DEVELOPMENT OF A GPS BASED SUN TRACKING SYSTEM FOR SOLAR POWER GENERATION ON A MOVING PLATFORM

By

PHEHELLO HENDRICK SELISA

211068160

Thesis submitted in fulfillment of a Cape Peninsula University of Technology Master of Engineering in Electrical Engineering Degree

in the faculty of Engineering and built environment

Supervisor: **Prof A. Raji**

Bellville campus

Date Submitted: **21 September 2022**

Declaration

I declare that this research dissertation is my own unaided work. It is being submitted for the Master's Degree at Cape Peninsula University of Technology, Cape Town. It has not been submitted before for any degree or examination at any other University.

(Signature)

Signed in Cape Town this __21__ day of _September_____________ 2022

Abstract

The use of renewable energy as means of electrical power generation on military Ships is rare with none in South Africa, especially in the era of advanced technologies. This encourages the use of diesel generators to generate electricity. Diesel generators emit toxic gases into the atmosphere and affect the climate negatively. Since SA Naval Ships also use diesel generators, this means that they are also contributing to the negative impact on the climate. To avoid the use of generators and reduce toxic gas emissions, solar power generation can be used, since solar panels are flat and can be installed without compromising the Ship's superstructure integrity.

A sun-tracking solar system would work perfectly on the Ship since the Ship is always on the move out at Sea. The system allows for sufficient sun ray exposure on panels. HOMER software is used to determine the solar power output in relation to the Ship's diesel generator power output. The model with the Ship placed in the different locations at Sea within SA's EEZ, where the Ship would normally operate is used to simulate solar PV power output.

The study investigates whether it is valid to install solar power generation on a Military ship and whether a tracking system can be used on the ship. The solar power generating system is modeled in HOMER and simulated in different locations around SA at sea. The results that are obtained from the simulations show that solar PVs can produce enough electrical power to serve the Ship's load demand. With sufficient power output from solar power to serve the Ship's load results in less use of diesel generators. This will reduce fuel and maintenance costs, not leaving behind zero toxic gas emissions.

Acknowledgments

I wish to thank:

- My wife, Daphney Selisa, for the great support she provided for me and the encouragement to achieve my degree.
- My supervisor, Prof A. Raji for the guidance and support towards the completion of this thesis.
- South African Navy for allowing me to use their Ship's electrical generation system and for the time to conduct the research.

The financial assistance of the South African Navy towards this research is acknowledged. Opinions expressed in this thesis and the conclusions arrived at, are those of the author, and are not necessarily to be attributed to the National Research Foundation

Contents

List of Figures

List of Tables

Thesis Title

Development of a GPS-based sun-tracking system for solar power generation on a moving platform

List of Abbreviations

A	Ampere
AC	Alternating Current
BESS	Battery Energy Storage System
CO2	Carbon Dioxide
DG	Distributed Generation/Diesel Generator
DC	Direct Current
EEZ	Economic Exclusive Zone
EL	East London
GHG	Green House Gas
GHI	Global Horizontal Irradiation
HOMER	Hybrid Optimization of Multiple Energy Resources
I - V	Current - Voltage
IEEE	Institute of Electrical and Electronic Engineers
IEA	International Energy Agency
MPPT	Maximum Power Point Tracking
NREL	National Renewable Energy Laboratory
PV	Photo-voltaic
P – V	Power Voltage
SAS	South African Ship
SAN	South African Navy
V	Voltage
W	Watt
WTGs	Wind Turbine Generators

Glossary of terms

Capacity Factor	The average power output of the PV array (in kW) divided by its rated power, in %
Charger Controller	Is the circuit which limits the rate at which electric current is added to or drawn from electric batteries
Deferrable load	An electrical load that requires a certain amount of energy within a given time period, but the exact timing is not important; it can wait until power is available
Distributed energy resources	Sources of electric power that are not directly connected with a bulk power transmission system; these include Both generation and energy storage technologies
Distributed generation	The process of generating electricity using renewable energy resources – these resources generating the electricity are usually distributed over an area, like a photovoltaic farm. Electricity obtained by distributed generation is usually fed into a micro-grid
Distribution network	A system of cables that deliver power to consumers at usage voltage levels
Electric power system	An assemblage of equipment and circuits for generating, transmitting and distributing electrical energy
Excess electricity	Surplus electrical energy that must be dumped (or curtailed) because it cannot be used to serve a load or charge batteries.
Electrical Load	An electrical component or portion of a circuit that consumes active electric power
Generator	An electric machine that converts mechanical energy to electrical
Generation System	Is the bulk movement of electricity energy from generating site to electrical distribution substations
Grid	A system of high tension cables by which electrical power is distributed throughout a region power grid, or power system.
Hours of Operation	The number of hours of the year during which the PV array output was greater than zero

IEC 61850	An international standard for communication in substations, also extensible to the rest of the power system
Inverter	A device or system that converts direct current to alternative
Megawatts	A unit of power (rate of energy consumption) 1 megawatt is equal to 1 000 000 Watts
Model	A depiction of real world systems in a software Environment such as Simulink for improved understanding
Levelized Cost	The Levelized cost of energy of the PV array, in R/kWh
Mean Output	The average power amount of the PV array over the year, in kW and kWh/day
Minimum Output	The minimum power output of the PV array over the year, in kW
Maximum Output	The maximum power output of the PV array over the year, in kW
PV Penetration	The average power output of the PV array divided by the average primary load, in %
Rated Capacity	The rated capacity of the PV array under standard conditions, in kW
Total Production	The total power output of the PV array over the year, in kWh/yr
Simulink	An environment for block diagrams where multi-domain simulations and Model-Based Designs are carried out.
Method	The procedures and techniques characteristics, orderly arrangement of parts or steps to accomplish an end.
Modeling	Refers to electrical power system simulation of the designed network in order to analyze electrical power systems data offline or real-time
Renewable	Refers to those energy resources whose common characteristic is that they are non-depletable or naturally replenishable
Renewable generation	The process of generating electricity using renewable energy resources – these resources generating the electricity are usually distributed over an area, like a photovoltaic farm

Simulator	Simulator A machine for simulating certain environmental and other conditions for purposes of training or experimentation.
Unmet load fraction	Is the proportion of the total annual electrical load that went unserved because of insufficient generation

Chapter 1 INTRODUCTION

This chapter discusses the background and motivation, research problem, research question, objectives, the context of the work, significance, delineation, methodology as well as organization of the research.

1.1 BACKGROUND AND MOTIVATION

Once the ship leaves the shoreline, it becomes an island itself (Anish, 2021). As the Ships carry goods/cargo and people, it requires to have essentials like electricity. To generate electricity, they use generators. Normally a ship will have a certain number of generators depending on its size and purpose, as well as the emergency generator. This is a traditional method that the Shipbuilders used to generate electricity for the ships since the introduction of electricity generation to the ships. Naval ships also use this traditional method of generating electricity, from their old ships to their latest ships. All these ships are built already to utilize the generators. This adds to CO_2 emissions which are increasing. Some of these ships have a big enough surface on the superstructure to integrate solar power energy. Therefore, the study will bring the idea to integrate solar energy into the ships, especially to start with the supply & support ships as they have enough space.

According to Adnanes A. K. (2003), Electrical generators have been used on Ships since the 1920s to generate electricity onboard Ships. It started by using steam turbine generators to provide electricity for the ships, and as technology improves, it moved to diesel generators. This was the best method to turn generators, but unfortunately have a negative impact on the climate.

South African Naval Ship (SAS) DRAKENSBERG is the support ship, that was built in 1984 and launched in 1986. It was also built to use diesel generators to generate electricity for the entire ship. Due to its size, it uses more than one generator, which means it has high CO_2 emissions and consumes a lot of diesel, not leaving behind the costs of operating and maintaining the generators. Its superstructure size allows for the installation of solar energy generation panels.

