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Modelling and Analysis of Electric Ship Propulsion System

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***Abstract:* This paper deals with modeling and characteristic analysis of a large powered electric ship propulsion system. Particularly, electric power system modeling has been accomplished in accordance with the electric power network mainly composed of generators, switchboards, variable frequency devices, electric motors, and etc. In addition, electric power system analysis has been performed via load flow analysis. In particular, abnormal operating condition of the short circuited network is thoroughly investigated for estimating the short circuited current with the short time rating and implementing the system safety with the protection relay.**
***Keywords:* Propulsion system, Load flow analysis, Short circuit analysis, Faulted bus, Main bus**

I. INTRODUCTION

Since the 1980's, there has been an explosion in number and variety of electrically propelled ships built around the world, such as cruise liners, war ships, LNG ship, and etc. The electric ship propulsion system, most prospective in marine business and technology, has the power-train arrangements such as diesel-engine (or gas turbine), generator, inverter (usually referred as variable frequency devices in marine engineering society), electric propulsion motor, and propeller [I].It is required to build the electric power network with the specified electric power compatible to the ship performance and electric power utilization. Main and sub generators combined with a diesel engine or a gas turbine should be sized to fulfill the electric power consumption mainly for ship propulsion and auxiliary hotel loads as well. In particular, it has been requisite to install more than one generator and propulsion motor for the purpose of optional redundant operations for the higher system efficiency and survivability in emergency [2]. In addition, phase-shifted power transformer should be installed for mitigating the harmonic influences originated from the switching devices by implementing 12pulses or 24 pulses. In this paper, modeling of electric power network and individual components has been performed with the software for the large powered LNG carrier with 4 generators and 2motors. In addition, characteristic analysis of the electric propulsion system has been performed with the load flow analysis on the modeled system, which manifests the validity of the system configuration designed by the proposed process [3]. Current flow within the allowable rating and electric power compatibleness can be visualized as results of the software running. In addition, abnormal operating condition of short circuit network can be considered for investigating the safety of system components under the overload condition or emergency [4]. Furthermore, the capacity of the protective devices like relays and circuit breakers has been regulated from the short circuited current under 3-phase fault of main BUS.

