# SUITABLE LNG DRIVER SELECTION

**Tina Owodunni, Shaun Mohammed, Rodolfo Tellez-Schmill, and Vikas Singh, KBC Advanced Technologies (a Yokogawa Company),** examine factors to consider when creating an integrated gas turbine model in order to evaluate its performance and emissions under varying off-design scenarios.

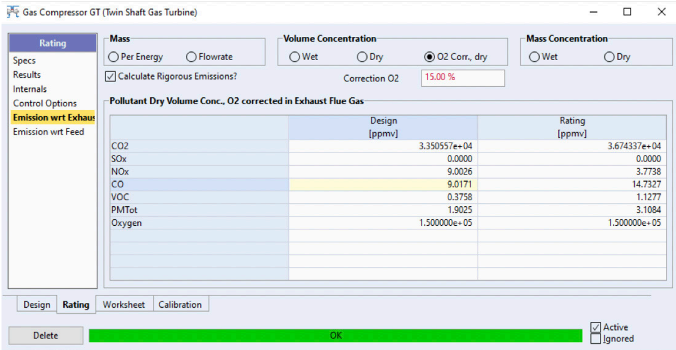
LNG is gaining awareness as a cleaner energy alternative as opposed to other types of fossil fuels because of its low carbon emissions and ability to transport large quantities of energy at relatively low cost. At the same time, LNG plants have the reputation of being energy and cost-intensive since they need significant power for compression and refrigeration. Consequently, one of the primary issues in the LNG industry is to boost the effectiveness of the existing natural gas liquefaction processes, while also reducing costs.

The composition of an LNG supply chain is important, as it provides insight into the actual cost, value, and system benefits of LNG compared to other natural gas transportation options. Five main components make up the LNG supply chain, including: upstream gas supply, liquefaction to form LNG, shipping, storage, and regasification and delivery to the end user.

In the production phase of LNG, various technologies are used. The most popular include APCI C3MR, Phillips Optimized Cascade, Shell DMR, and Linde. Regardless of the technology, one common limitation is the circulation rate of refrigerant(s) in the liquefaction process, which is normally influenced by the compressor size used in the respective refrigeration cycle.

Traditionally, a gas turbine drives these compressors, which imposes another limitation (horse-power) due to 'AMBIENT'.

High ambient temperatures cause heat retention in the refrigerant loops because of a loss of de-superheating ability. The compressor may not be able to provide the additional cooling requirement due to the increase in vapour traffic as it is already constrained on the driver end due to horse-power limitations of the turbine.




| | Design [ppmv] | Rating [ppmv] |
|---|---|---|
| CO2 | 3.350557e+04 | 3.674337e+04 |
| SOx | 0.0000 | 0.0000 |
| NOx | 9.0026 | 3.7738 |
| CO | 9.0171 | 14.7327 |
| VOC | 0.3758 | 1.1277 |
| PMTot | 1.9025 | 3.1084 |
| Oxygen | 1.500000e+05 | 1.500000e+05 |