1.2 RESEARCH PROBLEM

Continued use of fossil fuel to generate power for the ships in the SA Navy contributes to the fuel cost incurred and contributes to the emissions of toxic gases to the climate (Visa, et al., 2016; Wu and Xia, 2018; Chacko and Paulson, 2019). According to Paulson and Chacko (2019), the shipping industry faces the challenge of fuel price hikes and marine pollution as diesel generators use fossil fuel and releases immense quantities of exhaust gases. In addition, fuel consumption is also a critical problem for the shipping industry (Wu and Xia, 2018). This has a negative impact on the climate, as it adds to global warming and also impacts the finances of the organizations. (Aijjou, et al., 2019) found out that maritime transport emits around 1 billion tons of CO2 annually and is responsible for about 2.5% of global greenhouse gas emissions from fuel combustion. Peralta, et al. (2019) Also found out that shipping represents around 2% of global CO2 emissions as their power system has a high dependence on fossil fuels. Unfortunately, little attention has been said in the literature to encourage owners to expedite the implementation of recommended solutions.

1.3 RESEARCH QUESTION

The literature review indicates that installing solar energy tracking systems on military Ships is very rare. Contrary to this background, the research question will read as follows:

What type of solar energy tracking system would be suitable to be used on the SA Navy Ship to reduce the usage of diesel generators, operational and maintenance costs, and toxic gas emissions?

1.3.1 Investigative Questions

Below mentioned investigative questions that will support the research question will be researched:

1.3.1.1 What type of Solar tracking system would be suitable to be used on the ship?

1.3.1.2 What impact would solar energy power have on a ship's diesel generator usage?

1.3.1.3 What impact would solar energy have on the reduction of CO2 emissions to the climate?

1.3.1.4 How would a GPS-based Solar tracking system be installed on the ship?

1.3.1.5 How would a solar energy power system installed on the Ship benefit the environment?

1.4 OBJECTIVES

Renewable energy, especially solar energy power as the main focus of the study is rarely used in the military ship and none in the SA Navy. Keeping that in mind, the study looks at how to introduce renewable energy on the military ship to benefit SA Navy. The focus will be to validate if the solar power could satisfy the electrical load of the ship when at sea and in the harbor. The main objectives of the research are:

1.4.1 To identify which suitable solar energy tracking system could be installed on the South African Naval Ship.

1.4.2 To prove that solar energy can supply enough power for the Ship's power demand.

1.4.3 To validate that solar energy could reduce fuel and maintenance costs on the Ship's diesel generators.

1.4.4 To validate that a GPS-based solar energy tracking system can be utilized on the Ships.

1.4.5 To validate that solar energy could reduce the Ship's CO2 emissions.

1.5 SIGNIFICANCE

The research into integrating renewable energy into a ship's power generation will be significant to the SA Navy. The research is significant because it will enable SA Navy to reduce fuel costs, diesel generators' running hours, as well as maintenance costs, while on the other hand benefiting the environment by reducing CO2 emissions to the climate.

1.6 DELINEATION

The research will be limited to solar power generation for the military support ship in the South African Navy. Power distribution to end users within the ship will not be covered.

1.7 METHODOLOGY

The research will be based on a modeling and simulation approach. The results will be modeled and simulated and compared to the ship's data. The following data will be collected from the Ship's technical records:

- Diesel generators running hours, maintenance costs, and fuel consumption.
- Ship's power demand on full load and minimum load requirement.
- Ship's superstructure dimensions.

The literature will be reviewed to establish a suitable sun-tracking system for solar power generation for the Ship, taking into consideration the size of the solar array type, power output, and size of the possible installation space on the ship.
Ethics approval is required, and therefore an application for ethics clearance through the faculty ethics committee is submitted.

1.8 ORGANIZATION OF DISSERTATION

This dissertation is made up of six chapters, References, and Appendices which are structured as follows:

1.8.1 Chapter 1

Chapter 1 presents the background and motivation, research problem, research question, objectives, the context of work, significance, delineation, and methodology as well as the organization of the dissertation

1.8.2 Chapter 2

This chapter introduces and acknowledges the literature review that is related to this research. It includes 8 sections which cover the introduction, electrical power generation on ships, renewable energy power on ships, solar tracking and methods, solar tracking systems, global positioning system receivers, South African economic exclusive zone, and carbon dioxide emissions respectively.

1.8.3 Chapter 3

In this chapter, the research design, and methodology including how the data was acquired as well as the analysis and presentation of the results are discussed.

1.8.4 Chapter 4

Chapter 4 discusses and reports on the results of the simulations and modeling of the solar system.

1.8.5 Chapter 5

In chapter 5, the results of the simulations are discussed as per the sub-sections of chapter 4.

1.8.6 Chapter 6

This chapter reports on the conclusions of the research and recommendations.

1.8.7 References

In this section, a list of references that are relevant and used in the research is given.

1.8.8 Appendices

The appendices in this dissertation present the key diagrams obtained after the simulation and modeling of the system.

Chapter 2 LITERATURE REVIEW AND THEORY

2.1 CHAPTER REVIEW

This chapter introduces the literature review on electrical power generation on ships as well as renewable energy power on ships. The chapter will further discuss solar tracking and methods, Solar tracking systems, Global positioning system (GPS) receivers, South African Economic Exclusive Zone (EEZ), and Carbon dioxide (CO2) emissions.

2.2 INTRODUCTION

International shipping provides most of the world's trade and depends on fossil fuel/diesel. They are the suspects for a significant amount of Greenhouse gas (GHG) emissions due to exhaust gases they produce, and these results from the fuel combustion of main engines and diesel generators. A significant impact on the environment is observed from these emissions. To reduce this impact, the shipping industry needs to venture into renewable energy which will replace the traditional energy sources onboard the ships (Visa, et al., 2016).

Visa, et al. (2016), when he simulates his modeled experiment, he showed that; a solar converter ensures a better collection of solar radiation, through which some vary with the seasons. And thus they are able to produce power for the ship. In his simulations, he used fixed-tilt solar converters which indicated to be able to produce 69%-88% of solar radiation throughout the season. As for the dual-axis solar tracking system, he was able to indicate that it can collect almost 100% of solar radiation.

The introduction of renewable energy to the ships to integrate into its power generation system will not only provide power generation redundancy but also protect the environment. With the depletion of oil, economist predicts that global oil resources will be exhausted by 2050. Therefore, renewable energy in ships will assist the owners in coping with the high fuel price. On other hand, the renewable energy in the ships will provide endurance, less fuel consumption, low noise, and less maintenance costs to the diesel generators. The simulation results demonstrated that renewable energy systems are able to produce enough power to sustain the ship (Cheng, et al., 2020).

2.3 ELECTRICAL POWER GENERATION ON SHIPS

Ships require electricity to operate their electrical systems including navigation systems, pumps, lighting, and ventilation. Since the ship is like an island whilst at sea, it requires its electrical generation. Ships use diesel generators to generate their electrical power as a typical installation shown in figure 2.1. Unlike land-based electrical power generation systems, in the Ship, more than one generator is used for electrical power generation. Since the ship is an isolated system, there is a short distance between the generator and consumers or end users, which results in a short cable running distance. In some Ships, diesel power generation is used for propulsion (Adnanes, 2003).

