BACHELOR THESIS & COLLOQUIUM – ME184841

ANALYSIS OF UNBALANCE VOLTAGE FOR SHIP'S DYNAMIC POSITIONING ELECTRICAL SYSTEM ON A LABORATORY SCALE

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DOUBLE DEGREE PROGRAM
DEPARTEMENT OF MARINE ENGINEERING
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TUGAS AKHIR – ME184841

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APPROVAL FORM

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BACHELOR THESIS

Submitted as one of Requirements to obtain Bachelor Degree in Engineering
on
Marine Electrical and Automation System (MEAS)
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Surabaya, August 2019

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Analysis of Unbalance Voltage for Ship's Dynamic Positioning Electrical System on a Laboratory Scale

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Abstract

Dynamic Positioning system is a system that maintains an offshore structure and also ships so that the structure can maintain its position on certain coordinate that the have been assigned. The dynamic positioning system uses thrusters to maintain is position, that is causing a lot of more power needed to supply. Because of that consumption of fuel also increased. In installing a dynamic positioning system, the configuration is usually in a split bus configuration. As of lately, there are a lot of concern in changing to a close bus configuration because in theory the system will have high efficiency and low emission. This analysis is done to analyze the condition of unbalance voltage of dynamic positioning system of a ship that have been modelled onto a laboratory scale system. Several scenarios and variations are used to see the condition of the unbalance. Some of the result are the system results in 220V∠0°, 218V∠-113.7°, 218V∠123.18° in scenario 1 variation 1, 220V∠0°, 220V∠-120°, 218∠120° in scenario 2 variation 1, and last 219∠0°, 220∠-120°, 220∠120° for scenario 3 variation 1. The highest unbalance condition happens on scenario 1 variation 3 with a PVUR of 0.78%.

Keywords: Dynamic Positioning System, Unbalance Voltage, Closed Bus System

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Analysis of Unbalance Voltage for Ship's Dynamic Positioning Electrical System on a Laboratory Scale

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Abstrak

Sistem dynamic positioning merupakan sebuah sistem yang merupakan sistem yang membantu bangunan lepas pantai dan juga kapal agar dapat mempertahankan posisi mereka di suatu koordinat yang sudah di tentukan. Sistem dynamic positioning memerlukan jumlah thruster yang lebih yang berkerja sebagai penggerak dalam menstabilkan posisi objek. Dalam hal itu, sistem memerlukan daya yang lebih besar, sehingga konsumsi bahan bakarpun lebih besar. Dalam penginstalan sistem dynamic positioning, sistem split bus merupakan konfigurasi yang sering di lakukan, yaitu satu thruster digerakkan oleh satu generator. Hal tersebut membuat sistem dynamic positioning lebih cenderung untuk mengalami kegagalan. Penelitian ini mengarah kepada sistem dynamic positioning yang menggunakan sistem closed bus dengan memodelkan rangkaian kedalam bentuk peralatan laboratorium yang sudah ditentukan. Penelitian ini akan lebih mengarah kepada masalah ketidakseimbangan daripada sistem dan dampak yang terjadi daripada sistem dynamic positioning. Dari hasil analisa yang dilakukan ketidakseimbangan tidak terjadi pada sebagian besar skenario dan variasi. Salah satu ketidakseimbangan terjadi pada skenario 1 variasi 1 menghasilkan hasil ratio ketidakseimbangan sebesar 0.61% yang merupakan nilai yang lebih dari batas 0.5% yang sudah ditentukan. Salah satu hasil dari pengamatan adalah 220V∠0°, 218V∠-113.7°, 218V∠123.18° pada skenario 1 variasi 1, 220V∠0°, 220V∠-120°, 218∠120° pada skenario 2 variasi 1, dan terakhir 219∠0°, 220∠-120°, 220∠120° untuk skenario 3 variasi 1. Hasil ketidakseimbangan terbesar terjadi pada skenario 1 variasi 3 dengan hasil PVUR sebesar 0.78%.

Keywords: Dynamic Positioning System, Unbalance Voltage, Closed Bus System

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PREFACE

Praises to Allah SWT for His blessing and grace, so that this bachelor thesis titles " Analysis of Unbalance Voltage for Ship's Dynamic Positioning Electrical System on a Laboratory Scale" can be completed. This thesis is submitted as one of the requirements to obtain bachelor's degree of Engineering in Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya.

Many Obstacles came during the completion of this thesis. Therefore, author would like to extend gratitude to everyone who helped finishing this thesis by giving support, idea and suggestion, as follow:

1. The author's parents, Mr. Suhardono and Mrs. Elsie Desianty, alongside the author's brother, Muhmmad Farhan Fadhilla, who have help and give strength to the author in finishing this thesis
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10. All of SALVAGE'15, especially for the Double Degree batch 2015 who are going through this together
11. And others who the author can't name all but grateful about

In order to improve this thesis, any critics and suggestion are expected due to the imperfections of this thesis. Author hopes this thesis can provide any knowledge for readers and give contribution in development of marine technology.

Surabaya, August 2019

Author

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CHAPTER 1
INTRODUCTION

1.1 Background

Voltage unbalance is a condition where the value and/or the sinusoidal angle of each phase are different. Ideally each of the phase in a three phase electrical system have the same magnitudes. With each of the phase differentiate 120° between in each of the phases. Though in reality this could slightly shift a bit, where the value of each phase is different and the angle as well.

Electrical system comes in a lot of types such as an open system, and a close system. Some ships have a system that is called a Dynamic Positioning System or DP system. The DP system is used to maintain the position of a ship or vessel at a certain determined position.

Dynamic positioning system usually runs using a split bus system. But in recent years, research have been done in work to reduce fuel consumption and emission due to the open circuit system. Thus, the close bus system is suggested to give higher efficiency in fuel consumption and decrease of emission.

In running these electrical systems, some electrical fault could happen during it. Such as voltage unbalance, short circuit, harmonics, etc. This could happen because a lot of aspects are influencing the system. It could be the machines or equipment that are at fault, it could be technical problems, and also human error when running the system.

Errors and faults in electrical system could harm and danger the equipment and even the human lives. Because of that, regulations are implanted so that these error does not grow larger. In electrical system, the associations that governs this are usually the IEEE and IEC. Other organizations also have authorities but its usually from IEEE and IEC.

This thesis will focus the aspect of unbalance voltage. Unbalance voltage could happen because of an unbalance load and unbalance current that flow on the close bus system. Single phase loads are one of the reasons that an unbalance load occur. This thesis will analyze if an unbalance voltage happen on the DP system and how to fix it. The analyzing will be using rules from IEEE and IEC to see if the system have an unbalance conditions and how will it affect the system.

1.2 Problem Statements

The problem statements for this bachelor thesis are:

1. What does unbalance voltage do to the performance of a Dynamic Positioning system on a ship with a closed circuit system?
2. What correlations do unbalance voltage have with Voltage Unbalance Factor on ship's thruster generator?

1.3 Scope of Problems

The scope of problems that are used for this bachelor thesis are:

1. The data will be gathered experimentally using the equipment at Marine Electrical and Automation System (MEAS) Laboratory

2. The topic will be focused only on the Dynamic Positioning system of Anchor Handling Tugs Supply (AHTS) BNI Castor vessel
3. The methods that are used are only for research purposes
4. The simulation will not be using a simulation application
5. Costs are not considered

1.4 Objectives

The objectives for this bachelor thesis are:

1. To get the Unbalance Voltage condition caused by a Dynamic Positioning on ship with a closed bus electrical system.
2. To get solutions to minimize the unbalance voltage effect in DP system with a close bus electrical system

1.5 Benefits

The benefits for this bachelor thesis are:

1. As information in using ship's Dynamic Positioning system in operating it in a closed bus electrical system.
2. As information in ship's Dynamic Positioning system planning

CHAPTER 2
LITERATURE STUDY

2.1 Anchor Handling Tug and Supply (AHTS) Vessel

Anchor Handling Tug and Supply (AHTS) vessel is vessel or ship that is used to tug not only ships but also oil-rigs. These AHTS vessels are one of the most important aspect in placing an oil rig in sea areas. Anchor handling tug vessel have winches or cranes that can be attached to oil rigs and will move it. The name anchor supply means that the ship will help the oil rig to be sunk in sea and keep it steady.

Figure 2.1 AHTS Vessel
Source: (www.offshoreenergytoday.com)

AHTS vessels are a type of supply vessels that supply tugs and anchors not just oil rigs but also to cargo-carrying barges, an example of an AHTS vessel can be seen on Figure 2.1. Technically, an AHTS vessel is a very huge naval vessel, mainly because of the equipment that it carries, tugs and anchors along with the winches. In order to transport such a heavy bulk in a manner that they are lost while the AHTS is moving, it is but natural that the design, and construction of such ships has to be accommodating to fit such equipment easily.

On the contrary, AHTS vessels are only designed to perform certain tasks that are practically impossible for the other specifically designed offshore work boats such as the dedicated Platform Support vessels (PSVs), Multi-Platform support vessels (MPSVs)

2.2 Dynamic Positioning

Ship's Dynamic Positioning (DP) is a procedure that automatically maintains a vessel's position and heading by using her own propellers and thrusters. This allows operations at sea where mooring or anchoring is not feasible due to deep water, congestion on the sea bottom (pipelines, templates) or simply the place where DP operations are needed.

DP is defined by (IMCA, 2003), (International Marine Contractors Association) as: A system which automatically controls a vessel position and heading exclusively by means of active thrust. The definition includes remaining at fixed location, precision maneuvering, tracking and other specialist positioning abilities. To infer the mentioned positioning capabilities, a set of well-defined tasks must be carried out. Furthermore, to carry out such tasks a set of resources or DP equipment is essential. Such tasks and resources are depicted in Picture 2.2.

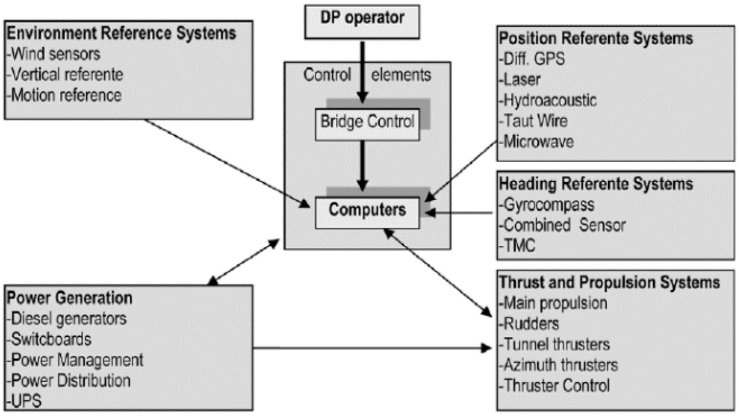

Figure 2.2 Schematic diagram of general DP system showing tasks and resources
Source: (C.S Chas and R. Ferreiro,2008)

The general arrangement of a DP system is shown on Picture 2.3. The necessary equipment to implement a DP system is also shown. With regard to this picture, a set of sensors acquires the necessary information,

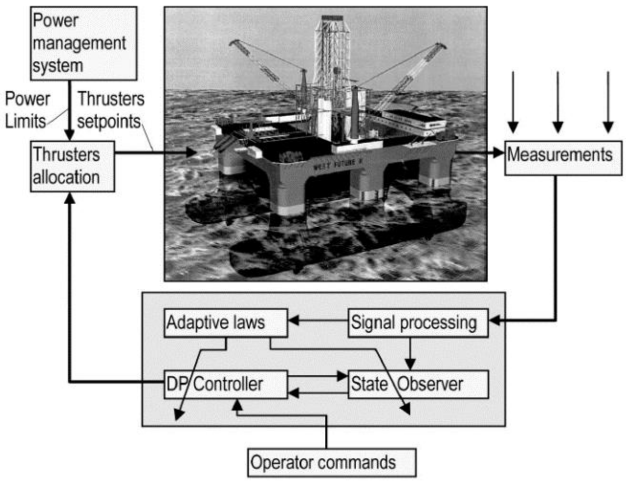

Figure 2.3 The general arrangement of a DP system
Source: (C.S Chas and R. Ferreiro, 2008)

which is processed before entering the control algorithm. The control algorithm computes the thruster setpoints as function of position, speed and environment conditions to operate the thrusters according power demand.

Any vessel can move in six degrees of freedom, three rotations (yaw, pitch and roll) three translations (surge, sway and heave). Dynamic Positioning conventionally is concerned with the automatic control of surge, sway and yaw. Surge and sway are related to the position of the vessel, while yaw is defined by the vessel heading.

Every vessel is subjected to forces from wind, waves and tidal movements (currents) as well as forces generated from the propulsion system and other external elements as fire monitors. The movement of the vessel with changes of position and heading is the result of these forces. Position is measured by position reference systems, while heading information is provided from gyrocompasses.

The vessel must be able to control position and heading within acceptable limits facing the external forces. If these forces are measure directly, the control computers can apply immediate compensation.

The DP control system calculates the offsets between the measured values of position and heading the required values, and after that it calculates the forces that the thrusters must generate in order to reduce the errors to zero.

2.3 Dynamic Positioning Propulsion Systems

The DP capability of the vessel is provided by thrusters. In general, three types of thrusters are fitted in DP vessels; main propellers, tunnel thrusters and azimuth thrusters.

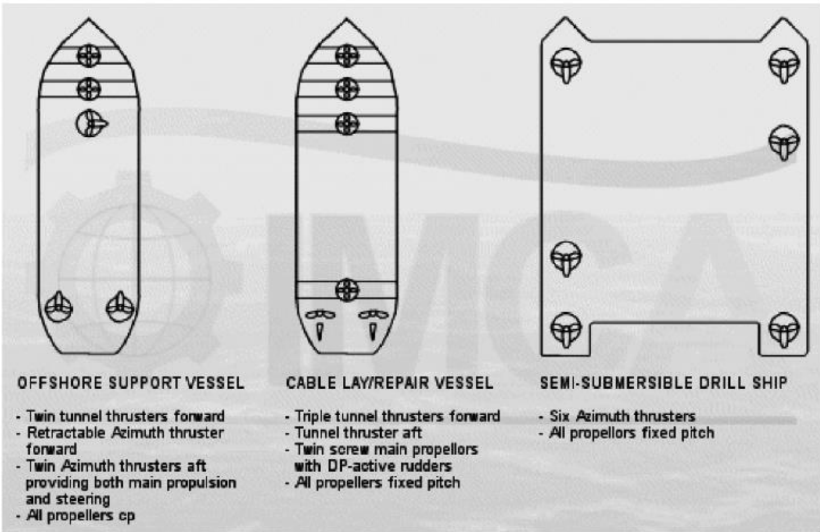

Figure 2.4 Typical Propulsion System Layouts
Source: (C.S Chas and R. Ferreiro, 2008)

In DP vessels propellers may be controllable pitch (cp) running at constant rpm or variable speed. DC motors or frequency – converter systems enable variable speed to be used with fixed-pitch propellers. Main propellers are usually accompanied by conventional rudders and steering gear.

In addition to main propellers, a DP must have well positioned thrusters to control position. Typically, a conventional monohulled type DP vessel will have six thrusters; three at the bow and three aft. Forward thrusters are common, operating together but controlled individually, as are azimuth or compass thrusters aft. Azimuth thrusters project beneath the bottom of the vessel and can be rotated to provide thrust in any direction.

2.4 Three Phase Induction Motor

Induction motor is a motor where its current is a result of induction that happened because of a relative difference between the rotor rotation with the rotational field that the stator current produces. Induction motor have two type based on its phase, which are: Three Phase Induction Motor, can be seen on Figure 2.5, and Single Phase Induction Motor.

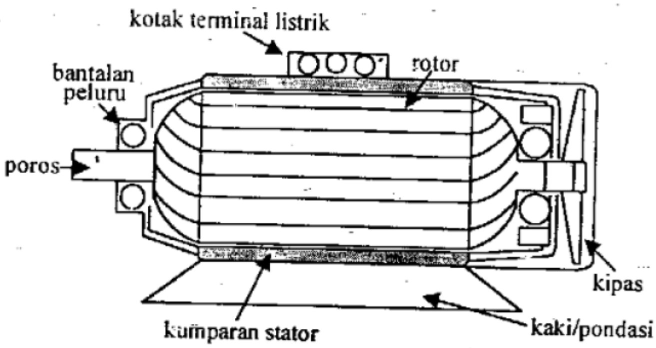

Figure 2.5 Three Phase Induction Motor
Source: (Wijaya Mochtar, 2001)

2.5 Work Principle of Three Phase Induction Motor

There are several work principles for motor induction (Zuhal, 1998):

1. If a three phase source is connected to a stator, a rotational field will occur with a speed of:

   $$n_s = 120\frac{f}{p}$$

   Whereas:

   N_s = Stator speed
   f = frequency
   p = Pole(s) number
2. Stator rotational field will go through the conductor on the rotor

3. Induction voltage (ggl) will occur because of it, which results in

   $$E_{2s} = 4.44 f_2 N_2 \phi_m$$

   Whereas:

   E = Induction voltage (Volt)
   N = Number of windings
   Φ = Flux Maximum (Wb)
4. Because it's a close circuit, ggl will produce current
5. The current will produce Force (F) because of magnetic field on the rotor
6. If the force is strong enough the rotor will move according to the stator field
7. For the voltage to get inducted there is need a relative difference between the stator speed (n_s) and rotor speed (n_r)

8. The difference between n_s and n_r is called slip and can be determined by:

$$S = \frac{n_s - n_r}{n_s} \text{ x } 100\%$$

Whereas:

n_s = Stator speed

n_r = Rotor speed

9. If $n_s = n_r$ there will be no induction and the current wont flow
10. Based on its work principles, induction motor can also be called an async motor

2.6 Unbalance Voltage

Unbalance voltage is an event that occur because the magnitude of phase or line voltages are different and the phase angles differ from the balanced conditions, or both.

2.7 Unbalance Voltage Definition Based by NEMA, IEEE and True Definition

The three definitions of voltage unbalanced are stated below:

1. *NEMA (National Equipment Manufacturer's Association) Definition*: The NEMA definition of voltage unbalance, also known as the line voltage unbalance rate (LVUR), is given by:

$$\%\text{LVUR} = \frac{\text{max voltage deviation from the average line voltage}}{\text{average line voltage}} \text{ x } 100$$

$$\%\text{LVUR} = \frac{\text{Max } [|\text{Vab} - \text{Vavg}| \text{ x } |\text{Vbc} - \text{Vavg}| \text{ x } |\text{Vca} - \text{Vavg}|]}{\text{Vavg}}$$

where as $\text{Vavg} = \frac{\text{Vab+Vbc+Vca}}{3}$

The NEMA definition assumes that the average voltage is always equal to the rated value, which is 480 V for the US three-phase systems and since it works only with magnitude, phase angles are not included.

