LNG Fuel Flexibility in Siemens' Land-Based Gas Turbine Operations

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ABSTRACT

Liquefied Natural Gas (LNG) from offshore reserves is expected to supplement United States' domestic natural gas consumption in the near future. The quality and hydrocarbon contents of the natural gas imported from these international sources will be different than those of domestic natural gas. With the variations in fuel characteristics that are known to exist among LNG sources, use of LNG in gas turbine engines could violate applicable fuel specifications, and lead to operational issues such as, but not limited to, combustion dynamics, flashback, increased emissions, or decreased component life. Another potential issue for gas turbines generating power is sudden changes in the fuel characteristics that may lead to substantial load swings.

Fuel flexibility is dominantly tied to the combustion system design. Conventional diffusion flame combustion systems are more tolerant of wide variations in fuel compositions but produce higher emissions levels. The more advanced premixed flame combustors, the Dry Low NO_x (DLN) and Ultra Low NO_x (ULN) combustion systems have significantly better performance, in terms of emissions, but they demand tighter control over the variability in fuel constituents.

Siemens has proactively addressed the challenge associated with the impending influx of LNG on gas turbine operability. Siemens performed rig and field tests utilizing commercially available combustion hardware to identify a preferred set that is capable of robust operation over varying fuel compositions. In addition to the internal combustion hardware requirements, Siemens has designed the Integrated Fuel Gas Characterization (IFGC) system (Patent Pending) to allow engines to accommodate faster fuel variations without substantial load swings. This IFGC system acts like an early warning system and feeds forward signals into the plant control system. The combustion system hardware and the IFGC system, which includes the Combustion Dynamics Protection System (CDPS), represent some of the technologies Siemens employs to address variations in fuel gas compositions associated with LNG.

INTRODUCTION

Most of the power generation capacity added in North America during the last five years consists of gas-fired turbines. Due to declining production of natural gas in the United States, the importation of additional gas supplies is being used to help meet demands. The quality and hydrocarbon contents of the natural gas imported from these international sources can be different than that of the typical domestic supply.

To transport significant quantities of natural gas effectively from other countries, the natural gas must go through a process of liquefaction. Before the liquefied gas enters the gas distribution pipelines in America, the fuel must be re-vaporized to its gaseous state. Through this process, most of the inert components - like N_2 and CO_2 - and higher hydrocarbons (C6+) are removed from the fuel, while retaining all of the original levels of Ethane, Propane and Butane. This leads to increased Wobbe Index (defined as higher heating value over the square root of specific gravity) as compared to domestic natural gas.

The United States currently has only six gasification facilities in operation (Figure 1) [1]. According to published reports [1], several additional terminals (Figure 2) have been approved for construction and more proposals are under review by federal authorities. Siemens has a number of gas turbines near these current and proposed LNG terminals.

