Safe, reliable, efficient rotating & electrical solutions for 2–7 MTPA LNG applications

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ABSTRACT

The paper discusses the design and selection, of rotating and electrical equipment in order to achieve highest reliability, efficiency and safety for 2-7 MTPA LNG applications, while addressing current market pressure in reducing capital cost.

The paper describes the methodology for optimum configuration of the entire refrigerant compression system, consisting of compressors, variable speed drive systems, power transmission and power generation. Key focus in reducing investment costs is achieved through modularization of equipment leading to shorter construction period and faster return on investment. Siemens provides highly efficient low emission compressors for refrigerant applications driven by variable speed electrical motors and industrial / aero derivative gas turbines.

In addition, the paper will discuss, rigorous aerodynamically and electro-mechanically studies for compressor string selection, including further studies for startup from settling out pressure, shut down and load shedding. In these studies the entire system, including power generation and transmission, is considered as a complete system. Such compression-driver string dynamic simulations supplemented with grid stability studies will ensure a fit for purpose equipment selection and highest plant availability/reliability and safety. Thorough testing of the equipment, such as compressor start-up, transient torsional measurements and grid stability are discussed in more detail.

This holistic view ensures an optimum selection and configuration of mechanical and electrical equipment for liquefaction plants, leading low project risk and well-balanced solution between thermal efficiency, lower capital costs and shorter project schedule.

PROJECT PLANING AND EARLY PROJECT CONSIDERATIONS.

Size wise and location wise LNG projects can be defined as a

- Base load project about 15 mtpa
- Mid-scale project up to 3 mtpa
- Peak shaving and small scale units
- Onshore or off-shore solution

Depending on the gas reserves available, the size and the refrigeration process has to be selected. There are in general LNG processes which use pure gas as refrigerants or a composition of different gases, called mixed refrigerants. Now, depending on these gas properties and on the amount of refrigerant to be compressed, the section of compressor inclusive drive system needs to be done. As these compression strings are among the key components in the LNG production chain it is recommended to investigate the selection carefully and as early as possible.

To liquefy natural gas a lot of energy is needed. In most cases it is natural gas to be made available for the gas turbine, either as mechanical drive or as generator drive. Looking ahead, save and high for LNG production will be necessary in the future. Electrical drivers and combined cycle power plants can be an answer for these questions now and in the future. On the way of energy transfer from gas source to refrigerant compression Siemens offers highly efficient products and solutions for such a "Power to compression" system (see Figure 1).

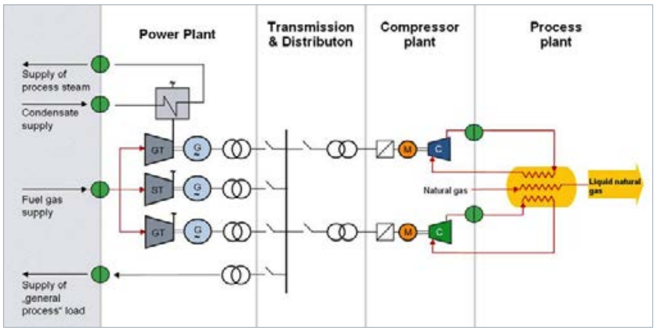

Figure 1: From power to compression

Siemens offers a whole portfolio of solutions for the LNG value chain and industry like

- Single shaft and integrally geared turbo-compressors
- Electrical drive systems -fixed speed as well as variable speed- up to 90 MW
- Industrial type gas turbines as a mechanical drive and generator drive up to 160 MW ISO
- Aero-derivative gas turbines as a mechanical drive and generator drive
- Steam turbines as mechanical and generator drive
- Power plants
- Electrical equipment for power transmission and distribution
- Grid studies and entire system dynamic simulations

In order to achieve high efficient reliable and profitable solutions, early involvement of potential equipment suppliers is necessary. The whole project execution and later production will profit when the first investigations taken in the concept design phase lead to optimized system solution. This is a major difference to single component optimization, please see figure 2. Siemens is prepared and capable to support LNG projects to find optimum solutions for the LNG industry already from very early project stage to production.

Many times, when the operators find a way to enlarge the production, Siemens can offer solution for upgrades of products and solutions.

Figure 2: Overall optimization vs. single component optimization

HIGH EFFICIENT COMPRESSOR STRING SOLUTIONS

Compression of refrigerant may lead to a following design challenges:

- High flow requirements as well as high Mach numbers at the impeller inlet may determine compressor maximum operating speed. This is an important design criterion for the selection of the compressor and driver.
- Typically, high Mach number reduces the operational flexibility and efficiency which finally leads to higher operational costs.
- In order to ensure proper compressor and driver selection, rotor dynamic and torsional studies, proper mechanical design and adequate material selection needs to be carried out in early project phase.

