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MECHANICAL DRIVERS FOR LNG PROJECTS – A COMPILATION OF KNOWHOW

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TechnipFMC

This paper is a compilation of knowledge about mechanical driver selection for LNG projects based on the recent experience from numerous EPC projects and studies. It presents the main trends in LNG machinery over the last 50 years and summarizes and comments the recent trends towards drivers that for the first time have been deliberately developed with the LNG market in mind – large machines that reduce investment, reduce emissions and allow new execution strategies based on modularization.

Steam turbines, gas turbines and electric motor drivers have been all implemented as mechanical drivers in LNG projects. For some LNG projects, such as expansions, the choice of the mechanical driver may be obvious. For new developments a detailed techno-commercial selection study is usual.

Subject to operator preference and project requirement, the main mechanical driver selection needs to meet power and efficiency objectives, consider whether a starter motor is required and determine the shaftline configurations, which includes the combinatory distributions of drivers and the various driven refrigerant compressors on the same or separate shafts, in single or parallel arrangements.

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INTRODUCTION

Early LNG plants (in the 60s – 70s) used steam turbines as mechanical drivers for the main refrigerant compressors. During this period mechanical driver available with high power capacity was the steam turbine, as early as 1972 reaching 80 MW; for the SKIKDA project (1 MTPA).

Although steam turbines were extensively used in power generation with power capacities of up to 1200 MW (ex: those used in nuclear power plants), refrigerant compressors in LNG plants had limitations from the axial and centrifugal compressors themselves, which remain today.

Gas turbines driving main refrigerant compressors in LNG plants were introduced massively in the 80's after years of proven operation in the power industry. Prior to this period, gas turbines were considered as new products with limited reliability and thus were mainly used intermittently catering for during peak power demand.

Today, Heavy-Duty gas turbines are the most common mechanical driver selected for LNG plants with ISO ratings extending from 30 MW to 130 MW. Developments in Heavy-Duty gas turbine technologies and the need for higher LNG plant capacities favoured the choice of having Heavy-Duty gas turbines as main drivers for refrigerant compressors. Figure 1 reveals the growth trend in LNG plant capacity.

Aeroderivative gas turbines were recently gaining in popularity due to the higher efficiency levels, lighter weight and 2-shafts design with higher starting torque that avoids the need of a big starter motor.

Variable Speed electric motors have also been used in recent LNG plants (late 90s onwards) as a main driver for refrigerant compressors with power up to 80 MW, but still did not gain the same momentum as that of gas turbines and are more usually employed as starter and helper motors associated with Heavy-Duty gas turbine.

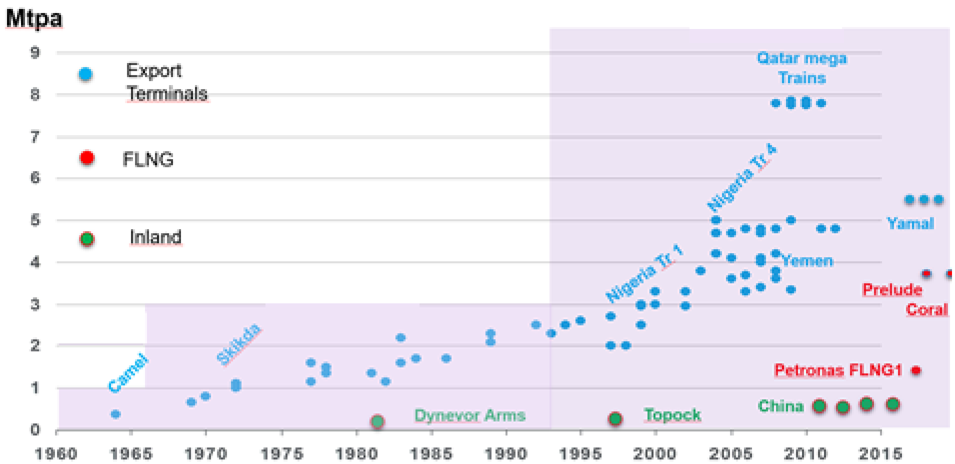

Figure 1: LNG Production Growth

Nowadays, new developments in the LNG industry are influenced by market offerings of higher power mechanical drivers, such as the dual-shaft Heavy-Duty gas turbines (around 100 MW of output ISO power), aeroderivative gas turbines (around 70 MW of output ISO power), and variable speed electric drivers (close to 80 MW of nameplate power).

