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LNG Terminal Reserve Planning Optimum Performance for Integrated Gas and Power Generation System

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Abstract

In this article, a scheduling model for optimizing the integrated system of LNG Reserve is developed. This model considers the impact of LNG supply risks on the operation of the integrated gas power generation system in a multi-Gas provider supply setting. The optimization goals of this model are focused on minimizing the annual cost of the integrated system. It achieves this by taking into account the operating simulations of various common scenarios that occur over a 52-week period in a single year, as well as the annualized investment in LNG Tanks. The arrival of LNG and the operational mode of LNG terminals are key factors in establishing the operational targets for each possible scenario. A comprehensive evaluation network based on IEEE-39, featuring a Greenville LNG 20-node network, has been successfully developed. The evaluation network allows for the determination of the optimum reserve duration. Furthermore, the impact of load levels and various modes of operation on reserve scheduling has been thoroughly investigated.

Keywords: LNG, Terminal, Model, Tank, System, Scheduling

1. Introduction

The planning and optimization of LNG (Liquefied Natural Gas) terminal reserves play a crucial role in ensuring the optimum performance of integrated gas and power generation systems. With the increasing demand for clean and sustainable energy sources, LNG has emerged as a vital component of the global energy landscape. LNG terminals serve as critical points for the import, storage, regasification, and distribution of LNG.

The efficient management of LNG terminal reserves is essential to maintain a reliable and uninterrupted supply of natural gas for both industrial and domestic consumption. However, traditional reserve planning approaches often fail to account for the dynamic requirements of integrated gas and power generation systems. This has led to inefficiencies, operational challenges, and suboptimal utilization of LNG reserves.

This comprehensive study aims to address these challenges and explore the concept of LNG terminal reserve planning for optimum performance in integrated gas and power generation systems. By considering factors such as demand forecasting, seasonal variations, market dynamics, and operational constraints, this study seeks to develop robust models and strategies for efficient reserve planning.

One of the primary objectives of this study is to optimize the allocation of LNG reserves to meet the demand for both gas supply and power generation. By integrating the gas and power sectors, the study aims to achieve synergies and maximize the utilization of available resources. This includes identifying strategies to balance the supply-demand dynamics, minimize energy losses, and enhance the flexibility and resilience of the integrated system.

Moreover, the study will explore the application of advanced technologies, such as predictive analytics, machine learning, and real-time monitoring, to improve reserve planning accuracy and responsiveness. These technologies can enable operators to make data-driven decisions, anticipate demand fluctuations, and optimize the regasification and distribution processes.

The findings and recommendations from this study will provide valuable insights for stakeholders involved in LNG terminal operations, power generation, and energy planning. It has the potential to guide policy development, infrastructure investments, and operational strategies for achieving optimum performance in integrated gas and power generation systems.

In this study recognizes the significance of LNG terminal reserve planning in ensuring the seamless operation and optimum performance of integrated gas and power generation systems. By considering the dynamic nature of demand and leveraging advanced technologies, this study aims to contribute to the development of efficient and sustainable energy systems. The outcomes of this research are expected to play a crucial role in shaping the future of LNG infrastructure and its integration with power generation.

2. Model of Optimisation for LNG Reserve Planning

2.1 Optimization objective

The objective of the optimisation is to lessen the yearly operational cost of the integrated system and the LNG tank's annualised investment cost.

$$\min f = IC + OC(V_r) \tag{1}$$

$$IC = C_{u,a} \cdot V_{s \cdot m} \tag{2}$$

NG tank's annualised investment cost per unit capacity and Vs-m is the LNG terminal's storage capacity in cubic metres. The capacity is the sum of the terminal's reserve volume Vr and the LNG ship's output V1.

$$V_{s \cdot m} = V_l + V_r \tag{3}$$

ation cost

$$OC = \sum_{\omega} N_{\omega} \cdot OC_{\omega} \tag{4}$$

h each typical scenario happens during the year is denoted by Nw, where w is the index of the whole year's typical scenario. Total system operating expenses under various conditions Cost of coal-fired units and the price of natural gas used to generate electricity make up OCw.