In many cases the electrical variable speed drive system offers the highest degree of the flexibility in order to fulfill all process duty requirements. Such systems (VSDS) are available up to 90 MW. VSDS design concept has been studied in an early project stage with the target to optimize the overall LNG plant solution and in order to avoid interharmonics in operating speed range. In principle, generated harmonic torque oscillations may have an essential impact on the torsional vibration behavior of the entire train. Dynamic and accurate speed control via electronic variable speed controllers is possible. Soft start and fully torque controlled operation offers a potential ability to restart fully loaded compressors. Consequently the driver and compressor manufacturers must carry out detailed analysis to examine the operational condition of the rotating equipment. Therefore close collaboration of driver and compressor manufacturer in designing and engineering of such a VSDS driven train is essential.

The working principle of a turbo compressor is transferring kinetic energy continuously to the fluid through a rotating impeller. Within the impeller pressure and absolute velocity will increase. In the following, flow elements such as vaned or vaneles diffusors the kinetic energy will be converted to static pressure. The complete configuration of inlet, impeller, diffuser, return guide vanes/volute is called a compressor stage.

The compressor stages will be designed to match exactly the process specification. This means that the final dimensions of the compressor inlet, inlet guide vanes, impellers, return channels, side streams and discharge volutes will be determined individually for the given application.

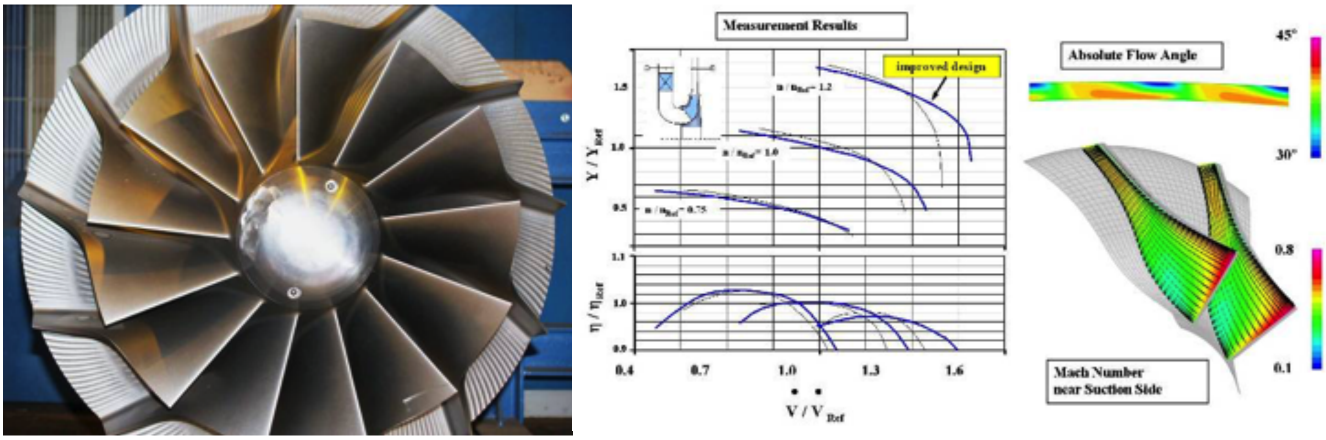

Figure 3: Siemens continuous R&D work on aero design of the impeller will allow to build compressors with improved efficiency and operational envelope for LNG applications.

In cryogenic applications like LNG or ethylene, compression of refrigerant gases with relatively high molecular weight and low temperatures at compressor inlet is required. As mentioned above, high gas velocities, high molecular weight and low temperatures result in a high Mach number at the impeller. An optimized compressor design is finally a compromise between efficiency, operating range and mechanical design and driver selection.

A generic impact of Mach number is shown above (Figure 3)

COMPRESSOR PERFORMANCE AND CONTROL

The compressor characteristic shows the possible flow/pressure combination in which the turbo compressor is operating safely. The range of this possible operation depends in a high degree of the control method. There are few possibilities to control the performance. Possible are:

- Suction throttling
- Speed control
- Adjustable Inlet Guide Vane control (IGV)
- Combination of above
- Discharge pressure control

Operational flexibility is another key criterion for large turbo compressor strings. A combination of an electrical variable speed drive system with an adjustable inlet guide vane control offers a widest operating range. With a proper electro-mechanical design of the compression string, the achievable speed range can easily reach 70% to 105%. Such a system also offers a high accelerating torque available from a very low speed up to maximum continuous speed of the string. In most cases start-up of the compressor equipped with adjustable IGV without flaring is possible, the overall availability of the plant will be higher. Electro-mechanical design means also motor and compressor are not considered separately, but as one unit or one entire system, which has to be engineered taking all interfaces between the electrical and the mechanical parts into account. For example, the impact of interharmonics needs to be studied to avoid potential torsional vibrations issues in a later project phase.

In case that a large turndown is required, adjustable IGV's can be an appropriate method of control. The indicative performance map in figure 4 shows a general comparison of achievable performance characteristics. The combination of IGV and speed control normally offers the widest range of operation and therefore significantly improves the flexibility of plant operation.

