



BACHELOR THESIS & COLLOQUIUM – ME 141502

**CONTROLLING AND MONITORING BASED ON ARDUINO UNO
ON IMPRESSED CURRENT CATHODIC PROTECTION FOR
HULL**

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DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA 2019



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APPROVAL FORM

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BACHELOR THESIS

**Submitted in fulfilment of the requirement for the degree of Bachelor in
Engineering**

at

**Marine Electrical and Automation System (MEAS) Laboratory
Bachelor Program Department of Marine Engineering Faculty of Marine
Technology
Institut Teknologi Sepuluh Nopember**

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PREFACE

Author would like to praise and thanks Allah SWT for giving the knowledge, strength, and wisdom in order to complete this studies and bachelor thesis. In expectation, the result of this bachelor thesis would be a beneficial aspect both for the author knowledge and surroundings that are involves in this aspect. Author would give the warmest regards and appreciation for those who had helped and contributed highly by guiding and providing knowledge in the completion of this bachelor thesis.

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Surabaya, 2020

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CONTROLLING AND MONITORING BASED ON ARDUINO UNO ON IMPRESSED CURRENT CATHODIC PROTECTION FOR HULL

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ABSTRACT

Impressed Current Cathodic Protection (ICCP) is a cathodic protection method that works by sending controlled DC currents to submerged surfaces with the help of zinc electrodes and metal oxide combined anodes. The application of excess current to the ICCP technology and protective coating will cause inefficiency on generators and cause an electro-endomosis process that triggers the damage of the protective coating layer so that the application of ICCP technology with an excess current will tend to be detrimental. Therefore, it is necessary to install a controlling and monitoring system at ICCP to regulate the amount of current released by ICCP so that the use of ICCP can be more efficient. This controlling and monitoring system consists of several components such as sensors, microcontroller, actuators, and software.

Water sensor will detect water level. Then the water sensor will send a signal in the form of data to the Arduino microcontroller. Then Arduino will send commands to the transistor to control the current coming from the power supply, as needed. Then to find out the amount of current that will enter the anode, a current sensor is needed.

In this study, it was found that the simulation with Arduino Uno conducted was able to control the output of the ICCP current to make efficient use of generators on ships. Based on the calculations performed, the value of current requirements obtained at full load conditions is 162 Amperes, at half load conditions is 115 Amperes, and at ballast load conditions is 87 Amperes.

Keyword: Corrosion, ICCP, Controlling, Monitoring

PENGENDALIAN DAN PEMANTAUAN PADA *IMPRESSED CURRENT CATHODIC PROTECTION* UNTUK LAMBUNG KAPAL MENGGUNAKAN ARDUINO UNO

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ABSTRAK

Impressed Current Cathodic Protection (ICCP) adalah metode perlindungan katodik dengan mengirimkan arus DC yang terkontrol ke permukaan yang terendam air laut dengan bantuan elektroda berupa zinc dan anoda gabungan oksida logam. Arus yang berlebih pada ICCP akan mengurangi efisiensi penggunaan generator dan dapat menyebabkan proses elektro-erosi yang dapat memicu kerusakan lapisan pelindung yang akan merugikan. Oleh karena itu, diperlukan pemasangan sistem pengendalian dan pemantauan pada ICCP sehingga penggunaannya akan lebih efisien. Sistem pengendalian dan pemantauan terdiri dari serangkaian komponen seperti sensor, mikrokontroler, aktuator, dan perangkat lunak.

Ketinggian air dideteksi dengan sensor air. Sensor air akan mengirimkan sinyal dalam bentuk data ke mikrokontroler Arduino. Lalu Arduino akan mengirimkan perintah ke transistor untuk mengatur arus dari sumber tenaga sesuai yang dibutuhkan. Sensor arus akan digunakan untuk mengetahui jumlah arus yang akan memasuki anoda.

Pada penelitian ini, didapatkan bahwa simulasi dengan Arduino Uno yang dilakukan mampu mengontrol keluaran arus ICCP untuk mengoptimalkan penggunaan generator pada kapal. Berdasarkan kalkulasi yang dilakukan, didapatkan nilai kebutuhan arus pada kondisi full load sebesar 162 Ampere, dan pada kondisi half load sebesar 150 Ampere.

Kata kunci: Corrosion, ICCP, Controlling, Monitoring

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CHAPTER I

INTRODUCTION

1.1. Background Overview

The Indonesian archipelago is a country that has a tropical climate and has a wide sea scapes, with a high level of humidity, the corrosion process is something that cannot be avoided. By most people, corrosion is also referred to as rust, corrosion is a destructive symptom that affects almost all metals. Although iron is not the first metal used by humans, it can't be denied that it is the most widely used metal.

Corrosion is the process of decay or degradation of metals (degradation of metal quality). Corrosion originates from the process of releasing electrons from metals in electrolyte solution. One of the biggest sources of damage to marine vessels is corrosion due to sea water. This is because the main ingredient in shipbuilding is iron / steel However, iron and steel have very reactive properties that are vulnerable to seawater.

When viewed in terms of construction on the ship plate, the hull plate is the most vulnerable to corrosion, this is because the surface of the hull plate, especially those below the water line are always submerged in sea water. Corrosion to the hull plate can cause the decline in the hull plated rigidity, reduce the speed of the ship, and reduce the safety and security of cargo and passenger loads. To avoid greater losses due to seawater corrosion, the hull plates need to be given protection from periodic corrosion attacks. In an effort to prevent corrosion on ships, there are several types of methods used, namely by giving a coating (coating), and doing cathodic protection. Cathodic protection methods include *Sacrificial Anode Cathodic Protection* (SACP) and *Impressed Current Cathodic Protection* (ICCP).

Protection of the hull against corrosion using the cathodic protection method is principally an electrochemical cell for controlling corrosion by concentrating the reaction of oxygen to galvanic cells and suppressing corrosion of the cathode in the same cell. In cathodic protection, the metal to be protected is made into a cathode and oxidation reactions occur at the anode. There are two types of cathodic protection, namely Sacrificial Anode Cathodic Protection (SACP) and Impressed Current Cathodic Protection (ICCP).

Impressed Current Cathodic Protection (ICCP) is a cathodic protection method that works by sending a controlled DC current to a submerged surface with the help of a zinc electrode and a combined metal oxide anode. Electric current flow will continue to be monitored by the ICCP system in order to help prevent corrosion before it occurs.

At the present time, several ships have been using Impressed Current Cathodic Protection (ICCP) system, especially LNG and Container vessels

In its use to prevent corrosion of the hull, ICCP requires a controlling system to control the large currents that must be released by the ICCP. Because when a ship floats, the loads carried may vary. There are times when the ship does not carry any cargo at all, there are times when the ship only carries half-full cargo, there are times when the ship carries full cargo, etc. In those cases, the draft on the ship will differ in each situation. Because of these conditions, the area of the hull that must be protected for each condition will require different amount of current.

When the ballast tank is not in full condition, it is possible to apply excessive current to the ICCP. In some literature it is mentioned that the application of overcurrent to ICCP and protective coating technology will cause an electro-osmosis process that triggers damage to the protective coating layer so as to cause corrosion between the protective coating layer and steel. This will make the application of ICCP technology with excessive flow does not provide the proper benefits, and tends to harm instead.

Therefore, it is necessary to install a controlling system in the ICCP, this controlling system serves to regulate the amount of current released by the ICCP to prevent corrosion in the hull according to their needs. So that with this controlling system, the amount of current released will be more efficient and saves generator usage on ships.

1.1. Formulation of Problems

Formulation of problems that will be analysed in this thesis are

1. What level of protection that ICCP need to protect by the system in each load case.
2. How can the design of an Arduino-based ICCP flow control & monitor system make efficient the use of ICCP in preventing hull corrosion ?

1.2. Research Limitations

Limitation problems or scope of this research are as follows :

1. Part of the ship to be analyzed is the immersed hull.
2. Calculation of ship's wetted surface area is divided only into 3 load cases.
3. Sea water is assumed to be in no waves condition.

1.3. Research Objectives

The objectives to be achieved in this research are as follows :

1. To determine the value of voltage and current required on the DC rectifier to slow down the corrosion in each load cases
2. To find out how to design of an Arduino-based ICCP flow control and monitor system can make efficient the use of ICCP in preventing hull corrosion

1.4. Research Benefits

The benefits of this research are expected to be as follows :

1. Provide recommendations using Arduino Uno-based controlling system so that using ICCP technology to prevent corrosion in the hull of the ship can run efficiently and effectively.

CHAPTER II

LITERATURE STUDY

2.1. Corrosion

Corrosion is the process of metal degradation due to reaction with a corrosion environment. Corrosion can also be interpreted as damage to metals because metals react chemically or electrochemically with their environment. Electrochemical reactions cause displacement of electrons which are the result of redox reactions. Corrosion process that occurs in materials made of metal is caused by the flow of electricity from the anode (negative electrode) to the cathode (positive electrode). The flow of current causes loss of metal in the part where the current is released into the environment (oxidation). The process occurs if there are substances that are electrolyte that can conduct electricity. Corrosion is a complex phenomenon that does not only occur with metal and non-metal materials [6].

There are four main components that can cause corrosion. If one of them is absent, corrosion cannot occur [9]. The components are

a. Anode

Anode is a component that releases electrons. Anode is a place of oxidation reaction. With the potential difference, it can cause an electric current. Electric current will flow from a high potential to a lower potential, while electrons flow in the opposite direction to the electric current. The anode has a more negative electron potential compared to the cathode, so electrons at the anode flow through metallic contact to the cathode.

b. Cathode

The cathode is a component that receives electrons. The cathode is where reduction reaction occurs. The cathode receives electrons from the anode so that a cathodic reaction occurs on the surface of the cathode. Electrons will be on the surface of the cathode so that they will react with positive ions from the electrolyte.

c. Electrolyte

Electrolytes are the environment where cathode and anode are exposed. The function of electrolyte solution is to work as an electrical conducting medium. Electrolyte ions will help delivering free electrons released from the oxide reaction in the anode region to the reduction reaction in the cathode region.

d. Metallic Connection

Metallic connection is the place where electrons flow. By making a contact between the anode and the cathode, the electrons will flow from the anode to the cathode. Therefore, a metallic connection is needed to move electrons, because electrons cannot flow in the electrolyte.

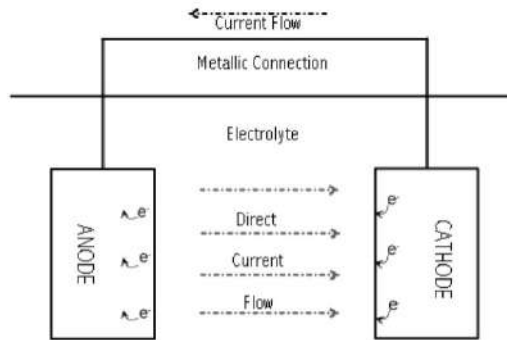


Figure 2.1 Corrosion Mechanism

2.2. Corrosion Rate

Corrosion is the process of electrochemical reactions. The speed of a chemical reaction or the amount of current that flows will affect the rate of corrosion. Corrosion rate is directly proportional to the amount of current flowing in the electrochemical corrosion cell. To calculate the corrosion rate can be done by two methods. The first method is the weight gain loss method. The weight gain loss is generally considered to be a loss of mass of plate. This method is done by observing the difference in initial mass before corrosion testing with final mass after corrosion testing. This method can be calculated by using the following equation [7] :

$$CR = \frac{K \cdot m}{A \cdot t \cdot \rho} \text{ (mpy/mmpy)} \quad [2.1]$$

Electrochemical method is a method of measuring the rate of corrosion by measuring the potential difference of an object, so that the corrosion rate is obtained. This method can estimate the rate of corrosion in a long time. This method has the advantage, in which we can know the rate of corrosion directly when being measured, and the measurement does not take a long process. Corrosion rate measurement by electrochemical method with polarization and corrosion potential can be calculated by using a formula based on Faraday's Law, as follows [2] :

$$CR = \frac{a \cdot i}{n \cdot D} \text{ mmpy} \quad [2.2]$$

2.3. Cathodic Protection

Cathodic protection is a technique used to control rust or corrosion on metal surfaces by making the metal surface a cathode of an

electrochemical cell. Generally cathodic protection is a process of controlling the corrosion rate that is resulted from cathodic polarization of corroded metal surfaces.

Cathodic protection is widely used to control corrosion in oil pipelines, ship hulls, offshore drilling rigs, gas pipes, and underground water pipes. Cathodic protection can be done in two ways, namely by using sacrificial anodes (Sacrificial Anode) and forced currents (Impressed Current).

2.3.1. Sacrificial Anode Cathodic Protection (SACP)

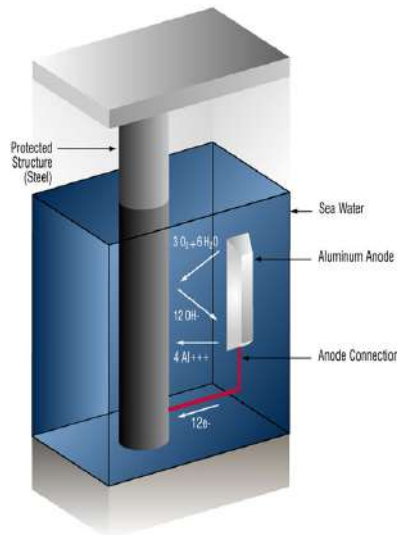


Figure 2.2 Sacrificial Anode

Sacrificial Anode is a cathodic protection that use a more reactive metal (anode) which is then connected to the metal that is to be protected. Types of metals commonly used in this protection are active metals such as zinc (zinc) or special Aluminium which has a greater positive current than the metal. The difference in voltage causes the attraction of negative free electrons that are greater than the attraction of ions on the metal. This results in more reactive metals that will be damaged by corrosion and other metals will be protected from corrosion [6]. The most commonly used sacrificial anode is zinc, allumunium, and magnesium. The three anodes have different characteristics in protecting the cathode metal. These three metals are widely used in seawater. The material has a potential that is negative enough to be a sacrificial anode that protects steel from an electrolyte solution (seawater). According to the composition of these metals when used as anode is very important, the composition must meet the following property procedures :

1. Has sufficient negative potential to ensure cathodic protection in special environments
2. Its ability to carry on corrosion during use and not forming a passive or protective layer on the surface
3. High anode efficiency

2.3.2. Impressed Current Cathodic Protection (ICCP)

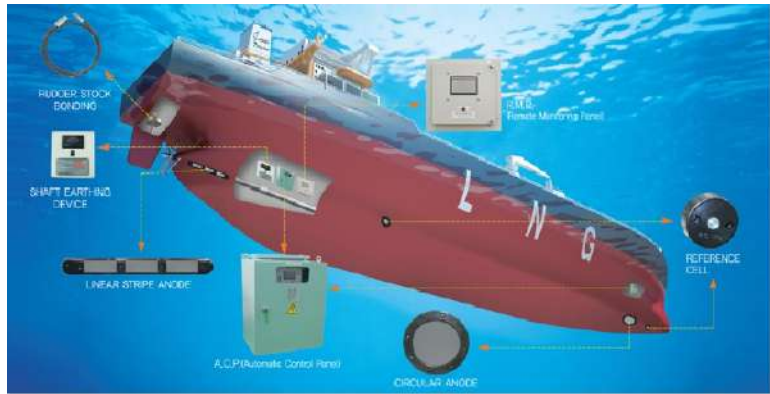


Figure 2.3 Impressed Current Cathodic Protection

ICCP is done by changing the AC current from the generator into a DC current using a rectifier. This cathodic protection works by sending a controlled DC current to a surface that is submerged in water with the aid of a zinc electrode and a combined metal oxide anode. Electric current flow will continue to be monitored by the ICCP system in order to help prevent corrosion before it occurs.