2. *IEEE Definition*: The IEEE definition of voltage unbalance, also known as the phase voltage unbalance rate (PVUR), is given by:

$$\%\text{PVUR} = \frac{\text{max voltage deviation from the average phase voltage}}{\text{average phase voltage}}$$

$$\%\text{PVUR} = \frac{\text{Max } [|\text{Va} - \text{Vavg}| \text{ x } |\text{Vb} - \text{Vavg}| \text{ x } |\text{Vc} - \text{Vavg}|]}{\text{Vavg}}$$

where as $\text{Vavg} = \frac{\text{Va+Vb+Vc}}{3}$

The IEEE uses the same definition of voltage unbalance as NEMA, the only difference being that the IEEE uses phases voltages rather than line to line voltages. Here again, phase angle information is lost since only magnitudes are considered.

3. *True Definition*: The true definition of voltage unbalance is defined as the ratio of the negative sequence voltage component to the positive sequence voltage component. The percentage voltage unbalance factor (%VUF), or the true definition is given by:

$$\%VUF = \frac{\text{negaative sequence voltage component}}{\text{positive sequence voltage component}}\ x\ 100$$

Based by the definition from NEMA, IEEE, and True Definition, Picture 2.6 will show the correlation of True Definition and NEMA for 2% and 5% of NEMA unbalance voltage.

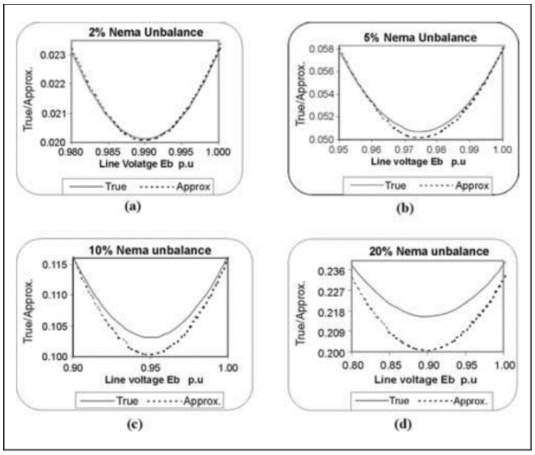

Figure 2.6 Relationship between the true definition of voltage unbalance and NEMA definition for 2%, 5%, 10% and 20% values of NEMA unbalance Relationship between the true definition of voltage unbalance and NEMA definition for 2%, 5%, 10% and 20% values of NEMA unbalance
Source : (P. Pillay et. All, 2001)

2.6 Rules for Unbalance Voltage Based by IEC

One of the other rules that are used in this bachelor thesis to know the Unbalance Voltage for the Dynamic Positioning system if its okay or not okay is the International Electrotechnical Commission (IEC). The IEC regulates many things regarding electrical installation and electrical equipment such as its standard for designing an installation to get high efficiency. One of the parts that IEC regulate is the quality of voltage for electrical installation and electrical equipment. The quality of voltage that was mentioned is the unbalance voltage for electrical installation and electrical equipment. IEC/ TR 61000-3-14 Chapter 10-Unbalance Emission Limits for Unbalanced Installation LV systems shows on Table 2.1.

Table 2.1 IEC Rules

Type of Installation	Lighting %	Other uses %
A – Low voltage installations supplied directly from a public low voltage distribution system	3	5

2.7 Static VAR Compensator

Static VAR compensators (SVCs) contain shunt capacitors and reactors, which are controlled by thyristors. They provide solutions to two types of compensation problems normally encountered in practical power systems:

- The first is load compensation, where the requirements are usually are to reduce the reactive power demand of large and fluctuating industrial loads, and to balance the real power drawn from the supply lines.

- The second type of compensation is related to voltage support of transmission lines at a certain point response to disturbance of both load and generation

The main objectives of dynamic VAR compensation are to increase the stability limit of the power system, to decrease voltage fluctuations during load variations and to limit overvoltage due to large disturbance. The two fundamental thyristor-controlled reactive power device configurations are:

- Thyristor-switched shunt capacitors: The capacitor bank is split into small capacitor steps and those steps are switched on and off individually. It offers stepwise control, virtually no transients and very little harmonic generation. The average delay for executing a command from the regulator is half a cycle
- Thyristor-switched shunt reactors: The fundamental frequency current component through the reactor is controlled by delaying the closing of the thyristor switch with respect to the natural zero crossings of the current.

Harmonic currents are generated from the phase-angle-controlled reactor. These are two methods to reduce the magnitude of the generated harmonics. The first method consists of splitting the reactor into smaller steps, with only one thyristor-controlled step while the other reactor steps are either on or off.
The second method involves the 12-pulse arrangement, where two identically connected thyristor-controlled reactors are used, one operated from wye-connected secondary winding, and the other from a delta-connected winding of a step-up transformer.
Thyristor-switched reactors are characterized by continuous control, and there is a maximum of one half-cycle delay for executing a command from the regulator. In many practical applications, combination of these two thyristor-controlled devices are used, with the SVC consisting of a few steps of thyristor-controlled capacitance and one or two thyristor-controlled reactors. The basic configuration of a static VAR compensator are shown on Figure 2.7.

It is important to note that applying static VAR compensators to series-compensated AC transmission lines results in three distinct resonant modes:

1. Shunt capacitance resonance involves energy exchange between the shunt capacitance (line charging plus any power factor correction and SVCs) and the series inductance fo the lines and the generator
2. Series-line resonance involves energy exchange between the series capacitor and the series inductance of the lines, transformers and generators.
3. Shunt-reactor resonance involves energy exchange between shunt reactors at the intermediate substations of the line and the series capacitors

Due to the above, it is crucial to represent any compensators in transient electrical simulation programs.

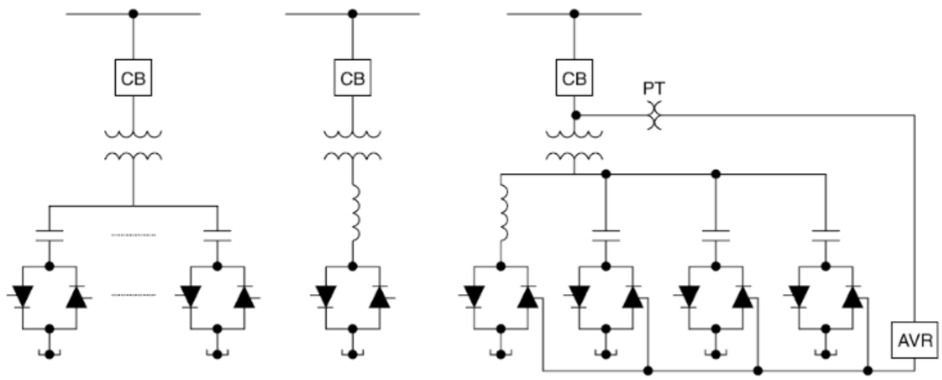

Figure 2.7 Basic static VAR compensator configurations
(*Source:* Practical Power Distribution for Industry)

CHAPTER 3
METHODOLOGY

3.1 Methodology Flow Chart

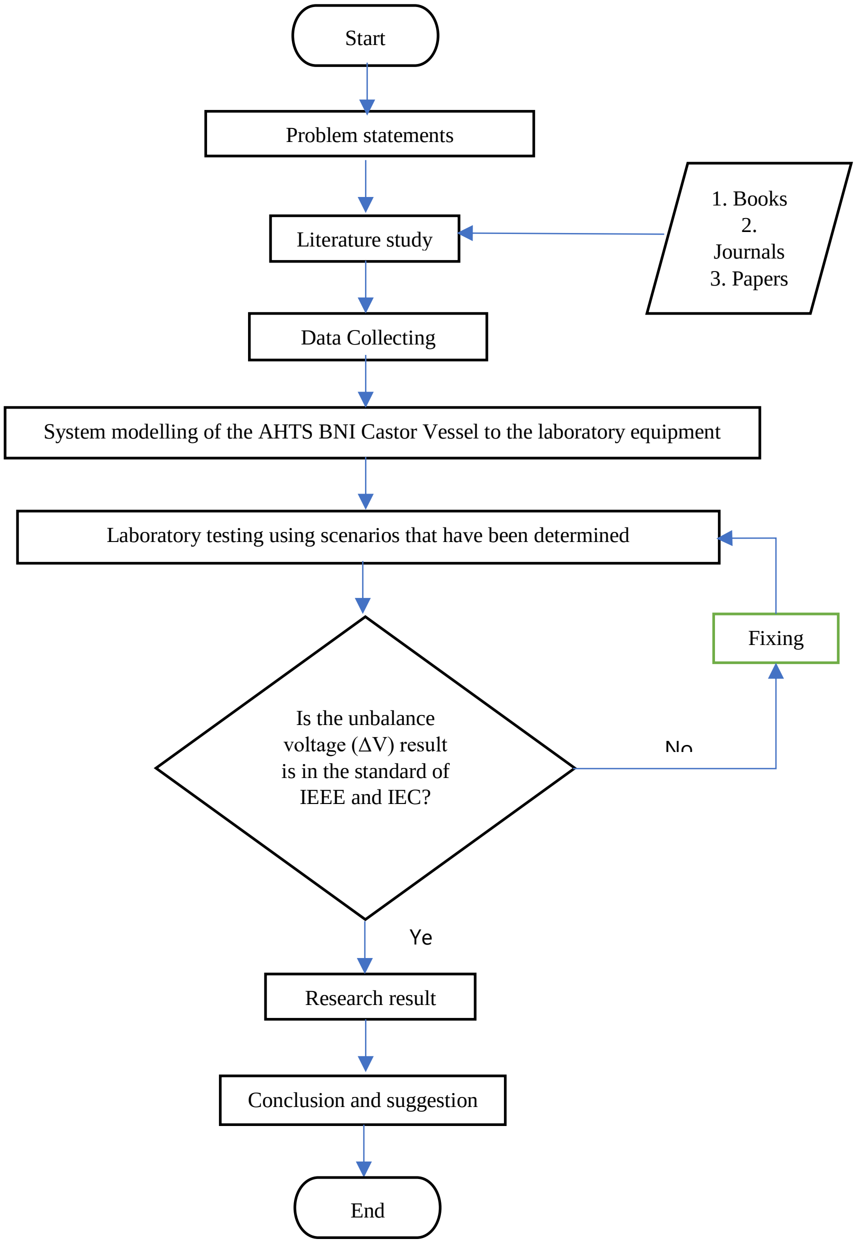

Figure 3.1 Flow chart methodology

3.2 Problem Statements

Finding the problem statements is the first step in doing this bachelor thesis. In this part, a problem is found is a topic is selected. The problem that were chosen was the faults that can occur on an electrical system. The faults that were chosen is the Unbalance Voltage that occur in the Dynamic Positioning system.

3.3 Literature Study

Study literature is a step where the basic theory the is correlating with the topic is searched and studied. The source of literature study can be in form of books, journal, and also international papers. Basic theory of Dynamic Positioning, motors, and unbalance voltage are studied form books and journals. International papers of past researches regarding unbalance voltage is also being gathered and studied and can be used as a reference.

3.4 Data Collecting

Data collecting is used as a data reference for this bachelor thesis. The data that is needed for this bachelor thesis are:

1. AHTS BNI Castor vessel data
2. Laboratory equipment data
3. Standards from IEEE, IEC, and ABS Classification Rules

The data that are gathered from AHTS BNI Castor vessel are the ship's single line diagram and ship's electrical load which can be seen in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6. All of these data that are gathered are only for educational purposes only.

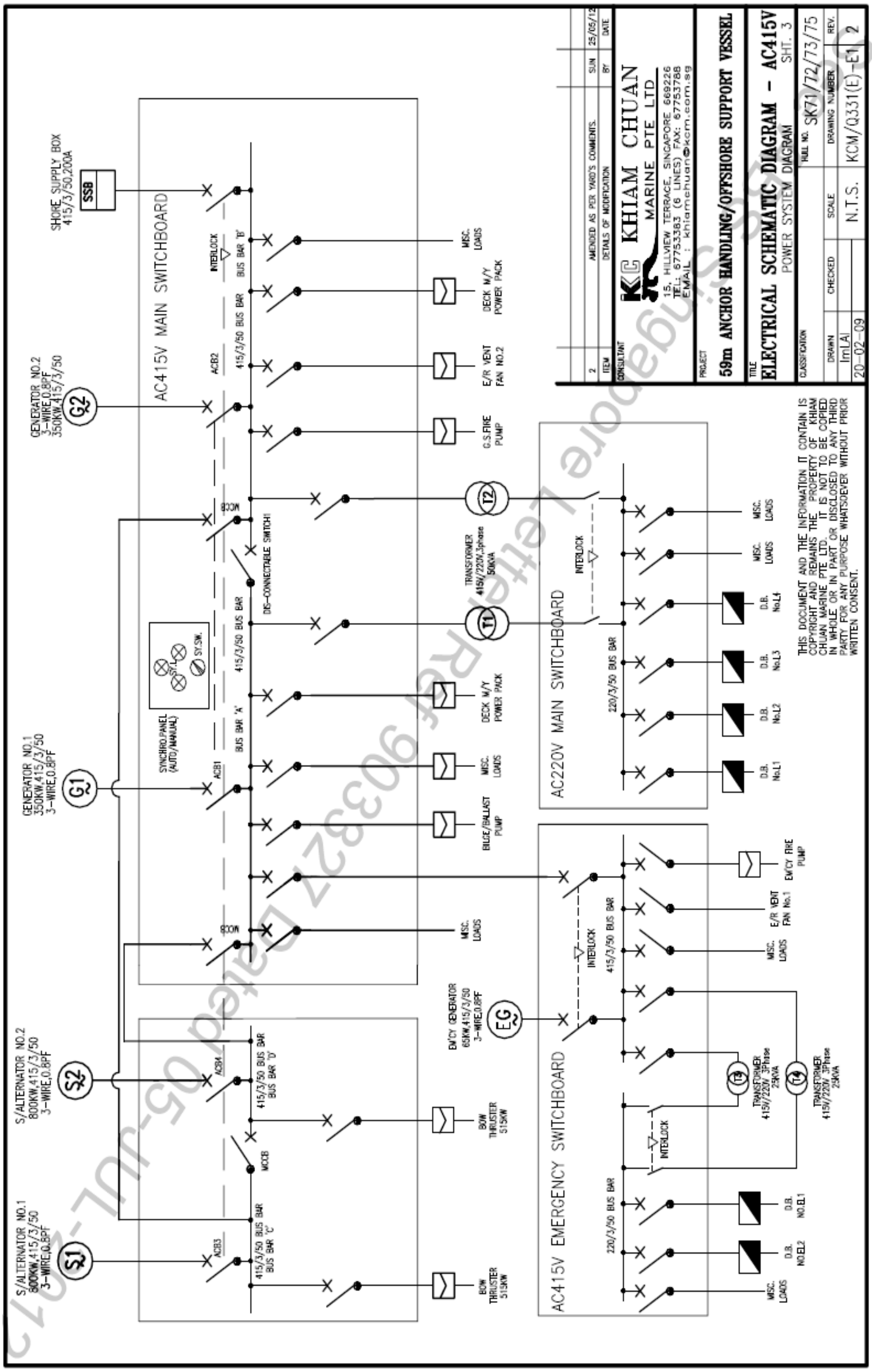

Figure 3.2 Electrical Single Line Diagram AHTS BNI Castor

KCM/Q331(E)-E5(HULL No.SK60/61/62)

REVIEWED
as indicated in
ABS letter
ABS

Document title:
Electrical Load Analysis

Contents:

Consumers on 220V ESB(Designload for 415/230V Emergency Transformer)
Consumers on 415V ESB
Consumers on 220V MSB(Designload for 415/230V Transformer)

Explanation of the Electrical Load Balance:

The abbreviation " L.F. " means Load Factor,and is actual a factor made up of the power efficiency of a consumer and the utilization of the same consumer,i.e. the relationship between the size of .e.g. an electrical motor and the power requirment.
The abbreviation " D.F. " means Diversity Factor. and indicates the degree of probability of a consumer to run simultaneously with other consumers.

The following power sources/generators are available:
2 x 800Kw, 415V, 50Hz,diesel generator set.
2 x 350Kw, 415V, 50Hz,diesel generator set.
1 x 65Kw, 415V, 50Hz,diesel generator set.
1 x 200A, 415V, 50Hz shore connection.

