

Design Study of Power Management System for Parallel Operation of Generator Set of a Ship's Diesel Electric Power Plant

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Abstract – Through the 20th century and up to present day, ship's diesel electric power plant have typically operated with an excess of parallel generator capacity online providing redundancy to ensure that all vital system have power in the casualty event. Power Management System (PMS) is most crucial system in the ship diesel electric propulsion plant. It in-charge to manage power generate by prime mover and being distributed to consumer in electric propulsion system. The PMS entails the integration of the ship's electric plant and electric load management with ship operation and machinery system control as an automated control function. The parallel operation of generators will be introduced to get best performance of the PMS. The vessels that have this system are typically electrical ship such as cruise ship, LNG carrier and modern container ship. This thesis will highlight the parameters and methods that were used in the design of the PMS. The study involved the parallel operation of generators and electric propulsion plant in the system which are control system and other components. Control system are one the most important components in PMS to make sure the generating sets and power distribution are managed wisely by the system. Besides, the thruster is crucial component and major consumer in electric propulsion system and it should be managed cautiously because to prevent blackout occur. There a lot important parameter in PMS such as frequency, power, inertial time constant and others. The control system are used by the approach methods in design of the PMS to deliver all signals to consumers to ensure the power being distributed according to the operation of ship demand. **Copyright © 2016 Penerbit Akademia Baru - All rights reserved.**

Keywords: PMS, Parallel Operation, Generator, Control System, Signal, Parameter, Methods

1.0 INTRODUCTION

Through the 20th century and up to present day, the field and industries of shipping is growing rapidly and the technology is getting more advanced. Then the shipping industries began demanding on technology enhancement on power management system. For example the ship's diesel electric power plant has become more famous and acceptable rather than conventional power plant due to its reliability and versatility in operation. Power management system (PMS) is a crucial part of the automation and power system on marine vessels and in particular for ships with electric propulsion. The PMS entails the integration of the ship's electric plant and electric load management with ship operation and machinery system control as an automated

control function. It is a very important system because it will control the power system in order to assure adequate electrical power supply to the various consumers and maximize the blackout prevention capabilities. Then it also can decrease the maintenance cost through protecting the equipment against fault and malfunction. Besides, it will be proposed is to minimize the fuel consumption. The parallel operation of generators will be introduced to get best performance of the power management system. The easiest way to setup a parallel system is to use generators that are same or at least have the equal output rating and alternator pitch. Another flexible approach to backing up the power requirement is to have two or more generators of variable output.

In addition, these can be connected in parallel with paralleling switchgear to achieve maximum output during peak requirement or the desired minimal during other times. There are many benefits from multiple paralleling generators which are reliability, operational flexibility, easier maintenance scheduling, avoiding partially loaded generator sets, easier system expansion and energy cost saving. In this thesis, the study on the electrical ships which are liquefied natural gas ship (LNG), container ship and cruise are to identify the component in electrical propulsion system and their interaction with the PMS. The parameters and methods of design of PMS is present as a result at the end of the project.

2.0 LITERATURE REVIEW

A complete shipboard electric plant is similar to the electric power generating, distribution and utilization system of industrial installation. Electric power is required for motor driving propulsion plant, deck machinery, interior and exterior illumination, air-conditioning, sanitary system and casualty machinery such as fire and bilge pump. Then the electric power must also be supplied for interior communication system, radio communication, alarm systems and others electronic aid to navigation. For the diesel electric propulsion, the prime movers are generally connected to synchronous generators supplying the switchboard with active and reactive power. The main switchboard is usually split in two or three section to incorporate adequate redundancy. During the operation, the buses are usually split to be tolerant to failure of one switchboard [4].

