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BACHELOR THESIS & COLLOQUIUM – ME184841

SHORT CIRCUIT STUDY ON SHIP DYNAMIC POSITIONING ELECTRICAL SYSTEM BASED ON LABORATORY SCALE EXPERIMENT

TANGGUH SETIA RAMADHAN
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DOUBLE DEGREE PROGRAM
DEPARTEMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
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JURUSAN TEKNIK SISTEM PERKAPALAN
FAKULTAS TEKNOLOGI KELAUTAN
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SURABAYA
2019

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APPROVAL FORM

SHORT CIRCUIT STUDY ON SHIP DYNAMIC POSITIONING ELECTRICAL SYSTEM BASED ON LABORATORY SCALE EXPERIMENT

BACHELOR THESIS

Submitted as one of Requirements to obtain Bachelor Degree in Engineering
on
Marine Electrical and Automation System (MEAS)
Bachelor Program in Marine Engineering Department
Faculty of Marine Technology
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DECLARATION OF HONOR

I hereby who signed below declare that:

This final project has written and developed independently without any plagiarism act. All contents and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

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Surabaya, July 2019

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SHORT CIRCUIT STUDY ON SHIP DYNAMIC POSITIONING ELECTRICAL SYSTEM BASED ON LABORATORY SCALE EXPERIMENT

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Abstract

Along with the demands of an ever-evolving era, human activities are not only focused on land. Now the offshore activites have started to be crowded by people, be it industrial activities, exploration, exploitation, transportation, and other activities that enable humans to make a living in this world. Dynamic Positioning is a controll system that can maintain ship position to the object on horizontal axis. With the degree of freedom of the ship, the Dynamic Positioning system maintains the position of the ship from sway and surge movements. The term short circuit fault is used to explain that the conductor is briefly connected. There are two values of short circuit current failure that must be evaluated. The first is the maximum short circuit current. The maximum value of the short circuit current will be related to the short circuit current in the terminal around the protection device. Second, the short circuit current is minimal. The value of this current is important to use when selecting the current-time curve for circuit breakers and fuses. There are several method to calculate the value of short circuit current including impedance, composition, and conventional method. On this papper, author use impedance method that based on IEC 60909 standart. Based on experiment that held on laboratorium, each load variation and scenario have their own trend value. The highest initial symetrical short circuit current that obtain both on impedance method and conventional method were found at 2nd scenario and 60%-60% load variation, the value that obtain in impedance method is 2.5158 Amphere and the value that obtain on with conventional method is 3.91 Amphere.

Keywords-Bow thruster, AHTS vessel, Short circuit, Impedance method.

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SHORT CIRCUIT STUDY ON SHIP DYNAMIC POSITIONING ELECTRICAL SYSTEM BASED ON LABORATORY SCALE EXPERIMENT

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Abstrak

Seiring dengan tuntutan era yang terus berkembang, aktivitas manusia tidak hanya terfokus di daratan. Sekarang kegiatan lepas pantai sudah mulai ramai oleh orang-orang, baik itu kegiatan industri, eksplorasi, eksploitasi, transportasi, dan kegiatan lain yang memungkinkan manusia untuk mencari penghidupan di dunia ini. *Dynamic Positioning* adalah sistem kontrol yang dapat mempertahankan posisi kapal ke objek pada sumbu horizontal. Dengan derajat kebebasn pada kapal, sistem *Dynamic Positioning* menjaga posisi kapal dari pergerakan yang bergoyang dan bergelombang. Istilah *short circuit* merupakan suatu gangguan dimana konduktor pengkantar saling terhubung tanpa memlalui beban atau dengan nilai impedansi atau resistansi yang relatif rendah. Ada dua nilai kegagalan arus hubung singkat yang harus dievaluasi. Yang pertama adalah arus hubung singkat maksimum. Nilai maksimum arus hubung singkat akan terkait dengan arus hubung singkat di terminal di sekitar perangkat perlindungan. Kedua, arus hubung singkat minimal. Nilai arus ini penting untuk digunakan saat memilih kurva waktu-saat ini untuk pemutus sirkuit dan sekering. Ada beberapa metode untuk menghitung nilai arus hubung singkat termasuk impedansi, komposisi, dan metode konvensional. Pada laporan ini, penulis menggunakan metode impedansi yang berdasarkan standar IEC 60909. Berdasarkan percobaan yang diadakan di laboratorium, setiap variasi dan skenario beban memiliki nilai tren masing-masing. Arus hubung singkat simetris awal tertinggi yang diperoleh pada metode impedansi dan metode konvensional ditemukan pada skenario ke-2 dan variasi beban 60% -60%, nilai yang diperoleh dalam metode impedansi adalah 2,5158 Amphere dan nilai yang diperoleh dengan metode konvensional adalah 3,91 Amphere.

Keywords-Bow thruster, AHTS vessel, Short circuit, Impedance method.

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PREFACE

All praise belong to Allah the Almighty for all His mercy and guidance, the writer can complete the thesis entitled " Short Circuit Study on Ship Dynamic Positioning Electrical System Based on Laboratory Scale Experiment " in order to full fill the Final Assignment Course (ME4834) of the Department Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

During this final process, many authors received moral assistance and assistance from various parties, therefore:

1. My beloved Mother and Father who alway give moral support and material support on finishing the process of this thesis and also who always give motivation to writer to be better person
2. Mr Ir. Sardono Sarwito M.Sc as supervisor of this bachelor thesis who give guidance and knowledge and insight
3. Mr Indra Ranu Kusuma ST. M.Sc as supervisor of this bachelor thesis
4. Mr Taufik Fajar Nugroho ST. M.Sc as academic supervisor that gives author academical knowledge and non-academical knowledge either in class or outside the class
5. Mr. Dr. Eng. M. Badrus Zaman, S.T., M.T. and Mr. Semin, S.T., M.T., Ph.D. as Head and Secretary of the Department Marine Engineering FTK - ITS.
6. Every technician on Department Marine Engineering especialy at Marine Electrical and Automation Laboratory who helped author to finish this experiment
7. All author laboratory partners
8. And SALVAGE family, as a batch who accompany author in college life
9. And any other parties that cannot be mentioned one by one, the authors give thanks as much as possible

The author hopes for constructive criticism and suggestions for the sake of related research in the future. Hopefully this final project can benefit readers.

Surabaya, July 30, 2019

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CHAPTER I
INTRODUCTION

1.1. Background

Along with the demands of an ever-evolving era, human activities are not only focused on land. Now the offshore activites have started to be crowded by people, be it industrial activities, exploration, exploitation, transportation, and other activities that enable humans to make a living in this world. In the beginning, activities that used the ocean were limited to transportation activities to support trade and exploration of new places. However, the more days pass, activities in the ocean are also developing, such as exploitation of natural resources in the offshore area.

To support these activities, ship technology is also required to continue to grow. In the begining, ship only used to transport people and goods that traded by people. But now, ships have a wider function, ships still retain their functions as sea transportation but can support other industrial activities, such as exploration and exploitation. In exploration and exploitation activities, there is AHTS Vessel (*Anchor Handling Tug Supply*) . This ship have purpose tu support exploitation and exploration activities, such as supplying offshore building, towing offshore building from shipyard to the oil well. On its operation, in which this ship is a support vessel for offshore buildings, this vessel needs the ability to maintain its relative position towards the offshore buildings it supports, therefore the ship is installed DP (Dynamic Positioning) System

Dynamic Positioning is a controll system that can maintain ship position to the object on horizontal axis. With the degree of freedom of the ship, the Dynamic Positioning system maintains the position of the ship from sway and surge movements . On it's aplication, *Dynamic Positioning System* also can be used to move the ship in rotational motion. In running a dynamic positioning system, there is an electrical system to supply electricity so that the supporting equipment of this system is able to work. There is two configuration to running this system, that is closed bus and split bus, In general, ships use closed bus configuration types in the form of configurations where all loads get the power supply from the main bus supplied by several generators. But this system have deficiency, that if the main bus is failed, so all of the electrical load that connected to the main bus were unable to run. For ships with a DP system, generally use a split bus configuration, it is configuration where one load is supplied by an independent generator to improve its reliability. However, this configuration condition has disadvantages, its efficiency aspects and high emission levels caused by power supply.

On electrical system, there is some failure that can be found. One of the failure is short circuit. Based on IEC 60909, short-circuit is a intentional connection between conduction through obstacles or impedances that are quite a potential difference. In electrical power system design, a short circuit is an important thing to be considered. A short circuit occurs when a conductor / conductor that has a voltage connected to another voltage conductor or is connected directly to a neutral conductor (ground). With a closed bus power configuration system that is applied in a ship's electrical system, where several generators are connected to supply power to all loads through the main bus, when the system is running, a short circuit in the conductor can occur. With the power supply of several generators passing through one main bus, this can occur causing excess current

The term short circuit fault is used to explain that the conductor is briefly connected. To handle this fault, a short circuit analysis is needed so that an appropriate protection system can be determined in the power system. Short circuit disturbance analysis that discusses the analysis that studies the contribution of short circuit faults that might flow to each branch in the system when a short circuit noise might occur in the power system.

Based on the things that have been stated above, the basis is used to compile a study of the analysis of short circuit currents in the AHTS electrical system due to the use of electric thruster using the lab scale simulation method.

1.2. Problem Formulation

The problem formulation based on backgound above that we can discuss among them :

1. How much the electrical short circuit current value that occurs on AHTS Vessel because the usage of electric thruster on closed bus configuration?
2. How is the calculation of the circuit breaker to protect the system in the event of a failure?
3. How to decreasing initial symetrical short circuit current, in order to minimize damage because of short circuit?

1.3. Problem Scope

Limitation of the problem is made so that the scope of this study is more focused, namely:

1. Simulation using trial with avaliable equipment on MEAS laboratory
2. Analysis made focus on circuit breaker settings
3. Did not discuss economical aspect

1.4. Objective

The purpose of this research is :

1. Obtain the maximum and minimum short-circuit current values that occur in the AHTS electrical system due to the use of electric thruster.
2. Obtain the value of the circuit breaker calculation to protect the system when a fault occurs.
3. Obtain method to reduce initial symetrical short circuit current

1.5. Advantages

The advantages of this research is:

1. The results can be used as a basis for protection settings due to short circuit currents that occur on ships using dynamic positioning systems.
2. The result can be opperational refference when failure occurs

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CHAPTER II
LITERATURE REVIEW

2.1. AHTS Vessel

AHTS stand for *Anchor Handling Tug & Supply*, AHTS vessel is a special ship designed to support offshore activities, such as tow and tug an offshore building from the shipyard to its operational location, supplying the needs of offshore buildings and so on. Sometimes AHTS vessels can be used for *Emergency Response & Rescue Vessel* (ERRv) which the purpose is as a responsive unit when another ship is in emergency condition. AHTS also have a setting to do *Quick Realease Anchor*, that can be operated from *bridge* or another deck that connected to the *bridge*. AHTS vessel also have a capability to maintain its relative position to another object , so this vessel equiped with now thruster, stern thruster, also azhimuth thruster that controlled by Dynamic Positioning system so maintain its relative position to an object.

AHTV vessel have vatious design, depend on track record and area where the vessel will be operated. In general AHTS vessel can be categorized among them : *North European Anchor Handling Tug, American Anchor Handling Tug* dan *Anchor Handling Tug and Suplly Vessel*. The following characteristic of AHTS vessel are: First, the vessel have widen stern area. The shape that widens on the stern are to carry the payload and operation of *anchor handling* towing *towing* of those vessel itself. Second, on the side of the cargo area there is an elevated bulwark. THis construction purpose to cover the cargo, crew, and the equpment that caried by this vessel from extreme envirioment . Third, on the stern side there is also an open area. On that area were installed *stern roller* that can be roatate, this rotational movement is to assist the process of operating anchor dropping or lifting anchors in offshore buildings also to maket his vessel capable to tow offshore building.

Figure 2. 1 AHTS Vessel

(Source: www.marinetraffict.com)

At the front of the cargo area there are towing winch houses and accommodation blocks. *Towing winch house* placed on main deck, in line with *cargo handling*. Another *Towing winch*, *Towing wire* and *anchor handling* equipment also placed on this place. Although the design of AHTS varies depending on needs, in general, the functions of the system and equipment on the ship are almost the same with most ships. The following operational criteria for an AHTS ship are:

1. Ship hull design with cargo deck area at the rear, this is purposed to carry cargo and equipment from one platform to another platform and open deck on the forepeak are use for anchor handling operational.
2. The designed hull shape purpose is to maintain manuveribility when the ship is operating at slow speed or static conditions. Large surface area that affected by wind is a distinct disadvantage for AHTS ships when anchor operation or when towing operations. Large surface area that affected by wind make AHTS susceptible to external forces when performing static operations, so the power consumption will increase when the vessels need to maintiain its position.
3. Manouvering system is an importan thing when the vessel need to maintain its relative position.

2.2. Dynamic Positioning System

Dynamic Positioning system can be said to be a new technology in the shipping world, especially in offshore oil & gas exploration and exploitation during the 1960s and 1970s. This technology is an answer that appear to the problem that occur to the vessels that support offshore exploration and exploitation. Because of the extreme surrounding conditions, where oil wells are located at the bottom of the ocean, causing the surrounding wave conditions to be relatively high, while the ship's position is required to be followed oil refinery position, Dynamic Positioning technology starts to develop.

Dynamic Positioning is a system that have functions to support ship maneuverability, specifically on maintaining ship position relative toward an object. Beside that, according to Sorensen, Dynamic positioning on a ship is a procedure wherein automatically maintains the position and heading of the ship using its own propeller and thruster (Sorensen, 1996). Definition of Dynamic positioning system "is a controll system that have funtion to maintain position and direction of ship using its own propeller and thruster". The position of the ship refers to sonar sensors and gyro compass, the information then combined with other information such as wave conditions, wind conditions, and then the controller process all those onformation and give command to actuator -on this case thruster and propeller- to maket he ship position stay on place. Dynamic positioning can maintain the relative position of the ship against the seabed object, against other vessels or offshore buildings. Also, the ship can be positioned at an optimal angle towards wind, waves and currents

To regulate this Dynamic Positioning system, the Association of Dynamic Positioning Vessels was formed in 1990 (DPVOA). This association collects incident data and develops guidelines based on that information. DPVOA cooperates with IMO to produce the Maritime Safety Committee Circular 645. In 1995, DPVOA merged with AODC to form the International Marine Contractors Association (IMCA), which until now has become the only institution that regulate about Dynamic Positioning system standard.

Dynamic positioning usually used by offshore vessels for accurate maneuvering, to maintain a fixed position or for maintenance (laying pipes / cables). Usually the DP system can be found at:

- Offshore drilling (Ship drilling and Semi-submersible). A Drilling vessel will use a DP to maintain its position at the repair site while drilling in deep water
- Offshore support vessels: Platform supplier vessels (PSVs), Well intervention vessels, Diving Support Vessel. Support vessel used DP to maintain the distance between vessel and the oil rig.
- Launch and offshore construction vessels. Pipe-laying vessel use DP to maintain positions and track locations.
- Dredging vessels. Suction Hopper dredgers, rock towers and excavating vessels

- Shuttle tanker, used when FPSO dismantling.

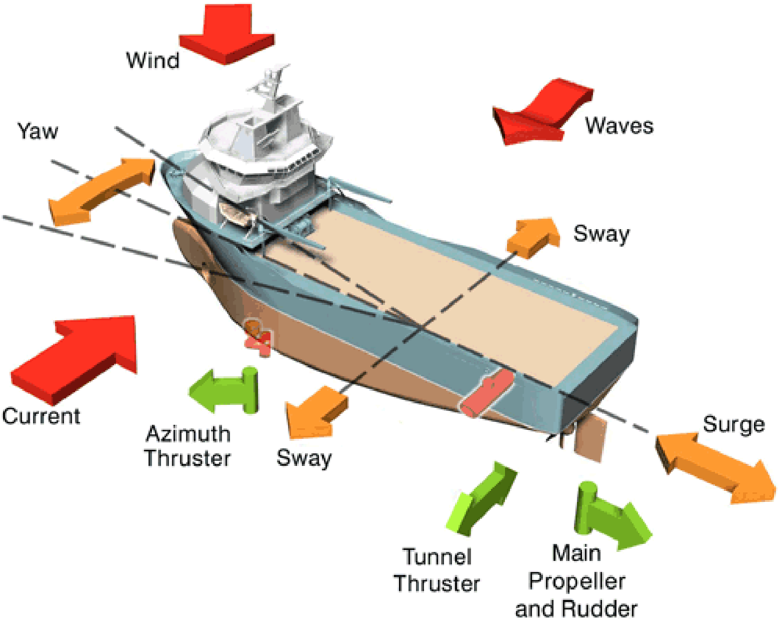


Figure 2. 2 Vessels with dynamic positioning system
(source : https://www.km.kongsberg.com)

Each ship has 6 degrees of freedom, namely yaw, surge, sway, heave, serta pitch and roll. The movement is produced due to forces derived from wind, waves, ocean currents and others. The response given by the ship due to these force is a change in position and heading. the Dynamic Positioning system cannot control heave and pitch movements. This Dynamic Positioning system measures the deviation value between the actual position point of the ship and desirable position, then calculates the force where the thruster must produce to obtain the smallest possible deviation. This system controls the movement of the ship in 3 degrees of freedom, namely, surge, sway and yaw.

There are internal and external forces acting on the ship, which makes the ship have 6 degrees of freedom at sea, a ship can move to 6 axes of motion, among others; three movements in translation, namely surge (forward / astern), sway (starboard / port), heave (up / down), and three movements in rotation: roll (rotation about surge axis), pitch (rotation about sway axis) and yaw (rotation about heave axis) . The Dynamic Positioning system has a computer program that makes surge, sway and yaw movements can be automatically controlled, to maintain the position of the ship or other marine buildings. The computer will get data from the referrer and sensors and compare it with the pre-data set. Then the Dynamic Positioning control system will control the propulsion system to eliminate errors between the actual position and data headings and pre-data sets (Li, 2013).

