Electric power system design and analysis for FLNG vessel

Geunbo Lee[†] · Jaehyeoung Jang[2] · Sungkak Lyu[3] · Jinyeol Yu[4]

Abstract: The electrical reliability of the power generation and distribution system of Floating Liquefied Natural Gas vessels has been analyzed according to the operating modes using Electrical Transient Analysis Program in this paper. Electricity is used for the topside processes, cargo pumps for off-loading, thrusters for heading control and marine equipment. It is very important to improve the safety, efficiency, and stability of the electrical power system for successful operation. The voltage variation of the high and the low voltage bus shall be within the primitive limitation range at normal operation loads both in steady state and in the transient state. The power system was simulated and compared with class rule for design verification.

Keywords: Floating Liquefied Natural Gas, Electrical Transient Analysis Program

1. Introduction

The FLNG concept allows energy companies to produce natural gas in more remote areas and in deeper water than would have been economically possible with other technology, like fixed piled structures. Furthermore, it has storage capacity for the natural gas produced and is equipped with an offloading system to transfer it to shuttle tankers for shipment to the shore.

The electrical distribution system of FLNG is quite similar to typical redundant system of FPSOs except liquefaction process is added. It means that the designers consider the hazards of fire and explosion, 24-hours operation, and meeting the needs of the rules and regulations related to oil and gas industry.

The electrical power system is analyzed using ETAP [1]-[8] and the results are compared with IEC standard and the class rule for the design ver-

ification [9]-[10]. It shows that the equipment ratings and electrical parameters meet the needs of the rule and regulation requirements.

2. Electric system structure of FLNG

The process is illustrated in the FLNG topsides flow diagram **Figure 1**. The overall purpose of the facilities is to produce LNG from natural gas and extract LPG and condensate. The feed gas to the processing plant is gas from subsea wells of an offshore gas field. The refrigerant compressors are driven by gas turbines, other equipment is electric motor driven. Power generation is done by dual fuel gas turbines.

The power generation and distribution system is illustrated in the overall single line diagram **Figure 2**. The main gas turbine generators supplies electrical power to the electrical consumers through the power distribution network. They supply power to

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all consumers on the vessel while under normal operation including LNG off-loading. There are two essential generators and they will be run when the gas turbines are not available, during transit or to start the first gas turbine. The process will not be in operation at this time. The essential power will be distributed using the same network as the main power. The emergency generator supplies emergency power to the emergency consumers which are designated by rules and regulations on the vessel.
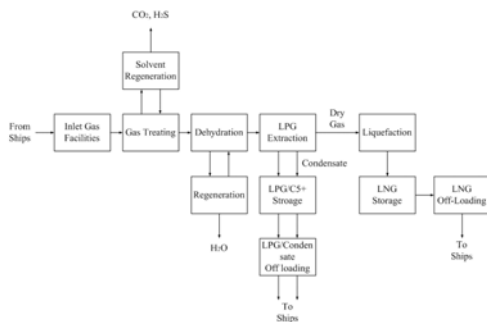

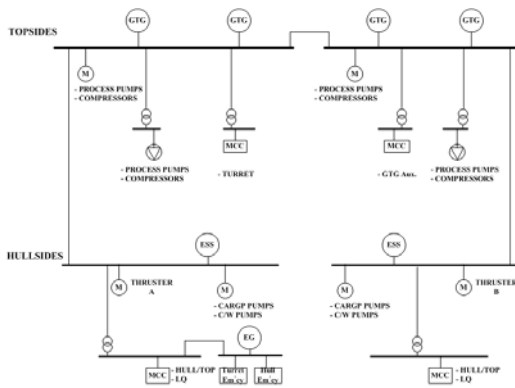**Figure 1:** The FLNG topsides flow diagram

Figure 2: Overall single line diagram

3. Static characteristic analysis

3.2 Load flow analysis

Load flow analysis performs power flow analysis and voltage drop calculations to get results about bus voltages, power factors, currents, and power flows throughout the electrical system. The simulation was executed based on different operating modes to verify overloading, the stability of the bus voltage, and direction of power flows in this paper.