When cathodic is on a coated surface, the potential on the surface will decrease. The object is electrically connected to the object that is electrically connected to the rectifier system, so that it can shut the electricity network. The advantage of the impressed current cathodic protection is in its usage of galvanic cathodic which is cathodic protection current is better compared to other protection materials. Anode used as protection will get current from ICCP so that anode used in protection will tend to have a longer active period.

Principally, the impressed current cathodic protection system is the same as the sacrificial anode, only the demand for electron current is supplied from outside the system which is from the anode that is connected to a DC current source. [6].

2.3.2.1 Components of ICCP

Impressed Current Cathodic Protection system consists of 4 main components. Basically, these components are the same as the components in a sacrificial anode cathodic protection system. Principally, this protection system is only manipulating the natural processes that occur in metals when it is in contact with the environment that can cause corrosion, so that the system can control corrosion. The four main components of impressed current cathodic protection system are;

a. Anode

Anode used here is usually inert and has a high resistance to corrosion. The shape and size are various, it can be in the form of wire, tube, plate, bar, and plate. The ideal criteria for anodes according to Shreir and Hayfield are those that have low consumption rates, low polarization rates, high electrical conductivity, ease of installation, are physically strong, so they are not easily damaged, resistant to abrasion and erosion, easily formed, and low costs.

b. Cathode

Cathode component referred to here is the metal that is to be protected. The metal is made to act as a cathode so that the potential is in an immune area that is resistant to corrosion. In the impressed current cathodic protection system/ICCP, the metal which is made into a cathode is called a working electrode. Cathode can be made from materials such as iron, steel or alloy metal.

c. Electrolytes

Electrolytes here act as electrical lines which are the medium to transfer electron. Due to the ion contents, electrolytes become corrosive. Electrolytes are contained in the soil with a certain depth and sea water, so that when a metal without protection is in the environment then the metal will be corroded.

d. Current Source

A DC current source is a direct current power source (Direct Current), which is usually in the form of transformer-rectifier. This equipment uses alternating current / AC (Alternating Current) as its main source of electricity and converts it into direct current, so this equipment is widely used as an energy

source (Power Supply) in providing DC voltage and current. To complete the electrical circuit in the ICCP system, the positive terminal power supply is connected to the anode while the negative terminal is connected to the cathode, so the DC current will flow from the power supply to the anode through the electrolyte until it reaches the cathode and finally back to the power supply.

2.4. Current Protection Needs

Before calculating the need for sacrificial anodes, protection currents are required. The data required in the calculation of hull protection using a sacrificial anode are; The size of the hull plate area to be protected, the seawater resistivity using the reference to DNV RPB 401 concerning the resistivity at which the water temperature, the lifetime of protection needs on large objects for such as the hull will require a detailed cathodic protection design with the design concept of cathodic protection. Before doing cathodic protection, protection current is needed. Calculation of the need for current protection refers to the DNV-RP-B401 rules regarding the design of cathodic protection. [2].

$$I_c = A_c \cdot f_c \cdot i_c \quad [2.3]$$

If the area in the area to be protected (A_c) is multiplied by the current density design (i_c), and the coating breakdown factor (f_c), then the current request (I_c) will be obtained. While the area to be protected can be obtained using the formula :

$$A_c = (2T + B) \times Lbp \times p \quad [2.4]$$

The data required in the calculation of hull protection using a sacrificial anode are; The size of the hull plate area to be protected, seawater resistivity using the reference to DNV RPB 401 concerning resistivity where the water temperature, protection life, coating breakdown factor (Subsea Engineering Handbook), and current density. To calculate the need for protection current obtained from Ohm's law

$$I_c = N \cdot I_a = \frac{N(E_c^\circ - E_a^\circ)}{R_a} = \frac{N \cdot \Delta E^\circ}{R_a} \quad [2.5]$$

To calculate the need for current out of the sacrificial anode, the formula of the ohm law is used [2]. Where the potential protection design is reduced the closed-circuit design potential is divided by the anode resistance

$$I_s = \frac{E^{\circ} c - E^{\circ} a}{R_a} \quad [2.6]$$

Anode closed circuit potential is based on the potential closed-circuit table of anode for Al and Zn based on sacrificial anode [2].

Tabel 2.5.1 Closed-circuit potential of anode for Al and Zn [2].

Macam Material Anoda	Lingkungan	Sirkuit Tertutup Anoda Potensial
Al	Air Laut	-1,05
	Endapan	-0,95
Zn	Air Laut	-1,00
	Endapan	-0,95

2.5. Sacrificial Anode Needs

After obtaining the amount of protection current needs, the calculation of the sacrificial anode needs to be done on the ship by calculating the weight needs of the sacrificial anode using the following equation [1].

$$M = \frac{I_c \cdot T \cdot 8760}{\mu \cdot \epsilon} \quad [2.7]$$

Whereas the need for protection current (I_c) is multiplied by the protection life (T) which refers to the BKI regulation, then divided by the sacrificial anode use factor (μ) and electrochemical efficiency (ϵ). Electrochemical efficiency is based on the electrochemical efficiency table of the sacrificial anode used in calculating the required sacrificial anode weight [4].

Tabel 2.6.1 Electrochemical Efficiency [4]

Elemen	Electrochemical Efficiency (Ah/kg)
Al	2000
Zn	700

But according to the Biro Klasifikasi Indonesia in Regulation for the Corrosion Protection and Coating, the most recommended anode to be used on ships is the zinc sacrificial anode [4].

Tabel 2.6.2 Zinc sacrificial anode on seawater media applications [4].

Elemen	KI- Zn1	KI- Zn1
Al	0,100 - 0,500	$\leq 0,0100$
Cd	0,025 - 0,070	$\leq 0,0040$
Cu	$\leq 0,005$	$\leq 0,0050$
Fe	$\leq 0,005$	$\leq 0,0014$
Pb	$\leq 0,006$	$\leq 0,0060$
Zn	$> 99,22$	$\leq 99,880$
Potential (T=20°C)	-1,03 Volt Ag/AgCl/See	-1,03 Volt Ag/AgCl/See
Qg (T=20°C)	780 Ah/kg	780 Ah/kg
Efficiency (T=20°C)	95%	95%

2.6. Microcontroller

Microcontroller is a chip which functions as an electronic circuit controller and generally can store programs in it. Microcontroller is a chip that functions as an electronic circuit controller and generally can store programs in general consisting of CPU (Central Processing Unit), memory, certain I/O and supporting units such as Analog-to-Digital Converter (ADC) that has been integrated in it. The main advantage of the microcontroller is the availability of RAM and supporting I/O equipment so that the size of the microcontroller board is very concise. Almost all equipment related to our activities all have a microcontroller, for example: Mobile Phone which used for communication, LCD screens, cars, motorcycles, digital cameras and many other equipment.

Basically, a microcontroller is a device that integrates a number of components of a microprocessor system into a single microchip. There are three main components of a microcontroller, including: CPU processor, memory and input/output (I/O).

2.6.1. Arduino

Arduino is an open source microcontroller. The hardware on the microcontroller is programmed using a wiring-based programming language based on syntax and library. To facilitate the development of its applications, Arduino microcontrollers use Integrated Development (IDE) based processing [2]. Arduino can be paired with various types of actuators and other sensors, such as mechanical sensors, ultrasonic sensors, heat sensors, light sensors, Ethernet Shield, Led Display, and others (Ade Pramono, 2012). Arduino Uno can load all the components needed to support a microcontroller. Arduino Uno can work only by connecting to a computer via USB or by providing DC voltage from a battery or AC to DC adapter.



Figure 2.4 Arduino Uno

2.7. Sensor

Sensor is a device that has an important role in an automatic control system. The quantities of the control system such as electric quantities, physical quantities, and so on. To use electric quantities in a control system, usually quantities that are not electric quantities will first be converted into an electrical signal through a device called a transducer. The sensor is a tool that serves to detect symptoms or signals that come from the changes in energy. Examples include electrical energy, physical energy, chemical energy, mechanical energy, and others.

Generally, sensors are divided into 3 types based on their function and usage, which are ;

a. Mechanical Sensor

Mechanical sensor is a type of sensor that detects changes in mechanical motion, such as displacement or shift in position, pressure, flow, level, position of straight and circular motion, and so on. Examples of mechanical sensors are strain guage, LVDT, proximit, potentiometer, load cell, bourdon tube, etc.

b. Optical Sensor

Optical sensor is a sensor that detects changes in light found in the light source, refractive light that affects objects or rooms, and reflected light. Examples of optical sensors are photo cell, photo transistor, photo diode, photo voltaic, photo multiplier, optical pyrometer, etc.

c. Thermal Sensor

Thermal sensor is a sensor that is used to detect those related to the symptoms of temperature changes in a certain dimension of space or an object space. Examples of thermal sensors are bimetallic, thermistor, thermocouple, RTD, infrared pyrometer, hygrometer, etc.

2.7.1. Water Sensor



Figure 2.5 Water Sensor

Water sensor brick is designed for water detection, which can be widely used in sensing rainfall, water level, and even liquid leakage. Connecting a water sensor to an Arduino is a great way to detect a leak, spill, flood, rain, etc. It can be used to detect the presence, the level, the volume and/or the absence of water. While this could be used to remind you to water your plants, there is a better Grove sensor for that. The sensor has an array of exposed traces, which read LOW when water is detected.

2.7.2. Current Sensor



Figure 2.6 Current Sensor

Current Sensor can measure high or low side DC current, the bus voltage, and have it automatically calculate the power. It can do so over impressive voltage, current, and temperature ranges with better than 1% accuracy, all while delivering the data in an easy to use format over I2C.

Works great with any microcontroller that is CircuitPython or Arduino compatible as well as single board computers such as the Raspberry Pi. It is compatible with 3V or 5V logic and can measure bus voltages up to +36VDC. Not for use with AC voltages.

2.8. Actuator

Actuator is a moving device. Actuator is the output part that converts supply energy into work energy which will then be utilized. The output signal will be controlled by the control system, then the actuator will be responsible for the control signal through the final control element. The other type of output section is used to indicate the control status of the system or actuator (Dentha, 2013). An actuator is a device that converts electrical signals into mechanical motion. Actuators are usually used as a continuation of the process data output generated by the controller [8].

2.8.1. MOSFET



Figure 2.7 MOSFET

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device that is widely used as a switch and as a signal amplifier on electronic devices. MOSFET is the core of an IC (integrated circuit) that is designed and fabricated with a single chip because of its very small size. MOSFET has four terminal gates including Source (S), Gate (G), and Drain (D). (Rahmadi, 2014). MOSFETs work electronically varying along the path of the charge carrier (electron or hole). Electric charges enter through the Channels at the Source and exit through the Drain. The width of the channel is controlled by the voltage at the electrode which is called the Gate or gate that is located between the Source and Drain. it is isolated from channels near the very thin layer of metal oxide. MOS capacity is the main part component of MOSFET.

MOSFET functions to control Voltage and Current through between Source and Drain. This component is almost entirely as a switch. MOSFET work depends on the MOS capacity. MOS capacity is a major part of MOSFET. Semiconductor surface in the oxide layer below which lies between the source terminal and the drain. This can be reversed from p-type to n-type by applying positive or negative gate voltages, respectively. When we apply a positive gate voltage, the hole under the oxide layer with disgusting force and load is pushed down with the substrate.

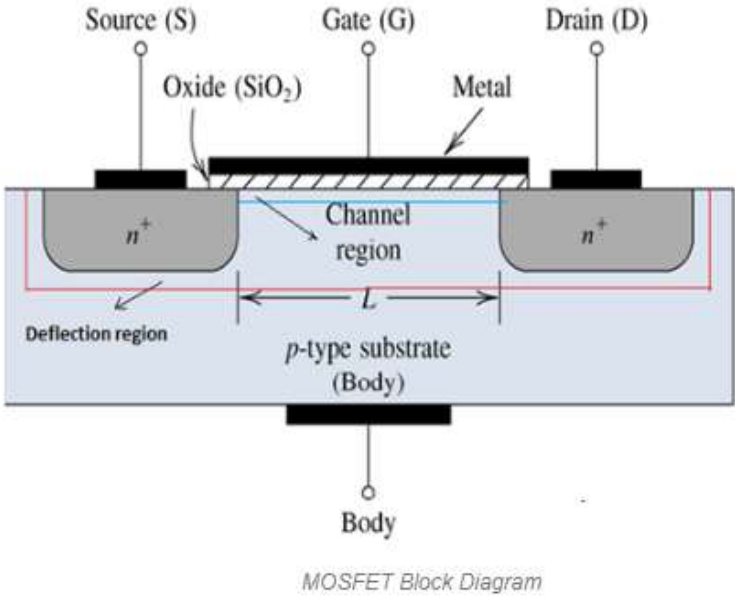


Figure 2.8 MOSFET Block Diagram

2.9. Ground Step Down



Figure 2.9 Ground Step Down

LM2596 stepdown module is a module that has LM2596 IC as it's main component. LM2596 IC is an integrated circuit that functions as a Step-Down DC converter with a current rating of 3A. There are several variants of this IC series which can be grouped into 2 types. The first one is the adjustable version, whose output voltage can be regulated. The other one is fixed voltage output version whose output voltage is fixed.

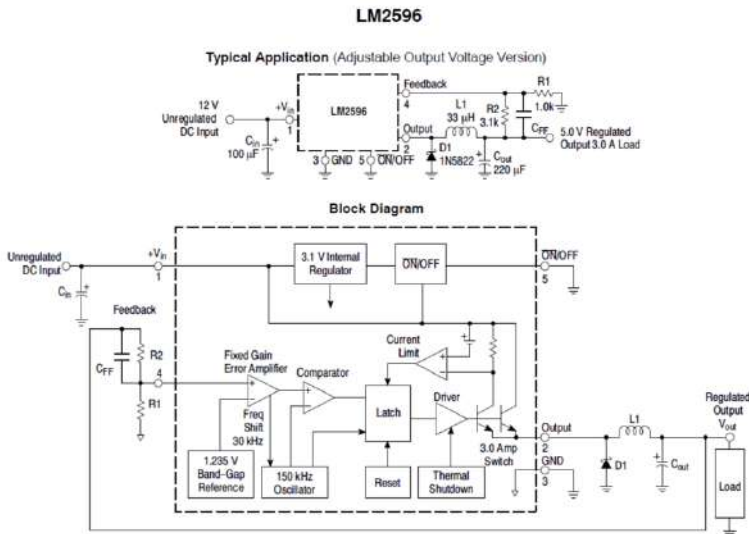


Figure 2.10 Ground Step Down Block Diagram

2.10. Bluetooth HC-05



Figure 2.11 Bluetooth HC-05

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. HC-05 Bluetooth Module can be used in a Master or Slave configuration, making it a great solution for wireless communication. This serial port bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature) [10].

2.11. Power Supply



Figure 2.12 Power Supply

Almost all electronic circuit require a regular DC voltage source to operate. This supply can be done directly by the battery, but more generally the power supply is obtained from a standard AC source which is the converted to a DC voltage.