MECHANICAL DRIVERS FOR LNG PROJECTS

It is roughly estimated that each one MTPA (Million Tons per Annum) of LNG produced requires around 40 MW of power for driving the main refrigerant compressors. The mechanical drive power could be achieved by steam turbines, gas turbines and/ or electric drive motors, or a combination of different types.

Steam Turbines

Special purpose steam turbines are specified according to API 612, while API 611 standard applies for general purpose steam turbines. Steam turbines for LNG project are considered as “special purpose”.

One of the main advantages of steam turbines is their stability of power output which is not affected by the daily and/ or seasonal fluctuations in ambient temperatures. In addition, steam turbines are very reliable and highly available. Steam turbines are simple in design and technologically proven. Steam turbines offer flexibility in operation due to capability of running at a wide range of speed. The starting torque requirements for a shaftlines could be easily catered by steam turbine drivers.

However, the main disadvantage in steam turbine drivers is the requirement of an extended layout in the plant. This mandates an extended steam generation and condensate recovery systems. Steam turbine auxiliaries impose heavier weight and consume a lot of space and a distributed footprint.

In recent LNG applications, steam turbine drivers have been selected for Prelude FLNG project in the range 50-60 MW. The main advantages compared to applying gas turbines instead were the higher availability levels (less requirement for plant shut-down for maintenance), in addition to other considerations such as the elimination of high pressure (HP) fuel gas piping (could reach up to 50 barg) which would have been needed in case of use of gas turbines in this floating plant which is subject to stresses from sea motion and accelerations.

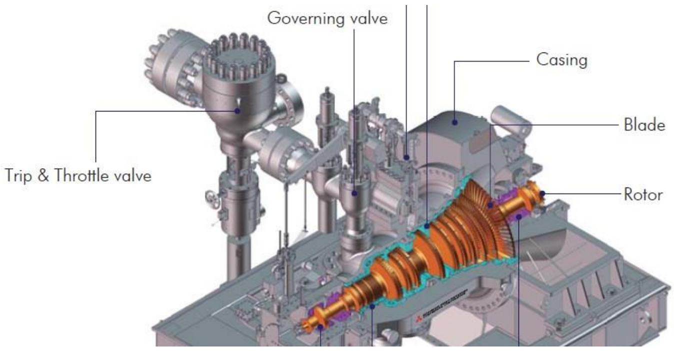

Figure 2: Typical Steam Turbine

Gas Turbines

Gas Turbines are selected in compliance with API 616. The two families of gas turbines that are used in LNG plants are “Heavy-Duty” gas turbines and “Aeroderivative gas” turbines, although a third family of “Industrial” gas turbines also exists.

Heavy-Duty Gas Turbines

Heavy-Duty gas turbines have thermal efficiency up to 38% which is better than steam turbines (boilers and water auxiliaries), and require less foot print. However, power output from gas turbines is subject to fluctuations with daily and/ or seasonal changes in ambient temperature.

In general, Heavy-Duty gas turbines are single shaft machines, with some exceptions where a dual shaft machine is applied such as BHGE’s Frame-5 gas turbine. Furthermore, new BHGE’s Frame-7 and MHPS’s H-100 (Figure 3.1) for larger power is a major development of LNG specific machinery. Such dual-shaft Heavy-Duty gas turbines combine both high power capacity as a mechanical drive and robustness, but without the need for a big starter motor and the need for extra investment in oversizing the electric power station and additional power distribution and control.

In a single shaft machine, the gas turbine the starting torque might not be sufficient to start the shaftline from zero speed, and accordingly a starter motor or steam turbine is added in the shaftline to assist the gas turbine start from a standstill condition. Heavy-Duty gas turbines operate at near-fixed speed (97% to 103% of rated speed).