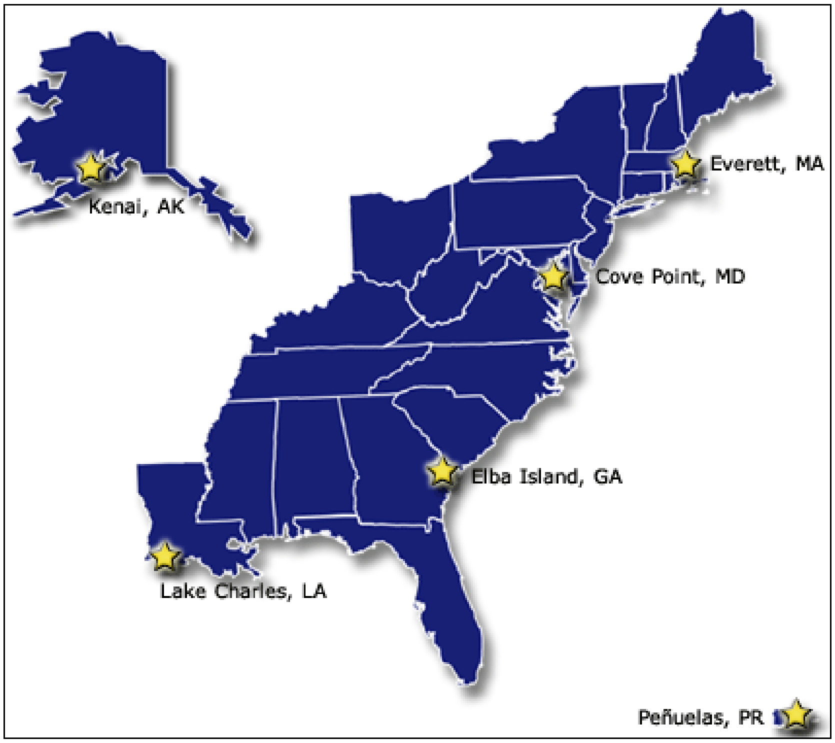

Figure 1: Existing LNG terminals in the United States

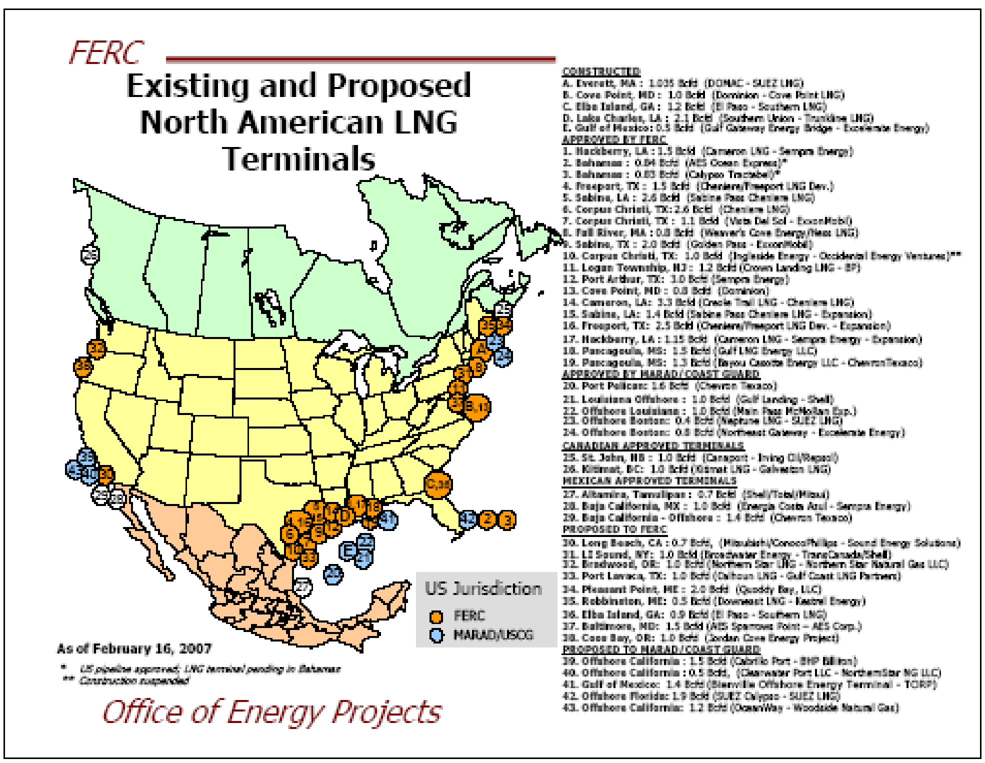

Figure 2: Existing and Proposed North American LNG Terminals

With the variations in fuel characteristics that are known to exist in the LNG supply chain, use of LNG in gas turbine engines would violate currently applicable fuel specifications, and lead to operational issues such as, but not limited to, combustion dynamics, flashback, increased emissions, or decreased component life. Another potential issue for these units is sudden changes in the fuel characteristics that may lead to substantial load swings.

SIEMENS' PHILOSOPHY FOR LNG INTERCHANGEABILITY

Siemens has approached the challenge of LNG operability in a unique way. Siemens has evaluated most of their commercially available combustion system configurations and has down-selected the set of combustion hardware which is the most robust to changes in fuel compositions on the basis of rig and field testing. This will allow operation on LNG type fuels while keeping emissions within acceptable limits dependant upon fuel characteristics and permit levels.