2.11.1. Battery



Figure 2.13 Battery

(Battery) are energy source that can convert the stored chemical energy into electrical energy that can be used like electronic devices. The battery consists of a cathode, anode, and electrolyte. The output electric current from the battery is direct current (DC). Batteries consist of 2 main type. The first one is primary batteries that can only be used once (single use battery). The second one is secondary batteries that can be recharged (rechargeable batteries).

2.12. Android



Figure 2.14 Android

Android is an operating system for Linux-based mobile devices which includes an operating system, middleware, and applications. There are two types of distributors on the Android operating system. The first one comes with full support from Google or Google Mail Services (GSM) and the other one is free without direct support from Google which also known as Open Handset Distribution (OHD). Android is an open source operating system so it can be distributed and used by any vendor. At present there are already many smartphone vendors producing Android-based smartphones, such as Samsung, Sony, Oppo, Vivo, LG, and many more. Android applications are developed in the Java programming language using the Android software development kit (SDK). The SDK consists of a set of development tools, including a debugger, software library, QEMU-based handset emulator, documentation, sample code, and tutorials. Officially supported by the Eclipse Integrated Development Environment (IDE), which uses the Android Development Tools (ADT) plugin. Other development

tools available include the Native Development Kit for applications or extensions in C or C ++, Google App Inventor, a visual environment for novice programmers, and various cross-platform mobile web application frameworks.

2.13 ArduTooth

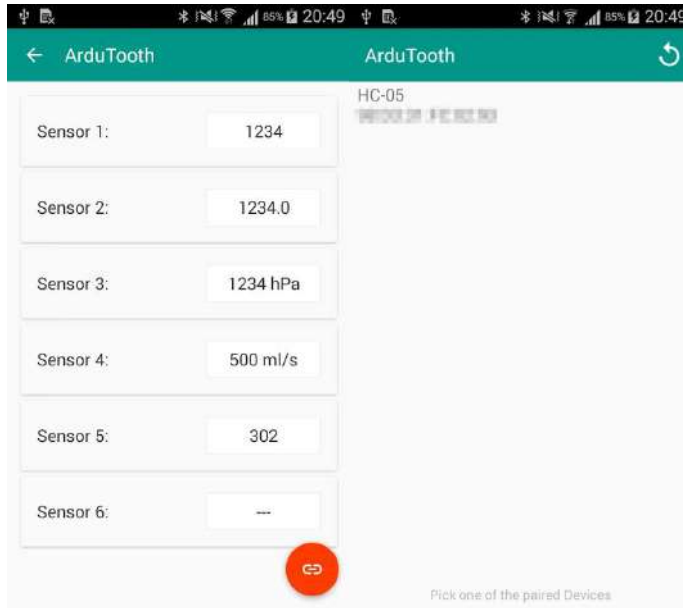


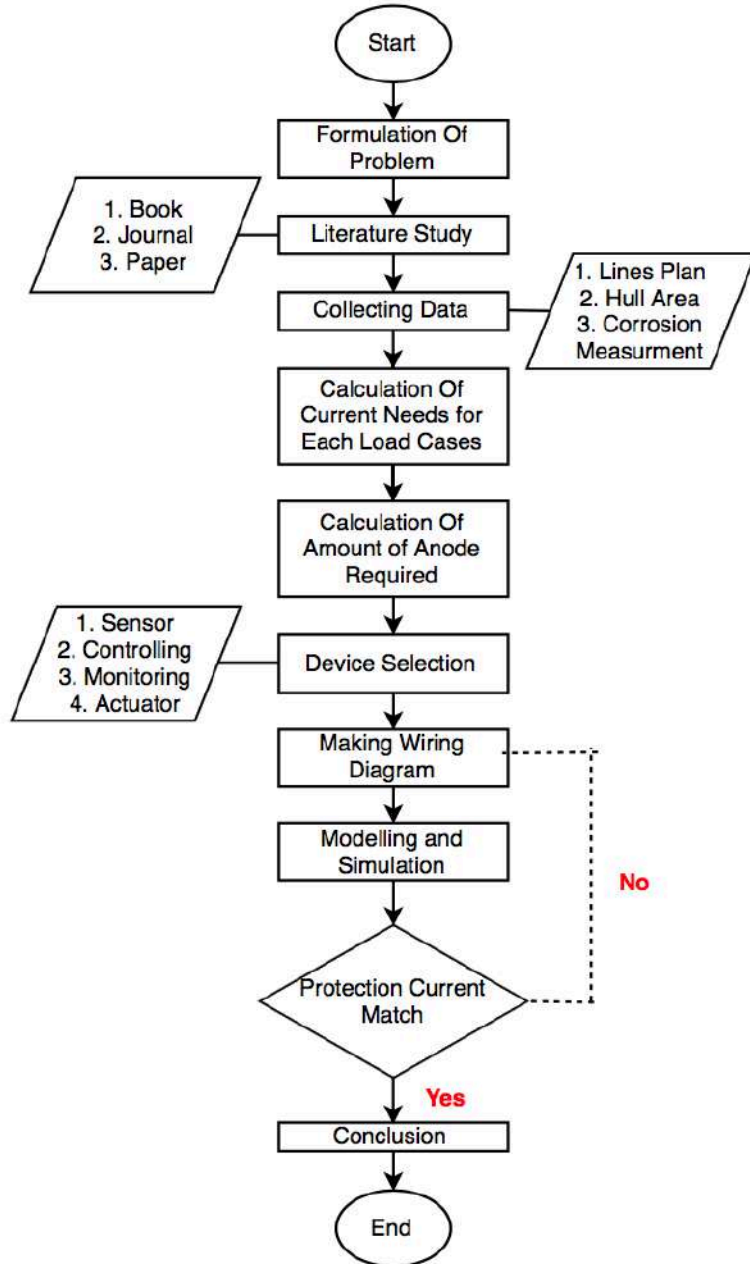
Figure 2.15 ArduTooth

ArduTooth is an application on Android, which functions as an Arduino monitor. This application is written for visualizing measurement data from a microcontroller via Bluetooth. Before starting this application, the Bluetooth device has to be coupled to the smartphone. In the special case of the HC-05 the default PinCode for coupling process is 1234 or 0000.

CHAPTER III

METHODOLOGY

3.1. Methodology Flow Chart



3.2. Formulation of Problem

The first step is to identify the problem that will be examined, and then formulate the problem to be used as an object of research. The problem that will be raised in this thesis is how to install the controlling system design and ICCP current monitoring with Arduino Uno-based microcontroller to make efficient use of electricity in ship generators.

3.3. Literature Study

The purpose of a literature review is to summarize the basic theories and supporting information that will be discussed and then become the basis of this research. This literature review is carried out by summarizing reference sources related to this research. This literature review is obtained from books, journals, papers, and others.

3.4. Data Collection

This stage is carried out in parallel with the literature review. This stage is the process of collecting data and technical information related to the problem object that serves as a basis for research. Data collected at this stage include ship's lines plan, immersed surface area of the hull (Wetted Surface Area) which vary on each load case, and calculation of corrosion rate on ship.

3.5. Calculation of Current Needs for Each Load Cases

After getting the corrosion rate calculation data on the ship, the next step is to calculate the need of protection current for Impressed Current Cathodic Protection (ICCP). In this study there is a problem limitation for calculating the surface area of submerged vessels which is only divided into 3 load cases. Therefore, the calculation of protection current requirements is only limited when the condition of the ship is full, the condition of the ship is in a half load, and the condition of the ship is empty.

3.6. Calculation of Amount of Anode Required

After getting the results of the calculation of current requirements in each load case. Furthermore, the number of anode requirements in the ICCP protection system is calculated by calculating the anode weight requirements on the ship. After the weight of the anode is obtained, it is then divided by the weight of each anode. Next is to get the number of sacrificial anode needs on ship, which will then be added by 20% as a critical place factor.

3.7. Device Selection

Electronic devices selection serves to determine what electronic components will be used in the manufacture of controlling and monitoring system designs for ICCP, along with their types. The electronic devices include, the selection of sensor types, the selection of devices as tools for controlling, the choice of software and electronic devices for monitoring, as well as the selection of actuators to drive the design of controlling and monitoring systems at ICCP.

The estimated tools and materials that will be used in this thesis include:

a. FSO Vessel Prototype

The vessel prototype that will be used as dynamic positioning system model and will be tested is FSO type vessel. Following is ship's dimensions that will be used

Table 3.7.1 Ship Data

Parameter	Real Ship
LPP	171 m
LOA	172,25 m
Breadth	32,2 m
Depth	18,8 m
Draft (Full Load)	12,1 m
----- Half Load	10,082 m
----- Ballast Load	7,147 m
Deadweight	45,789 ton

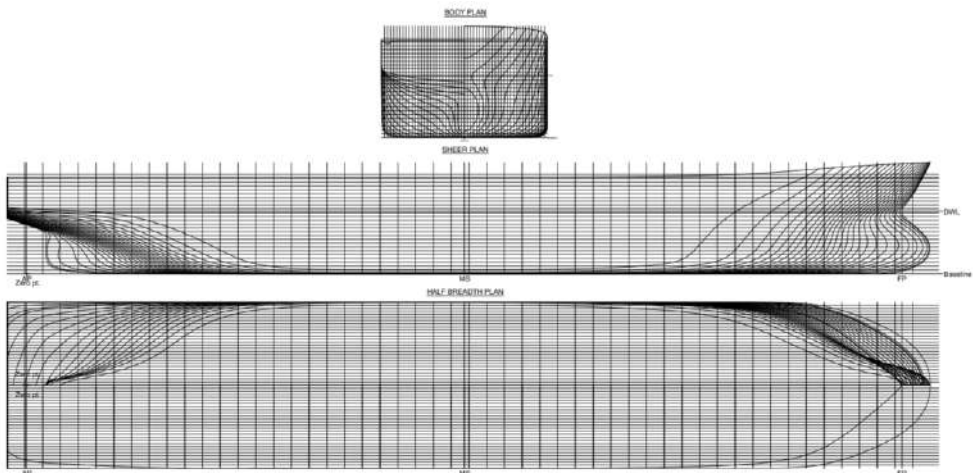


Figure 3.1 Lines Plan

b. Microcontroller Arduino



Figure 3.2 Arduino Uno

In this final project, Arduino Uno microcontroller is used. Arduino is a microcontroller that serves to detect and receive data from the reading of the Water Level sensor. Then Arduino will process the data and send commands to the SCR Transistor to regulate the current that will be issued by the ICCP power source (Generator).

c. Water Sensor



Figure 3.3 Water Sensor

In this final project the sensor used is the water level sensor. Water Level Sensor is a sensor that is cheap and easy to use. This sensor consists of a number of lines arranged in parallel to determine the height of the water surface. The conversion value of water level to the analog signal generated can be directly read on the Arduino board

d. MOSFET

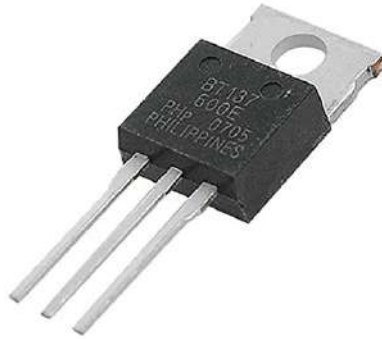


Figure 3.4 MOSFET

MOSFET has four terminal gates including source (S), Gate (G), Drain (D), and Body (B). MOSFET work electronically varying along the path of the charge carrier (electron or hole). MOSFET has functions to control voltage and current through between source and drain. This component is almost entirely as a switch.

In this final project the SCR acts as a drive system and is used to control the output current of the Power Supply in accordance with the appropriate amount ordered by the control system (Arduino).

e. Batteries



Figure 3.5 Batteries

In this final project. The power supply that will be used is Batteries. With batteries, there is no need to connect the power

source cord to the terminal to be able to active our electronic devices so it can be easily carried.

f. Jumper Wire



Figure 3.6 Jumper Wire

Jumper wire is used to connect components as electric current conductor.

g. Current Sensor



Figure 3.7 Current Sensor

In this final project, the current sensor is used to receive data signals sent from the water sensor. The current sensor is used to detect the current requirements needed in each load case.

h. Ground Step Down



Figure 3.8 Ground Step Down

In this final project, the ground step down serves to reduce the voltage from the power supply from 12 Volts to 5V. Because to turn on Arduino only requires a voltage of 5V.

i. LED



Figure 3.9 LED

LED are used as a marker of the amount of current released in each load case. The greater current needed, the more light levels will be brighter. Vice versa.

3.8. Making Wiring Diagram

Making wiring diagrams is done to make a simple working picture/diagram illustrating the wiring and maintenance circuit on electronic equipment using symbols in simplified form. Wiring diagrams can be likened to a map showing the function of electronic equipment and its constituent components which are connected as an electronic circuit. Wiring diagrams also function as indicators of current flow in electronic circuits.

3.9. Simulation Model Making

There are several ways that can be done to design, analyze, and operate a system. One of them can be done by making a model of the system. The model can be defined as a logical description of how a system works. By making a simulation model of a system, analyzing can be done more easily.

The simulation process for controlling design and monitoring at ICCP is carried out using software for Arduino Uno. Software simulation is done by inputting the flow of protection needs on ship in each load case, to see whether the mathematical calculations are appropriate or not.

3.10. Current Protection Match

After going through the software simulation stage, the protection current will be obtained according to the extent of the WSA that will be protected in each load case. If it is suitable, it will proceed to the next stage. If the protection current is not suitable or fails; it will return to the wiring stage. Did an error occur in the process of making the wiring diagram design, so that the current could not protect the entire hull that was immersed.

3.11. Conclusion

The final step of research for this final project is to draw conclusions from the entire process that has been carried out, along with providing answers to some existing problems. Then proceed with giving recommendation based on the results of this study, which will then be used as a basis for further research, both directly related to this thesis and data and methodology that will be used as reference materials.

CHAPTER IV

RESULT AND DISCUSSION

4.1 Calculation of the Corrosion Rate

4.1.1 Wetted Surface Area

Before calculating the corrosion rate, it is necessary to find the wetted surface area in each load case. To find the area in each load case, Maxsurf application can be used by entering the DWT in each load case.