$$OC_{\omega} = \sum_{t} \sum_{s} \rho_{s,t} \cdot g_{s,t} + \sum_{t} \sum_{i} F_i(P_{i,t}) \tag{5}$$

Natural gas system constraints are frequently included into the yearly operating simulation of a combined gas and power system, gas and electricity coupling constraints, and power system constraints. Additionally, this study takes the LNG tank's capacity restriction into account.

$$V_{s,t} = V_{s0} + V_r + I_{l,t} \cdot V_{l,t} - T_0 \sum_{t} g_{s,t} \cdot r_v \tag{6}$$

2.3 Operation's goal

The LNG supply risk at the terminal affects the combined gas and power system's operating mode. Fig. 1 depicts the LNG terminal's operational cycle. According to estimates, each LNG terminal will receive LNG from two LNG ships, each of which has a 12-day sail time. The port's 2-day unloading period results in a 14-day transit cycle for LNG ships. Each LNG ship is accountable for the terminal's 7-day supply of LNG during each transport cycle as the port of the LNG terminal can only take one ship at a time.

Therefore, taking into account the risk of the LNG supply from the terminal, this research uses a dispatch cycle of 7 days for the combined gas and power system. Because petrol consumption varies seasonally among people, this article uses a 6-hour unit dispatch time.

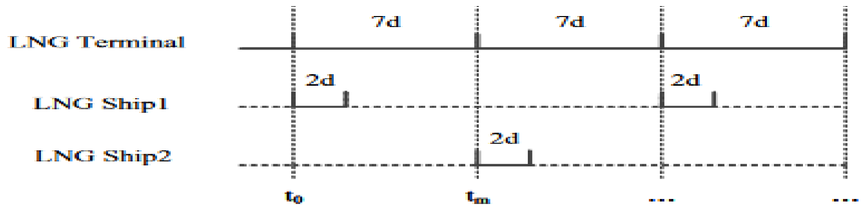

Fig. 1. Operation cycle chart of LNG terminal

If there was heavy weather at sea, the LNG ship might not be able to get to port on time. The LNG terminal could only deliver reserve LNG to load during the subsequent dispatch cycle as a result. The integrated system has three operational modes depending on whether an LNG ship arrives.

- Mode 1: An LNG ship docks, and the terminal is operational as usual.

If the LNG ship arrives on schedule at the initial dispatch time, the LNG terminal has enough LNG to provide natural gas to the gas load. As a result, the LNG terminal runs regularly, and the combined system's operation goal is to minimise co-operation costs. i.e.

$$\min\left\{\sum_t\sum_s g_{s,t}\cdot\rho_{s,t}+\sum_t\sum_i F_i\left(P_{i,t}\right)\right\} \tag{7}$$

- Mode 2: The LNG ship does not arrive, and the terminal continues to operate properly.

If bad weather prevents the LNG ship from making its scheduled arrival at the port at the scheduled dispatch time, yet the weather does not persist for very long. As stated in equation (7), regular operations at the terminal continue, and the overall system's operational purpose is to limit operating expenses.

- Mode 3: No LNG ship arrives, and the terminal works cautiously.

If the prediction indicates that the adverse weather will last a long period and the LNG tanker will not make it to the port by the scheduled departure time. The integrated system's operation purpose is to maximise the quantity of LNG stored at the terminal at the end of the dispatch cycle while limiting running expenses, while the terminal itself runs conservatively. i.e.

$$\min\left\{\sum_t\sum_s g_{s,t}\cdot\rho_{s,t}+\sum_t\sum_i F_i\left(P_{i,t}\right)-\sum_s v\cdot V_{s,t_m}\right\} \tag{8}$$

Vs,tm is the amount of LNG stored in the terminal at the conclusion of the dispatch period; v is the penalty factor.