There are many research have been done regarding the problem of hydrodynamic interaction between multiple bodies and strip theory and potential theory are normally used to analyze the motions of the floating structures. Ohkusu [17] adopted strip theory to analyze the ship's motion around large floating structure. The results described clearly the effects of position of a smaller body in opposition to a large body. Ohkusu's method is extended by Kodan [14] to investigate the hydrodynamic interaction between two parallel structures in oblique waves. In order to support the validity of strip theory, he compared his investigation with model experiment but neglecting the speed effect and the results obtained are satisfactory with the experimental results. Fang and Kim [8] also utilized the strip theory to predict the motion between two ships due to hydrodynamic effect in oblique sea. Their method is different with previous researcher where the speed effects are taken into account, however, some deficiencies popped up due to the assumptions of two-dimensional.

Electric ship power system is an integrated system which is consist of components that operate together to perform a task to supply power to each unit of load. Generally, in an integrated electric power system, propulsion power is supplied to the propeller through a generator and

motor combination. An integrated power system ties the production of the electricity consumed by propulsion motors and the rest of the ship's electrical equipment to shared generators.

2.1 LNG Ship

An LNG carrier is a type of ship designed for transporting liquefied natural gas. Alternative power plants have been introduced to replace the old steam power plant like diesel dual fuel engine and dual fuel electric.

An LNG carrier for this type is equipped with prime mover driven generators which are dual fuel diesel engines. It is feasible to use 6.6 kV main switchboards to distribute to the various consumers which are propulsion transformers, frequency converters, electric propulsion motors and propeller. This LNG are consists four generators that power of propulsion is 38,500 kW.

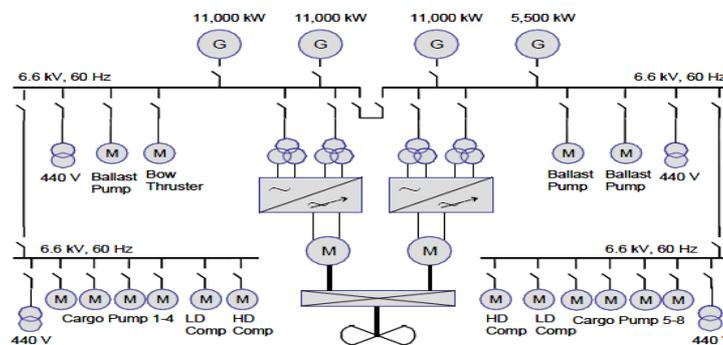


Figure 1: Layout system for power and propulsion system of a LNG ship.

Close vessels in waves and the results obtained were satisfactory but the results for resonance region were quite unsatisfactory. Wu et al. [23] reviewed numerically and experimentally on the motion of a moored semi-submersible in regular waves and the wave-induced internal forces in the semi-submersible. For numerical method, the linearized equations of motions of the semi-submersible which is modelled as an externally constrained floating body are obtained in a common reference system fixed on the body. The results between the numerical and experiment in the practical wave-frequency range achieved very good agreement.

2.2 Key Consideration in Setting Up Parallel System

In most situations, each individual system in a parallel system consists of five to six micro-controllers that are compiled together. The complexity of installation will increase if the individual generator have been manufactured by different vendor and the controller are based on a combination of digital technologies. These key featured are discussed to get of some of things involved in setting up parallel system such as speed control, synchronization, load balance, voltage regulation, generator set controller, and proactive relay.

In the modern world now, there are many types of the paralleling systems but only two major types that always be priority which are: (1) Sequential Paralleling. In sequential paralleling, the generators set are connected to the bus in predetermined order. The lead engine is connected to the bus first and when the generators selected as number 2 is ready to be connected, the synchronizer is connected between the output terminal of generator 2 and bus. Then the

generator is in synchronism, its paralleling circuit breaker is closed and connecting it to the bus. The restriction normally imposed to the limit the controls will consume in attempting to synchronize and parallel a set to the bus before reconnecting the control to the next set in sequence. (2) Random Paralleling. In random paralleling, the random access permits simultaneous synchronizing of each set to the bus. The random method is faster than sequential paralleling but it more expensive. The codes mandating emergency loads to be reconnected within ten seconds may require the method of operation.