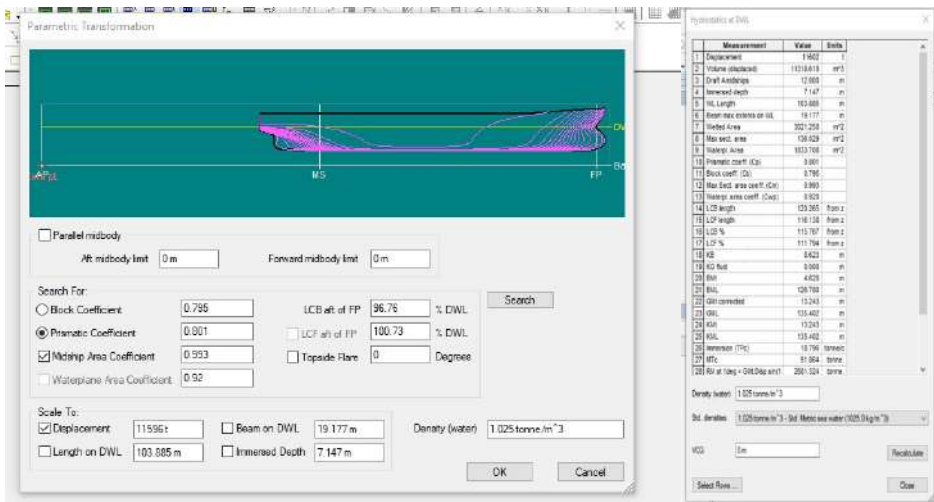


Figure 4.1 Maxsurf Calculation for Ballast Load

Table 4.1.1.1 Wetted Surface Area Ballast Load

Draft	7,147	m
Displacement Full Load	55,453	ton
DWT	45,789	ton
Displacement (Ballast Load)	11,5968	ton
Wetted Area	3021,25	m ²

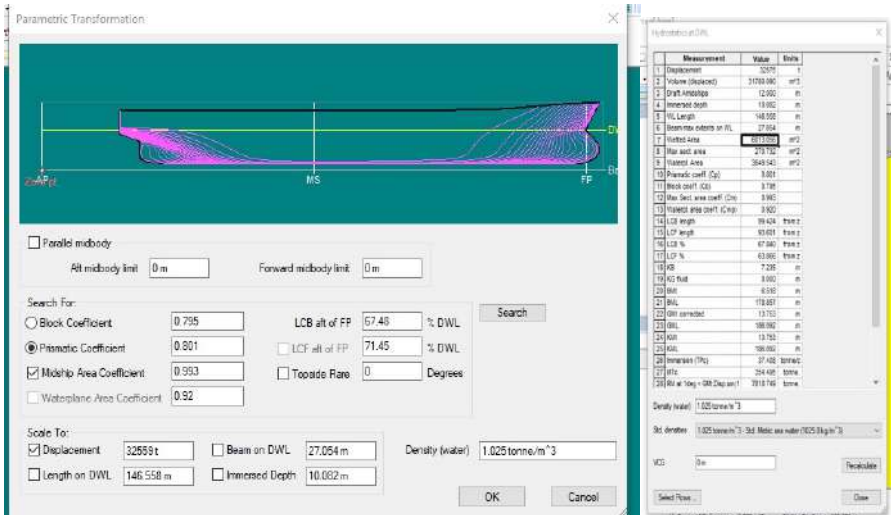


Figure 4.2 Maxsurf Calculation for Half Load

Table 4.1.1.2 Wetted Surface Area Half Load

Draft	10,082	m
Displacement Full Load	32,5585	ton
Wetted Area	6013,056	m ²

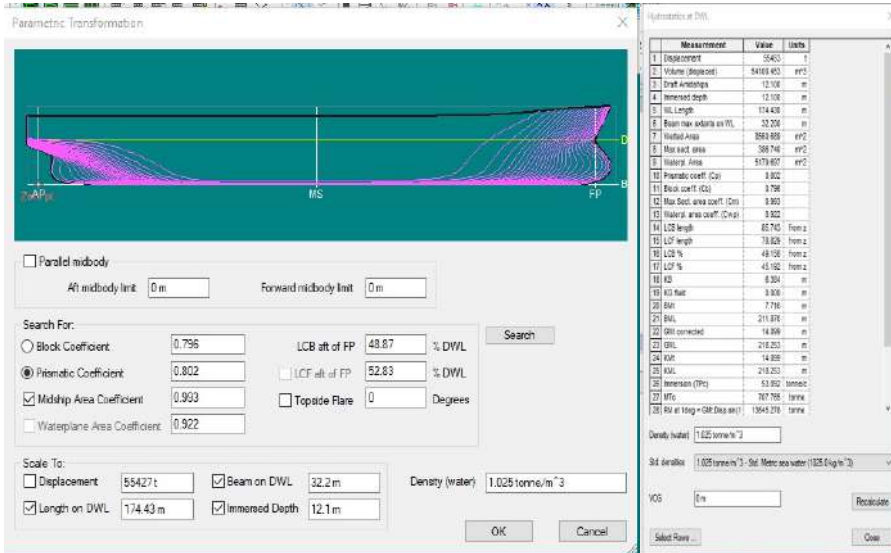


Figure 4.3 Maxsurf Calculation for Full Load

Table 4.1.1.3 Wetted Surface Area Full Load

Draft	12,100	m
Displacement Full Load	55,453	ton
DWT	45,789	ton
Wetted Area	8560,689	m^2

After getting the wetted surface area in each load case, the results of these areas are then scaled to be applicable in the ship modeling system. For the scale used in this thesis is 1: 175.

Table 4.1.1.4 Wetted Surface Area Ballast Load (Scaled)

Draft	0,715	m
Displacement Full Load	5,5453	ton
DWT	4,5789	ton
Displacement (Ballast Load)	1,15968	ton
Wetted Area	302,125	m^2

Table 4.1.1.5 Wetted Surface Area Half Load (Scaled)

Draft	1,008	m
Displacement Full Load	3,25585	ton
Wetted Area	601,3056	m^2

Table 4.1.1.6 Wetted Surface Area Full Load (Scaled)

Draft	1,210	m
Displacement Full Load	5,5453	ton
DWT	4,5789	ton
Wetted Area	856,0689	m^2

4.1.2 Assumptions of the Corroded Mass

Caused by the data of the mass that is corroded every year is not available, an assumption is made for the corroded steel plate mass. Assumptions are made by referring to the corroded mass data of other ships of the same type. Then from these data the average annual reduction in the mass of the steel plate can be known (in percent).

Table 4.1.2.1 Data Reference of the Corroded Mass

STRAKE POSITION PLATE POSITION	'F' STRAKE															Max. Allow. Dimin. mm.		
	No. or Letter	Org. Thk. mm.	Forward Reading						Aft Reading						Mean Dimin.			
			Gauged		Diminution P		Diminution S		Gauged		Diminution P		Diminution S		%			
			P	S	mm	%	mm	%	P	S	mm	%	mm	%	P		S	
7th	F1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8th	F2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5th	F3-1	18.0	17.8	17.8	0.2	1.1	0.2	1.1	17.8	17.7	0.2	1.1	0.3	1.7	1.1	1.4	4.5	
4th	F4	18.0	17.8	17.8	0.2	1.1	0.4	2.2	17.9	17.7	0.1	0.6	0.3	1.7	0.8	1.9	4.5	
3rd	F5	18.0	18.0	17.4	0.0	0.0	0.6	3.3	17.9	17.8	0.1	0.6	0.2	1.1	0.5	2.2	4.5	
2nd	F6	18.0	18.0	17.8	0.0	0.0	0.2	1.1	17.7	18.0	0.3	1.7	0.0	0.0	0.8	0.6	4.5	
1st Fwd	F7	18.0	17.8	17.7	0.2	1.1	0.3	1.7	17.9	17.6	0.1	0.6	0.4	2.2	0.8	1.9	4.5	
Amidship	F8	18.0	17.8	17.7	0.2	1.1	0.3	1.7	17.8	17.6	0.2	1.1	0.4	2.2	1.1	1.9	4.5	
1st Aft	F9	18.0	17.9	17.8	0.1	0.6	0.2	1.1	17.9	17.8	0.1	0.6	0.2	1.1	0.6	1.1	4.5	
2nd	F10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
3rd	F11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
4th	F12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5th	F13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6th	F14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
7th	F15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Referred to corroded mass data belonging to other ships, the average annual reduction in the mass of the steel plate can be assumed to be 2.5%. Then the corroded mass is assumed for 3 years according to the age of corrosion protection that refers to BKI [4].

1. Initial plate weight (55,453 - 45,789) ton = 9,664 ton = 9.664.000 gram
2. Assumptions of Corroded mass = 9.664.000 gram x 2.5 % = 241.600 gram/ year 1
3. 9.664.000 gram – 241.600 = 9.442.400 x 2.5 % = 235.560 gram / year 2
4. 9.442.400 - 235.560 = 9.206.850 x 2.5% = 229.671 gram / year

Then the result of the assumption of the difference in plate weight for 3 years based on the original area of the ship is 706,831 grams. As for the calculation of the difference in plate weight assumptions, the scale is as follows:

1. Initial plate weight = 55.222,8571 gram
2. Assumptions of Corroded mass = 55.222 gram x 2.5 % = 1380,57 gram/ year 1
3. 55.222 gram – 1380,57 = 53.842,28 x 2.5 % = 1346 gram / year 2
4. 53.842,28 gram - 1346 gram = 52.496,22 x 2.5% = 1312,4 gram / year 3

Then the result of the assumptions of the difference in plate weight for 3 years based on scaled area of the ship is 4.039 grams.

4.1.3 Corrosion Rate

The rate of corrosion in corrosion prevention must be taken into account to estimate the time of anode replacement. Corrosion rate can be expressed by the rate of loss of metal in units of volume and units per year in surface area. To calculate the corrosion rate of a ship, it can be stated as follows [7].

$$CR = \frac{K \times W}{A \times D \times T}$$

- CR = Corrosion Rate
- K = Constanta = 87.600
- W = Difference of initial and final weight
- A = Wetted Surface Area
- D = steel plate density
- T = age of protection

Based on the formula above the corrosion rate can be calculated as follows:

a. Ballast Load Condition

K	87600
W	706831 gram
A	3021250 cm^2
T	26280 hour
D	7,85 $gram/cm^2$

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{3021250 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

$$CR = 0,09934317 \text{ mm/year}$$

b. Half Load Condition

K	87600
W	706831 gram
A	6013056 cm^2
T	26280 hour
D	7,85 $gram/cm^2$

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{6013056 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

$$CR = 0,04991481 \text{ mm/year}$$

c. Full Load

K	87600
W	706831 gram
A	8560689 cm^2
T	26280 hour
D	7,85 $gram/cm^2$

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{8560689 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

$$CR=0,03506033 \text{ mm/year}$$

d. Ballast Load Condition (Scaled)

K	87600
W	4039,03429 gram
A	17264,2857 cm^2
T	26280 hour
D	7,85 gram /cm^2

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{3021250 \text{ cm}^2 \times 7,85 \text{ gram /cm}^2 \times 26280 \text{ h}}$$

$$CR = 0,09934 \text{ mm/year}$$

e. Half Load Condition (Scaled)

K	87600
W	4039,03429 gram
A	34360,32 cm^2
T	26280 hour
D	7,85 gram /cm^2

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{6013056 \text{ cm}^2 \times 7,85 \text{ gram /cm}^2 \times 26280 \text{ h}}$$

$$CR = 0,04991481 \text{ mm/year}$$

f. Full Load Condition (Scaled)

K	87600
W	4039,03429 gram
A	48918,2229 cm^2
T	26280 hour
D	7,85 gram /cm^2

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{8560689 \text{ cm}^2 \times 7,85 \text{ gram /cm}^2 \times 26280 \text{ h}}$$

$$CR = 0,03506033 \text{ mm/year}$$

4.2 Calculation of Current Needs

The data needed to calculate the need of current protection is; cathode surface area, coating breakdown factor and average current density. The average current density is 0.100/m² [5] .

4.2.1 Cathode Surface Area

To get the cathode surface area, it can be calculated using the following formula [5].

$$Ac = \{(2T)+B\} \times Lpp \times \rho$$

T = Ship's draft

B = Ship's breath

Lpp = Length per pendicular

ρ = efficiency factor based on ship's type

a. Ballast Load

T	7,147 m
B	32,2 m
Lpp	171 m
ρ	0,7

$$Ac = [(2T)+B] \times Lpp \times \rho$$

$$Ac = [(2 \times 7,147)+32,2] \times 171 \times 0,7$$

$$Ac = 5565,3318 \text{ m}^2$$

b. Half Load

T	10,082 m
B	32,2 m
Lpp	171 m
ρ	0,7

$$Ac = [(2T)+B] \times Lpp \times \rho$$

$$Ac = [(2 \times 10,082)+32,2] \times 171 \times 0,7$$

$$Ac = 6267,9708 \text{ m}^2$$

c. Full Load

T	12,1 m
B	32,2 m
Lpp	171 m
ρ	0,7

$$Ac = [(2T)+B] \times Lpp \times \rho$$

$$Ac = [(2 \times 12,1)+32,2] \times 171 \times 0,7$$

$$Ac = 6751,08 \text{ m}^2$$

d. Ballast Load (Scaled)

T	0,7147 m
B	3,22 m
Lpp	17,1 m
ρ	0,7

$$Ac = [(2T)+B) \times Lpp \times \rho$$

$$Ac = [(2 \times 0,7147)+3,22) \times 17,1 \times 0,7$$

$$Ac = 55,653318 \text{ m}^2$$

e. Half Load (Scaled)

T	1,0082 m
B	3,22 m
Lpp	17,1 m
ρ	0,7

$$Ac = [(2T)+B) \times Lpp \times \rho$$

$$Ac = [(2 \times 1,0082)+3,22) \times 17,1 \times 0,7$$

$$Ac = 62,679708 \text{ m}^2$$

f. Full Load (Scaled)

T	1,21 m
B	3,22 m
Lpp	17,1 m
ρ	0,7

$$Ac = [(2T)+B) \times Lpp \times \rho$$

$$Ac = [(2 \times 1,21)+3,22) \times 17,1 \times 0,7$$

$$Ac = 67,5108 \text{ m}^2$$

4.2.2 Coating Breakdown Factor

The coating breakdown factor is a function of coating properties, operation parameters and time. The coating breakdown factor describes the extent of current density reduction due to the application of a coating. As a simple engineering, coating breakdown factor can be expressed as :

$$fc = (K_1 + K_2) \times t$$

Where t (years) is the coating lifetime and K_1 and K_2 are constants that are dependent on coating properties and the environment. Four paint coating categories have been defined for practical use based on the coating properties in DNV [1].

Table 4.2.2.1 DNV Coating Categories

Depth (m)	Coating Category			
	I	II	III	IV
	$k_1 = 0.1$	$k_1 = 0.05$	$k_1 = 0.02$	$k_1 = 0.02$
	k_2	k_2	k_2	k_2
0–30	0.1	0.03	0.015	0.012
>30	0.05	0.02	0.012	0.012

To determine the coating category for FSO vessels, references from ISO 8501-1 to assume the largest minimum DFT are used.