Along with the said combustion hardware upgrade, Siemens has also designed an Integrated Fuel Gas Characterization (IFGC) system (Patent Pending). This IFGC system utilizes an IFGC Meter (a Wobbe Meter with a redundant integrated Gas Chromatograph), Combustion Dynamics Protection System (CDPS) and a fuel gas buffer tank. The IFGC meter is installed upstream of the Econopac™ and the signals from this meter is fed into the plant control system. Depending on the changes in the Wobbe Index of the incoming fuel, the control system is designed to adjust the engine tuning settings to compensate for this change. The buffer tank is designed to accommodate for the slight delay in the response of the IFGC Meter. The CDPS system represents a second line of defense against impact on dynamics and emissions. This feeds the dynamics response into the control system and adjusts the fuel settings to ensure the engine is within allowable emissions and dynamics limits. The combustion system hardware and the IFGC system represent some of the ways that Siemens will address variations in the fuel gas compositions from LNG.

TEST RESULTS AND DISCUSSION

Siemens has been involved in the development of a LNG capable gas turbine using advanced premixed combustion systems for over five years. This experience has shown that the combustion system is significantly impacted by the variations in fuel quality between natural gas and LNG. Furthermore, this knowledge drove Siemens to investigate and identify robust combustion system configurations that are capable of reliable LNG operation. In pursuit of this effort, Siemens performed multiple LNG test campaigns for the SGT6-5000F (W501F) engine both in test rigs and in operating engines. Rig tests for the SGT6-3000E (W501D5A) and the SGT-6000G (W501G) have also been accomplished.

Diffusion combustion systems are much less susceptible to variations in fuel quality. They have the highest degree of fuel flexibility and are considered the combustion system of choice when fuel quality is not as controlled. However, their emissions levels are generally higher as well. Premixed combustion systems operate at much lower combustion temperatures due to the premixing of air and fuel, leading to lower emission levels than those of diffusion combustion systems [2]. Projections for LNG use have increased significantly over the last few years, driving development studies that address premix combustor applications, namely Dry Low NOx (DLN) and Ultra Low NOx (ULN) [3] configurations.

Without having LNG in the fuel gas pipelines, it was difficult to test its impact. Hence mixing skids were used to blend the different fuel components to simulate LNG blends. Figure 3 shows some pictures of the combustor test rig set-up and mixing skid set-up during the tests.

Figure 3: Test rig & mixing skid setup during LNG testing

The objectives of these tests were to determine the operating and emission characteristics of the SGT6-5000F (W501F) combustion system. These tests were conducted across the normal steady state operating range, from partial load to base load, using different gas compositions. Ignition tests were also performed to ensure successful ignition capability using both natural gas and LNG fuels.

A detailed investigation into the US and global gas reserve base shows that the US domestic natural gas reserve has a Wobbe Index of approximately 1342 Btu/scf (Figure 4). The variability in the domestic reserve is approximately +/- 2%. However, the Wobbe Indices of the fuels from the international sources have quite a variability and range anywhere from 1366 to 1441 Btu/scf.

