BACHELOR THESIS & COLLOQUIUM – ME141502

ANALYSIS OF THREE PHASE SYNCHRONOUS GENERATOR EFFICIENCY DUE TO UNBALANCED ELECTRIC LOAD ON LABORATORY SCALE

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NRP. 04211441000027

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DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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SKRIPSI–ME 141502

ANALISA EFFISIENSI GENERATOR SINKRON TIGA FASA AKIBAT BEBAN LISTRIK TIDAK SEIMBANG DENGAN SKALA LABORATORIUM

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APPROVAL FORM

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BACHELOR THESIS

Submitted in fulfillment of the requirement for the degree of Bachelor in Engineering
at
Marine Electrical and Automation System (MEAS) Laboratory
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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DECLARATION OF HONOR

I hereby who signed below declare that :

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Bachelor Thesis Title	: Analysis of Three Phase Synchronous Generator Efficiency Due to Unbalanced Electric Load on Laboratory Scale
Department	: Marine Engineering

If there is plagiarism act in the future, I will fully responsible and receive the penalty given by ITS according to the regulation applied.

Surabaya, August 2018

Kevin

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ANALYSIS OF THREE PHASE SYNCHRONOUS GENERATOR EFFICIENCY DUE TO UNBALANCED ELECTRIC LOAD ON LABORATORY SCALE

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ABSTRACT

There is many research that has been conducted to analyze the performance of generator. The unbalanced load is one of a problem that occurs in the generator. Unbalanced load are when the three load impedances are not equal to each other, the phasor sum and the neutral current IN are not zero. The unbalanced load on the generator occurs when the loading on the three phase is not equal.

This final project analyzed the efficiency that the generator produces at unbalanced condition. In this research conducted a simulation of the operational generator on a laboratory scale. The methodology for this research is Statement of problem, study literature, design of unbalanced load experiment, setting of the generator driven by DC and AC motor experiment, measurement, and then conclusion. In this research contain about the efficiency that generator produced in chart, and the data of power that generator mover need. The research conclusion are when phase R,S, and T are balanced the efficiency is increasing according to the increase in load or the power output. The power that needed for the motor to move the generator is increasing too according to increase in load. When unbalanced load and the load is the same with the balanced load, the efficiency didn’t change too much.

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ANALISA EFISIENSI GENERATOR SINKRON TIGA FASA AKIBAT BEBAN LISTRIK TIDAK SEIMBANG DENGAN SKALA LABORATORIUM

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ABSTRAK

Ada banyak penelitian yang telah dilakukan untuk menganalisis kinerja generator. Beban yang tidak seimbang adalah salah satu masalah yang terjadi di generator. Beban tidak seimbang adalah ketika beban tidak sama dengan yang lain, jumlah fasor dan arus netral tidak nol. Beban tidak seimbang pada generator terjadi ketika pemuatan pada tiga fasa tidak sama.

Tugas akhir ini menganalisa efisiensi yang dihasilkan oleh generator pada kondisi yang tidak seimbang. Pada penelitian ini dilakukan simulasi generator operasional pada skala laboratorium. Metodologi untuk penelitian ini adalah Pernyataan masalah, literatur studi, desain eksperimen beban tidak seimbang, pengaturan generator yang digerakkan oleh motor DC dan AC, pengukuran, analisa hasil eksperimen dan kemudian kesimpulan. Dalam penelitian ini terdapat efisiensi generator yang dimuat dalam bentuk grafik, dan data daya yang dibutuhkan penggerak generator. Hasil penelitian adalah ketika fase R, S, dan T seimbang, efisiensi meningkat sesuai dengan peningkatan beban atau daya output. Daya yang dibutuhkan motor untuk menggerakan generator juga meningkat sesuai dengan peningkatan beban. Ketika beban pada keadaan tidak seimbang dan beban pada keadaan seimbang sama, efisiensi tidak berubah terlalu banyak.

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PREFACE

A lot of gratitude for Allah SWT because of His grace, the author can finish this bachelor thesis with the title “ANALYSIS OF THREE PHASE SYNCHRONOUS GENERATOR EFFICIENCY DUE TO UNBALANCED ELECTRIC LOAD AT LABORATORY SCALE” in order to comply the requirement of obtaining a Bachelor Engineering Degree on Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

The author realizes that this writing can not be finished on time without the support of various parties both morally and materially. Therefore, the authors would like to express their gratitude to all those who have helped in the preparation of this bachelor thesis especially to :

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12. Great amounts of friends that can’t be mentioned, for their support, help and ideas for this thesis.

The author realizes that this bachelor thesis remains far away from perfect. Therefore, every constructive suggestion and idea from all parties is highly expected by author for this bachelor thesis correction and improvement in the future.

Finally, may Allah SWT bestow His grace, contentment and blessings to all of us. Hopefully, this bachelor thesis can be advantageous for all of us particularly for the readers.

Surabaya, 1 August 2018

Author

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CHAPTER 1
Introduction

1.1 Background

There are many research that has been conducted to analyze the performance of the generator. The unbalanced load is one of the problems that occur in the generator. Unbalanced load are when the three load impedances are not equal to each other, the phasor sum and the neutral current IN are not zero. The unbalanced load on generator occurs when the loading on the three phase is not equal. This occurs when the generator are used to powering single phase loads such as domestic lightning, one phase induction motor and etc. Some three phase loads such as induction furnaces and drives can also create unbalanced loading.

The unbalanced load in generator is making some effect to the performance of the generator. One of the performances that may be affected by unbalance load is the power used. Therefore, there should be further analysis of the effect of unbalanced load to the power used so it can be proofed are the unbalanced load can affect the power used or not, and how much it will affect it.

1.2 Statement Of Problems

1. What is the impact of unbalanced load on each phase to the motor that driven the generator?
2. How the efficiency of generator is effected by unbalanced load?

1.3 Research Limitation

The limitations of this thesis are;

1. The load which used in a laboratory experiment is an incandescent light bulb and fluorescent lamp.
2. This final project only analyzed efficiency in balanced and unbalanced load.

1.4 Research Objective

The objectives of this thesis are;

1. Knowing the effect of unbalanced load on generator efficiency.

CHAPTER 2
Literature Review

2.1 Electric Motor

An Electric motor is a machine which converts electric energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic Held, it experiences a mechanical force whose direction is given by Fleming's Left hand Rule and whose magnitude is given by F = B/I Newton. (Theraja)

2.1.1 DC Motor

There are main component in direct current motor, such as armature, commutator, brushes, field winding. In a motor, the armature receives current from an external electrical source. This causes the armature to turn. The voltage generated in the armature is then connected to an external circuit. In brief, the motor armature receives current from an external circuit (the power supply), and the generator armature delivers current to an external circuit (the load). Since the armature rotates, it is also called a rotor. In a generator, the armature is rotated by an external mechanical force.

Commutator A dc machine has a commutator to convert the alternating current flowing in its armature into the direct current at its terminals (in the case of the generator). The commutator consists of copper segments with one pair of segments for each armature coil. Each commutator segment is insulated from the others by mica. The segments are mounted around the armature shaft and are insulated from the shaft and armature iron. Two stationary brushes are mounted on the frame of the machine so that they contact opposite segments of the commutator.

Brushes, These graphite connectors are stationary and spring-mounted to slide or “brush” against the commutator on the armature shaft. Thus, brushes provide a connection between the armature coils and the external load.

Field Winding This electromagnet produces the flux cut by the armature. In a motor, current for the field is provided by the same source that supplies the armature. In a generator, the field-current source may come from a separate source called an exciter or from its own armature output.

2.1.2 AC Motor

Induction Motor Principle

The induction motor is the most commonly used type of ac motor because of its simple, rugged construction and good operating characteristics. It consists of two parts: the stator (stationary part) and the rotor (rotating part). The stator is connected to the ac supply. The rotor is not connected electrically to the supply. The most important type of polyphase induction motor is the three-phase motor. (Three-phase machines have three windings and deliver an output between several pairs of wires.) When the stator winding is energized from a three-phase supply, a rotating magnetic field is created. As the field sweeps across the rotor conductors, an emf is induced in these conductors which causes current to flow in them. The rotor conductors carrying current in the stator field thus have a torque exerted upon them that spins the rotor.

2.2. Generator

2.2.1 Types of Electric Generator

Electric generators may be classified many ways, but the following are deemed as fully representative:

- By principle
- By application domain

The application domain implies the power level. The classifications by principle unfolded here include commercial (widely used) types together with new configurations, still in the laboratory (although advanced) stages. By principle, there are three main types of electric generators:

- Synchronous (Figure 2.1)
- Induction (Figure 2.2)
- Parametric, with magnetic anisotropy and permanent magnets (Figure 2.3)

Parametric generators have in most configurations doubly salient magnetic circuit structures, so they may be called also doubly salient electric generators.