Table 4.2.2.2 Coating System for Cargo Tanks

Surface Preparation	Coating System	Minimum DFT	Number of stripe coats
ISO 8501-1 Sa 2½	Epoxy primer Epoxy undercoat Epoxy finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy phenolic primer Epoxy phenolic undercoat Epoxy phenolic finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy isocyanate primer Epoxy isocyanate undercoat Epoxy isocyanate finish	90 microns 90 microns 90 microns	2
ISO 8501-1 Sa 2½	Zinc silicate	80 microns	1
ISO 8501-1 Sa 2½	Cyclosilicon epoxy Cyclosilicon epoxy	150 microns 150 microns	1-2

Based on reference ,coating category for FSO is coating category II (Depth < 30m).So the calculation for coating breakdown of FSO can be expressed as :

K1	0,05
K2	0,03

$$fc = (0,05 + 0,03) \times 3$$

$$fc = 0,24$$

4.2.3 Current Demand

To calculate the current demand, to provide adequate polarizing capacity and to maintain cathodic protection during the design life, the individual surface areas, of each CP unit shall be calculated according to subdivision of CP project and multiplied by the relevant design current density and the coating coating breakdown factor [1]. Current demand can be expressed as :

$$I_c = A_c \cdot i_c \cdot fc$$

The following are the results of the calculation of the need for protection current in each load case :

a. Ballast Load

ic	0,1 A/m ²
Ac	5565,3318 m ²
fc	0,24

$$I_c = ic \cdot Ac \cdot fc$$

$$I_c = 0,1 \times 5565,3318 \times 0,24$$

$$I_c = 87,067963 \text{ Ampere}$$

b. Half Load

ic	0,1 A/m ²
Ac	6267,9708 m ²
fc	0,24

$$I_c = ic \cdot Ac \cdot fc$$

$$I_c = 0,1 \times 6267,9708 \times 0,24$$

$$I_c = 115,431299 \text{ Ampere}$$

c. Full Load

ic	0,1 A/m ²
Ac	6751,08 m ²
fc	0,24

$$I_c = ic \cdot Ac \cdot fc$$

$$I_c = 0,1 \times 6751,08 \times 0,24$$

$$I_c = 162,02592 \text{ Ampere}$$

d. Ballast Load (Scaled)

ic	0,1 A/m ²
Ac	55,653318 m ²
fc	0,24

$$I_c = ic \cdot Ac \cdot fc$$

$$I_c = 0,1 \times 55,653318 \times 0,24$$

$$I_c = 0,8706796 \text{ Ampere}$$

e. Half Load (Scaled)

ic	0,1 A/m ²
Ac	62,679708 m ²
fc	0,24

$$I_c = i_c \cdot A_c \cdot f_c$$

$$I_c = 0,1 \times 62,679708 \times 0,24$$

$$I_c = 1,154313 \text{ Ampere}$$

f. Full Load (Scaled)

ic	0,1 A/m ²
Ac	67,5108 m ²
fc	0,24

$$I_c = i_c \cdot A_c \cdot f_c$$

$$I_c = 0,1 \times 67,5108 \times 0,24$$

$$I_c = 1,6202592 \text{ Ampere}$$

4.3 Anode Required Calculation

4.3.1 Anode Utilization Factor

The anode utilization factor indicates the fraction of anode material that is assumed to provide cathodic protecting current. Performance becomes unpredictable when the anode is consumed beyond a mass indicated by the utilization factor. The utilization factor of an anode is dependent on the detailed anode design, in particular dimensions and location of anode cores.

Table 4.3.1.1 Anode Utilization Factor

Anode Type	Anode Utilization Factor
Long 1) slender stand-off	0.90
Long 1) flush-mounted	0.85
Short 2) flush-mounted	0.80
Bracelet, half-shell type	0.80
Bracelet, segmented type	0.75

The type of anode used in this system is the Zinc Bolt on Bar anode of the Marine CC brand with a flush-mounted type with an anode weight of 12.8 kg. Zinc anode has an electrochemical efficiency of 700 Ah / kg.



Figure 4.4 CC Marine Zinc Anode Catalog

4.3.2 Anode Calculation

The next step is to determine the total required mass of the sacrificial anodes. The total net anode mass required to maintain cathodic protection throughout the design life is to be calculated from current demand for each unit of the protection object

$$M = \frac{I_c \times T_f \times 8760}{\mu \times \varepsilon}$$

I_c = Current Demand

T_f = Coating life time

μ = Anode Utilization Factor

ε = Anode Electrical Capacity

a. Ballast Load

I_c	133,568
T_f	3
μ	0,85
ε	700

$$M_a = \frac{133,567 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 5899,43878 \text{ kg}$$

Anode Required	460,89365	461
	553,07239	553

In accordance with the calculation results of the sacrificial anode requirements above, it is obtained that the number of sacrificial anodes installed on the plate area below the waterline on the ship during ballast conditions amounted to 461 pieces with an additional 20% as a critical

factor. So that the number of anodes needed during ballast conditions is 553 anodes.

b. Half Load

Ic	150,431299
T	3
μ	0,85
ε	700

$$M_a = \frac{150,431299 \text{ A} \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 6644,25974 \text{ kg}$$

Anode Required	519,08279	519
	622,89935	623

In accordance with the calculation results of the sacrificial anode requirements above, it is obtained that the number of sacrificial anodes installed on the plate area below the waterline on the ship during half load conditions amounted to 519 pieces with an additional 20% as a critical factor. So that the number of anodes needed during ballast conditions is 623 anodes.

c. Full Load

Ic	162,02592
T	3
μ	0,85
ε	700

$$M_a = \frac{162,02592 \text{ A} \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 7156,37173 \text{ kg}$$

Anode Required	559,09154	559
	670,90985	671

In accordance with the calculation results of the sacrificial anode requirements above, it is obtained that the number of sacrificial anodes installed on the plate area below the waterline on the ship during full load conditions amounted to 559 pieces with an additional 20% as a critical factor. So that the number of anodes needed during ballast conditions is 671 anodes.

d. Ballast Load (Scaled)

lc	0,8706796
T	3
μ	0,85
T	700

$$M_a = \frac{0,8706796 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 0,19263474 \text{ kg}$$

Anode Required	38,456237	39
	46,147484	47

e. Half Load (Scaled)

lc	1,154313
T	3
μ	0,85
ε	700

$$M_a = \frac{1,154313 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 0,21695542 \text{ kg}$$

Anode Required	50,983774	51
	61,180529	62

f. Full Load (Scaled)

lc	1,6202592
T	3
μ	0,85
ε	700

$$M_a = \frac{1,6202592 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 0,23367744 \text{ kg}$$

Anode Required	71,563717	72
	85,876461	86

4.4 Overview of the Controller System

The following are the components of the Arduino-based ICCP flow control system that will be used in this final project ;

Tabel 4.4.1 Components of the Arduino-based ICCP flow control system

Sub System	Component
Model :	Ship Model with length 60cm

Sensor :	Water Level Sensor Current Sensor AdaFruit INA269
Control System :	Microcontroller Arduino UNO
Actuator :	MOSFET IRF540
Power Supply :	Battery 1.5 volt (8pcs)

Water sensor will detect water level. Different water levels will cause the area of the hull to be immersed differently, thus causing the need for the protection current issued by the different power supply. Then the water sensor will send a signal in the form of data to the Arduino microcontroller. Then Arduino will send commands to the transistor to divide the current coming from the power supply, as needed. Then to find out the amount of current that will enter the anode, a current sensor is needed.

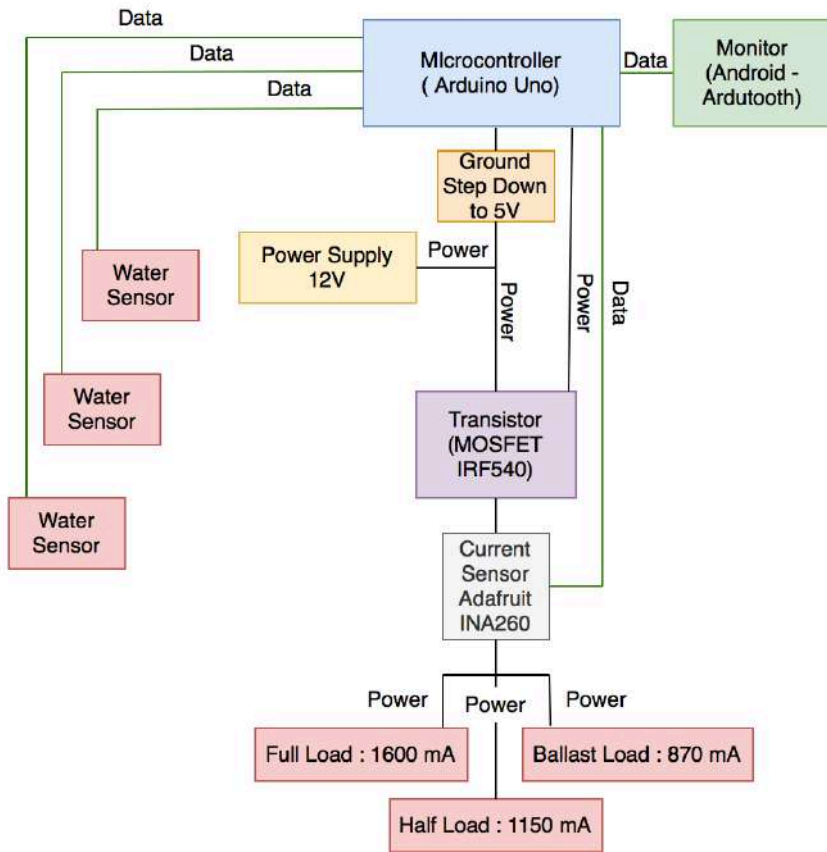


Figure 4.5 System's Block Diagram

4.5 Expected Response

In this final project, the model will be tested in a pond by being given a different volume of water so that it gives different variations in water level. With the different water levels at the time of testing, the expected system response is;

- Able to detect the existing water level, then after the water level is detected the data will be processed by a microcontroller and produce a PWM value in the form of output current needs at that water level.
- This controller system is able to control current requirements based on three different conditions

4.6 Ship's Model Data

The ship model that will be used as an Arduino-based controlling and monitoring model and will be tested is the type of work boat. The following dimensions of the ship to be used

Table 4.6.1 Ship's Model Data

Parameter	Real Ship	Ship's Model
LPP	171 m	60 cm
LOA	172,25 m	
Breadth	32,2 m	
Depth	18,8 m	
Draft (Full Load)	12,1 m	1,210 m
----- Half Load	10,082 m	1,008 m
----- Ballast Load	7,147 m	0,715 m
Deadweight	45,789 ton	

4.7 Electronic System Design

4.7.1 Tools and Materials

a. Microcontroller Arduino

In this final project, Arduino Uno microcontroller is used. Arduino is a microcontroller that serves to detect and receive data from the reading of the Water Level sensor. Then Arduino will process the data and send commands to the SCR Transistor to regulate the current that will be issued by the ICCP power source (Generator).

Table 4.7.1.1 Pin Arduino

Pin	Connection
Ground Parallel	Ground Water Level 1 Ground Water Level 2 Ground Water Level 3 Ground MOSFET IRF 540 Ground Step Down Ground INA260 Current Sensor Ground Bluetooth Module (HC-05)
VCC	VCC Water Level 1 VCC Water Level 2 VCC Water Level 3 VCC INA260 Current Sensor VCC Bluetooth Module (HC-05)
Vin	Output (+) Step Down
Digital Pin 0	Pin TX Bluetooth Module
Digital Pin 1	Pin RX Bluetooth Module
Digital Pin 3	Pin Gate MOSFET IRF540
Digital Pin 5	Pin Signal Water Level 1
Digital Pin 6	Pin Signal Water Level 2
Digital Pin 7	Pin Signal Water Level 3
Pin i2c SCL	Pin SCL INA260 Current Sensor
Pin i2c SDA	Pin SDA INA260 Current Sensor

b. Water Level Sensor

In this final project the sensor used is the water level sensor. Water Level Sensor is a sensor that is cheap and easy to use. This sensor consists of a number of lines arranged in parallel to determine the height of the water surface. The conversion value of water level to the analog signal generated can be directly read on the Arduino board

Table 4.7.1.2 Water Sensor Specs

Type	Analog
Voltage	DC 3-5V
Current	20mA
Dimension	62mmx20mmx8mm
Weight	3,5kg

c. Current Sensor

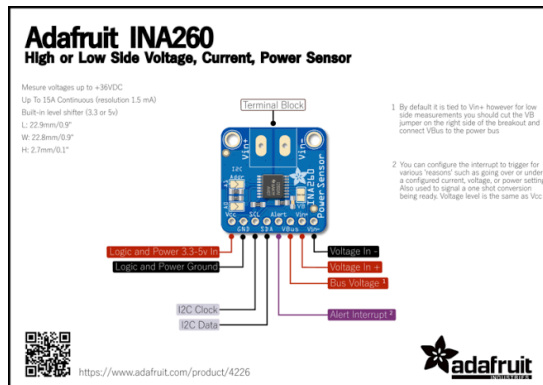


Figure 4.6 Current Sensor Datasheet

To read the required current output, a current sensor is needed. The current sensor used in this final project is Adafruit brand type INA260. After the water sensor reads the water level, the water sensor will send a signal to the current sensor. The current sensor will read current requirements needed then current sensor will send signal to Microcontroller Arduino Uno.

d. MOSFET

In this final project the MOSFET acts as a drive system and it used to control the output current of the Power Supply in accordance with the appropriate amount ordered by the control system (Arduino).

Specifications

Hardware features

- Typical -80dBm sensitivity.
- Up to +4dBm FF transmit power.
- Low Power 1.8V Operation, 3.3 to 5 V I/O.
- PIO control.
- UART interface with programmable baud rate.
- With integrated antenna.
- With edge connector.

Software features

- Save default Baud rate: 9600, Data bits:8, Stop bit:1,Parity:No parity.
- PICO9 and PICO8 can be connected to red and blue led separately. When master and slave are paired, red and blue led blinks 1time/2s in interval, while disconnected only blue led blinks 2times/s.
- Auto-connect to the last device on power as default.
- Permit pairing device to connect as default.
- Auto-pairing PINCODE:"1234" as default.
- Auto-reconnect in 30 min when disconnected as a result of beyond the range of connection.

Figure 4.7 MOSFET Datasheet

e. Battery




Figure 4.8 Battery

In this final project, the power supply used is a 1.5 Volt Alkaline battery. The battery has a function as a DC current source.

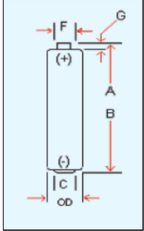
Panasonic Industrial
AA (LR6XWA)

Part Number: LR6XWA
(Replaces Panasonic part number AM-3PI)

Alkaline-Zinc/Manganese Dioxide



Industry Standard Dimensions mm (inches)
Dimensions Comply with ANSI and IEC Standards



Dimensions	Millimeters	Inches
A Max	50.5	1.988
B Min	49.5	1.949
C Min	7.0	0.276
F Max	5.5	0.217
G Min	1.0	0.039
OD Max	14.5	0.571
OD Min	13.5	0.531


Specifications

Chemical System:	Alkaline-Zinc/Manganese Dioxide (Zn/MnO ₂)
Designation:	ANSI-15A, IEC-LR6
Nominal Voltage:	1.5V
Operating Temperature Range:	-20°C to 54°C (-4°F to 130°F)
Typical Weight:	23 grams (0.8 oz.)
Typical Volume:	8.1 cm ³ (0.5 in. ³)
Terminals:	Cap and base
Shelf Life:	7 years (80% Capacity)
Heavy Metals Content:	No added Mercury, Cadmium or Lead

Batteries for every application and industry including:

- Medical
- Hotel/Motel/Restaurant
- Transportation
- Communications
- Government/Municipality
- HVAC
- Contractors
- Janitorial/Sanitation
- Power Plants
- Manufacturing
- Military/Defense
- Security

Important Notice: This data sheet contains typical information specific to products manufactured at the time of its publication.



Photos represent typical industrial applications but may or may not match the battery size on this data sheet.

Page 1 of 2

Figure 4.9 Battery Datasheet

J. Bluetooth



Figure 4.10 Bluetooth HC-05

In this final project, Bluetooth that will be used is Bluetooth type HC-05 which is commonly used for Arduino. This Bluetooth has a function for sending a signals to Bluetooth on smartphones. So that controlling data can be monitored via smartphone.

Specifications

Hardware features

- Typical -80dBm sensitivity.
- Up to +4dBm FF transmit power.
- Low Power 1.8V Operation, 3.3 to 5 V I/O.
- PIO control.
- UART interface with programmable baud rate.
- With integrated antenna.
- With edge connector.