Waste Heat Recovery units (WHRU) or Heat Recovery Steam Generator (HRSG) are often associated with gas turbines to recover some heat power and thus improve the plant efficiency.

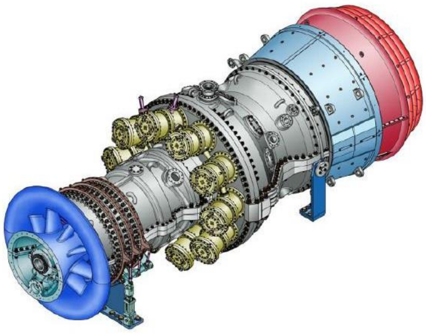

Figure 3: Heavy-Duty gas turbine (Courtesy MHPS - H100)

Aeroderivative Gas Turbines

While Heavy-Duty gas turbines were leading the market, aeroderivative gas turbines are gaining momentum in new LNG plant developments, with power outputs ranging from 25 MW to 75 MW

The advantages of these new gas turbines are the thermal efficiency (up to 43%), wider range of speed variation, and the limited downtime for maintenance (concept of the swap engine). They allow a start up in any conditions (from scratch or at settling out pressure) without the need for a starter motor. However, aeroderivative gas turbines are more sensitive to variations in combustion air temperature than the Heavy-Duty gas turbines and may require more frequent inspection and overhauls.

Figure 4: Aeroderivative gas turbine (Courtesy BHGE - PGT 25+G4)

Aeroderivative gas turbines are composed of multiple shafts; with or without a free power turbine. Figures 3.2 to 3.4 shows the various gas turbine shaft arrangement. By limiting the length of the shaftline, the footprint is less and consequently the installed CAPEX can be lower in high offshore or modularized plant.

As examples, aeroderivative gas turbines (Figure 4) have been applied in many LNG projects in Australia for Conoco Philips process, namely Curtis Island LNG project, Wheatstone LNG project, Gladstone LNG project …etc. Aeroderivative gas turbines have been also applied in recent FLNG projects (Figure 5) such as for Petronas FLNG (Saitu) and Coral South FLNG projects.

Figure 5: Floating LNG Plant

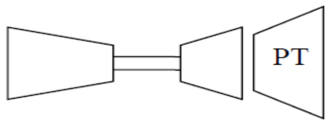

Fig. 3.1: Two-shafts Heavy-Duty Gas Turbine
(a major new development for LNG machinery)

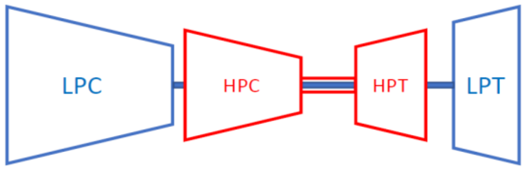

Fig. 3.2: Two-shafts Aeroderivative Gas Turbine
(**without** a free Power Turbine)

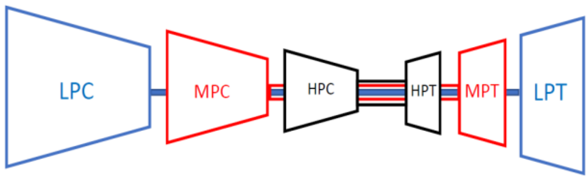

Fig. 3.3: Three-shaft Aeroderivative Gas Turbine

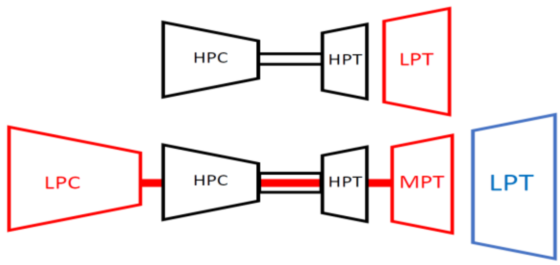

Fig 3.4: Two-shafts Aeroderivative Gas Turbines

(**with** free Power Turbine)