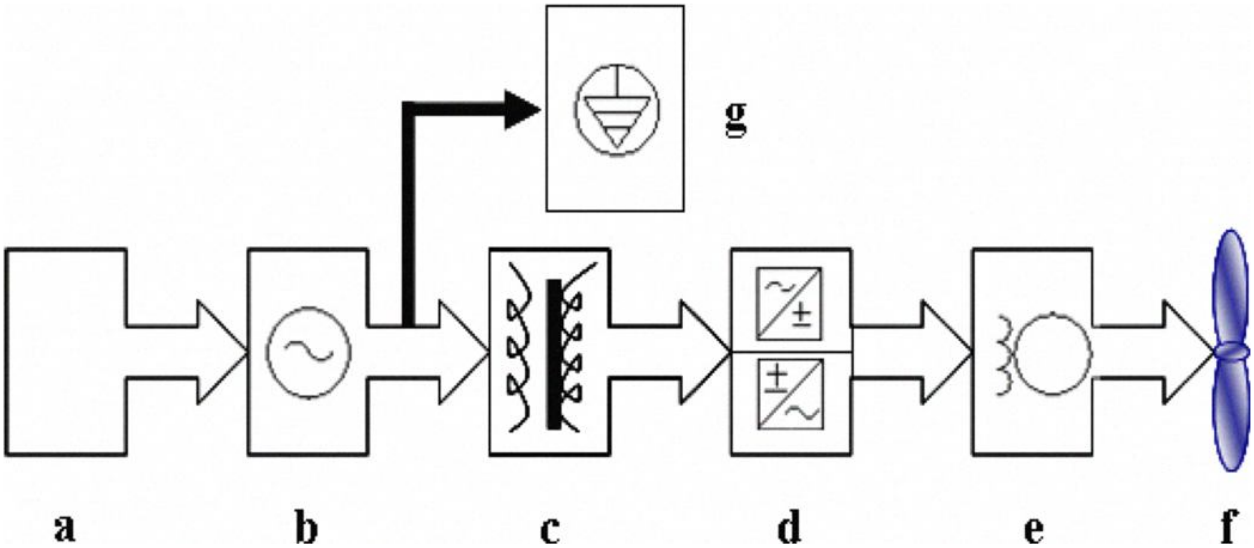
II. MODELING OF ELECTRIC SHIP PROPULSION SYSTEM OF A LARGE-SIZED LNG SHIP

A. Outline of electric propulsion system

As shown in Fig. 1, the structure of electric ship propulsion system makes up with various electrical components such as prime movers with diesel engines or gas turbines, generators, power transformer, variable frequency devices, electric propulsion motor, propeller, and electric loads [5] .

In this paper, electric power analysis has been performed with the software, ETAP (Electrical Transient Analyzer Program). More details about electric power system modeling and analysis using ETAP are summarized as follows.

1) Electric modeling of electric propulsion system and individual electric components.
2) Load flow analysis at the sea going under unloading LNG and carrying LNG. Short circuit analysis for the 3-phase fault condition of one main switchboard.
3) Capacity calculation of the protective device which connects twin switch boards each other.
4) Analysis of electric power flow with a part of system out of function when the emergency happened.



a. Prime mover b. Synchronous generator c. Power transformer d. Motor drive e. Propulsion motor f. Propeller
g. Other load demands
Fig. I. Typical electric ship propulsion

B. System modeling

Electric propulsion system can be modeled with the equivalent circuit as shown in Fig 2. Particularly, redundancy of generators and propulsion motors are shown for the optional operating mode. The specifications of each component are summarized in the appendix. Overall structure of electric ship propulsion system consists of 2 main generator with IIMW, 2 sub generators with 6MW, 4 propulsion motors with 12MW including 2 redundant ones, 2 cargo pump with 2.2MW, and service power loads with I.5MVA.