**Figure 1.** A sample result page from GT-SIM.

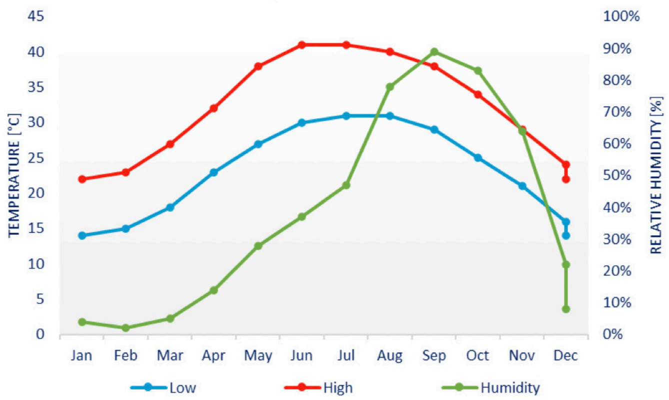



**Figure 2.** Monthly ambient conditions.

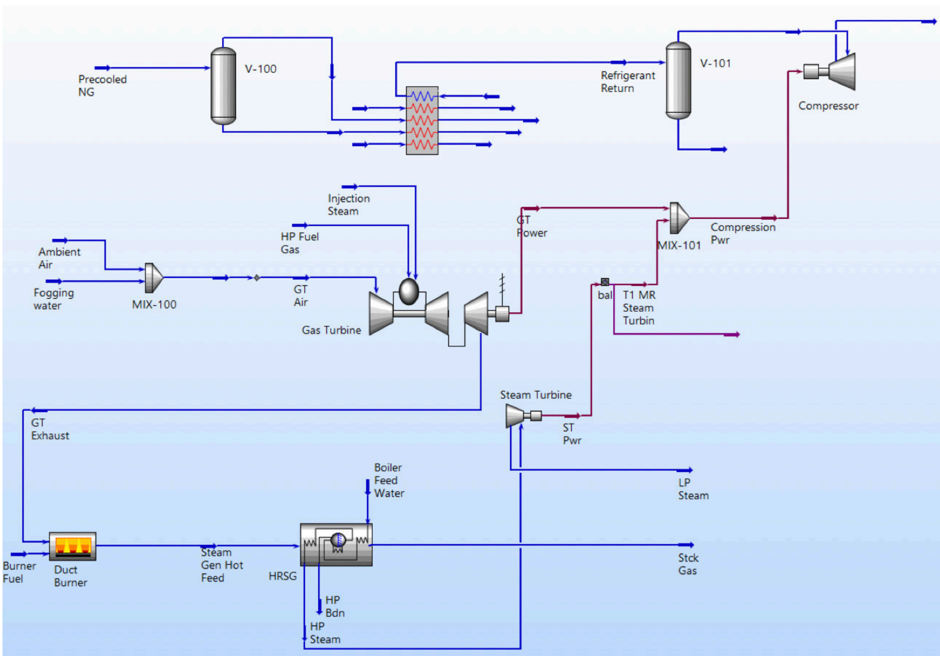



**Figure 3.** Integrated gas turbine simulation setup.

Reducing gas flow is a viable option, but counterproductive. Removing excess heat generates a net positive effect as the demand on the compressor and turbine is reduced. Excess heat can be reduced at these peak ambient conditions by:

1. Placing a fogging system on ambient coolers.
2. Applying additional coolers at peak times.
3. Adding variable frequency drives (VFDs) on fin fan motors that allow speeds a percentage above nominal.
4. Using high-efficient ambient coolers, e.g. Whizz wheels.

Each of the preceding options carries a level of consideration, whether it is corrosion (for fogging) or additional energy consumption/excess emissions. Thus, the mitigation option chosen should only be used during peak periods to stabilise compression power. Even when the compression power is maintained, ambient conditions still produce problems with the gas turbine.

## Reviewing modelling gas turbine performance

Modelling gas turbine performance can help evaluate options for compressor driver selection to mitigate the effects of varying environmental conditions.

### Gas turbines as compressor drivers in LNG liquefaction

LNG projects are capital-intensive. The costliest component of the chain is the liquefaction plant – it often accounts for over 25% of the project. To minimise the LNG life-cycle costs, it is essential to choose the right refrigeration compressors and drivers.

LNG refrigeration compressors use three types of drivers: electric motors, steam turbines, and gas turbines. In the LNG industry, gas turbines have replaced steam turbines as the preferred driver. Gas turbines offer several advantages over steam turbines, including smaller plot space, lower installation and transportation costs, and do not require costly boiler feed water treatment.

### Ambient conditions influence gas turbine performance

Atmospheric air serves as the medium for transferring energy as heat and power in gas turbines. This introduces a challenge for gas turbine operation because inlet air conditions vary daily, impacting the power delivery. The rise of air temperature or humidity decreases its density, leading to lower gas turbine air intake, which reduces the gas turbine's power delivery and efficiency. Installing turbine air inlet cooling or conditioning facilities may help overcome this negative ambient; however, this option may not be feasible for offshore LNG plants, such as a floating LNG.

During high temperature seasons, the power output of gas turbines often drops and requires helper drivers to supplement the power. One such helper driver is the steam turbine; the exhaust from the gas turbine is used to generate steam, with or without supplementary firing, which is then used to supply extra power in the steam turbine. Some LNG projects, such as expansions, may have an obvious choice of mechanical driver. Usually, new developments require a detailed technocommercial selection study. Such a study requires modelling performance of the gas turbine, associated units, and impact of ambient changes.

