Floating Gas Power Plants

Hyun-Soo Kim[1*]

〈Abstract〉

Specification selection, Layout, specifications and combinations of Power Drives, and Ship motions were studied for FGPP(Floating Gas-fired Power Plants), which are still needed in areas such as the Caribbean, Latin America, and Southeast Asia where electricity is not sufficiently supplied. From this study, the optimal equipment layout in ships was derived. In addition, the difference between engine and turbine was verified through LCOE(Levelized Cost of Energy) comparison according to the type and combination of Power Drives. Analysis of Hs(Significant Height of wave) and Tp(spectrum Peak Period of wave) for places where this FGPP will be tested or applied enables design according to wave characteristics in Brazil and Indonesia. Normalized Sloshing Pressures of FGPP and LNG Carrier are verified using a sloshing analysis program, which is CFD(Computational Fluid Dynamics) software developed by ABS(American Bureau of Shipping). Power Transmission System is studied with Double bus with one Circuit Breaker Topology. And the CFD analysis allowed us to calculate linear roll damping coefficients for more accurate full load conditions and ballast conditions. Through RAO(Response Amplitude Operator) analysis, we secured data that could minimize the movement of ships according to the direction of waves and ship placement by identifying the characteristics of large movements in the beam sea conditions. The FGPP has been granted an AIP(Approval in Principle) from a classification society, the ABS.

Keywords : Floating Gas Power Plant, Floating Power Plant, LCOE, Bi-Power, Power Transmission, ship motion

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1* Energy Plant Research Center, Marine and Offshore Institute, Samsung Heavy Industries Co., Ltd.,, Republic of Korea, Senior Engineer

1. Introduction

Electricity enhances the quality of people's lives and stimulates the development of countries. Today, most of the developed countries already have access to the energy. however, large parts of the world still suffer from its insufficiency. The shortage is concentrated especially in emerging countries whose electric consumption is increasing. Countries in the South East Asia region including the Philippines, Indonesia, Papua-New-Guinea and Malaysia with thousands of islands and Caribbean sea countries need electricity.

The idea of the development of a LNG(Liquefied Natural Gas) as fuel for power plants is derived from the same dynamic as the use of LNG as a ship fuel in terms of supply chain expansion, emission restrictions and a relatively stable price level. An additional merit of this study of FGPP(Floating Gas-fired Power Plants) is that by arranging a power plant on a barge, its assembly and tests of a complete unit can be carried out at a shipyard before dispatching it to an operation site.

This simplification is of paramount importance in areas where it is difficult to build a power plant due to the lack of suitable construction infrastructure and unfavourable local conditions.

2. SYSTEM OVERVIEW

The FGPP consists of LNG containment systems, power generation blocks, a compressor and machinery room, a re-gasification plant, an E&I(electrical and instrumentation) building, an accommodation building, and a GCU(Gas Combustion Unit), etc. as shown in Figure 1.

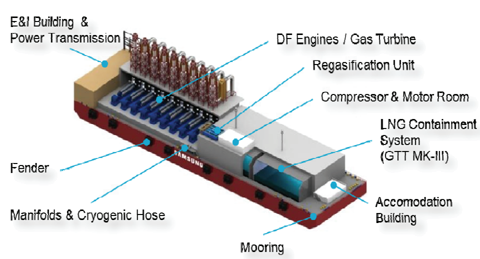


Fig. 1 FGPP Layout

Power generation blocks are separated in two blocks; one block includes nine DF(Dual Fuel, Gas and Liquid Fuel) Engines and one steam turbine. Each Engine has one electrical generator. They are situated on the topside of the deck.

A LNG containment system, in which LNG fuel is stored, is positioned inside a hull structure. The LNG containment system is composed of two membrane-type tanks, pump towers, a cofferdam, etc..

For the mooring system, the FGPP is equipped with auxiliaries such as fenders, windlasses, winches.