Software features

- Save default Baud rate: 9600, Data bits:8, Stop bit:1,Parity:No parity.
- PIO9 and PIO8 can be connected to red and blue led separately. When master and slave are paired, red and blue led blinks 1time/2s in interval, while disconnected only blue led blinks 2times/s.
- Auto-connect to the last device on power as default.
- Permit pairing device to connect as default.
- Auto-pairing PINCODE:"1234" as default.
- Auto-reconnect in 30 min when disconnected as a result of beyond the range of connection.

Figure 4.11 Bluetooth HC-05 Datasheet

J. ArduTooth

In this final project the application used to monitor the current output on ICCP is Arduetooth. This application is written for visualing measurement data from a microcontroller via Bluetooth.

4.7.2 Electric Component Layout

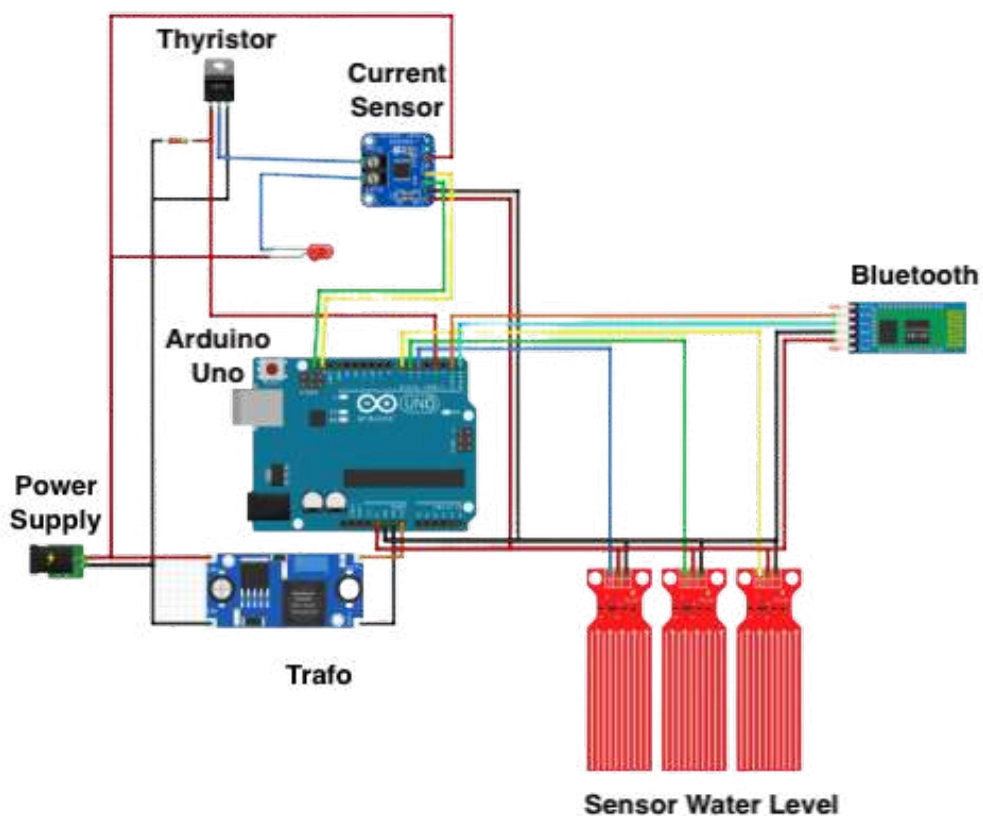


Figure 4.12 Wiring Diagram

4.8 Electric Component Instalation

In this final project, the components are installed on a ship model with length of 60 cm

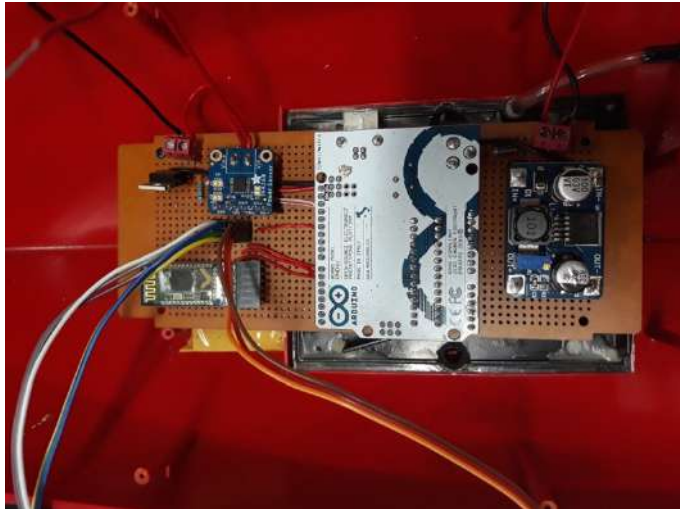


Figure 4.13 Electric Component Installation



Figure 4.14 Water Level Sensor Installation



Figure 4.15 LED and Power Supply Installation

4.9 Microcontroller Programming

This is the following steps of the programming code for Arduino Uno-based ICCP controlling system

```
#include <Adafruit_INA260.h>  
(The program will use the Adafruit INA206 current sensor)
```

```
Adafruit_INA260 ina260 = Adafruit_INA260();  
(create objects to access the current sensor)
```

```
#define sen1 5  
(define pin 5 as the first sensor, at Full Load condition)
```

```
#define sen2 6  
(define pin 6 as the second sensor, at Half Load condition)
```

```
#define sen3 7  
(define pin 7 as the third sensor, at Ballast Load condition)
```

```
#define pwm_out 3  
(define pin pwm as a gate voltage regulator MOSFET)
```

```
int kp = 2;  
(constant p for controller PD)
```

```
int kd = 0;  
(constant d for controller PD)
```

```
void setup() {  
(Data or Commands to be procced by Arduino)  
Serial.begin(9600);
```

```
pinMode(sen1, INPUT);  
(Set mode pin first sensor as input)
```

```
pinMode(sen2, INPUT);  
(Set mode pin second sensor as input)
```

```
pinMode(sen3, INPUT);  
(Set mode pin third as input)
```

```
pinMode(pwm_out, OUTPUT);  
(Set mode pin PWM Output as output)
```

```

if (!ina260.begin()) {
// Serial.println("Couldn't find INA260 chip");
  while (1);
  (If no current sensor is found, the process stops, and the program cannot be run)
}
// Serial.println("Found INA260 chip");
}

int pwm = 0;
  (Initialization of pwm which will be issued according to the desired current)
int arus = 600;
  (initialization of the desired current)
int error = 0;
  (variable initialization to hold the error, between the set point and the original value)
int last_error = 0;
  (variable initialization to hold the last error to be used as a derivative)
int out = 0;
  (the final pwm initialization to be issued)
void loop() {
  int current = ina260.readCurrent();
  (accommodating current value to 'current' variable)
  int power = ina260.readPower();
  (accommodating power value to 'power' variable)
  bool isSen1 = digitalRead(sen1);
  (accommodating the first sensor to 'isSen1' variable)
  bool isSen2 = digitalRead(sen2);
  (accommodating the second sensor to 'isSen2' variable)
  bool isSen3 = digitalRead(sen3);
  (accommodating the third sensor to 'isSen3' variable)

  if(isSen1){
    arus = 1600; // miliAmper
    (if the first sensor is detected, the current sensor will send a signal to Arduino to instruct the actuator to control the output current, at 1600 mA)
    goto skip;
  }
  (if the first sensor is not detected, the sensor will continue to detect the next sensor)
  if(isSen2){
    arus = 1150; // miliAmper
    (if the second sensor is detected, the current sensor will send a signal to Arduino to instruct the actuator to control the output current, at 1150 mA)
  
```

```

goto skip;
}

```

(if the second sensor is not detected, the sensor will continue to detect the next sensor)

```

if(isSen3){
  arus = 870; // miliAmper

```

(if the third sensor is detected, the current sensor will send a signal to Arduino to instruct the actuator to control the output current, at 870 mA)

```

  goto skip;
}

```

(if the third sensor is not detected, the sensor will continue to detect the next sensor)

```

arus = 0; // miliAmper
skip;

```

(if there is no sensor detected, the output of current become 0 mA)

```

error = arus - current;

```

(accommodate the difference between the desired current value and the actual current value)

```

out = kp*error + kd*(error-last_error);

```

(accomodate the pwm out value obtained from th PD controller)

```

last_error = error;

```

(accommodate the current error value to be used as a derivative controller for the next loop)

```

pwm += map(out, -2000, 2000, -20, 20);

```

(scale to 100:1 to minimize changes in pwm out and add them to the previous pwm out valuer)

```

if(pwm > 255) pwm = 255;

```

(limit the maximum value of pwm output to 255)

```

if(pwm < 0) pwm = 0;

```

(limit the minimum value of pwm output to 0)

```

analogWrite(pwm_out, pwm);

```

(issuing the value of pwm output)

```

// Serial.println();
Serial.print(isSen1);
Serial.print(',');

```

(order to display the first sensor data result into the monitor)

```

Serial.print(isSen2);
Serial.print(',');

```

(order to display the second sensor data result into the Monitor)

```

Serial.print(isSen3);
Serial.print(',');

```

(order to display the third sensor data result into the Monitor)

```
Serial.print(current);
```

```
Serial.print(" mA,");
```

(commanding the monitor to display the amount data of output current, according to the detected sensors. The data displayed in the form of number.)

```
Serial.print(power);
```

```
Serial.print(" mW;");
```

(commanding the monitor to display the amount data of output power, according to the detected sensors. The data displayed in the form of number.)

```
delay(500);
```

```
}
```

(commanding the digital signal to enter the trigger to not turn on for 500 microseconds)



Figure 4.16 Simulation Position



Figure 4.17 Test Pool

The DC current source on the ship comes from batteries with voltage of 12 Volts. The LED light used as a reference or current marker has been flowed from the battery. The level of light brightness is also a reference to the amount of current released based on the ship's weight conditions.

The simulation is carried out when the ship is in 3 conditions. The first condition is when the ship does not carry cargo or ballast load. The second condition is when the ship carries a half load of cargo. The third condition is when the ship carries a full load of cargo.



Figure 4.18 Controlling Simulation at Ballast Load Condition

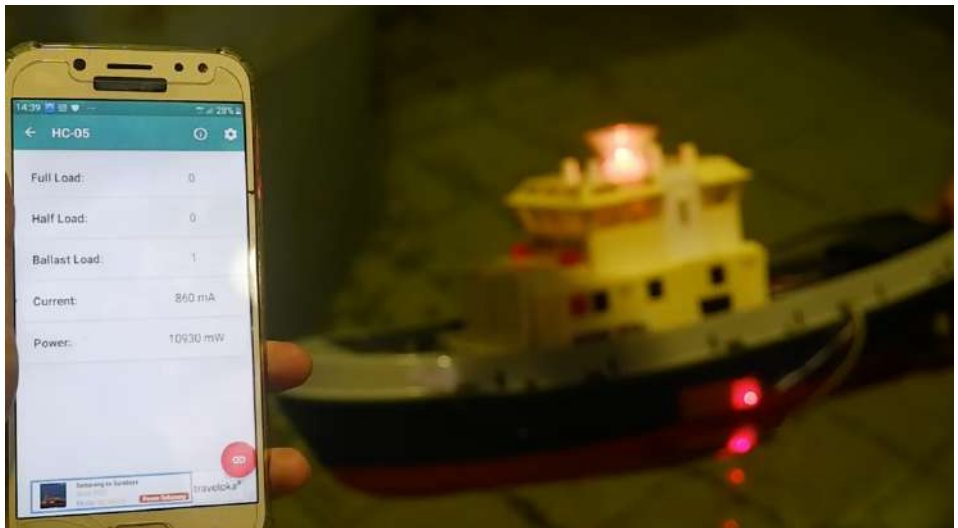


Figure 4.19 Monitoring Simulation at Ballast Load Condition

The first simulation is done when the condition of the ship does not carry a load / ballast load. The water level sensor that will read in this

condition is the sensor located at the very bottom of the ship's hull. When the sensor is exposed to water, the sensor will send data signals in the form of binary numbers to Arduino. Then Arduino will process the data and send a command in the form of data on the amount of output current needed under these conditions to the current sensor.



Figure 4.20 Controlling Simulation at Half Load Condition



Figure 4.21 Monitoring Simulation at Half Load Condition

Then the second test is done at half load condition. The water level sensor that will read in this condition is the sensor in the middle of the ship's hull.



Figure 4.22 Controlling Simulation at Half Load Condition

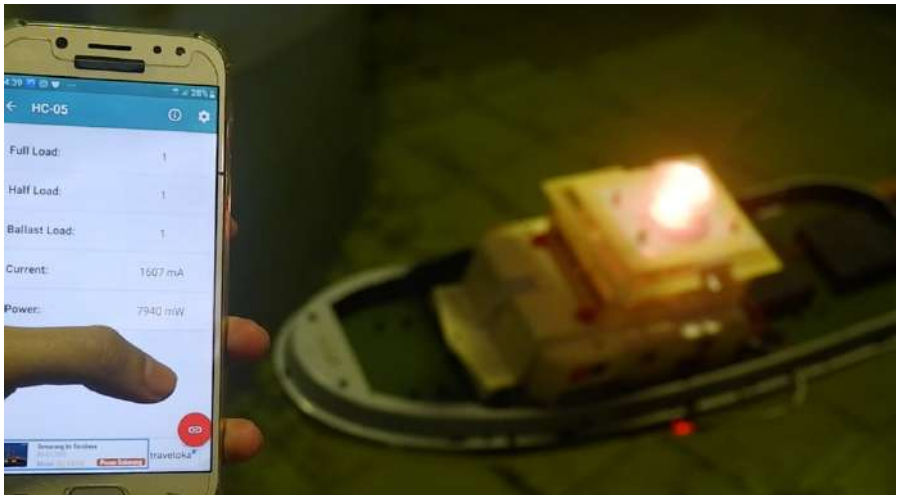


Figure 4.23 Monitoring Simulation at Full Load Condition

Then the third test is done at half load condition. The water level sensor that will read in this condition is the sensor located at the very top of the hull.

4.10 Result

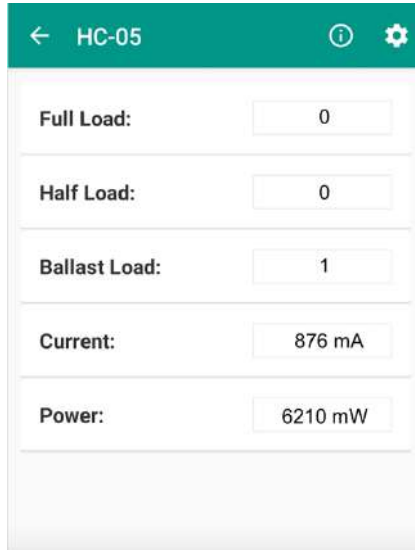


Figure 4.24 Controlling Result at Ballast Load

In Ballast Load conditions, sensors that are detected and read are sensors located at the bottom of the ship's hull. The amount of output current in this condition is around 870 mA. This condition is the smallest current output of all conditions, so the LED light in this condition becomes dim.