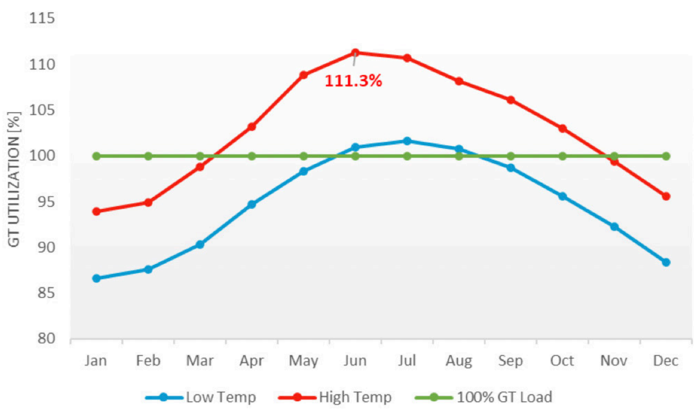



**Figure 4.** Significant impact of ambient temperature variations on H-100 operability.

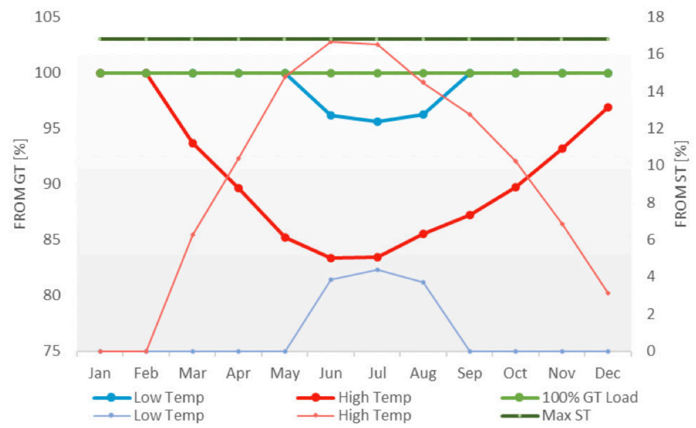



**Figure 5.** Steam turbine supplies up to 16% of requirement to prevent gas turbine's peak load.

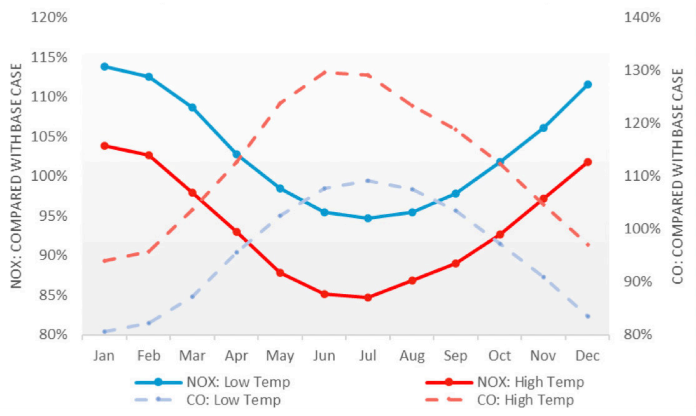



**Figure 6.** $NO_X$ emissions reduce when steam turbine is in use.

## Gas turbine modelling challenges

Traditionally, simulating gas turbines were disengaged from processing facilities. Also, variations in ambient air conditions may have been overlooked, and emission calculations, especially nitric oxide ($NO_X$) emissions, were rarely attempted. Unfortunately, this loose method of modelling could lead to choosing the wrong driver.

In the past, building a gas turbine model in a process simulation environment was a tedious procedure. It required the process flowsheet to combine three individual unit operations: air compressor, combustor, and expander. When conducting gas turbine sizing sensitivity analysis, several inputs had to be meticulously updated and verified. This traditional practice was inefficient and prone to human errors. Parametric case studies were also time-consuming and onerous, so the full range of options was rarely considered systematically.

## Gas turbine simulation model

Unlike traditional models, KBC's GT-SIM gas turbine simulation model can be integrated with the processing facility's simulation in Petro-SIM® to model the gas turbine performance and ensure the liquefaction compressors have enough power. In the model, relative air humidity and ambient air temperatures can be included if these parameters change significantly across seasons.