By using diesel generator sets, it is reasonable to expect that emergency bus will established within then ten second limit in random access system because any one of the generators can be first on line.

The consideration in load control and load sharing are also important for parallel system. (1) Load control. When generators or engine are paralleled, the load should be divided and controlled so that the system will not be overloaded. The overloading is an emergency system that will cause voltage and frequency deviation and maybe cause the entire system will be failed. Besides, the loads prioritization is necessary and loads can be grouped into block consistent with prime mover size. Then the system can control the connection of load to bus in a prioritized sequence. For example the system must disconnect in reverse order of priority to ensure maximum continuity of power to the highest priority load. It is necessary to consider the means to achieve the switching after set the basic for load connection and shedding. There are several ways to switch the load such as use the remote-control switches or contactor to open and close, adding and shedding the load. (2) Load Sharing. The load sharing is dependants upon the characteristic of the governor. The speed would not change between no loads to full load condition if the governor has an isochronous characteristic. In parallel operation of generators, the mechanical input of prime mover is increased in one generator by adjusting the governor, the phase of induced voltage of the generator precedes compare to other generators. The synchronization force is produced between preceding and behind generator and the result shows the load of preceding generators in increased and the load of other generators is decreased. Hence, this is the common rule of the load sharing in parallel operation of multiple generators. The isochronous governor is quite unstable because small change in speed will produce large change in load and governor usually has 2 or 3% of speed droop

2.3 Excitation control

The speed of generator rotor is rotate at rated frequency which is in constant excitation or in stable condition. This condition can be achieved by keeping generator magnetic field held in constant. Synchronous generator and diesel engines are synchronised to a grid in parallel with other generators and diesel engines. The current flow out from generator stator windings increases the torque of the shaft the generator convert the torque to stator ampere.

2.4 Blackout

Blackout is a condition where the ship experiences a total loss of electric power. The term partial blackout is sometimes used to describe loss of electric power in parts of electric system such as in one part of a redundant system [4]. In addition, blackouts in electrical power system are normally caused by short circuit and overload or by fault in the active or reactive load sharing systems. There a lot causes of blackout that can be expressed such as human error, protection system, fail or lack maintenance, lacks of procedures and project and commissioning

2.5 Power Generation Management

Generation of electricity had produce power purposely need management system so it can properly distribute. The concept of micro grid has been studied comprises of real power and reactive power. It is focusing on how strategy to manage them by observing real and reactive power references for each generators unit. The micro grid assigns real and reactive power references for the distribution generation unit to efficiently share the real and reactive power requirement of load among them and quickly respond to disturbance and transients due to the changes in the system operating mode Once generators are connected through the bus-bar, each distributed generators can be controlled to generate specify real and reactive power know as real/reactive bus (PQ-bus). In addition, each distributed generated also generate specify real power and regulate its terminal voltage also known as real/voltage-bus (PV-bus). The utility grid is to ensure to support the difference in real and reactive power requirements and maintain frequency.

The system used independent real and reactive power control strategy to determine the output power requirement of each unit. The d -axis (rotor part) and q -axis (stator part) component is implement for controlling purpose. The offset current at d -axis component determines real power generation. While the q -axis component determines the reactive power absorb of the unit. Figure 2.2 shows a block representation of the control system, the PMS and interface medium which is voltage source converter.