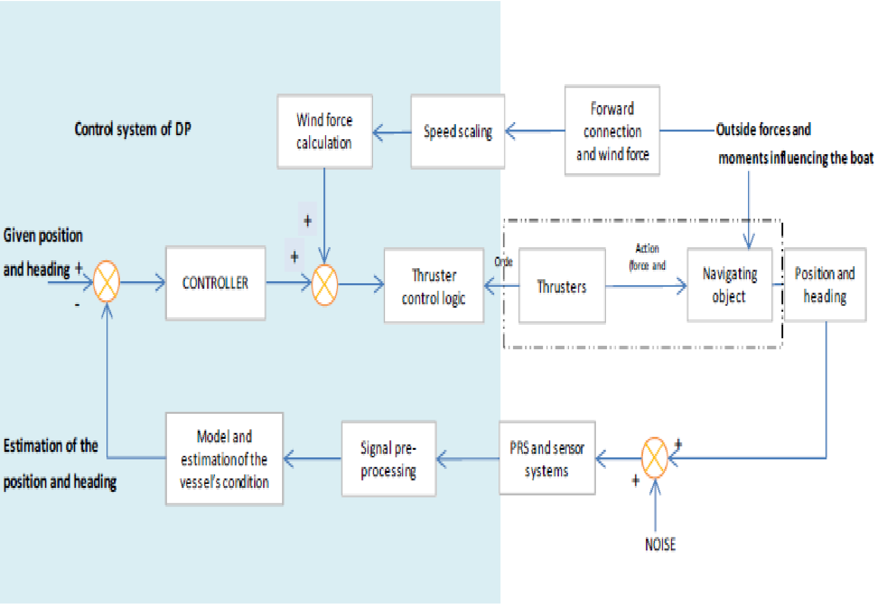


Figure 2. 3 Dynamic Positioning System Schematic Diagram

(Source : DYNAMIC POSITIONING OF OFFSHORE ANCHOR HANDLING TUG
SUPPLY (AHTS) VESSELS (UT 788 CD Project)

Dynamic positioning system consists of 3 main parts, namely ;

1. DP control system : consists of several sub-systems, namely: dynamic positioning control system; sensor systems; display system; associated cabling and positioning refrence system. Positioning refrence system, this system provides all reference data for DP systems, such as DGPS systems, wire position refrence system links, and acoustic position refrence systems.
2. Power systems: all important components and systems to supply power to the DP system. System power consists of: prime movers with other important support systems; generator; switchboards; uninterruptable power supplies and batteries; distribution system; power management system (Lloyd rules).
3. Thruster System : generally, there are two types commonly used on ships with DP systems: tunnel thruster and azimuth thruster. An azimuth thruster can give force to 360 degrees of movement. Besides the thruster itself, the thruster system also includes control parts and power supply parts (Li, 2013).

Based on marine technology society, there are three types of dynamic positioning vessels based on industrial work, namely mobile offshore drilling units (MODUs), Project construction vessel, and Logistics vessel (marine technology comitee marine technology comitee, 2012). Each ship has a different operating mode to complete different missions, but in general there are six modes of operation on ships with a DP system according to DPC, marine technology society, namely:

1. Manual Mode / Joystick Allows the operator to manually control the ship using the joystick for position control and rotary controller for post control.
2. Auto Position mode and Auto Heading automatically maintains the desired position and heading.
3. Auto Area Position Mode automatically keeps ships within the allowed area and within the theme limits allowed when using the minimum amount of power.
4. Auto Track Mode (High speed and low speed) ships have the ability to follow certain paths which are have been set before.
5. Autopilot Mode allows the ship to automatically direct on a predetermined path.
6. Follow Target Mode Allows ships to automatically follow ever-changing set points (Holvik, 1998)

IMO Marine Safety Committee Circular 645 (MSC 645), 'Guidance for Vessel with Dynamic Positioning Systems ', 1994 intended to provide international standards for Dynamic positioning systems . This document defines three classes of DP equipment intended to provide different levels of station reliability that can be adjusted to the consequences of losing position. The three classes of equipment are defined by the effects of failure and the habbit of failure that must be considered. IMO MSC 645 not discussing the ship's industrial mission. The class of ship equipment required for certain operations must be agreed between the ship owner and their respective customers based on an analysis of the risk of losing the position. Some coastal states apply minimum class equipment requirements for activities carried out within their area (Lloyd registers, 1994). The DP system is designed to have a certain level of capability, reliability and redundancy. DP System class notation discusses reliability based on DP system redundancy and fault tolerance. Next is the DP equipment class:

1. For ships with DPS-0, or DPS-1 notation, loss of position can occur if a single error occurs, there is no requirement for a redundancy system. For DPS-0 notation, the dynamic positioning system is a manual position control system. For DPS-1 notation, dynamic positioning systems are included in automatic dynamic positioning systems and manual position control systems.
2. For ships with DPS-2 notation, loss of position may not occur if a single error occurs on any active component or system (generators, boosters, switchboards, DP control computers, sensors, remote control valves, etc.), excluding loss compartment.

3. For ships with DPS-3 notation, loss of position may not occur if a single error occurs on the component or active or static system, including loss of compartment due to fire or flood (Lloyd registers, 1994)

Besides class classification based on Equipment there is a classification from Norwegian Maritime Authority (NMA) which determines what classes should be used based on the risk of operation. In the NMA Guidelines and Notes No. 28, the enclosure has four classes defined:

1. Class 0 An operation where loss of ability to maintain a position is not considered to endanger human life, or cause damage.
2. Class 1 operations where loss of ability to maintain position can cause minor damage or pollution.
3. Class 2 operations where loss of ability to maintain a position can cause injury, pollution or damage with major economic consequences.
4. Class 3 operations where losing the ability to maintain a position can cause fatal accidents, or pollution or severe damage with major economic consequences.

Based on the type of vessels it is determined for each operation:

1. Class 1 DP units with class 1 equipment must be used during operations where loss of position is not considered to endanger the human life, causing significant damage or more than minimal pollution.
2. DP class 2 units with class 2 equipment must be used during operations where loss of position can cause personnel injury, pollution or damage with large economic consequences.
3. A DP class 3 unit with class 3 equipment must be used during operations where loss of position can cause fatal accidents, heavy pollution or damage with major economic consequences.

2.3. Short Circuit Failure

Short circuit failure can be classified into two types, namely short circuit symmetry and asymmetry. This failure can make over flow current on failured phase. Beside that, this failure also can cause a voltage increase on the phase that has no failure. Almost all failure that occurs in the electric power system is an asymmetry.

Short circuit failure occur due to internal factors and external factors. The internal factor of the failure is damage to electrical equipment. While external factors are bad weather, storms, rain, disasters, lightning, and others. In addition to internal and external factors, the failure consists of temporary or permanent failure. Temporary disturbances are usually secured by a CB (Circuit Breaker) or other safety component, while permanent disturbances are those that cause permanent damage to the system. Such as insulator failure, conductor damage, and damage to equipment. In permanent disturbances it often occurs in underground channels. Short circuit interference is a disorder that often occurs in electric power systems. Some of the consequences arising from the existence of short circuit currents, namely the flow of current becomes large. The amount of electric current that flows can damage electrical equipment if the device is not equipped with an appropriate protection system. The size of the short circuit current is influenced by the location of the disturbance. If the interference gets closer to the source, then the noise current will be even greater so vice versa. The expansion of the electric power system needs to be re-analyzed to find out the level of voltage breaker equipment, for example Circuit Breaker (CB). So that the Circuit Breaker (CB) can secure from interference with the power system. Short circuit disturbances consist of symmetrical interference and a symmetrical short circuit. The calculation of symmetrical and asymmetrical short circuit fault current can be done with calculation tools, namely digital computers with the help of software.

As it is known that when a short circuit occurs, there are three conditions of current or reactance that exist in the generator, namely subtransient, transient, steady current. Therefore, current settings and delay times should also consider these conditions.

Flow adjustments should also consider these conditions. The current adjustment should be greater than the nominal current rating of the generator so that it allows the generator to withstand more loads for a few seconds. The important thing for the safety of the generator against overcurrent is the existence of security coordination, both the amount of current and the time delay (time delay). Besides that, it is also necessary to consider the back up of the generator.

Electrical installations almost always require protection against short circuits wherever there is an electrical discontinuity. This most often corresponds to points where there is a change in the cross section of the conductor. Current short-circuit relationships must be calculated at each level in the installation in view of determining the characteristics of the equipment needed to withstand or damage the fault current.

There are two values of short circuit current failure that must be evaluated. The first is the maximum short circuit current. The value of this current is used to determine the breaker capacity of the circuit breaker, the manufacturing capacity of the circuit breaker, and the capacity to withstand electrodynamics from the wiring and switchgear systems. The maximum value of the short circuit current will be related to the short circuit current in the terminal around the protection device. This value must be calculated accurately and added to the safety margin.

Second, the short circuit current is minimum. The value of this current is important to use when selecting the current-time curve for circuit breakers and fuses, especially when: cables are long and or source impedances are relatively high, (such as generators, UPS), life-time protection depends on the use of circuit breakers or fuses , especially in the case of IT electrical systems. It should be noted that the short-circuit current is minimal depending on the short circuit current at the end of the protective network, generally phase to ground for LV and phase to phase for HV (neutral not distributed), under the worst operating conditions (error at the feeder end and not only downstream from protection devices, one transformer in service when two can be connected, etc.).

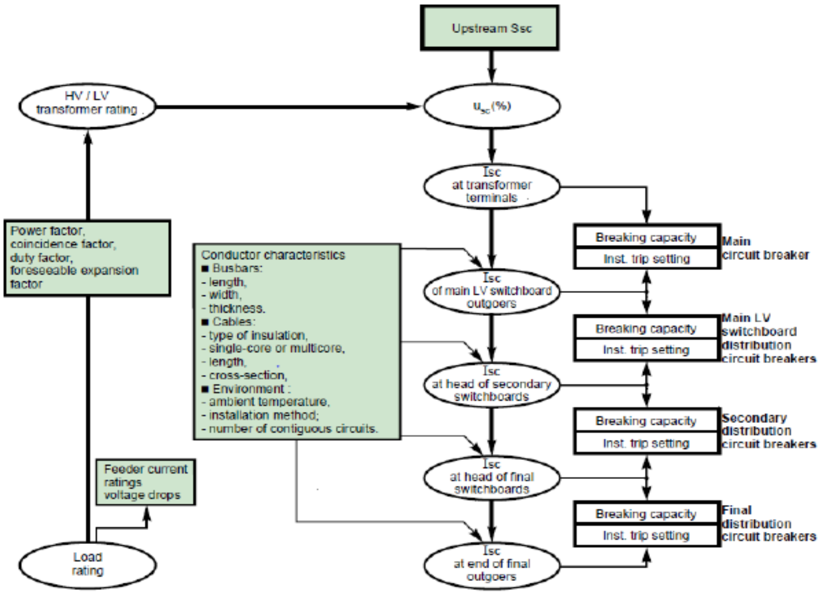


Figure 2. 4 Procedure for calculating short circuit current (Isc) when designing electrical installations

(source : Calculation of Short-Circuit Currents, Cahier Technique No. 158)

Protection system is a safety system for electrical equipment such as generators, transformers, motors etc. against abnormal conditions. The main function of the protection system is to avoid or reduce damage to electrical equipment , accelerate the localization of disturbed areas, secure humans from the danger of electricity (Hutahuruk, 1991).

Short circuit calculations for switchgear selection and protection coordination are carried out in accordance with established national and international practices, the most important and widely accepted are IEC and ANSI / IEEE Standards. The IEC 60909 standard applied in this paper covers various network voltage levels, configurations, operating conditions and generating and load equipment^{6}.

Protection coordination in the electrical system requires some special learning, one of which is in the way of designing trip times. A circuit breaker must be set the pickup time so that it can operate quickly and have high selectivity in sensing and isolating interference with surrounding equipment. Protection equipment must be prepared to cut off any overcurrent flowing in the motor or electrical circuit before the current can cause a temperature rise that damages insulation, connection, termination or conductor around.

To protect a system must be considered about the boundaries of the area to be secured, so that a protection system will respond to disturbances that occur around the affected area. Ideally the protection area must overlap, so that every part of the system gets protection. Between the main circuit breaker and the backup circuit breaker (backup) must be coordinated to produce a perfect protection system.

In general, backup protection has a time delay, this is so that the main potency can protect it first, and if the main protection fails, then the backup protection will operate later (Wahyudi, 2008). To fulfill this function, the main protection trip time is set faster than the backup protection trip. Safeguards with good selective capabilities are needed to achieve high system reliability because with fast and precise security it will isolate interference to a minimum. (Warrington, 1962).

Some short circuit currents can occur in electrical installations. There are main characteristics that this disorder has, namely :

- Duration (self-extinguishing, transient, dan steady-state)
- Source : Mechanic (break in one conductor, accidental electrical contact between two conductors through an conductive object from the outside), internal or atmospheric overvoltage
- Insulation damage due to heat, humidity or corrosive environment.
- Location: inside or outside the engine or electrical switchboard
- Phase to ground (80% of failure)
- Phase to phase (15% of failures). This type of failure is often classified into 3 phase failure
- Three phases (only 5% of total failures)[7]

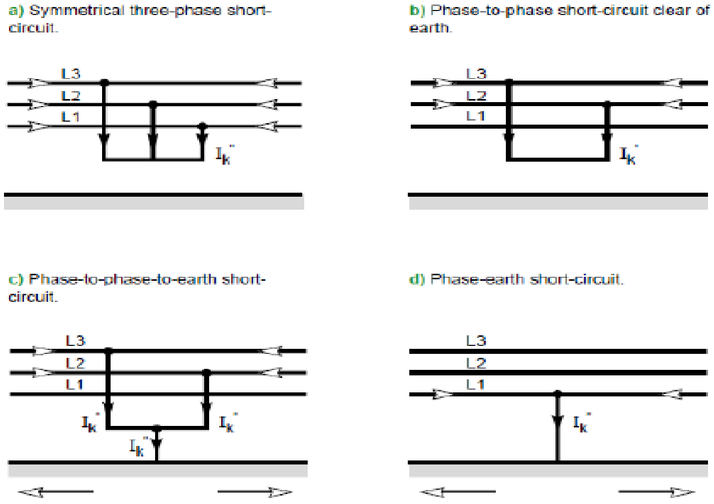


Figure 2. 5 Differences in types of short circuit current types

(Source : Calculation of Short-Circuit Currents, Cahier Technique No. 158)

There are several consequences that will be obtained when a short circuit current is occured. The consequences obtained vary depending on the type and duration of the disturbance, the installation point where there is interference, and the power of the short circuit current. The consequences obtained are also included:

a. At the location of the failure, the appearance of an electric arc results in:
   - Insulation damage
   - Damage to conductor caused by welding
   - Cause fire and endangers safety

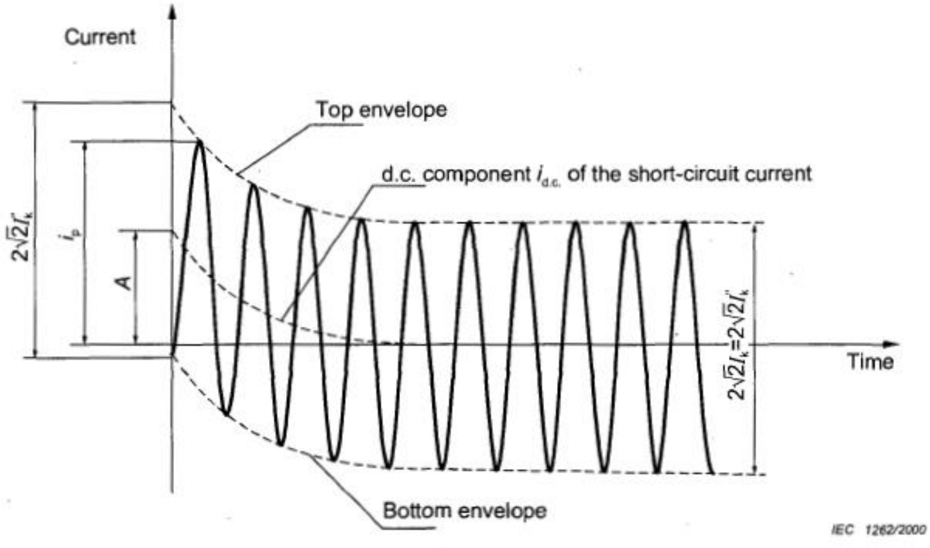
b. On the failure circuit (faulty circuit):
   - Electrodynamic force, caused :
     - Busbar deformation
     - Breaking cable
   - Temperature rise due to an increase in joule losses, with the risk of damage to the isolation caused by electrodynamics

c. On other circuits on the network or close to the network, interference occurs :
   - The voltage drops during the time needed to clear the interference, starting from a few milliseconds until some parts of the network shutoff, the extent to which the part depends on the network design and the differet levels offered by the protection device
   - interference with control and monitor circuits.

2.3.1. Calculation Method for Short Circuit Current Based on IEC 60909-0

2.3.1.1. Impedance Method

A complete calculation of short-circuit currents should give the currents as a function of time at the short-circuit location from the initiation of the short circuit up to its end, corresponding to the instantaneous value of the voltage at the beginning of the short circuit



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

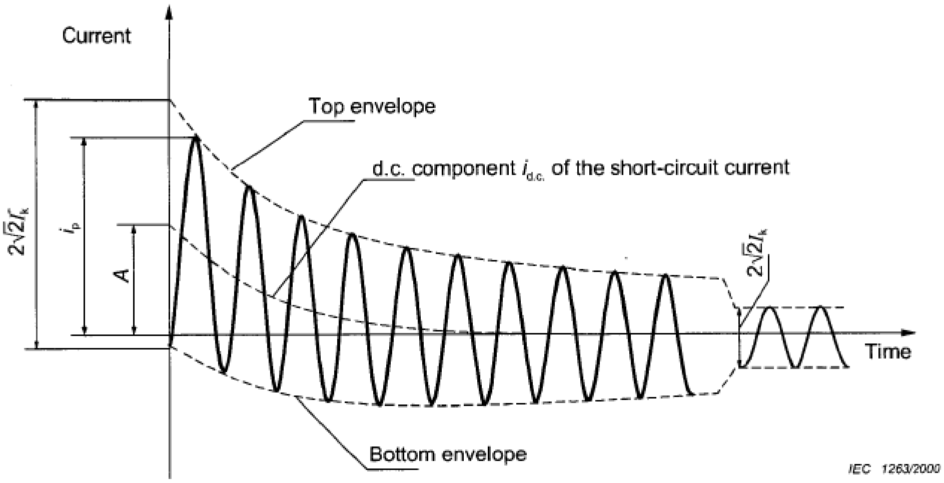
I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure 2. 6 Short-circuit current of a far-from-generator short circuit

with constant a.c. component (schematic diagram)
(Source : IEC 60909-0)



I''_k = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure 2. 7 Short-circuit current of a near-to-generator short circuit

with decaying a.c. component (schematic diagram)
(Source : IEC 60909-0)

In most practical cases a determination like this is not necessary. Depending on the application of the results, it is of interest to know the r.m.s. value of the symmetrical a.c. component and the peak value i, of the short-circuit current following the occurrence of a short circuit. The highest value i, depends on the time constant of the decaying aperiodic component and the frequencyf, that is on the ratio RIX or XIR of the short-circuit impedance &, and is reached if the short circuit starts at zero voltage. i, also depends on the decay of the symmetrical a.c. component of the short-circuit current.