Project: 59m ANCHOR HANDLING/ OFFSHORE SUPPORT VESSEL					SEA GOING			STAND-BY			CARGO LOAD/ DISCH. (HARBOUR)			DP-1 MANOEUVR. /FIFI/AHT			HARBOUR RESTING			EMERGENCY		
Ref. SFI	CONSUMER	No. off	Rated in W	L.F.	D.F.	No. in use	Load (W)	D.F.	No. in use	Load (W)	D.F.	No. in use	Load (W)	D.F.	No. in use	Load (W)	D.F.	No. in use	Load (W)	D.F.	No. in use	Load (W)
B201	DISTRIBUTION BOARD No.EL1	1	1880	1.0	0.8	1	1504	0.8	1	1504	0.8	1	1504	0.8	1	1504	0.4	1	752	1	1	1880
B202	DISTRIBUTION BOARD No.EL2	1	3200	1.0	0.8	1	2560	0.3	1	960	0.3	1	960	0.7	1	2240	0.2	1	640	1	1	3200
B203	NAVIGATION LIGHT PANEL	1	1440	1.0	0.8	1	1152	0.5	1	720	0.4	1	576	0.6	1	864	0.4	1	576	1	1	1440
B204	EM'CY OUTSIDE LIGHTS	1	1120	1.0																1	1	1120
B205	GMDSS	1	1500	1.0	0.8	1	1200	0.3	1	450	0.3	1	450	0.7	1	1050	0.2	1	300	1	1	1500
B206	Miscellaneous Consumes	1	1500	0.8	0.8	1	960	0.4	1	480	0.4	1	480	0.6	1	720	0.3	1	360	0.8	1	960
B207	24V DC EM'CY SWITCHBOARD	1	4300	0.8	0.6	1	2064	0.6	1	2064	0.6	1	2064	0.6	1	2064	0.6	1	2064	0.9	1	3096
LOAD 220V ESB (transfered to 415V ESB)							9440			6178			6034			8442			4692			13196
415/230V TRANSFORMERS AND LOAD IN %		2	25000	VA		1	47%		1	31%		1	30%		1	42%		1	23%		1	66%

Average Power Factor of Consumers for Calculation of Transformer Load in %: 0.8

Figure 3.3 Electrical Load AHTS BNI Castor (1/4)

Project: 59m ANCHOR HANDLING/ OFFSHORE SUPPORT VESSEL					SEA GOING			STAND-BY			CARGO LOAD/ DISCH. (HARBOUR)			DP-1 MANOEUVR. /FIFI/AHT			HARBOUR RESTING			EMERGENCY		
Ref. SFI	CONSUMER	No. off	Rated in kW	L.F.	D.F.	No. in use	Load (kW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)
	Emergency Transformer (from 220V ESB)		30.00	KVA			9.44			6.18			6.03			6.18			4.69			13.20
B101	Rescue Boat Davit	1	9.00	0.9	0.1	1	0.81	0.1	1	0.81	0.1	1	0.81	0.1	1	0.81	0.1	1	0.81	1.0	1	8.1
B102	STARTER FOR STEERING GEAR	2	11.0	0.8	0.8	2	14.1	0.5	2	8.8	0.8	2	14.08	0.8	2	14.08	0.4	2	7.04	1.0	1	8.8
B103	Emergency Generator Room Fan	1	1.00	1.0																1.0	1	1.00
B104	CO2 ROOM VENT FAN	1	0.04	1.0																1.0	1	0.04
B105	Emergency Fire Pump	1	15.0	0.60																1.0	1	9.00
B106	ENGINE ROOM VENTILATION FAN 1	1	15.0	0.80	0.8	1	9.6	0.8	1	9.6	0.8	1.0	9.60	0.8	1	9.60	0.8	1	9.60	1.0	1	12.00
B107	No.2 STARTER AIR COMPRESSOR	1	5.5	1.00	0.6	1	3.3	0.6	1	3.3	0.6	1.0	3.30	0.6	1	3.30	0.6	1	3.30	1.0	1	5.50
LOAD 415V ESB (transfered to 415V MSB)							**37.23**			**28.69**			**33.82**			**33.97**			**25.44**			**57.64**

Project: 59m ANCHOR HANDLING/ OFFSHORE SUPPORT VESSEL					SEA GOING			STAND-BY			CARGO LOAD/ DISCH. (HARBOUR)			DP-1 MANOEUVR. /FIFI/AHT			HARBOUR RESTING			EMERGENCY		
Ref. SFI	CONSUMER	No. off	Rated in kW	L.F.	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)
A201	Engine Room DB L1	1	2.58	0.8	0.8	1	1.7	0.8	1	1.7	0.8	1	1.7	0.8	1	1.7	0.8	1	1.7			
A202	Main Deck DB L2	1	22.00	0.8	0.7	1	12.3	0.7	1	12.3	0.7	1	12.3	0.7	1	12.3	0.7	1	12.3			
A203	F'cle Deck DB L3	1	6.70	0.8	0.8	1	4.3	0.8	1	4.3	0.8	1	4.3	0.8	1	4.3	0.8	1	4.3			
A204	Upper F'cle Deck DB L4	1	12.70	0.8	0.8	1	8.1	0.8	1	8.1	0.8	1	8.1	0.8	1	8.1	0.8	1	8.1			
A205	W/H Deck DB L5	1	3.60	0.8	0.8	1	2.3	0.8	1	2.3	0.8	1	2.3	0.8	1	2.3	0.8	1	2.3			
A206	NAVIGATION LIGHT PANEL	1	1.44	0.8	0.8	1	0.9	0.5	1	0.6	0.4	1	0.5	0.6	1	0.7	0.4	1	0.5			
A207	DISTRIBUTION BOARD No.EL2	1	3.20	0.8	0.8	1	2.0	0.3	1	0.8	0.3	1	0.8	0.7	1	1.8	0.2	1	0.5			
A208	CONTAINER REEFER	2	6.00	0.8	0.5	1	2.4	0.5	1	2	0.5	1	2	0.5	1	2						
A209	Miscellaneous Consumes	1	1.50	0.8	0.6	1	0.7	0.6	1	1	0.6	1	1	0.6	1	1	0.6	1	1			
LOAD 220V MSB (transfered to 415V MSB)							**34.8**			**33.2**			**33.0**			**34.3**			**30.4**			
415/230V TRANSFORMER LOAD IN %		2	50.0	kVA		1	87%		1	83%		1	83%		1	86%		1	76%			

Average Power Factor of Consumers for Calculation of Transformer Load in %: 0.8

Figure 3.4 Electrical Load AHTS BNI Castor (2/4)

KCM/Q331(E)-E5(HULL No.SK60/61/62)

Project: 59m ANCHOR HANDLING/ OFFSHORE SUPPORT VESSEL					SEA GOING			STAND-BY			CARGO LOAD/ DISCH. (HARBOUR)			DP-1 MANOEUVR. /FIFI/AHT			HARBOUR RESTING			EMERGENCY		
Ref. SFI	CONSUMER	No. off	Rated in kW	L.F.	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)
	415/220V Transformer (from 220V MSB)		50.00	kVA			34.8			33.2			33.0			34.3			30.4			
	415V Emergency Switch Board (from 415V ESB)						37.2			28.7			33.8			34.0			25.4			
A101	Reefer Sockets	2	25.00	1.0	0.6	1	15.0	0.6	1	15.0	0.6	1	15.0	0.6	1	15.0						
A102	Bulk Cement Compressor	2	75.00	1.0							0.5	1	37.5									
A103	Bulk Cement Compressor Cooling Pump	2	2.20	1.0							0.5	1	1.10									
A104	Fresh Water Cargo Pump	1	55.00	0.85							0.5	1	23.4									
A105	Ballast/Bilge Pump	2	30.00	0.85	0.1	1	2.6	0.1	1	2.6	0.1	1	2.6	0.1	1	2.6	0.1	1	2.6			
A106	Fuel Oil Cargo Pump	1	75.00	0.85							0.5	1	31.9									
A107	Mud Pump	2	95.00	0.85							0.5	2	81									
A108	Bow Thruster Cooling Pump	2	0.55	1.00							0.5	2	0.6	0.5	2	0.6						
A109	No.1 STARTER AIR COMPRESSOR	1	5.50	1.00	0.6	1	3.3	0.6	1	3.3	0.6	1	3.3	0.6	1	3.3	0.6	1	3.3			
A110	POWER PACK FOR KARM FORK TOW PIN	1	20.00	0.8										0.5	1	8.0						
A111	Deck Machinery Hydraulic Power Pack	3	90.00	0.8										0.5	2	72.0						
A112	Deck Machinery Hydraulic Power Pack	2	7.50	0.8										0.5	2	6.0						
A113	ELECTRIC STOVE	1	22.00	1	0.5	2	22	0.5	2	22	0.5	2	22.0	0.5	2	22	0.5	2	22			
A114	Refrigeartion Set.	1	11.00	1.0	0.4	1	4.4	0.4	1	4.4	0.4	1	4.4	0.4	1	4.4	0.3	1	3.3			
A115	Air Condition Plant	1	80.00	0.9	0.8	1	57.6	0.8	1	57.6	0.8	1	57.6	0.8	1	57.6	0.5	1	36.0			
A116	Air Condition Plant Cooling Pump	1	15.00	0.9	0.8	1	10.8	0.8	1	10.8	0.8	1	10.8	0.8	1	10.8	0.5	1	6.8			
A117	Fresh Water Maker	1	2.20	0.9	0.8	1	1.6	0.8	1	1.6	0.8	1	1.6	0.8	1	1.6	0.5	1	1.0			
A118	Miscellaneous Vent Fan	1	20.00	0.9	1.0	1	18.0	1.0	1	18.0	1.0	1	18.0	1.0	1	18.0	1.0	1	18.0			
A119	S/G Room Vent Fan	1	1.10	0.9	1.0	1	0.99	0.5	1	0.50	0.5	1	0.50	1.0	1	0.99			0.0			
A120	Engine Room Fan 2	1	15.00	0.9	0.8	1	10.8	0.8	1	10.8	0.8	1	10.8	0.8	1	10.8	0.8	1	10.8			
A121	Bow Thruster Compt,Vent Fan	1	1.50	0.9	1.0	2	2.7	1.0	2	2.70	1.0	2	2.7	1.0	2	2.70	1.0	2	2.7			
A122	Fresh Water Pressure Pump	1	1.10	0.9	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7			
A123	Sea Water Pressure Pump	2	1.10	0.9	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7			
A124	Sewage Treatment System	1	3.80	0.9	0.7	1	2.39	0.7	1	2.39	0.7	1	2.39	0.7	1	2.39	0.7	1	2.39			
A125	Fuel Oil Transfer Pump	1	2.20	0.9	0.2	2	0.6	0.2	2	0.6	0.2	2	0.6	0.2	2	0.6			0.0			
A126	Oily/Bildge Water Separator	1	2.20	0.9	0.6	1	1.2	0.6	1	1.2	0.6	1	1.2	0.6	1	1.2	0.4	1	0.8			
A127	Dirty Oil/Sludge Pump	1	1.50	0.9	0.4	1	0.5	0.4	1	0.5	0.4	1	0.5	0.4	1	0.5	0.4	1	0.5			
A128	General Service & Fire Pump	1	30.00	0.9	0.1	1	2.7	0.1	1	2.7	0.1	1	2.7	0.1	1	2.7	0.1	1	2.7			

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Figure 3.5 Electrical Load AHTS BNI Castor (3/4)

KCM/Q331(E)-E5(HULL No.SK60/61/62)

Project: 59m ANCHOR HANDLING/ OFFSHORE SUPPORT VESSEL					SEA GOING			STAND-BY			CARGO LOAD/ DISCH. (HARBOUR)			DP-1 MANOEUVR. /FIFI/AHT			HARBOUR RESTING			EMERGENCY		
Ref. SFI	CONSUMER	No. off	Rated in kW	L.F.	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)	D.F.	No. in use	Load (KW)
A129	Central Water Heater	1	30.00	0.80	0.40	1	9.6	0.4	1	9.6	0.4	1	9.6	0.4	1	9.6	0.4	1	9.6			
A130	FIFI System	1	1.00	1.0			0.0			0.0				0.5	1	0.5			0.0			
A131	Air-Condition for ECR	1	3.40	1.0	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7			
A132	Air-Condition fo W/H	1	3.40	1.0	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7	0.8	1	2.7			
A133	F.O. Purifier	1	5.50	0.9	0.6	1	2.97	0.6	1	2.97	0.6	1	2.97	0.6	1	2.97	0.6	1	2.97			
A134	Drill Water Pump	1	45.00	0.9							0.5	1	20.3									
A135	Deck Crane	1	22.00	0.9										0.4	1	7.9						
A136	B.A. Recharging Compressor	1	5.00	0.9	0.1	1	0.5	0.1	1	0.5	0.1	1	0.5	0.1	1	0.5	0.1	1	0.5			
A137	Welding Equipment	1	12.00	0.9	0.1	1	1.1	0.1	1	1.1	0.1	1	1.1	0.1	1	1.1	0.1	1	1.1			
A138	CPP HYDRAULIC UNIT	2	5.50	0.9	0.6	2	5.9	0.5	2	5.0	0.6	2	5.9	0.6	2	5.9	0.4	2	4.0			
	Bow Thruster	2	515.00	1.0							1.0	2	1030.0	1.0	2	1030.0						
LOAD 415V S/ALTERNATORS													1030.0			1030.0						
LOAD 415V MSB							256			244			446			347			194			

Project: 59m MULTI-PURPOSE OFFSHORE SUPPLY/ ANCHOR HANDLING VESSEL	SEA GOING	STAND-BY	CARGO LOAD/ DISCH. (HARBOUR)	DP-1 MANOEUVR. /FIFI/AHT	HARBOUR RESTING	EMERGENCY
LOAD 415V MSB	256	244	446	347	194	
LOAD 415V S/ALTERNATORS			1030.0	1030.0		
LOAD 415V ESB (emergency operation)						57.64

DIESEL GENERATOR SETS WORKING AND LOAD IN %

SHAFT GENERATORS	2	800.00			1	32%		1	31%		2	64%		2	64%					
DIESEL GENERATORS	2	350.00			1	73%		1	70%		2	64%		2	50%		1	55%		
EMERGENCY GENERATOR	1	65.00																	1	89%

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Figure 3.6 Electrical Load AHTS BNI Castor (4/4)

3.5 System Modelling of AHTS BNI Castor Electrical System to Laboratory Scale

To analyze the system in a laboratory scale, some sort of modelling is needed so the analyzing can be done. For that, a simplified model is done in a one line diagram. The one line diagram can be seen on Figure 3.2.

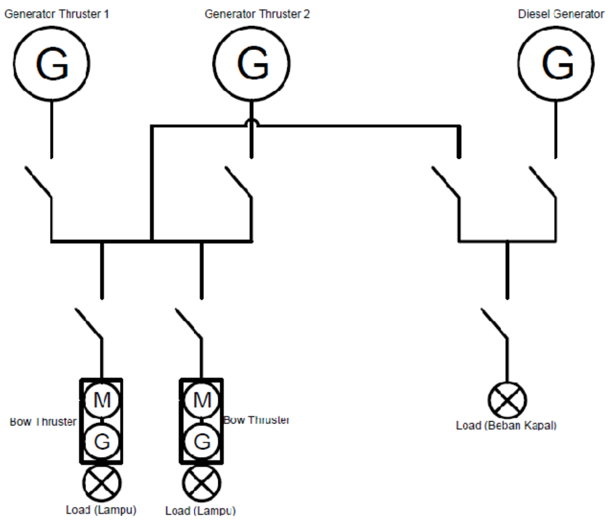

Figure 3.7 Single Line Diagram

3.6 Tests Using Laboratory Equipment

The tests will be done using the laboratory equipment that is designed based on the ship's electrical system model. The test will be done using a series of scenarios that are mentioned in Table 3.1.

Table 3.1 Tests Scenarios

Scenario	Power Supply	Load	Variations
1	2 Generator Thruster	2 Bow Thruster	60% - 75% 100%-80% 100%-100% 110%-110%
2	1 Generator Thruster	2 Bow Thruster	40%-40% 50%-50% 60%-60%
3	1 Generator Thruster, 1 Generator Diesel	2 Bow Thruster	75%-75% 80%-80% 85%-85%

3.7 Result Validation and Checking

After doing the tests using the laboratory equipment, checking and validation of the result are done. Checks are done by using the result of the unbalance voltage that happen in every scenario that were done. The results will be checked and validated based on the standards, the standards such as IEEE.

3.8 Results

The last step after checking and validating is giving conclusion. The conclusion will be made to answer the question that was made according to the problem statement. Suggestions are welcome to give this bachelor thesis more input to fix and also can be made for future thesis or researches.

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CHAPTER 4
DATA ANALYSIS

4.1. Data Collecting

Before the system modelling can be start, data from the actual ship is needed. The data are collected from *PT. Bahtera Niaga Internasional*, which are used for educational purposes only, therefor data that are collected are mentioned in the following:

4.1.1. Main Ship Data

For this analysis, an AHTS ship is used, namely AHTS BNI Castor. The main data of the ship consists of:

Ship Type	: Anchor Handling / Offshore Support Vessel
Ship Name	: AHTS BNI Castor
Class	: ABS
Gross Tonnage	: 1350
Deadweight	: 1678
LOA	: 59,25 m
B	: 14,95 m
H	: 6,15 m
T:	: 4,95 m
Generator set	: Diesel Engine, Caterpilar C18 Alternator, Leroy Somer ARCB 592; Output 350 kW
Generator Thruster	: Shaft Alternator; Output 800 kW
Bow Thruster	: ABB Shanghai Motors co., ltd ; Output: 515 kW, Propeller Speed: 475 RPM

4.1.2. Components Specification

For this particular analysis, the components that are being observed are the generators. There are 4 generators that are onboard the ship, which is 2 main diesel generators and 2 shaft generators. Main diesel generators are destined to supply the ship and shaft generators for bow thrusters. The two generators are on separated bus but is connected with a single connection so in case of more power needed, the generators can be paralleled. The following will be the specification for the main generator and shaft generator.

1. Main Generator
   The specification for the generator is listed on Table 4.1.
2. Thruster Generator
   The Specification for the thruster generator is listed on Table 4.2.

Table 4.1 Main Generator Specification

Type	Shaft Alternator
Power	800 kW
kVA	1000 kVA
Frequency	50 Hz
RPM	1500 RPM
Voltage	415 Volt
Power Factor	0.8

Table 4.2 Thruster Generator Specification

Brand	Shaft Alternator
Type	ARCB 592
Power	350 kW
kVA	438 kVA
Frequency	50 Hz
RPM	1500 RPM
Voltage	415 Volt
Power Factor	0.8

Other than the generators, the specification of electric motors that are used to move the bow thruster is needed. The electric motors that are moving the bow thruster is powered by the thruster generator and can be seen on Picture 4.2. of the single line diagram for the ship. The specification of electric motor will be shown on Table 4.3.