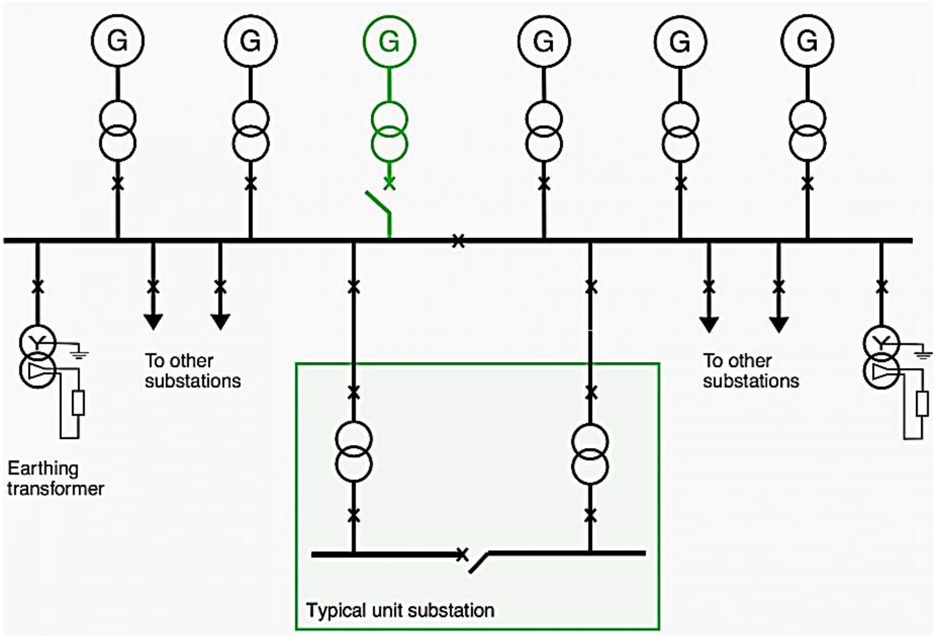


Figure 2.1: Typical installation of diesel generators on the ship (**Edward, 2017**)

2.4 RENEWABLE ENERGY POWER ON SHIPS

Aijjou, et al. (2019), conducted a study to demonstrate the influence of renewable energy on Ship energy efficiency. In his study, he used a Feeder Container vessel. According to his study; maritime transport emits around 1 billion tons of CO_2 annually and is responsible for 2.5% of GHG emissions from fuel combustion. To curb CO_2 emissions, reduce fuel consumption, and save on fuel costs and maintenance costs, the shipping industry has to venture into renewable energy as a promising solution. In his study, he used a container ship that trades between North and West Africa with enough solar radiation to produce solar energy for the ship. His study was able to indicate that implementing solar energy generation on the ship will reduce fuel consumption and GHG emissions.

The capability of solar energy generation for Ships is further explained in (Atkinson, 2016). He showed that the solar energy use on the ships is limited as of the increasing use on land-based establishments. He used the Ferry to conduct his study and was able to indicate that solar energy can be used as an alternative power source for Ships. In his trials, he was able to indicate the power output of the solar Photovoltaic (PV) system and an average daily total electrical production. Therefore, this further proves that a solar energy generation system can generate enough electricity to certify the ship's power demand at sea.

Integration of PV systems to the ships and comparison between on-land and onboard Ship PV systems are reviewed in (Paulson and Chacko, 2019). The Ship's movement at sea can also affect the PV modules. As explained in the case study by (Qiu, et al., 2019). Therefore, power generation from the PV modules will depend on navigation routes, the position of the Ship, the date, local time, and time zone. The study was conducted using COSCO TENGFEI PCTC Ship. However, in the study (Qiu, et al., 2019) also provides a solution to mitigate the impact on PV modules depending on the location, navigation routes, and time.

Wu and Xia (2018) further described the benefits of integrating renewable energy into Ships. The study also describes that the renewable energy that is installed on the Ship can also be connected to an off-shore system to save on power tariffs. Other many options can be considered for the generation of electrical power for Ships globally. Some of these options will be briefly explained below as the literature review states.

2.4.1 SOLAR POWER GENERATION

The solar power generation is depicted in figure 2.2. Solar photovoltaic is the process of converting light from the sun into electricity. The conversion takes place through the PV solar energy cells. The particle of solar energy strikes the surface of the exposed cells, and then the photovoltaic effect takes place. The DC is then generated. The DC will be converted to AC for AC loads and the other DC will be for DC loads.

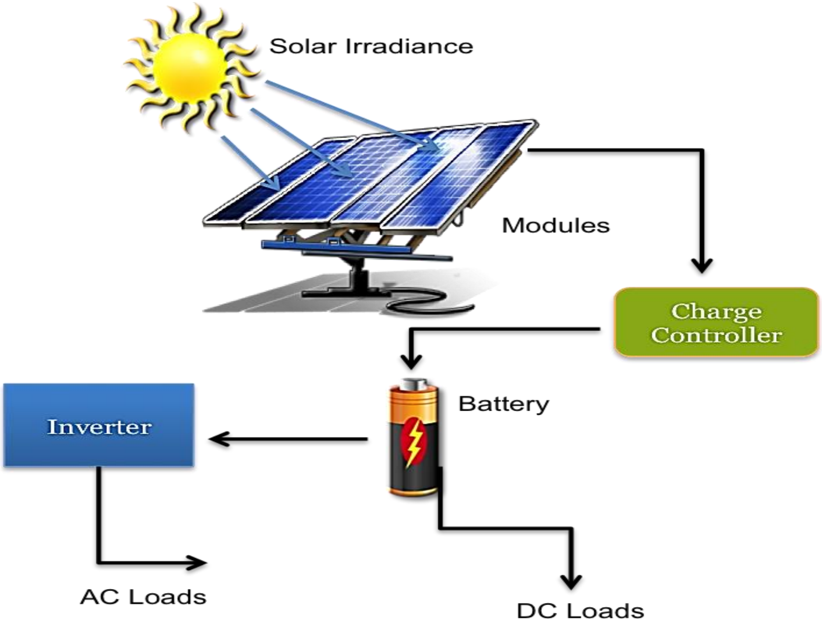


Figure 2.2: Typical Solar power is generation (**Chartier**)

Sea at its great size has sufficient sunlight and temperatures that will allow for solar power energy generation. Introducing solar power energy generation systems in Ships' electrical power systems could play an effective role in solving marine pollution and CO2 emissions to the atmosphere. Especially, the large sea-going Ships that travel long distances using diesel generators and military ships that conduct operations at sea.

Solar energy power is used in households and industries to supplement the grid power or as a redundant power source. It is commonly used on land. However, it can be significant to the marine world as well. It can be used to power ships and for propulsion. Shi and Wei Lou (2018) Analyzed the use of the PV solar power system on Ships. The increase in water transport especially in tourism comes with the increase in water, noise pollution as well as air pollution. The pollution is caused by the oil or spills or CO2 that is emitted by Ships' exhausts. This encouraged the development of green ships. In his research, he highlights that the integration of a solar PV system in a large sea-going vessel does not only involves the Ship's power system but the structure of the hull and the safe operation of the ship. When one intends to integrate PV solar power on the ship, the arrangement and installation of the solar PV panels must be considered as it could impact the safe working spaces or be in way of machinery equipment, pipelines, and passageways.

Likewise, solar energy power can be used to power propulsion systems in the ship. It can be used as a hybrid by combining it with the ship's diesel generator which already exists on the Ship or is used as the only electrical energy supply to handle all loads on the ship. However, the hybrid system is suitable for bigger Ships due to the space that is required for all required components and to overcome load requirements. Standalone solar energy power can work better on small ships (Kurniawan, 2016). When a ship departs or enters the port, its power demand varies due to the switching on/off of the electrical systems. This is due to a change in load power requirement. But, when the ship is at sea, and sailing under normal conditions power requirements become stable. At this point, it is where solar power energy can be efficient to power the ship's electrical systems. However, the output power of PV solar power may vary due to the change in direction of the ship. This change in direction affects the intensity of the solar radiation on the PV solar panels. Kurniawan (2016) in his experiment integrated solar power energy with diesel generators, which can compensate for the variation of solar power due to changes in output power. He determined that this hybrid system reduces fuel consumption and CO2 emissions significantly.

As Lan, et al. (2016) modeled and analyzed, They also determined that though the solar irradiation is static, the output power of the solar PV modules onboard the ship will vary with the ship's movement. i.e. roll yawl, pitch, and heading direction. In 60 seconds the solar irradiance varies from 700 to 1010w/m2 as the Ship moves in different movements. This creates a change in power generation. In 3 cases that he modeled, he indicates the impact of integrating solar PV power generation and FESS into the ship power generation system.

Installing a solar PV system on the ship provides some kind of relief to the owners or operators as it reduces the fuel costs and maintenance costs on the diesel generators and the CO2 emissions. However, the solar panels are installed on the superstructure of the ship and are directly exposed to the elements. At sea, they are exposed to seawater which has high concentrations of salt. The salt particles can cause a layer on the panels as sea water splashes on them. The layer of salt particles affects the solar PV power output as it reduces the solar irradiance on the panels. The output can reduce by 6% due to the layer of salt particles formed on the PV panels. There are means of solving this challenge (Zhang and Yuan, 2021).