The calculation of maximum and minimum short-circuit currents is based on the following simplifications.

- For the duration of the short circuit there is no change in the type of short circuit involved, that is, a three-phase short circuit remains three-phase and a line-to-earth short circuit remains line-to-earth during the time of short circuit.
- For the duration of the short circuit, there is no change in the network involved.

- The impedance of the transformers is referred to the tap-changer in main position. This is admissible, because the impedance correction factor KT for network transformers is introduced.
- Arc resistances are not taken into account.
- All line capacitances and shunt admittances and non-rotating loads, except those of the zerosequence system, are neglected.

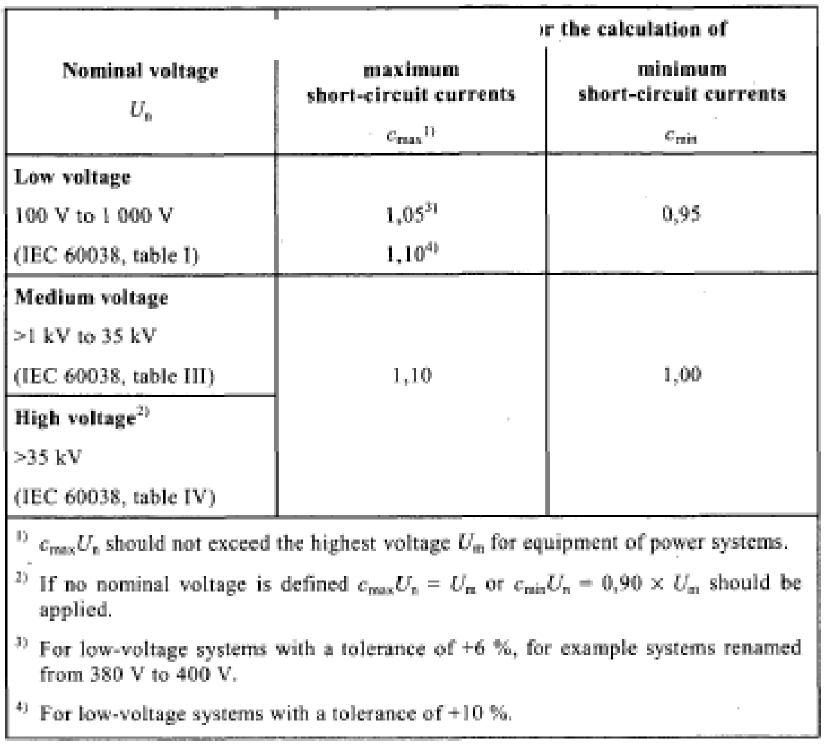
When calculating short-circuit currents in systems with different voltage levels, it is necessary to transfer impedance values from one voltage level to another, usually to that voltage level at which the short-circuit current is to be calculated. For per unit or other similar unit systems, No. transformation is necessary if these systems are coherent, i.e. UrTHV/UrTLV = UnHV/UnLV for each transformer in the system with partial short-circuit currents. UrTHV/UrTLV is normally not equal to UnHV/Un. The impedances of the equipment in superimposed or subordinated networks are to be divided or multiplied by the square of the rated transformation ratio t,. Voltages and currents are to be converted by the rated transformation ratio t,.

The method used for calculation is based on the introduction of an equivalent voltage source at the short-circuit location. The equivalent voltage source is the only active voltage of the system. All network feeders, synchronous and asynchronous machines are replaced by their internal impedances. In all cases it is possible to determine the short-circuit current at the short-circuit location F with

The help of an equivalent voltage source. Operational data and the load of consumers, tapchanger position of transformers, excitation of generators, and so on, are dispensable; additional calculations about all the different possible load flows at the moment of short circuit are superfluous.

Table 2. 1 Voltage factor c

(Source: IEC 60909-0 Short-circuit currents in three-phase a.c. systems)



Nominal voltage U_n	r the calculation of	
	maximum short-circuit currents c_{max}[1]	minimum short-circuit currents c_{min}
Low voltage 100 V to 1 000 V (IEC 60038, table I)	1,05[3] 1,10[4]	0,95
Medium voltage >1 kV to 35 kV (IEC 60038, table III)	1,10	1,00
High voltage[2] >35 kV (IEC 60038, table IV)		

[1] $c_{max}U_n$ should not exceed the highest voltage U_m for equipment of power systems.

[2] If no nominal voltage is defined $c_{max}U_n = U_m$ or $c_{min}U_n = 0{,}90 \times U_m$ should be applied.

[3] For low-voltage systems with a tolerance of +6 %, for example systems renamed from 380 V to 400 V.

[4] For low-voltage systems with a tolerance of +10 %.

In general, the initial symmetrical short-circuit current $I"_K$ shall be calculated using equation below with the equivalent voltage source $\frac{cU_n}{\sqrt{3}}$ at the short-circuit location and the short-circuit impedance $Z_k = R_k + jX_k$

$$I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}} \qquad (2.1.)$$

The equivalent voltage source $\frac{cU_n}{\sqrt{3}}$ shall be introduced at the short-circuit location (see figure below) with the factor c according to table above.

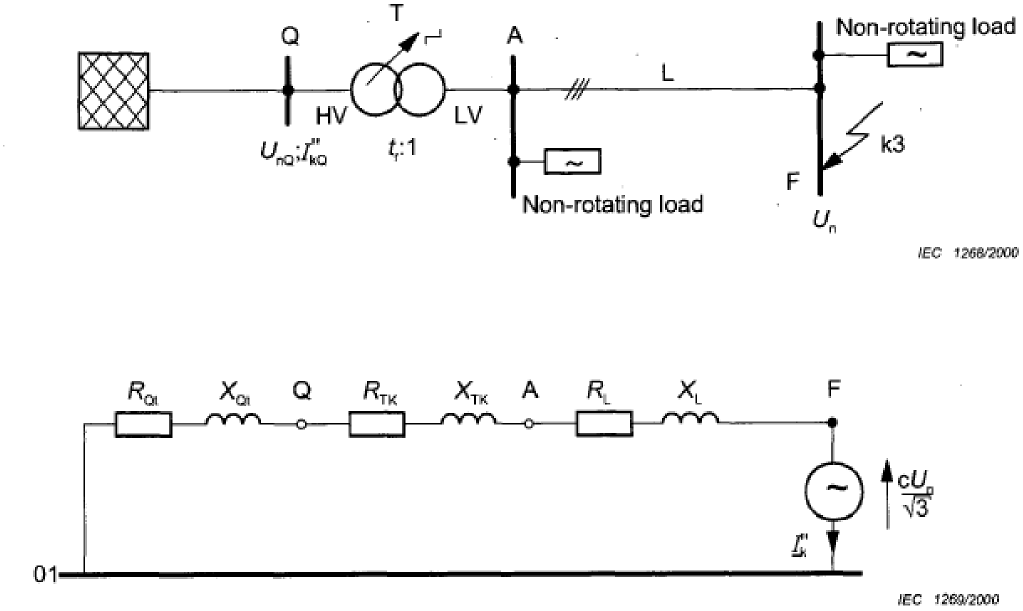


Figure 2. 8 Illustration for calculating the initial symmetrical short-circuit current I l in compliance with the procedure for the equivalent voltage source

(Source: IEC 60909-0 Short-circuit currents in three-phase a.c. systems)

2.3.1.1.1. Determine Various Impedance of Short Circuit Fault

2.3.1.1.1.1. Syncronous Generator

Engine impedance is generally expressed as a percentage, for example: Xd = 5%. In addition to the impedance value, it is usually given the value of R / X. This value is used to determine the total impedance of the engine.

$$Xg = \frac{Xd}{100}\,x\,\frac{V^2}{MVA\,x\,10^6} \qquad (2.2.)$$

(de Metz-Noblat et al., n. d. 2005)

Where:

Xg = Generator reactance

Xd = Generator reactance on 3 phase fault (%)

V = System Voltage (V)

MVA = *Apparent power Of Generator (MVA)*

2.3.1.1.1.2. Asyncronous Motor

Asynchronous motor impedance is generally expressed as a percentage. Generally it is worth 15% -25%. In addition to the impedance value, it is usually given the value of R / X. This value is used to determine the total impedance of the engine.

$$Xm = \frac{Xd}{746}\ x\ \frac{V^2}{HP}, \qquad (2.3.)$$

(Lackovic, 2005)

Where :

Xm = Electric Motor reactance
Xd = Percentage of electric motor reactance on 3 phase fault (%)
HP = System Voltage (V)
V = *Active Power* of motor (HP)

2.3.2. Symetrical Breaking Current

The symetrical breaking current is the effective value of the short circuit current I''_k, which flows through the switch at the time of the first contact separation and is used for near-to-generator short circuit feeder. For far from generator short circuits, the breaking currents are identical with the initial short circuit currents (Kalsicki,2002). The formula for symetrical breaking current is shown on equation below

$$I_a = \mu \, . I''_k \qquad (2.4.)$$

I_a depends on the duration of the short circuit installation of the switchgear at the position of the short circuit. μ characterizes the decay behavior of the short circuit current and is a function of the variables I''_{kG}/I''_{rG} and t_{min} that can be obtain on figure below or equation below.

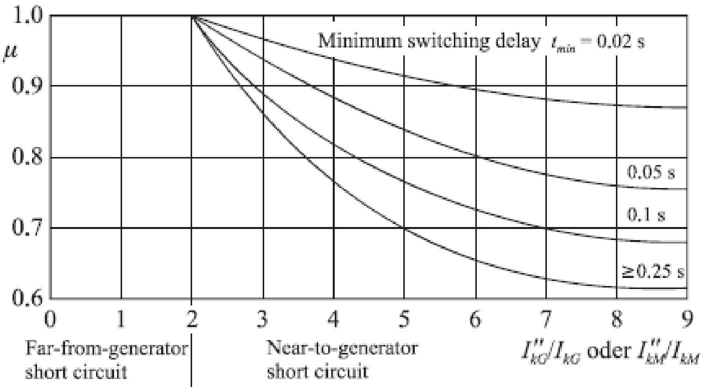


Figure 2. 9 Factor μ for calculating the symetrical breaking current

(Source: Ismail Kalsicki, Short Circuit On Power Grid)

The factor μ alsi can be taken from following equation :

$\mu = 0.84 + 0.26\ e^{-0.26} I"_{kG}/I_{rG}$ t= 0.02 (2.5.)

$\mu = 0.71 + 0.51\ e^{-0.3} I"_{kG}/I_{rG}$ t= 0.05 (2.6.)

$\mu = 0.62 + 0.72\ e^{-0.32} I"_{kG}/I_{rG}$ t= 0.15 (2.7.)

$\mu = 0.56 + 0.94\ e^{-0.38} I"_{kG}/I_{rG}$ t= 0.25 (2.8.)

CHAPTER III
RESEARCH METHODOLOGY

The following is a flow diagram of a research methodology that describes the overall research

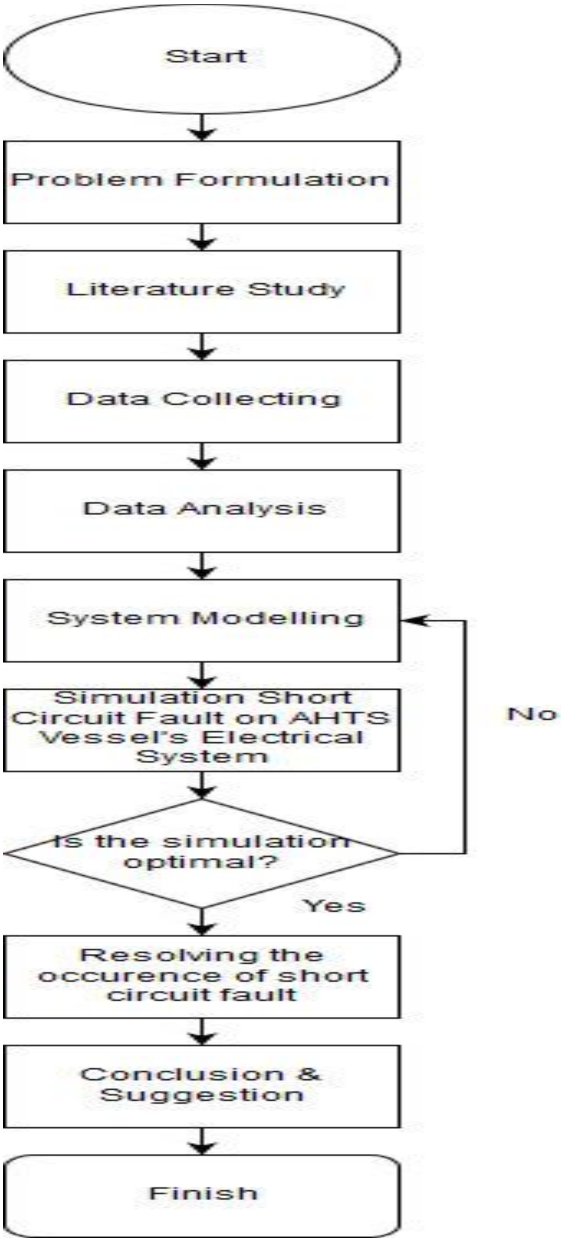


Figure 3. 1 Workflow

3.1. Problem Formulation

Formulation of problem is the starting point of this research. This step is important, on this step we know, what the problem that we review and we can find the solution of the problem as the conslution and the suggestion for the problem. Formulation of the problem is done by collecting information about the problems that occur at this time. On this step, the goal of the research can be found. In this bachelor thesis, the problem to be discussed and solved is regarding the analysis of short circuit currents in the AHTS electrical system due to the use of electric thruster using lab scale simulation.

3.2. Literature Study

After we know the problem, the next step is collecting study of literature. On this step we looking for every information that have corellation with the problem, it also including the solution and suggestion. So we know what we have to do and we can lookig for solution of the problem propperly. This study of literature step can be done by reading papper, journal and also rules and regulation that have corellation whit this problem.

3.3. Data Collecting

On this step we have to collect the data that support this bachelor thesis, such as :

1. Vessels Principal dimension
2. Oneline diagram of electrical circuit thruster AHTS vessel
3. Wiring diagram of electrical circuit thruster AHTS vessel
4. Spesification of component that we used on laboratory
5. IEC, IEEE, Standart for this problem

3.4. Data Analysis

Next step is make lab scale model the circuit based on oneline diagram of the AHTS vessel to know the system and the total electrical load that carry by the system

3.5. System Modelling

At this stage, modeling with laboratory equipment accordance with the real conditions on the AHTS ship. The existence of specification data for each component that works in the dynamic positioning maneuver mode will help modeling according to real conditions.

3.6. Simulations of Short Circuit Current in AHTS Ship Electrical Systems

After we maket he lab scale model of electrical circuit, then we running the circuit and do the simulation on three phase and single phase short circuit and then calculate the maximum and minimum short circuit current on the system. If this step were sucsess then we can dot he next step, but if this step were failed, we have to remodeling the system and running the new model.

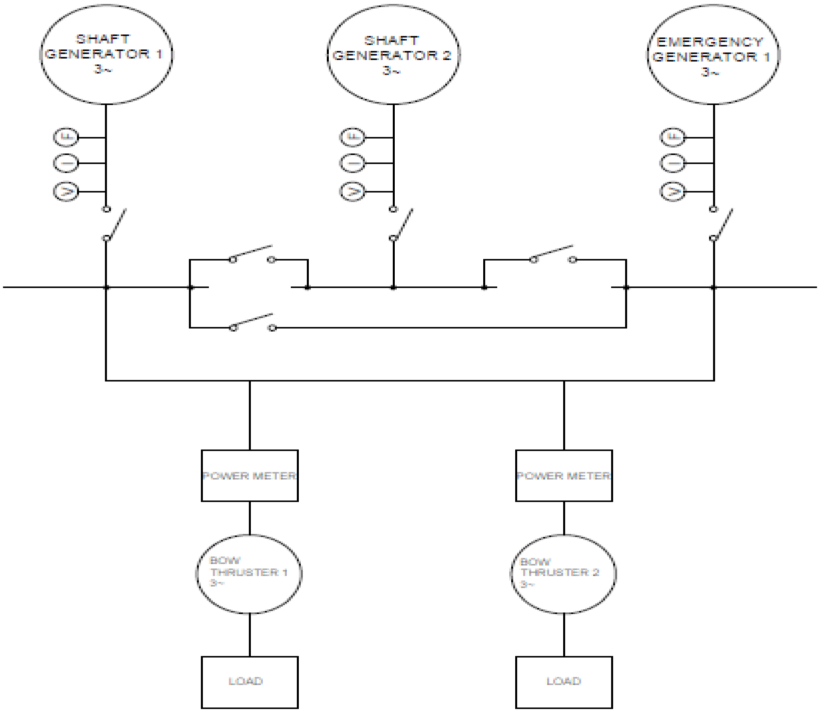


Figure 3. 2 Oneline diagram system model used in laboratory scale experiment

Table 3. 1 Load Scenario & Variation

Scenario	Supply Power	Electrical Load	Load Variation	
			Bow thruster 1	*Bow thruster* 2
1	2 *Shaft Generator*	2 *Bow thruster*	60% 100% 100% 110%	75% 80% 100% 110%
2	1 *Shaft Generator* (Split Plan)	2 *Bow thruster*	40 % 50 % 60 %	40 % 50 % 60 %

3	1 *Shaft Generator*, 1 *Diesel generator* (Closed Bus)	2 *Bow thruster* and 480 Watt of constant load	75% 80% 85%	75% 80% 85%

3.7. Resolving the Occurance of Short Circuit Fault

At this stage a process is found to find a solution to overcome the occurrence of short circuit currents that occur in the AHTS electrical system according to the simulation results that have been made. From the simulation results, it will be known, in the scenario and the variation of the bow thruster loading that there is a short circuit flow and find a way to overcome it. After obtaining a solution to overcome the short circuit current in the AHTS electrical system, a re-analysis is conducted whether there is a change from the simulation results that have been obtained.

3.8. Conclusion & Suggestion

The conclusions section contains a summary of the results of the analysis and answers to the problem statement. Suggestions contain about things that need to be studied further regarding this final assignment and other similar things that would like to be studied further for the next study.

CHAPTER IV
DATA ANALYSIS AND DISCUSSION

4.1. Data Collecting

On this step, data that collected to support this experiment is the main data such as one line diagram of electrical system that attached in appendix.