According to the class requirement of offshore standard, power generation system was designed based on an N+1 basis. In normal operating mode with LNG off-loading three gas turbine generators supply electrical power to the loads and one gas turbine generator is a stand-by. The result of the load flow analysis **Table 1.**

Table 1: Results on normal operating mode

ITEMS	RESULTS
Comparison about the output of generator and total load	In accordance
Overload situation of the generator	Normal state (59.7% in use)
Overload situation of the generator (In case 1.3 factor was applied at the pre-FEED stage)	Normal state (77.6% in use)
Overload situation of the transformer	Within the maximum capacity ranges
Stability of BUS voltage	Within 1% voltage drop
Load flow direction	Normal state

3.2 Short circuit analysis

Short circuit analysis is performed to analyze the effect of fault currents on electrical power systems. The short circuit analysis makes it easy to go from selecting elements from the comprehensive libraries of short circuit current ratings to performing dozens of different types of short circuit analysis with the purpose of finding the worst-case fault current device duty.

Figure 3 shows short circuit analysis result. The calculated initial system short circuit current on the 13.8kV topside switchgear is 47.7kA rpm and initial
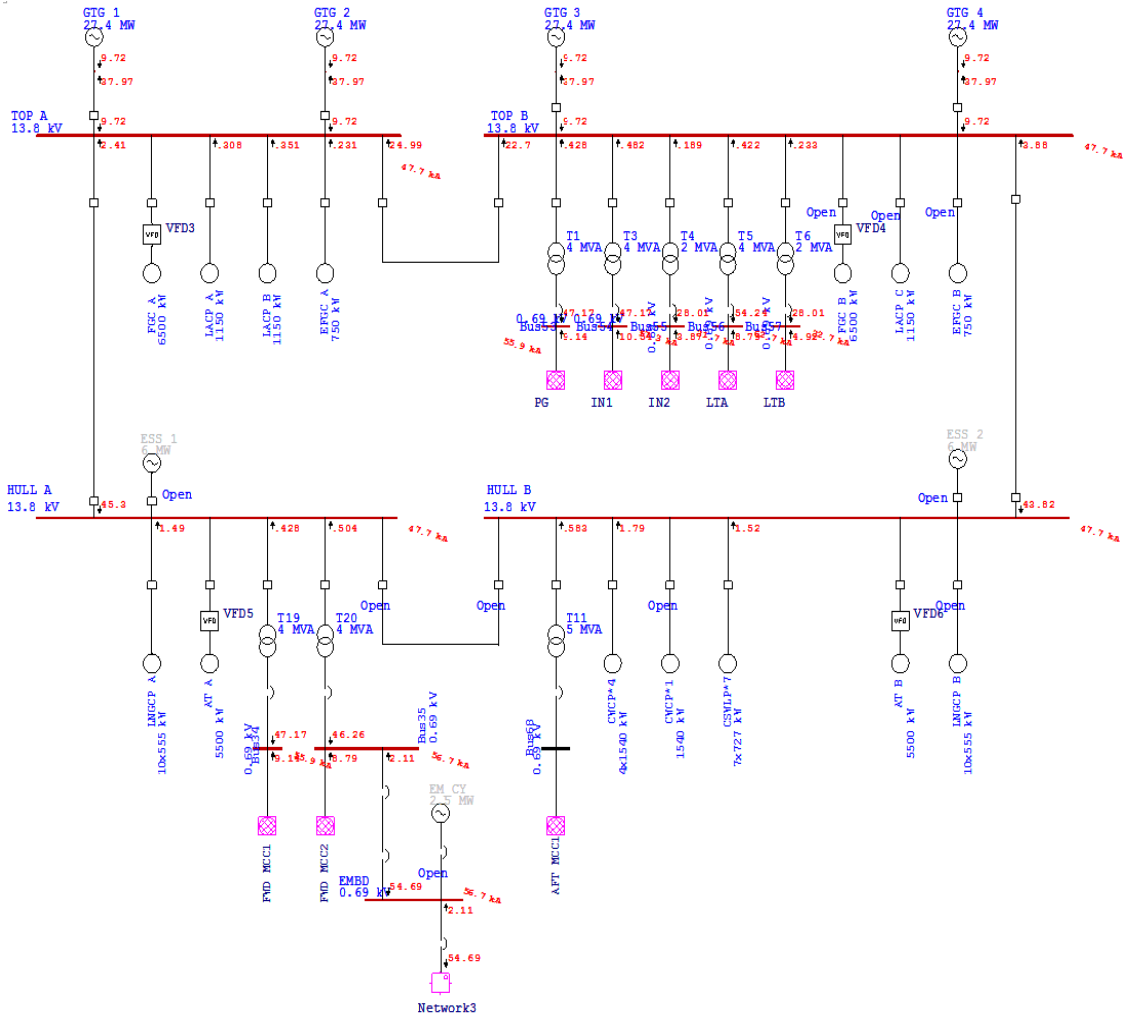
Figure 3: Short circuit analysis result