For the overhaul and maintenance of DF Engines, zip cranes can be installed on the platform of power generation blocks; otherwise, the barge equipped with crawler cranes can be dispatched to the FGPP. The zip crane can be also used to handle cryogenic hoses connected to the manifolds of the FGPP for the loading operation of LNG. By using the installed overhead cranes, DF Engines can be transported to a touchdown area, in which DF Engines can be lifted by zip cranes.

The E&I building is furnished with step-down transformers used for on-board electrical distribution, GISs(Gas Insulated Switchgears), and control panels, etc.

The step-up transformers for power transmission to power consumption area or grid are placed near DF Engines outside the E&I building.

Table 1. Specification of FGPP

Model Name	SEP-T150E
Power Capacity [MW]	165MW (ISO condition, 60Hz)
LOA [m]	175.0
Breadth [m]	43.4
Depth [m)	11.0
Draught [m]	7.0
Power Generation System	9 off. 17.1MW DF Generator 1 off. 11MW Steam Turbine
Power Distribution System	Transformer / Switchgear
LNG Containment System	GTT Mark-III
LNG Loading System	Cryogenic Hose
Fuel Supply System	HP Pump / Vaporizer / LP Compressor

Finally, Table 1 summarizes the general specification of the FGPP.

3. POWER DRIVE

The FGPP operating at below 150MW incorporates an Engine as power drive while the one operating at above 150MW includes a Gas Turbine. The FGPP contains 9 off 17.1MW DF Engines and 1 off 11MW Steam Turbine as power drive.

The common advantages of an engine over gas turbines are that it has less limitations or impact on maintenance schedules and costs, has quick start and shutdown, fast ramp-up capability, can black start without external power, and has less impact on power generation performance. Gas Turbine, on the other hand, has a high fuel economy during continuous operation. Utilizing the characteristics of the engine and turbine, the FGPP was designed to cover the base load and the engine to cover the peak load. The layout is shown in Figure 2.

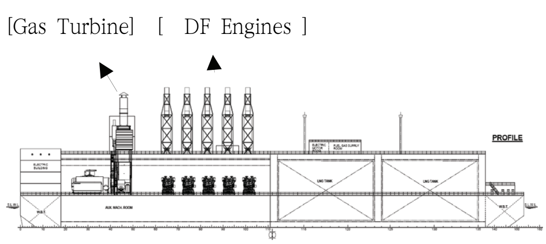


Fig. 2 General Arrangement of Bi-Power FGPP

A LCOE(Levelized Cost of Energy) is investigated for the following three cases:

- Turbine CC(combined cycle)
- Turbine CC + Engine SC(simple cycle)
- Engine SC

Table 2 displays the LCOE comparison for three cases above when Turbine CC is based on 100.

Table 2. LCOE Comparison

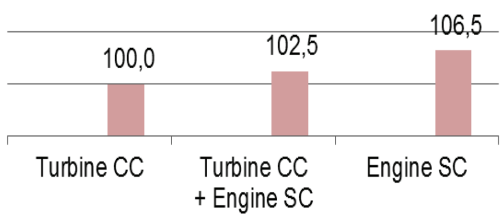


Table 3 shows LCOE conditions of Table 2 LCOE Comparison.

Table 3. LCOE Conditions

Equity share	30%
Cost of Equity	14%
Debt interest rate	7%
Effective tax	25%
Power Degradation factor	0.1%
Fixed O&M cost - escalator	1.5%
Variable O&M cost - escalator	1.5%

4. LNG Containment System

As FGPP uses LNG as fuel, it needs a LNG CCS(Cargo Containment System) that can store nature gas at -163℃ in liquefied state.

According to IGC code, the CCS is mainly classified as independent tanks and membrane tanks. While the independent tank is mounted to the hull after manufactured separately from a hull, the membrane tank is manufactured by assembling pieces of insulation to a FGPP hull.