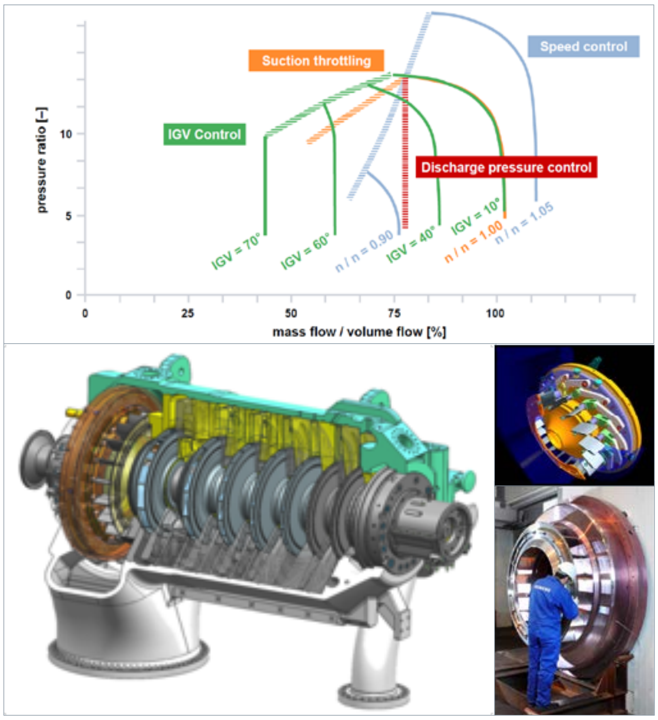

Figure 4. Comparison of compressor control methods. Typical IGV solution

Using adjustable IGV in compressor offers another major advantage: The torque requirements during compressor start-up will significantly be reduced, thus facilitating a restart from settling out conditions. This has been successfully demonstrated for a 90 MW application; with two consecutive re-starts from settle out pressure, the first start with normal IGV setting, the second start with the IGV further closed. figure 5 shows the measured curves for torque and speed with the corresponding reduction in torque during full load string test.

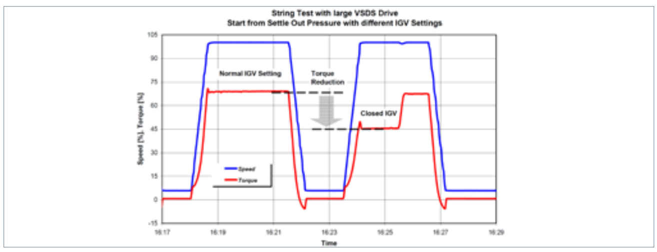

Figure 5. Torque reduction during start up using an adjustable inlet guide vane

MECHANICAL COMPRESSOR STRING DESIGN

In order to achieve acceptable lateral and torsional vibration levels compressor train machinery design aspects have to be considered adequately already in the earliest stage of the project. Therefore a proper rotor dynamic design of the compressor and driver rotor is an essential task. For large electric motor driven compressors with variable speed drive, converter and operating speed set-up of the entire train to avoid torsional resonances within the operating speed – caused by interharmonic excitations generated in the converter – is one of the most important design aspect.

Figure 6. Compressor String during a Full Load Full Speed Test

In principle the rotor dynamic design of motor rotors has to fulfill the design criteria as specified in the API 541. A multiplicity of influencing parameter has to be considered in such an analysis in order to achieve a lowest vibration levels and a reliable string design.

Main influencing parameters are as follows:

- Rotor geometry (including masses and stiffness's)
- Damping and stiffness properties of the journal bearings
- Operating speed range
- Unbalance forces distribution
- Thermal rotor bending effects
- Thermal stator effects
- Bearing pedestal properties
- Module or steel frame and/or concrete foundation properties

Especially support effects caused by the bearing pedestal and the foundation and the thermal deflection of rotor and stator components are of paramount importance for large motor designs. Nevertheless all influencing parameter have to be considered most accurately.

For a reliable train design the torque transmitting elements of the entire train must be designed in order to withstand the stationary operating torques at normal operating conditions. In addition also dynamic torque during start-up, and during electrical fault conditions, like short circuit conditions, etc., has to be transmitted.

However, during operation of compressor trains with integrated variable speed drive system (VSDS), integer and non-integer harmonic currents, also called interharmonics, they are generated in the frequency converter. As illustrated in figure 7 variable speed drive systems rectify alternating line current (AC) of 50 Hz or 60 Hz, to direct current (DC), and invert the DC to a variable frequency AC current in order to operate the motor at variable speeds. As illustrated the electrical conversion from line side to the motor side, quite small harmonic distortion of the inverter output current causes forced torsional vibration. Due to small excitation amplitudes, this is outside the resonances of a well endurable load for the train components. Unfortunately, the vibration is amplified when the excitation frequency of torque ripples match a torsional natural frequency (TNF) with a suitable mode shape to excite the mechanical train.