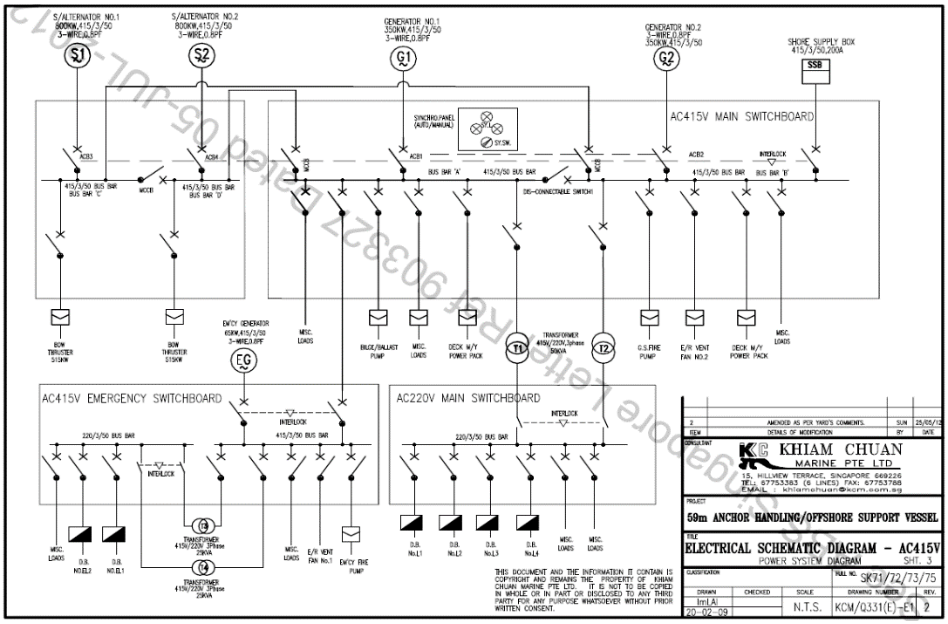
Table 4.3 Electric Motor Specification

Brand	ABB Shanghai Motors co., ltd
Model	KT-72B3
Type	Three Phase Induction Motor
Propeller Speed	475 RPM
Input Shaft Speed	1450 RPM
Rated Power	515 kW
Frequency	50 Hz
Voltage	415 Volt
Phase	3 Phase

Specification for other load such as load of the ship will be attached on the attachments.

4.2. System Modelling

For modelling the system, a reference of the actual system is needed. That is why the single line diagram of the system is also gathered as a reference to model the system. The single line diagram is representation of a three – phase system. The single line diagram for the AHTS BNI Castor ship can be seen on Picture 4.2, and for the larger picture will be on attachments.



Picture 4.2. Single Line Diagram for AHTS BNI Castor

From the single line diagram can be seen that there are 2 main generators that is supplying the ship's needed power on one bus and 2 thruster generators used for powering the electric motor that will move the bow thrusters.

After knowing how the single line diagram of the three phase system looks like and how it flows, the modelling can be start. So, because the main aspect that is going to be observe is the generators, 2 main and 2 thruster generators. The load will consist of 2 loads, the electric motor and the ship load. By knowing that, we can draw a simple model using AutoCAD that is shown on Figure 4.1.

In the model, it can be seen that 2 thruster generator is supplying the bow thrusters through one bus. While as the diesel generator is supplying the ship load on the other bus. The bus is connected using a single line so that a parallel usage is available. From the model, equipment will be gathered from the lab to make the most possible scheme that will represent the model

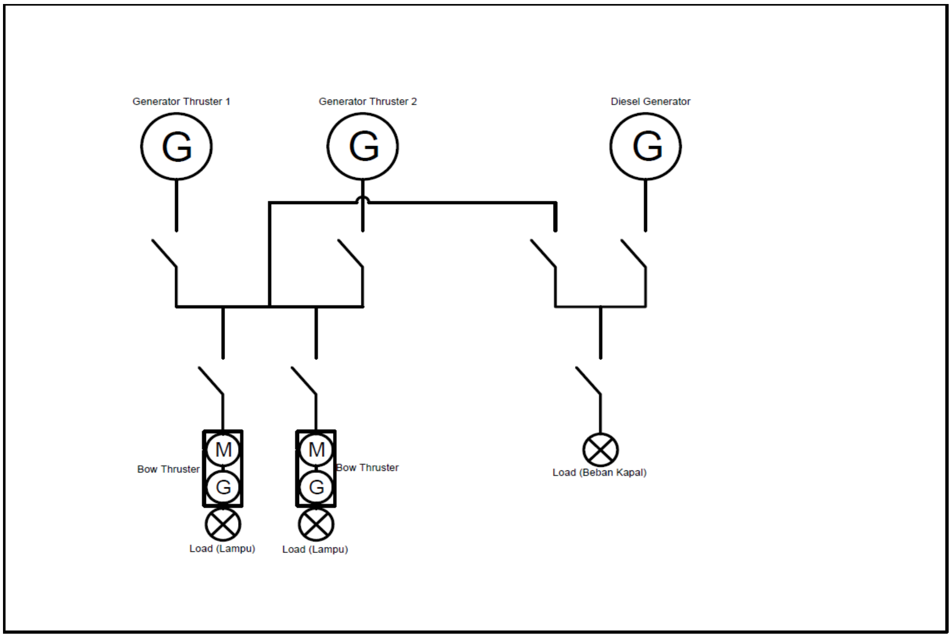


Figure 4.1 Model of Single Line Diagram AHTS BNI Castor

From the single line diagram, the system are made using the equipment that are available on the laboratory which will later translate to the figure on Figure 4.2.

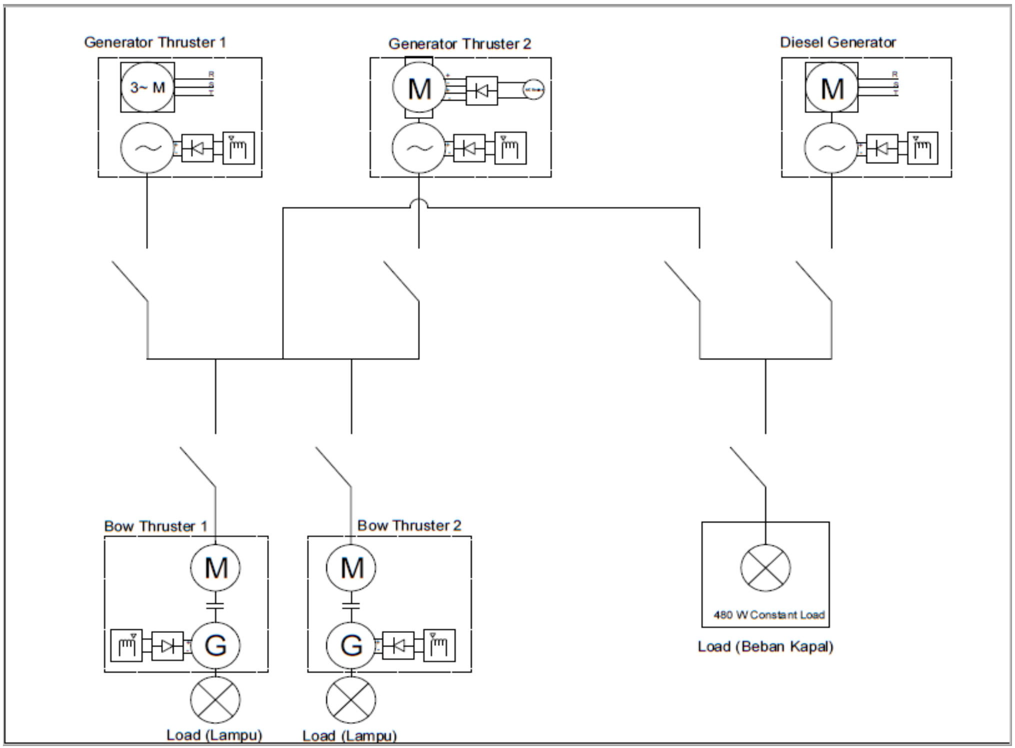


Figure 4.2 Diagram of the system on the laboratory

4.3. Laboratory Equipment

For this experiment, equipment are needed to build the model and can make it into play. The necessary equipment are generators, cables, electric motors and the loads. For this laboratory experiment, several adjustments have been made. The generator will be moved by a corresponding motor that are available at the laboratory. For differentiating the load and to be able to be observed, the load of the motor will be in a form of generator that will power a lamp. List of the equipment will be listed below.

1. Generator
2. Motor
3. Regulator
4. Rectifier
5. Feedback Motor and Generator
6. Panel
7. Load (Lamp)
8. Multimeter
9. Tachometer
10. Tang meter
11. Cables
12. Oscilloscope

4.4. Experiment Scenario and Variations

In analyzing the unbalance voltage, a scheme or scenarios are prepared at different variations. These variations will determine the load that the generator will handle. The scenario and variation that will be tested are:

1. 1st Scenario

The first scenario is configured with a closed bus configuration. 2 thruster generators are used with 2 electric motor as load is used. The load will be controlled with a generator coupled with an electric motor and the load will be visualize and variated by using lamps. The variations for the 1st scenario are shown on Table 4.4.

Table 4.4 1st Scenario Variations

1st Scenario Variations		
No	Bow Thruster 1	Bow Thruster 2
1	60%	75%
2	100%	80%
3	100%	100%
4	110%	110%

2. 2nd Scenario

The second scenario is configured with a split plan configuration. Using only 1 thruster generator with the load being 2 electric motors. The variations for the 2nd scenario are shown on Table 4.5.

Table 4.5 2nd Scenario Variations

2nd Scenario Variations		
No	Bow Thruster 1	Bow Thruster 2
1	40 %	40 %
2	50 %	50 %
3	60 %	60 %

3. 3rd Scenario

The third scenario is configured with closed bus configuration. In this configuration, 1 thruster generators will be used with the addition of 1 diesel generator. For the load that will be present are the 2 electric motors. The variations for the 3rd scenario are shown on Table 4.4.3.

Table 4.6 3rd Scenario Variations

3rd Scenario Variations		
No	Bow Thruster 1	Bow Thruster 2
1	75%	75%
2	80%	80%
3	85%	85%

These scenarios can be summarized with Table 4.7.

Table 4.7 Scenario and Variations

Scenario	Power Supply	Load	Variations
1	2 Generator Thruster	2 Bow Thruster	60% - 75% 100%-80% 100%-100% 110%-110%
2	1 Generator Thruster	2 Bow Thruster	40%-40% 50%-50% 60%-60%
3	1 Generator Thruster, 1 Generator Diesel	2 Bow Thruster	75%-75% 80%-80% 85%-85%

4.5. Unbalance Voltage Calculation

In calculating the unbalance voltage, several data are needed first to calculate if a system is in an unbalance state or not. The data that will be gathered are the line voltage, phase voltage, and current. Line voltage will be measured using a Multi meter from one of the lines to another line. So, the data will be RS, ST, and TR, which means the alphabet that represent the lines that are being measured.

Phase voltage will be measured form one of the lines to the neutral line. The data will be RN, SN and TN. The current will be measure with a Tang meter from each of its line. The current of phase R, phase S, phase T, and neutral are measured. In calculating the unbalance voltage, several rules are used in this calculation namely from NEMA, IEE and IEC. The formula from each rule are:

1. NEMA

Calculation using definition given by NEMA going by the formula:

$$\%\text{LVUR} = \frac{\text{max voltage deviation from avg line voltage}}{\text{avg line voltage}} \text{ x } 100$$

Max deviation from avg line voltage means that the difference between the highest different from each of the line voltage to the average. Then will be divided with its average line voltage.

2. IEEE

Calculation given by the IEEE Std 141 goes by:

$$\%\text{PVU} = \frac{\text{max voltage deviation from avg phase voltage}}{\text{avg phase voltage}} \text{ x } 100$$

It’s the same as from the NEMA rules but with phase voltage and not line voltage.

3. True Definition

True definition come with a formula that used negative and positive sequence voltage, that goes with the formula:

$$\%\text{voltage unbalance} = \frac{\text{Voltage Negative Sequence}}{\text{Voltage Positive Sequence}} \text{ x } 100$$

Negative and Positive sequence will be calculated with their corresponding formula that are explained on the calculation steps.

4.6. Results for calculation

For this experiment, the conditions that are going to be analyze are the balance and unbalance conditions. Both of these conditions will be calculated and the aspects that are affected by the unbalance are going to be analyzed.

4.6.1. Scenario 1 and Scenario 2

Scenario 1 and Scenario 2 in a sense is the condition where the balance conditions happens. Balance conditions is the conditions where there are no single phase load that will cause either one of the phases to be unbalance. In theory, a balance conditions is where the value of each phase is the same and/or the sinusoidal angle is the same. But those conditions are almost impossible, at least to a certain degree. For that there are conditions where something is called unbalance. With this, the balance conditions will be measured and calculated to see the difference later on with the unbalance conditions.

1. Calculations

The following will be the steps in calculations.

- Main aspect measurement

Measurements are done to find the magnitude of phase voltage, line voltage, and currents. For example, is for the 1st scenario. Phase voltages are 220 V, 218 V, and 218

V for each phase. Line voltages are 380 V, 380 V, and 378 V. And the currents are 1.31 A, 1.27 A, 1.28 A, and 0.4 A.

- Line Voltage Unbalance Ratio (LVUR) calculation

As was mentioned earlier, three aspects of unbalance definitions are being calculated, which are LVUR, PVUR, and VUF. For the sake of calculation, LVUR is being calculated first. The known line voltages are:
$V_1 = 380\text{ V}$
$V_2 = 380\text{ V}$
$V_3 = 378\text{ V}$
From the voltages we can calculated the average voltage resulting in 379.33 V. After knowing the average line voltage, the difference between each voltage to its average can be calculated to find the max deviation to the average line voltage. The voltages are 380 V, 380 V, and 378 V, which results in 0.67 V, 0.67 V and 1.33 V deviation respectively. That means that the max deviation is 1.33 V. From there the LVUR can be calculated using the formula:

$$\text{LVUR}(\%) = \frac{\text{max devitaion from average line voltage}}{\text{avg line voltage}} \text{x}100$$

$$\text{LVUR}(\%) = \frac{1.33}{379.33} \text{x}100 = 0.35\%$$

This result is still acceptable for balance conditions because the percentage is still lower than 3%. IEC 60002-2-2 states that unbalance over 3% is not acceptable because it will harm the longevity of the motors.

- Phase Voltage Unbalance Ratio (PVUR) calculation

For the PVUR calculation the phase voltage are use. Phase voltage is the phase to phase voltage, is usually around 380 V / 415 V.
$V_1 = 220\text{ V}$
$V_2 = 218\text{ V}$
$V_3 = 218\text{ V}$
The average voltage from 220 V, 218 V, and 218 V is 218.67 V. The deviation of each voltage to the average voltage are 1.33 V, 0.67 V and 0.67 V respectively. From there it can be concluded that the max deviation is 1.33 V. From there, the following formula can be used to calculate the PVUR.

$$\text{PVUR}(\%) = \frac{\text{max deviation from average phase voltage}}{\text{average voltage}} \text{x}100$$

$$\text{PVUR}(\%) = \frac{1.33}{218.67} \text{x}100 = 0.61\%$$

This result gives a result that does not comply to the rules that states that the PVUR should be below 5%.

- Voltage Unbalance Factor (VUF)

VUF or voltage unbalance factor is an indicator that were given by IEC to determine if an equipment is in a balance or unbalance state base on its line to neutral voltage. The formula uses negative and positive sequence of the voltage. The formula is:

$$\%\mathrm{VUF} = \frac{\text{Voltage Negative Sequence}}{\text{Voltage Positive Sequence}} \text{ x } 100$$

Negative and positive sequence have their own formula in calculating their respective result. The negative sequence can be calculated with:

$$V_n = \frac{V_a + (a^2 \text{ x } V_b) + (a \text{ x } V_c)}{3}$$

While the positive sequence one will be calculated by:

$$V_P = \frac{V_a + (a \text{ x } V_b) + (a^2 \text{ x } V_c)}{3}$$

The calculation involves the use of imaginer and polar number. The letter a and a^2 indicates a constant of $a\angle 120$ and $a^2\angle - 120$, because of the constants are in polar number the calculation will resolve around it. The following sequence of equation is an example of using the negative and positive sequence to find the VUF. The VUF uses line to neutral voltage, and in this example the data from scenario 1 variation 1 that will be use. First the line to neutral voltage data.

$V_a = 220\angle 0°$
$V_b = 218\angle - 113.7°$
$V_c = 218\angle 123.18°$

After determining the voltage with its polar components, the calculation can continue. The calculation will go as follow:

$$V_n = \frac{220 + (1\angle - 120)(218\angle - 113.7) + (1\angle 120)(218\angle 123.18)}{3}$$

$$V_n = \frac{220 + (218\angle - 233.7) + (218\angle 243.18)}{3}$$

$$V_n = 6.75\angle 68.47°$$

For the positive sequence, the calculation follows the same step but with different formula.

$$V_p = \frac{220 + (1\angle 120)(218\angle - 113.7) + (1\angle - 120)(218\angle 123.18)}{3}$$

$$V_p = \frac{220 + (218\angle 6.3) + (205\angle 3.17)}{3}$$

$$V_p = 218.4\angle 3.15°$$

After the value of positive and negative sequence are acquired, VUF can be calculated.

$$\%\mathrm{VUF} = \frac{6.75}{218.4} \text{ x } 100$$

$$\%\mathrm{VUF} = 3.09\%$$

The value of VUF more is 3.09%, and according to the rules from IEC the value of voltage unbalance is not more than 5%.So, the result of scenario 1 variation 1 does meet the required value to pass the rules.

2. Result Summary

The step for calculating each of definitions is done for each generator and each motor to see its condition. The following will show the result for each scenario.

- 1st Scenario

This scenario is where 2 thruster generators are used to supply power to 2 bow thrusters. Four variations are done with different load percentage on each variation. Generator 1 indicates the first thruster generator which uses an AC motor in the laboratory while generator 2 is the second generator which uses DC motor. The following will show the result for each variation.

  - Variation 1

Variation 1 is where the load on the bow thrusters are 60% and 75%. Table 4.7 will show the result of variation 1. From the result shown from table 4.8 it can be seen that result for the LVUR is 0.35%, 0.61% for PVUR and 3.09% VUF for the first generator. 0.44% LVUR, 0.61% PVUR and 2.94% for VUF. Based on the rules for unbalance voltage, the voltage ratio for both LVUR is still acceptable because they are still below the maximum threshold which is 3% for LVUR. Although the PVUR is a bit over the limit with the result of 0.61% and 0.77% with the limit of 0.5%. For the VUF both of the result are all below the limit of 5% with the result of the first generator being 3.09% and the second generator being 2.94%. The result of the PVUR being not complying to the rules because of losses that runs in the neutral line. It can be seen that the voltage on both the S and T phase below the value of the R phase, meaning that to supply the same power the current should've been higher but its lower.