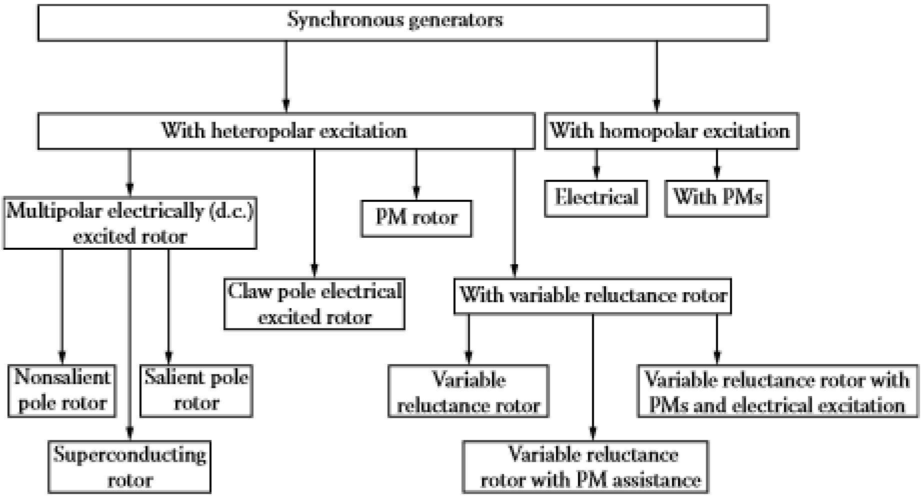

Figure 2. 1 Synchronous Generator
Source: Synchronous Generator, Boldea I

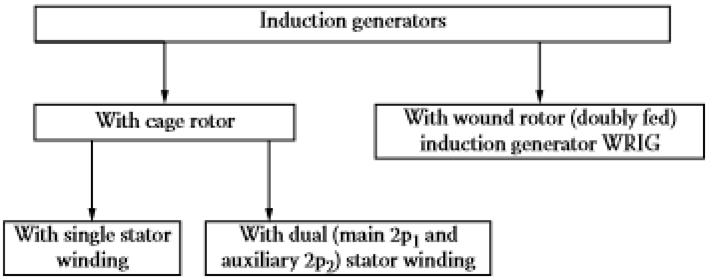

Figure 2. 2 Induction Generator
Source: Synchronous Generator, Boldea I

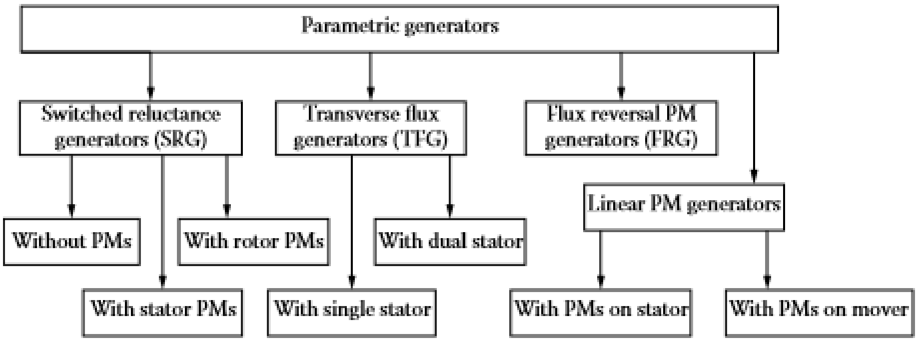

Figure 2. 3 Parametric Generator
Source: Synchronous Generator, Boldea I

2.2.2 AC Generator

Alternating-current generators are also called alternators. Almost all electric power for homes and industry is supplied by alternators in power plants. A simple alternator consists of (1) a strong, constant magnetic field; (2) conductors that rotate across the magnetic field; and (3) some means of making a continuous connection to the conductors as they are rotating. The magnetic field is produced by current flowing through the stationary, or stator, field coil. Field-coil excitation is supplied by a battery or other dc source. The armature, or rotor, rotates within the magnetic field. For a single turn of wire around the rotor, each end is connected to a separate slip ring, which is insulated from the shaft. Each time the rotor turn makes one complete revolution, one complete cycle of alternating current is developed. A practical alternator has several hundred turns wound into the slots of the rotor. Two brushes are spring-held against the slip rings to provide the continuous connection between the alternating current induced in the rotor or armature coil and the external circuits.

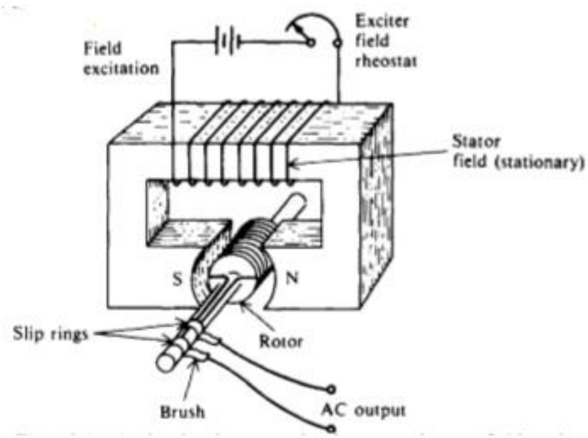

Figure 2. 4 Simple Alternator

Source: Schaum's outline of theory and problems of basic electricity

The amount of generated voltage of an ac generator depends on the field strength and speed of the rotor. Since most generators are operated at constant speed, the amount of emf depends on field excitation.

The frequency of the generated emf depends on the number of field poles and on the speed at which the generator is operated, or

$$f = \frac{pn}{120} \quad (2.1)$$

where:
f = frequency of generated voltage, Hz
p = total number of poles
n = rotor speed, revolutions per minute (rpm)

Regulation of an ac generator is the percentage rise in terminal voltage as load is reduced from the rated full-load current to zero, with the speed and excitation being constant, or no-load voltage - full-load voltage full-load voltage. (Gussow, 1983)

$$\text{Voltage regulation} = \frac{no\text{-}load\ voltage - full\text{-}load\ voltage}{full\text{-}load\ voltage} \quad (2.2)$$

2.3 Unbalanced Load

2.3.1 Definition

When the three load impedances are not equal to each other, the phasor sum and the neutral current I_N are not zero, and we have an unbalanced load. (Gussow, 1983)

Unbalanced loads on A.C. generator are when other connected loads like motor loads are fed with unbalanced set of voltages additional losses occur in the motors as well. Hence, the load on the A.C. generators should be balanced as far as possible. Where single phase loads are predominant, consideration should be given for procuring single phase A.C. generator. (Bureau of Energy Efficiency)

2.3.2 Symmetrical Component

The electrical power system operates in a balanced three-phase sinusoidal operation. When a tree contacts a line, a lightning bolt strikes a conductor or two conductors swing into each other we call this a fault, or a fault on the line. When this occurs the system goes from a balanced condition to an unbalanced condition. In order to properly set the protective relays, it is necessary to calculate currents and voltages in the system under such unbalanced operating conditions. (Marx and Bender, 2013)

In Dr. C. L. Fortescue's paper he described how symmetrical components can transform an unbalanced condition into symmetrical components, compute the system response by straight forward circuit analysis on simple circuit models, and transform the results back into original phase variables. When a short circuit fault occurs the result can be a set of unbalanced voltages and currents. The theory of symmetrical components resolves any set of unbalanced voltages or currents into three sets of symmetrical balanced phasors. These are known as positive, negative and zero-sequence components. Fig. 2.4 shows balanced and unbalanced systems. (Marx and Bender, 2013)

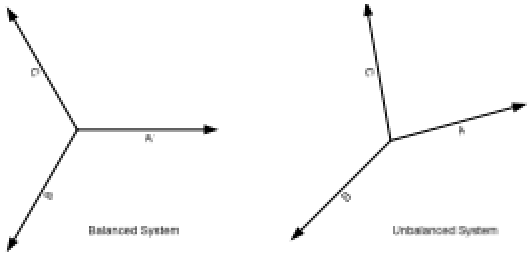

Figure 2. 5 Balanced and Unbalanced Phasor
Source: An Introduction to Symmetrical Components, System Modeling and Fault Calculation

Consider the symmetrical system of phasors in Figure 2.2. Being balanced, the phasors have equal amplitudes and are displaced 120° relative to each other. By the definition of symmetrical components, V_{b1} always lags V_{a1} by a fixed angle of 120° and always has the same magnitude as V_{a1} . Similarly V_{c1} leads V_{a1} by 120°. It follows then that

$V_{a1} = V_{a1}$ (2.3a)
$V_{b1} = (1\angle 240°)V_{a1} = a^2V_{a1}$ (2.3b)
$V_{c1} = (1\angle 120°)V_{a1} = aV_{a1}$ (2.3c)

Where the subscript (1) designates the positive-sequence component. The system of phasors is called positive-sequence because the order of the sequence of their maxima occur *abc*.

Similarly, in the negative and zero-sequence components, we deduce

$V_{a2} = V_{a2}$ (2.4a)
$V_{b2} = (1\angle 240°)V_{a2} = a^2V_{a2}$ (2.4b)
$V_{c2} = (1\angle 120°)V_{a2} = aV_{a2}$ (2.4c)

$V_{a0} = V_{a0}$ (2.5a)
$V_{b0} = V_{a0}$ (2.5b)
$V_{c0} = V_{a0}$ (2.5c)

Where the subscript (2) designates the negative-sequence component and subscript (0) designates zero-sequence components. For the negative-sequence phasors the order of sequence of the maxima occur cba, which is opposite to that of the positive-sequence. The maxima of the instantaneous values for zero-sequence occur simultaneously.

