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

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Research Article

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Abstract – In order to guarantee that all essential systems have power in the case of a casualty, ships' diesel electric power plants have generally run with an excess of parallel generator capacity online throughout the 20th century and up to the present. The most important system of a ship's diesel electric propulsion plant is the Power Management System (PMS). In an electric propulsion system, it is responsible for controlling the power generated by the prime mover and distributing it to the consumer. The PMS comprises an automated control function that integrates ship operation and mechanical system control with the ship's electric plant and electric load management. To maximize PMS performance, parallel generator operation will be used. Typically, electrical ships like cruise ships, LNG carriers, and contemporary container ships are equipped with this technology. The factors and techniques used in the PMS's design will be highlighted in this thesis. The research examined how the system's control system, electric propulsion plant, and generators operated in parallel. One of the most crucial parts of PMS is the control system, which ensures that the system manages the power distribution and producing sets effectively. In addition, the thruster is an essential part of the electric propulsion system and a significant consumer, therefore it should be handled carefully to avoid blackouts. PMS has several crucial parameters, including power, frequency, inertial time constant, and others. In order to guarantee that power is distributed in accordance with ship demand, the control system is used by the approach techniques in the design of the PMS to provide all signals to consumers.

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

1.0 INTRODUCTION

The shipping industry has grown quickly during the 20th century and continues to do so now, and technology is becoming more sophisticated. Subsequently, the maritime industry started to seek improvements in power management system technology. For instance, because of its dependability and adaptability, the ship's diesel electric power plant has gained greater notoriety and acceptance than traditional power plants. A vital component of the automation and power system aboard marine boats, especially those with electric propulsion, is the power management system (PMS). The PMS comprises the automated integration of ship operation and mechanical system control with the ship's electric plant and electric load management.

function of control. It is a crucial system because it will manage the power system to optimize blackout avoidance capabilities and guarantee a sufficient supply of electricity to all users. By shielding the equipment from defects and malfunctions, it may help save maintenance costs. Additionally, reducing gasoline use will be suggested. To maximize the power management system's efficacy, generators will operate in parallel. Using generators with identical output ratings and alternator pitches is the simplest approach to set up a parallel system. Having two or more variable-output generators is another adaptable way to backup the power need.

Additionally, they may be linked in parallel using paralleling switchgear to produce the

appropriate minimum output at other times or the highest output during peak requirements. Reliability, operational flexibility, faster maintenance scheduling, avoiding partly loaded generator sets, quicker system expansion, and energy cost savings are only a few advantages of using multiple paralleling generators. The purpose of this thesis is to identify the components of the electrical propulsion system and how they interact with the PMS in electrical ships, such as cruise ships, container ships, and LNG ships. At the conclusion of the project, the PMS design parameters and techniques are provided.

2.0 LITERATURE REVIEW

An whole shipboard electric plant is comparable to an industrial installation's electric power generation, distribution, and use system. Motor-driven propulsion plants, deck equipment, air conditioning, interior and exterior lighting, sanitary systems, and casualty equipment like fire and bilge pumps all need electricity. Alarm systems, radio communication, internal communication systems, and other electronic navigation aids all need electric power. The prime movers are often coupled to synchronous generators that deliver active and reactive power to the switchboard for diesel electric propulsion. To provide sufficient redundancy, the main switchboard is often divided into two or three sections. In order to withstand the breakdown of a single switchboard, the buses are often divided during operation [4].

The issue of hydrodynamic interaction between several entities has been the subject of many studies, and the movements of floating structures are often analyzed using strip theory and potential theory. Strip theory was used by Ohkusu [17] to examine how the ship moved around a massive floating structure. The consequences of positioning a smaller body in opposition to a larger body were clearly outlined by the findings. Kodan [14] extends Ohkusu's approach to examine the hydrodynamic interaction between two parallel structures in oblique waves. He contrasted his research with a model experiment while ignoring the speed impact in order to bolster the validity of strip theory, and the results are in line with the experimental findings. Additionally, Fang and Kim [8] used the strip theory to forecast how two ships would move in an oblique sea owing to hydrodynamic effects. Although their approach differs from that of other researchers who considered speed impacts, several shortcomings emerged as a result of the two-dimensional assumptions.

The electric ship power system is an integrated system made up of parts that work together to give electricity to every load unit. In an integrated electric power system, the propeller typically receives propulsion power from a generator and

motor combination. An integrated power system connects shared generators to the generation of the energy used by the ship's propulsion motors and other electrical devices.