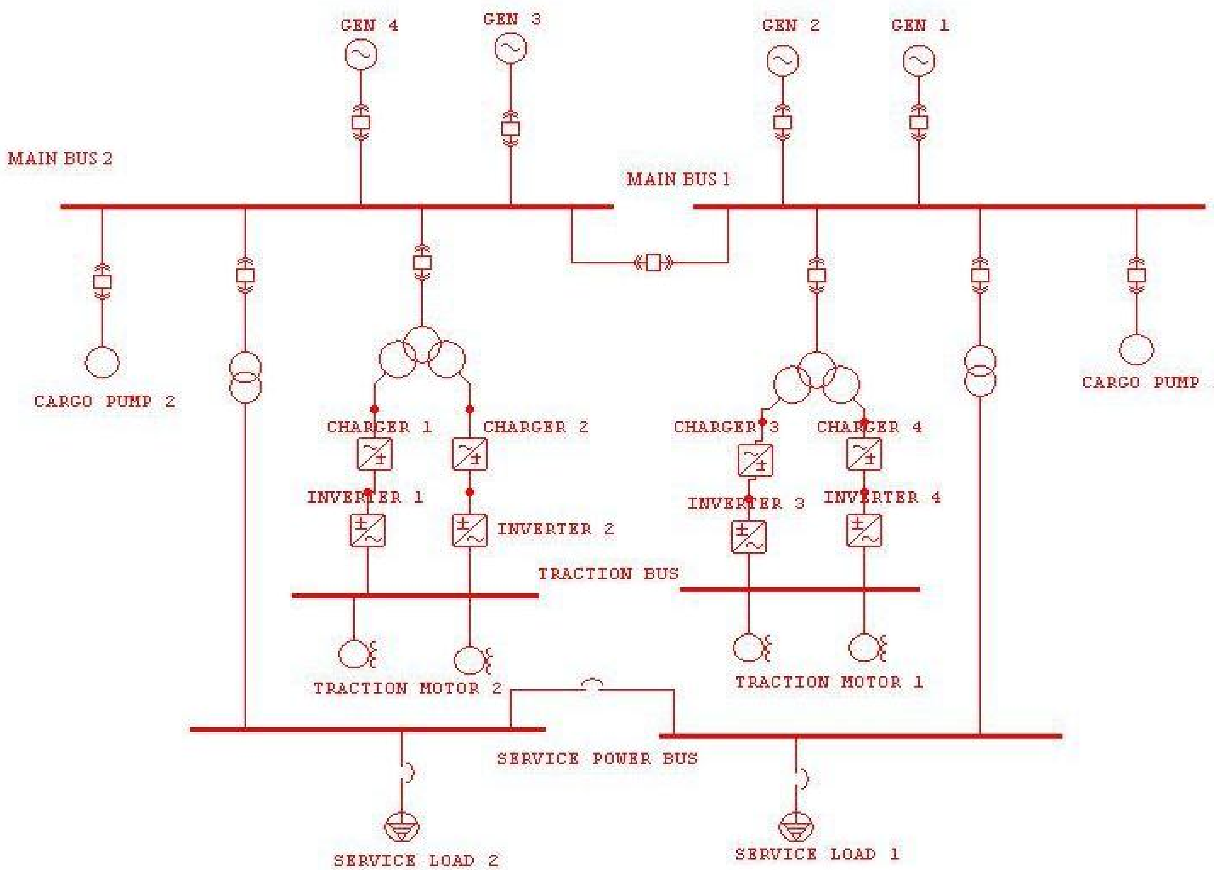


Fig.2. Modeling of the electric ship propulsion system

III. ELECTRIC POWER ANALYSIS OF ELECTRIC SHIP PROPULSION SYSTEM

A. Load flow analysis

Load flow analysis is an important tool involving numerical analysis applied in a power system. It use simplified notation such as one line diagram and per unit system and focuses on various forms of A.C power (voltage, voltage angle, real power, reactive power). It analysis the power system in normal steady state operation. It is important for planning future expansion of power system as well as in determining the best operation of existing system. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage of each bus and real and reactive power flowing in each in each line.

Sea going under unloading LNG. Four generators are used with 2 propulsion motors. We set up the power blending strategy for generators and the propulsion motors, always sharing the loads evenly.

