Technology trends for LNG compression using innovative electric solutions

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Abstract. During the last 30 years, there has been a significant evolution and innovation of electric driven compressors in replacement of steam or gas turbines. Technology trends are highlighted in this paper with a focus on LNG Compression, covering standalone and integrated compression fed by Variable Frequency Drives (VFDs), and the emergence of the induction squirrel cage motor up to 120MW.

1. Introduction
Electric variable speed helpers used for Liquefication Natural Gas (LNG) application in combination with gas turbines to drive large compressors have well-known advantages, including reduced downtime and accurate speed control, and are independent of ambient temperature [1-3]. A helper can also be used as a starter, reducing the gas flared during startup. The full electric drive solution (e-LNG) is an alternative to the traditional train driven by heavy duty gas turbine especially when it is necessary to contain dimension and weight at site and to reduce environmental impacts. In addition, the LNG train driven by Variable Frequency Drive (VFD) allows regulating the operating speed in a wider range giving more flexibility and efficiency in term of compressor operating points and startup without depressurization due to torque availability avoiding flaring of gas before start-up. After removing CO2, sulfur compounds, water and mercury, the pretreated gas is first pre-cooled with propane (or ethylene) refrigerant, then is sent to the Main Cryogenic Heat Exchanger, where it is further cooled by a lower-temperature mixed refrigerant. Electric LNG plants are usually more expensive in terms of capital expense, especially if power generation facilities have to be built. With the natural increase of the demand and the selling price of gas in the coming years, and the new regulations governing the reduction of greenhouse gas emissions, it makes sense to consider for new investments replacement of power generation with turbines by islanded production of electricity from wind and solar farms supplemented by the public electric grid when available.

2. Electric System
Based on a fixed grid configuration, the optimum system combines the input transformer, the drive, the motor and the compressor, maximizing the return of investment and the availability.

Only two parameters must be considered as key drivers:
- the voltage defining the transformer, the drive and the stator of the motor,
- the speed defining the best compressor performance and efficiency, and the rotor of the motor, in a gearless solution.
Only three configurations of drive and motor combinations are feasible (see fig.1):

- LCI (Load Commutated Inverter) with double-star synchronous motor adjusting the motor Power Factor at PF=0.9 leading requested by the drive for the thyristor switch-off commutation
- VSI (Voltage Source Inverter) with single-star synchronous motor operating at PF=1
- VSI (Voltage Source Inverter) with squirrel cage Induction motor operating at PF maximizing the torque generation.

Replacing the Load Commutated Inverter, the high power VSI inverter is available since more than 10 years in a 3-level topology with the Neutral Point Clamped by diodes delivering around 15 MVA with an output voltage of 3.3 to 3.6 kV. In a refinement of the diode-clamped converter, the so-called Neutral-Point Clamped (NPP) converter, the clamping diode valves are replaced by Injection Enhanced Gate Transistors (IEGT) giving additional controllability. Each valve is commutating with only half the DC bus voltage, reducing the devices commutation losses by three, downsizing the cooling unit. For power above 15MW, the inverter is slipped into two identical 3-level inverters, cascaded in series and controlled in such a way that their pulses are shifted providing thus at their AC output a 5-level waveform (see fig.2). The rectifier of a VFD is connected to the supplying grid. The Diode Front End rectifier (DFE) is composed of diode bridges when the Active Front End rectifier (AFE) is composed of IEGTs as a mirror symmetry of the inverter. The AFE does not require any reactive power from the grid and can be used to support the weak grid in providing reactive power when the supplying voltage drops in case of load impact, or in absorbing reactive power when the supplying voltage raises in case of a sudden load shedding [4-5].

![Figure 1. The three possible architectures of electric compression.](image1)

![Figure 2. 9.9kV output voltage - 5-level NPP VSI topology.](image2)

3. Standalone electric compression for LNG

3.1. LNG train with electric starter helper

Large Load Commutated Inverter (LCI) systems utilizing 4-pole synchronous machines are a proven and widely implemented approach for the helper system in LNG train applications. The system efficiency is improved by 1 to 2% when using a 2-pole motor, eliminating the gearbox.

Nevertheless, the LCI absorbs reactive power from both the grid and synchronous motor when commutating thyristors and generates current harmonics that flow back into the grid reducing grid stability and interacting with source impedance to create voltage distortion. Additionally, inter-harmonics on the load side of the LCI drive may induce main air-gap torque pulsations from motors [6]. Keeping in mind that the accidental loss of a helper motor is extremely intrusive to the process and that a false trip can amount in production losses, it makes sense to improve the robustness and the reliability of the helper system moving to VSI drive. The VSI induces overall very low torque ripples to the motor and does not produce significant inter-harmonic interactions in between the grid and the motor as for torsional sub-synchronous excitation improving a lot the system reliability. It highlights the simplification of the electrical lineup and details the elimination of the large reactive power
compensators (capacitors) and of the harmonic filters, the downsizing of the cooling units. Compared to a VSI drive operating at PF=1, the capacitive reactive power (PF=0.9) requested by the LCI drive over-sizes the weight of the active parts of the synchronous motor up to 25%, more rotor current increasing the electromotive force, more stator current (see fig.3 and fig.4). The ultimate solution consists of selecting a 2-pole induction motor VSI system, more advantageous in term of CAPEX and OPEX. The squirrel cage induction motor compared to the synchronous motor has no system of excitation and simplified rotor construction, leading to longer run-time with fewer maintenance issues (see fig.5).