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.

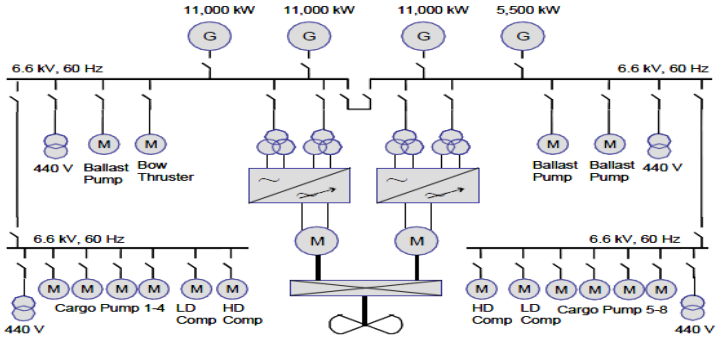


Figure 1: Layout system for power and propulsion system of a LNG ship.

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 intro 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 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.

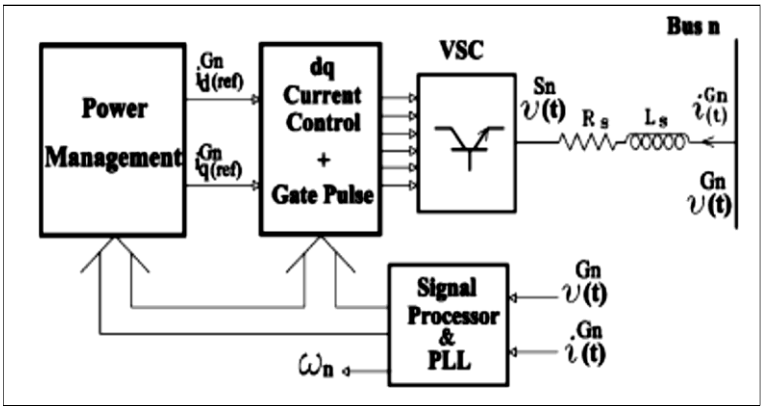


Figure 2: PMS and interface medium [4].

2.5 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.

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.

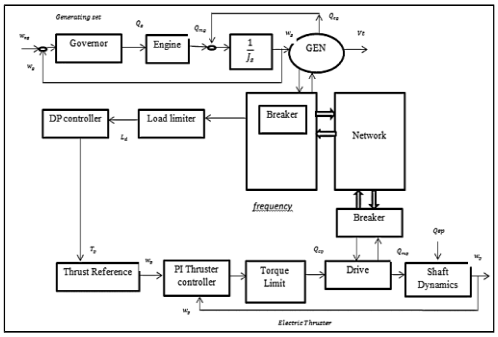


Figure 3: Existing load limiting control in power system.

2.6 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.

2.7 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.

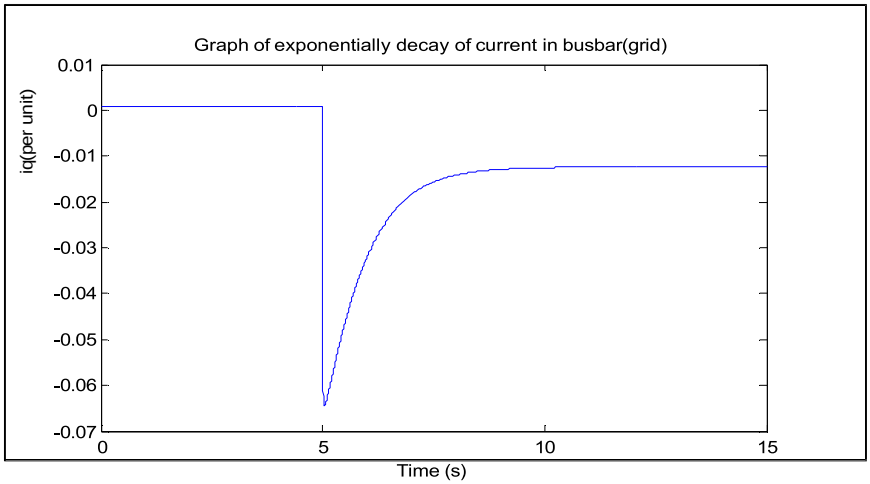


Figure 4: Graph of signal current of bus-bar.