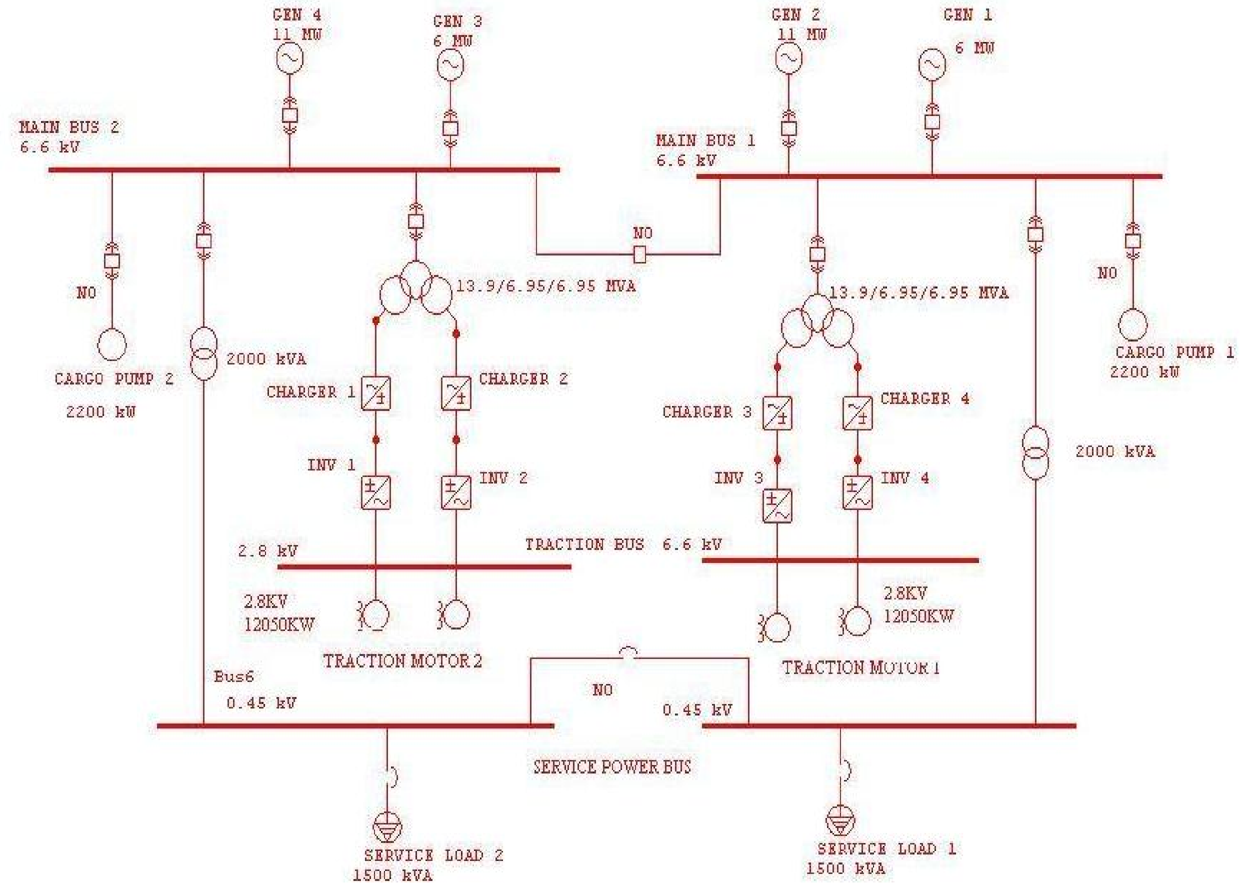


Fig. 3 Unloading sea going condition

Table 1 Bus loading under unloading condition

Bus name	Steam turbine		Duel fuel		Gas turbine		Two stroke	
	MW	MVAR	MW	MVAR	MW	MVAR	MW	MVAR
Bus 1	5.237	3.246	5.237	3.246	5.237	3.246	5.237	3.246
Bus 2	5.237	3.246	5.237	3.246	5.237	3.246	5.237	3.246
Bus 3	5.237	3.246	5.237	3.246	5.237	3.246	5.237	3.246
Bus 4	5.237	3.246	5.237	3.246	5.237	3.246	5.237	3.246
Main bus 1	11.822	7.302	11.822	7.302	11.822	7.302	11.822	7.302
Main bus 2	11.822	7.302	11.822	7.302	11.822	7.302	11.822	7.302
Service bus 1	1.274	0.790	1.274	0.790	1.274	0.790	1.274	0.790
Service bus 2	1.274	0.790	1.274	0.790	1.274	0.790	1.274	0.790
Traction bus 1	25.363	9.604	25.363	9.604	25.363	9.604	25.363	9.604
Traction bus 2	25.363	9.604	25.363	9.604	25.363	9.604	25.363	9.604

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Table 2 Branch losses under unloading condition

Circuit/ branch	Steam turbine		Dual fuel		Gas turbine		Two stroke	
	KW	KVAR	KW	KVAR	KW	KVAR	KW	KVAR
T3	2.41	0.41	2.2	0.2	2.34	0.35	2.25	0.3
T4	2.41	0.41	2.2	0.2	2.34	0.35	2.25	0.3
T1	71.61	21.66	71.4	21.4	71.51	21.61	71.55	21.5
T2	71.61	21.66	71.4	21.4	71.51	21.61	71.55	21.5

Case 2Sea going under loading LNG. One generator is used with two cargo pumps which are used to carry LNG. The total values of active power used in cargo pumps and service loads are same to ones supplied from generator.