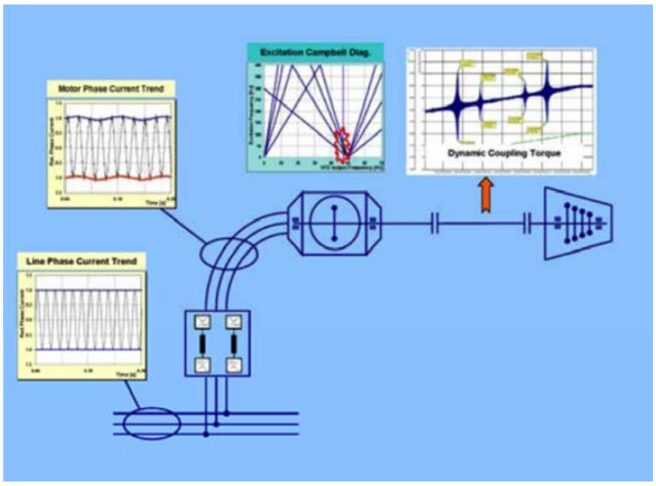

Figure 7. Electro-Mechanical Interaction for motor driven compressor

If a resonance with an interharmonic excitation is detected and countermeasures are found to be necessary, one can today choose from a wide range of proven alternatives. These can be sorted into one of the following categories:

- Torsional damping increase
- Torque excitation reduction
- Torque transmitting components fatigue capability increase
- Avoiding of torsional resonance in operating speed range

Taken into account the pros and cons of the well-known alternatives the most reliable strategy is to avoid torsional resonances within the operating speed range. This design concept of selecting converter type, motors number of pole pairs and corresponding operating speed range is described in detail in Hütten et. al. (2012). For large VSDS driven trains 12-pulse LCI are typically used. The design concept for an LCI fed motor can be explained as follows:

First of all the mechanically relevant harmonic and interharmonic excitations of the selected frequency converter have to be well understood (Figure 8). Electrical motors can be built in 2, 4, 6, ... pole design (equivalent to number of pole pairs (NPP) of 1, 2, 3, ...) and this leads to operating speed of:

$$n_{op} = (f_{do} / N_{PP}) *60 \qquad (1)$$

n_{op} = Motor operating speed

f_{do} = VFD output frequency

N_{PP} = Number of pole pairs

Therefore, a motor rotor with a number of pole pairs of 1 runs with supply frequency. Whereas a motor rotor with a number of pole pairs of 2 at half of supply frequency and with a number of pole pairs of 3, at one third of the supply frequency accordingly. This is an essential fact in order to find resonance free train design solutions within this new design concept.

Based on these considerations, the electrical supply frequency ranges which should be avoided are separated. In addition, the ranges of motor supply frequency without resonances caused by the inverter operation are identified and can be used for designing compressor trains. The determined exclusion ranges are transferred into a motor speed related diagram for the chiefly used number of pole pairs 1, 2 and 3. Focused on the most relevant exclusion range of the resonance conditions caused by interharmonics, it becomes obvious that the center of the most important exclusion range shifts from 3000 rpm to 1500 rpm and finally to 1000 rpm for a number of pole pairs of 1, 2 or 3, accordingly.

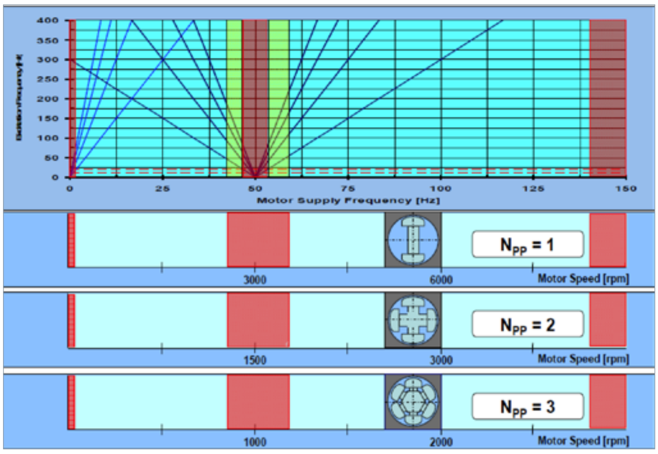

Figure 8. Exclusion Ranges Transferred into Motor Speeds.

The main result of this concept is shown in a motor speed related bar diagram (Figure 9). This illustration collects all the relevant information in order to avoid torsional resonances caused by a 12-pulse LCI operation. The allowable speed ranges are marked in green, whereas motor speeds which should be excluded are marked in red.