Solar PV power systems are also usable in inland ships (Ma, et al., 2019). He analyzed the efficiency of solar PV energy on steel flat-top passenger ship which is widely used in rivers. His results conclude that solar PV systems are suitable to be used on inland Ships. There is a range of specialized and flexible solar PV modules that can withstand harsh conditions at sea. Amongst these PV modules, some can be installed with marine-grade frames. These are suitable PV modules and frames for a range of ships with different sizes and purposes. Therefore, the type of solar PV to be installed must be considered thoroughly before installing them (Eco Marine Power).

There are other countries like India and the United States of America that are already moving into renewable energy. Indian Navy has installed a solar PV power generation system on its Ship. The move sees the Indian Navy saving on maintenance costs for diesel generators. Solar power is reliable and efficient for power communications systems, general lighting, and battery change onboard the ship, as seen in figure 2.3 (The Economic Times News, 2017).

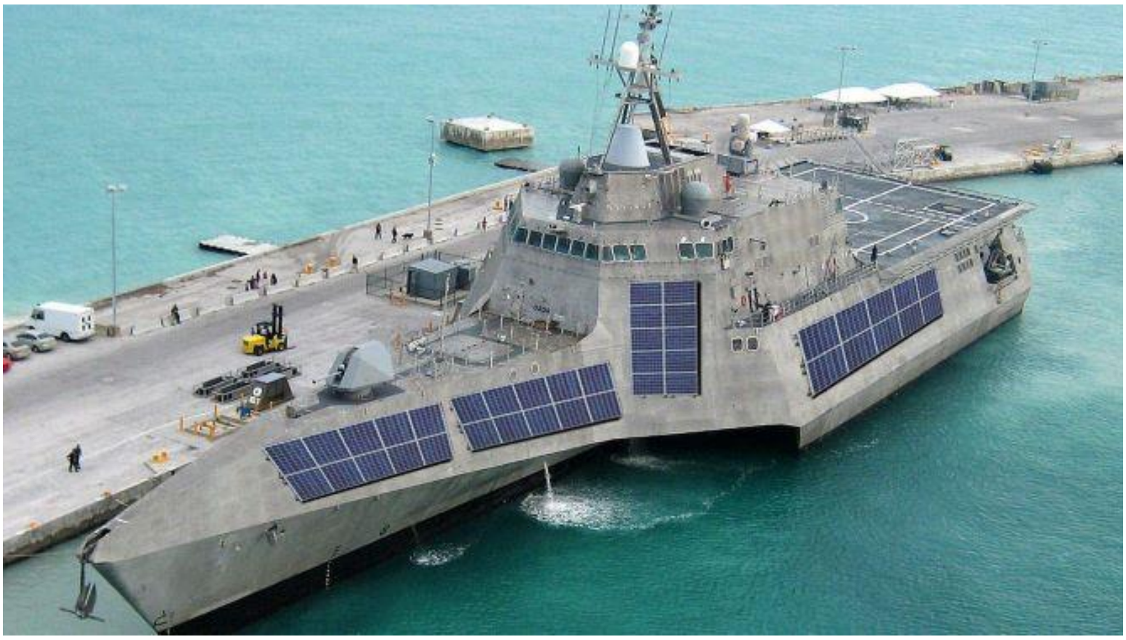


Figure 2.3: Image of Indian Ship INS SARVEKSHAK (**The Economic Times News, 2017)**.

2.4.2 WIND POWER GENERATION

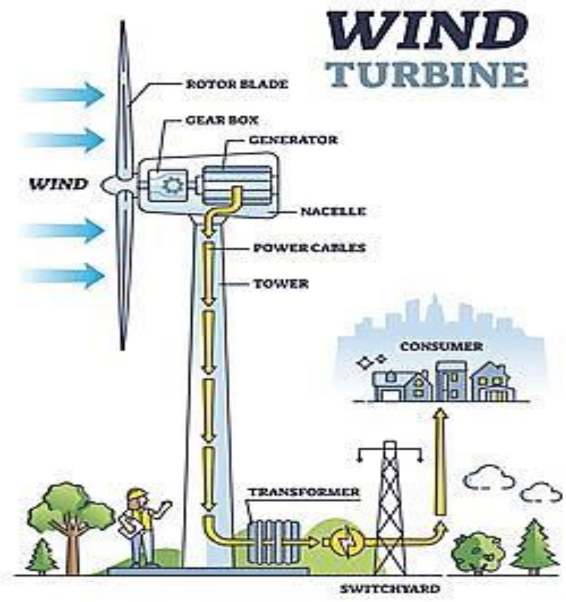


Figure 2.4: Typical wind turbine (**How do wind turbines work?)**

Wind power generation is the principle of turning wind energy into electricity. This takes place through aerodynamic force from the rotor blades. When the wind flows through the blades of the turbine, they turn the shaft which turns the generator. Electricity is then generated and supplied to the end users through a transformer as seen in figure 2.4 (How do wind turbines work?). The turbines can also be installed on the ships even though there is a very little literature review. Some researchers have shown some interest and options as seen in figure 2.5. But looking at the structure of the turbine, it could affect the structure of the ship negatively. The wind turbine must be at a certain height to allow for blades to turn, therefore having an extended structure on the ship and taking into consideration the winds out at sea could result in the Ship's structure being damaged. The Ship's stability can also get affected (Carlso and Nilsson, 2015).

Figure 2.5: Example of typical wind turbines installed on the Ship **(Carlso and Nilsson, 2015)**

At sea, wind becomes an abundant natural resource, especially since there are no mountains and heals which affect its flow. This is an advantage for generating electrical power for the ships while at sea. Wind electrical power generating systems can be integrated into the Ship's main grid bus system. Using different methods of harvesting wind at sea assists in determining the best method to be used on the ships. These methods use types of wind turbines such as Horizontal axis wind turbines (HAWT), Savonius, Darrieus, and H-Rotor turbines as seen in figure 2.6. Depending on the size, requirements, and design of the ship, any of the types can be used.

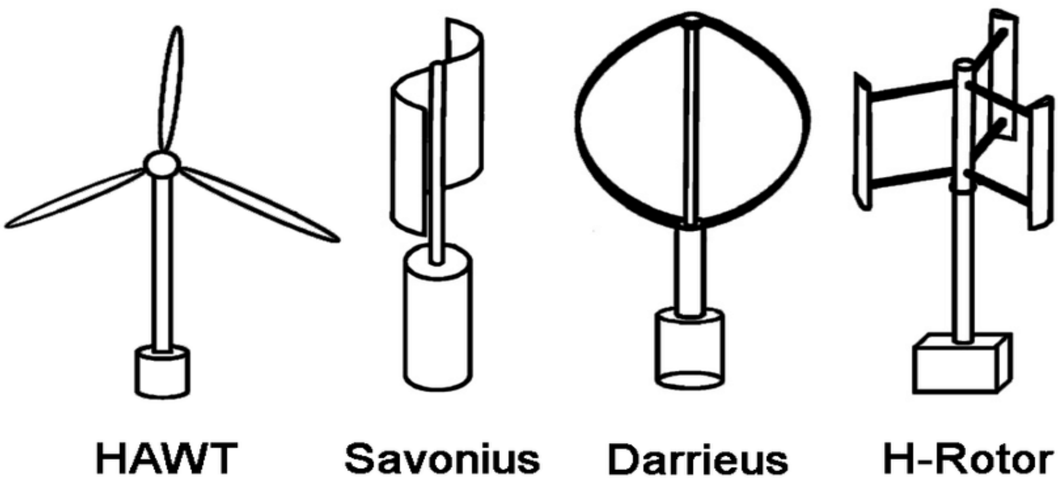


Figure 2.6: Typical Methods of harvesting wind at sea **(Kozak, 2014)**

2.4.3 NUCLEAR POWER GENERATION

The electricity in Nuclear power generation is generated when the steam turns the turbine which turns the electrical generator. The steam is created in the process of chemical chain reaction in the reactor. The water that is pumped from the heat exchanger collects thermal energy. The hot water from the heat exchanger transfers the energy to the cooler water which is in the closed loop with a steam turbine. The generated steam blows onto the turbine vanes and makes them turn and create kinetic energy. As seen in figure 2.7.