GT-SIM offers a built-in database of design specifications from the Gas World Turbine Handbook. In the case examined in this article, the Mitsubishi H-100 gas turbine is applied. This high efficiency (39%) twin shaft gas turbine is available in both 50 Hz and 60 Hz, and used for simple cycle and mechanical drive applications. Combined cycle applications are also possible with the gas turbine since it exhausts at temperatures over 533˚C. In LNG applications, the H-25 gas turbine is commonly used and serves as the basis for the H-100. The GT-SIM tracks the gas turbine's performance and emissions for varying off-design operating conditions, such as:

- Air and fuel conditions.
- Part-load operations.
- Injection steam rates.
- Pressure drops at the inlet (due to air filters) and outlet.

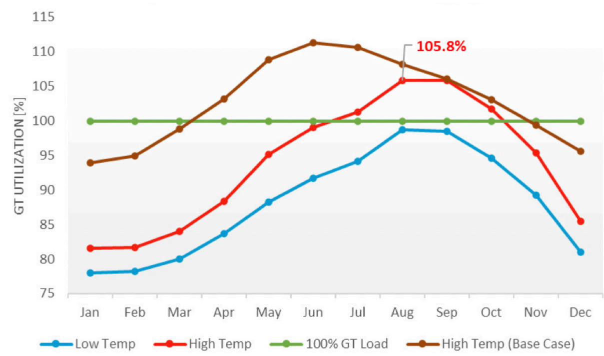



**Figure 7.** Inlet air fogging increases H-100 performance.

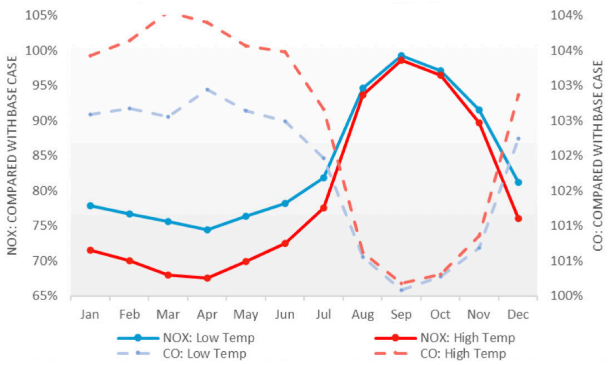



**Figure 8.** Inlet air fogging reduces $NO_X$ emissions but maintains same CO emissions.

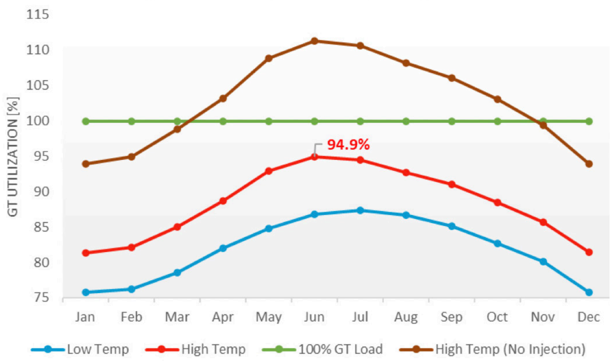



**Figure 9.** Steam injection keeps load within 100% throughout the year.

In these situations, GT-SIM tracks the gas turbines efficiency and emissions, including $NO_X$ and carbon monoxide (CO) emissions (Figure 1).

Figure 2 demonstrates the variations in ambient conditions (Middle East) that apply to the case being studied.

## Case study

The integrated gas turbine-processing facilities simulation is setup as in Figure 3.

Due to the large difference between monthly high and low temperatures, both temperature extremes needed to be considered to properly size the gas turbine. With the traditional method to evaluate the gas turbine, the user needed to perform 24 sets of runs with the monthly ambient variations. Using GT-SIM, a single run could determine the performance of the H-100 over the year. For instance, the monthly ambient conditions could be included in the scenarios and time series functionalities, which are embedded in Petro-SIM software. Petro-SIM technology also provides other routes through which several case studies can be completed in one single run.

## Case: H100 gas turbine

Figure 4 shows the gas turbine performance was adequate until early March, with total compression power being lower than 100% of gas turbine load during the hottest hours. As inlet air became hotter, the gas turbine power soon failed to meet demands. Activating up to 110% of peak load allowed most demand to be satisfied. However, prolonged use of the gas turbine at peak loads could damage the engine, so other means were needed to satisfy the shortfall.