Table 4.8 Result of Scenario 1 Variation 1

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	380	RN	$220\angle 0°$	R	1.31	LVUR(%)	0.35
ST	380	SN	$218\angle -113.7°$	S	1.27	PVUR(%)	0.61
TR	380	TN	$218\angle 123.18°$	T	1.28	VUF(%)	3.09
				N	0.40		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	381	RN	$219\angle 0°$	R	0.44	LVUR(%)	0.44
ST	378	SN	$217\angle -113.7°$	S	0.38	PVUR(%)	0.77
TR	380	TN	$216\angle 123.18°$	T	0.36	VUF(%)	2.94
				N	0.44		

  - Variation 2

Variation 2 is where the load on the bow thrusters are 80% and 100%. Table 4.8 will show the result of variation 2. Table 4.9 is showing the result of measurement and observation of voltage and current and also the calculation of the voltage ratio based on different definitions. Just like the first scenario the result of LVUR are both to the rules. Which the LVUR are 0.18% and 0.44%. The PVUR though have different result. One of the generators does comply to the rule with 0.47% on the second generator while the first generator doesn't with 0.62%. The VUF with its result of 3.09% and 3.23 is acceptable by rules standard. The first generator that have its PVUR above the maximum allowable PVUR is caused by the losses that runs from the neutral line, making the phase voltage and currents for the S and T phase differ from phase R.

Table 4.9 Variation 2 Result

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	377	RN	$217\angle 0°$	R	1.25	LVUR(%)	0.18
ST	376	SN	$215\angle -113.7°$	S	1.36	PVUR(%)	0.62
TR	376	TN	$215\angle 123.18°$	T	1.28	VUF(%)	3.09
				N	0.83		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	375	RN	$216\angle 0°$	R	0.37	LVUR(%)	0.44
ST	374	SN	$214\angle -113.7°$	S	0.37	PVUR(%)	0.47
TR	377	TN	$215\angle 123.18°$	T	0.39	VUF(%)	3.23
				N	0.45		

- Variation 3

Variation 3 is where the load on the bow thruster motors are 100% - 100%. Table 4.10 will show the result of variation 3

Table 4.10 Variation 3 Result

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	372	RN	$215\angle 0°$	R	1.20	LVUR(%)	0.45
ST	375	SN	$213\angle -113.7°$	S	1.37	PVUR(%)	0.62
TR	373	TN	$213\angle 123.18°$	T	1.34	VUF(%)	3.08
				N	0.84		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	373	RN	$214\angle 0°$	R	0.38	LVUR(%)	0.72
ST	375	SN	$212\angle -113.7°$	S	0.42	PVUR(%)	0.78
TR	370	TN	$211\angle 123.18°$	T	0.43	VUF(%)	2.78
				N	0.45		

Results for variation 3 is shown on Table 4.10. The result for the definitions are 0.45% and 0.62% fo∠r the LVUR, 0.62% and 0.78% for the PVUR and 3.08% and 2.78% for the VUF. The LVUR are all below the limit of how much the unbalance ratio could occur. Although the result of PVUR is above the limit with its result of 0.62% and 0.78%. For the VUF, the generators had its VUF still below the limit of VUF which is 5% . The result of the PVUR being above the limit is also caused by the current flowing in the neutral line. For the first generator even though the current for S and T being higher than the R phase because its voltage is lower than the R voltage, the current flowing in the neutral line is quite high. The same also applies to the second generator.

- Variation 4

Variation 4 is the scenario where the load on the bow thruster motors are at 110% load. In this scenario the bow thruster motors could not handle the 110% load scenario that the motors always shuts down. It is a possibility that due to the age of the equipment that the motor itself could not comply the load.

- 2nd Scenario

The second scenario is the scenario where 1 generator is used to supply 2 bow thruster motors. The following will show the result for each variation.

- Variation 1

First variation is the variation where the load is at 40%-40% for each bow thruster motors. Table 4.11 will show the result of variation 1 for scenario 2

Table 4.11 Variation 1 Scenario 2 Result

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	381	RN	$220\angle 0°$	R	0.80	LVUR(%)	0.17
ST	381	SN	$220\angle -120°$	S	0.84	PVUR(%)	0.61
TR	382	TN	$218\angle 120°$	T	0.79	VUF(%)	0.30
				N	0.62		

From the first variation of scenario as shown in Table 4.11 it can be seen that all of the result for the definition is all below the maximum limit of each of its definition except for the PVUR. The LVUR is at 0.17% which the limit is 3%, and the VUF is at 0.30% which the limit is 5%. The PVUR however is a bit over the limit with its 0.61% result, the threshold for PVUR is 0.5%. That's a 0.11% more than the rule. The reason for this is the unbalance in the phase voltage on the T phase with the 218V result. Thus, making the PVUR high. The reason for this is losses that can be seen that the phase current is high while the current on the T phase itself it's not higher than the other phase.

- Variation 2

The second variation comes with a 50% for each of the bow thruster motors. Table 4.12 will show the result of variation 2 for scenario 2.

Table 4.12 Variation 2 Scenario 2 Result

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	384	RN	$220\angle 0°$	R	0.80	LVUR(%)	0.61
ST	380	SN	$219\angle -126.5°$	S	0.83	PVUR(%)	0.30
TR	383	TN	$220\angle 116.76°$	T	0.76	VUF(%)	3.14
				N	0.14		

The second variation of the second scenario shows that all the definitions are all passable that can be seen on Table 4.12. The LVUR is at 0.61% with the limit of LVUR is 3%. Limit for PVUR is 0.5% and that is also slightly passable with its 0.30% result. The result for VUF is a bit high though it is still below its threshold of 5% VUF. This high result of VUF is the result of the slight shift of angle for the phase voltage that can be seen on Table 4.12.

- Variation 3

The third variation, the last variation for this scenario, used 60%-60% for both of the bow thruster motors. Table 4.13 will show the result of variation 3 for scenario 2. The result for the last variation of scenario 2 can be seen on Table 4.13. The same as the previous variation, the result for each definition is all still in the range of the limit. The LVUR is 0.35% which is still below 3%. The PVUR is at 0.30%, and the limit is 0.5% so it is still okay. The VUF have its result at 3.3% and that's still below the 5% limit. The reason for the high VUF is because of the shift of angle from 120° that can be seen on the phase voltage column.

Table 4.13 Variation 3 Scenario 2 Result

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	384	RN	$220\angle 0°$	R	0.80	LVUR(%)	0.35
ST	384	SN	$220\angle -123.2°$	S	0.81	PVUR(%)	0.30
TR	382	TN	$219\angle 113.7°$	T	0.80	VUF(%)	3.30
				N	0.30		

4.6.2. Scenario 3

As was mentioned before, an unbalance condition can be influenced by a many aspect, for this analysis the aspect that is going to be inputted is single phase load. Single phase load is a load where the load only needs 1 phase and 1 neutral line, hence the name single phase load. An example for single phase load is lamps, and that's what the single phase load that is being use for this analysis. The load will be loads that describe the load of ship. The load will be paralleled with the previous 2 three phase loads, to see the effect of single phase load to the generators. Observation will be same, using the same scenarios and variations. Currents and voltage data are recorded.

1. Calculations

   Calculations uses definitions of unbalance voltage to see if the unbalance conditions is still allowed based on the rules. The definitions that are use are Phase Voltage Unbalance Ratio (PVUR), Line Voltage Unbalance Ratio (LVUR), and Voltage Unbalance Factor (VUF).

- Main Aspect of Calculation

Data that are used for the calculation are the line voltage and phase voltage. The current uses the same formula but doesn't really have a rule to govern the exact value that really damaged the equipment, but from some researches 6 – 10% increase of current are estimated if an unbalance voltage. The following section will elaborate the calculations. For this example, data from scenario 3 variations 2 are used. Phase voltages are 220 V, 229 V, and 219 V. Line voltages are 409 V, 408 V, and 409 V.

- LVUR Calculation

Calculation for LVUR uses the line voltage of the equipment. Line voltage is the phase to neutral voltage, which is usually around 110 V / 220 V.

$V_1 = 220$ V

$V_2 = 220$ V

$V_3 = 219$ V

These voltages are the line voltage of phase to neutral line for the generator. In LVUR, the formula uses the max deviation from these three voltages from their average value. Then the max deviation will be divided by the average line voltage. So, the formula goes by:

$$\%\text{LVUR} = \frac{\text{max deviation from average line voltage}}{\text{average line voltage}} \text{x } 100$$

First is the max deviation. The max deviation is the maximum or the biggest difference of value between the three voltage to the average. The average of 220 V, 220 V, and 219 V is 219.67 V. The difference from the three voltage to is average are 0.33 V, 0.33 V, and 0.67 V. The biggest difference is 0.67 V so that voltage is used for calculation. Following the formula, we can get the LVUR.

$$\%\text{LVUR} = \frac{0.67}{219.67} \text{x}100$$

$$\%\text{LVUR} = 0.30\%$$

The result for the LVUR is 0.30%. It is allowed going by the 3% limit of unbalance.

- PVUR Calculation

For the PVUR calculation the phase voltage are use. Phase voltage is the phase to phase voltage, is usually around 380 V / 415 V.

$V_1 = 409$ V
$V_2 = 408$ V
$V_3 = 409$ V

The PVUR have the same formula as LVUR, except is uses the phase voltage. The formula for PVUR is:

$$\%\text{PVUR} = \frac{\text{max deviation from average phase voltage}}{\text{average phase voltage}} \text{x } 100$$

The deviation from each of the phase voltage are calculated to know the max deviation. The average of 409 V, 408 V and 409 V is 408.67 V. The difference of each phase to the average are 0.33 V, 0.67 V, and 0.33 V. Based on that, the max deviation is 0.67 V. Following the formula, we can calculate the PVUR.

$$\%\text{PVUR} = \frac{0.67}{408.67} \text{ x } 100$$

$$\%\text{PVUR} = 0.16\%$$

The result for the PVUR is 0.16%, which is still below the limit of how much unbalance can occur based on then PVUR definition of 0.5%.

- VUF Calculation

VUF or voltage unbalance factor is an indicator that were given by IEC to determine if an equipment is in a balance or unbalance state base on its line to neutral voltage. The formula uses negative and positive sequence of the voltage. The formula is:

$$\%\text{VUF} = \frac{\text{Voltage Negative Sequence}}{\text{Voltage Positive Sequence}} \text{x } 100$$

Negative and positive sequence have their own formula in calculating their respective result. The negative sequence can be calculated with:

$$V_n = \frac{V_a + (a^2 \text{ x } V_b) + (a \text{ x } V_c)}{3}$$

While the positive sequence one will be calculated by:

$$V_P = \frac{V_a + (a \text{ x } V_b) + (a^2 \text{ x } V_c)}{3}$$

The calculation involves the use of imaginer and polar number. The letter a and a^2 indicates a constant of $a\angle 120$ and $a^2\angle -120$, because of the constants are in polar number the calculation will resolve around it. The following sequence of equation is an example of using the negative and positive sequence to find the VUF. The VUF uses line to neutral voltage, and in this example the data from scenario 2 variation 2 that will be use. First the line to neutral voltage data.

$V_a = 220\angle 0°$

$V_b = 220\angle -123.2°$

$V_c = 219\angle 113.7°$

After determining the voltage with its polar components, the calculation can continue. The calculation will go as follow:

$$V_n = \frac{220 + (1\angle -120)(218\angle -113.7) + (1\angle 120)(218\angle 123.18)}{3}$$

Vn=220+1∠-120220∠-123.2+(1∠120)(219∠113.7)3

$$V_n = \frac{220 + (220\angle -243.2) + (219\angle 233.7)}{3}$$

$$V_n = 7.248\angle -65.8$$

For the positive sequence, the calculation follows the same step but with different formula.

$$V_p = \frac{220 + (1\angle 120)(220\angle -123.2) + (1\angle -120)(219\angle 113.7)}{3}$$

$$V_p = \frac{220 + (220\angle -3.175) + (219\angle -63)}{3}$$

$$V_p = 219.4\angle -3.15$$

After the value of positive and negative sequence are acquired, VUF can be calculated.

$$\%VUF = \frac{7.248}{219.4} \text{ x } 100$$

$$\%VUF = 3.3\%$$

The value of VUF is 3.3%, which is by IEC standard is still allowed because the limit of VUF is 5.

2. Result

The data that were measured and gathered from the laboratory experiment and the calculation of the definitions of LVUR, PVUR, and VUF are going to be shown on the following subsection.

- Scenario 3

Scenario 3 is where one thruster generator and the ship diesel generator is used. Generator 1 will indicate the diesel generator and generator 2 will indicate the thruster generator.

- Variation 1

Variation 1 of scenario 2 is where the load are loaded up to 75% on both bow thrusters. Table 4.14 will show the result of scenario 3 variation 1. The result for variation 1 of scenario 3 is shown on Table 4.14. It can be seen that the result of LVUR are 0.33% and 0.42%, the result for PVUR are 0.46% and 0.30% and the result for VUF is 0.15% and 0.26. From these results it can be concluded that all of the result are allowable in term of their own definitions. The 0.5% for PVUR, the 3% for LVUR and 5% for VUF . The only thing that is unbalance is the load. The unbalance of the load can be seen from the high number of current flowing in the neutral line. Because of that, the current is unbalance that can be seen on the current column especially on the first generator.

Table 4.14 Result of Scenario 3 Variation 1

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	398	RN	$219\angle 0°$	R	1.54	LVUR(%)	0.33
ST	400	SN	$220\angle -120°$	S	2.7	PVUR(%)	0.30
TR	400	TN	$220\angle 120°$	T	3.5	VUF(%)	0.15
				N	4.11		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	400	RN	$220\angle 0°$	R	1.36	LVUR(%)	0.42
ST	397	SN	$219\angle -120°$	S	1.20	PVUR(%)	0.46
TR	398	TN	$218\angle 120°$	T	1.21	VUF(%)	0.26
				N	2.9		

- Variation 2

Variation 2 of scenario 2 is where the load are loaded up to 80% on both bow thrusters. Table 4.5 will show the result of scenario 3 variation 2.The second variation of scenario 3 also have good result regarding its definition with the result can be seen on Table 4.15. The LVUR resulting in 0.16% and 0.41%, the PVUR resulting in 0.30% and 0.30% and VUF resulting in 3.30% and 3.08. These results are all in range of the maximum value of unbalance for each of their definitions. The bad result for the variation can be seen on table is current. The current give a high amount of current in the neutral line meaning the load is unbalance.

Table 4.15 Result of Scenario 3 Variation 2

Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	409	RN	$220\angle 0°$	R	2.22	LVUR(%)	0.16
ST	408	SN	$220\angle -123.2°$	S	1.69	PVUR(%)	0.30
TR	409	TN	$219\angle 113.7°$	T	1.82	VUF(%)	3.30
				N	3.6		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	409	RN	$220\angle 0°$	R	1.01	LVUR(%)	0.41
ST	410	SN	$220\angle -123.2°$	S	1.02	PVUR(%)	0.30
TR	407	TN	$219\angle 113.7°$	T	1.00	VUF(%)	3.08

				N	2.87		

- Variation 3

Variation 3 of scenario 2 is where the load are loaded up to 85% on both bow thrusters. Table 4.26 will show the result of scenario 3 variation 3. The result for third variation of scenario 3 is shown on Table 4.16. From the table it can be seen that the result for LVUR are 0.33% and 0.58%, the result for PVUR are 0.61% and 0.31%, and the last the result for VUF are 3.09% and 3.30%. The one definition that gave the result above the limit is the PVUR on the first generator with its PVUR being 0.61%. The result gave about 0.11% more than the standard of 0.5%.

Table 4.16 Result of Scenario 3 Variation 3

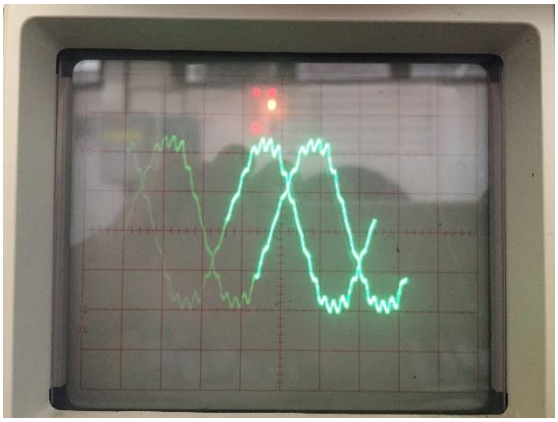
Generator 1							
Line Voltage		Phase Voltage		Current		Definitions	
RS	403	RN	$221\angle 0°$	R	1.58	LVUR(%)	0.33
ST	403	SN	$219\angle -123.2°$	S	1.58	PVUR(%)	0.61
TR	405	TN	$219\angle 113.7°$	T	1.75	VUF(%)	3.09
				N	3.70		
Generator 2							
Line Voltage		Phase Voltage		Current		Definitions	
RS	405	RN	$218\angle 0°$	R	0.96	LVUR(%)	0.58
ST	402	SN	$218\angle -123.2°$	S	0.89	PVUR(%)	0.31
TR	401	TN	$217\angle 113.7°$	T	0.92	VUF(%)	3.30
				N	2.74		

4.6.3. Graphs and Phasor Diagram

Graphs and phasor diagram are shown to show how the unbalance on each scenario and variation looks like. The graphs are observed using an oscilloscope and are reshown using excel graphs. The following segment will show the steps and elaborate them on how the process from the oscilloscope to the excel.

- Oscilloscope Observation

First of all, the graphs of the voltage that are needed are observed and are recorded using a camera. Figure 4.2 will show how the recorded picture looks like. This



is done to know how much the angles for each voltage phase actually are. From these results the wave will be transmitted onto excel form for to make the analysis easier.

Figure 4.3 Result of oscilloscope observation
Source: Authors Personal Picture

- Making the Sinusoidal Wave using Excel

After the sinusoidal wave of the voltage is recorded, the wave then is redrawn using excel. An example of how the wave will look like is shown on Figure 4.3 which is the result of scenario 2 variation 2.

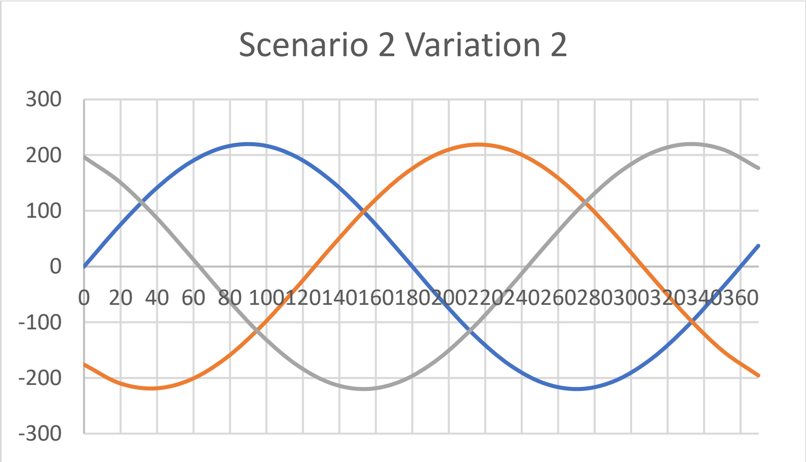


Figure 4.4 Example of sinusoidal wave

On Figure 4.3 it can be seen the angle of the wave are not 120° which indicate that there's a slight unbalance happened. Each of the phase for this scenario are $220\angle 0^{\circ}$, $219\angle -126.5^{\circ}$, and $220\angle 116.76^{\circ}$. Each scenario and variation are redrawn in excel form for a better view on how the sinusoidal wave of each scenario and variation looks like.