For starter-helper system, the selection of the speed is fixed by the turbine at 3600 rpm. When feasible, the longest direct drive configuration of the gas turbine with three compressors and a 2-pole induction motor is very attractive because it can accommodate all the services (propane pre-cooling, mixed refrigerant Low, Medium and High Pressure) on the same shaft for a single liquefaction train (see fig.6). The liquefaction plant can have several identical parallel train configurations, granting 365 days of production including maintenance of one driver [7-10].
3.2. Full electric LNG (eLNG)

The current biggest full electric LNG system (eLNG) in US is composed by three trains with a nominal capacity of 4.64 MTPA each. Each train is composed by three motor driven refrigerant compression lines with 75 MW shaft power. From the process point of view, each string is designed with three large single compressors (Propane, Low Pressure LP Mixed Refrigerant, Medium/High Pressure M/HP Mixed Refrigerant) on three independent shaft lines driven by a large 2-pole synchronous motor fed by the 60Hz public electric network through a Load Commutated Inverter (LCI) system requested by the customer (see fig.7 and fig.8). The speed is 3000 rpm to avoid any risk of inter-harmonic coupling with the grid and torque pulsations with the shaft-line. The selection of motor as prime mover is driven mainly by necessity to contain dimension and weight to better adapt to plant characteristics. With respect to a traditional solution driven by gas turbine, an electric motor of same power size allows a length reduction to approximately half time and consistent weight reduction and the elimination of air filter chamber of the gas turbine [11].

![Figure 7. 75MW 2-pole synchronous motor fed by LCI for large scale eLNG compression](image)

The recent validation of an 80MW 2-pole induction motor demonstrator opens the door to the use of direct drive squirrel cage motors for power above 25MW (see fig.9). With its rotor technology and design robustness (no exciter), the induction motor can operate at much higher speeds of synchronous motors: 4000rpm at rated speed and 4200rpm at maximum continuous speed for instance for this demonstrator. Two choices of optimization of compression system are then possible. The first choice is to increase in an identical way the speed of all compressors beyond 3600rpm. The second choice is to optimize the speed and to cope with the volume flow of each compressor minimizing the weight and the footprint and maximizing the efficiency of each compressor, introducing the use of centrifugal compressors for high pressure and the axial compressor for low pressure of the mixed refrigerant for
example. Due to the large flexibility of speed range of the induction motor, it is possible to use identical electric systems for all compression services.

75MW@3000rpm Synchronous  
Two-star stator winding 11kV  
Weight 260tons - Power Factor 0.9  
Motor Efficiency 98.2%

80MW@4000rpm Induction  
One-star stator winding 11kV  
Weight 150tons - Power Factor 0.87  
Motor Efficiency 98.2%

**Figure 8.** 2-pole eLNG synchronous motor.  **Figure 9.** 2-pole eLNG induction motor.

4. **Integrated electric compression for small scale LNG (SSLNG)**  
Thanks to the development of high-speed induction motors and active magnetic bearings, integrated moto-compressors (see fig.10) represent today an alternative solution to conventional compression for SSLNG. The process gas handled by the compressor is used to cool both the motor and the magnetic bearings making the unit fully hermetic, allowing to remove the gas dry seals and the associated conditioning system, and reducing the footprint by 40% [12-16]. In addition, the integrated motor compressors are not sensitive to the load start conditions and do not need to modify the processing conditions to lower the Settle Out Pressure (SOP) before starting. This technology was developed during the 80’s for pipeline stations requiring high gas flows and low-pressure ratio [17-18]. Since this time more than 80 systems are in operation all over the world with cumulated hours over 4.000.000 hours. The first mixed refrigerant integrated compression for Small Scale LNG was delivered in 2017 with a capacity of 1.75 MSm³/day operating at 8MW@9400 rpm (see fig.11). This technology is scalable up to 30MW.
5. Conclusion

This paper described the trends of technology about electrification of LNG compression. The availability of IEGT high-power transistors makes possible to build VSI-AFE drives up to 120MW replacing first-generation LCI drives, avoiding network inter-harmonic pollution and torque harmonic pulsations. 2-pole squirrel cage induction motor compatible with Voltage Source Drive (VSD) are also available up to 120MW, replacing synchronous motors more complex and less reliable. With the emergence of green islanded grids combined with the public electric network, gas turbines can be replaced with full electric systems. The speed range of each induction motor can be adapted to the best conditions of compressor operability in efficiency, compactness and reliability. Below 30MW, standalone electric arrangements can be replaced by fully hermetic integrated motor-compressor using high-speed-induction rotor (see fig.12) more flexible, compact and reliable. Integrated motor-compressor can be also used for natural gas storage up to 300 bars in serial-parallel arrangement (see Fig.13) and for the full electric off-shore compression [19-20] improving the process operability through its flexibility.

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