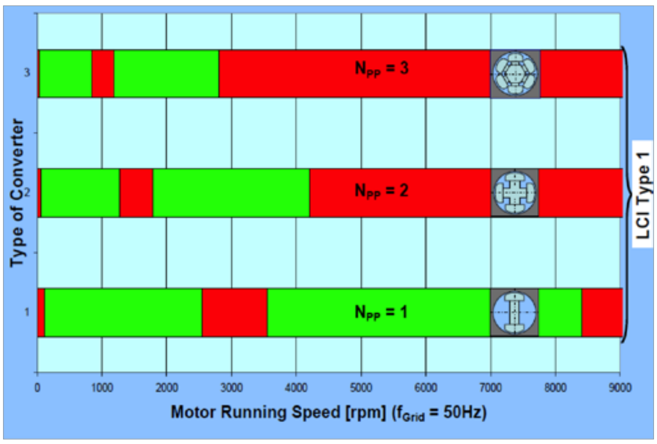

Figure 9. Bar Diagram of Motor Speeds for 12-puls LCI

Currently a 4-pole motor design operated at frequencies higher than 60 Hz represents an uncommon design in the turbomachinery industry. Nevertheless, it offers the opportunity of a torsional resonance free operation by using a reliable standard design. Based on this diagram it is obvious for an operating speed range between 2500 rpm and 3500 rpm to use a 4-pole motor design.

ELECTRICAL COMPONENTS AND REQUIRED INFRASTRUCTURE

The described VFD train design concept has been successfully verified for a 78,7 MW driven LNG train. The dynamic torque in the train elements were measured via strain gauges during string testing. For the mentioned example of the large VSDS system the calculated and therefore expected torsional resonances caused by interharmonic excitation were successfully verified during testing. During string testing of the motor compressor train and also during Back-to-Back testing of the motor a torsional resonance free operating speed range has been demonstrated (Figure 11).

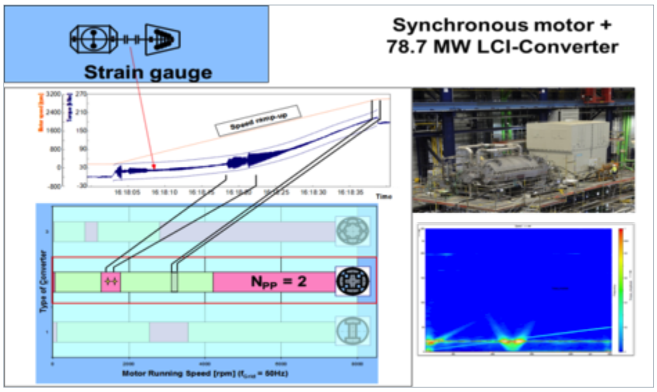

Figure 11. Verification of VFD-train design concept

Variable speed drive systems in the sizes mentioned in this paper are of modular design and most of the components are required to execute a complete unit test in a test facility as shown in figure 12.

Figure 12. Arrangement of Electrical equipment for back to back and full load string testing

The following major components of the Variable speed drive system (VSDS) must be shipped and installed:

- Transformer and HV switchgear
  Converter transformers match the distribution line voltage to the converter supply voltage, provide fault limiting reactance and will isolate the drive from the power system. The line supply voltage and frequency in the test facility may differ to the actual planning levels at site. In this case it might be required to install matching transformers for the testing period to allow the use of job equipment to the highest extend possible. To control and protect the drive equipment a HV switchgear and additional protection equipment is required for the testing period

- Power modules with pre-installed drive, control and cooling equipment
  In the described power range the load commutated inverter (LCI) is still the common choice in the Industry and the LCI is installed in a power module to allow easy transport to the test facility as well as afterwards to the plant site.

For a compressor string in this power range, additional electrical components are required such as: Excitation system for the synchronous motor, cooling equipment for the LCI and LV distribution and control equipment for the compressor string. These components are also needed for the set-up of the complete unit test and therefore need to be shipped and installed at the test facility. The use of power modules reduces the installation work significantly and is a common industry practice. The power module installation and commissioning is a major task and needs to be planned and executed similar to the actual work site during a later phase of the project.

- The synchronous motor
  For large e-driven compressors the typical choice is a synchronous motor with a cylindrical rotor and a brushless exciter. The LCI fed synchronous motor for the given example is water cooled with the cooling water supply provided by the test facility. The synchronous motor is directly coupled to the compressor without gear
  (Figure 13).

Figure 13. Synchronous and induction motors

- Harmonic filter
  Frequency converters represent nonlinear loads for the power system and as such produce harmonic currents and reduce the power factor as a function of the motor speed. The harmonic filter system design must cover the unique requirements in the test facility as well as the requirements at plant site. It is required to design the harmonic filter in a way to cover both cases with minimum adjustments necessary. A harmonic filter study and measurements are mandatory and in most cases must be discussed in detail with the electrical utility company prior to any testing. The measurements of the total harmonic distortion during the tests will prove the simulation models and design of the harmonic filter for the test site and is another step to reduce design risks for the site installation.