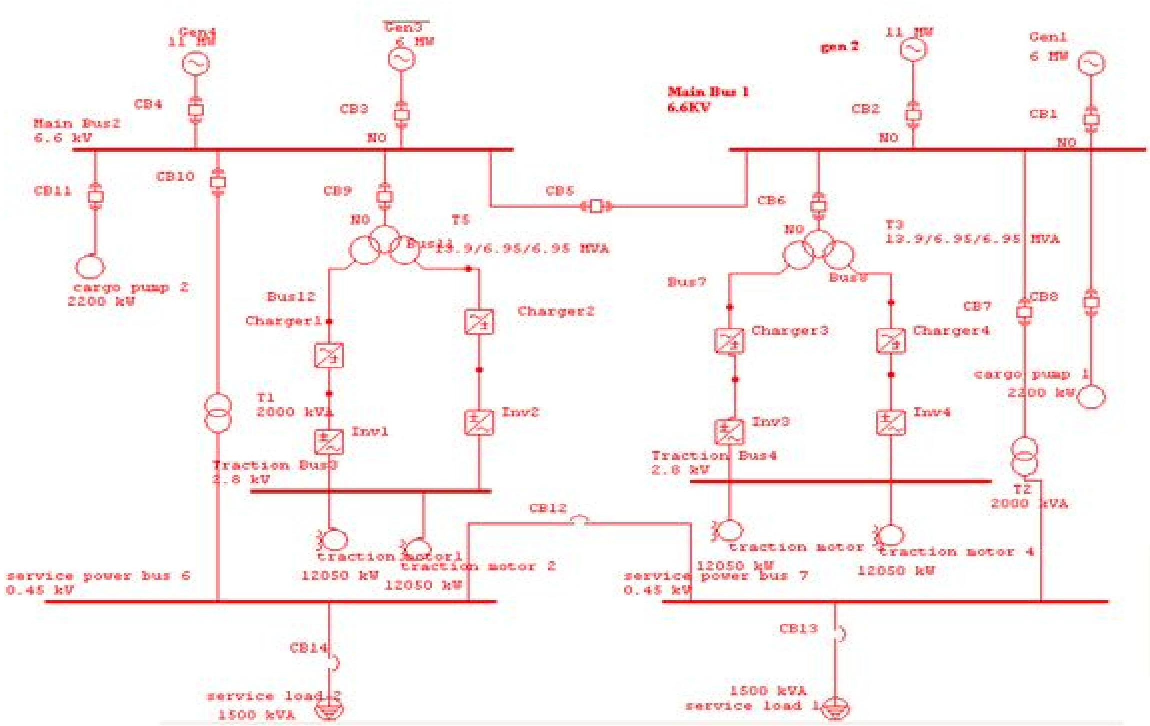

Fig. 4 Loading sea going condition

Table 3 Bus loading under loading condition

Bus name	Steam turbine		Dual fuel		Gas turbine		Two stroke	
	MW	MVAR	MW	MVAR	MW	MVAR	MW	MVAR
Main bus 1	3.614	1.727	3.614	1.727	3.614	1.727	3.614	1.727
Main bus 2	7.227	3.454	7.227	3.454	7.227	3.454	7.227	3.454
Service bus 1	1.274	0.790	1.274	0.790	1.274	0.790	1.274	0.790
Service bus 2	1.274	0.790	1.274	0.790	1.274	0.790	1.274	0.790

Table 4 Branch losses under loading condition

Circuit/ branch	Steam turbine		Dual fuel		Gas turbine		Two stroke	
	KW	KVAR	KW	KVAR	KW	KVAR	KW	KVAR
T3	2.41	0.41	2.2	0.2	2.34	0.35	2.25	0.3
T4	2.41	0.41	2.2	0.2	2.34	0.35	2.25	0.3

Table 5 Losses in propulsion system

Types of propulsion	Apparent losses	
	MW	MVAR
Steam turbine	0.135	0.086
Dual fuel	0.132	0.078
Gas turbine	0.134	0.080
Two stroke	0.133	0.085

Considering representative two cases of sea going mode under unloading LNG and carrying LNG, load flow analysis at the sea going under unloading LNG was performed at first . On sea going, 4 generators are used with 2 propulsion motors as shown in Fig. 3and 4. We set up the power blending strategy for generators and the propulsion motors, always sharing the loads evenly. According to the simulation results, output of generator takes up to 77.2% of maximum allowable rating. In principal, the total value of active power used in load is same to one supplied from generators. Also, the range of fluctuation for BUS voltage is less than 0.1%, which satisfies voltage qualifications (IEEE Std. 141-1993). The direction of load flow proceeds from generators to loads. Thus, we summarized in TABLE 1 and 3 about the load flow analysis at sea going concluding that it is suitably modeled and stabilized for sea going under unloading LNG.