Figure 6: Gas Turbine Shaft Arrangement

New developments of higher power aeroderivative gas turbines (reaching around 70 MW of output ISO power), such as Siemens's SGT-A65 (which is a development from the Rolls Royce's Industrial Trent gas turbine) and the BHGE's LM9000 (which has been derived from GE-90 aircraft engine) would revolutionize the upcoming LNG plants. These lightweight gas turbines would reduce the number of shaftlines in an LNG plant down to half (for instance 6 x PGT25 in Darwin LNG plant could be replaced by 3 x LM9000) and make modularization feasible specifically for large scale Floating LNG (FLNG) projects, or nearshore LNG applications such as for Arctic-II LNG project.

Electric Motor Drivers

Electric motor can be used to drive refrigerant compressors, with power requirements up to 80 MW, they are robust and reliable and don't require any specific maintenance plans and reduce the footprint requirements. However, a motor in DOL (Direct on Line) arrangement will require 6 to 7 times the rated power to start from standstill condition, a motor equipped with soft starter, would require 1 to 2 times the rated power.

For small LNG plants where the required power is limited and based on the assumption that the grid or local network can deliver the power, a DOL motor can be used. The compressor operating point adjustment can be done via IGV (Inlet Guide Vane) or throttling valve (TV).
For large LNG plant motor with soft starter, and by extension variable speed drive system (VSDS) are selected. The VSDS is selected to tune the compressor operating points and to start the unit with low inrush current.

Recent developments of larger electric motors with higher nameplate power associated with the emergence of Voltage Source Inverter (VSI) topology of drives for variable speed control are favouring the Electric LNG (ELNG) such as Freeport LNG and Yangling mid-scale LNG.

One of the main advantages of electric motors over the Heavy-Duty gas turbines are the increased plant availability (estimated at an average of one week per year) and emissions-free operation at plant location.

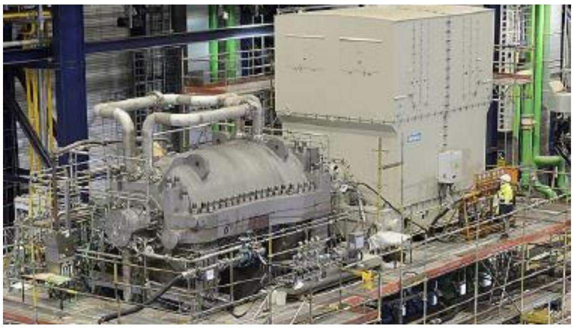

Figure 7: 77 MW E-Drive (Courtesy: Siemens)

SHAFTLINE CONFIGURATIONS FOR REFRIGERANT COMPRESSORS

The selection of the main mechanical driver goes hand in hand with the selection of the shaftlines configurations of the refrigerant compressors.

The optimum selection of refrigerant compressor shaftline configuration is very critical for the optimum plant performance and LNG plant commercial success. Numerous shaftline configurations have been used to date for refrigerant compressors:

Single Main Mechanical Driver only:

- Gas Turbine (Heavy-Duty or Aeroderivative); such as for Propane compressors in Qatargas LNG Project;
- Steam Turbine driven Refrigerant Compressor, such as in Prelude FLNG Project;
- Electrical Motor; such as in Snøhvit LNG plant and Freeport LNG project;

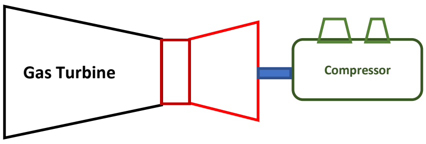

Figure 8: Gas Turbine driven Refrigerant Compressor (without helper)

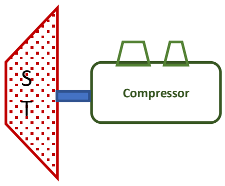

Figure 9: Steam Turbine driven Refrigerant Compressor

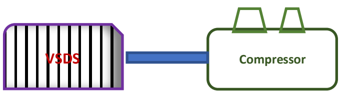

Figure 10: Variable Speed Electric Motor driven Refrigerant Compressor

Mixed Main and Helper Mechanical Drivers:

- Heavy-Duty gas turbine as a main driver with variable speed electric motor as a starter/ helper on the same shaft line, this is a very common configuration in many LNG projects such as in RasGas LNG plant and Yemen LNG plant …etc.; (Figure 12)
- Aeroderivative gas turbine without a helper/ starter motor such as in Lake Charles LNG project (Figure 11);
- Gas turbine with a helper steam turbine on the same shaft line; such as for Tangguh LNG project (deep combined cycle application) (Figure 14);
- Gas Turbine with a Gearbox; such as for the propane compressors in Oman LNG plant (Figure 13);

A large starter motor is required with a single shaft Heavy-Duty gas turbine. This motor may then be used as a helper motor at hot ambient conditions. The starter/ helper could be an electrical variable speed drive motor or a steam turbine.

The requirement for a gearbox is driven by the need to adjust excessive speed from a gas turbine and match refrigerant compressor constraints, for instance to stay within the referenced limitations of impellers machine Mach number (ex: less than 1.1 peripheral Mach number for Propane compressors).

Compressor Casing Arrangements:

a. Single Refrigerant compressor on a shaftline (Figure 11);
b. Multiple refrigerant compressors on a single shaftline; such as in YAMAL LNG project (Figure 15);
c. Multiple refrigerant compressors between two drivers such as for the Mixed Refrigerant compressors in Nigeria Bonny LNG plant (Figure 12);
d. Multiple refrigerant compressors coupled to two drivers from one side, as is the case in Qatargas II LNG plant (Figure 16);

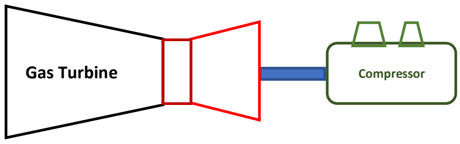

Figure 11: Aeroderivative gas turbine without starter/ helper motor

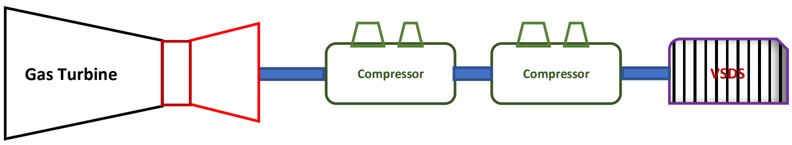

Figure 12: Gas Turbine/ Two Compressor Casings/ VSDS (Starter/ helper)

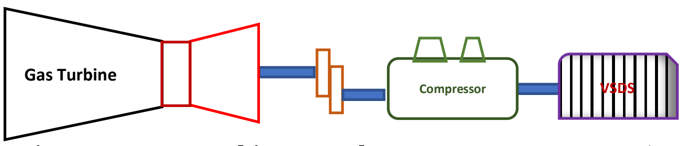

Figure 13: Gas Turbine/ Gearbox/ Compressor/ VSDS (starter/ Helper)

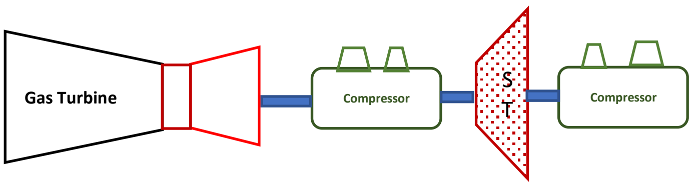

Figure 14: Gas Turbine / Two Compressor Casings/ Steam Turbine

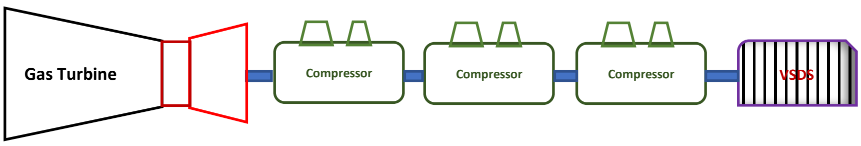

Figure 15: Long Shaft Line configuration with a Gas Turbine/ three compressor casings/ helper motor/ starter motor