$$Wobbe\ Index = \frac{Higher\ Heating\ Value}{\sqrt{specific\ gravity}}$$

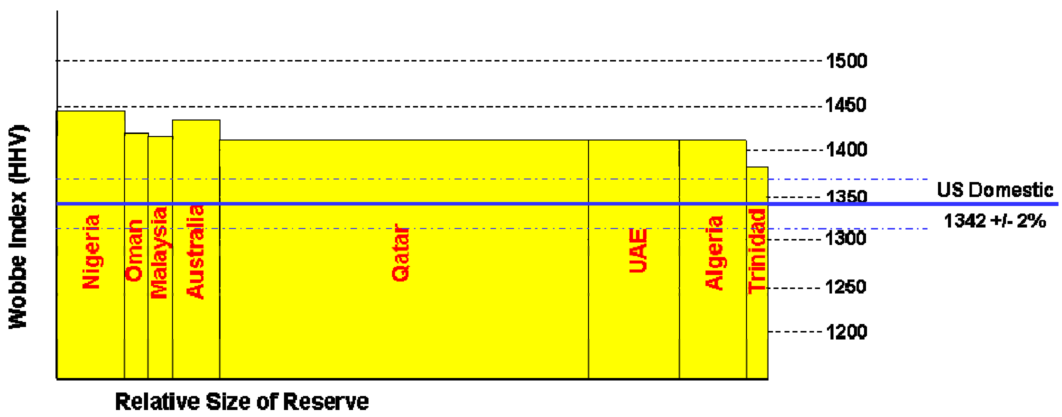

Figure 4: LNG reserves of the world
**source information through the Natural Gas Plus Sub-Committee.Provided for information only - actual constituents/concentrations may vary.

It was also seen that the components in the fuel varied widely between these reserves. However, it was generally seen that the maximum percentages of the higher hydrocarbons were about 14% ethane, 4% propane and 2.5% butane but not all together in one particular source. Considering this variation in fuel quality, Siemens opted to use 3 representative fuels for its testing purposes as described in Figure 5. It is reasonable to assume that most of the world's LNG sources would be accommodated in the LNG1 category. LNG2 covers almost all of the world's LNG reserves.

Nevertheless, Siemens tested an extreme condition which is denoted as LNG3 to verify system margin.

Constituent	Test Fuel		
	LNG 1	**LNG 2**	**LNG 3**
C2 – Ethane	10.0%	15.0%	1.5%
C3 – Propane	3.0%	5.5%	15.0%
C4 – Butane	1.5%	2.5%	5.0%

Figure 5: Test fuels and their components

Based on these tests, it was found (Figure 6) that typically NOx emissions increased with increase in Wobbe Index of the fuels. The increase in Wobbe Index also increased the propensity of flashback (the progression of flame in the reverse direction of flow and possible attachment to combustor hardware). Flashback is a great concern for combustion turbine operation since it damages parts quickly and may cause forced outages in extreme cases. Hence one of the principal objectives of the test campaigns was to evaluate the margin for flashback in the operation of the gas turbine. A positive impact of using LNG in combustion turbines was the improvement in combustion dynamics (Large amplitude pressure oscillations in combustion chamber, driven by heat release oscillations which are destructive to engine hardware). LNG having more heavier hydrocarbons provides a relatively more stable flame which in turn results in lower combustion dynamics. This provides the margin for additional emission optimization to regain some of the lost ground on NOx emissions.

As identified in a previous section, the philosophy of Siemens was to evaluate the capability of existing combustion systems for LNG applicability. This would have a positive impact on the costs and the risks as compared to introducing a new LNG compatible combustion system. It was found that certain combinations of combustion hardware were susceptible to flashback as well as had a high impact on NOx emissions. Other combinations of combustors fared significantly better in terms of the critical parameters as mentioned above. Figure 6 depicts some typical results from the tests that were performed on the DLN Combustion system configurations. Configuration B performed relatively better than configuration A in terms of NOx emissions. Although there was an increase in NOx, the combustors could be tuned down to achieve lower NOx levels as indicated by configuration B (tuned) curve. Configuration B was chosen as the preferred combustor configuration for DLN application.