B. Short circuit analysis

A low resistance connection established between two points in an electric circuit the tends to flow through the area of flow resistance by passing rest of the circuit. Short circuit analysis is generally performed to investigate the transient rising of current and voltage under the short circuited accidents. Here we are using momentary fault currents for 3 – phase fault of main bus connected with generator are concerned based on the short circuit current, we can specify the capacity of the protective device like protective relay or circuit breakers, where formulations are as follows

Rated interrupting = Current of short circuit

Closing and latching rms = 1.6 * rated interrupting

Closing and latching crest = 2.7 * rated interrupting

Short circuit current for 3-phase fault of short circuited main BUS under the sea going mode is shown in Fig. 5. It says that electric ship propulsion system can't operate in case that all protective devices are closed and all BUS voltage becomes zero. Therefore, we must set the protective device so that the opposite system of a faulted BUS side can survive. We decided the capacity of the protective device as TABLE 6 through the load flow analysis at steady state and short circuit analysis under 3-phase fault of main BUS.

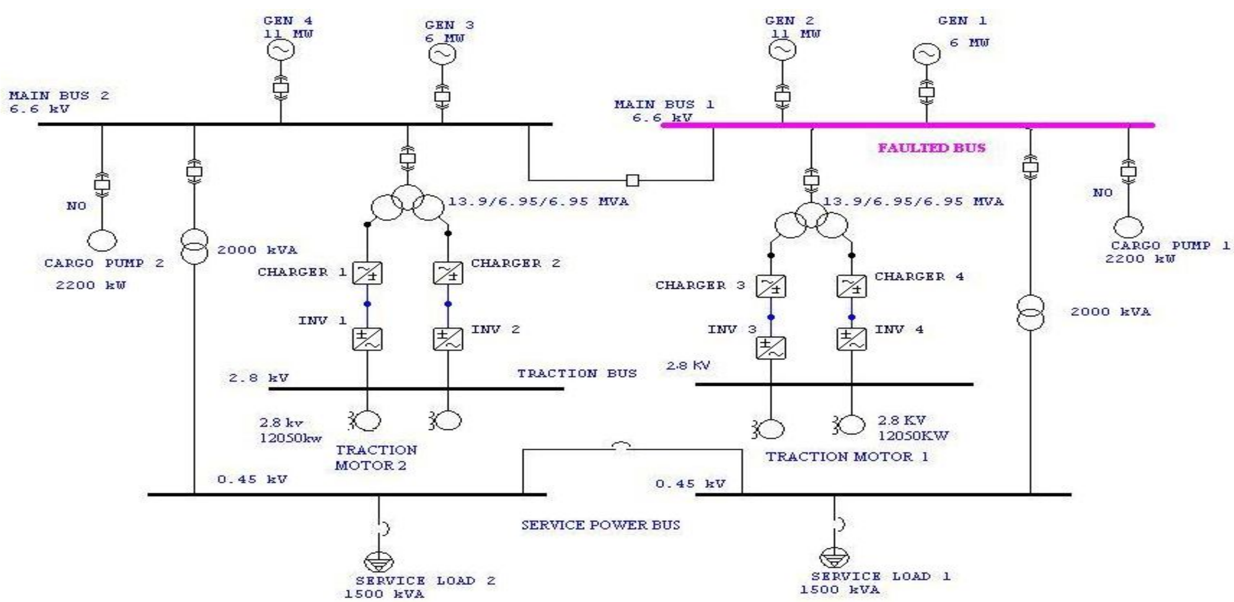

Fig 5 Main BUS 3 Φ fault

The results of the situation where the protective devices are opened as soon as the short circuit current flows are shown in Fig 6. The system of the right handed side can be isolated safely from the left side because the protective device makes BUS ties open immediately in emergency. Therefore, short circuit current of faulted BUS can't give any influence on the other side. Accordingly, it is maintained that electric propulsion system can survive and return back safely to the port when accidents happened.