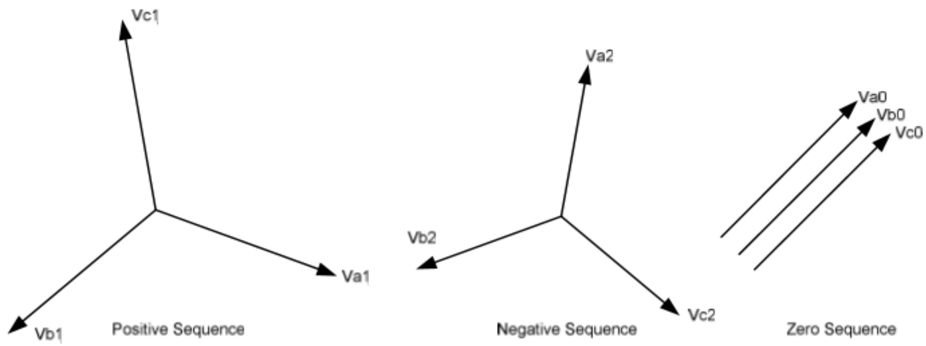

Figure 2. 6 Sequance Example
Source: An Introduction to Symmetrical Components, System Modeling and Fault Calculation

In all three systems of the symmetrical components, the subscripts denote the components in the different phases. The total voltage of any phase is then equal to the sum of the corresponding components of the different sequences in that phase. It is now possible to write our symmetrical components in terms of three, namely, those referred to the a phase

$$V_a = V_{a0} + V_{a1} + V_{a2} \quad (2.6a)$$
$$V_b = V_{b0} + V_{b1} + V_{b2} \quad (2.6b)$$
$$V_c = V_{c0} + V_{c1} + V_{c2} \quad (2.6c)$$

We may further simplify the notation as follows; define

$$V_0 = V_{a0} \quad (2.7a)$$
$$V_1 = V_{a1} \quad (2.7b)$$
$$V_2 = V_{a2} \quad (2.7c)$$

Substituting their equivalent values

$$V_a = V_0 + V_1 + V_2 \quad (2.8a)$$
$$V_b = V_0 + a^2V_1 + aV_2 \quad (2.8b)$$
$$V_c = V_0 + aV_1 + a^2V_2 \quad (2.8c)$$

These equations may be manipulated to solve for V_0, V_1, and V_2 in terms of V_a, V_b, and V_c.

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \qquad (2.9a)$$
$$V_1 = \frac{1}{3}(V_a + aV_b + a^2V_c) \qquad (2.9b)$$
$$V_2 = \frac{1}{3}(V_a + a^2V_b + aV_c) \qquad (2.9c)$$

It follows then that the phase currents are

$$I_a = I_0 + I_1 + I_2 \qquad (2.10a)$$
$$I_b = I_0 + a^2I_1 + aI_2 \qquad (2.10b)$$
$$I_c = I_0 + aI_1 + a^2I_2 \qquad (2.10c)$$

The sequence currents are given by

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) \qquad (2.11a)$$
$$I_1 = \frac{1}{3}(I_a + aI_b + a^2I_c) \qquad (2.11b)$$
$$I_2 = \frac{1}{3}(I_a + a^2I_b + aI_c) \qquad (2.11c)$$

The unbalanced system is therefore defined in terms of three balanced systems. Eq. (2.6) may be used to convert phase voltages (or currents) to symmetrical component voltages (or currents) and vice versa. (Marx and Bender)

2.4 Electrical Load

2.4.1. Resistive Load

Resistive load (R) is a load consisting of only ohm resistance components, such as heating elements and incandescent lamps. This type of load only consumes active load only and have a power factor equal to one. The nature of resistive load is the current resistive load in phase with its voltage or power factor cos $\varphi = 1$

Active Power $P = V.\ I \cos \varphi$ (Watt)

Reactive Power $Q = V.\ I \sin \varphi$ (VAR)

If $\cos \varphi = 1$ then $\sin \varphi = 0$

and the active power becomes the maximum and zero reactive power.

2.4.2 Inductive Load

Inductive load (L) is a load consisting of a coil of wire wrapped around a core, such as a coil, transformer, and solenoid. This load can cause phase shift in the current so that it is lagging. This is because the stored energy in the form of a magnetic field will cause the current phase to shift to lag behind the voltage. This type of load absorbs active power and reactive power. Inductive load properties Inductive load current 90^0 lags against its voltage or power factor : cos φ = 0

Active Power P = V. In .Cos φ(Watt) = V. I .Cos 90 ° = V. I . 0

Reactive Power Q = V. In . Sin φ(VAR) = V. In .Sin 90 ° = V . In .1

If Cos φ = 0 then Sin φ = 1 and active power becomes zero, reactive power became maximum.

2.5 Power Calculation in Three Phase Circuit

The total apparent power ST in voltamperes and the total reactive power QT in voltamperes reactive are related to total real power PT in watts Therefore, a balanced three-phase load has the real power, apparent power, and reactive power given by the equations (Gussow, 1983)

$$PT = \sqrt{3}\ V_L I_L \cos \Phi$$

$$ST = \sqrt{3}\ V_L I_L$$

$$QT = \sqrt{3}\ V_L I_L \sin \Phi$$

where : PT = total real power, W
ST = total apparent power, VA
QT = total reactive power, VAR
VL = line voltage, V
IL = line current, A
Φ = load phase angle
√3 = 1.73, a constant

2.6 Generator Efficiency

Efficiency (Eff) is the ratio of the useful power output to the total power input: loss, field-excitation copper loss, and mechanical losses. (Gussow, 1983)

$$\text{Eff} = \frac{output}{input} \qquad (2.12)$$

CHAPTER 3
Methodology

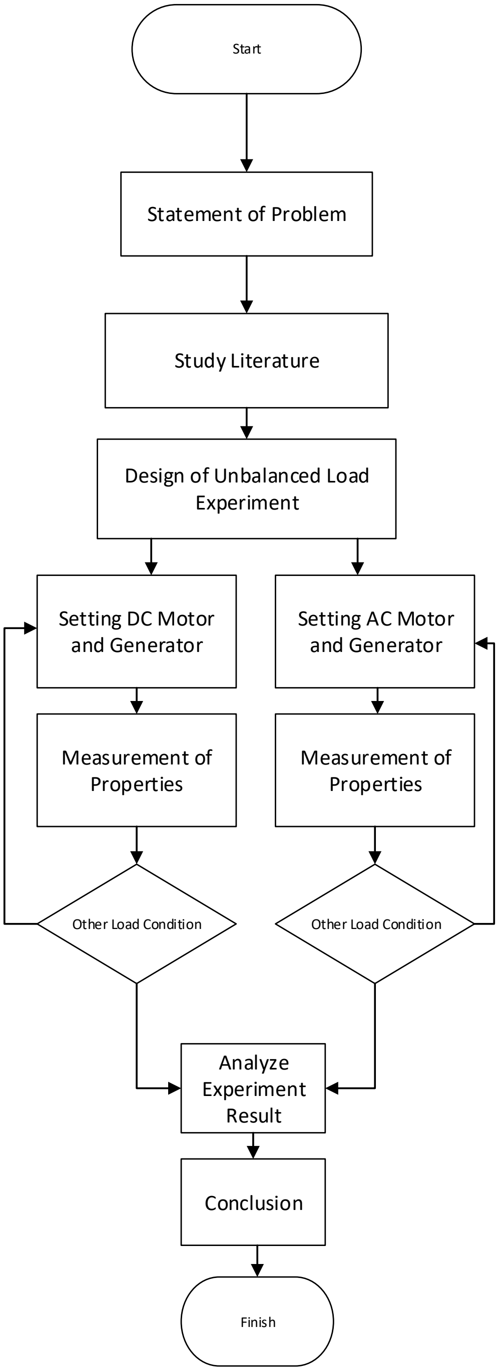

Figure 3. 1 Methodology Flow Chart

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3.1 Definition of Methodology Flow Chart

1. Statement of Problem
   In this stage is the base to create a thesis. In this stage the question for problem are prepared specifically in order to find the objective of this thesis. The content of this thesis is to answer all the statement of problem and it will be done by collecting some data and information about the problem.

2. Study Literature
   After finding the problem, a literature study is needed to connect the problem with existing theories and fact from many source. The required literature is literature that contain anything about any aspect that this thesis needed. The study of literature is done by reading journals, paper, thesis, and literature book that contain about what the thesis needed.

3. Design of Unbalanced Load Experiment
   Preparing the Unbalanced Load Experiment by designing plot for the experiment.

4. Setting of generator driven by DC and AC motor Experiment
   In this stage after preparing the unbalanced load experiment, inputting the setting that needed such as the load condition, and scale so the experiment can be started.

5. Measurement
   This stage is when measuring the parameter of total load, voltage, current, speed and fuel consumption.

6. Analyze the Experiment Result
   In this stage the correlation between the fuel consumption and balanced or unbalanced load will be described in chart. Graphical result will be the output of this stage.

7. Conclusion
   This stage is the last stage, it contains about the conclusion of the result of this thesis. On this stage will explain about the result of data collecting, also the question of problem will be answered in this stage.