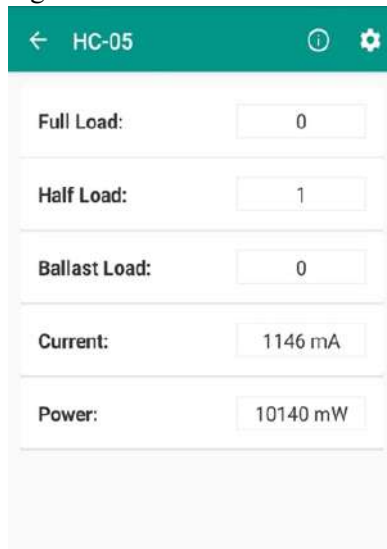


Figure 4.25 Controlling Result at Half Load

In the Half Load condition the sensor that is detected and reads is a sensor that is in the middle of the ship's hull. The amount of output current in this condition ranges from approximately 1154 mA

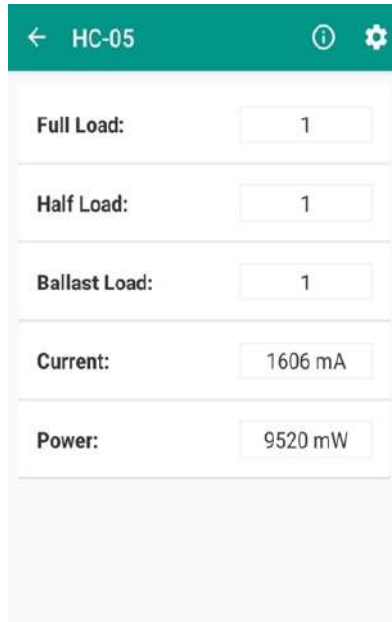


Figure 4.26 Controlling Result at Full Load

In Full Load condition all water sensors are detected. However, the only sensor read is the sensor that is at the top / the first sensor. The amount of output current in this condition ranges from approximately 1610 mA. This condition is the brightest current output of all conditions, so that the LED light in this condition becomes the brightest.

CHAPTER V

CONCLUSION AND SUGGESTION

5.1. Conclusion

Based on the research that has been done in this thesis, it can be concluded that:

1. The amount of current requirements needed in real ship conditions is; the Full Load condition is 162 Amperes, the Half Load condition is 115.43 Amperes, and the Ballast Load condition is 87.56 Amperes. Whereas the current needs on a model ship that has been scaled are; at Full Load 1.62 Amperes, at Half Load 1.154 Amperes, and at Ballast Load 0.87 Amperes. The greater the area of the hull that is immersed, the greater the current requirements needed. Conversely, if the area of the immersed hull is smaller, then the current needed will be less.
2. With this controlling system, over current for the ICCP will not be happen. So that this system can make the use of generators on ships more efficient. In addition, this system can also prevent the electroendosmosis process that often occurs in ICCP because the current released will be in accordance with the extent of the hull being immersed. In that way, this system can prevent damage to the coating due to electroendosmosis.

5.2. Suggestion

Suggestion from the author based on the research that has been done in this thesis, as follows.

1. In further research, technical development can be carried out to have an economic impact, things that can be done include: Calculation of the life time of the Arduino Uno-based ICCP controlling system compared to the usual ICCP system, and the economic analysis of the Arduino Uno-based ICCP controlling system

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AUTHOR BIOGRAPHY

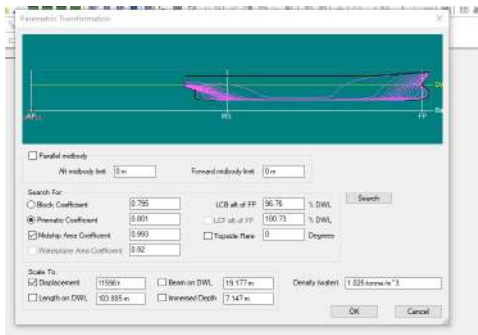


Allysha Prista Augustiana was born in Jakarta, August 14th 1998, and the firstborn of two siblings from Nur Primawira and Riesta Rachmantini. Grew up in Jakarta, Allysha completed her high school from SMA Taruna Nusantara Magelang (2013-2016). Author then continue her education in Double Degree Program of Marine Engineering Departement, Institut Teknologi Sepuluh Nopember, Surabaya with Hochschule Wismar, Germany. During the study, author has been actively involved in some organization. She was active in Himasiskal FTK-ITS as External Relation Staff (2017-2018) and Head of Media and Information Department (2019). She was also active in Marine Icon as the Decoration and Documentation Committee (2017) and External Funding Committee (2018). Author has done her internship two times; (1) *PT Daya Radar Utama Shipyard* in Lampung, (2) *SKK Migas* in Jakarta. During the research of the bachelor thesis, author was taking a part as a member of Marine Electrical and Automation System (MEAS) Laboratory.

ATTACHMENT

WETTED SURFACE AREA

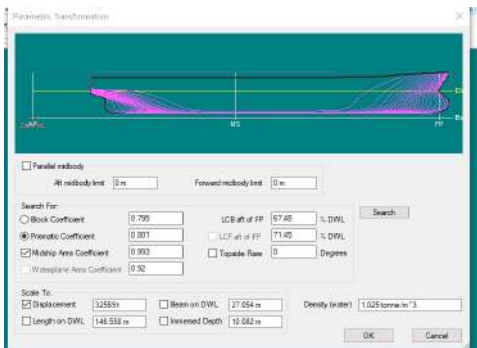
Ballast Load



Measurement	Value	Units
1 Displacement	11596.000	t
2 Volume displaced	11596.000	m ³
3 Draft amidships	12.000	m
4 Increased depth	7.147	m
5 Hull Length	142.000	m
6 Length over water (LOA)	142.000	m
7 Wetted area	392.250	m ²
8 Water plane area	124.000	m ²
9 Wetted area	893.768	m ²
10 Prismatic coeff. (CP)	0.801	
11 Block coeff. (Cb)	0.795	
12 Max. hull area coeff. (CMA)	0.900	
13 Wetted area coeff. (CWA)	0.800	
14 LCB length	120.000	Point
15 LCF length	116.188	Point
16 LCF %	118.997	Point
17 LCF %	111.978	Point
18 LCB	0.000	m
19 LCB offset	0.000	m
20 LCB	144.780	m
21 CWP moment	12.000	m
22 CWP	119.400	m
23 CWP	12.000	m
24 LCB	119.400	m
25 Increased DTH	7.147	Global
26 DTH	0.000	Global
27 Top Flare	0.000	Global
28 Top Flare	0.000	Global
29 Density (water)	1.025	tonne/m ³

Draft	7,147	m
Displacement Full Load	55,453	ton
DWT	45,789	ton
Displacement (Ballast Load)	11,5968	ton
Wetted Area	3021.25	m ²

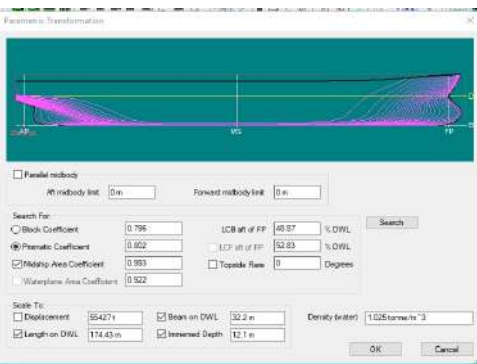
Half Load



Measurement	Value	Units
1 Displacement	12559.000	t
2 Volume displaced	12559.000	m ³
3 Draft amidships	12.000	m
4 Increased depth	12.062	m
5 Hull Length	142.000	m
6 Length over water (LOA)	142.000	m
7 Wetted area	1010.000	m ²
8 Water plane area	200.000	m ²
9 Wetted area	3040.042	m ²
10 Prismatic coeff. (CP)	0.801	
11 Block coeff. (Cb)	0.795	
12 Max. hull area coeff. (CMA)	0.900	
13 Wetted area coeff. (CWA)	0.800	
14 LCB length	96.000	Point
15 LCF length	97.680	Point
16 LCF %	67.680	Point
17 LCF %	71.450	Point
18 LCB	0.000	m
19 LCB offset	0.000	m
20 LCB	119.997	m
21 CWP moment	12.000	m
22 CWP	119.997	m
23 CWP	12.000	m
24 LCB	119.997	m
25 Increased DTH	12.062	Global
26 DTH	0.000	Global
27 Top Flare	0.000	Global
28 Top Flare	0.000	Global
29 Density (water)	1.025	tonne/m ³

Draft	10,084	m
Displacement Full Load	32,5585	ton
Wetted Area	6013,056	m ²

Full Load



Measurement	Value	Units
1 Displacement	55427.000	t
2 Volume displaced	55427.000	m ³
3 Draft amidships	12.100	m
4 Increased depth	12.100	m
5 Hull Length	174.430	m
6 Length over water (LOA)	174.430	m
7 Wetted area	8861.000	m ²
8 Water plane area	366.100	m ²
9 Wetted area	3179.000	m ²
10 Prismatic coeff. (CP)	0.800	
11 Block coeff. (Cb)	0.795	
12 Max. hull area coeff. (CMA)	0.900	
13 Wetted area coeff. (CWA)	0.800	
14 LCB length	80.740	Point
15 LCF length	78.820	Point
16 LCF %	48.190	Point
17 LCF %	49.190	Point
18 LCB	0.000	m
19 LCB offset	0.000	m
20 LCB	274.000	m
21 CWP moment	12.100	m
22 CWP	274.000	m
23 CWP	12.100	m
24 LCB	274.000	m
25 Increased DTH	12.100	Global
26 DTH	0.000	Global
27 Top Flare	0.000	Global
28 Top Flare	0.000	Global
29 Density (water)	1.025	tonne/m ³

Draft	12,100	m
Displacement Full Load	55,453	ton
DWT	45,789	ton
Wetted Area	8560,689	m ²

CORROSION RATE

W --> Asumption diminution 2,5 % / year

$$CR = \frac{K \times W}{A \times D \times T}$$

Dimana :

CR = Laju korosi (mm/th)
 W = Massa yang terkorosi (gram)
 A = Luas tercelup (cm²)
 K = 8.76 x 10⁴
 T = Waktu (jam)
 D = Densitas (gram/cm³)

Berat Plat Awal	Displacement - DWT
	9,664 ton
	9664000 gram

Corrosion Asumption	year 1	241600 gram
	year 2	235560 gram
	year 3	229671 gram
	total	706831 gram

Ballast Load

K	87600
W	706831 gram
A	3021250 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{3021250 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,09934317 mm/year

Half Load

K	87600
W	706831 gram
A	6013056 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{6013056 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,04991481 mm/year

Full Load

K	87600
W	706831 gram
A	8560689 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 706831 \text{ gram}}{8560689 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,03506033 mm/year

CURRENT PROTECTON NEEDS

Cathode Surface Area

Kebutuhan arus proteksi :

$$I_c = A_c \times f_c \times i_c \text{ (Ampere)}$$

Dimana :

A_c = Luas plat lambung kapal yang diproteksi dengan paduan zink (m²)

$$A_c = \{(2T) + B\} \times L_{pp} \times \rho \dots (\text{m}^2)$$

Ballast Load

T	7,147 m
B	32,2 m
L _{pp}	171 m
ρ	0,7

$$A_c = [(2T) + B] \times L_{pp} \times \rho$$

$$A_c = [(2 \times 7,147) + 32,2] \times 171 \times 0,7$$

$$A_c = 5565,3318 \text{ m}^2$$

Half Load

T	10,084 m
B	32,2 m
L _{pp}	171 m
ρ	0,7

$$A_c = [(2T) + B] \times L_{pp} \times \rho$$

$$A_c = [(2 \times 10,082) + 32,2] \times 171 \times 0,7$$

$$A_c = 6268,4496 \text{ m}^2$$

Half Load

T	12,1 m
B	32,2 m
L _{pp}	171 m
ρ	0,7

$$A_c = [(2T) + B] \times L_{pp} \times \rho$$

$$A_c = [(2 \times 10,082) + 32,2] \times 171 \times 0,7$$

$$A_c = 6751,08 \text{ m}^2$$

Coating Breakdown Factor

6.4.2 The coating breakdown factor is a function of coating properties, operational parameters and time. As a simple engineering approach, f_c can be expressed as:

$$f_c = a + b \cdot t$$

where t (years) is the coating lifetime and a and b are constants that are dependent on coating properties and the environment.

Guidance note:

The effect of marine growth is highest in the upper 30 meters where wave forces may further contribute to coating degradation. Another factor is periodic cleaning of marine growth in this zone.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.4.3 Owner should preferably specify constants a and b for calculation of coating breakdown factors based on his own practical experience of specific coating systems in a particular environment. When Owner has not specified any such data, the default values in Table 10-4 of Annex A shall be used. The coating breakdown factors as established in Annex A are based on considerations addressed in 5.8.3.

6.4.4 Once a and b are defined, mean and final coating break-

The coating breakdown factor describes the extent of current density reduction due to the application of a coating. The value $f_c = 0$ means the coating is 100% electrically insulating, whereas a value of $f_c = 1$ implies that the coating cannot provide any protection.

The coating breakdown factor is a function of coating properties, operational parameters and time. The coating breakdown factor f_c can be described as follows:

(17.11)

where t is the coating lifetime, and k_1 and k_2 are constants that are dependent on the coating properties.

Four paint coating categories have been defined for practical use based on the coating properties in DNV [9]:

Category I: one layer of primer coat, about 50-μm nominal dry film thickness (DFT);

Category II: one layer of primer coat, plus minimum one layer of intermediate top coat, 150- to 250-μm nominal DFT;

Category III: one layer of primer coat, plus minimum two layers of intermediate/top coats, minimum 300-μm nominal DFT;

Category IV: one layer of primer coat, plus minimum three layers of intermediate top coats, minimum 450-μm nominal DFT.

The constants k_1 and k_2 used for calculating the coating breakdown factors

down factors, f_{cm} and f_{cf} , respectively, to be used for CP design purposes are to be calculated by introducing the CP design life, t_f (yrs):

$$f_{cm} = a + b \cdot \frac{t_f}{2}$$

$$f_{cf} = a + b \cdot t_f$$

For certain protection objects, with large uncoated surfaces, the initial coating breakdown factor, $f_{c,i}$ = a, may be applied to calculate the initial current demand to include coated surfaces.

SOURCE = DNV-RP-B401

Table 1: Coating Systems for Cargo Tanks

Surface Preparation	Coating System	Minimum DFT	Number of stripe coats
ISO 8501-1 Sa 2½	Epoxy primer Epoxy undercoat Epoxy finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy phenolic primer Epoxy phenolic undercoat Epoxy phenolic finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy isocyanate primer Epoxy isocyanate undercoat Epoxy isocyanate finish	90 microns 90 microns 90 microns	2
ISO 8501-1 Sa 2½	Zinc silicate	80 microns	1
ISO 8501-1 Sa 2½	Cyclosilicon epoxy Cyclosilicon epoxy	150 microns 150 microns	1-2

ISO 8501-1, Preparation of Steel Substrates Before Application of Paints and Related Products-Visual Assessment of Surface Cleanliness

are given in Table

Table 17.3. Constants (k_1 and k_2) for Calculation of Paint Coating Breakdown Factors [10]

Depth (m)	Coating Category			
	I	II	III	IV
	$k_1 = 0.1$	$k_1 = 0.05$	$k_1 = 0.02$	$k_1 = 0.02$
	k_2	k_2	k_2	k_2
0-30	0.1	0.03	0.015	0.012
>30	0.05	0.02	0.012	0.012

Based on reference ,coating category for FSO is coating category II (Depth < 30m

K1	0,05
K2	0,03

1. PRINCIPAL PARTICULARS

Length	(LPP)	171.00 m
"	(L)	172.25 m
Breadth (mid)	(B)	32.20 m
Depth (mid)	(D)	18.80 m
Draft (mid)	(d)	12.10 m
Deadweight	(D/W)	45,789 t

$$F_c = (K_1 + K_2) \times t$$

$$F_c = (0,05 + 0,03) \times 3$$

$$0,24$$

Current Demand

quate polarizing capacity (6.3.1-6.3.4) and to maintain cathodic protection during the design life (6.3.5), the individual surface areas, A_c (m^2), of each CP unit shall be calculated according to (7.2) and multiplied by the relevant design current density, i_c (A/m^2), and the coating breakdown factor, f_c , if applicable:

$$I_c = A_c \cdot i_c \cdot f_c \quad (1)$$

i_c and f_c are then to be selected according to (6.3) and (6.4), respectively.