3. Case Study

3.1 The Case method

As shown in Fig. 2, the combined gas and electrical system in this study is an IEEE-39 test system and a Nigerian 20-node natural gas system. G1G10 denotes the generators linked to Bus3139. The G2G5 generators are gas-fired, whereas the others are coal-fired. Two gas sources S1S2, two compressors C1C2, and four gas storage tanks ST1ST4 comprise the natural gas system. S1 is an LNG terminal, while S2 is a typical gas field.

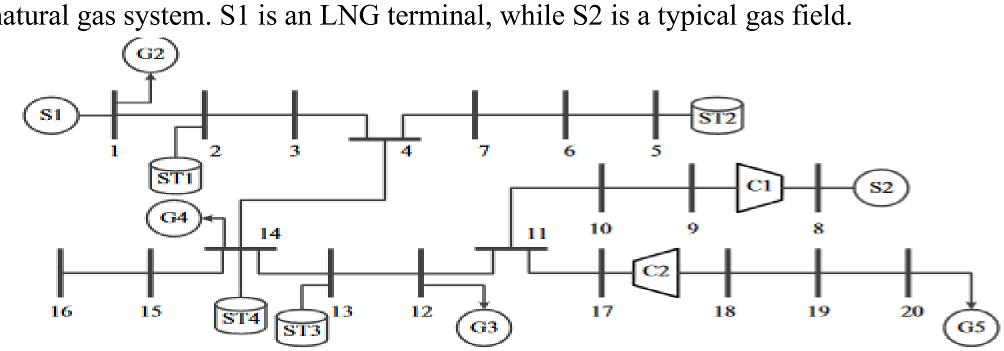

Fig. 2. The connection graph of combined gas and electricity system

This study specified three normal weekly combined load levels of the test system to represent the year fluctuation in combined load levels. Considering the LNG supply risk at varying load levels in the test system, the combined system would have three operation modes at each load level.

In light of this, the integrated system experiences 9 typical operational scenarios in a year, each of which occurs at a different time of year based on weather statistical data at varying load levels. Table 1 summarises how often various events occur during the year.

Table 1. Setting of typical scenarios in a year

Typical scenario number	Load number	Operation mode	The number of weeks
Typical scenario 1	Typical load 1	Mode 1	14
Typical scenario 2	Typical load 1	Mode 2	2
Typical scenario 3	Typical load 1	Mode 3	1
Typical scenario 4	Typical load 2	Mode 1	15
Typical scenario 5	Typical load 2	Mode 2	2
Typical scenario 6	Typical load 2	Mode 3	1
Typical scenario 7	Typical load 3	Mode 1	14
Typical scenario 8	Typical load 3	Mode 2	1
Typical scenario 9	Typical load 3	Mode 3	2

3.2 Result

Figure 3 depicts the annualised investment cost curve of LNG tanks, the annual operation cost curve of the integrated system, and the overall annual cost.

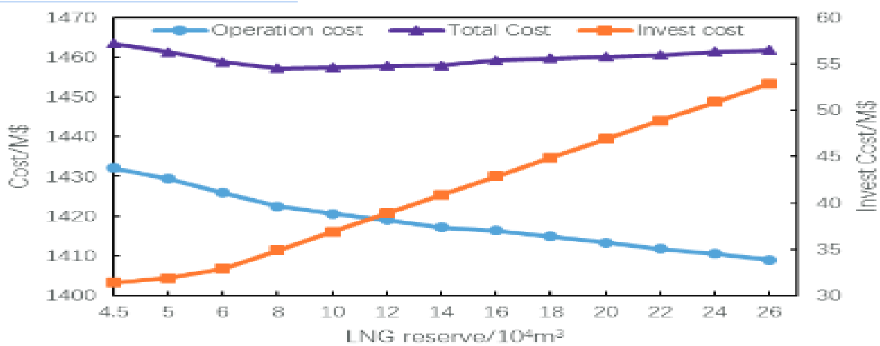

Fig. 3. Total, operation and invest cost curve of combined system

As shown in Figure 3, the minimum secure LNG reserve volume at the terminal is 4.5 x 10 m3, while the optimal LNG reserve volume is 8 x 10 m3. Maintaining the ideal LNG reserve volume results in an annual combined gas and power cost of 1457.3 million dollars. Figure 4 illustrates the operation cost curve of the integrated system for various common scenarios.