- Phasor Diagram

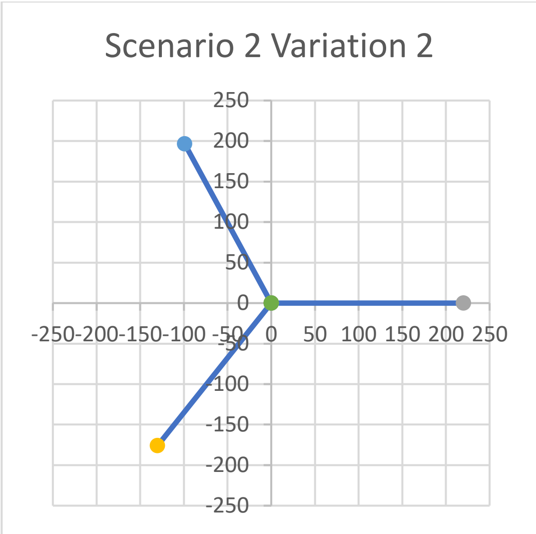


Figure 4.5 Example of phasor diagram

After the sinusoidal wave is done, the phasor diagram can be made. Phasor diagram is representation of the sinusoidal wave in vector form. For this example, the same data from scenario 2 variation 2 will be use which are $220\angle 0^{\circ}$, $219\angle -126.5^{\circ}$, and $220\angle 116.76^{\circ}$. Figure 4.4 is an example of how the result of scenario 2 variation 2 looks like.

2.1. Results

After all of sinusoidal wave are observed, recorded, and redrawn in excel, the following segment will show how each scenario and variation looks like.

- Scenario 1

Scenario 1 is the scenario where two thruster generators is used to power the two bow thruster motors.

- Variation 1

Variation 1 uses 60% - 75% load condition on the bow thruster motors. The result for this variation are $220\angle 0^{\circ}$, $218\angle -113.7^{\circ}$, and $218\angle 123.18^{\circ}$. The result for the sinusoidal wave are shown on Figure 4.5 and the phasor diagram are shown on Figure 4.6.

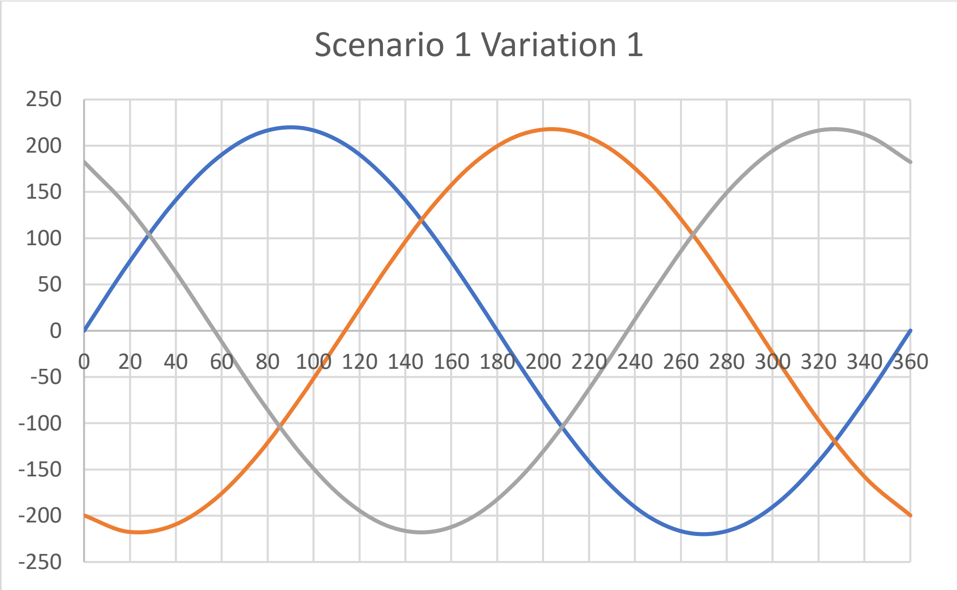


Figure 4.6 Sinusoidal wave for scenario 1 variation 1

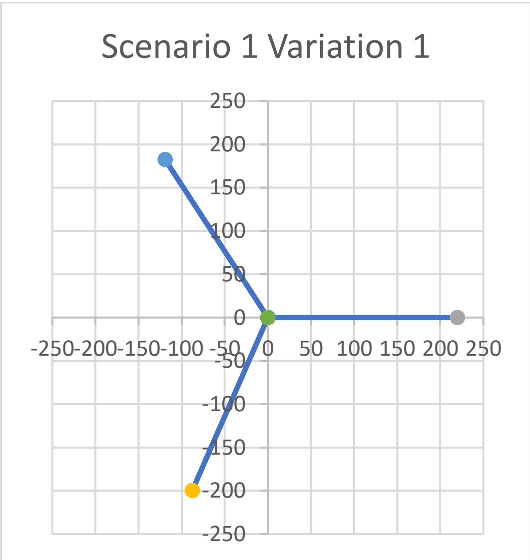


Figure 4.7 Phasor diagram for scenario 1 variation 1

- Variation 2

The second variation uses 80% - 100% load on the bow thruster motors. The result for this variation are $217\angle 0^{\circ}$, $215\angle -113.7^{\circ}$, and $215\angle 123.18^{\circ}$. The result for the sinusoidal wave are shown on Figure 4.7 and the phasor diagram are show on Figure 4.8.

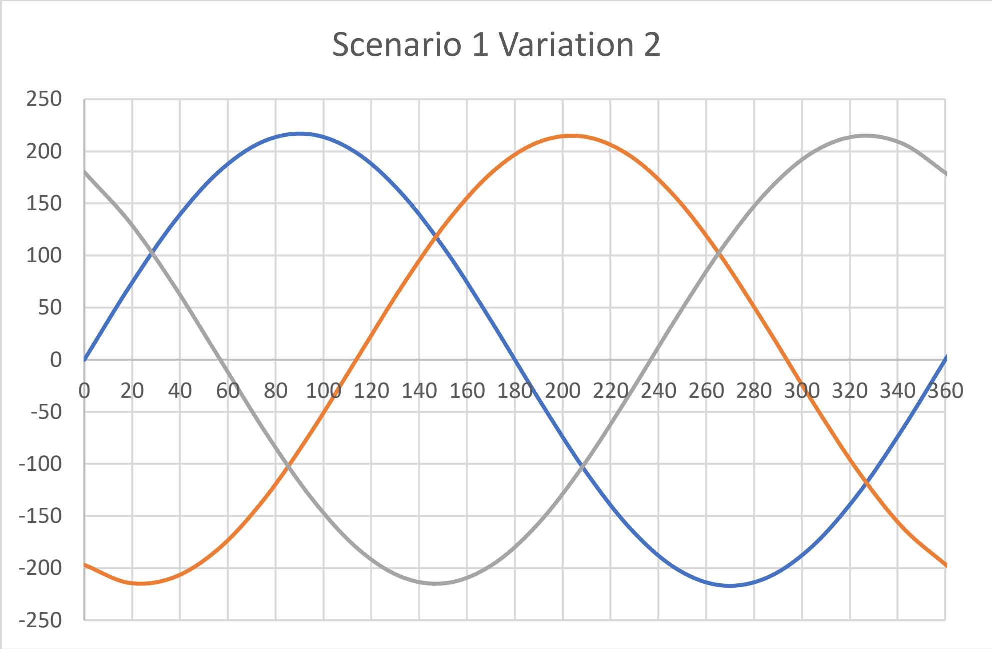


Figure 4.8 Sinusoidal wave for scenario 1 variation 2

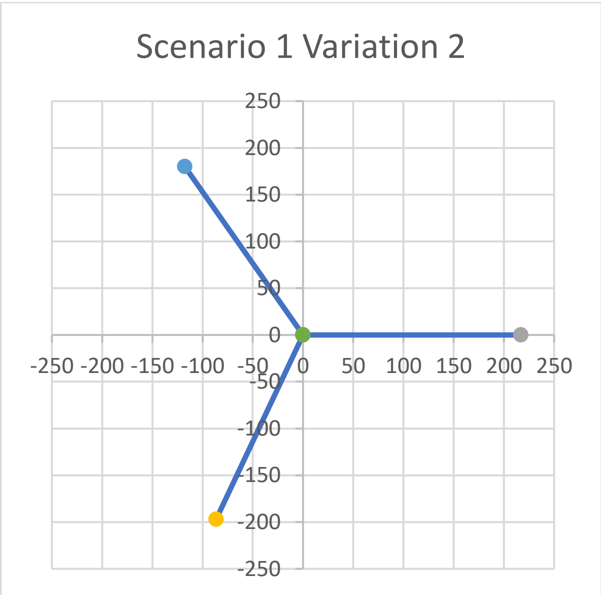


Figure 4.9 Phasor diagram for scenario 1 variation 2

- Variation 3

The second variation uses 100% - 100% load on the bow thruster motors. The result for this variation are $215\angle 0^{\circ}$, $213\angle -113.7^{\circ}$, and $213\angle 123.18^{\circ}$. The result for the sinusoidal wave are shown on Figure 4.9 and the phasor diagram are show on Figure 4.10.

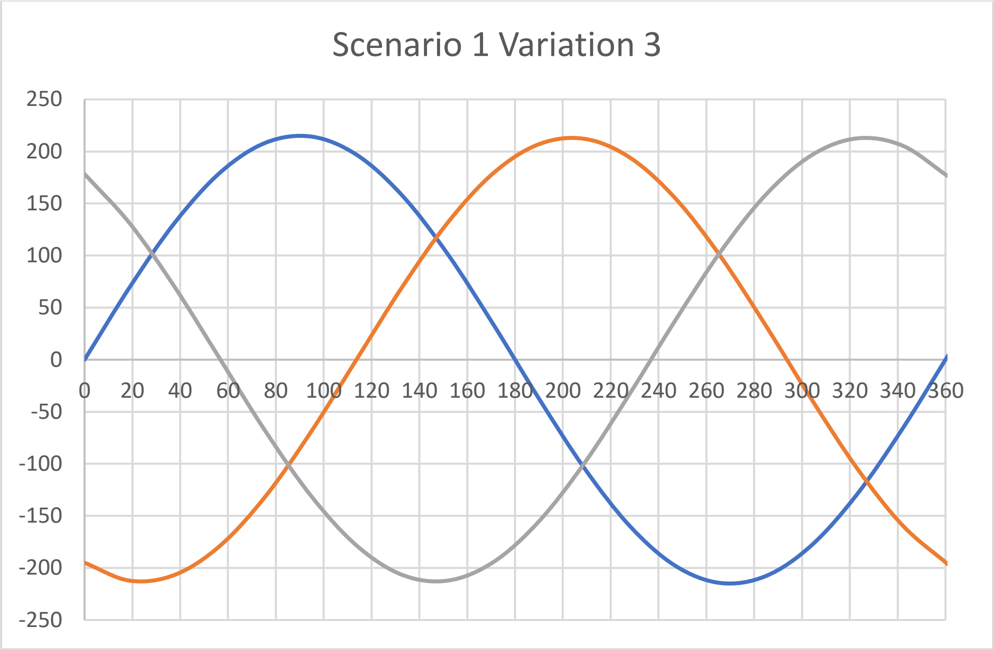


Figure 4.10 Sinusoidal wave for scenario 1 variation 3

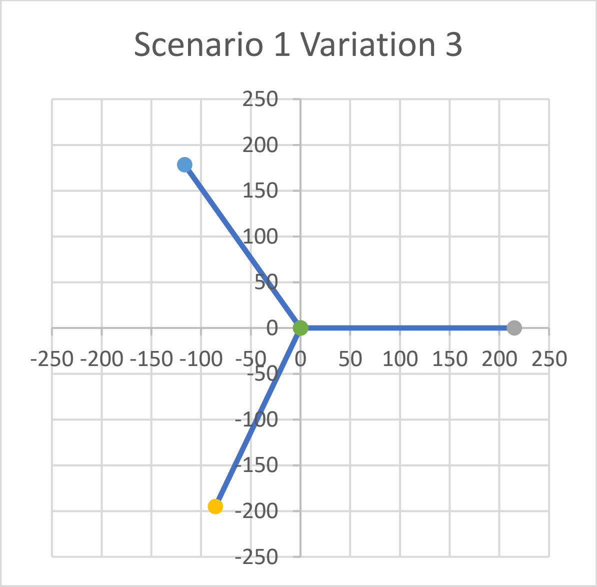


Figure 4.11 Phasor diagram for scenario 1 variation 3

- Variation 4
  For variation 4 with the load being 110%-110% the motors cannot be run.

- Scenario 2
  Scenario 2 is the scenario where one generator thruster is used powering two bow thrusters as load.

- Variation 1

  Variation 1 will involve 40% load on both the bow thrusters. The result for this variation are $220\angle 0^{\circ}$, $220\angle -120^{\circ}$, and $218\angle 120^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.11 and the phasor diagram is on Figure 4.12.

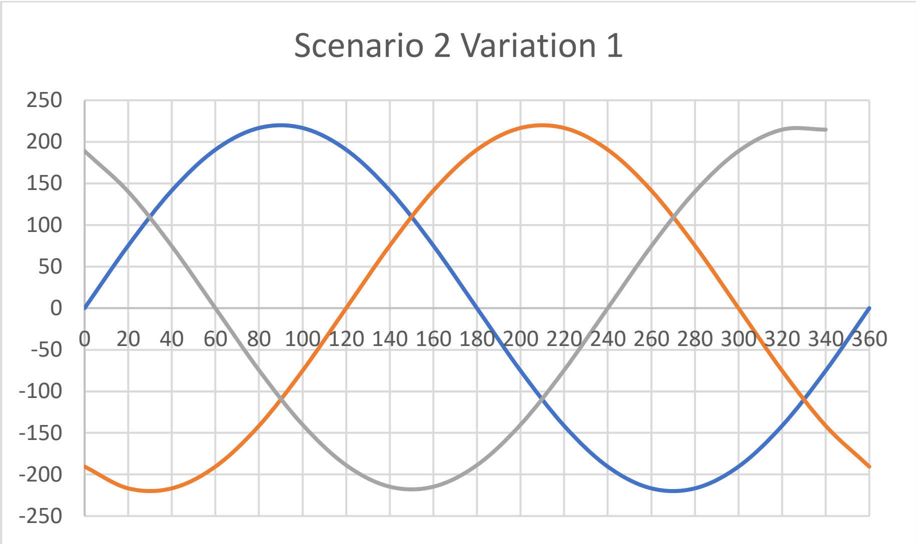


Figure 4.12 Sinusoidal wave for scenario 2 variation 1

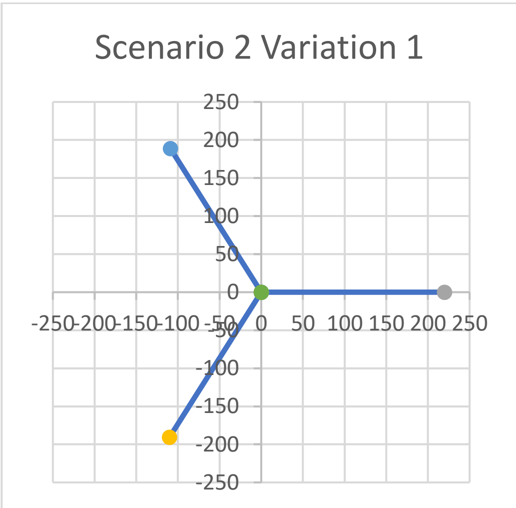


Figure 4.13 Phasor diagram of scenario 2 variation 1

- Variation 2

  Variation 2 will involve 50% load on both the bow thrusters. The result for this variation are $220\angle 0^{\circ}$, $219\angle -126.5^{\circ}$, and $220\angle 116.76^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.13. and the phasor diagram is on Figure 4.14.

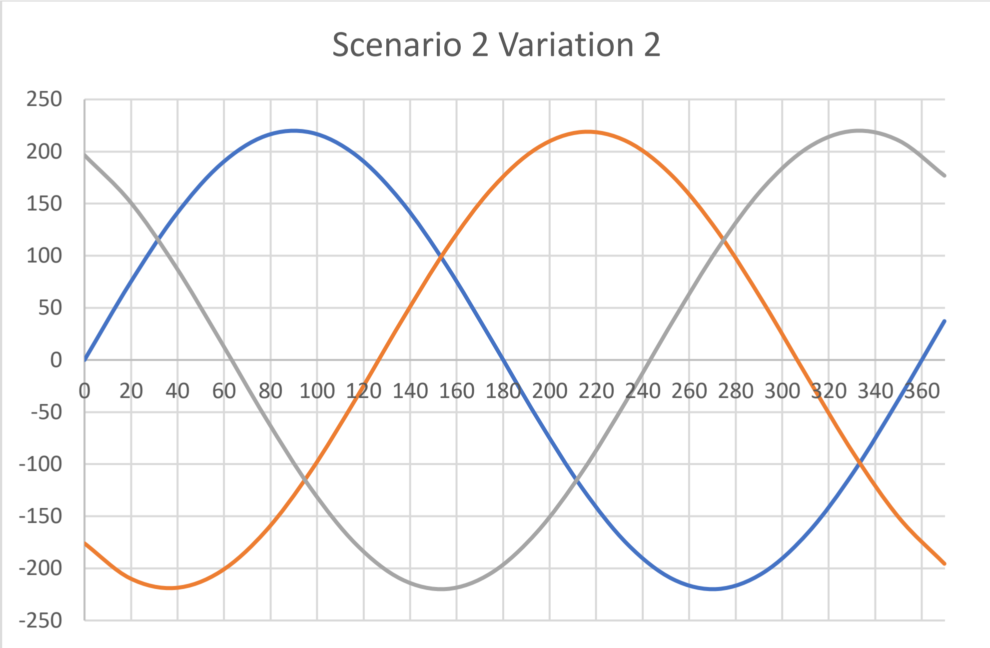


Figure 4.14 Sinusoidal wave of scenario 2 variation 2

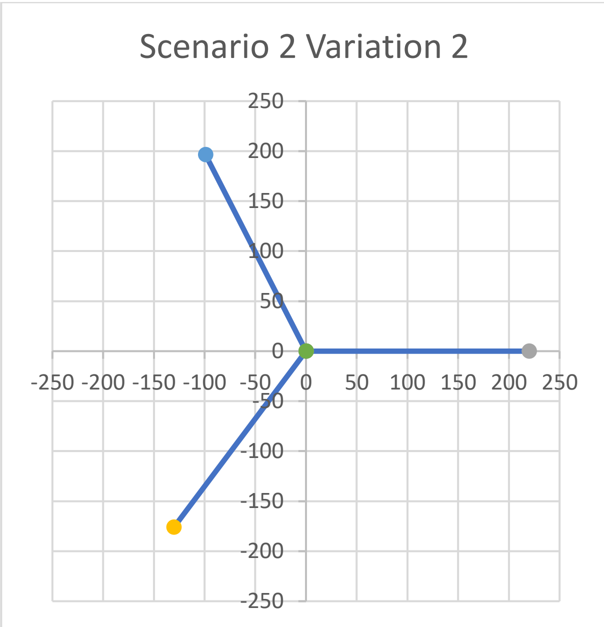


Figure 4.15 Phasor diagram of scenario 2 variation 2

- Variation 3

Variation 3 will involve 60% load on both the bow thrusters. The result for this variation are $220\angle 0^{\circ}$, $220\angle -123.2^{\circ}$, and $209\angle 113.7^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.15 and the phasor diagram is on Figure 4.16.