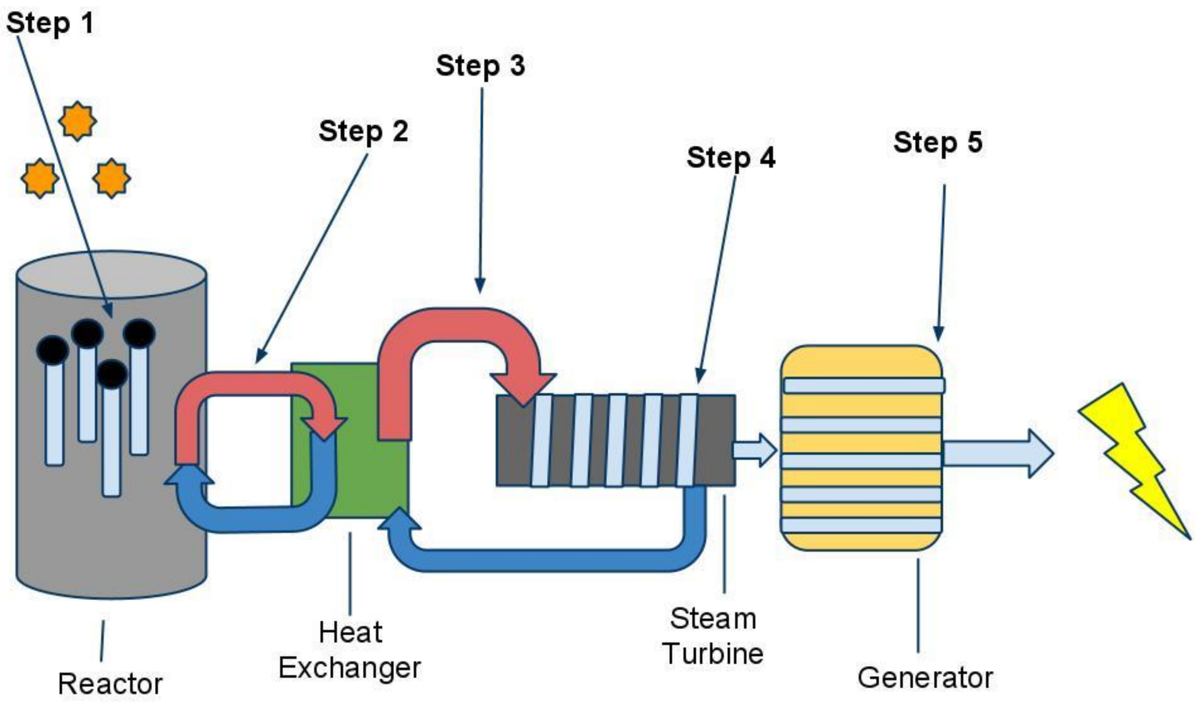


Figure 2.7: Typical Nuclear power generation diagram (Corr, 2010)

Nuclear power generation is already been used on ships and submarines and has been used for decades, especially in the military. Many countries use nuclear power in their naval ships and submarines, like Russia which has the nuclear power on its ships and submarines since the 1950s. Also, countries like the United States of America, India, and France use nuclear power generation on their naval ships and submarines (World Nuclear Association, 2021).

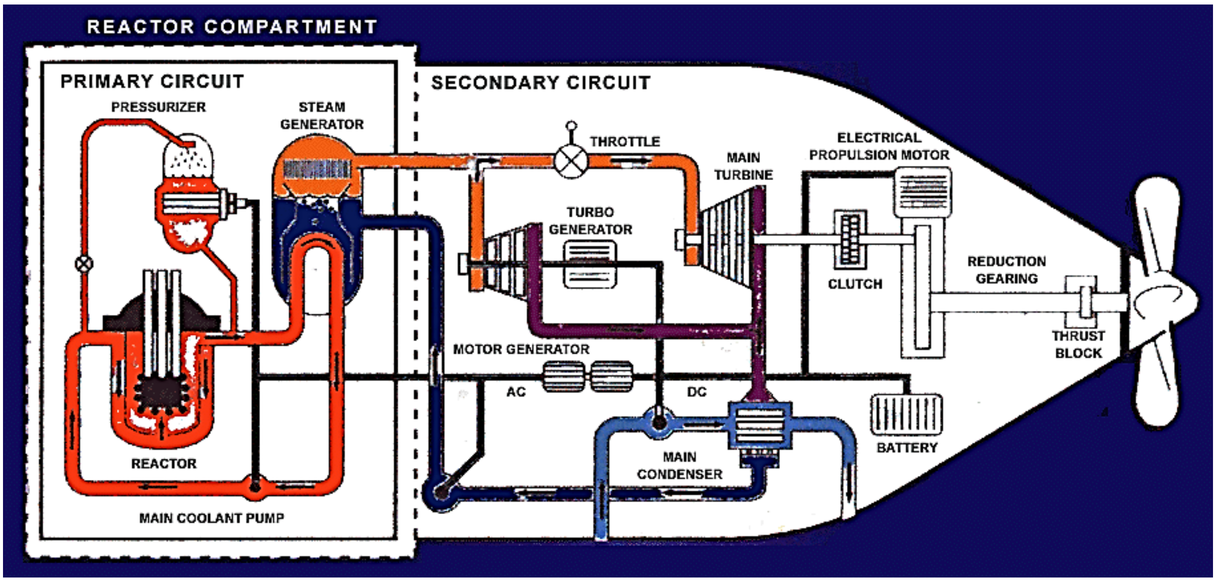


Figure 2.8: Typical nuclear power on a submarine (**World Nuclear Association, 2021**)

2.5 SOLAR TRACKING AND METHODS

Seme, et al. (2020) reviewed that tracking systems (single and dual-axis) are the future of solar energy power generation. Even though their operation and maintenance (O&M) costs are more than that of standard tilt photovoltaic systems due to moving parts, investing in a solar tracking system ensures maximum power generation from the sun. He further reviewed driving systems for tracking systems. They discussed the active and passive tracking systems, where active uses electrical drives and mechanical assemblies to operate, and passive use pressure differences of special liquids or gases. In their review, they further broke down the tracking systems into:

Single-axis tracking system has 3 different types which are:

- horizontal single-axis tracking system (HSAT,
- Vertical single-axis tracking system (VSAT), and
- Tilted single-axis tracking system (TSAT).

Dual-axis tracking system is divided into two types:

- Tip-tilt dual-axis tracking system (TTDAT), and
- Azimuth-altitude dual-axis tracking system (AADAT)

A review of solar tracking and types of sun tracking systems is discussed in (Whavale and Dhavalikar). A fixed panel system that is positioned with a tilted direction based on location, a single-axis tracking system that moves from east to west and allows solar radiation to be perpendicular to the panels, and a dual-axis tracking system that enables panels to move in both east-west and south-north directions for a maximum amount of sum radiation.

2.6 SOLAR TRACKING SYSTEMS

Salgaonkar, et al. (2017) Discussed the dual-axis tracking system. This tracking system allows the solar panels to remain as perpendicular to the sun's rays as possible and thus maximize stable energy generation. It allows the panels to follow the sun via azimuth altitude and adjust themselves every time without human intervention. (Salgaonkar, et al., 2017), in their experiment, used light-dependent resistors (LDR) to track the sunlight and give a signal to the main circuit for the panels' motion.