4.2. Experiment Equipment Data

Based on impedance method to calculate short circuit current value on network, we need several data such as resistance and reactance to get impedance value, also we have to run the system on each load variation to get voltage value on fault point. On this case, the vault that caused because usage of asyncronous three phase motor as bow thruster and the fault point placed on bus bar. Resistance and reactance data that obtained fror measuring each component is show on table below.

Table 4. 1 Equipment Data
(Source: Personal Data)

Synchronous Generator Input Data									
ID	Type	MVA	kV	RPM	%PF	θ	R/X	Rd	Xd
Diesel Generator 1	Generator	0,000263	0,415	1500	80	36,87	0,60	6,466667	10,77778
Thruster Generator 1	Generator	0,0006	0,415	1500	80	36,87	0,60	12,5	20,83333
Thruster Generator 2	Generator	0,0006	0,415	1500	80	36,87	0,60	12,36667	20,61111

Induction Machine Input Data									
ID	Type	HP	kW	kVA	PF%	θ	R/X	Rd	Xd
Bow Thruster 1	Motor	0,2144	0,16	0,20	80,00	36,8699	0,6000	111,17	185,2778
Bow Thruster 2	Motor	0,4556	0,34	0,45	75,00	41,40962	0,6614	59,77	90,35871

Cable Resistance Data						
ID	From	To	Lenght (mm)	A (mm^2)	ρ (Ωm)	R
Cable 1	Generator	Bus	6000,00	2,00	0,00000001680	0,0504
Cable 2	Bus	Motor	6000,00	2,00	0,00000001680	0,0504

Beside the equimpent data that used for calculation and experiment, some measurement instrument also used to measure rmp value, voltage value on each point, and current value on each point. Some measuring instrumen tis shown on table below

4.3. Load Variation Configuration

To find out tren value of short circuit current on system, we have to determine the load variation of the asyncronous three phase motor itself as bow thruster, then we measure voltage value and make fault on bus bar. The fault that we make is three phase fauls, so each phase got connected to each other to obtainshort circuit fault and its value. The load variation used as follows:

4.3.1. 2 Shaft Generator with 2 Bow Thruster Load

Table 4. 2 Scenario 1 load variation

Scenario	Supply Power	Electrical Load	Load Variation	
			Bow thruster 1	*Bow thruster* 2
1	2 *Shaft Generator*	2 *Bow thruster*	60% 100% 100% 110%	75% 80% 100% 110%

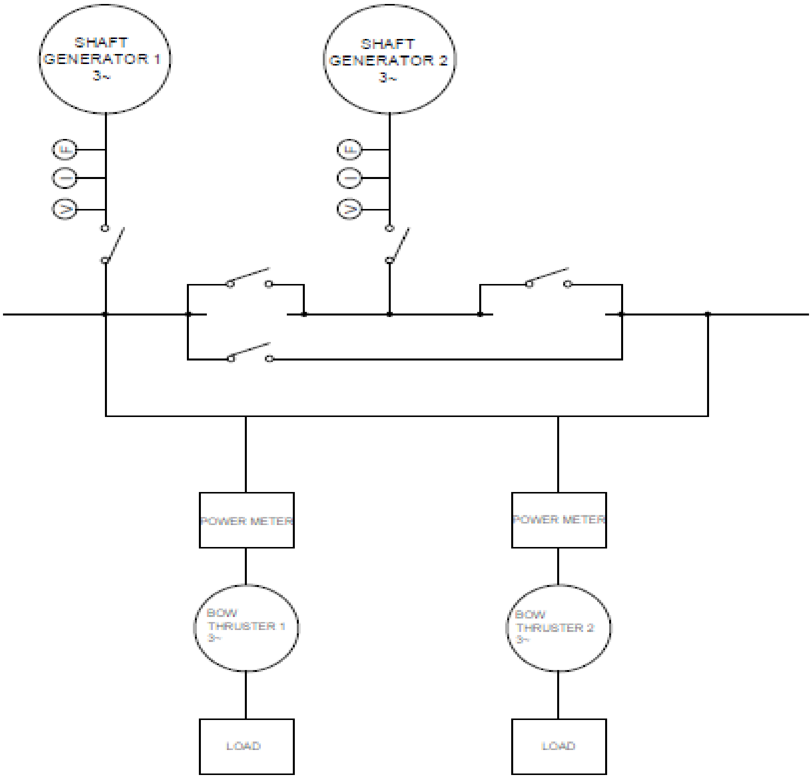


Figure 4. 1 One line diagram of scenario 1

On first variation, we used 2 shaft generator as power source of each motor, when we add the motor load we have to maintain voltage value from generator on 380V or close to those value by increasing the magnetic field that produce by generator and increasing excitation current.

4.3.2. 1 Shaft Generator with 2 Bow Thruster Load

Table 4. 3 Scenario 2 load variation

Scenario	Supply Power	Electrical Load	Load Variation	
			Bow thruster 1	*Bow thruster* 2
2	1 *Shaft Generator* (Closed Bus)	2 *Bow thruster*	40 % 50 % 60 %	40 % 50 % 60 %

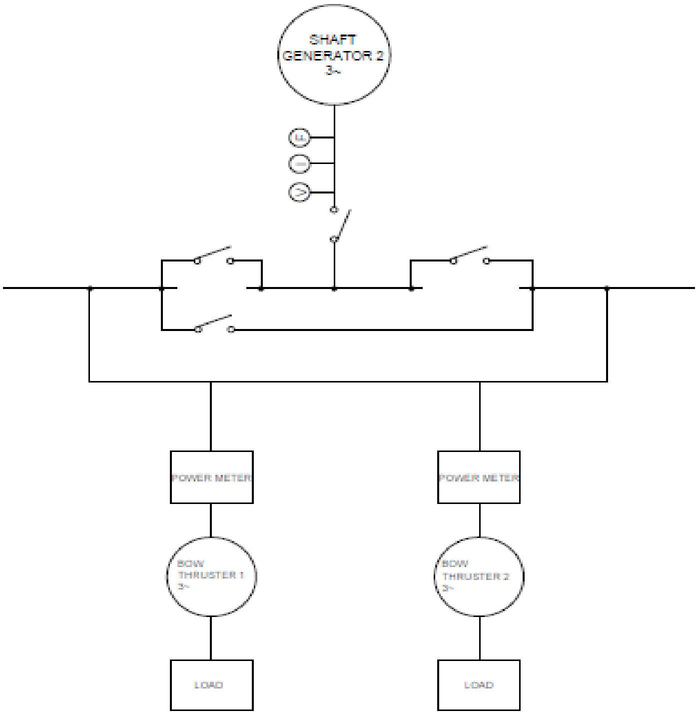


Figure 4. 2 One line diagram of scenario 2

On second variation, we used 1 shaft generator as power source of each motor, when we add the motor load we have to maintain voltage value from generator on 380V or close to those value by increasing the magnetic field that produce by generator and increasing excitation current.

4.3.3. 1 Shaft Generator, 1 Emergency generator with 2 Bow Thruster Load and 480Watt load

Table 4. 4 Scenario 3 load variation

Scenario	Supply Power	Electrical Load	Load Variation	
			Bow thruster 1	*Bow thruster* 2
3	1 *Shaft Generator*, 1 *Diesel generator* (Closed Bus)	2 *Bow thruster* + 480Watt	75% 80% 85%	75% 80% 85%

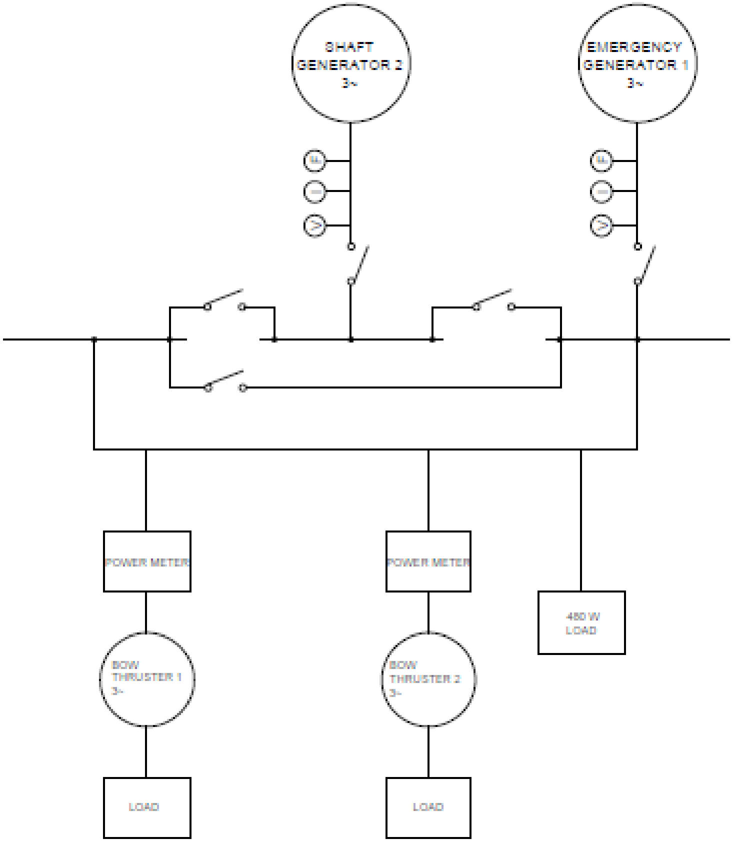


Figure 4. 3 One line diagram of scenario 3

On third variation, we used 1 shaft generator and 1 emergency generator as power source of each motor, when we add the motor load we have to maintain voltage value from generator on 380V or close to those value by increasing the magnetic field that produce by generator and increasing excitation current. To make this easier, we used generator with one prime mover that the rpm can be controlled, we used generator with dc motor as its prime mover

4.4. Short Circuit Calculation

To calculate shortcircuit current based on impedance method, we have to calculate impedane value in each load conditon, also voltage value on fault point while maintaining output voltage on generator arround 380V.

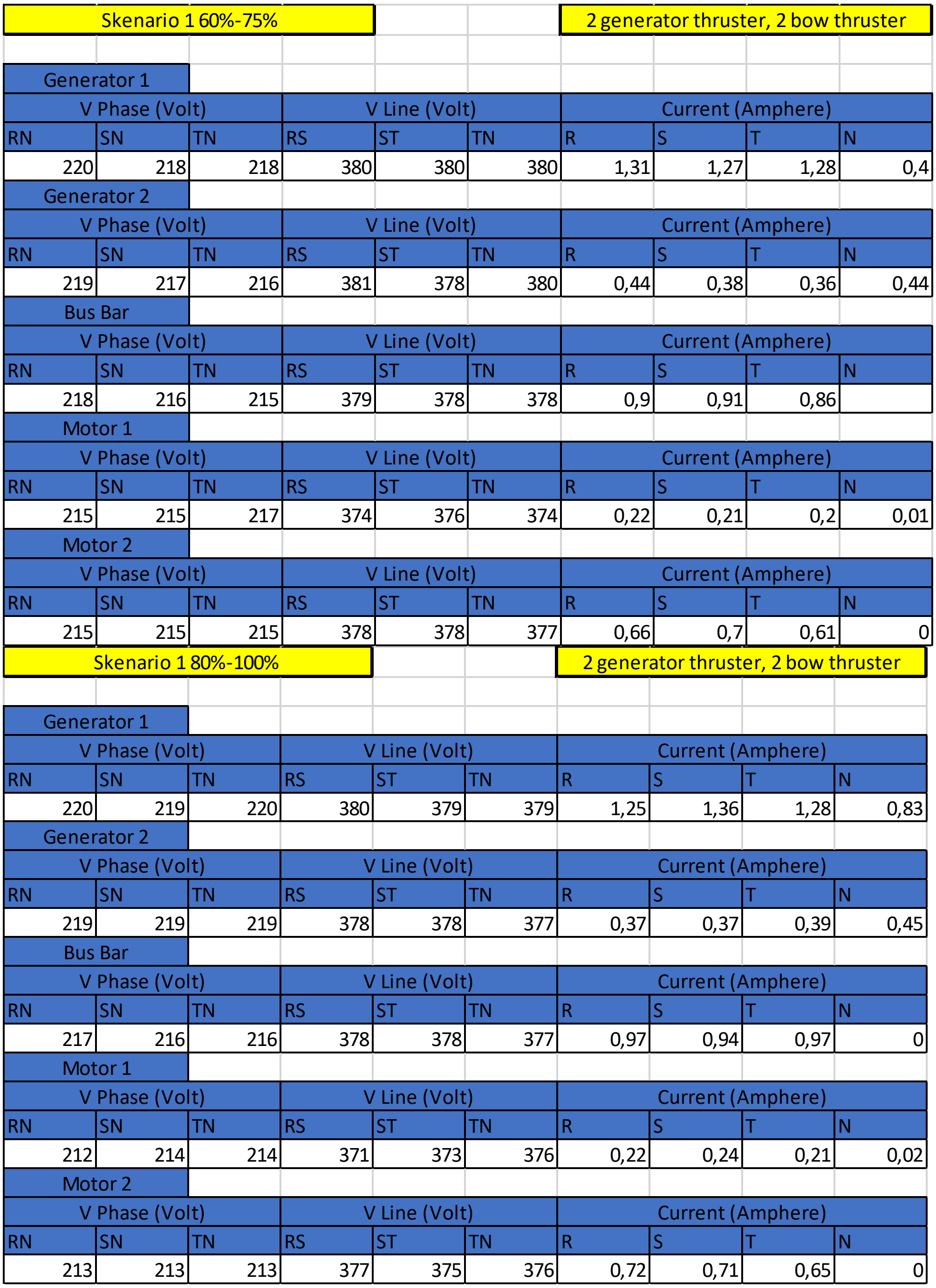
$$I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}} \qquad (4.1.)$$

Based on equation above, Initial short circuit current (I'' $_k$) is formula based on voltage fault point (Un), and total impedance value of the system ($\sqrt{R^2{}_k + X^2{}_k}$).

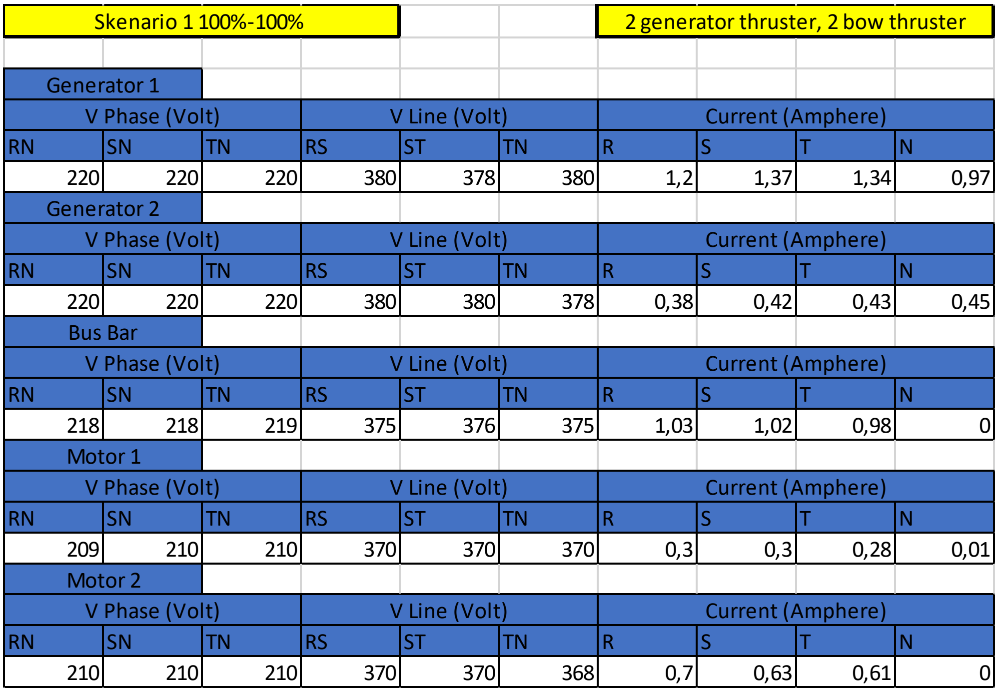
4.4.1. Scenario 1

After we running the scenario with each variation, the data we obtain as shown below.

Table 4. 5 Scenario 1 running result



Skenario 1 60%-75%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	218	218	380	380	380	1,31	1,27	1,28	0,4
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
219	217	216	381	378	380	0,44	0,38	0,36	0,44
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	216	215	379	378	378	0,9	0,91	0,86	
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
215	215	217	374	376	374	0,22	0,21	0,2	0,01
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
215	215	215	378	378	377	0,66	0,7	0,61	0
Skenario 1 80%-100%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	219	220	380	379	379	1,25	1,36	1,28	0,83
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
219	219	219	378	378	377	0,37	0,37	0,39	0,45
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
217	216	216	378	378	377	0,97	0,94	0,97	0
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
212	214	214	371	373	376	0,22	0,24	0,21	0,02
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
213	213	213	377	375	376	0,72	0,71	0,65	0



Skenario 1 100%-100%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	220	380	378	380	1,2	1,37	1,34	0,97
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	220	380	380	378	0,38	0,42	0,43	0,45
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	218	219	375	376	375	1,03	1,02	0,98	0
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
209	210	210	370	370	370	0,3	0,3	0,28	0,01
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
210	210	210	370	370	368	0,7	0,63	0,61	0

Here are the calculation example start form reactance and resistance and shortcircuit calculation

- Calculation Reactance

Based on equation $Xg = \frac{Xd}{100}\ x\ \frac{V^2}{MVA\ x\ 10^6}$, reactance of generator were calculated by Xd value that measured on each pole. So Reactance value are:

Xd = 33.6084
V = 380 V
MVA = 600 MVA

$$Xg = \frac{33.6084}{100}\ x\ \frac{380^2}{600\ x\ 10^6}\ ,$$

$$Xg = 94.15\ \Omega,$$

The same calculation step we applied for another generator and motor. But for the cable we used different R/X value. Based on *Cashier Technique No.150 for Short Circuit Calculation* reactance per unit value for spaced single core cable is 0,13 so reactance value for cable is shown on calculation below :

$$Xc = 0{,}13\ m\Omega/m \text{ x l x } 10^{-3}$$

$$Xc = 0{,}13\ m\Omega/m \text{ x 6000 mm x } 10^{-3}$$

$$Xc = 0{,}78\ \Omega$$

- Calculation Resistance

  After we obtained Xg value, by multiplying with X/R vaue that we obtain before, we can get resistance value. The calculation were shown below:

  $$\frac{R}{X} = 0{,}25$$

  $$R = 0{,}25 \text{ x Xd}$$

  $$R = 23.53\ \Omega$$

- Calculation Impedance

  While the resistance value we get from measuring.