LARGE COMPRESSION STRINGS WITH 160MW SGT 5-2000E

A single compression string per 5 mtpa train configuration consisting of propane compressor and low pressure mixed refrigerant compressor and a high pressure mixed refrigerant compressor is driven by single Siemens gas turbine SGT 5 2000 E and variable speed 40 MW helper motor. This configuration offers a significant capital expenditure advantage and cost savings compared to others solution. It requires less rotating equipment machinery. It needs one gas turbine for 5 mtpa, one helper motor only and one compressor casing less for the same production of LNG compared to two gas turbine driven strings. Also expenses for less dry gas seals, less couplings, one lube oil unit less, less control valves, less instrumentation and controls, and utilities can be reduced. Helper motor is located next to gas turbine. The high pressure mixed refrigerant compressor bundle can be removed without dismantling of the motor. For one single train cost reductions for construction, for maintenance, for spare parts, and for day to day production will be achieved. Further advantage of one string solution is less space required to integrate the machinery into plot plan on site. The result is further cost savings for civil works and also auxiliaries. The advantages of this configuration have no impact on the liquefaction process Less rotating equipment means also higher availability of the overall system (Figure 14).

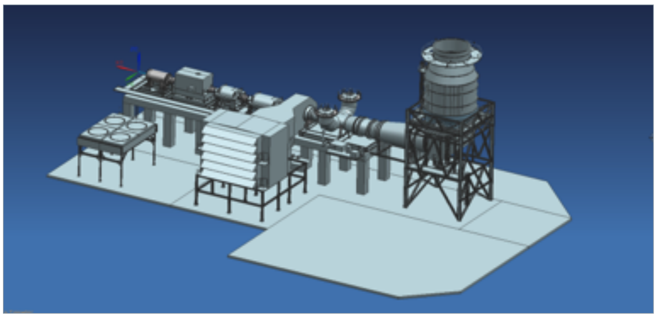

Figure 14. Example of a large compression train with SGT 5 2000 E

Compressors

Compressors are designed for 3000 rpm which is conservative design. This will lead to more robust operation compared to gas turbine speed of 3600 rpm. Compressors will be equipped with adjustable inlet guide vanes in order to improve operability and turn down capability of the production. A further major advantage of using adjustable inlet guide vanes is that closing the adjustable inlet guide vane will significantly reduce the torque requirement for startup. Flaring of refrigerant gases prior startup can be avoided and the plant can be in production much faster in operation after shut down compared to others solutions. The result is more production days on stream for LNG and more profitability of the plant.

Gas Turbine Drive

There are over 300 SGT 5 2000E with 20 million operating hours since 1981. This machine has been qualified and validated by **some** operators. The speed range is 97 to 103%. The SGT 5 2000 E offers 35% efficiency in open cycle. Silo combustors allow quicker inspections. SGT 5 2000 E requires a minor inspection (4 days) after 16.000 equivalent operating hours (EOH) and a major inspection (16 days) after 48.000 EOH.

Variable Speed Drive Systems

Siemens has large variable speed motors in operation and delivered starter helper drive systems for LNG application with others and in many countries. With the largest electrical drives ever built, 78,7 MW @ 3000rpm, for refrigerant compressor Siemens holds the world record.

Siemens Quality

In 2008 the Mega Test Center (MTC) for testing of large compressors with job project specific drivers has been put into operation in Duisburg. The largest electrical drive system ever built with mixed refrigerant compressor for LNG was tested at full load, full pressure, and full speed in MTC. This is again a world record. Siemens has the full capabilities of testing of the proposed string configuration consisting of SGT 5 2000 E, Starter Helper Motor, all compressor casings as a string test. Having all the test bed equipment already pre-installed and available, we can ensure a very attractive delivery period for the project and the highest quality of rotating equipment.

INDUSTRIAL TRENT 60 GASTURBINE FOR LNG APPLICATIONS

The industrial Trent with Rolls-Royce Aero Engine technology is designed for use in power generation and mechanical drive applications. It has the most mechanical drive experience in its class. It is designed to fulfill the most stringent environmental requirements on emissions.

Key features are:

- One of the most efficient gas turbines, it provides up to 66 MW in simple cycle service at 42,5% efficiency
- 100% Speed of 3400 rpm, speed range of 70 to 105%
- Minimal drop of efficiency at reduced speeds due to three independent shaft design
- Capability to restart a compressor from settling out pressure
- High break away torque capability
- High inert content fuel capability

The modular design of the engine allows for rapid exchange of components. Due to aero engine design maintenance can be accomplished quickly and easily. The engine change out can be done within 24 hours of working time. This design features will significantly reduce the turn down time. The industrial Trent can be integrated, together with its driven equipment in a common module- This solution will reduce the site installation time as well as minimize the number of interfaces.

Figures 15 show the possibility of solution for a 4–5 mtpa LNG train They may be 100% refrigerant flow or 50% flow solutions considered in order to find the most reliable, available and efficient one. Many of detailed studies have been carried out such as:

- Optimum aero and mechanical string design with compressors
- Dynamic simulations for startup and shut down
- 3D Models (Simulations) for maintenance
- Options for future upgrade of engines.