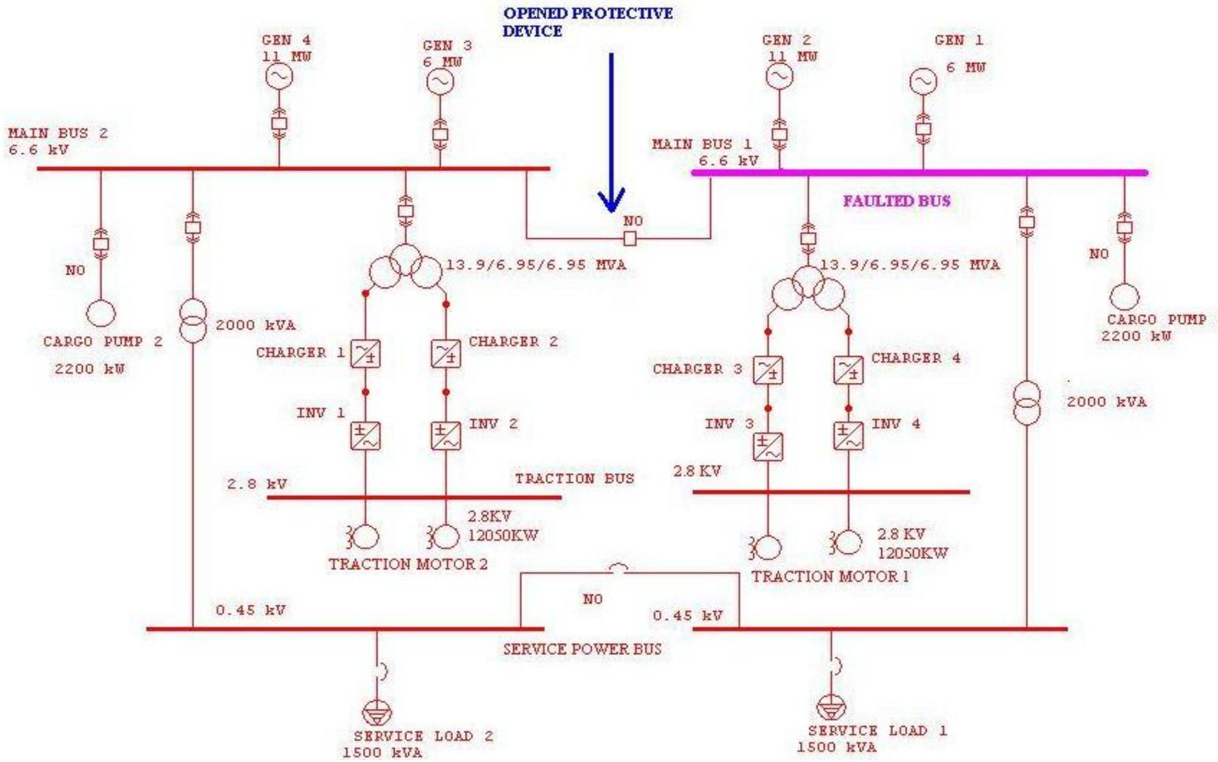

Fig. 6 Protective device is opened

Table 6 Short Circuit studies of different propulsion system

Types of propulsion	Steam turbine	Dual fuel	Gas turbine	Two stroke
Short circuit current (KA)	8.45	8.3	8.5	8.55
RMS value of Closed and latching current (KA)	13.6	13.28	13.760	13.920
Crest value of Closed and latching current (KA)	22.950	22.410	23.220	23.490

IV.CONCLUSION

In this paper, load flow analysis and short circuit analysis have been studied on the four type of propulsion model. The different propulsion solutions available for LNG carriers have been presented from the electrical power system point of view. All the different solutions require a High Voltage power system as the installed electrical power is more for all the systems. For steam and two-stroke propulsion the HV electric power plant is only needed for supplying the cargo pumps. This means that this power plant is only fully utilized at the unloading terminal. For electric propulsion vessels powered by Dual-Fuel Engine or Gas Turbines the electric power plant is dimensioned according to the propulsion requirement from seagoing conditions. The same power plant can then be used also for the cargo handling, hence minimizing the investment cost for propulsion and auxiliary machinery. Of all the alternatives, electric propulsion has the lowest total installed power, and the highest utilization of the installed electrical power plant. The performance of the electric propulsion system has been presented for one DFEP LNG in operation. In particular the system has proven excellent performance in sea-mode condition with operation in constant power mode, and crash stop situation.