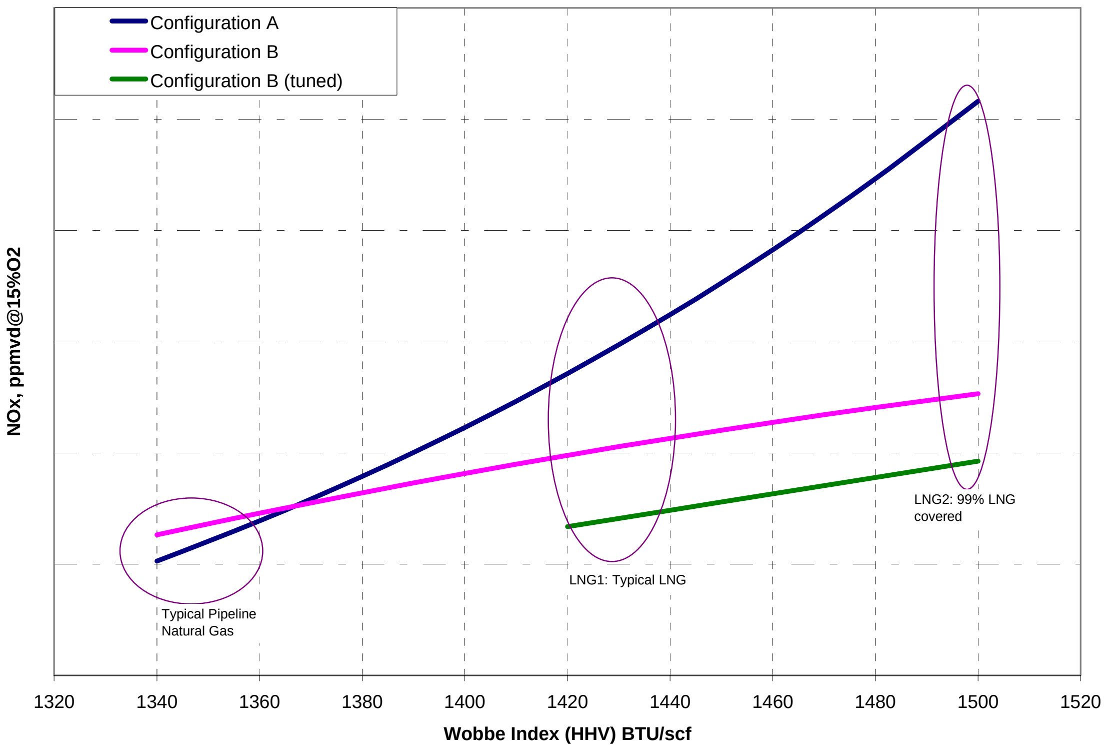

Figure 6: Typical impacts of LNG on Siemens Combustion Turbines with DLN combustors.

It was also found that the Ultra Low NOx (ULN) Combustion system [3] is much less susceptible to wider constituent variations that may be present in LNG. There was marginal impact on NOx emissions while operating on LNG1, LNG2 or even LNG3 type fuels. Flashback margin was also found to be acceptable. There was no measurable impact on combustion dynamics with the ULN Combustion system.

Overall, it is Siemens recommendation that LNG type fuels will be acceptable to be used in Siemens Gas Turbines [4] with the preferred combustion hardware in place along with the Integrated Fuel Gas Characterization System as described in the section below. A site specific evaluation would be required to determine the optimal system depending on the expected fuels that the unit would be operating with, along with the emissions permit levels associated with the site.

INTEGRATED FUEL GAS CHARACTERIZATION SYSTEM

A major hurdle in LNG applicability is to ensure that the gas turbine is operable with fuels containing heavier hydrocarbons. However, this is not the only hurdle that gas turbine manufacturers need to overcome. The rate of variability in fuel quality is a real threat to the smooth and continuous operation of power generation turbines. The nature of LNG is such that the quality of the fuel may significantly change with the barge that transports the LNG into the terminal. It is quite likely that the fuel quality will change significantly over a matter of days or in worst cases, several times in a given day. This rate of change would also depend on the location of the unit. For example, a unit which is close to a pipeline node and receives gas from two or more sources would be more susceptible to fuel quality variation.

In order to address this frequent and fast rate of change in the quality of the fuel, Siemens has designed the Integrated Fuel Gas Characterization (IFGC) system (Figure 7). The IFGC system (Patent pending) utilizes a rapid response Wobbe Meter with a redundant integrated Gas Chromatograph. This IFGC meter is installed upstream of the Econopac™ and the signals from this meter is fed into the engine control system. A fuel gas buffer tank is used to create a delay to accommodate for the response time of the IFGC meter.

Depending on the changes in the Wobbe Index of the incoming fuel, the control system is designed to adjust the engine tuning settings to compensate for this change. The Combustion Dynamics Protection System (CDPS) is an active control dynamics monitoring and control system. The CDPS receives signals from a Continuous Emissions Monitoring System (CEMS) at the turbine exhaust and compares this with the unit-specific emissions permit. Depending on the variation between the two, it adjusts the control settings to bring the unit within permitted emissions limits while maintaining acceptable levels of combustion dynamics.