The most important issue in applying membrane tanks is that the tank of FGPP must have no limitation of filling ratio, i.e., any filling condition. This limitation results from the sloshing load induced by the wave height as well as the resonance phenomena caused by the coincidence of the natural period of the ship motion and the tank.

The structural safety of the CCS for the sloshing load is generally verified by the model test due to the complicated phenomena.

However, because it takes considerable time and cost in the early stages of the concept development, the sloshing assessment of the CCS in this development was alternatively performed by using a sloshing analysis program, which is CFD(Computational Fluid Dynamics) software developed by ABS(American Bureau of Shipping) [1]. According to previous studies, the sloshing load is largest around 30 %H(% filling height) due to hydraulic jump or travelling bore [2].

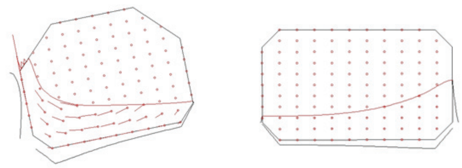
This sloshing load can be obtained through the wave scatter diagram and RAO(Response Amplitude Operators) for LTR(Long Term Response) corresponding to 10^{-8} probability of exceedance level. For wave conditions, LNGC(LNG Carrier) is designed under the harsh wave condition, i.e., IACS(International Association of Classification Societies) North Atlantic, while FGPP is designed under the mild wave condition like a sheltered area. It is recommended to use 1-year and 40-year wave conditions for beam and head seas, and the two-parameter Bretschneider spectrum is used [3].

The response of LNGC occurs largely due to the coincidence of the wave energy density and the peak RAO. In the case of FGPP, the response can be negligibly small since the wave energy density and the roll motion peak RAO are far from each other.

The sloshing occurs in the sloshing resonance range, which is defined from 70% to 130% of the tank natural period [3]. Although the tank natural period of LNGC is somewhat closer to the peak value of its RAO than FGPP, the motion of LNGC is seen to be very large due to the large LTR of LNGC as shown in Figure 3.

The sloshing loads obtained by SLOPE 2D are normalized by the maximum sloshing load generated at 30%H of LNGC for relative comparison as shown in Figure 4, of which the values were obtained by considering six degrees of freedom of the vessel.

Motion of the FGPP produces the only hydrostatic pressure without sloshing and its value is also remarkably smaller than the criteria of the any filling condition.



(a) LNGC (b) FGPP

Fig. 3 Tank Motion at 30%H

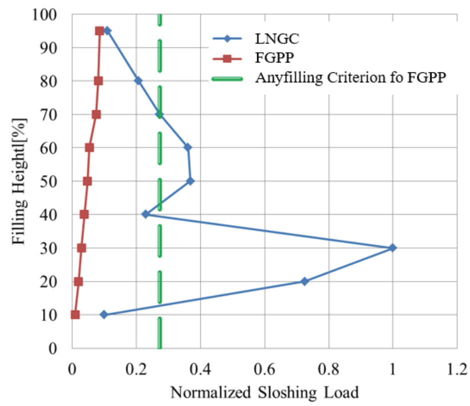


Fig. 4 Normalized Sloshing Pressure of LNGC and FGPP

5. Power Transmission System

Power Transmission System includes E&I Room, GISs, transformers to supply power to the Shore from 165MW FGPP. The applicable standards are in accordance with IEC and Brazil national Standards & Regulations.

Single Line Diagram is shown in Figure 5, and Double bus with one Circuit Breaker Topology was adopted to secure redundancy.