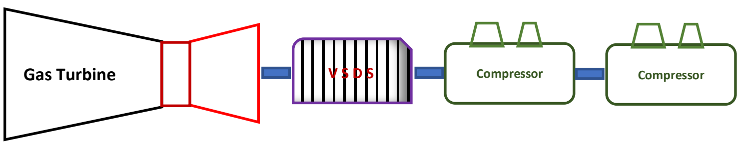

Figure 16: Gas Turbine / VSDS (Starter/ helper)/ 2 compressors (AP-X Process)

DRIVER & SHAFTLINE CONFIGURATION SELECTION

Mechanical driver selection for refrigerant compressors in LNG plants is usually done simultaneously with process selection or immediately after. The mechanical driver selection is based on choosing the main driver type and the necessity to have other helper or starter driver(s) on the same shaftline, taking into consideration the compressor(s) casings(s) distribution on same or multiple refrigerant compressor(s) shaftline(s).

The optimum selection is very much dependant on the owner's objectives for a project. Such objectives could be at various levels of importance for the project owner. In general, an optimum selection is a good balance between achieving maximized plant efficiency, higher levels of plant availability, and flexibility in operation. Plant efficiency and availability both contribute together to the nominal design capacity of an LNG plant in terms of year LNG production in million tonnes per annum (MTPA). The choice is also influenced by the LTSA (Long Term Service Agreement) that the owners would negotiate with the supplier. This contract will impact the OPEX cost and the availability of the plant.

Driver Selection Process

The selection process requires collaboration work between Process Licensor, Owner, Process Engineering and Machinery Specialist.

Although many combinations of drivers' types and shaftline configurations are possible, however the detailed selection process shall be done for a limited number few best choices.

Initially the following external factors shall be well considered:

- Availability of nearby sources of power:
  - Availability of power from electric grid at a competitive price;
  - Proximity to combined cycle power plants … etc;

- Ambient Temperature:
  - Daily and/or seasonal fluctuations in temperature would mandate the use of a helper motor to compensate for periods of high ambient temperature and/ or the addition of a air cooling systems;
  - Sub-zero conditions (ex: Arctic conditions) will necessitate that need for anti-icing systems and equipment winterization;

- Environmental Conditions & Location:
  - Sand storms would impose having Inlet Air filtration systems which will adversely affect the power output of gas turbines;
  - Sea motions and Accelerations (for Floating LNG applications);
  - Remoteness could favour the application of steam turbines for their reliability or aeroderivative gas turbines for their swap possibility;

In addition, the following LNG Process factors shall be considered:

- Liquefaction Cycle and estimated specific power (required power divided by LNG production rate);
- Refrigeration Loops of the liquefaction cycle;
- Initial decision on number of LNG production trains;
- Fuel Gas Composition(s) and Pressure(s);

Finally, the referenced market offerings of mechanical drivers with proven record of operation in same or similar applications shall be well known, and plant specific constraints shall be clearly determined.

Detailed Analysis

The type of a driver(s) on a shaftline, mandates how much maximum power could be available for the refrigerant compressors, while the shaftline configuration determines how this power is distributed to the various refrigerant compressors on the same shaftline, and accordingly the LNG production rate.

The decision on shaftline configuration includes the selection of:

- Main driver type and optimum operating speed; (ex: Aeroderivative gas turbine)
- Which compressors would be driven on the shaftline (ex: pre-cooling alone or combined with cooling);
- Distribution of casings per shaftline (ex: LP/ MP on separate shaftline or same shaftline);
- Requirement of starter mechanical drive if no free power turbine is available;
- Requirement of a helper mechanical drive to cater for ambient air variations;
- Whether parallel strings could be considered (ex: Split pre-cooling compressor in a 2 x 50% shaftline);

For each option the following are determined:

1. Main driver supplier and model (based in ISO power rating required) and quantities of main drivers;
2. Machinery configuration and quantities on each shaftline;
3. Parallel Operation or not;

Accordingly, the following could be estimated:
  - Layout and foot print requirements
  - Availability level;
  - Operational Flexibility/ turndown capabilities;

4. Maximum available power and % of power utilization (ex: in case of temperature fluctuation);
5. Fuel gas % of total feed gas;
6. Estimated LNG production rate;

Eventually the total cost of ownership could be estimated, then along with the % power utilization and estimated LNG production rate, the LNG plant commercial aspects are clarified, upon which a final techno-commercial selection could be made.