The GT-SIM enables the following evaluation options:

1. Steam turbine as helper driver.
2. Inlet air fogging.
3. Steam injection.

### Option 1: Steam turbine as helper driver

By using the steam turbine as a helper driver, the gas turbine can be prevented from exceeding its peak load. Steam is best produced through a heat recovery steam generator (HRSG) that uses the gas turbine exhaust as the heat source. If necessary, a duct burner in the HRSG can heat the gas turbine exhaust. When this gas turbine runs at 100% capacity, 132 tph of 70 bar steam can be generated from the HRSG without supplementary firing, generating up to 18 MW of power. This is sufficient for all cases where the steam turbine must supplement the gas turbine's production.

The base case requirement shows the steam turbine will need to supply up to 11% of the compression power from March – November. In the parametric run below, gas turbine utilisation is limited to 97% of full capacity, and steam turbines are used to cover any shortfalls. According to Figure 5, the steam turbine can supply up to 16% of the compression power, allowing the gas turbines to contribute 84%. As shown in Figure 6, the $NO_X$ emissions decrease while the CO emissions increase when the steam turbine load replaces the gas turbines peak load.

**Table 1.** Advantages and disadvantages of each option

| Scenarios | Advantages | Disadvantages |
|---|---|---|
| Option 1: Steam turbine as helper | - Provides enough power to completely avoid peak load operation<br>- Extra power to use elsewhere<br>- Moderate reduction in $NO_X$ emissions | - High CAPEX to install steam turbine<br>- Up to 30% increase in CO emissions |
| Option 2: Inlet air fogging | - Inlet air fogging facilities are lighter and cheaper compared to steam turbine<br>- Reduces $NO_X$ emissions to approximately 75% with little impact on CO emissions | - Unable to eliminate peak load operation<br>- 2nd highest CAPEX<br>- Little change in CO emissions |
| Option 3: Steam injection | - Provides enough power to completely avoid peak load operation<br>- Reduces $NO_X$ emissions to 20% | - Smallest CAPEX<br>- Increases CO emissions by 44% |

## Option 2: Inlet air fogging

Water fogging could decrease the gas turbine inlet air temperature and the gas turbine power output. Inlet air fogging is comprised of spraying finely atomised water, also known as fog, into the feed air to the gas turbine compressor. During evaporation, water droplets cool the air and decrease the compressor power intake, allowing the gas turbine to produce more power.

For each of the 24 cases, the flowrate of cooled water added to the ambient air was adjusted to achieve 90% relative humidity. This prevents free water from forming in the inlet air and damaging the gas turbine compressor. Inlet air fogging improved gas turbine output by up to 14.8% in 1H22. Then, June reported 12% more power when the relative humidity was low, so that fogging up to 90% humidity significantly reduced temperatures. However, improvement was limited during hot and humid months. For instance, at 40˚C and 78% humidity in August, and at 38˚C and 89% humidity in September, fogging could only reduce the temperature to 37˚C, so the gas turbine still needed to work at 106% capacity, as shown in Figure 7. Figure 8 shows that fogging significantly reduces $NO_X$ emissions, but barely affects CO emissions.

## Option 3: Steam injection

Injecting steam into the combustion chamber of the gas turbine is another way to meet the required compression power. The steam mass flowrate is limited to 5% of the air flowrate to minimise the impact on gas turbine maintenance. This study considers whether steam injection can satisfy the demands during the hotter seasons. Figure 9 shows how steam injection can avoid running the gas turbine at peak load throughout the year.

## Summary

Neither option 1, 2, nor 3 is perfect. Therefore, the best choice cannot be made until the cost and economics of each scenario have been calculated and evaluated against its respective risk. These evaluation factors will differ from project to project.

Table 1 summarises the pros and cons of each option.

## Conclusion

In this study, the quantitative review would have been difficult to obtain from traditional gas turbine simulation procedures. Typically, detailed information from gas turbine manufacturers is required to determine the off-design cases for alternative ambient conditions and fogging, and this can substantially slow down the process of machine selection. This either leads to over-conservative assumptions (i.e., install a steam turbine or select the larger machine, with an associated increase in CAPEX) or costly surprises during operations. With GT-SIM, the interdependency of the gas turbine and the production system can be understood in a single integrated process-utility simulation. Consequently, it enables the project team to select the most suitable driver setup whilst considering the economic and emission impact. **LNG**