  So the calculation summary for reactance and resistance value is show on table below:

Table 4. 6 Scenario 1 impedance summary

Branch	R	X
TG 1 + TG 2	46,7064	187
BT 1 + BT 2	0,1351	0,4829
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	47,1415	188,089

So by using equation $Z_k = R_k + jX_k$ we can obtain impedance value, the impedance calculation is shown below :

$$Z_k = R_k + jX_k$$

$$Z = \sqrt{R^2 + X^2}$$

$$Z = \sqrt{47.1415\ \Omega^2 + 188.089\ \Omega^2}$$

$$Z = 193.9062\ \Omega$$

- Calculation Initial Short Circuit Current

  After we obtain impedance value, then we used $I''_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$ equation. Constanta c were take 1.1 for 10% tolerance, and U_n were measured voltage on busbar while the motor load is on 40%-40%. Because the fault that were made is on busbar, so U_n value that used is the value on busbar. So the Initial symentrical short circuit current calculation is shown on below:

$$I''_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$$

$$I''_k = \frac{1{,}1\ x\ 379.33\ V}{\sqrt{3}\ x\ 193.9062\ \Omega}$$

$I''_k = 1.2391\ Amphere$

The other load variation on thos scenario were calculated by same step with previous one. The summary for second variation is shown on table below

Table 4. 7 Scenario 1 short circuit summary

Skenario	Variasi	V	Z	I"k
1	60%-75%	378,33	193,906	1,239
	80%-100%	377,67	193,726	1,23809
	100%-100%	375,33	193,590	1,23131

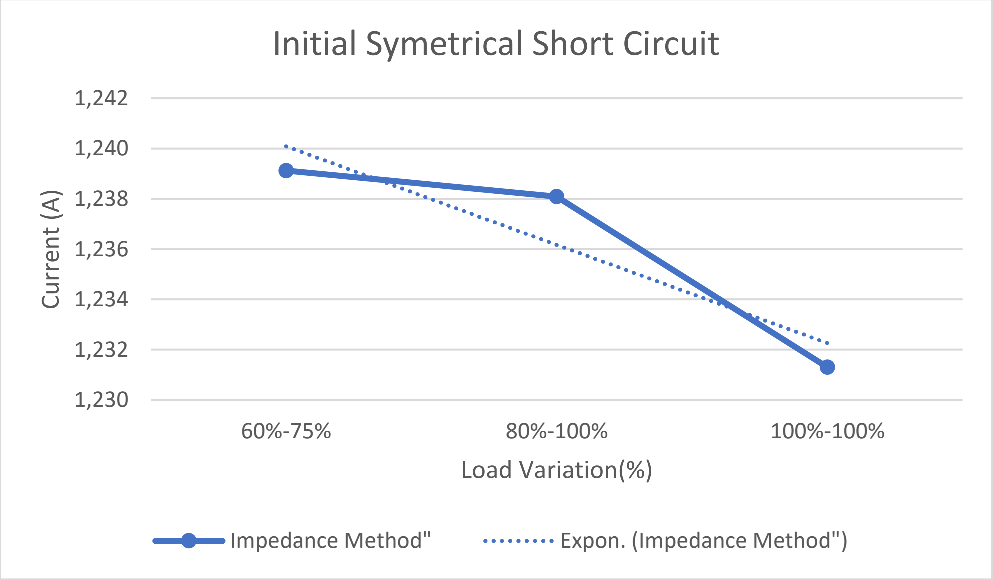


Figure 4. 4 Scenario 1 short circuit value each load variation

Based on experiment data that we obtain and calculate, we can see that in every increased load variation, the short circuit value by impedance method decreasing. On this scenario the smallest load value of each motor is at 60%-75% load and occur short circuit 1.239 Amphere, and the highest load on this scenario at 100%-100% short circuit current that occur is 1.231 Amphere.

- Calculation Circuit Breaker Breaking Capacity

  After we obtain initial symetrical short circuit current, then we have to calculate circuit breaker breaking capacity. This value is to determine circuit breaker capacity as a protection. Based on IEC 60909-0 standart, use $I_a = \mu . I"_k$ equation we have to find µ constanta based on graph below where the µ values is deppend on minimum switching delay and I”$_{kM}$/I$_{kM}$ ratio. Because the problem that reviewed on this thesis is short circuit current because the usage of bow thruster, the protective device that we placed on bus bar that supply asyncronous motor and I”$_{kM}$ is represent short circuit current on fault point and I$_{kM}$ is represent current value without short circuit fault.

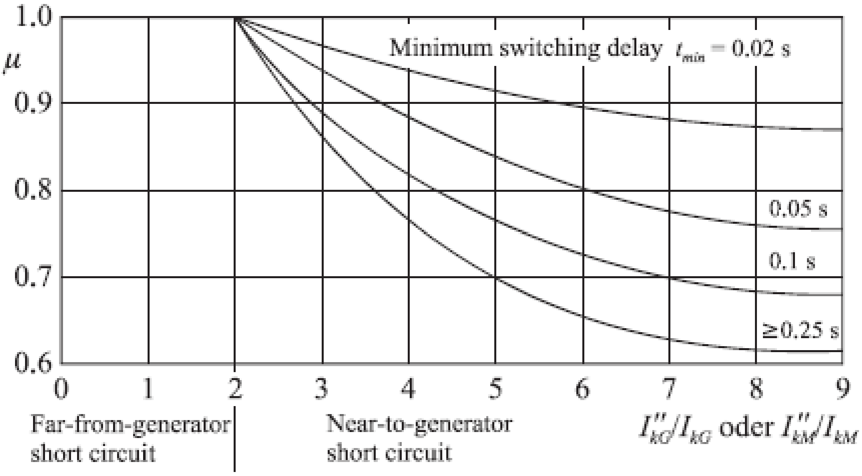


Figure 4. 5 Factor µ for calculating the symetrical breaking current

(Source: Ismail Kalsicki, Short Circuit On Power Grid

On this calculation minimum switching delay choosen os 0.02 second, because the faster breaking capacity is better for damage prevention on equipment. I”$_{kM}$ and I$_{kM}$ valuie respectively , so the calculation is shown below :

$$I_a = \mu . I''_k$$

$$I_a = 1.185 \text{ Amphere}$$

And the summary of peak short circuit current for this scenario is shown on table below:

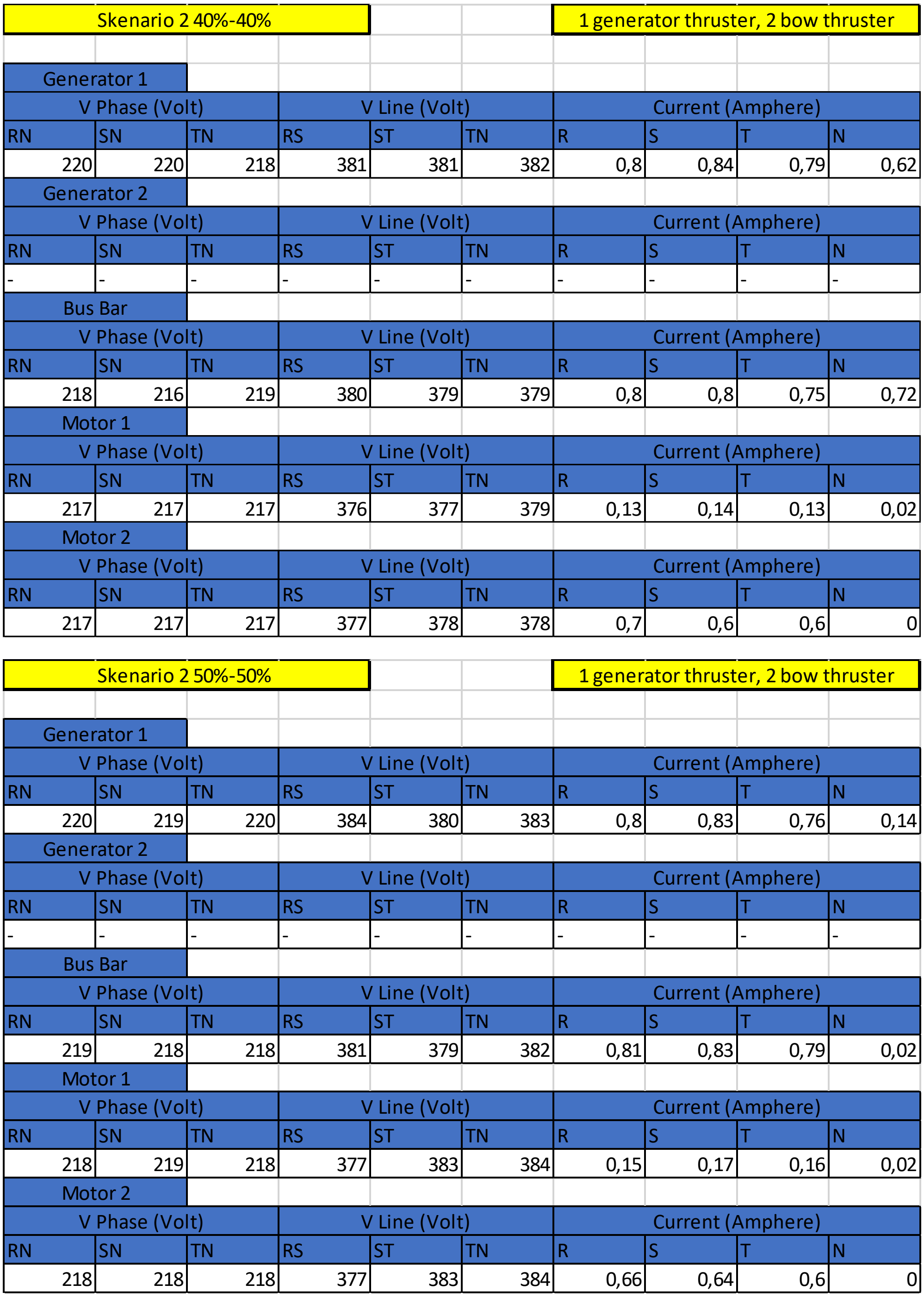
Table 4. 8 Scenario 1 initial symetrical breaking value summary

Skenario	Variasi	V	Z	I"k	Ia
1	60%-75%	378,33	193,9062	1,239125	1,185857111
	80%-100%	377,67	193,7256	1,238094	1,1601
	100%-100%	375,33	193,5901	1,231306	1,140931547

4.4.2. Scenario 2

After we running the scenario with each variation, the data we obtain as shown below.

Table 4. 9 Scenario 2 experiment result



Skenario 2 40%-40%						1 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	218	381	381	382	0,8	0,84	0,79	0,62
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
-	-	-	-	-	-	-	-	-	-
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	216	219	380	379	379	0,8	0,8	0,75	0,72
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
217	217	217	376	377	379	0,13	0,14	0,13	0,02
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
217	217	217	377	378	378	0,7	0,6	0,6	0

Skenario 2 50%-50%						1 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	219	220	384	380	383	0,8	0,83	0,76	0,14
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
-	-	-	-	-	-	-	-	-	-
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
219	218	218	381	379	382	0,81	0,83	0,79	0,02
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	219	218	377	383	384	0,15	0,17	0,16	0,02
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	218	218	377	383	384	0,66	0,64	0,6	0

Skenario 2 60%-60%						1 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	219	384	384	382	0,8	0,81	0,8	0,3
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
-	-	-	-	-	-	-	-	-	-
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
217	216	218	381	380	380	0,84	0,83	0,8	0,03
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	217	217	380	382	382	0,2	0,18	0,18	0,02
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
217	217	217	380	381	382	0,68	0,62	0,6	0

Here are the calculation example start form reactance and resistance and shortcircuit calculation

- Calculation Reactance

Based on equation $Xg = \frac{Xd}{100}\ x\ \frac{V^2}{MVA\ x\ 10^6}$, reactance of generator were calculated by Xd value that measured on each pole. So Reactance value are:

Xd = 33.6084
V = 380 V
MVA = 600 MVA

$$Xg = \frac{33.6084}{100}\ x\ \frac{380^2}{600\ x\ 10^6}\ ,$$
$$Xg = 94.15\ \Omega,$$

The same calculation step we applied for another generator and motor. But for the cable we used different R/X value. Based on *Cashier Technique No.150 for Short Circuit Calculation* reactance per unit value for spaced single core cable is 0,13 so reactance value for cable is shown on calculation below :

$$Xc = 0{,}13\ m\Omega/m\ \mathrm{x\ l\ x}\ 10^{-3}$$

$Xc = 0{,}13\ m\Omega/m \text{ x } 6000 \text{ mm x } 10^{-3}$
$Xc = 0{,}78\ \Omega$

- Calculation Resistance

  After we obtained Xg value, by multiplying with X/R vaue that we obtain before, we can get resistance value. The calculation were shown below:

  $\frac{R}{X} = 0{,}25$
  $R = 0{,}25 \text{ x Xd}$
  $R = 23.53\ \Omega$

- Calculation Impedance

  While the resistance value we get from measuring.

  So the calculation summary for reactance and resistance value is show on table below:

Table 4. 10 Scenario 2 impedance result summary

Branch	R	X
Thruster Generator	23,16652	92,66607
BT 1 + BT 2	0,244744	0,8780
Cable 1	0,3	0,7800
Cable 3 + Cable 4	0,15	0,3900
Total	23,86126	94,71408

So by using equation $Z_k = R_k + jX_k$ we can obtain impedance value, the impedance calculation is shown below :

$Z_k = R_k + jX_k$
$Z = \sqrt{R^2 + X^2}$
$Z = \sqrt{35{,}16286\ \Omega^2 + 59{,}59336\ \Omega^2}$
$Z = 97.56\ \Omega$

- Calculation Initial Short Circuit Current

  After we obtain impedance value, then we used $I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$ equation. Constanta c were take 1.1 for 10% tolerance, and U_n were measured voltage on busbar while the motor load is on 40%-40%. Because the fault that were made is on busbar, so U_n value that used is the value on busbar. So the Initial symentrical short circuit current calculation is shown on below:

$$I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$$

$$I"_k = \frac{1{,}1 \ x \ 379.33 \ V}{\sqrt{3} \ x \ 97.67 \ \Omega}$$

$$I"_k = 2.46 \ Amphere$$

The other load variation on thos scenario were calculated by same step with previous one. The summary for second variation is shown on table below

Table 4. 11 Scenario 2 initial symetrical short ciruit summary

Skenario	Variasi	V	Z	I"k
2	40%-40%	379,33	97,67	2,4665
	50%-50%	380,67	97,49	2,47977
	60%-60%	380,33	97,25	2,4838

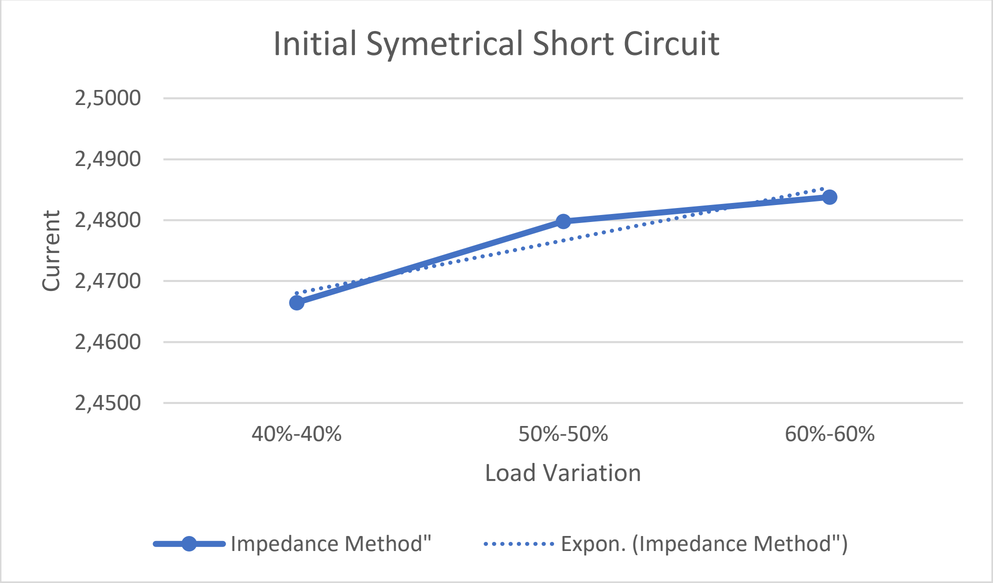


Figure 4. 6 Scenario 2 short circuit value each load variation

Based on experiment data that we obtain and calculate, we can see that in every increased load variation, the short circuit value by impedance method also increasing. On this scenario the smallest load value of each motor i sat 40%-40% load and occur short circuit 2.46 Amphere, and the highest load on this scenario at 60%-60% short circuit current that occur is 2.48 Amphere.

- Calculation Circuit Breaker Breaking Capacity
  After we obtain initial symetrical short circuit current, then we have to calculate circuit breaker breaking capacity. This value is to determine

circuit breaker capacity as a protection. Based on IEC 60909-0 standart, use $I_a = \mu . I"_k$ equation we have to find µ constanta based on graph below where the µ values is deppend on minimum switching delay and I”$_{kM}$/I$_{kM}$ ratio. Because the problem that reviewed on this thesis is short circuit current because the usage of bow thruster, the protective device that we placed on bus bar that supply asyncronous motor and I”$_{kM}$ is represent short circuit current on fault point and I$_{kM}$ is represent current value without short circuit fault.