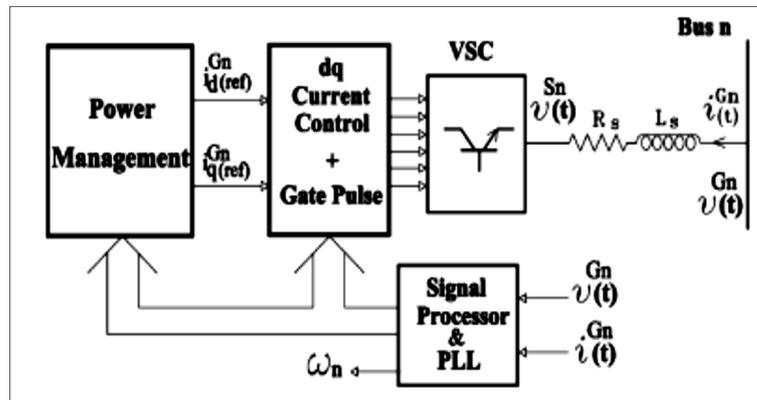


Figure 2: PMS and interface medium [4].

2.6 Power Distribution Management

As the power being generated, it will supply to the respective consumer. The main switchboard through it flexible switching architecture then will distribute power to local consumer for voyaging purpose. In integrated propulsion system, the electrical power is step down through the transformer according to requirement of load. The propulsion system will drive electrical thruster by electrical motor. In addition, frequency converter is to converts alternating current of one frequency to another frequency. They are control system implement in the motor so the power deliver to propeller is matching to power requirement.

Thruster is to provide a thrust to propeller. Control system is implemented in the thruster to provide right thrust to the vessel. In order to prevent blackout, the FLR method is introduced to prevent blackout.

2.7 Propulsion Load Rate Limiting

In electrical propulsion system, thrusters are the largest consumers. Therefore, the power fluctuations on the generators are mainly due to the power variations of the propulsion system. On the other hand, the power consumption mainly depends on the vessel's operational conditions influenced by weather condition as well. Hence, these variations can be determined from the thruster loading and losses.

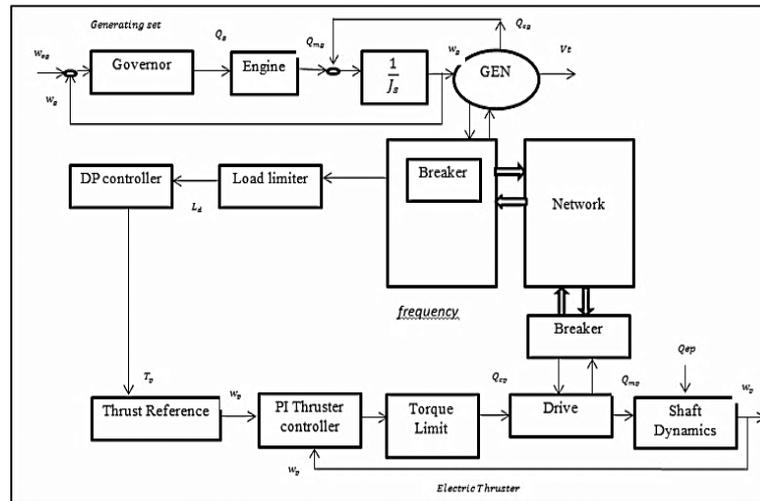


Figure 3: Existing load limiting control in power system.

2.8 Blackout Prevention Control

The cause of blackout is due the overloading in power system. When the system is overload, the generator will operate above allowable limit of operation. Then, the generator is trip due to power supply is not enough and need to overcome by PMS in order to ensure the system can prevent that faulty. In order to prevent the faulty occur in power system, fast load reduction (FLR) control methods is utilised to prevent blackout since blackout action is fast [6]. Hence, control system must response in a limited time.

2.9 Load Shedding

Load shedding is a function of PMS to disconnect heavy consumer that consumed a too much power to prevent blackout. It is based on switching off the groups of non-essential consumers when there is a deficit in power generated [3]. A load shedding is based on, available power and frequency.

3.0 RESULTS AND DISCUSSION

3.1 Result of Reactive Power Management

From Table 4 it shows steady state value of current is being restored by reactive power management which is voltage regulation.to maintain excitation. The error signal is deviation in voltage and it is being restored by q-axis controller to achieve steady-state signal in grid

connection. The settling time for a system is at 7 seconds to show that system is become more stable.