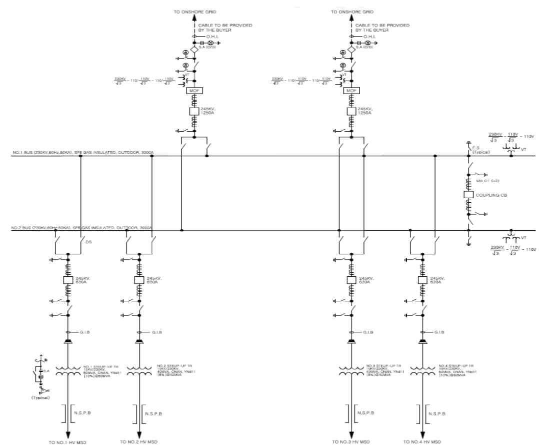


Fig. 5 Single Line Diagram of Power Transmission System

GISs are placed indoors to avoid salt damage, short circuit rating of the GISs is maximum 50kA 3sec, and technical specifications are as shown in Table 4.

Table 4. Specification of GIS

Type	Indoor 3P 3W, 60Hz
Insulation Type	SF6 Gas Insulated
Rated Voltage	245kV
Rated current, Transmission/Gen.	1,250A / 630A
Short-circuit withstanding current	50 kA / 3s
Operating cycle	O-0.3s-CO-3min.-CO

In addition, the 230kV XLPE Power Cable was selected as a Copper 400sqmm Al-Sheath type.

Power Cable is convenient to install and cost effective compared to NSPB(Non Segregated Phase Bus).

Step-up Transformer is installed outdoors for the convenience of fire protection and maintenance with ONAN(oil natural cooling and air natural cooling).

The Gantry Tower on the stern port is arranged in two layers as shown in Figure 6 due to space constraints.

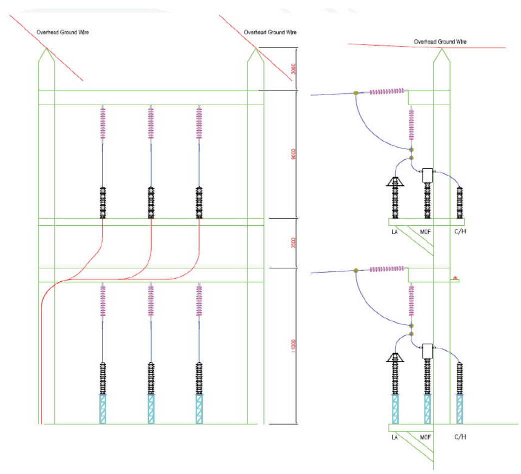


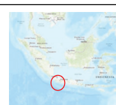
Fig. 6 Gantry Tower

Short circuit and voltage drop calculation were studied using the Calculation program named SKM Power Tools. External fault short circuit current is 42.3 kA and internal short circuit current is 33.8 kA.

6. ENVIRONMENTAL CONDITIONS AND SHIP MOTIONS

Environmental conditions are examined at three locations below due to the fact that ship motions are sensitive to wave height and wave period. Hs(significant height of wave) and Tp(spectrum peak period of wave) are the most effective elements for ship motion. Table 5. shows Hs & Tp as results. Tp of Indonesia shows very long time.

Table 5. Hs & Tp

Location	Hs & Tp	Map
Geoje (South Korea)	Hs: 1.8m Tp: 3.7sec	
Brazil	Hs: 1.5m Tp: 8.0sec	
Indonesia	Hs: 1.7m Tp: 26sec	

Free decay analysis is carried out to estimate Roll damping coefficient of 150MW class FGPP through Solver Star-CCM+11.06 as illustrated in Figure 7 and Figure 8. The linear Roll damping coefficient is about 3.4% under Full load condition and 5.6% under Ballast condition.