Figure 4 shows that the integrated system's operating costs under typical scenarios 1, 4, and 7 are unaffected by an increase in the LNG reserve volume. This is because the terminal's LNG capacity is sufficient in mode 1, therefore the demand level, rather than the LNG reserve volume, is what sets the terminal's operational costs. In addition, when the LNG resource increases, the operating expenses in the most prevalent scenarios 3, 6, and 9 do not change. This is because, in mode 3, natural gas from well S2 is sent to load ahead of LNG terminal S1 to boost LNG volume at the terminal at the end of the dispatch cycle. Therefore, the LNG terminal's gas consumption is based on the varying load levels. However, for common scenarios 2, 5, and 8, the integrated system's operating costs fall as the LNG reserve increases.

The Behavior of Operation, Investment, and Total Cost With Respect to Lng Reserve can be Explained as Follows:

1. Operation: The figure showcases how the operation of an LNG terminal is affected by the LNG reserve. As the LNG reserve increases, the operation of the terminal tends to become more efficient and cost-effective. This is because a larger reserve allows for a steady supply of LNG, reducing the need for frequent replenishment and potential disruptions. Consequently, the operation costs associated with storage, handling, and regasification of LNG are often optimized with a larger reserve.

2. Investment: The figure demonstrates that the investment in an LNG terminal is influenced by the LNG reserve. Generally, a larger reserve requires a higher upfront investment for the construction and expansion of storage tanks, processing facilities, and infrastructure. This is because a larger reserve capacity necessitates larger storage capacities and more extensive facilities. However, a larger reserve can also provide economies of scale and attract more investors due to the potential for long-term profitability and stability in the LNG market.

3. Total Cost: The figure depicts how the total cost of an LNG terminal is impacted by the LNG reserve. Initially, as the reserve and terminal capacity are small, the total cost might be relatively low due to the limited infrastructure and operational expenses. However, as the reserve increases, the total cost tends to rise due to the need for larger storage facilities, additional regasification units, and increased operational complexity. It is important to find the optimal balance between reserve capacity and total cost to ensure efficient and cost-effective LNG terminal operations.

Overall, the figure emphasizes the importance of considering the relationship between LNG reserve, operational efficiency, investment requirements, and total cost in planning and optimizing the performance of an integrated gas and power generation system within an LNG terminal.

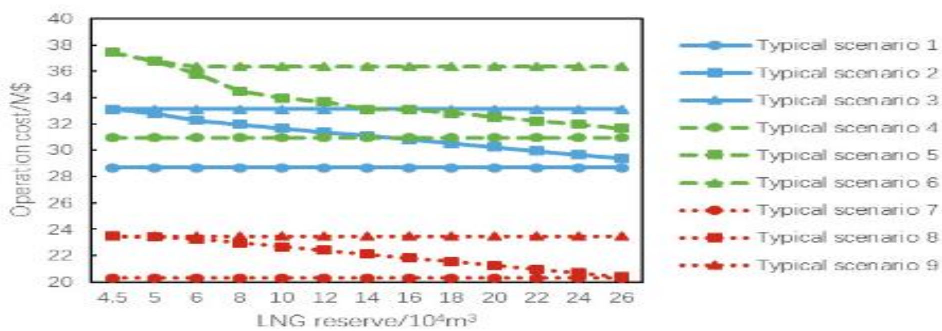

Fig. 4. Operation cost of each typical scenario

This is so that mode 2 of the LNG terminal may supply natural gas to load before the regular gas well.