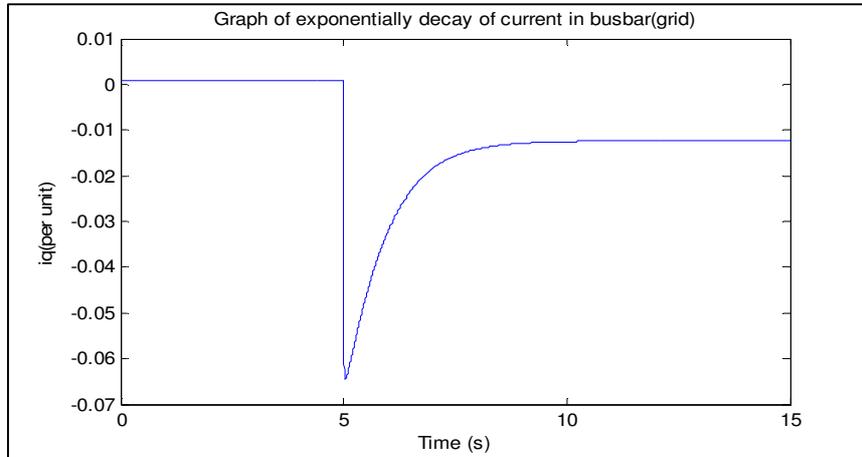


Figure 4: Graph of signal current of bus-bar.

3.2 Parameter Involved in the Design

Table 1: Generator parameter

No	Parameter	Description	Unit	Symbol
1	d-axis input	Stator winding flux linkage	Weber	ϕ_d
2		Terminal Voltage	Volt	V_d
3		Field winding	Voltage field winding when generator is excited	Volt
4	q-axis output	Stator winding flux linkage	Weber	ϕ_q
5		Terminal Voltage	Volt	V_d
6	Inertia time constant	Time constant of rotation of shaft (rigid body)	Joule per volt ampere	H
7	Moment of inertia	Moment inertia of shaft	Kg.m^2	J
8	Electrical base speed	Electrical angular frequency	rad/s	ω_B
9	Mechanical speed	Mechanical angular frequency	rad/s	ω
10	Armature resistance	Resistance in stator armature	ohm	R

3.3 Design Requirement

PMS should address the following requirement to achieve a performance desired by propulsion system.

- Power demand
- Generators
- Switchboard
- Protection relays
- Control system
- Propulsion motor

- Frequency converter
- Thruster
- Selection and sizing of generators

3.4 Design Criteria

The design criteria should fulfil in order to acquire best performance of PMS The main of criteria that should be considered which is the parallel operation of generators sets in ships diesel electric power plant. Other design criteria should be consider such as the real and reactive power management, power distribution management, consideration about rotor and stator in generator, power blackout prevention and thruster control.

3.5 The Importance of Design Parameter

3.5.1 Frequency

The value of the frequency is a function of RPM of the engine's shaft. When the load increases, the frequency of shaft rotation is deviate from it nominal value. Then, engine governor control the fuel admission to the engine to maintain the desired speed. Hence, to achieve nominal frequency, the fuel rack on the governor will adjust to a slightly higher set point to achieve nominal frequency. For instance, at rated frequency of 60 Hz, sudden change in load can contribute in deviation of rated frequency then the frequency restoration algorithm is introduced to restore the frequency according to rated RPM.

3.5.2 Power

Power generated consists of real power and reactive power. Real power represents the true power delivered mechanically by shaft. While, reactive power is power measure of energy exchange between source and reactive load. Apparent power is used to size the generator dimension. Available power is power for the actual operating condition and it is based on power reserved in the system. If the available power is not enough, operation of the system may delay and can contribute to blackout. In electrical propulsion system, power is important parameter in order to dimension the component that will implement in the system. In addition, power factor is also important parameter in the system. This parameter is a ratio of real power to apparent power.