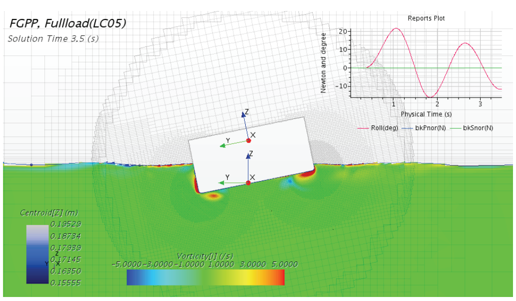


Fig. 7 Roll Decay CFD Simulation in Full load

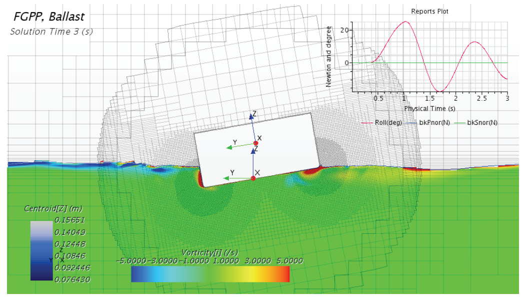


Fig. 8 Roll Decay CFD Simulation in Ballast load

A RAO is carried out for six motions according to wave directions from 0 to 180° degree through Hydrodynamic analysis. The Roll RAO in Full load condition shows 10.3 deg/m amplitude at resonant frequency for 90 degree wave direction as indicated in Figure 9 while the Roll RAO in Ballast load condition indicates about 5.7 deg/m as displayed in Figure 10. The legends in the

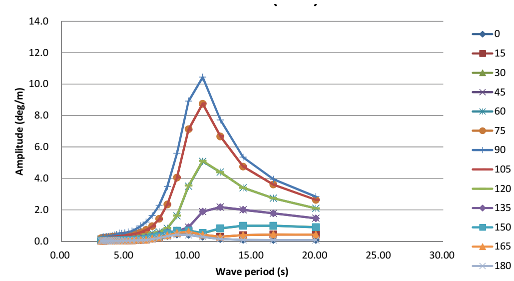


Fig. 9 Roll RAO analysis in Full load condition

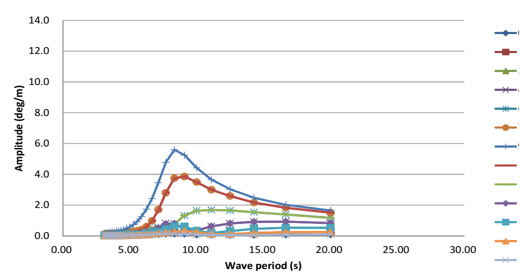


Fig. 10 Roll RAO analysis in Ballast condition

Figures refer to wave directions given in Figure 11.

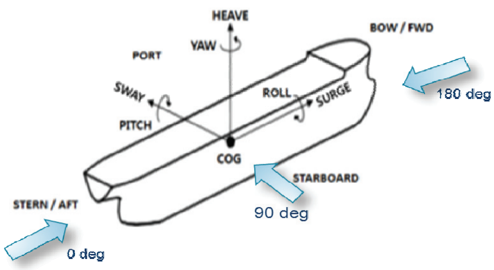


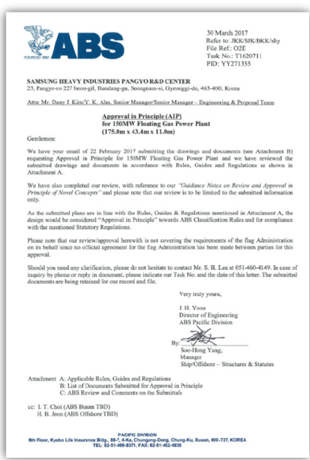
Fig. 11 Ship motion terminology and wave direction

Table 6. Specification, Drawings & Documents

● Power Plant Configuration : 9 sets DF engine + 1 Steam Turbine Generator ● LNG Tank : Membrane type ● Completed Drawings & Documents - General Arrangement - Trim & Stability Calculation - Freeboard Calculation - Midship Section - LNG Process Diagram - Electric Single Line Diagram - Outline Specifications ● Associated R&D - LNG Process Design - Motion Analysis & Mooring Analysis

7. AIP(Approval in Principle)

The Results of this study has achieved AIP from a Classification Society, ABS as Figure 12, based on the configuration and documents below as can be seen in Table 6.