CHAPTER 4
DATA ANALYSIS

4.1 Generator Specification

The generator that been used is located at Marine Electrical and Automation System (MEAS) Laboratory, Marine Engineering Department. This are the data of generator that was use in this experiment:

AC Motor Power = 4 kW
Generator Power = 2 kVA

DC Motor Power = 1,5 kW
Generator Power = 600 VA

4.2. Laboratory Equipment

These are the equipment that were used:

- Incandescent Light Bulb Lamp 40 Watt
- Tube Luminescent Lamp 36 Watt
- Electrical Source (In this case is three phase synchronous generator) in MEAS Laboratory
- Ampere Meter
- Multitester
- Three Phase Measurement
- Another Equipment

4.3 Experiment Stages

4.3.1 Balanced and Unbalanced Load Experiment Driven by DC Motor

The experiment stages describe as follows:

1. Turn on the switch on/off in regulator that connect to DC motor
2. rotate the regulator to drive the DC motor
3. Measure the value of current that going into the motor
4. Take the SO Phase value 220 Volt
5. Measure the value of phase voltage

6. Measure the value of each phase current
7. After the data was recorded, then use the same steps on variation of generator load with balanced and unbalanced load condition

4.3.2 Balanced and Unbalanced Load Experiment Driven by AC Motor

1. Turn on the switch on/off in AC motor panel
2. Rotate the regulator to give generator excitation current.
3. Turn on the load switch
4. Measure the value of properties in motor
5. Measure the value of properties in generator .
6. Change the load value and repeat step number 4 and 5.

4.4 Balanced and Unbalanced Load Experiment Driven by DC Motor

Basically, the procedure of the experiment in balanced and unbalanced load condition is same. But, different only on load condition. The position of load in each phase is different (total load in each phase is different).

4.4.1 Generator With Resistive Load

These are the result of the experiment on balanced and unbalanced resistive load on the generator that driven by DC Motor.

R (Watt)	S (Watt)	T (Watt)	IR (A)	IS (A)	IT (A)	RPM	RO (V)	SO (V)	TO (V)
160	160	160	0.59	0.59	0.59	1500	220	217	220
200	160	120	0.75	0.61	0.44	1510	218	217	217
240	160	80	0.95	0.6	0.28	1514	215	217	217

R (Watt)	S (Watt)	T (Watt)	RS (V)	RT (V)	ST (V)	F
160	160	160	380	370	370	50.5
200	160	120	380	385	386	50.5
240	160	80	383	375	385	50.5

R (Watt)	S (Watt)	T (Watt)	Vt (V)	J (A)	K (A)	A (A)	H (A)
160	160	160	73	0.02	0.3	9.92	9.92
200	160	120	74	0.02	0.1	10.2	10.2
240	160	80	74	0.03	0.11	10.2	10.1

Table 4. 1 DC Motor and Load Data on Resistive Load

Total Net Current Value

Experiment 1 (Balanced Load) = 0.59A + 0.59A + 0.59A
= 1.77A

Experiment 2 (Unbalanced Load) = 0.75A + 0.61A + 0.44A
= 1.8 A

Experiment 3 (Unbalanced Load) = 0.95A + 0.6A + 0.28A
= 1.83A

Input Power Motor DC

Experiment 1 (Balanced Load)

P = V x (Ij + Ia)
= 73 x (0.02A + 9.92A)
= 724.18 Watt

Experiment 2 (Unbalanced Load)

P = V x (Ij + Ia)
= 74 x (0.02A + 10.2A)
= 756.28Watt

Experiment 3 (Unbalanced Load)

P = V x (Ij + Ia)
= 74 x (0.03A + 10.2A)
= 757.02 Watt

Output Power (Generator Power)
Experiment 1 (Balanced Load)

P_R = V_R x I_R
= 220V x 0.59A
= 129.8 Watt

P_S = V_S x I_S
= 217V x 0.59A
= 128.03 Watt

P_T = V_T x I_T
= 220V x 0.59A
= 129.8 Watt

Poutput Total
Pout = $P_R + P_S + P_T$
= 129.8 + 128.03 + 129.8
= 387.63 Watt

Experiment 2 (Unbalanced Load)

P_R = V_R x I_R
= 218V x 0.75A
= 163.5 Watt

P_S = V_S x I_S
= 217V x 0.61A
= 132.37 Watt

P_T = V_T x I_T
= 217V x 0.449A
= 95.48 Watt

Poutput Total
Pout = $P_R + P_S + P_T$
= 163.5+ 132.37 + 95.48
= 391.35 Watt

Experiment 3 (Unbalanced Load)

P_R = V_R x I_R

= 215V x 0.95A

= 204.25 Watt

P_S = V_S x I_S

= 217V x 0.6A

= 130.2 Watt

P_T = V_T x I_T

= 217V x 0.28A

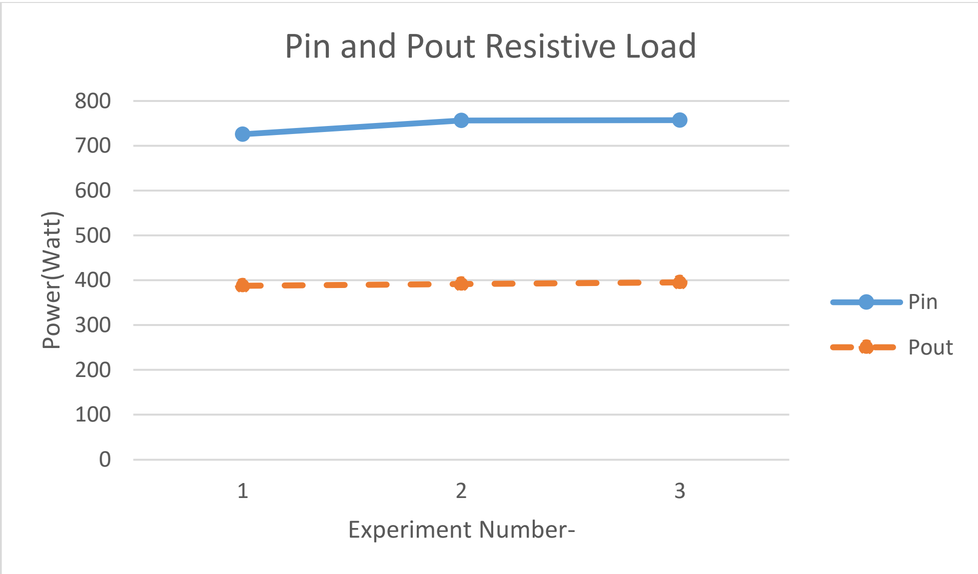
= 60.76 Watt

Poutput Total

Pout = $P_R + P_S + P_T$

= 129.8 + 128.03 + 129.8

= 395.21Watt



Graph 4. 1 The Relation Between Pin and Pout Resistive Load

Efficiency

Experiment 1 (Balanced Load)

Pin = 725.62 Watt

Pout = 387.63 Watt

Eff $= \frac{387.63}{725.62}$ x 100% = 53.4%

Experiment 2 (Unblanced Load)

Pin = 756.28 Watt

Pout = 391.35 Watt

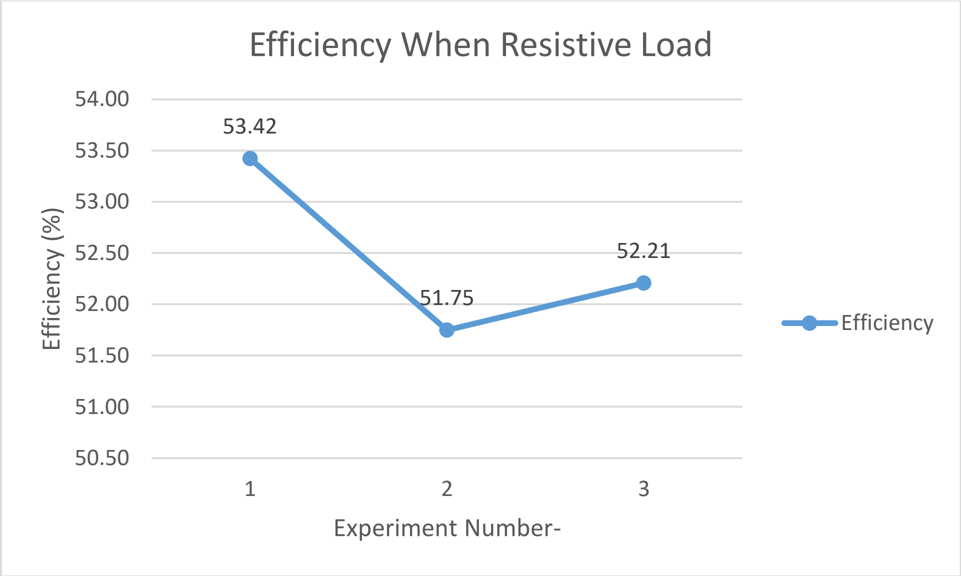
Eff $= \frac{391.35}{756.28}$ x 100% = 51.74%

Experiment 3 (Unbalanced Load)

Pin = 757.02 Watt

Pout = 395.21 Watt

Eff $= \frac{395.21}{757.02}$ x 100% = 52.2%



Graph 4. 2 The Relation Between Efficiency and Unbalanced Resistive Load

4.4.2 Generator With Resistive + Inductive Load

These are the result of the experiment on balanced and unbalanced, resistive and inductive load on the generator that driven by DC Motor.