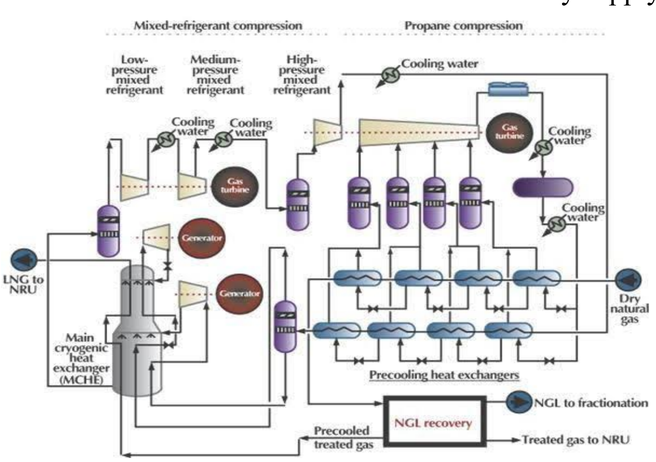

Figure 5: LNG plant overview

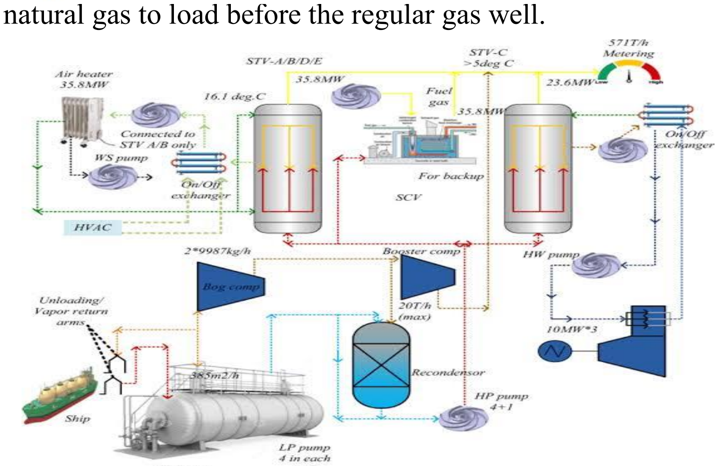

Figure 6: Schematic diagram of LNG terminal

Figure 7: LNG tool box modular plant

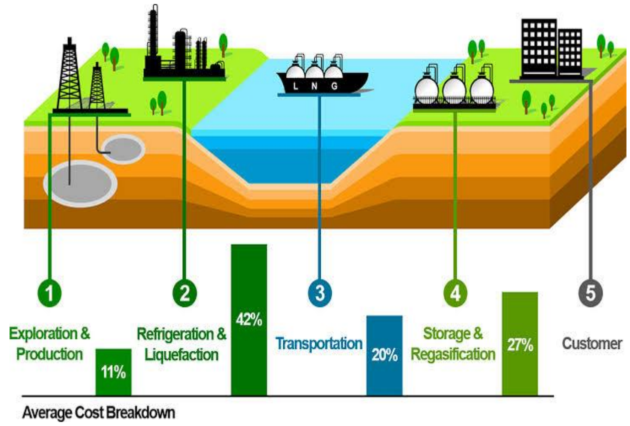

Figure 8: Key Issues and challenges in LNG

Figure 9: First LNG terminal with FSRU

Figure 10: LNG regasification terminal

Figure 11: LNG terminal

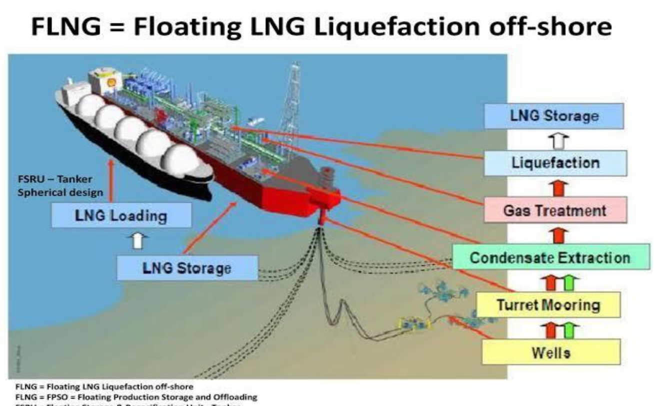

Figure 12: FLNG floating LNG liquefaction off-Shore

Here's an Overview of the Functions of Each of above Figures Mentioned:

Figure 5: LNG Plant Overview - This figure provides a comprehensive overview of an LNG (liquefied natural gas) plant. It showcases the different components and processes involved in liquefying natural gas for transportation and storage.

Figure 6: Schematic Diagram of LNG Terminal - This figure presents a visual representation of the various components and infrastructure of an LNG terminal. It highlights how LNG is received, stored, and distributed, including key equipment and processes.

Figure 7: LNG Tool Box Modular Plant - This figure showcases a modular plant design for LNG production. It demonstrates how different modules can be combined and integrated to create a flexible and scalable LNG production facility.

Figure 8: Key Issues and Challenges in LNG - This figure outlines the main challenges and considerations involved in the LNG industry. It may cover topics such as infrastructure development, safety regulations, environmental impact, market dynamics, and more.

Figure 9: First LNG Terminal with FSRU - This figure illustrates the concept of an LNG terminal utilizing a Floating Storage Regasification Unit (FSRU). It visualizes how LNG can be stored and regasified directly from a floating vessel, enabling flexible and cost-effective terminal solutions.

Figure 10: LNG Regasification Terminal and Floating LNG Liquefaction Off-Shore - This figure depicts the integration of a regasification terminal and a floating LNG liquefaction facility. It showcases how natural gas can be converted back to its gaseous state for distribution and, simultaneously, liquefied for storage or export.

Figure 11: LNG Terminal - This figure provides a detailed representation of an LNG terminal's infrastructure, including storage tanks, loading facilities, vaporization units, and more. It shows the various components necessary for the efficient handling and distribution of LNG.

Figure 12: FLNG Floating LNG Liquefaction - This figure focuses on a floating LNG liquefaction facility (FLNG). It demonstrates how liquefaction processes can be conducted on a floating vessel, enabling LNG production in remote offshore locations.

These figures collectively contribute to understanding LNG terminal reserve planning and optimizing the performance of integrated gas and power generation systems. They offer insights into the infrastructure, processes, challenges, and innovative solutions within the LNG industry.

4. Conclusions

In this study, an optimization model for LNG reserve planning in a combined gas and power system is developed. The model incorporates system operating simulations for a year and considers annualized investment costs associated with LNG tanks. By taking into account the risk of LNG supply and the duration of severe weather conditions, the operation simulation of the combined system explores various optimization targets, while also adhering to the limitations imposed by the power system and natural gas system. In this case study, the IEEE-39 test system is integrated with the Greenville LNG 20-node natural gas system. The findings of the study indicate that both the load level and operation mode significantly influence the optimization of LNG reserve planning.

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Conflicts of Interest:

The Authors declare that they have no conflict of interest.

Authors Contribution:

The first author wrote the draft under the guidance of the second author on the theme and content of the paper.

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Nomenclature

IC	annualized investment cost of LNG tanks [M$]
OC	yearly operation cost of combined system [M$]
$\rho_{s,t}$	gas price of gas source [M$/$10^4m^3$]
$g_{s,t}$	gas supply rate of gas well [10^4m^3/6h]
$V_{s,t}$	volume of LNG tank at the time of t [10^4m^3]
V_{s0}	initial volume of LNG tank at the beginning of dispatch cycle [10^4m^3]
$I_{l,t}$	LNG ship arrives or not [1/0]
T_0	unit dispatch period [6h]
r_v	LNG volume ratio to natural gas, 1/625