF THIS PROCESS

This process utilizes gas turbine-compressor modules, pre-cooling modules and liquefaction modules that can be combined in different sizes to yield plants with varying LNG production rates. For example, if 2 x LM6000 PF gas turbines, each coupled in a tandem arrangement with both a propane and mixed refrigerant compressor, are then operated in parallel, an LNG production rate of 1.8 MTPA can be achieved. The optimum number and sizes of the pre-cooling and liquefaction modules can be selected and designed to result in the lowest overall costs and occupied plot space.

LNG Production Rates Versus No. of Modules			
LNG Production Rate, MTPA	No. of Modules		
@ 0.93 Availability	GT – Compressors (1)	Pre-Cooling (2)	Liquefaction (2)
1.8	2 x GE LM6000 PF	2	2
3.7	4 x GE LM6000 PF	2	2
5.6	6 x GE LM6000 PF	3	3

Notes: (1) All the propane and mixed refrigerant compressors will be identical

(2) The number of pre-cooling and liquefaction modules per GT-compressor module can vary and do not need to be equal.

(3) Plant availability increases as the number of modules increase due to the fact that the plant can be kept running at part load if one module trips or needs to be taken out of service for maintenance.

CONCLUSIONS

While they do not yet have demonstrated or proven experience as mechanical drivers in LNG plants, the work done so far has identified the GE LM6000 and RR Trent 60 aeroderivative gas turbines as suitable candidates that could be used for the LNG process described in this paper. Further review of details, further test programs and/or demonstrated future performances in actual LNG plant services will likely be required to reduce risks to low levels.

The process described in this work has the following main characteristics:

(1) A single gas turbine that drives on one shaft, in a tandem configuration, both a propane and a mixed refrigerant compressor where both compressors are employed in a process to produce LNG,

(2) Many different gas turbines can be used as refrigerant compressor drivers in this process as well as electric motor drivers,

(3) If 2 x GE LM 6000 PF gas turbines are operated in this process in parallel, and each drives a propane and mixed refrigerant compressor in tandem, then the plant will produce (assuming 20 °C ambient) 1.8 MTPA of LNG,

(4) The propane centrifugal compressor will have three-stages while the mixed refrigerant centrifugal compressor will have a single casing in order to conserve drive shaft space,

(5) The propane refrigerant will pre-cool the feed gas and mixed refrigerant together in a single plate-fin exchanger while the mixed refrigerant will simultaneously condense the mixed refrigerant and liquefy the feed gas to LNG using a coil wound exchanger,

(6) Multiple sets of gas turbine-compressor modules, pre-cooling modules and liquefaction modules can be assembled in one plant to produce varying amounts of LNG suitable for small-scale, mid-scale or large base-load plants. The different modules in the same plant do not need to have the same throughputs, so economies of scale can be employed,

(7) Multiple sets of modules when used in this process will increase plant availability

(8) The process is designed with several features such as low specific power consumption, eliminating the flaring of refrigerants on plant shutdowns and eliminating the necessity to depressurize compressor suction lines prior to start ups. Other advantages are tabulated in the above sections of this paper.