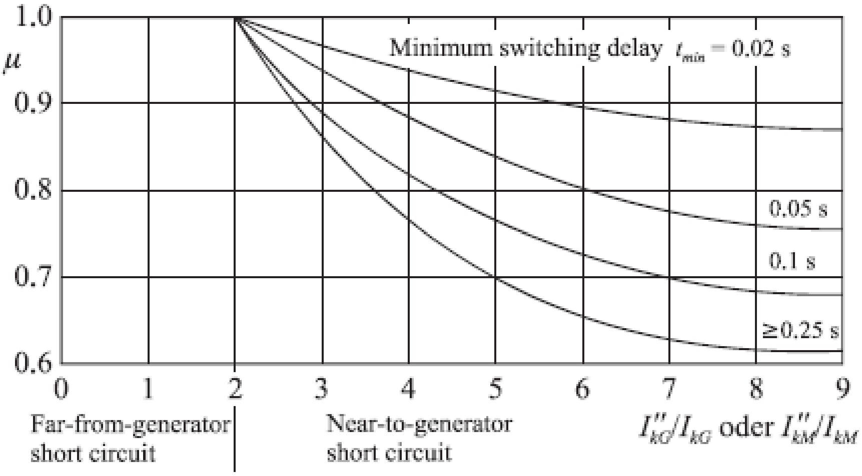


Figure 4. 7 Factor µ for calculating the symetrical breaking current

(Source: Ismail Kalsicki, Short Circuit On Power Grid)

On this calculation minimum switching delay choosen os 0.02 second, because the faster breaking capacity is better for damage prevention on equipment. I”$_{kM}$ and I$_{kM}$ valuie respectively , so the calculation is shown below :

$$I_a = \mu . I''_k$$

$$I_a = 2.46 \text{ Amphere}$$

And the summary of peak short circuit current for this scenario is shown on table below:

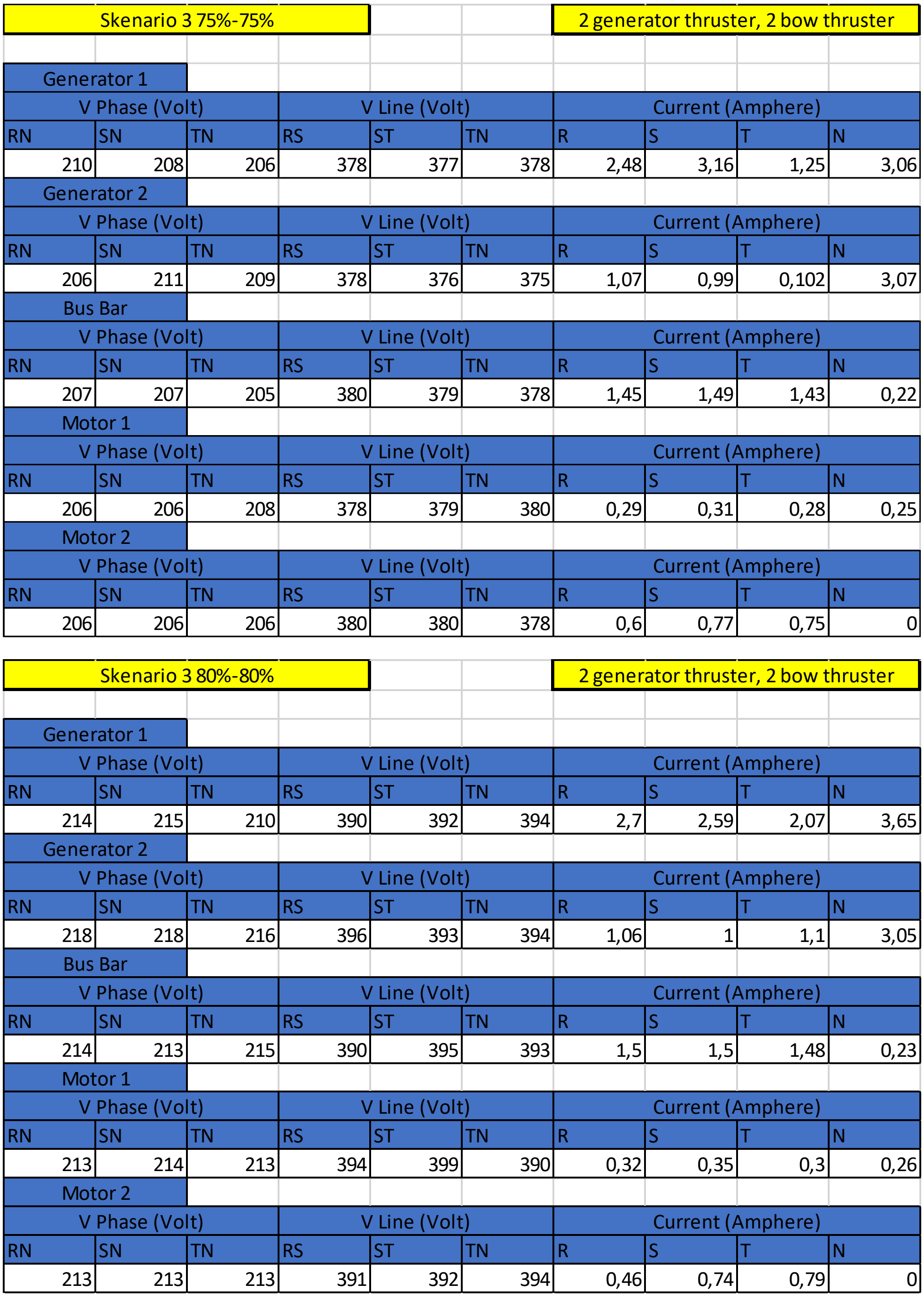
Table 4. 12 Scenario 2 initial breaking capacity summary

Skenario	Variasi	V	Z	I"k	Ia
2	40%-40%	379,3333	97,56889	2,469117	2,461802
	50%-50%	380,6667	96,2513	2,511715	2,517701
	60%-60%	380,3333	96,00832	2,515866	2,528588

4.4.3. Scenario 3

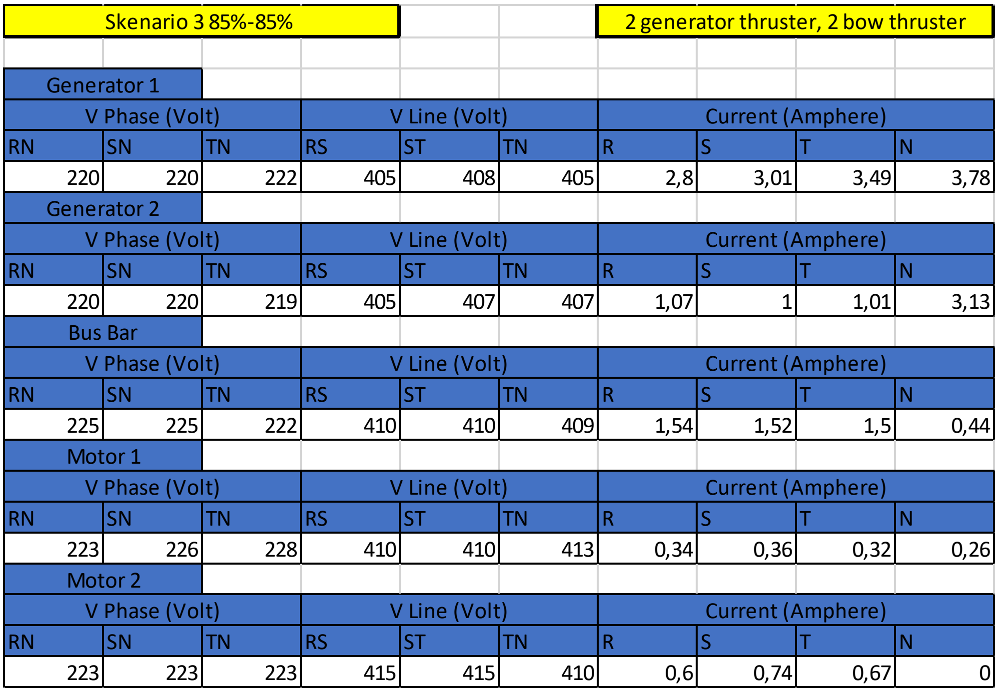
After we running the scenario with each variation, the data we obtain as shown below.

Table 4. 13 Scenario 3 experiment result



Skenario 3 75%-75%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
210	208	206	378	377	378	2,48	3,16	1,25	3,06
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
206	211	209	378	376	375	1,07	0,99	0,102	3,07
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
207	207	205	380	379	378	1,45	1,49	1,43	0,22
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
206	206	208	378	379	380	0,29	0,31	0,28	0,25
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
206	206	206	380	380	378	0,6	0,77	0,75	0

Skenario 3 80%-80%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
214	215	210	390	392	394	2,7	2,59	2,07	3,65
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
218	218	216	396	393	394	1,06	1	1,1	3,05
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
214	213	215	390	395	393	1,5	1,5	1,48	0,23
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
213	214	213	394	399	390	0,32	0,35	0,3	0,26
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
213	213	213	391	392	394	0,46	0,74	0,79	0



Skenario 3 85%-85%						2 generator thruster, 2 bow thruster			
Generator 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	222	405	408	405	2,8	3,01	3,49	3,78
Generator 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
220	220	219	405	407	407	1,07	1	1,01	3,13
Bus Bar									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
225	225	222	410	410	409	1,54	1,52	1,5	0,44
Motor 1									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
223	226	228	410	410	413	0,34	0,36	0,32	0,26
Motor 2									
V Phase (Volt)			V Line (Volt)			Current (Amphere)			
RN	SN	TN	RS	ST	TN	R	S	T	N
223	223	223	415	415	410	0,6	0,74	0,67	0

Here are the calculation example start form reactance and resistance and shortcircuit calculation

- Calculation Reactance

Based on equation $Xg = \frac{Xd}{100}\ x\ \frac{V^2}{MVA\ x\ 10^6}$, reactance of generator were calculated by Xd value that measured on each pole. So Reactance value are:

Xd = 33.6084
V = 410
MVA = 300 MVA

$$Xg = \frac{17.36}{100}\ x\ \frac{410^2}{300\ x\ 10^6}\ ,$$
$$Xg = 111.0745\ \Omega,$$

The same calculation step we applied for another generator and motor. But for the cable we used different R/X value. Based on *Cashier Technique No.150 for Short Circuit Calculation* reactance per unit value for spaced single core cable is 0,13 so reactance value for cable is shown on calculation below :

$$Xc = 0{,}13\ m\Omega/m \text{ x l x } 10^{-3}$$
$$Xc = 0{,}13\ m\Omega/m \text{ x 6000 mm x } 10^{-3}$$
$$Xc = 0{,}78\ \Omega$$

- Calculation Resistance

  After we obtained Xg value, by multiplying with X/R vaue that we obtain before, we can get resistance value. The calculation were shown below:

  $\frac{R}{X} = 0{,}25$

  $R = 0{,}25 \text{ x Xd}$

  $R = 27.7686\Omega$

- Calculation Impedance

  While the resistance value we get from measuring.

  So the calculation summary for reactance and resistance value is show on table below:

Table 4. 14 Scenario 3 impedance value summary

Branch	R	X
TG 1 + DG 1	50,93515	204
BT 1 + BT 2	0,13053	0,4683
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	51,36568	204,2089

So by using equation $Z_k = R_k + jX_k$ we can obtain impedance value, the impedance calculation is shown below :

$Z_k = R_k + jX_k$

$Z = \sqrt{R^2 + X^2}$

$Z = \sqrt{51.3656\ \Omega^2 + 204.2089\ \Omega^2}$

$Z = 210.5699\ \Omega$

- Calculation Initial Short Circuit Current

  After we obtain impedance value, then we used $I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$ equation. Constanta c were take 1.1 for 10% tolerance, and U_n were measured voltage on busbar while the motor load is on 75%-75%. Because the fault that were made is on busbar, so U_n value that used is the value on busbar. So the Initial symentrical short circuit current calculation is shown on below:

$$I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$$

$$I"_k = \frac{1{,}1\ x\ 379.33\ V}{\sqrt{3}\ x\ 210.5699\ \Omega}$$

$$I"_k = 1.1430\ Amphere$$

The other load variation on thos scenario were calculated by same step with previous one. The summary for second variation is shown on table below

Table 4. 15 Scenario 3 initial symetrical short circuit summary

Scenario	Variation	V	Z	I"k
3	75%-75%	379,00	210,5699	1,1431
	80%-80%	392,67	210,5395	1,1845
	85%-85%	409,67	210,4859	1,2361

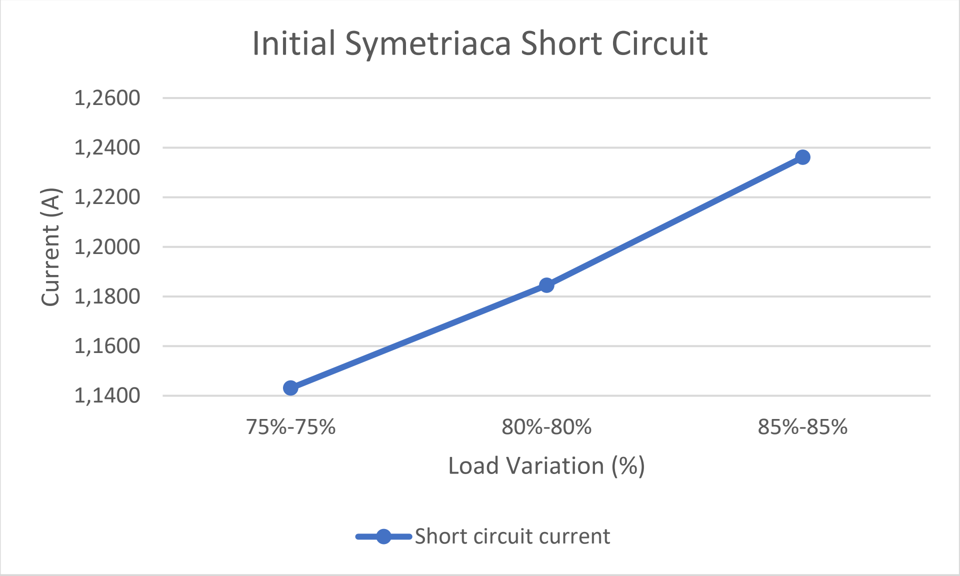


Figure 4. 8 Scenario 3 short circuit value each load variation

Based on experiment data that we obtain and calculate, we can see that in every increased load variation, the short circuit value by impedance method decreasing. On this scenario the smallest load value of each motor is at 75%-75% load and occur short circuit 1.1431 Amphere, and the highest load on this scenario at 85%-85% short circuit current that occur is 1.2631 Amphere. But on this scenario, there is an anomaly when we run the system, whenever the generator set to 220/380V after being loaded, the voltage output on generator change its voltage to 230/415 V and the voltage on busbar and motor got increased where theoritically it should be dropped.

- Calculation Circuit Breaker Breaking Capacity

  After we obtain initial symetrical short circuit current, then we have to calculate circuit breaker breaking capacity. This value is to determine circuit breaker capacity as a protection. Based on IEC 60909-0 standart, use $I_a = \mu \,.\, I"_k$ equation we have to find μ constanta based on graph below where the μ values is deppend on minimum switching delay and I”$_{kM}$/I$_{kM}$ ratio. Because the problem that reviewed on this thesis is short circuit current because the usage of bow thruster, the protective device that we placed on bus bar that supply asyncronous motor and I”$_{kM}$ is represent short circuit current on fault point and I$_{kM}$ is represent current value without short circuit fault.

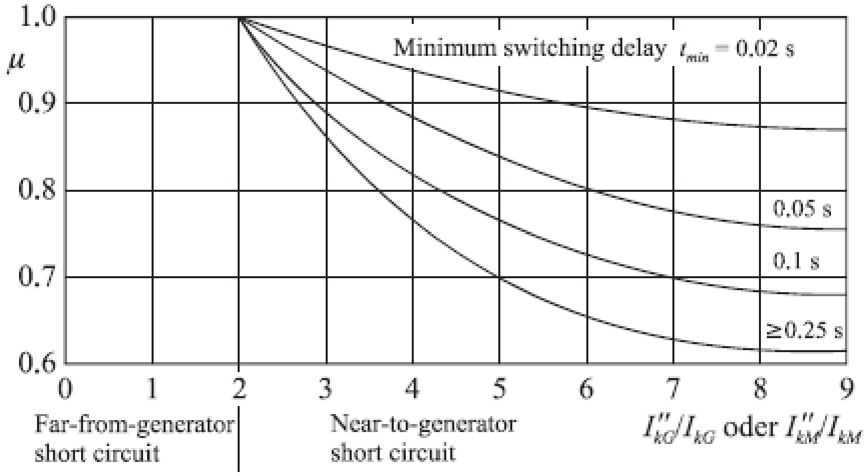


Figure 4. 9 Factor μ for calculating the symetrical breaking current

(Source: Ismail Kalsicki, Short Circuit On Power Grid)

On this calculation minimum switching delay choosen os 0.02 second, because the faster breaking capacity is better for damage prevention on equipment. I”$_{kM}$ and I$_{kM}$ valuie respectively , so the calculation is shown below :

$I_a = \mu \,.\, I''_k$

$I_a = 1.140007$ Amphere

And the summary of peak short circuit current for this scenario is shown on table below:

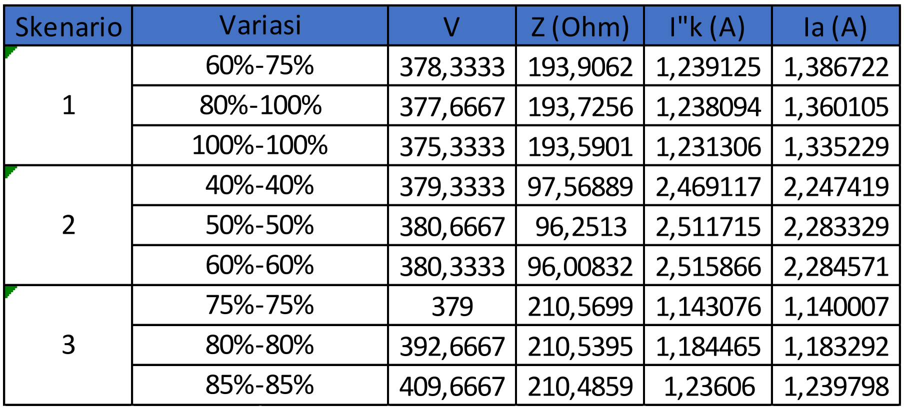
Table 4. 16 Scenario 3 initial breaking capacity summary

Scenario	Variation	V	Z	I"k	Ia
3	75%-75%	379,0000	210,5699	1,143076	1,140007
	80%-80%	392,6667	210,5395	1,184465	1,183292
	85%-85%	409,6667	210,4859	1,23606	1,239798

4.5. Resolving the occurance of short circuit failure

There are several consequences that will be obtained when a short circuit current is occured. Those damage such as insulation damage, busbar deformation, generator over current etc. To prevent this impact caused by short circuit fault, the fault source has to be disconnected immidiatelly. By using circuit breaker that we already calculate above, the effective breaking capacity of circuit breaker is the effective value of the short circuit current which flows through the switch at the time of the first contact separation. The calculation summary is shown on table below

Table 4. 17 Initial symetrical short circuit & initial breaking capacity value summary



Skenario	Variasi	V	Z (Ohm)	I"k (A)	Ia (A)
1	60%-75%	378,3333	193,9062	1,239125	1,386722
	80%-100%	377,6667	193,7256	1,238094	1,360105
	100%-100%	375,3333	193,5901	1,231306	1,335229
2	40%-40%	379,3333	97,56889	2,469117	2,247419
	50%-50%	380,6667	96,2513	2,511715	2,283329
	60%-60%	380,3333	96,00832	2,515866	2,284571
3	75%-75%	379	210,5699	1,143076	1,140007
	80%-80%	392,6667	210,5395	1,184465	1,183292
	85%-85%	409,6667	210,4859	1,23606	1,239798

By definition of initial breaking capacity itself is the effective value of the short circuit current which flow through the switch at the time of the first contact separation, so the circuit breaker that have to be installed to overcome this fault is like calculation above. But for some reason the breaker capcaity that needed were not avaliable, so to solve this problem we have to reduce the initial symetrical short circuit current value to reduce initial breaking capacity value, because the initial breaking capacity formula is $I_a = \mu \, . I''_k$, where initial breaking capacity is propotional with initial symetrical short circuit current. So to reduce the breaking capacity we have to reduce initial symetrical short circuit current.