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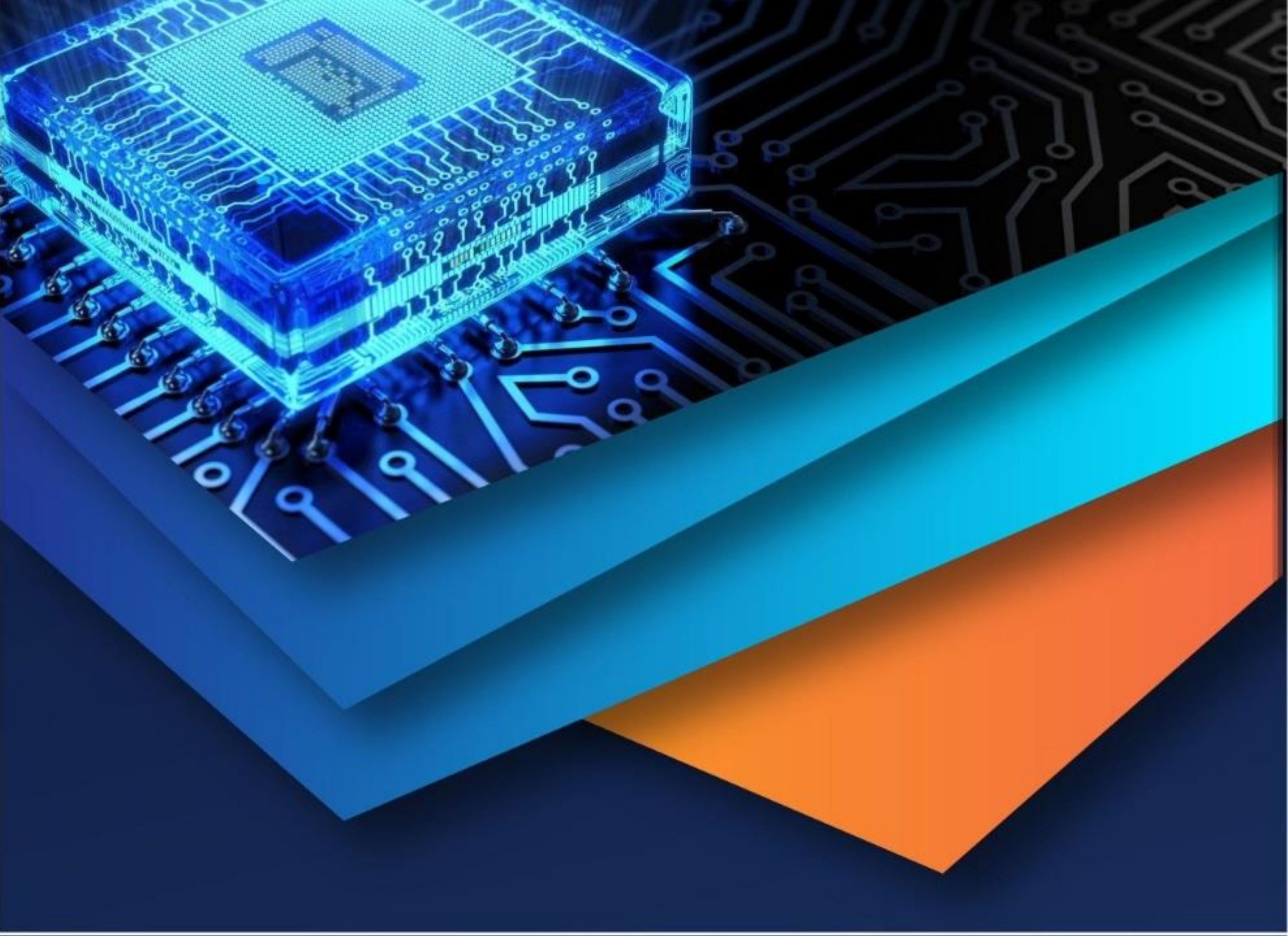

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