R (Watt)	S (Watt)	T (Watt)	IR (A)	IS (A)	IT (A)	RPM	RO (V)	SO (V)	TO (V)
120	40+72	108	0.45	0.82	0.92	1504	221	210	210
160	40+72	72	0.61	0.82	0.61	1528	218	210	213
200	40+72	36	0.75	0.82	0.28	1510	214	210	218

R (Watt)	S (Watt)	T (Watt)	RS (V)	RT (V)	ST (V)	F (Hz)
120	40+72	108	368	377	365	50.5
160	40+72	72	378	374	370	50.5
200	40+72	36	380	375	375	50.5

R (Watt)	S (Watt)	T (Watt)	Vt (V)	J (A)	K (A)	A (A)	H (A)
120	40+72	108	72	0.04	0.2	9	9.3
160	40+72	72	73	0.07	0.22	9.18	9.3
200	40+72	36	73	0.03	0.23	9.07	9.31

Table 4. 2 DC Motor and Load Data on Inductive and Resistive Load

Total Net Current Value

Experiment 1 (Balanced Load) = 0.45A + 0.82A + 0.92A
= 2.19A

Experiment 2 (Unbalanced Load) = 0.61A + 0.82A + 0.61A
= 2.04A

Experiment 3 (Unbalanced Load) = 0.75A + 0.82A + 0.28A
= 1.85A

Input Power Motor DC

Experiment 1 (Balanced Load)

$P = V \times (Ij + Ia)$
$= 72 \times (0.04A + 9\ A)$
$= 650.88$ Watt

Experiment 2 (Unbalanced Load)

$P = V \times (Ij + Ia)$
$= 73 \times (0.07A + 9.18A)$
$= 675.25$Watt

Experiment 3 (Unbalanced Load)

$P = V \times (Ij + Ia)$
$= 73 \times (0.03A + 9.07A)$
$= 664.3$ Watt

Output Power (Generator Power)

Experiment 1 (Balanced Load)

$P_R = V_R \times I_R$
$= 211V \times 0.45A$
$= 99.45$ Watt

$P_S = V_S \times I_S$
$= 210V \times 0.82A$
$= 172.2$ Watt

$P_T = V_T \times I_T$
$= 210V \times 0.92A$
$= 193.2$ Watt

Poutput Total

Pout	=	$P_R + P_S + P_T$
	=	129.8 + 128.03 + 129.8
	=	464.85 Watt

Experiment 2 (Unbalanced Load)

P_R	=	V_R x I_R
	=	218V x 0.61A
	=	132.98 Watt
P_S	=	V_S x I_S
	=	210V x 0.82A
	=	172.2 Watt
P_T	=	V_T x I_T
	=	210V x 0.61A
	=	128.1 Watt

Poutput Total

Pout	=	$P_R + P_S + P_T$
	=	132.98+ 172.2 + 128.1
	=	433.28 Watt

Experiment 3 (Unbalanced Load)

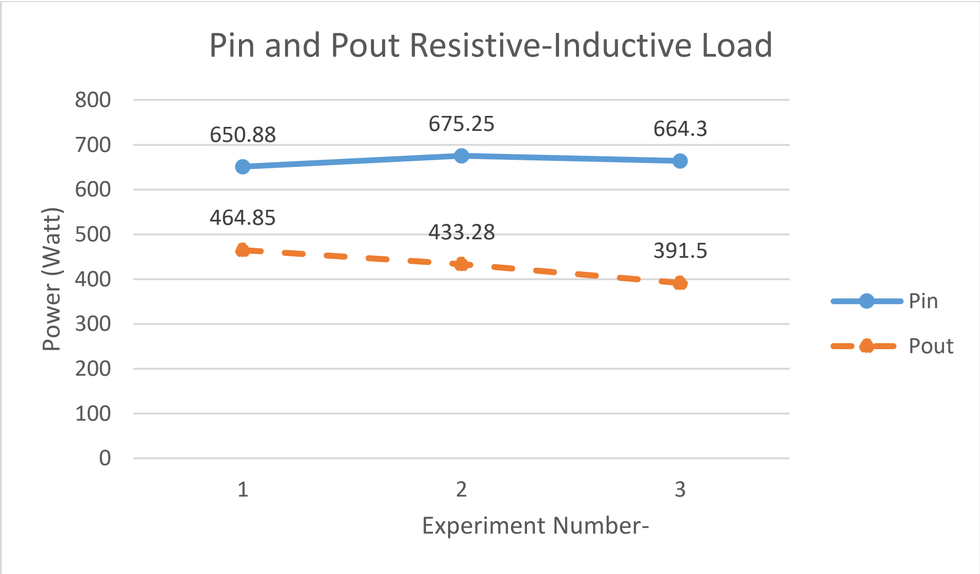
P_R	=	V_R x I_R
	=	214V x 0.75A
	=	160.5 Watt
P_S	=	V_S x I_S
	=	210V x 0.82A
	=	172.2 Watt
P_T	=	V_T x I_T
	=	210V x 0.28A
	=	58.8 Watt

Poutput Total

Pout = $P_R + P_S + P_T$

= 160.5 + 172.2 + 58.8

= 391.5 Watt



Graph 4. 3 The Relation Between Pin and Pout Resistive and Inductive Load

Generator Power Produced

Experiment 1 (Balanced Load)

Pin = 650.88 Watt

Pout = 464.85 Watt

Eff $= \frac{464.85}{650.88}$ x 100% = 71.41%

Experiment 2 (Unblanced Load)

Pin = 675.25 Watt

Pout = 433.28 Watt

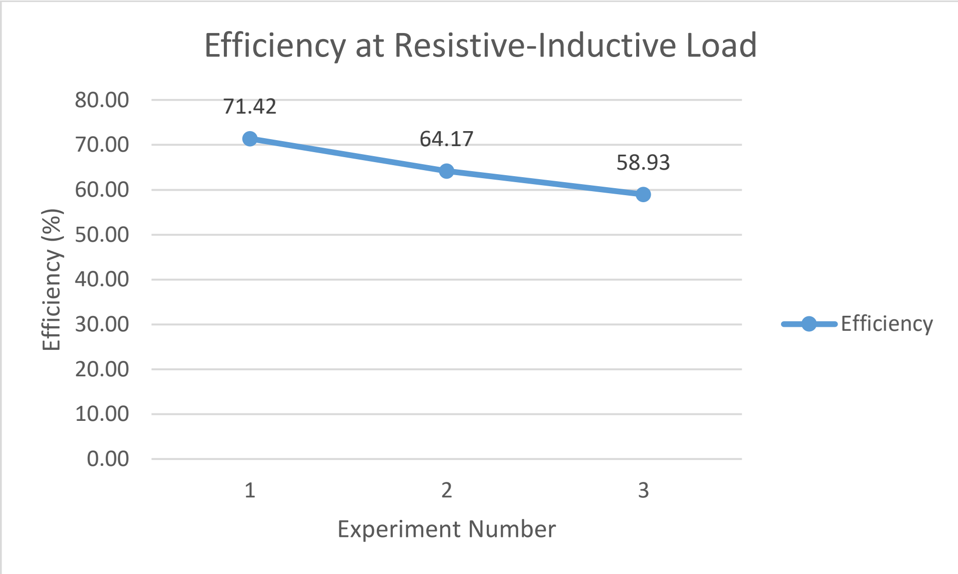
Eff $= \frac{433.28}{675.25}$ x 100% = 64.16%

Experiment 3 (Unbalanced Load)

Pin = 664.3 Watt

Pout = 391.5 Watt

Eff $= \frac{391.5}{664.3} \times 100\% = 58.93\%$



Graph 4. 4 The Relation Between Efficiency and Unbalanced Resistive Load

4.5 Balanced and Unbalanced Load Experiment Driven by AC Motor
4.5.1 Generator with Resistive Load

This are the result of of the experiment on balanced and unbalanced, resistive load on the generator that driven by AC Motor

Group	No	V	Load Each Phase (W)			Current Each Phase (A)		
			R	S	T	IR	IS	IT
A	1	394	200	200	200	5.6	5.81	5.79
	2	395	200	200	160	5.55	5.71	5.6
	3	394	200	200	120	5.59	5.71	5.71
	4	394	200	200	80	5.53	5.75	5.71
	5	395	200	200	40	5.65	5.73	5.74
B	1	394	200	160	160	5.66	5.86	5.8
	2	395	200	160	120	5.59	5.8	5.72
	3	395	200	160	80	5.57	5.77	5.64
	4	396	200	160	40	5.6	5.75	5.68
C	1	395	200	120	120	5.7	5.83	5.63
	2	396	200	120	80	5.66	5.86	5.71
	3	396	200	120	40	5.62	5.84	5.7
D	1	396	200	80	80	5.6	5.8	5.62
	2	397	200	80	40	5.62	5.78	5.65
	3	397	200	40	40	5.6	5.78	5.62
E	1	397	120	120	120	5.55	5.93	5.68
	2	398	120	120	80	5.52	5.83	5.65
	3	399	120	120	40	5.62	5.8	5.76
F	1	398	120	80	80	5.61	5.9	5.72
	2	398	120	80	40	5.55	5.83	5.65
	3	398	120	40	40	5.55	5.84	5.64
	4	398	120	40	0	5.62	5.82	5.58