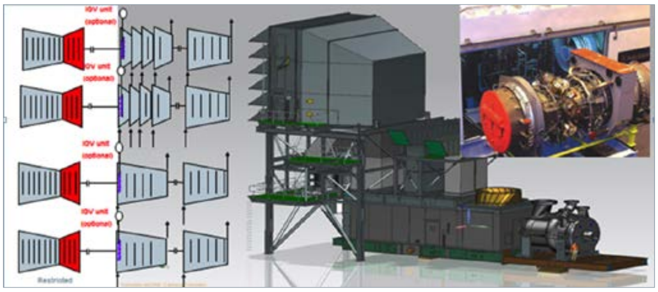

Figure 15. 2 times 50% flow configuration with Trent module

GEARED TYPE COMPRESSORS FOR MID-SCALE LNG APPLICATIONS

Compared to single shaft machines, integrally geared type machines serve the opportunity to select the impeller speed as close as possible to an optimum. This means the aero dynamical design of all impellers can be optimized to meet the process flow and pressure requirement with highest efficiencies available for radial turbo compressors in the industry. The efficiency improvement may be 7 to 10 percent compared to single shaft machines. Below you see a typical geared turbo compressor configuration, figure 15. Siemens integrally geared turbo compressors and related equipment are of well proven design in accordance with the latest compressor technology and science, incorporating all the benefits of the accumulated know-how and experience assessed during many years with a wide variety of specifications and applications. For specific projects, SIEMENS has delivered a first main refrigerant compressor as in integrally geared compressor. The compressor train consists of a 5-stage integrally geared centrifugal compressor with 2 process stages (1st process: stage 1–3, 2nd process: stage 4–5) and an asynchronous motor. The compressor is equipped with one inlet guide vane unit for each process stage in order to control each process stage individually. This provides the same advantages for the production process as already mentioned in the previous chapters. Multi service of compression solutions as well as integration of expanders is also possible. Of course this compressor can also be driven by both steam turbine and gas turbine. Combination of driver is possible.

The machine is arranged on a base plate which has additionally the function of the lube oil reservoir. The lube oil unit is mounted to this compressor baseplate. Such modular solution will reduce the site installation work to a minimum (Figure 16).

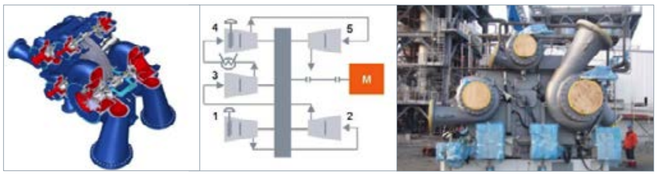

Figure 16. Geared Type Compressor Solution

INVESTIGATION OF THE SYSTEM DYNAMICS

The power plant for an eLNG design must comply with a number of requirements to match the electrical and often the thermal load requirements of the liquefaction process. The power plant will operate in island mode to produce the necessary active and reactive power for every mode of operation in the LNG facility. The power plant must follow the actual power demand with fast response to variations. Variations in power demand are caused by changes of process load or variation in generation or both. In all cases the power system must remain stable. It is important that the power plant provides uninterrupted power to ensure continuous LNG production. Synchronized spare generation capacity must be available in the event of a shutdown of any connected generator. Such synchronized reserve is referred to as N+1 or spinning reserve, where N is the number of generators required to power the LNG facility with one additional generating set securing the reserve capacity to cope with the loss of an individual generator. The spinning reserve capacity is normally distributed (load sharing of active and reactive power) amongst the number of generators in the N+1 operation scheme. This way, all generators on line will contribute in an optimum way for system recovery in case of disturbance to generation. Generator governors and automatic voltage regulators are set for droop mode operation with superimposed frequency and voltage control.

Shutdown of a generator cause instantaneous disturbance to the power balance. The amount of inertia/stored energy (MWs/MW) and speed of response from prime movers (dP/dt) defines the primary control capability of the power plant and is of essence to minimize transient frequency excursions. Restoration of system frequency and voltage following primary control is performed by superimposed, secondary control.

With N+1 operation the prime movers operate at part of rated capacity. Part load effects fuel efficiency and emissions so a careful selection of number and size of generators is needed to establish an optimal power plant configuration.

The relatively high power demand for eLNG designs often leads to the thought of larger turbines. Considering transient stability and part loading, it is important that an analysis of transient behaviour and efficiency versus part load is made.

Apart from the spinning reserve, a reserve capacity for maintenance of any generator is necessary. This reserve is kept as cold stand-by. The concept is referred to as N+2. Down time for generator maintenance exposes the LNG production to the risk of simultaneous faults in the power plant so these maintenance periods must be minimized. A possible way to minimize this down time is to apply an exchange concept for the GT core engines based on having a spare core engine available on site. Once exchanged, the core engine is overhauled on site in a dedicated maintenance work shop before use at the next exchange.

LNG production plants are operated in almost all cases as an island. Conventional LNG plants operate based on gas turbine driven compressors. Efficiency and availability of these mechanically powered plants are much lower than electrically driven compressors. Electrical LNG systems need less maintenance and are more reliable than mechanical systems.

The electrical power necessary to drive the plant must be produced in a power plant operating as an electrical island as an external electrical grid is quite often unavailable in the vicinity of the plant.