Ballast Load

i_c	0,1 A/m^2
A_c	5565,3318 m^2
f_c	0,24
I_c	87,56 Ampere

Half Load

i_c	0,1 A/m^2
A_c	6268,4496 m^2
f_c	0,24
I_c	115,44 Ampere

Full Load

i_c	0,1 A/m^2
A_c	6751,08 m^2
f_c	0,24
I_c	162,02592 Ampere

ANODE REQUIRED

Anode Utilization Factor

15.4.6 Anode Utilization Factor

The **anode** utilization factor indicates the fraction of anode material that is assumed to provide **cathodic protection** current. Performance becomes unpredictable when the anode is consumed beyond a mass indicated by the utilization factor. The utilization factor of an anode is dependent on the detailed **anode design**, in particular dimensions and location of anode cores. Table 15.3 gives the **anode utilization factor** for different types of **anodes** (DNV, 1993).

Table 15.5. Design utilization factors for different types of anodes.

Anode Type	Anode Utilization Factor
Long 1) slender stand-off	0.90
Long 1) flush-mounted	0.85
Short 2) flush-mounted	0.80
Bracelet, half-shell type	0.80
Bracelet, segmented type	0.75

6.8 Anode Utilization Factor

6.8.1 The anode utilisation factor, u , is the fraction of anode material of an anode with a specific design that may be utilised for calculation of the net anode mass required to sustain protection throughout the design life of a CP system (see 7.7.1). When an anode is consumed to its utilisation factor, the polarizing capacity (as determined by the anode current output) becomes unpredictable due to loss of support of anode material, or rapid increase of anode resistance due to other factors (see 7.9)

6.8.2 The utilisation factor is dependant on the anode design, particularly its dimensions and the location of anode cores (7.10.4). Unless otherwise agreed, the anode utilisation factors in Table 10-8 of Annex A shall be used for design calculations.

SOURCE = DNV-RP-B401

Anode

cc marine
and industrial supply

Zinc Anodes
Bolt On Bar Anode

PLU 14

Hole centres 229mm

WEIGHT		DIMENSIONS	
Gross	12.8 kg	Overall	457x102x64mm
Nett	12.0 kg	Anode	40x5mm

Element	Electrochemical Efficiency (Ah/kg)
Al	2000
Zn	700

Tabel 2.6.1 Electrochemical Efficiency (BKI, 2004)

Anode Type long flush-mounted 0,85

Anode Mass Calculation

7.7 Anode Mass Calculations

7.7.1 The total net anode mass, M_a (kg), required to maintain cathodic protection throughout the design life, t_f (yrs), is to be calculated from I_{cat} (A) for each unit of the protection object

SOURCE = DNV-RP-B401

(including any current drain):

$$M_a = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \epsilon} \quad (2)$$

In (2), 8760 refers to hours per year. u and ϵ (Ah/kg) are to be selected based on (6.8) and (6.5), respectively.

Ballast Load

I_c	87,56
T	3
μ	0,85
T	700

$$M = \frac{133,567 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 5899,439 \text{ kg}$$

Anode Required	460,893672	461	Anode
	553,072406	553	Anode dengan tambahan 20% faktor tempat kritis

Ballast Load

I_c	115,44
T	3
μ	0,85
ϵ	700

$$M = \frac{133,567 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 6644,767 \text{ kg}$$

Anode Required	519,122422	519	Anode
	622,946906	623	Anode dengan tambahan 20% faktor tempat kritis

Ballast Load

I_c	162,02592
T	3
μ	0,85
ϵ	700

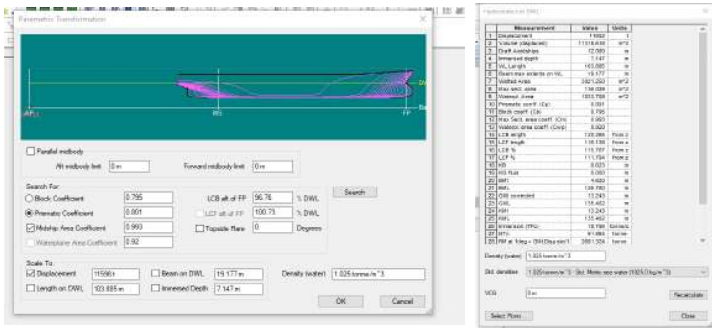
$$M = \frac{133,567 A \times 3 \text{ yrs} \times 8760}{0,85 \times 700}$$

$$M_a = 7156,372 \text{ kg}$$

Anode Required	559,091563	559	Anode
	670,909875	671	Anode dengan tambahan 20% faktor tempat kritis

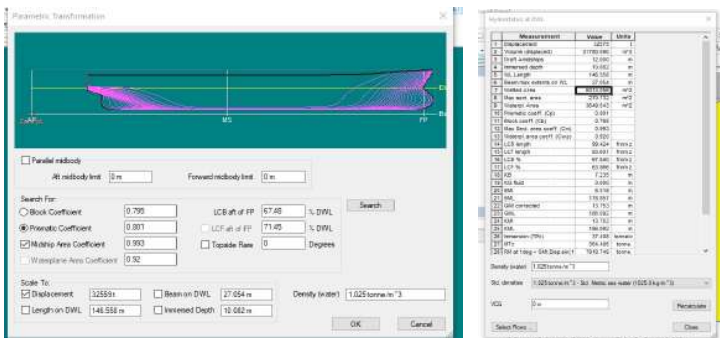
WETTED SURFACE AREA

Ballast Load



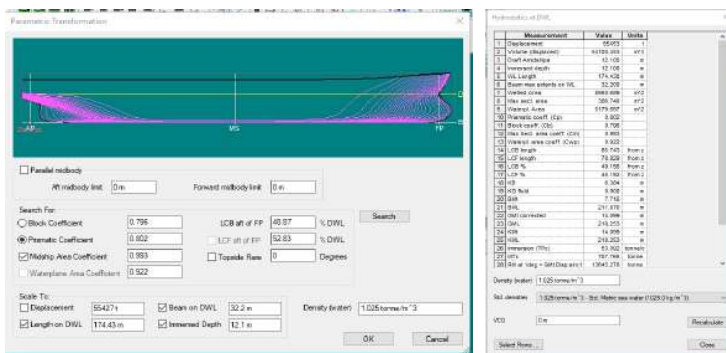
Draft	0,715	m
Displacement Full Load	5,5453	ton
DWT	4,5789	ton
Displacement (Ballast Load)	1,15968	ton
Wetted Area	302,125	m ²

Half Load



Draft	1,008	m
Displacement Full Load	3,25585	ton
Wetted Area	601,3056	m ²

Full Load



Draft	1,210	m
Displacement Full Load	5,5453	ton
DWT	4,5789	ton
Wetted Area	856,0689	m ²

CORROSION RATE

W --> Assumption diminution 2,5 % / year

$$CR = K \times W \div (A \times D \times T)$$

Berat Plat Awal	Displacement - DWT
	0,9664 ton

DIMANA :

CR = Laju korosi (mm/th)
 W = Massa yang terkorosi (gram)
 A = Luas tercelup (cm²)
 K = 8.76 x 10⁴
 T = Waktu (jam)
 D = Densitas (gram/cm³)

966400 gram

Corrosion Assumption	
year 1	24160 gram
year 2	23556 gram
year 3	22967,1 gram
total	70683,1 gram

942240
 918684

Ballast Load

K	87600
W	70683,1 gram
A	302125 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 70683,1 \text{ gram}}{3021250 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,09934 mm/year

Half Load

K	87600
W	70683,1 gram
A	601305,6 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 70683,1 \text{ gram}}{6013056 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,04991 mm/year

Full Load

K	87600
W	70683,1 gram
A	856068,9 cm ²
T	26280 hour
D	7,85 gram/cm ²

Densitas plat baja

$$CR = \frac{K \times W}{A \times D \times T}$$

$$CR = \frac{8700 \times 70683,1 \text{ gram}}{8560689 \text{ cm}^2 \times 7,85 \text{ gram/cm}^2 \times 26280 \text{ h}}$$

0,03506 mm/year

CURRENT PROTECTON NEEDS

Cathode Surface Area

Kebutuhan arus proteksi :

$$I_c = A_c \times f_c \times i_c \text{ (Ampere)}$$

Dimana :

A_c = Luas plat lambung kapal yang diproteksi dengan paduan zink (m²)

$$A_c = \{(2T)+B\} \times L_{pp} \times \rho \dots(\text{m}^2)$$

Ballast Load

T	0,7147 m
B	3,22 m
L _{pp}	17,1 m
ρ	0,7

$$A_c = \{(2T)+B\} \times L_{pp} \times \rho$$

$$A_c = \{(2 \times 0,7147)+3,22\} \times 17,1 \times 0,7$$

$$A_c = 55,653318 \text{ m}^2$$

Half Load

T	1,0082 m
B	3,22 m
L _{pp}	17,1 m
ρ	0,7

$$A_c = \{(2T)+B\} \times L_{pp} \times \rho$$

$$A_c = \{(2 \times 1,0082)+3,22\} \times 17,1 \times 0,7$$

$$A_c = 62,679708 \text{ m}^2$$

Half Load

T	1,21 m
B	3,22 m
L _{pp}	17,1 m
ρ	0,7

$$A_c = \{(2T)+B\} \times L_{pp} \times \rho$$

$$A_c = \{(2 \times 1,0082)+3,22\} \times 17,1 \times 0,7$$

$$A_c = 67,5108 \text{ m}^2$$

Coating Breakdown Factor

6.4.2 The coating breakdown factor is a function of coating properties, operational parameters and time. As a simple engineering approach, f_c can be expressed as:

$$f_c = a + b \cdot t$$

where t (years) is the coating lifetime and a and b are constants that are dependent on coating properties and the environment.

Guidance note:

The effect of marine growth is highest in the upper 30 meters where wave forces may further contribute to coating degradation. Another factor is periodic cleaning of marine growth in this zone.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.4.3 Owner should preferably specify constants a and b for calculation of coating breakdown factors based on his own practical experience of specific coating systems in a particular environment. When Owner has not specified any such data, the default values in Table 10-4 of Annex A shall be used. The coating breakdown factors as established in Annex A are based on considerations addressed in 5.8.3.

6.4.4 Once a and b are defined, mean and final coating breakdown factors, f_{cm} and f_{cf} , respectively, to be used for CP design purposes are to be calculated by introducing the CP design life, t_f (yrs):

$$f_{cm} = a + b \cdot \frac{t_f}{2}$$

$$f_{cf} = a + b \cdot t_f$$

For certain protection objects, with large uncoated surfaces, the initial coating breakdown factor, $f_{ci} = a$, may be applied to calculate the initial current demand to include coated surfaces.

SOURCE = DNV-RP-B401

The coating breakdown factor describes the extent of current density reduction due to the application of a coating. The value $f_c = 0$ means the coating is 100% electrically insulating, whereas a value of $f_c = 1$ implies that the coating cannot provide any protection.

The coating breakdown factor is a function of coating properties, operational parameters and time. The coating breakdown factor f_c can be described as follows:

(17.11) where t is the coating lifetime, and k_1 and k_2 are constants that are dependent on the coating properties.

Four paint coating categories have been defined for practical use based on the coating properties in DNV [9]:

Category I: one layer of primer coat, about 50-μm nominal dry film thickness (DFT);

Category II: one layer of primer coat, plus minimum one layer of intermediate top coat, 150- to 250-μm nominal DFT;

Category III: one layer of primer coat, plus minimum two layers of intermediate/top coats, minimum 300-μm nominal DFT;

Category IV: one layer of primer coat, plus minimum three layers of intermediate top coats, minimum 450-μm nominal DFT.

The constants k_1 and k_2 used for calculating the coating breakdown factors are given in Table

Table 17.3. Constants (k_1 and k_2) for Calculation of Paint Coating Breakdown Factors [10]

Depth (m)	Coating Category			
	I	II	III	IV
	$k_1 = 0.1$	$k_1 = 0.05$	$k_1 = 0.02$	$k_1 = 0.02$
	k_2	k_2	k_2	k_2
0-30	0.1	0.03	0.015	0.012
8gt;30	0.05	0.02	0.012	0.012

Table 1: Coating Systems for Cargo Tanks

Surface Preparation	Coating System	Minimum DFT	Number of stripe coats
ISO 8501-1 Sa 2½	Epoxy primer Epoxy undercoat Epoxy finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy phenolic primer Epoxy phenolic undercoat Epoxy phenolic finish	100 microns 100 microns 100 microns	2
ISO 8501-1 Sa 2½	Epoxy isocyanate primer Epoxy isocyanate undercoat Epoxy isocyanate finish	90 microns 90 microns 90 microns	2
ISO 8501-1 Sa 2½	Zinc silicate	80 microns	1
ISO 8501-1 Sa 2½	Cyclotrisilicon epoxy Cyclotrisilicon epoxy	150 microns 150 microns	1-2

ISO 8501-1: Preparation of Steel Substrates Before Application of Paints and Related Products—Visual Assessment of Surface Cleanliness

Based on reference coating category for FSO is coating category II (Depth < 30µm)

K1	0,05
K2	0,03

1. PRINCIPAL PARTICULARS

Length	(LPP)	171,00 m
#	(L)	172,25 m
Breadth (mid)	(B)	32,20 m
Depth (mid)	(D)	18,80 m
Draft (mid)	(d)	12,10 m
Deadweight	(D/W)	45,789 t

$$F_c = (K_1 + K_2) \times t$$

$$F_c = (0,05 + 0,03) \times 3$$

$$0,24$$

Current Demand

quate polarizing capacity (6.3.1-6.3.4) and to maintain cathodic protection during the design life (6.3.5), the individual surface areas, A_c (m^2), of each CP unit shall be calculated according to (7.2) and multiplied by the relevant design current density, i_c (A/m^2), and the coating breakdown factor, f_c , if applicable:

$$I_c = A_c \cdot i_c \cdot f_c \quad (1)$$

i_c and f_c are then to be selected according to (6.3) and (6.4), respectively.

Ballast Load

i_c	0,1 A/m^2
A_c	55,653318 m^2
f_c	0,24

I_c 0,87567 Ampere X

Half Load

i_c	0,1 A/m^2
A_c	62,679708 m^2
f_c	0,24

I_c 1,154313 Ampere X

Full Load

i_c	0,1 A/m^2
A_c	67,5108 m^2
f_c	0,24

I_c 1,6102592 Ampere X