Furthermore, Kuttybay, et al. (2020) discussed the single-axis tracking system. Single-axis tracking system uses a vertical axis of rotation. He compared the output results of a single-axis tracking system with that of a stationary PV installation. He conducted his experiments under various weather conditions. His results indicated that the efficiency of single-axis in sunny weather and cloudy/rainy weather is better as compared to stationary PV installation

2.6.1 Single-axis tracking systems

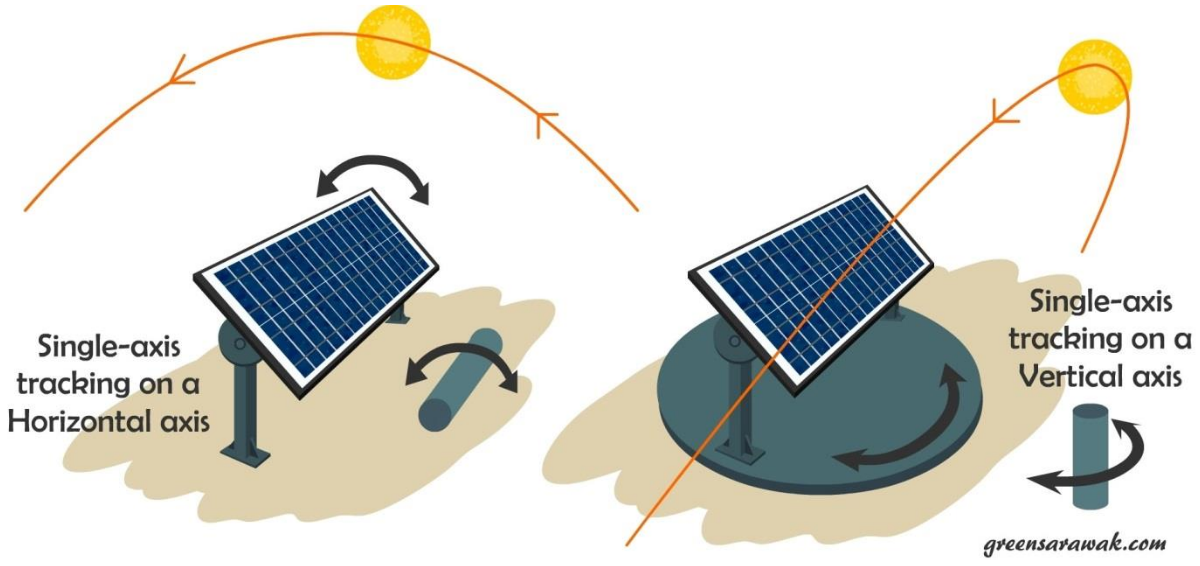


Figure 2.9: Single-axis tracking systems on a Horizontal and Vertical axis (**Solar Reviews, 2022**)

2.6.2 Dual-axis tracking systems

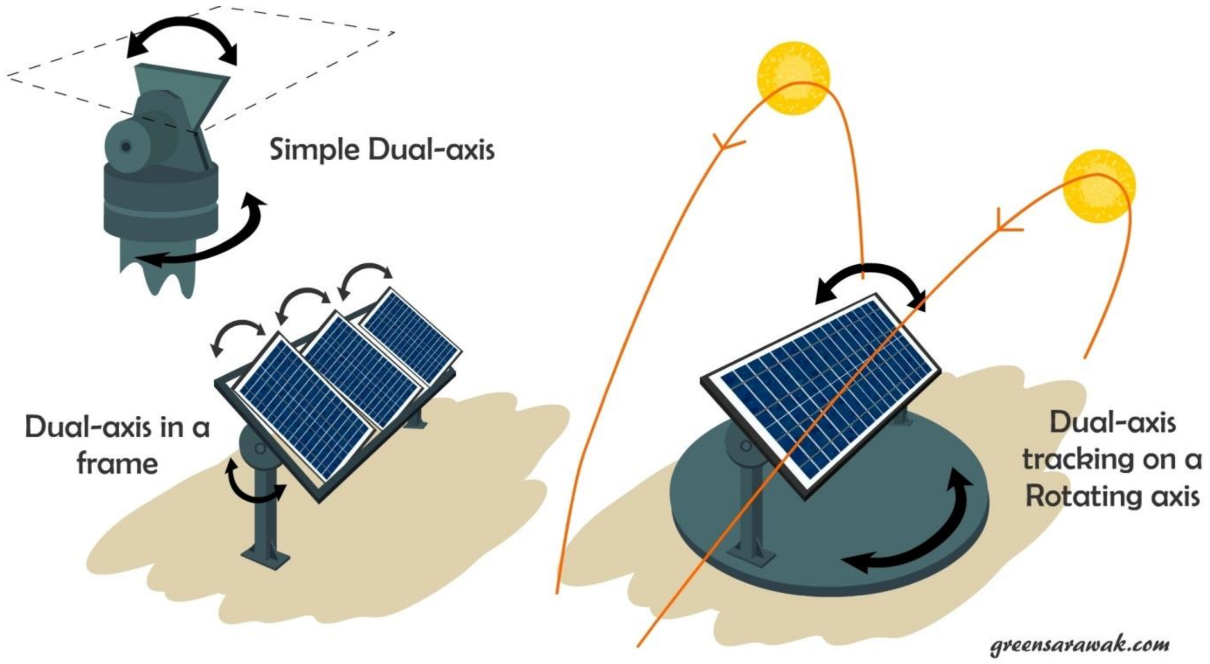


Figure 2.10: Dual-axis tracking systems (**Solar Reviews, 2022**)

2.7 GLOBAL POSITIONING SYSTEM (GPS) RECEIVER

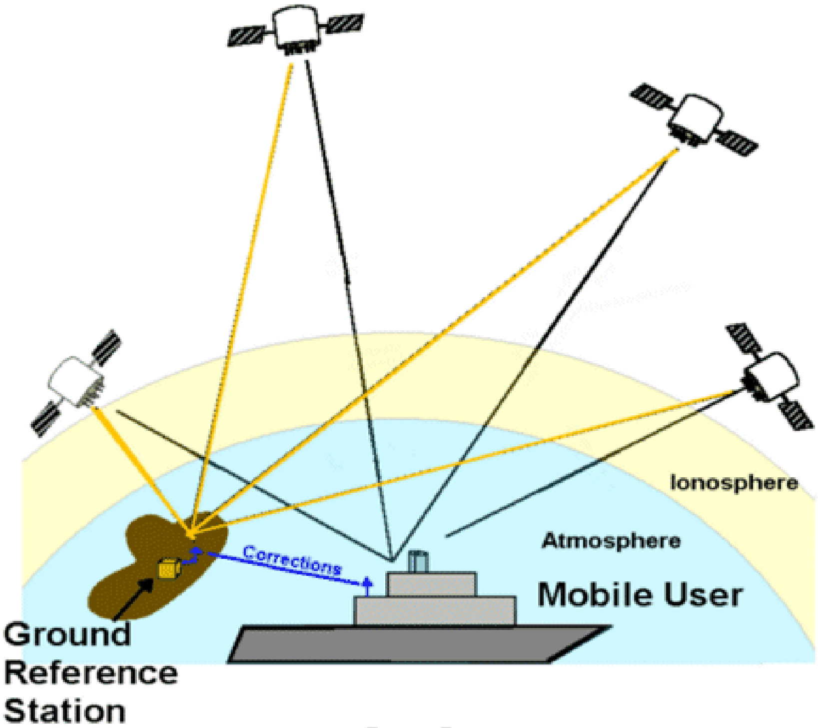


Figure 2.11: Global Positioning System receiver setup (**Clynch, 2001**)

GPS receiver receives a signal from at least four satellites, to determine its time and location. This signal contains data that enables the receiver to make adjustments for an accurate location. To calculate the distance, the receiver uses the time difference between the broadcast time and the reception time from the satellite to the receiver. The receiver avoids the need to use the atomic clock in the satellite by using the fourth satellite to calculate latitude, altitude, and time (Federal Aviation Administration).