The reliability of an electrical island depends on the stability of frequency and voltage in the plant. The sensitivity of an island against these parameters depends on several factors but particularly the outage of the generators or loads. The generation is typically designed following the "N+1 principal" so that outage of one generator does not result in unacceptable frequency instability. The main load components in electrical driven LNG plants are large in relation to the size of the generators and the overall installed generation capacity. In addition, outages of loads are not restricted to individual compressors but to outage of several compressors or, as a worst case outage, to the loss of a whole production train.

Outage of a generator is not only characterized by the loss of active power capacity, but also by the loss of reactive power capacity which changes the system voltage and the load behavior.

To improve the system efficiency to a maximum value (higher than 50%) eLNG's are powered by combined cycle (CC) power plants. The power produced by the steam turbines is strictly related to the availability of the gas turbines. In case of a gas turbine outage the power production in the steam turbine is influenced by loss of a steam turbine or loss of a CC-block.

Another important factor for system stability is the protection of the system against short circuits. The stability of the system (and the generation) depends on the type of short circuit and the time until the fault is cleared. 3 phase faults are more severe but less probable than single phase faults. Typical protection clearing time is 80–100 ms which is fast enough to avoid generator instability in an islanded electrical system. The longer the fault the longer is the voltage recovery time to reach pre-fault conditions which can influence the behavior of the electrical equipment and, therefore, the behavior of the mechanical compressors.

System frequency stability is one of the most important factors for a reliable eLNG system and is influenced by several factors.

Dynamic voltage and frequency excursions in the eLNG plant in islanded operation can be sufficiently determined by conducting computer-aided simulations. The simulations include various network events such as electrical faults, load rejection and generation outage on the simulation model of the facility. This study uses a detailed model of the eLNG plant. Its main components are the power plant, electrical network and LNG processing plant. The aim of the study is to show that eLNG can provide high reliability and efficiency in LNG production if designed in accordance with standards and guidelines for secure power system operations.

An example shows the typical results of a dynamic system investigation based on a combined cycle plant with six SCC-800 2x1C generator blocks (2SGT-800 with 49.2 MW and 1 SST-400 with 40 MW). The three trains are equipped with 2 MR compressors (52 MW each) and a propane compressor with 57 MW. The link between the gas turbines and steam turbine in a block is the heat recovery steam generator (HRSG). The HRSG is of once-through type. This type of the HRSG provides high degree of flexibility as quick changes in steam production are possible, however, steam reserve is limited and sudden decrease in the GTG produced heat will have an impact on the generated steam and ultimately STG generation within a few seconds. The simulation model captures this behavior. The LNG plant is connected with the power plant via a 132 kV busbar system and the power plant and the LNG facility operate as an island and there is no connection to an external electrical grid.

Figure 17 shows the frequency behavior in case of a cascading outage of the propane compressor (C3) followed by the loss of the two MR compressors when 5 GT's and 3 ST's are operated (plant load 240 MW).

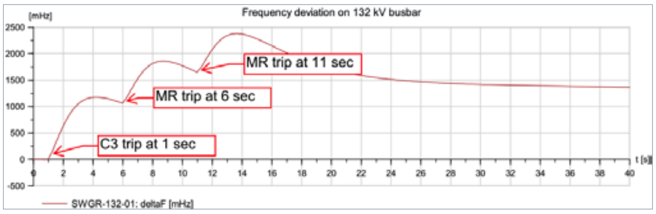

Figure 17. Simulation results for cascading loss of compressors

SUMMARY

In order to design and select a safe reliable solutions for complex LNG projects a detailed investigation of rotating and electrical equipment is necessary. Optimum configuration of the entire refrigerant compression system, consisting of compressors, variable speed drive systems, gas turbines, power transmission and power generation in an early project stage is a key for cost effective and on time delivery and commissioning of the plant. With all products required for power supply as well as for electrical and rotating equipment Siemens can support engineering and operating companies in planning and configuration of production systems from the beginning of the project up to day to day production of LNG. It is therefore important to involve all disciplines like process, rotating equipment, electrical engineers to review and understand all aspects of the project. This will ensure a proper exchange of information and will lead to effective project planning and execution.

NOMENCLATURE

AC	=	Alternating current	
CC	=	Combined cycle	
DC	=	Direct current	
EPC	=	Engineering and procurement contractor	
eLNG	=	Electrical driven LNG-plant	
f_{do}	=	VFD output frequency	[Hz]
f_l	=	Electrical line frequency	[Hz]
HRSG	=	Heat recovery steam generator	
I&C	=	Instrumentation and control	
LCI	=	Load commutated inverter	
LNG	=	Liquefied natural gas	
MTC	=	Mega Test Center	
MR	=	Mixed refrigerant	
n_{op}	=	Motor operating speed	[rpm]
N_{PP}	=	Number of pole pairs	[-]
SGT	=	Siemens Gas Turbine	
TNF	=	Torsional natural frequency	
VFD	=	Variable frequency drive	
VSDS	=	Variable speed drive system	

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