system short circuit current on the 690V topside PG switchboard is 55.9 kA. With reference to these values, the short time wit hstanding current and the peak rating of the switchboard are decided. Also, the possibility of changing the alternator reactance can be considered.

4. Dynamic characteristic analysis

4.1 Motor starting analysis

Motor starting analysis calculates the acceleration time of the motor and the voltage impact caused by the starting of the heavy motors on electrical power systems. For motors modeling, ETAP library model was used and the parameters are on **Table 2**.

Figure 4 shows motor starting analysis result for LNG cargo pumps. It shows that about 6% voltage drop is occurred when it starts. The transient oper-transient operation can be executed by transient stability analysis which is covered at chapter 4.2.1 of this paper.

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Table 2 Motor parameters for motor starting

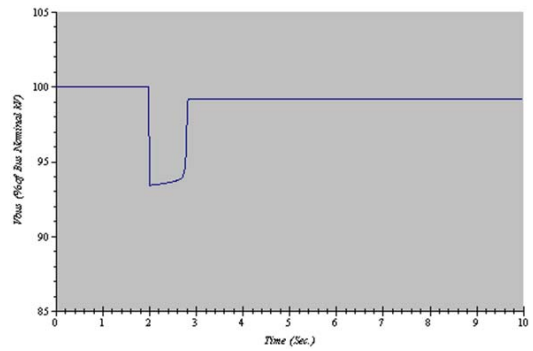| PARAMETER	VALUE
Rated output(kW)	115
Number of Pole	4
Rated Voltage(kV)	13.8
Efficiency(%)	96.36 (at rated loads)
Power factor	80.57 (at rated loads)
Speed at Full load(rpm)	1772
Moment of Inertia(kgm^2)	125