GPS can keep the sun tracking system facing and tracking the sun, even if the geographical location of the panels' changes. As experimented by (Altayeb, et al., 2018)

2.8 SOUTH AFRICAN ECONOMIC EXCLUSIVE ZONE (EEZ)

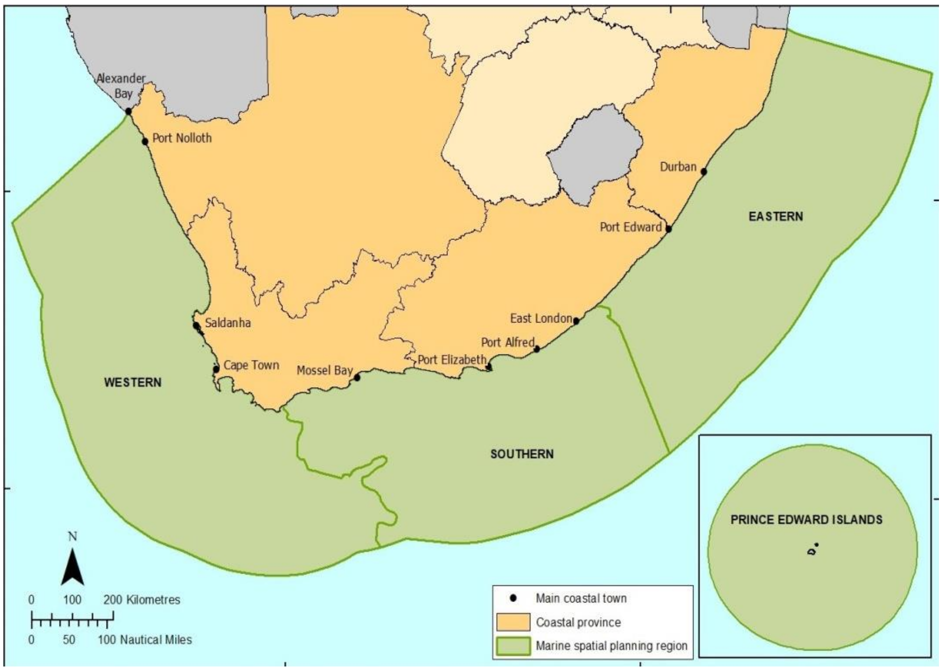


Figure 2.12: South African Economic Exclusive Zone (EEZ) (Operation Phakisa. Marine Spatial Planning)

South African EEZ is the zone from the shoreline to out to sea where South Africa has jurisdiction over natural resources. This area is where South African military ships will operate to patrol, enforce marine laws and protect marine resources.

2.9 CARBON DIOXIDE (CO2) EMISSIONS

Carbon Dioxide (CO2) causes damage to the climate and the need to reduce GHG emissions is the main priority. [3] In his research, he explains how the introduction of Li-ion batteries to the ship power system would assist in the reduction of CO2 emissions. He further explains that shipping account for 2% of global CO2 emissions. Between 1990 and 2010 only, maritime emissions increased by 3% per year, which is higher than GHG emissions of 1.1% per year. In his simulations, taking into consideration the capital costs, replacement costs, operation & maintenance (O&M) costs as well as stored energy, he was able to show that using Li-ion batteries assists in reducing CO2 emissions and fuel costs (Peralta, et al., 2019).

As per the South African Maritime Safety Authority (SAMSA) report (South African Maritime Safety Authority), South Africa is also taking part in mitigating GHG emissions by ships. It is an active member of IMO. Therefore, it is crucial to have its Navy's ships also implement other means of generating electricity that will not emit GHG.

As discussed by Olmer, et al. (2017), fuel consumption by the shipping industry increased from 291 million tons to 298 million tons (2.4%) between 2013 and 2015. This simply indicates how much Ships owners are spending on fuel and indicates the amount of CO2 emitted. IMO regulations require that all new ships should be built in such a way that they emit less CO2. However, as long as they still use fossil fuels, they emit CO2.

2.10 SUMMARY

The background of the electrical generation on the Ships is deliberated in this chapter. The use of diesel generators as means of electric generation in the Ship, especially in military Ships included. The use of renewable energy in military Ships of some countries is also elaborated. Discussed also are the types of renewable energies that can be used on the military Ships as well as the preferred renewable energy generation for SA Naval Ship. In relation to the literature review, which indicates that there is a rare use of renewable energy on military Ships and that none of the SA Naval Ships uses it. This study shows the benefits of integrating renewable energy into the SA Naval Ships' power generation. Therefore, contribute to the literature as it will give future researchers ideas to further studies in renewable energy in military Ships.

Chapter 3 RESEARCH METHODOLOGY

In this chapter, the research design and methodology that was used to gather data compare results, and draw conclusions for the study is described. The study was influenced by the observed problem in the South African Naval Ships. Hence the study is to address the continued use of fossil fuel to generate electrical power for the ships in the SA Navy, which contributes to the fuel cost incurred, maintenance costs, and contribution to the emissions of toxic gases. This method will assist in answering the standing question of what type of photovoltaic solar energy tracking system would be suitable to be used on the SA Navy ship.

The main objectives of the study are to identify which suitable solar energy tracking system could be installed on the South African Naval Ship and proof that solar energy can supply enough power for the war Ship's power demand. Also to indicate that solar energy could reduce CO2 emissions, fuel, and maintenance costs on the Ship's diesel generators.

3.1 MOVING PLATFORM SELECTION (MILITARY SHIP)

In this study, a SA Naval Ship, SAS DRAKENSBERG is used as a reference for the military Ship's power requirement, Fuel usage, and toxic gas emissions. The Ship's superstructure design and power requirements allow for possible solar power energy integration. It has enough space on the upper deck to install solar PVs. On its flag deck and antenna deck, there is flat and less used space. These areas are directly above the sections where the main switchboard room is. This means that it would be easy to run the cables from the solar panels to the switchboard room where they will be connected to the Ship's main busbar via the switchover breaker. The Ship is depicted in figure 3.1 below.

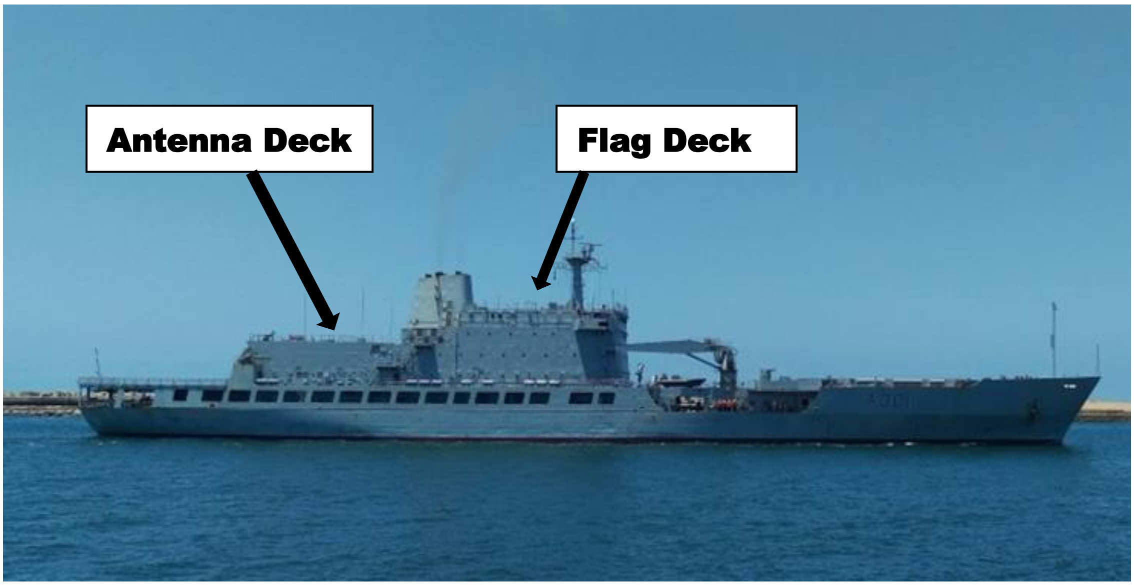


Figure 3.1: SA Naval Ship SAS DRAKENSBERG (**SA Naval Ship SAS DRAKENSBERG**)

3.2 RESEARCH DESIGN

The study is based on the desktop approach which uses modeling software. The hybrid Optimization Model for Multiple Energy Resources (HOMER) software is used in the study. This software is the global standard for optimizing microgrid design in all sectors. That is from residential utilities to grid-connected campuses and military bases (HOMER Software). The software enables one to download meteorological data for a specific location from global data. One can also model at any location including at Sea.

The perspective of this study is to develop sun-tracking systems for solar power generation that will be suitable to be installed on a moving platform which is the military Ship for this study. And also be able to satisfy the load requirement for the Ship's load demand at Sea and in the harbor. With this green alternative power producer, the Ship should be able to reduce the emissions of toxic gases, reduce the usage of fuel for diesel generators and reduce costs on operational and maintenance. The power output of the solar panels depends on the sun rays exposure at each location.