Table 4. 3 AC Motor Data

Group	No.	Voltage Phase - Netral (V)			Power Each Phase (W)			Power Factor	Power Total (W)
		RO	SO	TO	PR	PS	PT	Cosphi	
A	1	227	226	228	508	525	528	0.4	1560
	2	228	225	228	494	501	498	0.39	1490
	3	227	225	228	482	488	495	0.38	1460
	4	227	226	228	464	481	482	0.37	1430
	5	228	226	228	464	466	471	0.36	1400
B	1	227	226	228	488	503	503	0.38	1490
	2	227	226	228	470	485	483	0.37	1440
	3	227	226	228	455	469	463	0.36	1387
	4	227	226	228	445	455	453	0.35	1350
C	1	228	227	228	468	476	462	0.36	1400
	2	227	227	228	450	466	456	0.35	1370
	3	228	227	229	423	437	431	0.33	1290
D	1	227	227	228	407	421	410	0.32	1240
	2	229	227	228	399	407	399	0.31	1200
	3	228	228	229	383	395	386	0.3	1160
E	1	228	227	229	405	431	416	0.32	1250
	2	229	228	229	392	412	401	0.31	1210
	3	229	229	230	386	398	397	0.3	1180
F	1	228	228	240	384	404	412	0.3	1200
	2	229	228	230	381	399	390	0.3	1170
	3	229	227	230	369	384	376	0.29	1130
	4	228	229	230	372	387	372	0.29	1130

Table 4. 4 AC Motor Data

Group	No	Voltage (V)	Excitation (A)	Load (W)			Current Each Phase (A)		
				R	S	T	IR	IS	IT
A	1	350	0.46	200	200	200	0.86	0.86	0.86
	2	351	0.49	200	200	160	0.86	0.86	0.69
	3	352	0.5	200	200	120	0.86	0.87	0.51
	4	354	0.46	200	200	80	0.87	0.87	0.34
	5	356	0.48	200	200	40	0.86	0.87	0.17
B	1	352	0.48	200	160	160	0.87	0.69	0.69
	2	354	0.47	200	160	120	0.87	0.69	0.52
	3	357	0.46	200	160	80	0.87	0.7	0.34
	4	359	0.46	200	160	40	0.87	0.7	0.17
C	1	358	0.48	200	120	120	0.87	0.52	0.52
	2	359	0.48	200	120	80	0.88	0.52	0.34
	3	361	0.48	200	120	40	0.87	0.53	0.17
D	1	359	0.48	200	80	80	0.87	0.35	0.34
	2	363	0.49	200	80	40	0.88	0.35	0.17
	3	366	0.49	200	40	40	0.88	0.18	0.17
E	1	362	0.49	120	120	120	0.52	0.52	0.52
	2	364	0.49	120	120	80	0.52	0.52	0.36
	3	366	0.49	120	120	40	0.53	0.53	0.18
F	1	366	0.49	120	80	80	0.53	0.35	0.34
	2	368	0.49	120	80	40	0.52	0.35	0.17
	3	369	0.49	120	40	40	0.53	0.18	0.17
	4	371	0.46	120	40	0	0.52	0.18	0

Table 4. 5 AC Generator Data and Load Condition

Group	No.	Voltage Phase – Netral (V)			Power Each Phase (W)			Total Power (W)	Power Factor
		RO	**SO**	**TO**	**PR**	**PS**	**PT**	**Ptot**	**Cosphi**
A	1	205	207	206	176	176	177	529	1
	2	203	207	206	175	178	142	495	1
	3	203	209	207	175	180	107	462	1
	4	203	210	208	177	182	71.6	430.6	1
	5	203	212	210	175	184	36.3	395.3	1
B	1	206	208	206	179	142	142	463	1
	2	205	210	207	178	144	107	429	1
	3	205	213	208	178	149	70.9	397.9	1
	4	204	214	211	177	151	36.6	364.6	1
C	1	207	214	207	180	112	107	399	1
	2	206	214	208	181	112	71.2	364.2	1
	3	206	215	210	179	113	36.9	328.9	1
D	1	208	216	208	181	76	71	328	1
	2	207	218	211	182	76.3	36.5	294.8	1
	3	209	220	211	184	39.2	36.7	259.9	1
E	1	210	213	210	109	112	109	330	1
	2	209	215	212	109	113	72.4	294.4	1
	3	209	216	214	111	114	37.5	262.5	1
F	1	211	216	212	112	75.7	72.6	260.3	1
	2	210	217	212	109	76.2	36.9	222.1	1
	3	211	219	213	112	38.1	35.4	185.5	1
	4	212	221	215	110	37.8	0	147.8	0.98

Table 4. 6 AC Generator Data and Load Condition

AC Motor Apparent Power

S_{motor} = $V \times I \times \sqrt{3}$

= $415V \times 5.5A \times \sqrt{3}$

= 3948.725 VA

AC Motor Power Factor

$Cos\varphi$ = $P_{motor}(W)/S_{motor}(VA)$

= $1280/415V \times 5.5A \times \sqrt{3}$

= 0.324

Load Apparent Power

S_R = $V_R \times I_R$

= $205V \times 0.86A$

= 176.3 Watt

S_S = $V_S \times I_S$

= $207V \times 0.86A$

= 178.02 Watt

S_T = $V_T \times I_T$

= $206V \times 0.86A$

= 177.16 Watt

Soutput Total

Sout = $S_R + S_S + S_T$

= 176.3 + 178 + 177.16

= 531.5 Watt

Power Factor on Load

$Cos\varphi$ = P(Watt)/ Sout

= $529/415V \times 0.52A \times \sqrt{3}$

= 0.996

Efficiency Calculation

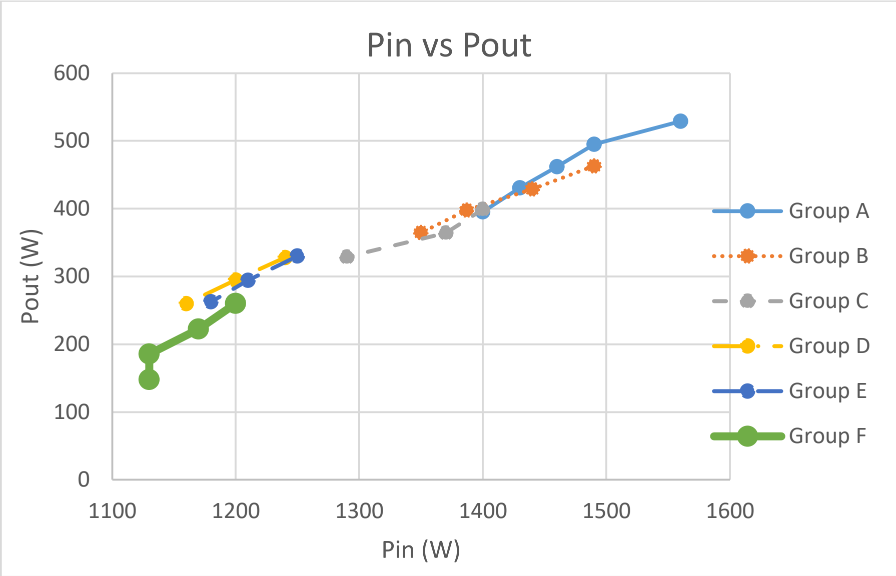
$$\text{Eff} = \frac{Pout}{Pin} \times 100\%$$

$$= \frac{529}{1560} \times 100\%$$

$$= 39.1\%$$

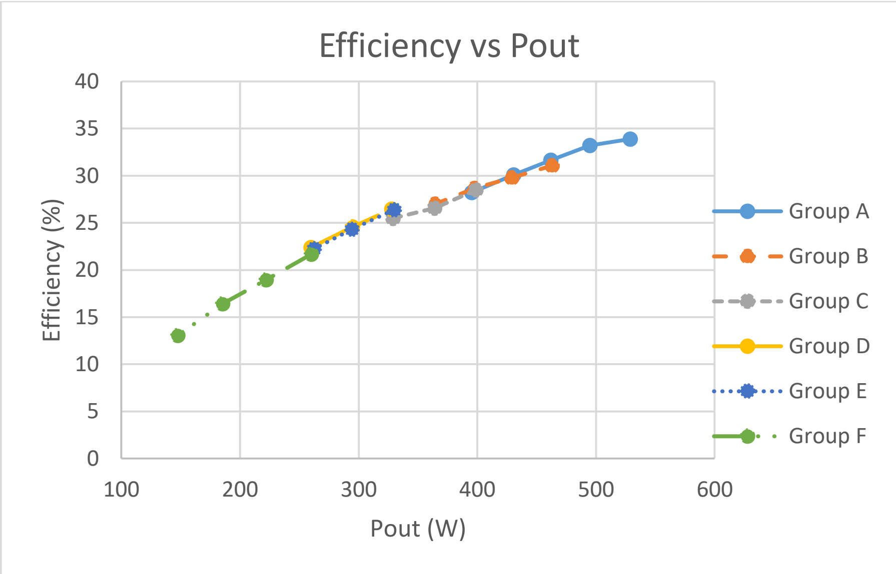
Group	No	Pout	Pin	Eff (%)
A	1	529.00	1560	33.91
	2	495.00	1490	33.22
	3	462.00	1460	31.64
	4	430.60	1430	30.11
	5	395.30	1400	28.24
B	1	463.00	1490	31.07
	2	429.00	1440	29.79
	3	397.90	1387	28.69
	4	364.60	1350	27.01
C	1	399.00	1400	28.50
	2	364.20	1370	26.58
	3	328.90	1290	25.50
D	1	328.00	1240	26.45
	2	294.80	1200	24.57
	3	259.90	1160	22.41
E	1	330.00	1250	26.40
	2	294.40	1210	24.33
	3	262.50	1180	22.25
F	1	260.30	1200	21.69
	2	222.10	1170	18.98
	3	185.50	1130	16.42
	4	147.80	1130	13.08