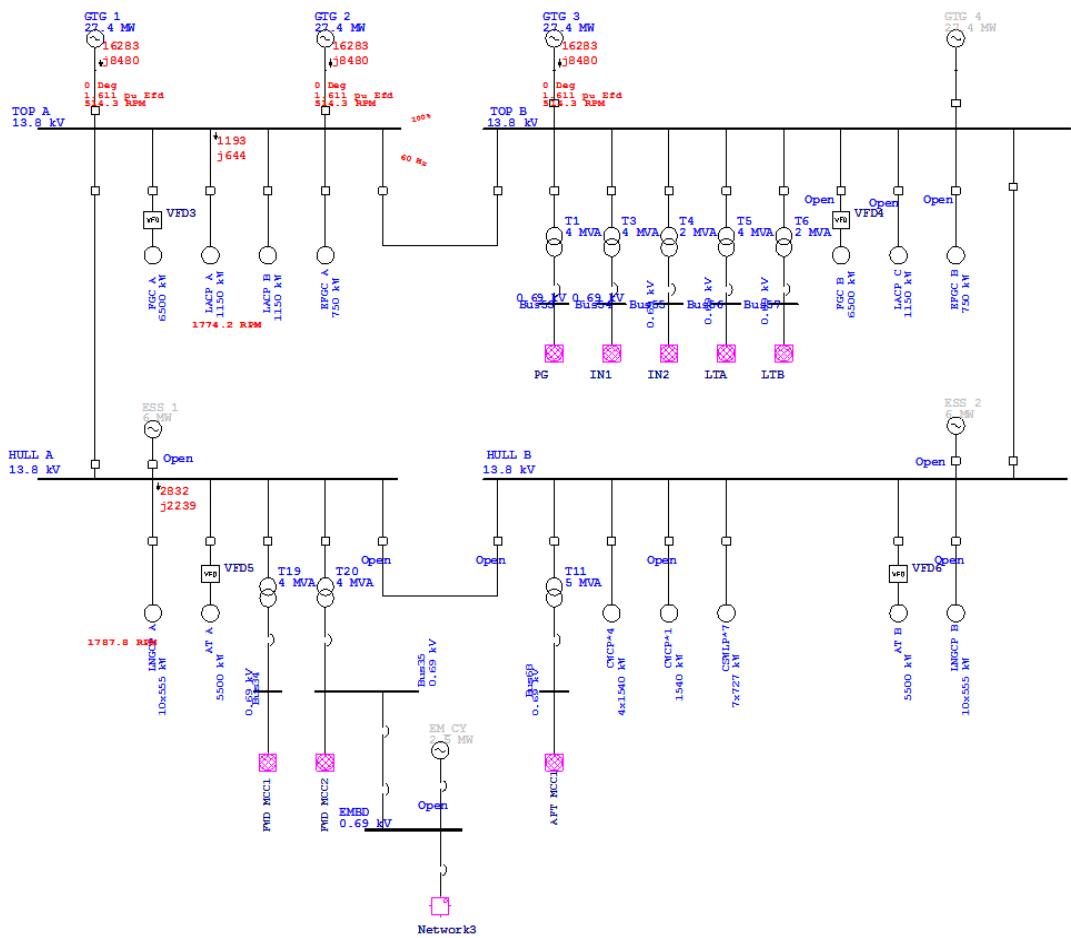**Figure 4:** Motor starting analysis

Figure 5: Transient stability analysis result

4.2 Transient stability analysis

The transient stability analysis calculates the dynamics and transient response of the electrical power system by simulating disturbances and other events according to the load change in different operating modes.

According to the class requirement, the voltage variations on main switchboards are maintained from 85% to 120% of nominal voltage. After a transient condition has been initiated, the voltage in distribution shall not differ from nominal system voltage by more than ±3% within 1.5 s.

The frequency variations with fixed nominal frequency shall be kept within the following limits 95 to 105% of rated frequency under steady load conditions and 90 to 110% of rated frequency under transient load conditions. **Figure 5** shows transient stability analysis result.

To model the power generation system governor and exciter library from ETAP has been used. **Figure 6** shows the block diagram of the exciter and AVR control system model.

Table 3 shows the parameters used for generator exciter model.

A governor is a device used to measure and regulate the speed of the engine. **Figure 7** shows the block diagram of gas turbine governor model.

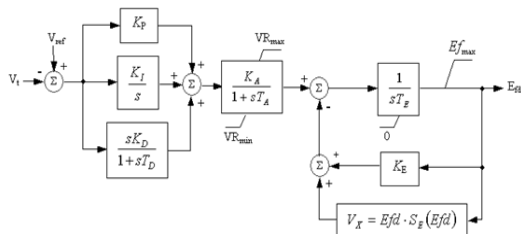**Table 4** shows the parameters used for generator governor model.