Based on formula $I''_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k + X^2{}_k}}$ initial short circuit current is depend on the voltage value on fault point and impedance value which consist of reactance and resistance value. The voltage value on fault point usualy depend on drop voltage that caused by electrical load that applied on system, where the value cannot be changed because the load required in the system is already determine. The value that we can change is the impedance, where the impedance value consist of resistance and reactance, so we have to find the correct reactance value to obtain desire initial symetrical short circuit current value.

There is several method to increasing impedance value, either by increasing the reactance value or the resistance value. Those method are:

4.5.1. Installing choke coil

Short circuit current limiting choke coils are used to limit the current flowing as a result of a fault condition in series system with insufficient stability against short circuit. They are used in order to reduce the breaking capacity of the circuit breaker to a permissible value (Kasikci, 2002).

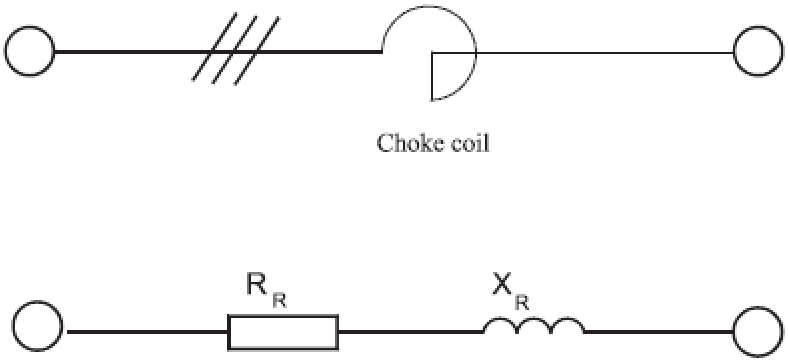


Figure 4. 10 Choke coil

The choke coil works because it can act as an inductor. When the current pass through will change as AC currents creates a magnetic field in the coil that works against that current. This is known as inductance and blocks most of the AC current from passing through. This result to the currents that do not change such as DC currents can continue passing through while those currents that are blocked by the magnetic field.

The formula to determining choke coil reactance value is show below :

$$X_R = \frac{u_{kR}}{100\%} \cdot \frac{U_n}{\sqrt{3}.I_{rR}}, R_R \ll X_R$$

(Kasikci, 2002)

Where

X_R = Reactance of choke coil
u_{kR} = Rated voltage drop of choke coil (given on nameplate)
U_n = Nominal power line voltage
I_{rR} = Rated current of choke coil (given on nameplate)
R_R = Resistance of choke coil

4.5.2. Reducing cross sectional area of wire

One of the way to increasing impedance value is increasing resistance value, like previous statement, that reactance and resistance of the motor and generator cannot be changed, so the posible resistance value that can be changed is cable. Based on theory, lenght of transmission line is proportional with resistance value and inversly proportional with cross sectional area. Because lenght of transmission line cannot ber reduce or increase, so the possible way is to decrease cross sectional area of cable to increase resistance value.

$$R = \rho \, . \frac{L}{A}$$

Where

R = Resistance
L = Lenght
A = Cross sectional are
ρ = Electrical conductivity

4.6. Discussion

4.6.1. Initial symetrical short circuit current

Based on data that obtained on running in each scenario, we know that every data have their own data tren. Like on table that summarized on table below.

Table 4. 18 Initial symetrical short circuit current impedance method summary

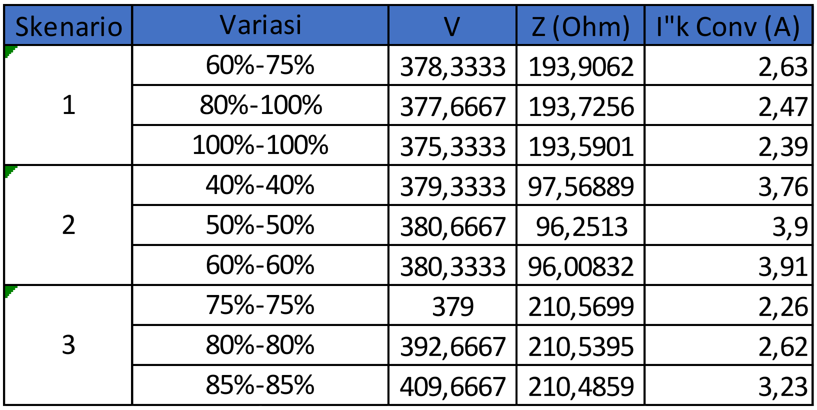
Skenario	Variasi	V	Z (Ohm)	I"k (A)
1	60%-75%	378,3333	193,9062	1,239124565
	80%-100%	377,6667	193,7256	1,238094489
	100%-100%	375,3333	193,5901	1,231306449
2	40%-40%	379,3333	97,56889	2,469117209
	50%-50%	380,6667	96,2513	2,511714708
	60%-60%	380,3333	96,00832	2,515866358
3	75%-75%	379	210,5699	1,143075541
	80%-80%	392,6667	210,5395	1,184465473
	85%-85%	409,6667	210,4859	1,236060065

We can see that on scenario 1, the initial symetrical short circuit current that obtained with impedance method is decreasing along with increasing of load. But on scenario 2 & scenario 3 the initial symetrical short circuit current that obtain with impedance method is increasing. And the highest initial symetrical short circuit value is appear in 60%-60% load variation on scenario 2. The 110%-110% load variation on 1st scenario cannot be tested because of limitation of laboratory equipment.

There is an anomaly that happend on the 3rd scenario, instead of deacrease voltage value in each load variation, the voltage increasing, moreover the voltage value were increasing more than 380V where in the other scenario, the output voltage on each generator were maintain around 380V value. This can be caused by the different working voltage of the second generator (working as diesel generator). Where one generator have to maintain voltage on its working voltage, and the other generator that have synronized with the 415V generator have to follow in order to keep in synronous condition with each other

To validate this value, take another method to obtain initial symetrical short circuit current with conventional method. This method we make a fault on bus bar by connecting R-S-T phase then measure the current that appear on measuring instrument. The data that obtained is shown on table below.

Table 4. 19 Initial symetrical short circuit current conventional method summary



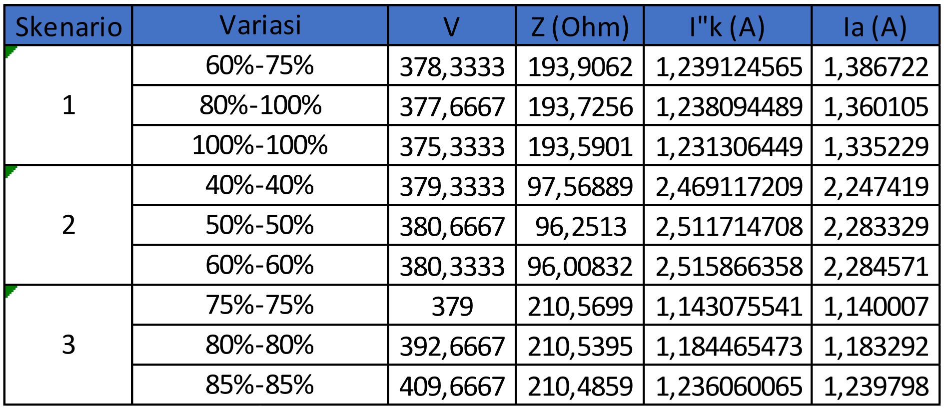
Skenario	Variasi	V	Z (Ohm)	I"k Conv (A)
1	60%-75%	378,3333	193,9062	2,63
	80%-100%	377,6667	193,7256	2,47
	100%-100%	375,3333	193,5901	2,39
2	40%-40%	379,3333	97,56889	3,76
	50%-50%	380,6667	96,2513	3,9
	60%-60%	380,3333	96,00832	3,91
3	75%-75%	379	210,5699	2,26
	80%-80%	392,6667	210,5395	2,62
	85%-85%	409,6667	210,4859	3,23

The table above is shown initial symetrical short circuit current on each load variation in each scenario that appear on amphere meter. Like the impedance method, the 1st scenario shown decreasing initial symetrical short circuit current value each load increase. Like the impedance method, the highest initial symetrical short circuit current value shown on 60%-60% load variation on 2nd scenario. But ne value didnt show that each methode have same scalling. Its because on impedace method the author cannot measure exact impedance value form each componen because wheatstone bridge that usualy used to measure impedance value is still broke, and author used some approach that given by IEC to determine impedance value from measuring reactance and resistance of each component

4.6.2. Circuit breaker capacity calculation

After we obtain initial symetrical short circuit value using impedance method, then we have to calculated circuit breaker capacity as protection device. By using $I_a = \mu \,.\, I''_k$ formula, the breaker capacity that obtained is shown on table below.

Table 4. 20 Initial symetrical short circuit & breaking current capacity summary



Skenario	Variasi	V	Z (Ohm)	I"k (A)	Ia (A)
1	60%-75%	378,3333	193,9062	1,239124565	1,386722
	80%-100%	377,6667	193,7256	1,238094489	1,360105
	100%-100%	375,3333	193,5901	1,231306449	1,335229
2	40%-40%	379,3333	97,56889	2,469117209	2,247419
	50%-50%	380,6667	96,2513	2,511714708	2,283329
	60%-60%	380,3333	96,00832	2,515866358	2,284571
3	75%-75%	379	210,5699	1,143075541	1,140007
	80%-80%	392,6667	210,5395	1,184465473	1,183292
	85%-85%	409,6667	210,4859	1,236060065	1,239798

So the breaker capacity that we have to used is the smaller one among those value that we obtained on each load variation on each scenario. Because when the smaller value is appear, the highest value will be covered, but when we used the highest value as breaker capacity value, the smallest value will not be covered.

4.6.3. Reducing short circuit current value

Based on formula $I"_k = \frac{cU_n}{\sqrt{3}\sqrt{R^2{}_k+X^2{}_k}}$ initial short circuit current is depend on the voltage value on fault point and impedance value which consist of reactance and resistance value. The value that we can change is the impedance, where the impedance value consist of resistance and reactance, so we have to find the correct reactance value to obtain desire initial symetrical short circuit current value.

- Installing choke coil

  The choke coil works because it can act as an inductor. When the current pass through will change as AC currents creates a magnetic field in the coil that works against that current. This is known as inductance and blocks most of the AC current from passing through. This result to the currents that do not change such as DC currents can continue passing through while those currents that are blocked by the magnetic field.

  $$X_R = \frac{u_{kR}}{100\%} \cdot \frac{U_n}{\sqrt{3}.I_{rR}}, R_R \ll X_R \qquad (4.2.)$$

  (Kasikci, 2002)

  Where

  X_R = Reactance of choke coil
  u_{kR} = Rated voltage drop of choke coil (given on nameplate)
  U_n = Nominal power line voltage
  I_{rR} = Rated current of choke coil (given on nameplate)
  R_R = Resistance of choke coil

- Reducing cross sectional area of wire

  One of the way to increasing impedance value is increasing resistance value. Based on theory, lenght of transmission line is proportional with resistance value and inversly proportional with cross sectional area. Because lenght of transmission line cannot ber reduce or increase, so the possible way is to decrease cross sectional area of cable to increase resistance value.

$$R = \rho \cdot \frac{L}{A} \tag{4.3.}$$

Where

R = Resistance
L = Lenght
A = Cross sectional are
ρ = Electrical conductivity

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CHAPTER 5
CONCLUSION & SUGGESTION

5.1. Conclusion

1. Based on experiment that held on laboratorium, each load variation and scenario have their own trend value. On 1st scenario, when increasing load variation, the initial symetrical short circuit current is decreasing, impedance calculation on this scenario was supported with short circuit data that obtained with conventional method, where the trend show that short circuit value is decreasing every increasing load variation. On the 2nd variation and 3rd variation each increasing load variation in both scenario, the initial symetrical short circuit current also increasing, this increasing tren also supported with conventional method value that also increaing. The highest initial symetrical short circuit current that obtain both on impedance method and conventional method were found at 2nd scenario and 60%-60% load variation, the value that obtain in impedance method is 2.5158 Amphere and the value that obtain on with conventional method is 3.91 Amphere. This caused by total impedance on 2 scenario were smaller than other scenario. The generator that used on this scenario is 1 thruster generator and 2 bow thruster that loaded untul 60% of its peak capacity.
2. Initial breaking capacity of each scenario were calculated based on I''_{kG} and I_{kG} ratio. Where those ratio also determining the value of μ that used to calculate initial symetrical breaking current. Based on calculation summary, $I''_{K} >> I_a$, each breaking capacity have to disconnect the failure point immidiatelly when the fault occur. The circuit breaker capacity that we have to used is the smaller one among those value that we obtained on each load variation on each scenario. Because when the smaller value is appear, the highest value will be covered, but when we used the highest value as breaker capacity value, the smallest value will not be covered.
3. Based on formula initial short circuit current is depend on the voltage value on fault point and impedance value which consist of reactance and resistance value. The value that we can change is the impedance, where the impedance value consist of resistance and reactance, so we have to find the correct reactance value to obtain desire initial symetrical short circuit current value.
    - Installing choke coil

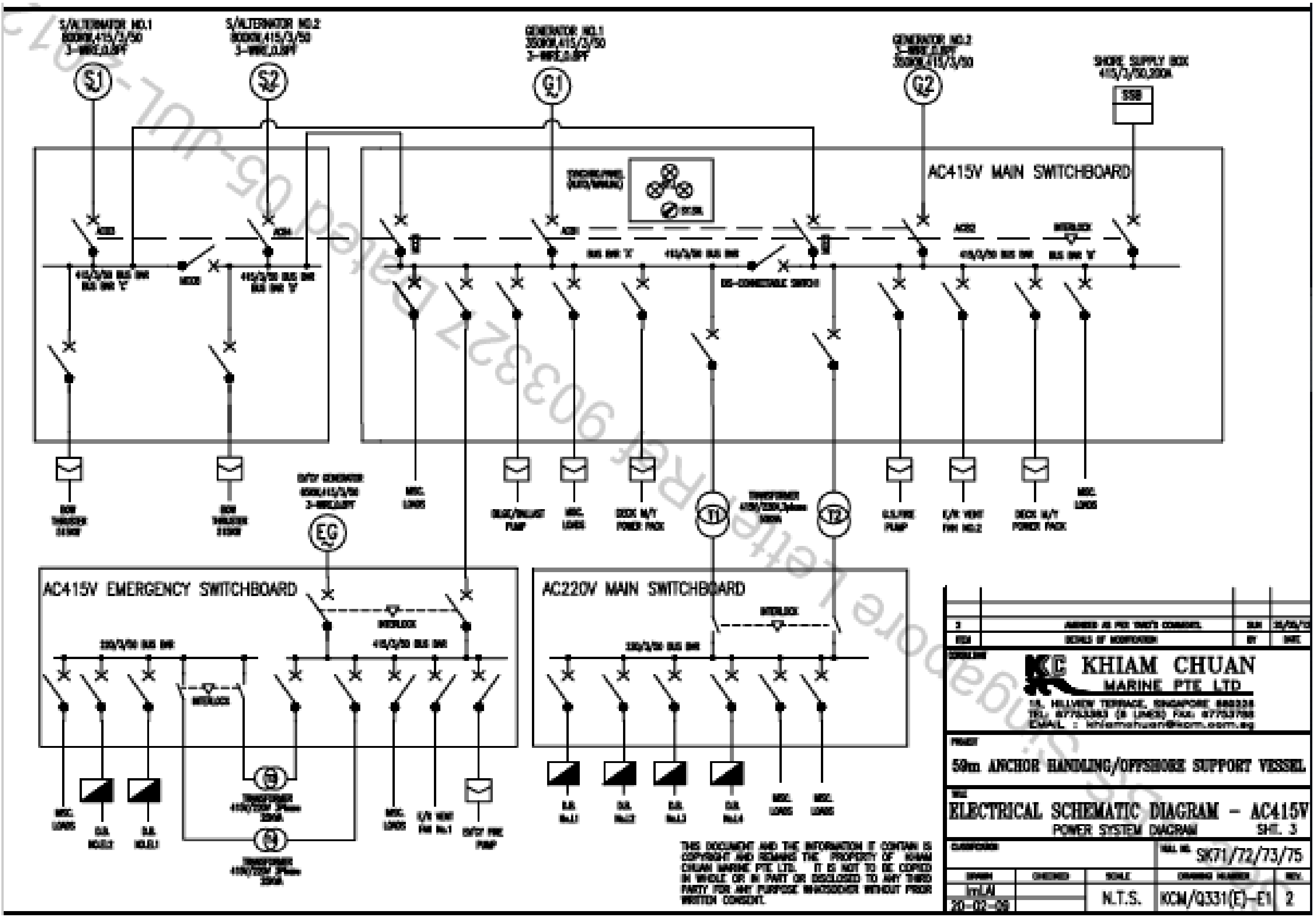
      The choke coil works because it can act as an inductor. When the current pass through will change as AC currents creates a magnetic field in the coil that works against that current. This is known as inductance and blocks most of the AC current from passing through. This result to the currents that do not change such as DC currents can continue passing through while those currents that are blocked by the magnetic field.

- Reducing cross sectional area of wire
  One of the way to increasing impedance value is increasing resistance value. Based on theory, lenght of transmission line is proportional with resistance value and inversly proportional with cross sectional area. Because lenght of transmission line cannot ber reduce or increase, so the possible way is to decrease cross sectional area of cable to increase resistance value.

5.2. Suggestion

1. To optimize experiment, every laboratory experiment have to be in good condition, including measuring instrument, load, cable incuvtor, safety component, etc
2. To optimize data that obtain in this experiment, scale from actual system and laboratory scale have to be pricisely scale
3. To validate this experiment, author suggest to carry out other experiment with methods that are more focused on conventional methods.