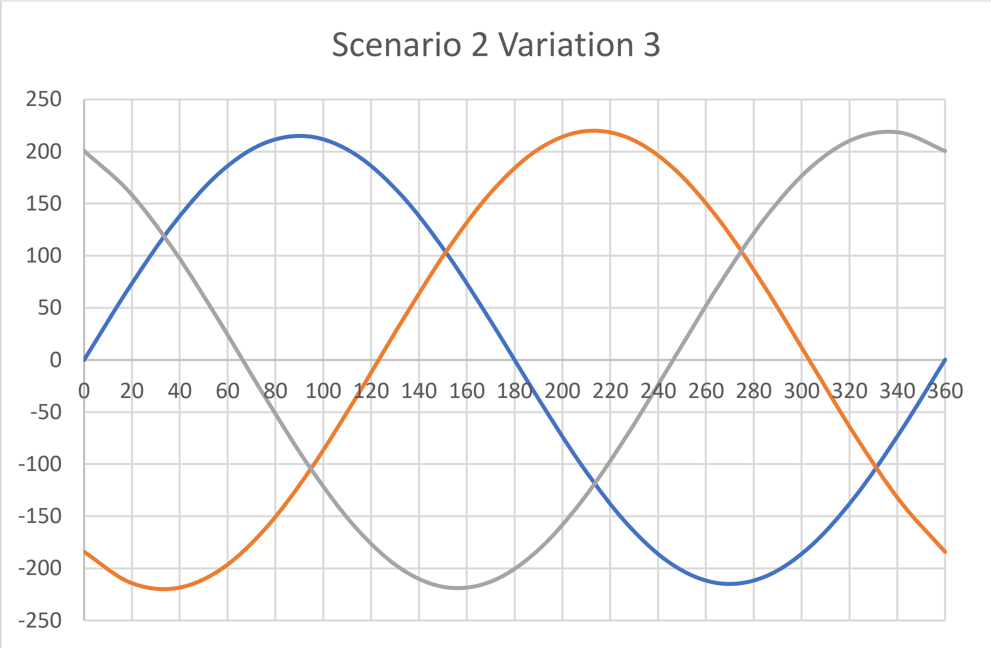


Figure 4.16 Sinusoidal wave for scenario 2 variation 3

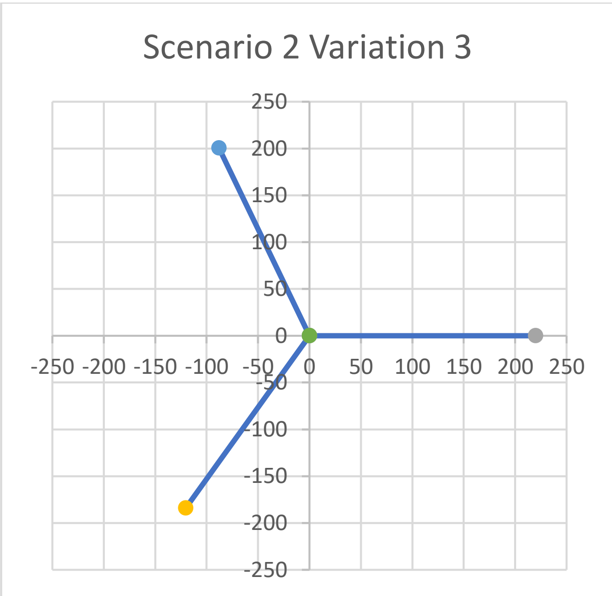


Figure 4.17 Phasor diagram of scenario 2 variation 3

- Scenario 3

Scenario 3 is the scenario where one thruster generator and one diesel generator is used to power two bow thrusters as load.

- Variation 1

Variation 1 will involve 75% load on both the bow thrusters. The result for this variation are $219\angle 0^{\circ}$, $220\angle -120^{\circ}$, and $220\angle 120^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.17 and the phasor diagram is on Figure 4.18.

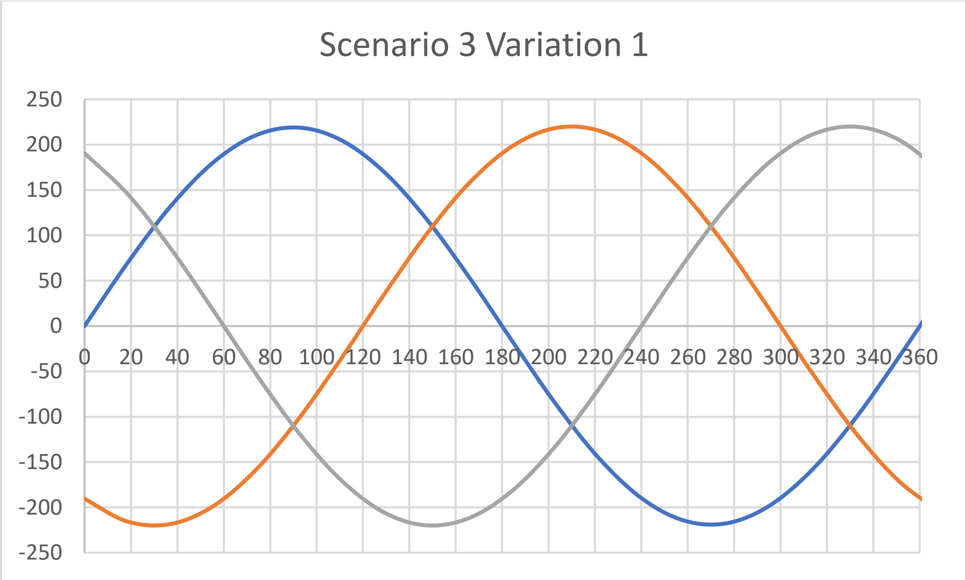


Figure 4.18 Sinusoidal wave for scenario 3 variation 1

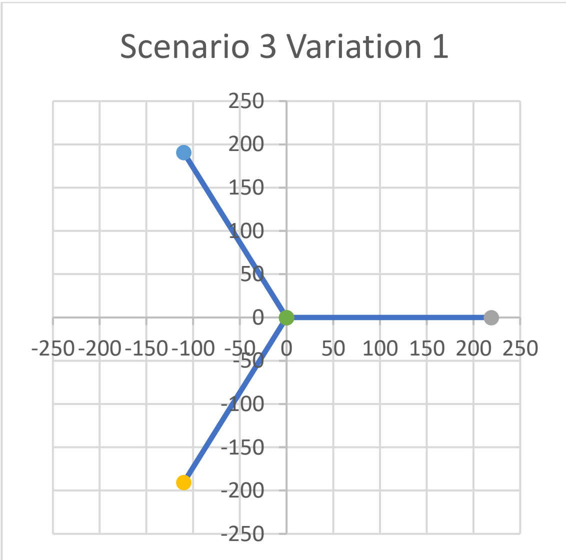


Figure 4.19 Phasor diagram of scenario 3 variation 1

- Variation 2

Variation 2 will involve 80% load on both the bow thrusters. The result for this variation are $220\angle 0^{\circ}$, $220\angle -123.2^{\circ}$, and $219\angle 113.7^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.19 and the phasor diagram is on Figure 4.20.

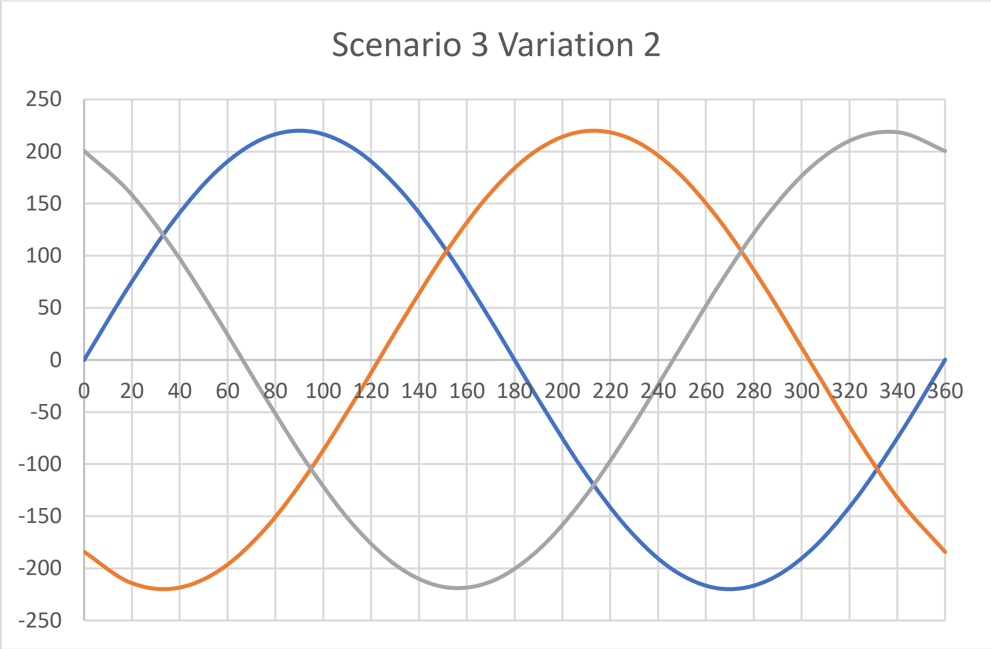


Figure 4.20 Sinusoidal wave for scenario 3 variation 2

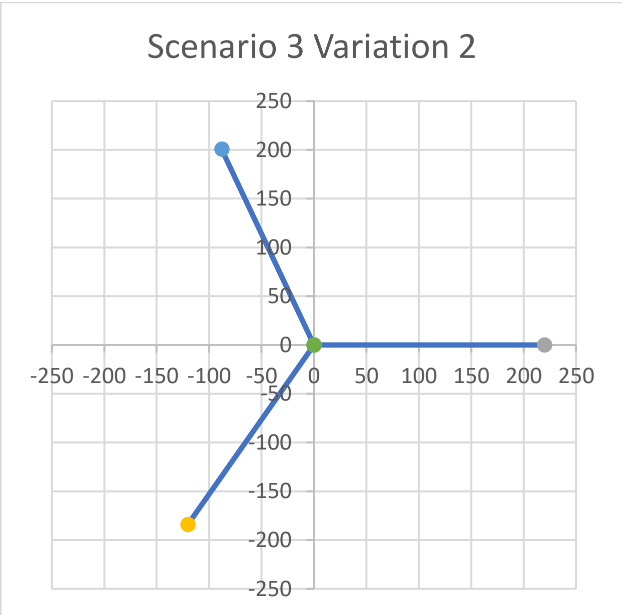


Figure 4.21 Phasor diagram for scenario 3 variation 2

- Variation 3

Variation 3 will involve 85% load on both the bow thrusters. The result for this variation are $221\angle 0^{\circ}$, $219\angle -123.2^{\circ}$, and $219\angle 113.7^{\circ}$. The result for the sinusoidal wave is shown on Figure 4.21 and the phasor diagram is on Figure 4.22.

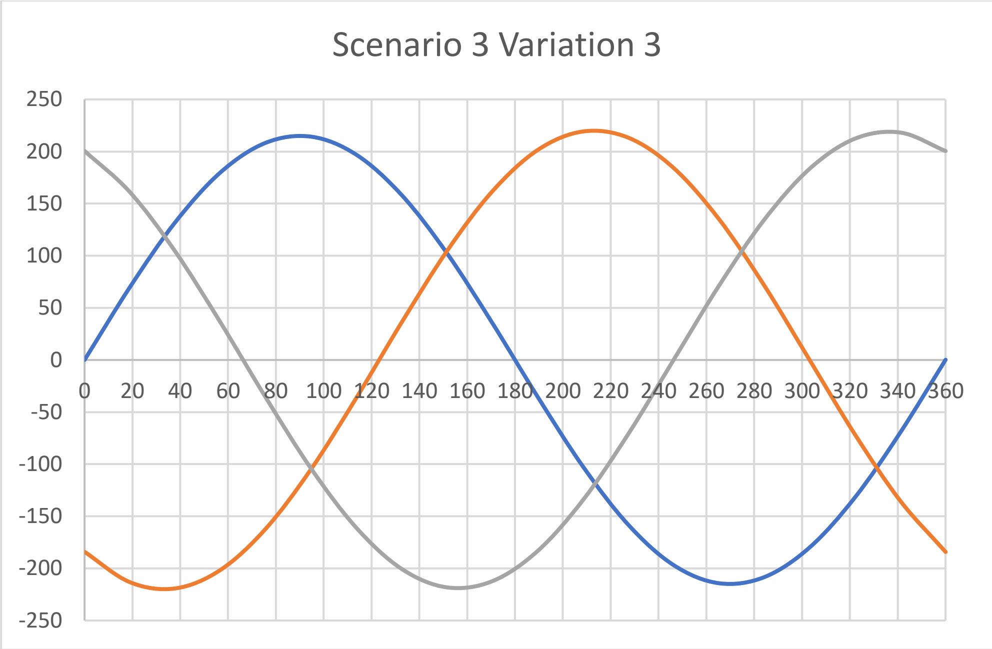


Figure 4.22 Sinusoidal wave for scenario 3 variation 3

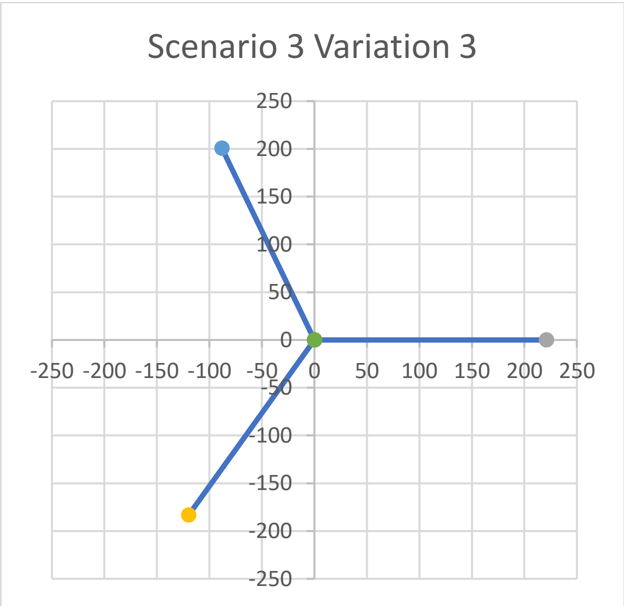


Figure 4.23 Phasor diagram for scenario 3 variation 3

4.7. Discussion

From the results that were presented on sub chapter 4.6, it can be seen that most of the problems that occur regarding each scenario comes from the unbalance current and the neutral current which some have a high amount especially on scenario 3. The reason for this is the use of different type of configuration for the motors that are used as load. One of the motors uses wye configuration while the other uses delta configuration, thus giving a bit of unbalance load and a loss of neutral line presence flowing to the delta configuration. Thus, giving the sense of an unbalance load that the neutral current is relatively high.

As for the other aspects in this analysis such as the voltage some have a slight drop in voltage due to the generator that are use cannot fully meet the requirement. A manual auto voltage regulator (AVR) by using a regulator to increase the generator excitation current thus increasing the voltage output of the generator. Though even after manually trying to get back the voltage to 220V/380V at certain scenario the generator cannot do it. This also affected the outcome of the measurement.

The difference incapability of the motors also affects this. Two motor were use in this analysis but have different power output value. One of the motors only have maximum output around 163W-180W while the other one have its output around 330W-346W. This also affects the system by not only giving different configuration but also different capability of the motors that are used as load.

Other than the motors as load being used are different, the difference in motors that are used to power the generators have different type and capability. One of the generators uses an AC motor and the other uses DC motor. This give the system a little bit restriction as the AC motor have constant frequency thus giving little room for the DC motor to be configured.

Not only the two generator that acts as the thruster generator but also the generator that is used as the diesel generator. The generator have a high output that doubles the output of the thruster generator with an output around 1kW while the thruster generator is only 480W. Not only that, the standard phase/line voltage for the generator is 230V/415V, thus making it a bit different than the standard for the other generator with 220V/380V.

Although there are a lot aspect that affects the outcome of the analysis, the modelled system are designed as close as possible using the present items available at the laboratory. The scale for the generator to the real generator of the real dynamic positioning system is about 1:1666.67 with the real generator being 800kW and the generator in the laboratory is about 480W. For the motors used as load is also around the same scale with 1 : 1560.60 for the motor with 330-346 capacity. Though for the second motor the scale is a bit distant difference with about 1 : 2861.11 with the other real motor to be about 515kW while the motor in the laboratory is about 180W. The system are designed as close as possible to the real system with how the system works. Two generators are paralleled to a bus than a switch is used to than power the load/bow thrusters. And most of the current that flows still follows the Kirchhoff law that the current inputted is the same to the current that is outputted. Although most of the current flows in an unstable condition and have high value of current in the neutral line.