Table 3: Generator exciter and AVR control system model parameters

PARAMETER	UNIT	DESCRIPTION	VALUE
VRmax	p.u	Maximum regulator output voltage	20
VRmin	p.u	Minimum regulator output voltage	0
SEmax	p.u	Saturation value of exciter at Efdmax	1.5
SE0.75	p.u	Saturation value of exciter at 0.75 Efdmax	1.36
Efdmax	p.u	Maximum exciter output voltage	4.5
KP	p.u	Proportional control gain	170
KI	p.u	Integral control gain	130
KD	p.u	Derivative control gain	300
KA	p.u	Regulator gain	1
KE	p.u	Exciter constant for self-excited field	1
TD	Sec.	Derivative control time constant	0.03
TA	Sec.	Regulator amplifier time constant	0
TE	Sec.	Exciter time constant	1

Figure 6: Generator exciter and AVR control system model diagram (AC8B)
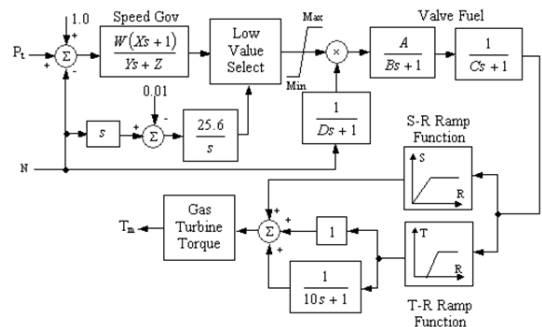
Figure 7: Gas Turbine Governor Model (GTS)

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Table 4: The parameters of governor for transient stability analysis

PARAMETER	UNIT	DESCRIPTION	VALUE
Mode		Droop or Isoch	Droop
Droop	%	Steady-state speed droop	5
Max	p.u.	Fuel upper limit	1
Min		Fuel lower limit	0.15
X	p.u.	Governor T/F coefficient	0
Y	p.u.	Governor T/F coefficient	0.05
Z	p.u.	Governor T/F coefficient	1
A	p.u.	Fuel System T/F coefficient	1
B	p.u.	Fuel System T/F coefficient	0.001
C	p.u.	Fuel System T/F coefficient	0.4
D	p.u.	Fuel System T/F coefficient	0.05
R	p.u.	Fast load pickup zone limit	0.6
S	p.u.	Fast load pickup zone limit	0.6
T	p.u.	Fast load pickup zone limit	0.4

To evaluate the transient response of the generator models three example cases are established and **Table 4** shows the established states for transient stability analysis.

Table 5: The states for transient stability analysis

	Initial state					Final state				
	Generator				LD	Generator				LD
	G1	G2	G3	G4	M1	G1	G2	G3	G4	M1
Case1	O	O	O	O	X	O	O	O	O	O
Case2	O	O	O	O	O	X	O	O	O	O
Case3	X	O	O	O	O	X	O	O	O	X

4.2.1 Case 1

All the gas turbine generators are in operation and Liquefied Natural Gas cargo pumps are started in 2 seconds.
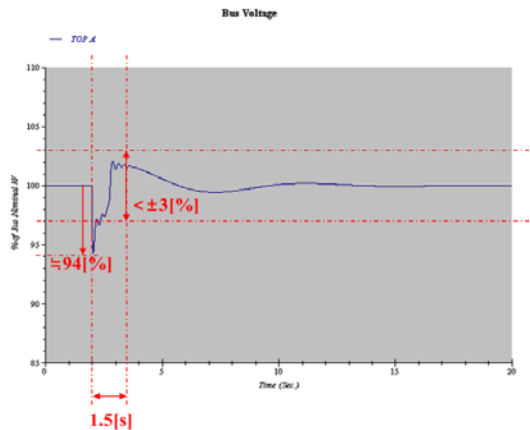