Some of the benefits of the IFGC system may include its ability to minimize power fluctuations. If the IFGC system is not used, the unit may see load swings as a result of the variation in fuel quality. This risk is mitigated by use of the IFGC system. The IFGC system also addresses the possibility of poor light-off scenarios associated with fuel quality. The IFGC system with its feed-forward control can accommodate this fuel quality variation and ensure adequate fuel flows for light-off. The IFGC system is linked to the CDPS system and it is designed to change fuel flow settings to respond to combustion dynamics. Flashback is a great risk for LNG fuels and this is also dependent on the fuel quality. The feed forward system using the buffer tank adjusts the control settings to minimize flashback.

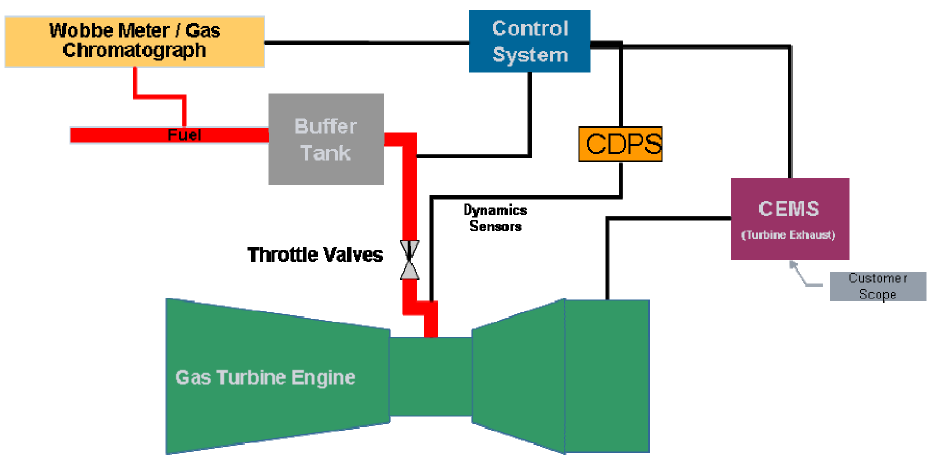

Figure 7: Integrated Fuel Gas Characterization System

FUEL SPECIFICATION EXPANSION

Based on the above mentioned engine and rig tests, Siemens has proposed to widen the fuel specifications [4] under which Siemens SGT6-5000F (W501F) Gas Turbines may operate. With the appropriate equipment and hardware installed, these units could operate using this widened fuel specification. A site-specific evaluation is required to assess the hardware, control systems and other equipment that may be necessary in order to continue to meet emissions permits of these power plants.

	Flexible Fuel Limits
Wobbe Index Variation	1288 to 1424 Btu/scf
Methane (CH4) (mol %)	Greater than or equal to 80%
Ethane (C2H6) (mol %)	Less than or equal to 15%
Propane (C3H8) (mol %)	Less than or equal to 5%
Butanes (C4H10+) (mol %)	Less than or equal to 3%

Figure 8: Fuel specification expansion for LNG Interchangeability

Siemens has developed modification packages to allow the expansion of applicable existing fuel specifications to within the levels in the table above (Figure 8). The intent of these modification packages is allowance of more variance in the fuel parameters within the compositions identified in Figure 8 above, without appreciably affecting NOx and CO emission levels.

CONCLUSIONS

These upgrade packages are intended to allow operation of Siemens SGT6-5000F (W501F) gas turbines on a wider range of fuels while maintaining exhaust emission levels. The upgrade packages are also expected to have a negligible effect on performance characteristics of gas turbine engines. By allowing greater flexibility in the fuel specification, the supply and demand relationships for Natural Gas can subsequently provide a better economic advantage for future dispatch of the units.

The combustion system hardware and the IFGC system which includes the Combustion Dynamics Protection System (CDPS) represent some of the ways that Siemens will address variations in the fuel gas compositions from LNG.

PERMISSION FOR USE

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