ABS

30 March 2017
Refer to: JKK/SJK/BKK/shy
File Ref.: O2E
Task No.: T1620711
PID: YY271355

SAMSUNG HEAVY INDUSTRIES PANGYO R&D CENTER
23, Pangyo-ro 227 beon-gil, Bundang-gu, Seongnam-si, Gyeonggi-do, 463-400, Korea

Attn: Mr. Dany J. Kim/Y. K. Ahn, Senior Manager/Senior Manager – Engineering & Proposal Team

Approval in Principle (AIP)
for 150MW Floating Gas Power Plant
(175.0m x 43.4m x 11.0m)

Gentlemen:

We have your email of 22 February 2017 submitting the drawings and documents (see Attachment B) requesting Approval in Principle for 150MW Floating Gas Power Plant and we have reviewed the submitted drawings and documents in accordance with Rules, Guides and Regulations as shown in Attachment A.

We have also completed our review, with reference to our *"Guidance Notes on Review and Approval in Principle of Novel Concepts"* and please note that our review is to be limited to the submitted information only.

As the submitted plans are in line with the Rules, Guides & Regulations mentioned in Attachment A, the design would be considered "Approval in Principle" towards ABS Classification Rules and for compliance with the mentioned Statutory Regulations.

Please note that our review/approval herewith is not covering the requirements of the flag Administration on its behalf since no official agreement for the flag Administration has been made between parties for this approval.

Should you need any clarification, please do not hesitate to contact Mr. S. H. Lee at 051-460-4149. In case of inquiry by phone or reply in document, please indicate our Task No. and the date of this letter. The submitted documents are being retained for our record and file.

Very truly yours,

J. H. Yoon
Director of Engineering
ABS Pacific Division

By:
Soo-Hong Yang,
Manager
Ship/Offshore – Structures & Statutes

Attachment A: Applicable Rules, Guides and Regulations
B: List of Documents Submitted for Approval in Principle
C: ABS Review and Comments on the Submittals

cc: I. T. Choi (ABS Busan TBD)
H. B. Jeon (ABS Offshore TBD)

PACIFIC DIVISION
8th Floor, Kyobo Life Insurance Bldg., 88-7, 4-Ka, Chungang-Dong, Chung-Ku, Busan, 600-737, KOREA
TEL: 82-51-460-8371, FAX: 82-51-462-4830

Fig. 12 AIP from ABS

8. Conclusions

In several regions such as Caribbean, Latin America and South East, a lot of people still do not have sufficient access to electricity. The proposed FGPP in this paper can bring significant advantages to those areas including greater safety, avoidance of Not in My Backyard (NIMBY) phenomenon, easier acquisition of permissions, more flexibility & higher quality, and easier transfer to another place.

Turbine has advantages in terms of continuous running and higher fuel efficiency while Engine has a plus point in its ability to start quickly and frequently. In this sense, Bi-Power generation is proposed to apply turbine and engine into base load and peak load, respectively, in line with change in power demand.

Analysis of Hs and Tp for places where

this FGPP will be tested or applied enables design according to wave characteristics in Brazil and Indonesia. And the CFD analysis allowed us to calculate linear roll damping coefficients for more accurate full load conditions and ballast conditions. Through the RAO analysis, we secured data that could minimize the movement of ships according to the direction of waves and ship placement by identifying the characteristics of large movements in the beam sea conditions.

And the developed FGPP has been granted an AIP from a classification society ABS.

References

[1] American Bureau of Shipping, 'User Manual on ABS Slosh v4.1b', 2012.

[2] J.J. Park, J.H. Seo, C.H. Jin, K.H. Joh, B.W. Kim, and Y.S. Suh, 'Sloshing Assessment of LNG Vessels for Unrestricted Tank Filling Operation', Proceedings of the 24th International Ocean and Polar Engineering Conference, Busan, Korea, ISOPE, pp 108-113, June 2014.

[3] American Bureau of Shipping, 'Guidance Notes on Strength Assessment of Membrane-type LNG Containment Systems under Sloshing Loads', 2009.

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