FUTURE PROSPECT

The prospect for LNG projects is favouring the development and optimization of more competitive mechanical drivers targeting LNG projects. Aeroderivative gas turbines are now capable of covering higher discrete power range from 30 MW to 70 MW. Some Heavy-Duty gas turbines are now offered with a free power turbine to eliminate the need for a large starter motor.

We can anticipate the following for the next generation of LNGs plants:

- Large electric motors with variable speed drive system (with Voltage Source Inverter (VSI) topology-based) when the use of external electric power is feasible: Green energy for example or high efficiency combine cycle power plants. This would also improve the environmental impacts through zero or limited emissions;
- The use of Heavy-Duty gas turbines (above 150 MW) driving large refrigerant compressors, associated with starter helper motor, would help to minimize the number of shaftlines for an LNG production train;
- Extensive use of aeroderivative gas turbines for medium size LNG plants would offer large redundancy and offer operational flexibility to the operator.
- Proven operation of aeroderivative gas turbines in recent FLNG applications could assure the development of more FLNGs;
- Developments of mid-scale and small-scale LNG plants could benefit from improved market competitiveness in mechanical driver offerings;
- Deep Combined Cycle applications (combing gas turbines and steam turbines as main mechanical drivers for refrigerant compressor shaftlines) could be a favourable solution for upcoming LNG projects;

CONCLUSIONS

Mechanical driver selection for liquefaction compressors has a direct impact on the liquefaction process efficiency; furthermore, the mechanical driver choice defines the availability level of the LNG plant. The selection of the mechanical driver is made for both the driver's type, and the shaftline arrangement including the driver(s) and compressor(s) casing(s) configurations on the same shaftline. This paper summarizes examples of configurations that have been already selected in previous LNG projects and provided general insights on the factors affecting the selection process and potential selections. Although many combinations are possible, however the detailed selection process shall be done for a limited number few best choices. New market offerings of higher power mechanical drivers will impact new LNG project developments by eliminating the need for big starter motor (and associated electrical requirements) by applying dual-shaft Heavy-Duty gas turbines instead of the traditional single-shaft Heavy-Duty gas turbines. Also, the improved power outputs of the light weight aeroderivative gas turbines would lower the capex in new LNG developments by minimizing the number of refrigerant compressors strings and by rendering FLNG modularized applications more feasible. Increased power of variable electric motors along with the technological developments in VSI topology and availability of electric power from power grids would push forward eLNG applications which could have commercial advantage and zero emissions at location.

NOMENCLATURES

API = American Petroleum Institute
BHGE = Baker Hughes General Electric
CAPEX = Capital Expenditure (Cost)
DOL = Direct On-line
ELNG = Electric Liquefied Natural Gas
FLNG = Floating Liquefied Natural Gas
GT = Gas Turbine
HP = High Pressure
HPT = High Pressure Turbine
HRSG = Heat Recovery Steam Generator
IGV = Inlet Guide Vane
ISO = International Standards Organization
LNG = Liquefied Natural Gas
LPT = Low Pressure Turbine
LSTA = Long Term Service Agreement
M2C = Modular Multilevel Converter
MHPS = Mitsubishi Hitachi Power Systems
MTPA = Million Tonnes per Annum
MW = Megawatts
OPEX = Operating Expenditure (Cost)
PT = Power Turbine
TCO = Total Cost of Ownership
TV = Throttling Valve
VSI = Variable Source Inverter
WHRU = Waste Heat Recovery Unit

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REFERENCES

(n.d.). Retrieved from Siemens Website: https://new.siemens.com/global/en.html

(n.d.). Retrieved from BHGE: https://www.bhge.com/#

(n.d.). Retrieved from Mitsubishi Hitachi Power System: https://www.mhps.com/

International Gas Union. (2018). 2018 World LNG Report.