3.5.3 Terminal Voltage

Generator terminal voltage shall keep in constant value. Usually, generator terminal voltage is excited by field voltage in 1 per unit value. Hence, control system participates to maintain excitation to achieve stability. If the terminal voltage cannot maintain excitation, the generator may trip due to loss of excitation. The real and reactive power management is to manage the voltage reference at *d-axis* and *q-axis* that shall keep at particular value so the frequency fluctuation is overcome.

3.5.4 Mechanical and electric base speed

Mechanical is the rotation of shaft measure as a torque and its unit in rad per second. This parameter is being converted to electrical base speed in per unit value. Typically the value is 1. The rotation of mechanical speed is according to electrical base speed based on

formula $\omega_e = \frac{p}{2} \omega_m$. The electrical speed is measure of performance of efficiency in power system and it is controlled by control system to acquire desired output.

3.6 Slew rate limits

The slew rate limit is the parameter used to define the limit frequency of shaft rotation. The equation is; $SR = 2\pi fV$ (V/s). The frequency fluctuation can be limited if the peak voltage of the signal is keeps in constant. When the output signal is constant (Voltage), the operating frequency will operate according to the nominal slew rate limit.

3.6.1 Fast load reduction time

FLR time is the parameter determines the time to reduce a load. It has to be set equal to the safe time limit ($t_{sl}=t_{FLR}$) to avoid load decreased on thruster faster than necessary. Otherwise, it may induce unnecessary torque stress in the shaft and the power transmission parts of the thruster. Thus, too fast load reduction should also be avoided in order to reduce damages on the thrusters. In blackout prevention control, FLR time is usually being set at 0.05 seconds in order to prevent blackout since it occur very fast in the system.

3.6.2 Inertial time constant

Inertial time constant is the time taken (from 0 second) for a rotor to rotate from a static state to reach its rated speed as a 1.0 per unit torque is applied on the shaft. This parameter is concern in the design because the shaft speed reference will be reduced every time the thrust loss occurs. Hence, nominal inertial time constant is necessary for control system to restore any deviation occur in the shaft. It variables are moment of inertia, nominal engine speed, and apparent power. In marine application, usually inertial time constant value is 1.5 to 2 seconds. While, moment of inertia is measures the resistance to change in angular velocity and it value is constant.

3.7 Method used in the PMS design

3.7.1 Real and reactive power management

Frequency restoration is an approach use to ensure real power being restored at nominal value. During mode of operation, frequency may vary and restoration algorithm is needed. In reactive power strategy, three methods are used to restore reactive power. They are voltage-droop characteristic, voltage regulation and power factor correction. AVR detects terminal voltage of generator and output current. The grid frequency is held constant to ensure speed control of synchronisation generator. Excitation system control will directly influence the voltage stability of power system's grid and reactive power output of generator. Power factor correction to improve power factor by compensates reactive power of load by generators unit to the load-bus

3.7.2 Fast Load Reduction

Available power-based load shedding is method used to disconnect heavy consumers and groups of non-essential consumers from the network by will trigger the circuit breaker. Frequency-based loads shedding utilised a protective relay switch in based on frequency deviation occur in the system. The relay technique is by sense the error on the system frequency

and disconnects the load when the system is overloading, it will disconnect the consumer respectively.

Event-Based FLR is to prevent power blackout by monitoring the network and generating system situation and reacts based on the generator tripping. Event-Based FLR take an action to disconnect the generator to prevent a blackout. However, problem may arise by using this method because the communication delays.

4.0 CONCLUSION

The objectives of this project are can be achieved through literature study on power generation, power distribution management and blackout prevention control. The methods used in the design of PMS and parameter had be achieved to fulfill the objective of this project. There are important parameter that involve in design of the PMS are as follow:

- Frequency
- Power
- Terminal Voltage
- Thrust
- Fast load reduction time
- Inertial time constant
- Slew rate limit

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