The result for the unbalance voltage calculation itself doesn’t really give a bad review to the system. Most of the voltage unbalance calculation is still in check to the rules even with different definition. It’s just that the in some cases where the voltage is higher than 2 V voltage could cause the unbalance ratio to not comply to the rules especially to the PVUR definition.

4.8. Minimizing Unbalance Voltage

The cause of an unbalance voltage is usually because of an unbalance load present in the system. So, to minimize the unbalance voltage is to always check the electrical system if the system have a uniformly distributed single phase load. Other than that voltage unbalance could be caused by:

1. Faulty operation of power factor correction equipment
2. Unbalance or unstable utility supply
3. Unbalance transformer bank supplying a three-phase load that is too large for the bank
4. Unevenly distributed single-phase loads on the same power system
5. Unidentified single-phase to ground faults
6. An open circuit on the distribution system primary

Based on the causes of voltage unbalance it can be concluded that to minimize the unbalance voltage is to always check the system, especially the supply terminal. By regularly monitoring the system, it can be known when an unbalance happen thus could prevent it. Researchers have shown that a large unbalance could harm the effect the life expectancy of the motors. To protect the motor or equipment from getting damage cause by voltage unbalance a phase balance relay could be use. The relay will trip the motor in case of excessive voltage unbalance happens. A compensator also could be used. A compensator contains a capacitor and reactors, so they can compensate incase an unbalance happen by giving them load compensation, where they reduce the reactive power demand and then will balance the real power drawn from the supply lines.

CHAPTER V
CONLUSIONS AND SUGGESTIONS

5.1. Conclusions

It can be concluded that from this analysis that:

1. The condition of the unbalance voltage for the dynamic positioning system are relatively okay with some exception on certain scenario, such as the third scenario. The unbalance voltage that happens mostly because of unbalance load in the system causing a high number of current in the neutral line. The condition of motor, generator, or equipment also could affect an unbalance. In this analysis for the modelled dynamic positioning system the unbalance conditions mostly related to the equipment in action and also unbalance load in the system. This is because based on the calculation using three different type of definitions, most of the scenario along with their variation have an unbalance ratio that does not go above the limit on each definition. Results given by the first scenario with the result of PVUR 0.61%, 0.62%, and 0.62% for variation 1, 2, and 3 gives a hint that the system or more specifically the generator are not generating balanced voltage. The reason being that the neutral current being 0.4 A, 0.83 A, and 0.84 A, indicating a loss on the system. Scenario 2 that uses only one generator gives a different result, showing that the unbalanced only happened on the 40% load with the result of 0.61% on the PVUR, while variation 2 and 3 with 50% and 60% load the PVUR are all okay with 0.30%. That means that the generator have more efficiency on load higher than 40%. It is also can be seen from the neutral current that the neutral current on variation 1 is 0.62 A, while the other current is at 0.14 A and 0.3 A for variation 2 and 3. The result for scenario 3 though have another different result. The PVUR give the bad result on variation 3 while the other variations are okay. The result for scenario 3 having the PVUR increased on variation 3 gives a result of the average current being decreased per variation. From the first variation giving the average current of 2.58 A, second variation giving the current of 1.94 A, and last the average current for the third current is 1.63 A. Meaning the system having losses, because as the load go higher the current supposed to go higher going by the rule of P = V x I while the voltage are supposed to be constant.
2. In preventing an unbalance voltage is mostly done by regularly checking the system. By always checking the system it can be see if an unbalance is happening. Unbalance mostly happens because an uneven distributed single phase load, and this cannot be seen unless the system is checked regularly. Other than that, a phase balance relay is also possible. The relay will trip the motor or equipment if the relay detect a surge of unbalance happens. Other equipment that is also being used to prevent or handle an unbalance voltage is the use of SVC or Static VAR Compensator. A compensator is basically an equipment that have both reactor and capacitor. The use of that is that if an unbalance happened because the apparent power rise goes inductive, the compensator will use its capacitor

giving a reactive power, so the power goes down. If the apparent power fell because it is going reactive, the compensator will use the reactor to give the system a inductive power, so the power goes normal.

5.2. Suggestions

Suggestion for this analysis are suggested for anyone who wants to learn or continue the analysis regarding an unbalance condition. More or less that an experiment using a modelled figure is no easy task especially if the equipment are limited. These are some suggestion that the author suggested to make the analysis easier.

1. Use an equipment that are in a good condition
2. In modelling a system, it is more preferred to use an equipment with the same scale
3. Trying different state of the voltage to know how much voltage it need so the unbalance ratio is not in check with the rules or definitions.

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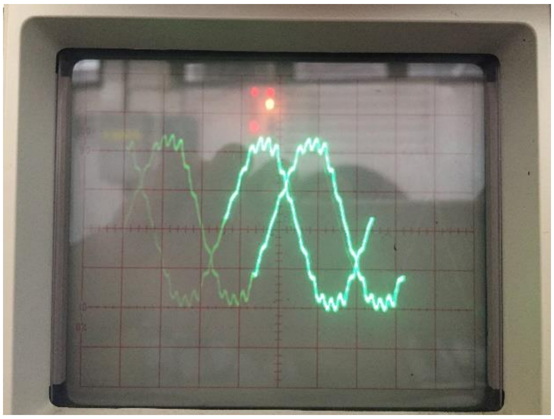
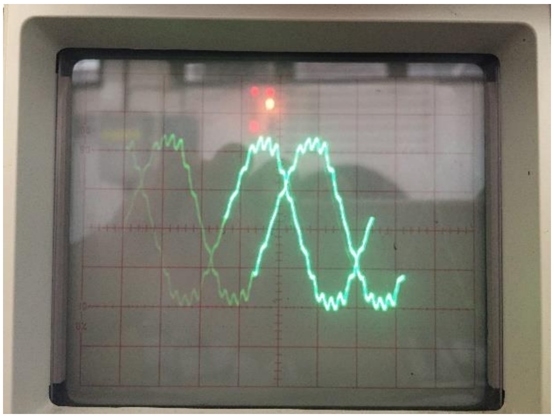
APPENDIX 1

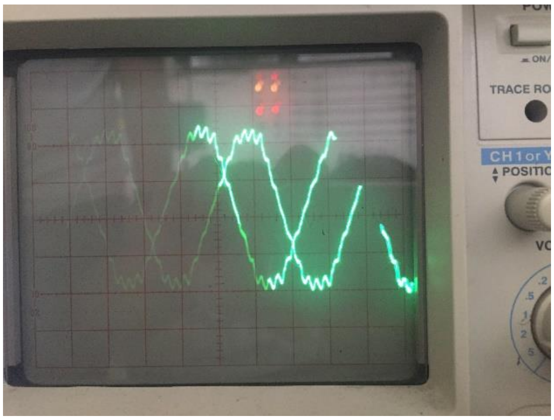
OSCILLOSCOPE RESULT

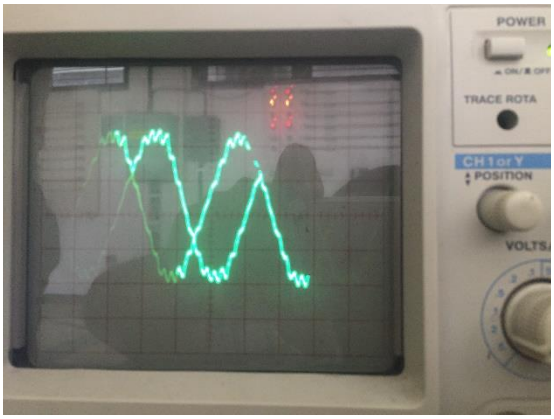
Oscilloscope result for Scenario 1 Variation 1



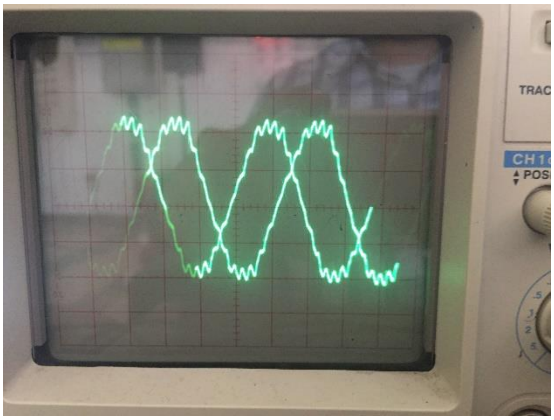


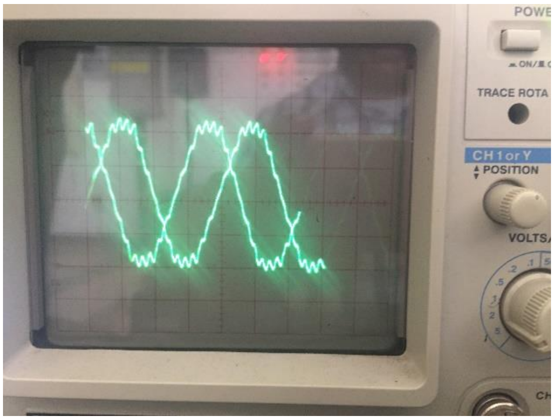
Oscilloscope result for scenario 1 variation 2



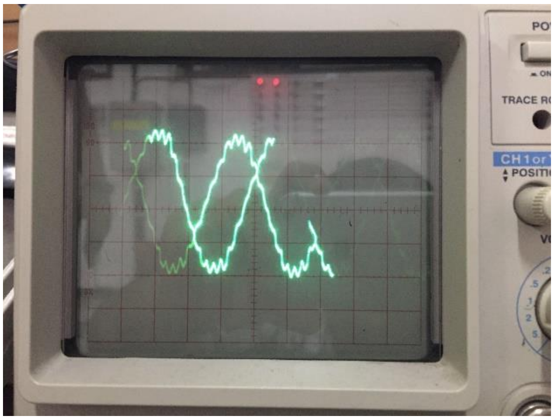


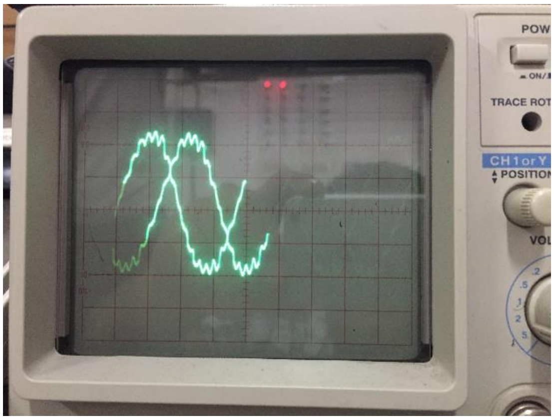
Oscilloscope result for scenario 1 variation 3



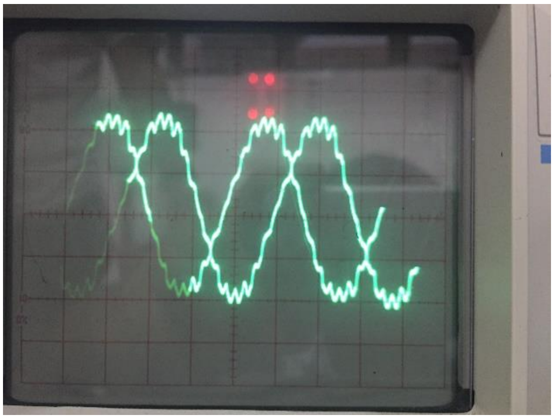


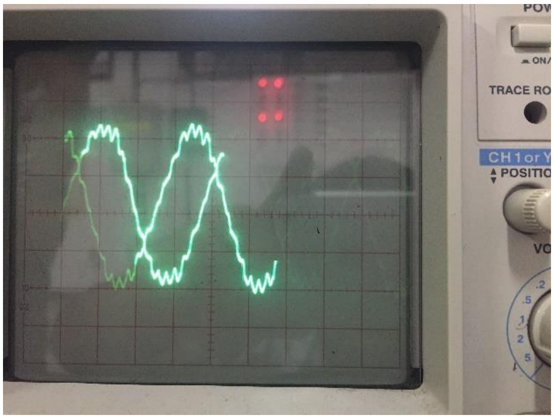
Oscilloscope result for scenario 2 variation 1



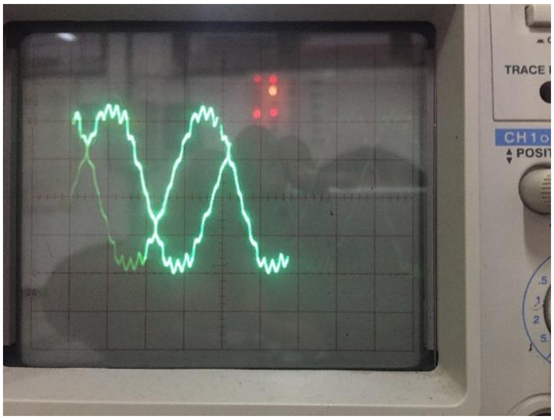


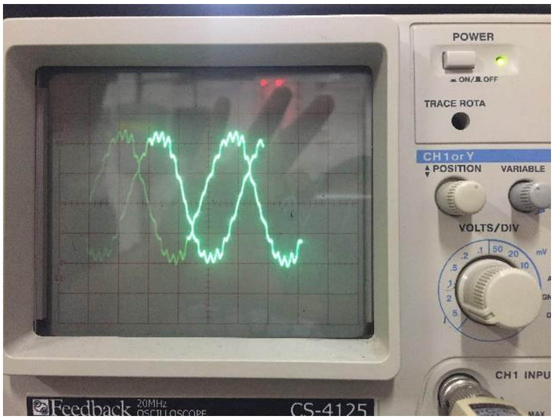
Oscilloscope result for scenario 2 variation 2



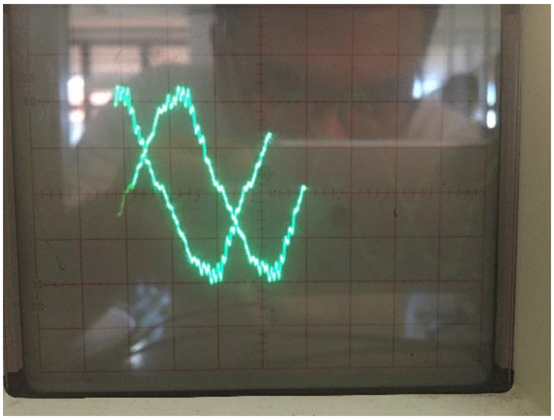


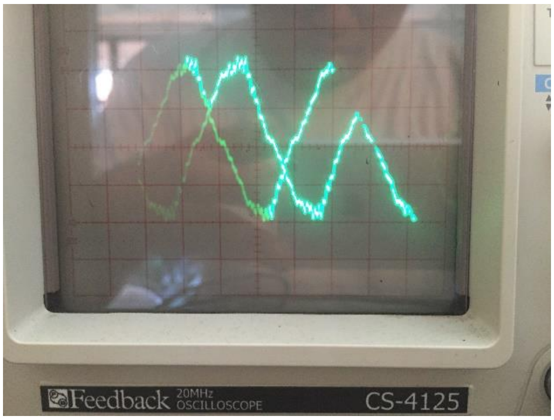
Oscilloscope result for scenario 2 variation 3



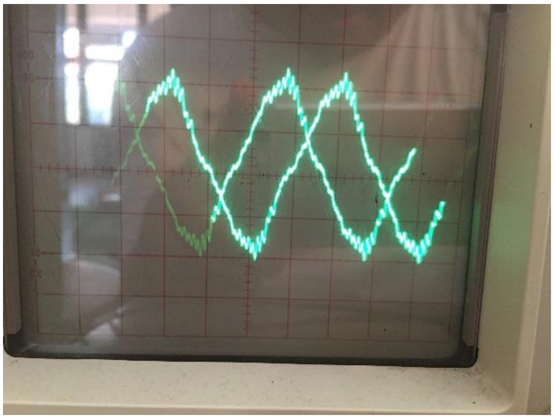


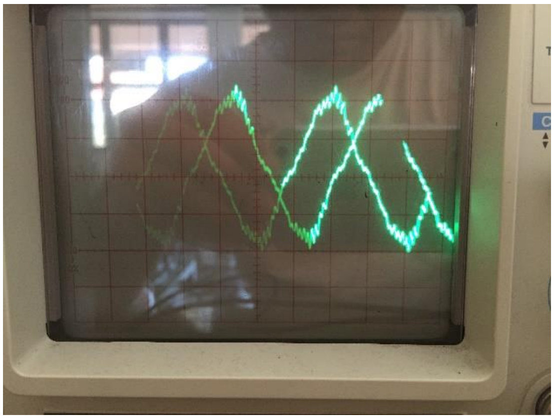
Oscilloscope result for scenario 3 variation 1



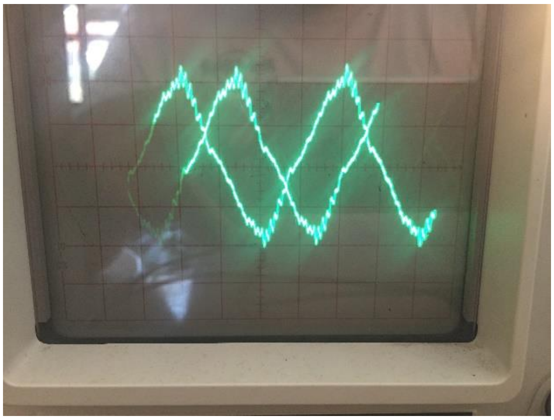


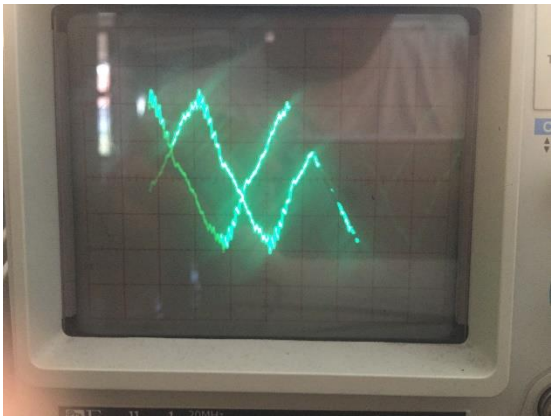
Oscilloscope result for scenario 3 variation 2





Oscilloscope result for scenario 3 variation 3





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