Meher-Homji, C., Messersmith, D., Hattenbach, T., Rockwell, J., Weyermann, H., & Masani, K. (2008). Aeroderivative Gas Turbines for LNG Liquefaction Plants. *ASME International Gas Turbine and Aeroengine Conference.* Berlin.

Bustos , E., Mossolly, M., & Herve, G. (2017). Tutorial on Large Steam Turbine Systems in Oil & Gas Applications. *Turbo Symposium.* Houston: Texas A&M - Turbomachinery Laboratory.

Bustos, E., & Mossolly, M. (2016). Perspectives on Technical Evaluation of Centrifugal Compressor Bids for Oil and Gas. *13th European Fluid Machinery Congress.* The Hague: Institute of Mechanical Engineers (IMECHE).

Bustos, E., Mossolly, M., Hotho, M., & Mastropasqua, A. (2018). Gas Turbines & Associated Auxiliary Systems in Oil & Gas Applications. *Turbo Symposium.* Houston: Texas A&M - Turbomachinery Laboratory.

Cyrus B. Meher-Homji, C., Yates, D., Weyermann, H., Masani, K., Ransbarger, W., & Gandhi, S. (n.d.). Aeroderivative Gas Turbine Drivers for Conocophillips Optimized Cascade LNG Process - World's First Application and Future Potential. *Paper PS2-6.*

Ganesan, V., Demmig, S., & Busse, S. (2016). Solutions to Requirements of Electrical Drivers in Oil & Gas Applciations. *Asia Turbomachinery and Pump Symposium.* Singapore.

Heckel, B., & Davis, F. (1998). Starter Motor Sizing for Large Gas Turbine (Single Shaft) Driven LNG Strings. *27th Turbomachinery Symposium.* Houston.

Krishnamurthy, G., Roberts, M. J., & Wehrman, J. G. (May 2015). Drive your LNG project to success with optimal machinery selections from Air Products of US. *LNG Journal*, 36-39.

Kurz, R., Brun, K., Gonzalez, F., & Meher-Homji, C. (2018). Industrial Gas Turbines (Short Course). *Turbomachinery and Pump Symposium.* Houston.

McMillan, D., & John, J. (n.d.). LNG Process Uses Aeroderivative Gas Turbines and Tandem Compressors. Technip.

Meher-Homji, C., Matthews, T., Pelagotti, A., & Weyermann , H. (2007). Gas Turbines and Compressors for LNG Service. *36th Turbomachiney Symposium.* Houston.

MHPS. (June 2015). World's Largest Class High-efficiency Dual-shaft H-100 Gas Turbine. *Mitsubishi Heavy Industries Technical Review*, Vol. 52 No. 2 (Pages 10 to 14).

Mossolly, M., & Bustos, E. (2015). Improved Energy Efficiency in LNG Plants through the Proper Selection of Turbomachinery. *World Gas Conference.* Paris: International Gas Union.

Mossolly, M., & Remy, P. (2015). Realization of over half a Billion USD worth Centrifugal Compressors for Mega Oil & Gas. *ADIPEC.* Abu Dhabi.

Paturzo, M., Johnson, B., Mossolly, M., & Belbol, C. (2018). Perspectives on Turbomachinery Selection and Design in Coral South FLNG. *Gastech 2018.* Barcelona.

Patwardhan, S., Meher-Homji, F., Musardo, A., Weatherwax, M., Cappetti, D., & Iannuzzi, G. (2016). Full Speed String Test on LM6000 PFGas Turbine Driven Refrigeration Compressors. *45th Turbomachinery Symposium.* Houston.

Phillips, R., Solis, T., & Konishi, H. (2005). Tangguh LNG – Energy Efficiency Measures through Life Cycle Cost Analysis. *Gastech.*

Songhurst, B. (October 2018). LNG Plant Cost Reduction 2014–18. The Oxford Institute for Energy Studies.

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