3.2 Parameter Involved in the Design

Table 1: Generator parameter

No	Parameter		Description	Unit	Symbol
1	d-axis input	Stator winding flux linkage	Flux in the stator winding	Weber	φ_d
2		Terminal Voltage	Voltage induces in the generator terminal voltage	Volt	V_d
3		Field winding	Voltage field winding when generator is excited	Volt	E_{fd}
4	q-axis output	Stator winding flux linkage	Flux in the stator winding	Weber	φ_q
5		Terminal Voltage	Voltage induces in the generator 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

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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 CONCLUSSION

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

REFERENCES

[1] Radan, Damir. "Integrated control of marine electrical power systems." Department of Marine Technology, Norwegian University of Science and Technology (2008).

[2] Sorensen, A. J., "Marine Control System." Norwegian University of Science and Technology (2012).

[3] International Marine Contractors Association. "A Guide to DP Electrical Power and Control Systems." (2010).

[4] Hansen, Jan Fredrik, and Alf Kåre Ådnanes. "Blackout Prevention & Recovery." In Dynamic Positioning Conference. 2009.

[5] Pedersen, Tom Arne, and Eilif Pedersen. "Bond graph modelling of marine power systems." Mathematical and Computer Modelling of Dynamical Systems 18, no. 2 (2012): 153-173.

[6] Katiraei, Faridaddin, and Mohammad Reza Iravani. "Power management strategies for a microgrid with multiple distributed generation units." Power Systems, IEEE Transactions on 21, no. 4 (2006): 1821-1831.

[7] Radan, Damir, Øyvind N. Smogeli, Asgeir J. Sørensen, and A. K. Adnanes. "Operating criteria for design of power management systems on ships." InProc. of the 7th IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC'06). 2006.

[8] Islam, M. M., "A Guide to Electrical Installation on Shipboard." Handbook to IEEE Standard 45, (2004).

[9] Morse, J. C., D.C. Simon, and T.V. Nguyen, "A Case for Power Management of Ship Power System: Improving Operational Efficiency while Maintaining Survivability and Operational Performance." Naval and Marine System Division Northrop Grumman Corporation, Charlottesville, Virginia USA, (2012).

[10] Amin, Engamria, Dr Hamdy Ahmed Ashour, and Dr Magdy Mostafa El-Attar. "Load Sharing Realization Of Parallel Operated Synchronous Generators Within Ship Micro-Grid Using Microcontrollers." (2013).

[11] Luo, Le, Lan Gao, and Hehe Fu. "The Control and Modeling of Diesel Generator Set in Electric Propulsion Ship." International Journal of Information Technology and Computer Science (IJITCS) 3, no. 2 (2011): 31.

[12] Wu, Ren-Hua. "A manipulation and control scheme of paralleled diesel-generating sets in China." In Telecommunications Energy Conference, 1992. INTELEC'92, 14th International, pp. 392-398. IEEE, 1992.

[13] Gawande, S. P., and K. B. Porate. "Review of parallel operation of synchronous generator and induction generator for stability." In Emerging Trends in Engineering and

Technology (ICETET), 2009 2nd International Conference on, pp. 716-721. IEEE, 2009.

[14] Koczara, Wlodzimierz, Marcin C. Moskwa, Neil L. Brown, Jawad Al-Tayie, and Emil Ernest. "Parallel operation of decoupled generation systems." InIndustrial Electronics, 2008. ISIE 2008. IEEE International Symposium on, pp. 1616-1621. IEEE, 2008.

[15] Radan, Damir, Tor A. Johansen, Asgeir J. Sorensen, and Alf Kare Adnanes. "Optimization of load dependent start tables in marine power management systems with blackout prevention." WSEAS Transactions on circuits and systems 4, no. 12 (2005): 1861-1866.

[16] Haque, M. H. "Demonstration of parallel operation of single-phase and three-phase induction generators for off-grid operation." In Sustainable Energy Technologies, 2008. ICSET 2008. IEEE International Conference on, pp. 40-45. IEEE, 2008.

[17] Mihic, Kresimir, Tajana Simunic, and Giovanni De Micheli. "Reliability and power management of integrated systems." In Digital System Design, 2004. DSD 2004. Euromicro Symposium on, pp. 5-11. IEEE, 2004.

[18] Radan, Damir, Øyvind N. Smogeli, Asgeir J. Sørensen, and A. K. Adnanes. "Operating criteria for design of power management systems on ships." InProc. of the 7th IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC'06). 2006.

[19] Yusri, A. S., "Design Study of Power Management System of a Ship's Diesel Electric Power Plant." Universiti Teknologi Malaysia, Johor, Malaysia (2012).