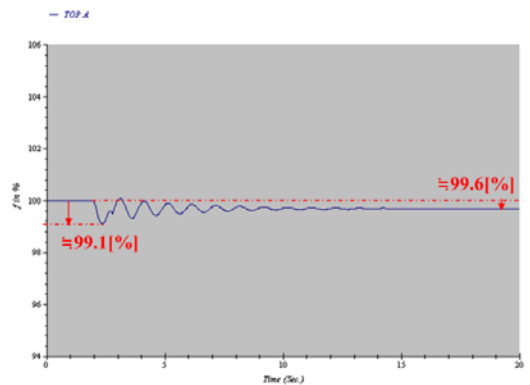**Figure 8:** Bus voltage variation in case 1

Figure 9: Bus frequency variation in case 1

4.2.2 Case 2

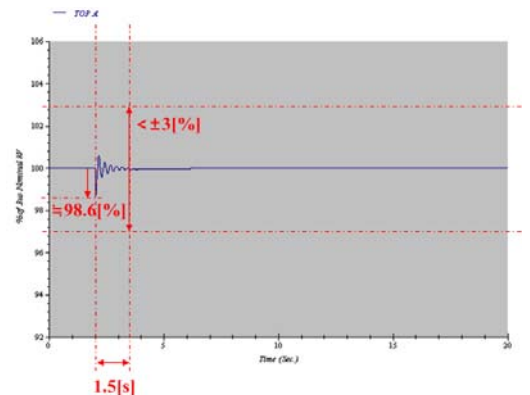Generator 1 is tripped to verify transient stability of voltage and frequency variations in 2 seconds.

Figure 10: Bus voltage variation in case 2

Figure 11: Bus frequency variation in case 2

Figure 12: Bus voltage variation in case 3

4.2.3 Case 3

LNG Cargo pumps are stopped to verify transient stability of voltage and frequency variations.

Figure 13: Bus Frequency variation in case 3

5. Conclusions

The electrical reliability of the electrical power system of FLNG vessels has been analyzed in steady and transient state using ETAP. The results were compared with IEC standard and the class rule for the design verification. It shows that the voltage variation of the high and the low voltage bus is within the primitive limitation range.

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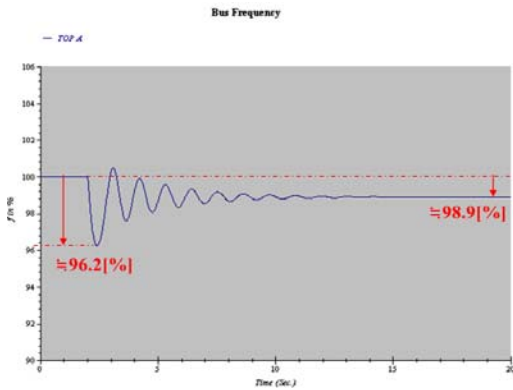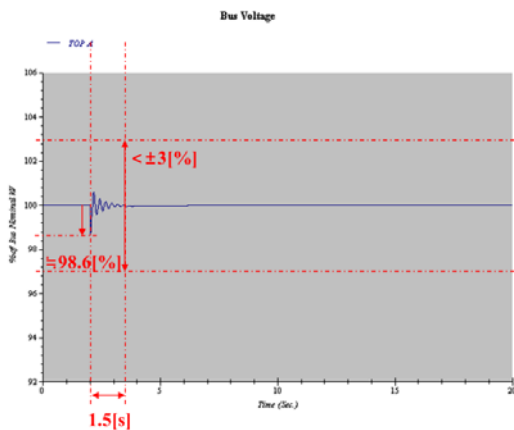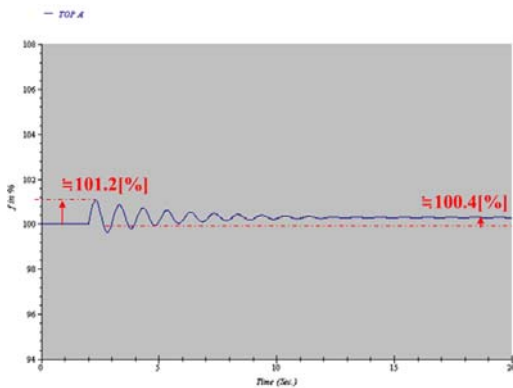
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