Table 4. 7 Efficiency Data



Graph 4. 5 The Relation Between Pin and Pout Unbalanced Resistive Load

From graph the relation between Input Power and Load are directly proportional. The higher the load the higher input power.



Graph 4. 6 The Relation Between Efficiency and Pout Unbalanced Resistive Load

From graph 4.6 the relation between efficiency and Power on load are directly proportional. The higher the load the higher efficiency.

4.5.2 Generator With Inductive and Resistive Load

This are the result of of the experiment on balanced and unbalanced, resistive and inductive load on the generator that driven by AC Motor

The data from running divided by 5 group and in each group there are difference in the percentage of unbalanced load

Group A are data with only resistive load
Group B are data on unbalanced load with resistive and inductive load (Unbalanced inductive load on phase T)
Group C are data on unbalanced load with resistive and inductive load (Unbalanced inductive load on phase S, and T)
Group D are data on unbalanced load with resistive and inductive load (Unbalanced resistive load on phase T)
Group E are data on unbalanced load with resistive and load (Unbalanced resistive load on phase S, and T

Group	No.	Current (A)	Voltage (V)	Load (W)			Current Each Phase (A)		
		I	V	R	S	T	IR	IS	IT
A	1	5.5	415	120	120	120	5.5	5.5	5.49
	2	5.48	415	120	120	80	5.5	5.5	5.46
	3	5.47	415	120	120	40	5.5	5.5	5.42
B	1	5.5	415	120 + 72	120 + 72	120 + 72	5.5	5.5	5.5
	2	5.5	416	120 + 72	120 + 72	120 + 36	5.5	5.5	5.5
	3	5.5	416	120 + 72	120 + 72	120	5.5	5.5	5.5
C	1	5.5	416	120 + 72	120 + 36	120 + 36	5.5	5.5	5.5
	2	5.5	416	120 + 72	120 + 36	120	5.5	5.5	5.5
	3	5.5	416	120 + 72	120	120	5.5	5.5	5.5
D	1	5.5	416	80 + 72	80 + 72	80 + 72	5.5	5.5	5.5
	2	5.5	416	80 + 72	80 + 72	40 + 72	5.5	5.5	5.5
	3	5.5	416	80 + 72	80 + 72	0 +72	5.5	5.5	5.5
E	1	5.5	416	80 + 72	40 + 72	40 + 72	5.5	5.5	5.5
	2	5.48	417	80 + 72	40 + 72	0 + 72	5.5	5.9	5.5
	3	5.48	417	80 + 72	0 + 72	0 + 72	5.5	5.5	5.5

Table 4. 8 AC Motor Data

Group	No.	Voltage Each Phase (V)			Power (kW)	Power Factor
		RO	SO	TO	Ptot	Cosphi
A	1.	242	239	237	1.28	0.32
	2.	243	240	238	1.23	0.31
	3.	242	240	237	1.2	0.3
B	1.	242	240	237	1.55	0.39
	2.	243	240	238	1.51	0.38
	3.	243	240	238	1.46	0.37
C	1.	242	240	237	1.47	0.37
	2.	242	240	238	1.47	0.36
	3.	242	240	238	1.38	0.35
D	1.	243	240	238	1.45	0.36
	2.	243	240	238	1.4	0.35
	3.	243	240	238	1.38	0.35
E	1.	243	240	238	1.38	0.35
	2.	242	241	238	1.32	0.33
	3.	243	241	238	1.29	0.33

Table 4. 9 AC Motor Data

Group	No.	Excitation (A)	Voltage (V)	Load			Current Each Phase		
		I	V	R	S	T	IR	IS	IT
A	1	0.52	380	120	120	120	0.53	0.53	0.53
	2	0.52	379	120	120	80	0.53	0.53	0.35
	3	0.53	384	120	120	40	0.53	0.53	0.17
B	1	0.82	382	120 + 72	120 + 72	120 + 72	1.16	1.17	1.17
	2	0.76	383	120 + 72	120 + 72	120 + 36	1.15	1.15	0.8
	3	0.71	378	120 + 72	120 + 72	120	1.14	1.14	0.54
C	1	0.71	384	120 + 72	120 + 36	120 + 36	1.13	0.81	0.8
	2	0.66	378	120 + 72	120 + 36	120	1.12	0.8	0.54
	3	0.63	376	120 + 72	120	120	1.11	0.53	0.54
D	1	0.78	384	80 + 72	80 + 72	80 + 72	1.01	1.03	1
	2	0.75	385	80 + 72	80 + 72	40 + 72	1	1.01	0.87
	3	0.75	379	80 + 72	80 + 72	0 +72	1.01	1	0.79
E	1	0.75	385	80 + 72	40 + 72	40 + 72	0.99	0.89	0.88
	2	0.7	381	80 + 72	40 + 72	0 + 72	0.96	0.86	0.76
	3	0.7	378	80 + 72	0 + 72	0 + 72	0.95	0.78	0.77

Table 4. 10 AC Generator Data and Load Condition

Group	No.	Voltage each Phase (V)			Power total (W)	Power Factor	Power each phase (W)		
		RO	SO	TO	Ptot	Cosphi	P1	P2	P3
A	1	220	223	219	348	1	116	117	117
	2	220	222	221	308	1	115	116	77
	3	221	223	223	273	1	117	118	39.1
B	1	222	225	220	625	0.81	209	211	203
	2	221	221	222	575	0.84	207	207	162
	3	220	219	227	532	0.88	204	205	122
C	1	218	225	224	528	0.87	201	164	162
	2	216	223	227	485	0.92	201	162	122
	3	220	226	226	439	0.96	197	121	121
D	1	218	224	223	505	0.75	169	173	169
	2	219	222	220	467	0.73	167	168	128
	3	218	222	222	428	0.7	167	170	91.8
E	1	218	225	221	429	0.7	163	131	127
	2	216	222	218	380	0.67	158	125	93.3
	3	216	222	218	343	0.63	156	88.3	94.5

Table 4. 11 AC Generator Data and Load Condition

AC Motor Apparent Power

S_{motor} = V x I x $\sqrt{3}$

= 415V x 5.5A x $\sqrt{3}$

= 3948.725 VA

AC Motor Power Factor

Cosφ = P_{motor}(W)/S_{motor}(VA)