ATTACHMENT


S/ALTERNATOR NO.1
800KW,415/3/50
3-WIRE,0.8PF
S1
S/ALTERNATOR NO.2
800KW,415/3/50
3-WIRE,0.8PF
S2
GENERATOR NO.1
350KW,415/3/50
3-WIRE,0.8PF
G1
GENERATOR NO.2
3-WIRE,0.8PF
350KW,415/3/50
G2
SHORE SUPPLY BOX
415/3/50,200A
SSB
AC415V MAIN SWITCHBOARD
415/3/50 BUS BAR
BUS BAR 'C'
415/3/50 BUS BAR
BUS BAR 'D'
BUS BAR 'A'
BUS BAR 'B'
DIS-CONNECTABLE SWITCH
INTERLOCK
BOW THRUSTER
BOW THRUSTER
E/SY GENERATOR
3-WIRE,0.8PF
EG
MISC. LOADS
BILGE/BALLAST PUMP
MISC. LOADS
DECK M/T POWER PACK
TRANSFORMER
T1
T2
G.S./FIRE PUMP
E/R VENT FAN NO.2
DECK M/T POWER PACK
MISC. LOADS
AC415V EMERGENCY SWITCHBOARD
INTERLOCK
220/3/50 BUS BAR
415/3/50 BUS BAR
INTERLOCK
MISC. LOADS
D.B.
D.B.
TRANSFORMER
TRANSFORMER
T3
T4
MISC. LOADS
E/R VENT FAN No.1
E/SY FIRE PUMP
AC220V MAIN SWITCHBOARD
INTERLOCK
220/3/50 BUS BAR
D.B. No.1
D.B. No.2
D.B. No.3
D.B. No.4
MISC. LOADS
MISC. LOADS
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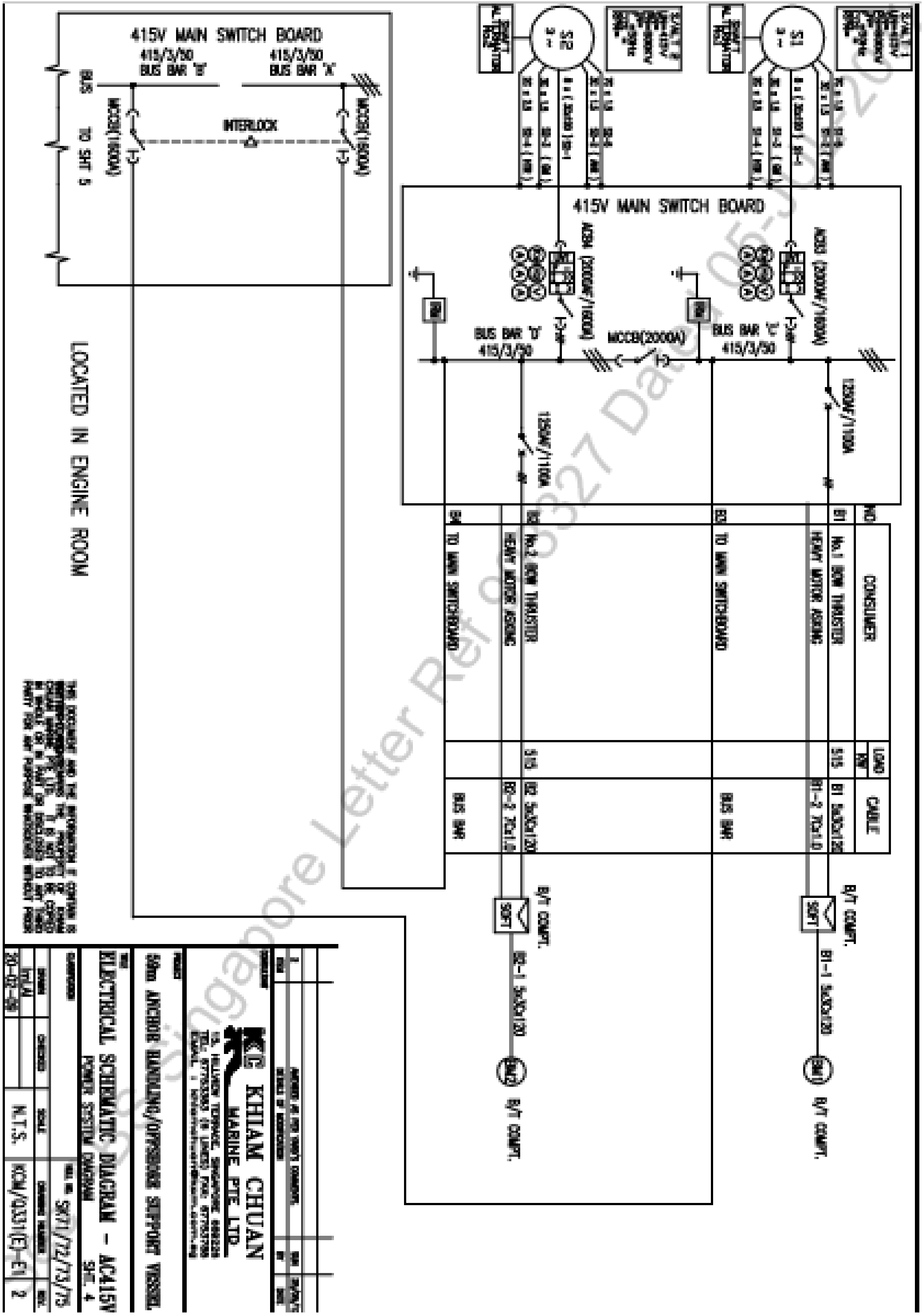
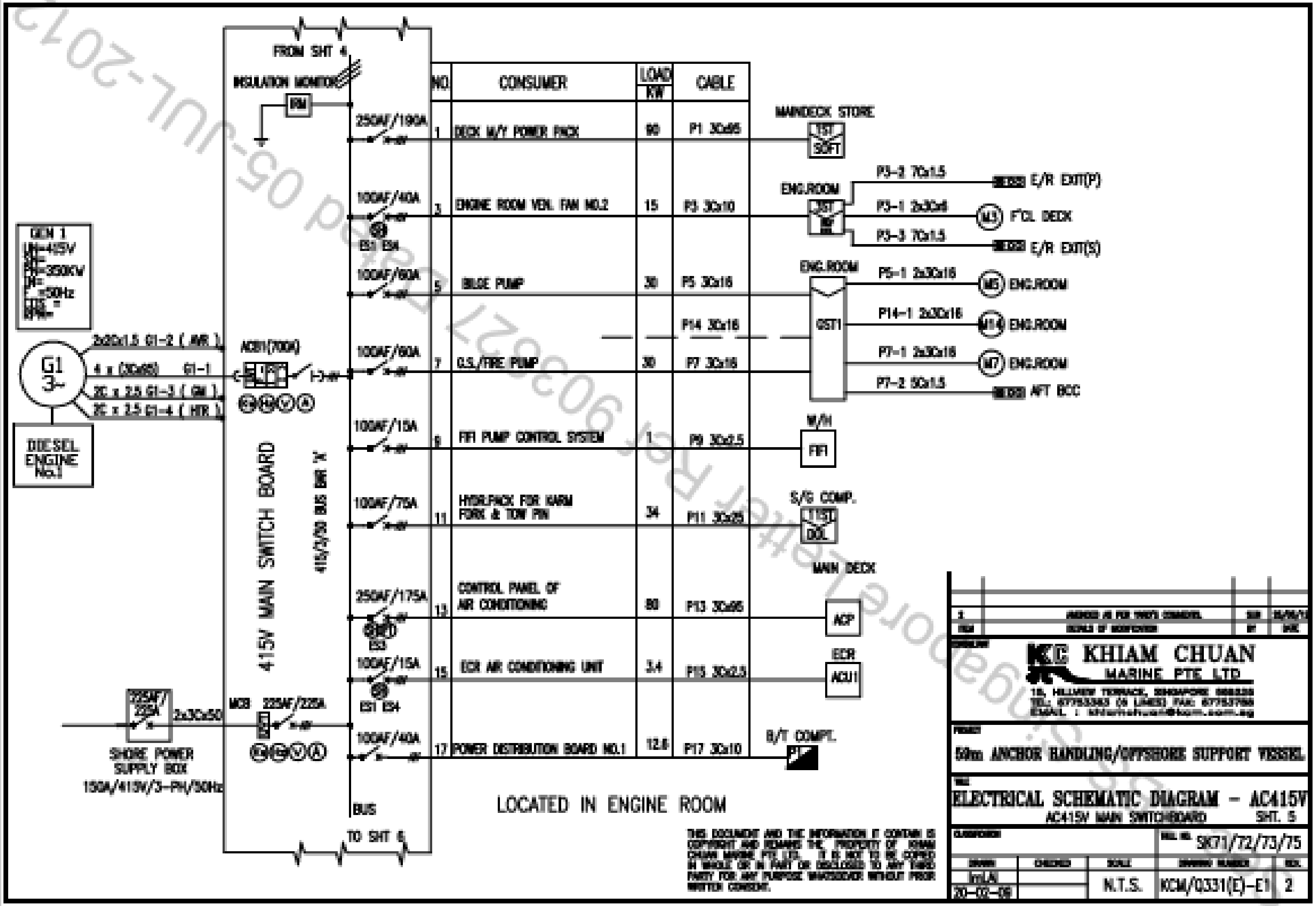
2
AMENDED AS PER YARD'S COMMENT
REV
DETAILS OF MODIFICATION
BY
DATE
KC KHIAM CHUAN
MARINE PTE LTD
EMAIL : khiamchuan@kcm.com.sg
PROJECT
59m ANCHOR HANDLING/OFFSHORE SUPPORT VESSEL
TITLE
ELECTRICAL SCHEMATIC DIAGRAM - AC415V
POWER SYSTEM DIAGRAM
SHT. 3
CLASSIFICATION
HULL NO. SK71/72/73/75
DRAWN
CHECKED
SCALE
DRAWING NUMBER
REV.
20-02-09
N.T.S.
KCM/Q331(E)-E1
2


415V MAIN SWITCH BOARD
415/3/50 BUS BAR 'B'
415/3/50 BUS BAR 'A'
MCCB(1600A)
INTERLOCK
BUS TO SHT 5
LOCATED IN ENGINE ROOM
S1
S2
415V MAIN SWITCH BOARD
ACB3 (2000AF/1600A)
ACB4 (2000AF/1600A)
BUS BAR 'C' 415/3/50
BUS BAR 'D' 415/3/50
MCCB(2000A)
1250AF/1100A
1250AF/1100A
NO
CONSUMER
LOAD (KW)
CABLE
B1
No.1 BOW THRUSTER
HEAVY MOTOR ASKING
515
B1 3x3Cx120
B1-2 7Cx1.0
B2
No.2 BOW THRUSTER
HEAVY MOTOR ASKING
515
B2 3x3Cx120
B2-2 7Cx1.0
B3
TO MAIN SWITCHBOARD
BUS BAR
B4
TO MAIN SWITCHBOARD
BUS BAR
B/T COMPT.
SOFT
B1-1 3x3Cx120
BM1
B/T COMPT.
B/T COMPT.
SOFT
B2-1 3x3Cx120
BM2
B/T COMPT.
KC KHIAM CHUAN MARINE PTE LTD.
60m ANCHOR HANDLING/OFFSHORE SUPPORT VESSEL
ELECTRICAL SCHEMATIC DIAGRAM – AC415V
POWER SYSTEM DIAGRAM
SHT. 4
SKT1/72/73/75
N.T.S.
KCM/Q331(E)-E1
2
20-07-06



NO.	CONSUMER	LOAD KW	CABLE
1	DECK M/Y POWER PACK	90	P1 3Cx95
3	ENGINE ROOM VEN. FAN NO.2	15	P3 3Cx10
5	BILGE PUMP	30	P5 3Cx16
			P14 3Cx16
7	G.S./FIRE PUMP	30	P7 3Cx16
9	FIFI PUMP CONTROL SYSTEM	1	P9 3Cx2.5
11	HYDR.PACK FOR KARM FORK & TOW PIN	34	P11 3Cx25
13	CONTROL PANEL OF AIR CONDITIONING	80	P13 3Cx95
15	ECR AIR CONDITIONING UNIT	3.4	P15 3Cx2.5
17	POWER DISTRIBUTION BOARD NO.1	12.6	P17 3Cx10

- Short Circuit Calculation Scenario 1

Skenario 1 (2 generator thruster dan 2 bow thruster)

Fault at Bus D

Component	R	X	Z = R + jX		
Thruster generator 1	23,53988	94,15953	23,53988	+ j	94,15953
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,964816	3,859262	0,964816	+ j	3,859262
Bow Thruster 2	0,157097	0,551994	0,157097	+ j	0,551994
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + TG 2	46,7064	187
BT 1 + BT 2	0,1351	0,4829
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	47,1415	188,089

Z= 193,9062

Pembebanan bow thruster 60% - 75%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 193,9062

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$

, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,239125 A

0,001239 kA

Component	R	X	Z = R + jX		
Thruster generator 1	23,53988	94,15953	23,53988	+ j	94,15953
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,25	2,894447	0,25	+ j	2,894447

Bow Thruster 2	0,2846	0,331196	0,2846	+ j	0,331196
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + TG 2	46,7064	187
BT 1 + BT 2	0,13309	0,2972
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	47,13949	187,903

Z= 193,7256

Pembebanan bow thruster 80% - 100%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 193,7256

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$

, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,238094 A

0,001238 kA

Component	R	X	Z = R + jX		
Thruster generator 1	23,53988	94,15953	23,53988	+ j	94,15953
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,434167	1,736668	0,434167	+ j	1,736668
Bow Thruster 2	0,056555	0,198718	0,056555	+ j	0,198718
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + TG 2	46,7064	187
BT 1 + BT 2	0,050037	0,1783

Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	47,05644	187,784

Z= 193,5901

Pembebanan bow thruster 100% - 100%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 193,5901

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$

, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,231306 A

0,001231 kA

- Short Circuit Calculation Scenario 2

Skenario 2 (1 generator thruster dan 2 bow thruster)

Fault at Bus D

Component		R	X	Z = R + jX		
Thruster generator 2		23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1		1,447223	5,788894	1,447223	+ j	5,788894
Bow Thruster 2		0,294558	1,034988	0,294558	+ j	1,034988
Cable 1		0,3	0,78	0,3	+ j	0,78
Cable 3		0,3	0,78	0,3	+ j	0,78
Cable 4		0,3	0,78	0,3	+ j	0,78

Branch	R	X
Thruster Generator	23,16652	92,66607
BT 1 + BT 2	0,244744	0,8780
Cable 1	0,3	0,7800
Cable 3 + Cable 4	0,15	0,3900
Total	23,86126	94,71408

Z= 97,67353

Pembebanan bow thruster 40% - 40%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 97,67353

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$, dengan c = 1,1 untuk 10% toleransi

I"k3 = 2,466472 A

0,002466 kA

Component	R	X	Z = R + jX		
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	1,157779	4,631115	1,157779	+ j	4,631115
Bow Thruster 2	0,235646	0,82799	0,235646	+ j	0,82799
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1	23,16652	93
BT 1 + BT 2	0,195795	0,7024
Cable 1	0,3	0,7800
Cable 3 + Cable 4	0,15	0,3900
Total	23,81231	94,538

Z= 97,49129

Pembebanan bow thruster 50% - 50%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 97,49129

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$, dengan c = 1,1 untuk 10% toleransi

I"k3 = 2,479768 A
0,00248 kA

Component		R	X	Z = R + jX		
Thruster generator 2		23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1		0,771852	3,08741	0,771852	+ j	3,08741
Bow Thruster 2		0,157097	0,551994	0,157097	+ j	0,551994
Cable 1		0,3	0,78	0,3	+ j	0,78
Cable 3		0,3	0,78	0,3	+ j	0,78
Cable 4		0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1	23,16652	93
BT 1 + BT 2	0,13053	0,4683
Cable 1	0,3	0,7800
Cable 3 + Cable 4	0,15	0,3900
Total	23,74705	94,304

Z= 97,2483

Pembebanan bow thruster 60% - 60%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 97,2483

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$

, dengan c = 1,1 untuk 10% toleransi

I"k3 = 2,483787 A
0,002484 kA

- Short Circuit Calculation Scenario 3

Skenario 3	(1 generator thruster + 1 Diesel Generator dan 2 bow thruster + 480watt load)

Fault at Bus D

Component	R	X	Z = R + jX

Diesel generator 1	27,76863	111,0745	27,76863	+ j	111,0745
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,771852	3,08741	0,771852	+ j	3,08741
Bow Thruster 2	0,157097	0,551994	0,157097	+ j	0,551994
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + DG 1	50,93515	204
BT 1 + BT 2	0,13053	0,4683
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	51,36568	204,2089

Z= 210,5699

Pembebanan bow thruster 75% - 75%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 210,5699

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$

, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,143076 A

0,001143 kA

Component	R	X	Z = R + jX		
Diesel generator 1	27,76863	111,0745	27,76863	+ j	111,0745
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,723612	2,894447	0,723612	+ j	2,894447
Bow Thruster 2	0,147279	0,517494	0,147279	+ j	0,517494
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + TG 2	50,93515	204
BT 1 + BT 2	0,122372	0,4390
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	51,35752	204,1796

Z= 210,5395

Pembebanan bow thruster 80% - 80%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 210,5395

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,184465 A

0,001184 kA

Component	R	X	Z = R + jX		
Diesel generator 1	27,76863	111,0745	27,76863	+ j	111,0745
Thruster generator 2	23,16652	92,66607	23,16652	+ j	92,66607
Bow Thruster 1	0,638481	2,553924	0,638481	+ j	2,553924
Bow Thruster 2	0,129952	0,456612	0,129952	+ j	0,456612
Cable 1	0,3	0,78	0,3	+ j	0,78
Cable 2	0,3	0,78	0,3	+ j	0,78
Cable 3	0,3	0,78	0,3	+ j	0,78
Cable 4	0,3	0,78	0,3	+ j	0,78

Branch	R	X
TG 1 + TG 2	50,93515	204
BT 1 + BT 2	0,107975	0,3874
Cable 1 + Cable 2	0,15	0,3900
Cable 3 + Cable 4	0,15	0,3900
Total	51,34312	204,1279

Z= 210,4859

Pembebanan bow thruster 85% - 85%

$$Z\ net = \sqrt{R^2 + X^2}$$

Z net = 210,4859

$$I''k_3 = \frac{c\ Un}{\sqrt{3}\ x\ Zsc}$$, dengan c = 1,1 untuk 10% toleransi

I"k3 = 1,23606 A

0,001236 kA

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