= 1280/415V x 5.5A x $\sqrt{3}$

= 0.324

Load Apparent Power

S_{load} = V x I x $\sqrt{3}$

= 415V x 0.52A x $\sqrt{3}$

Power Factor on Load

Cosφ = P(Watt)/V x I x $\sqrt{3}$

= 348/415V x 0.52A x $\sqrt{3}$

= 1

Efficiency Calculation

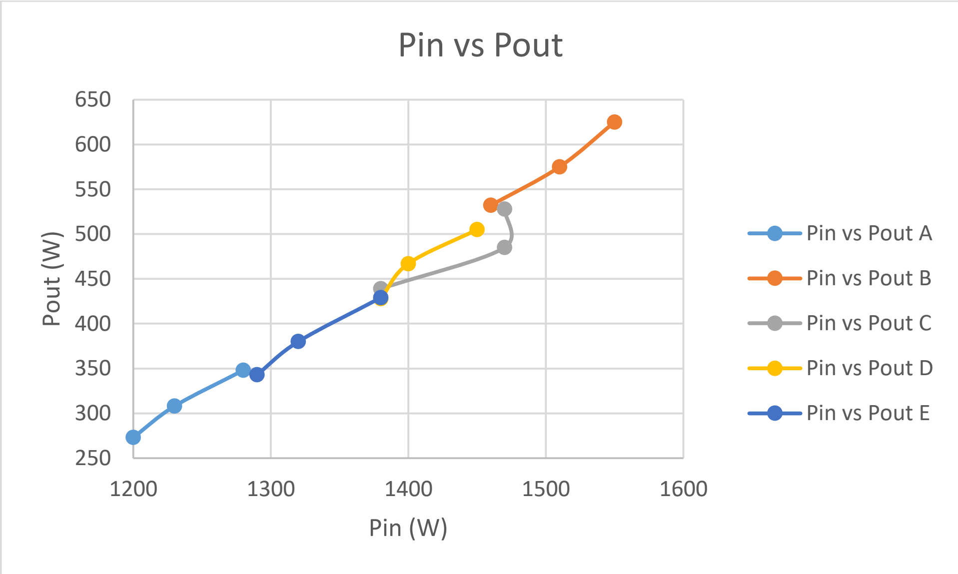
Eff = $\frac{Pout}{Pin}$ x 100%

= $\frac{348}{1280}$ x 100%

= 27.2%

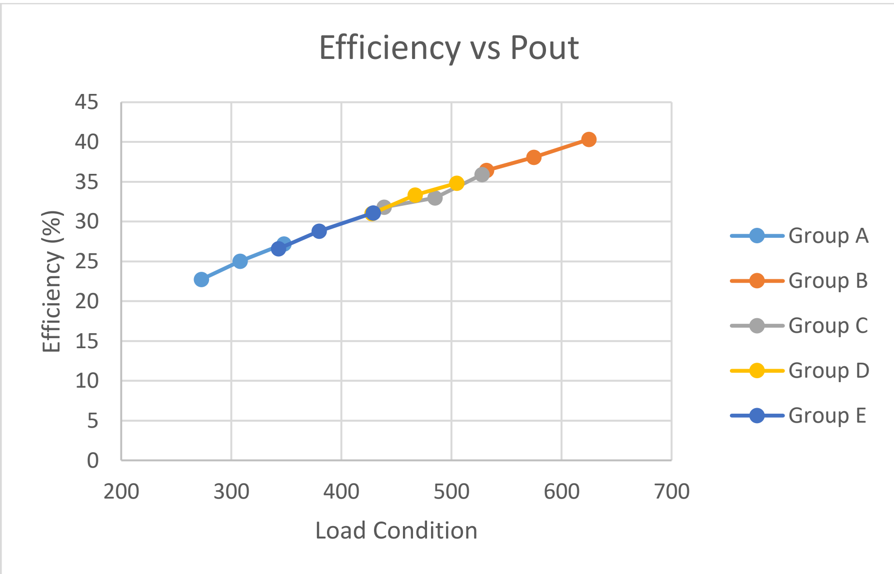
Group	No.	Pin	Pout	Eff
A	1	1280	348	27.19
	2	1230	308	25.04
	3	1200	273	22.75
B	1	1550	625	40.32
	2	1510	575	38.08
	3	1460	532	36.44
C	1	1470	528	35.92
	2	1470	485	32.99
	3	1380	439	31.81
D	1	1450	505	34.83
	2	1400	467	33.36
	3	1380	428	31.01
E	1	1380	429	31.09
	2	1320	380	28.79
	3	1290	343	26.59

Table 4. 12 Efficiency Data.



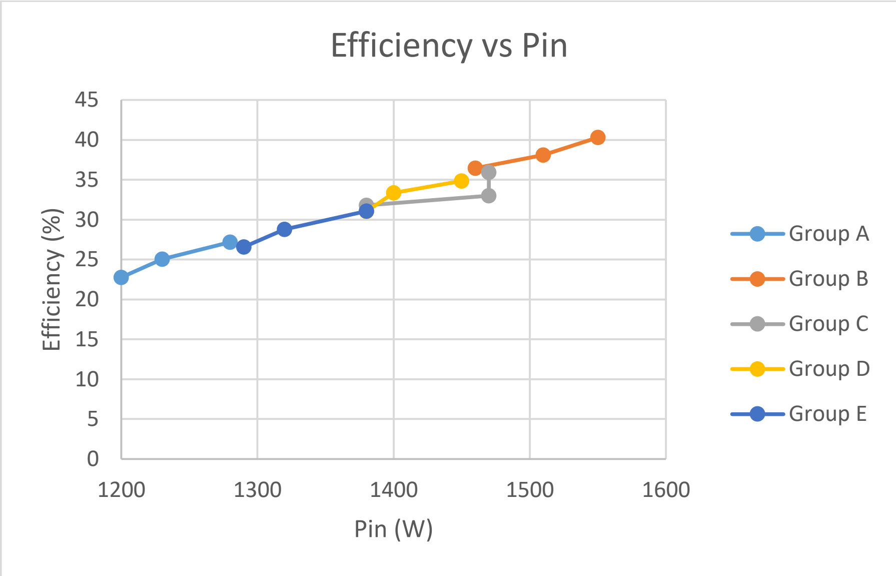
Graph 4. 7 The Relation Between Pin and Pout Unbalanced Resistive and Inductive Load

From graph above the relation between input power and output power are directly proportional, if the load power increase the input power is increase too.



Graph 4. 8 The Relation Between Efficiency and Pout Unbalanced Resistive and Inductive Load

From graph 4.8 the relation between efficiency and Power on load are directly proportional. The higher the load the higher efficiency.



Graph 4. 9 The Relation Between Efficiency and Pin Unbalanced Resistive and Inductive Load

From graph 4.9 the relation between efficiency and Power on Motor are directly proportional. The higher the power input the higher efficiency.

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CHAPTER 5
CONCLUSION

5.1 Conclusion

After analyze the result of experiment can be concluded that :

1. The difference in phase load didn't make effect on the motor that drive the generator. The one that effect the motor is the difference in Load power.

2. On experiment using AC motor if the load increase then the power on motor is increasing too. Same goes to the efficiency, when the load is increasing the efficiency is increasing too. According to data, if the unbalanced load difference is increase, the efficiency will decreasing too if the load power decrease. But if the load have the same power but different unbalanced state the efficiency not so much affected.

5.2 Suggestion

The Suggestion from this research are:

1. There is further research on experiment with higher load.
2. There is further research on experiment measuring the temperature increase on generator when unbalance load.
3. There is further research using auxiliary engine on ship.

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Lanang, Sang: Sardono Sarwito: Indra Ranu K:(2013) Analisa Pengaruh Beban Induktif dan Resistif pada Generator Induksi pada Pembangkit Listrik Tenaga Gelombang Laut (PLTGL). Institut Teknologi Sepuluh Nopember, Surabaya

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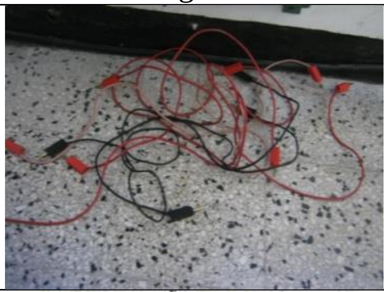
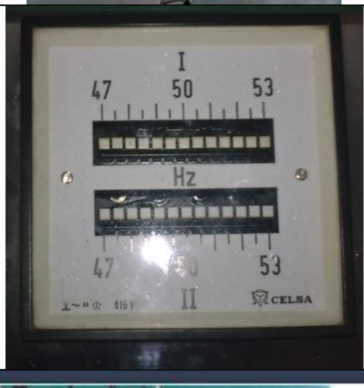
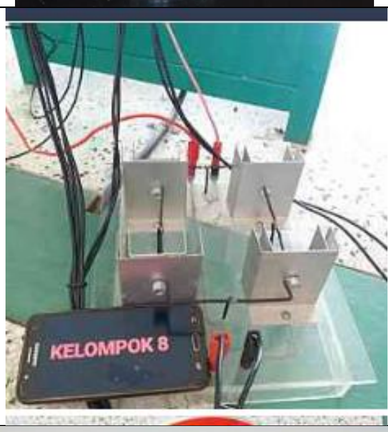
LIST OF LABORATORY EQUIPMENT

No.	Equipment	Figure	Function
1.	Cable		To connect the system
2.	Tangmeter		To measure current
3.	Multitester		To measure voltage
4.	Regulator		To set the excitation

No.	Equipment	Figure	Function
5.	Three Phase Induction Motor		Generator Mover
6.	DC Shunt Motor		Generator Mover
7.	Three Phase Synchronous Generator		Generate Electricity
8.	Incandescent Light Bulb		Load

No.	Equipment	Figure	Function
9.	Fluorescent Lamp		Load
10.	Frequency Meter		Measure Frequency
11.	Rectifier		Change current from AC to DC
12.	Three Phase Measurement		Measure voltage, current, power.

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AUTHOR BIOGRAPHY

The Author's name is Kevin, born on 23 May 1996 in Jakarta. As the second child of two siblings. Derived from a simple familywith a Father named Adri Sarosa and Mother named Sri Ami Sulistyaningrum. Author had completed the formal education at SD Pembangunan Jaya(2002-2008) for elementary school, he continued his study at SMP Negeri 19 Jakarta(2008-2011) for junior high school, and SMAN 29 Jakarta(2011-2014) for senior highschool. In 2014, author proceed to pursue bachelor degree at Department of Marine Engineering (Double Degree Program with Hochschule Wismar), Faculty of Marine Engineering, Institut Teknologi Sepuluh Nopember Surabaya specializes in Marine Electrical and Automation System field. During the study period, Author did On Job Training at PT. Dok dan Perkapalan Surabaya and PT. Pelindo Marine Service. For further discussion and suggesting regarding this research, author can be contacted with email below

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