HOMER application has many components in its library to choose from when modeling the design. In this study, the solar PV with specifications as shown in table 3.1 was chosen. To ensure a complete system to enable the software to simulate, the components were modeled as shown in figure 3.2. The industrial load was chosen since the load demand of the Ship is similar to this load demand. The model was set up in such a way that the solar PV power production is measured daily with the daily load demand.

Name	Studer VarioString VS-120
Abbreviation	VarioString VS-120
Panel Type	Flat plate
Rated Capacity (kW)	680.08
Temperature Coefficient	-0.41
Operating Temperature	45
Efficiency (%)	17.3
Manufacture	Studer Innotec SA

Table 3.1: The Solar PV Specifications

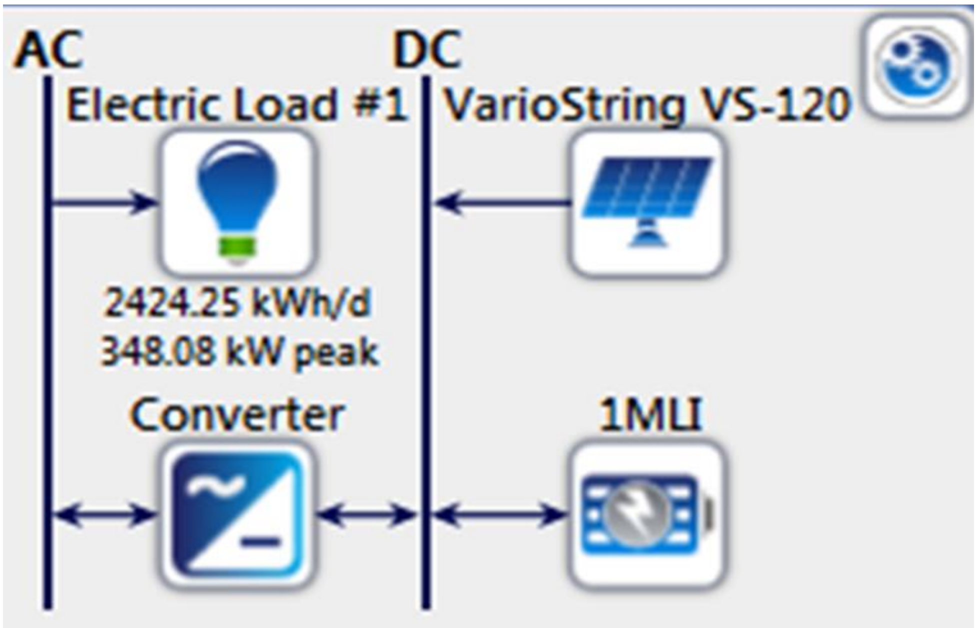


Figure 3.2: Modelled solar PV power production

The model of a diesel generator is also simulated in the study to compare its power output with that of solar power. The schematic of the model is shown in figure 3.3. The generic GenSet with a similar rated power of 450 kW, as the generators that are used on the Ship is used. In the model, the similar load that was to be served by the generator is the same as the one that would be served by the solar power generator.

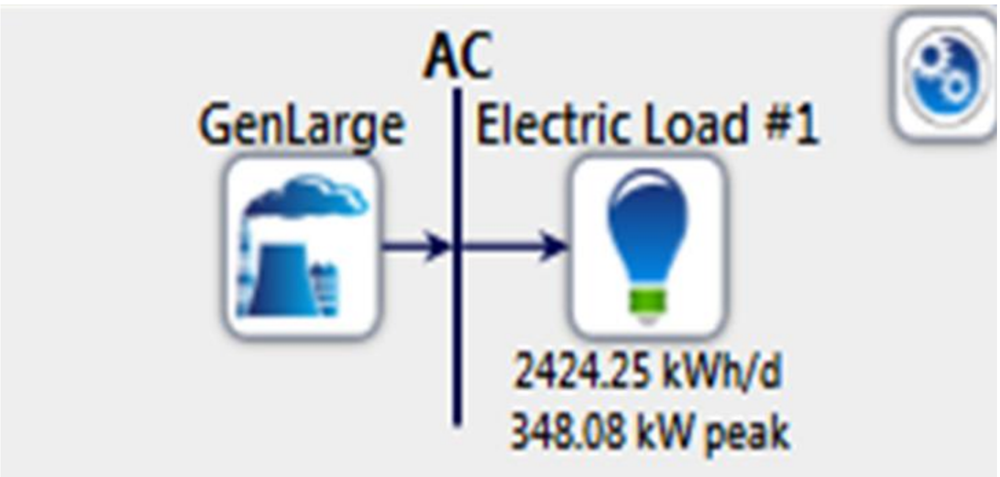


Figure 3.3: Diesel Generator power production model

The simulations of the models are conducted in different locations, specifically the simulations of solar PV power. The simulations of the diesel generators are conducted in the harbor, due to the fact that the usage for when the Ship is in the harbor and when at Sea, gives the same power requirements. HOMER software has no GPS integration and movement of the Ship capability. Hence I placed the Ship in different locations at Sea. I identified the locations according to the temperature profiles of these locations. In the simulations, I set the sun tracking system to continuous tracking to accommodate for the movement of the Ship while at Sea.

The first simulations are conducted with the Ship in the harbor. To determine that solar PV can produce power while the Ship is placed in the harbor. In the harbor, I placed the Ship in two different locations, Inner and Outer basins. These are the common locations where this Ship would be placed while in the harbor. Indeed the solar PV produced sufficient power to serve the load demand as modeled. The expectation was to observe the power production as produced by solar PVs. Furthermore, to determine the solar PV power production at Sea, I Placed the Ship in different locations in the SA's EEZ (see figure 3.4) and in the Mozambique area. These are the typical areas where the Ship would operate while at Sea.

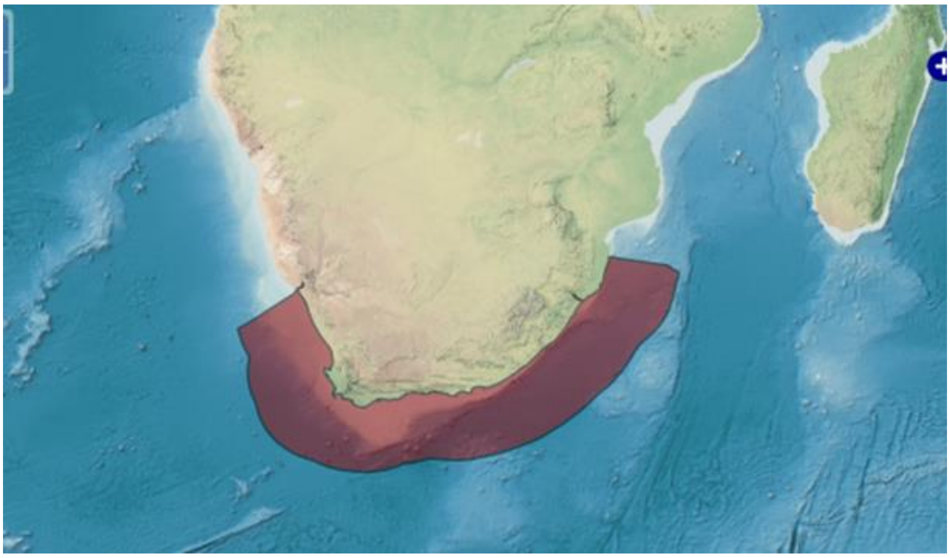


Figure 3.4: South African Economic Exclusive Zone (Marineregions.org)

Within the SA's EEZ I divided the areas into three sides; Western, Southern, and Eastern side. I then placed the Ship in the different locations on these sides using GPS coordinates. The intention of placing the Ship in different locations is to simulate the movement of the Ship with the solar panels installed. The simulation results yielded that with the differences in temperature in these areas, solar PVs were able to produce sufficient power to serve the load. I modeled the system to simulate the power production yearly and the served to load be calculated yearly.

3.3 RESEARCH METHODOLOGY

To achieve reliable and accurate results, correct data must be acquired from reliable sources. The sources include datasheets, technical manuals, subject matter experts, modeling software, etc.

3.3.1 Data

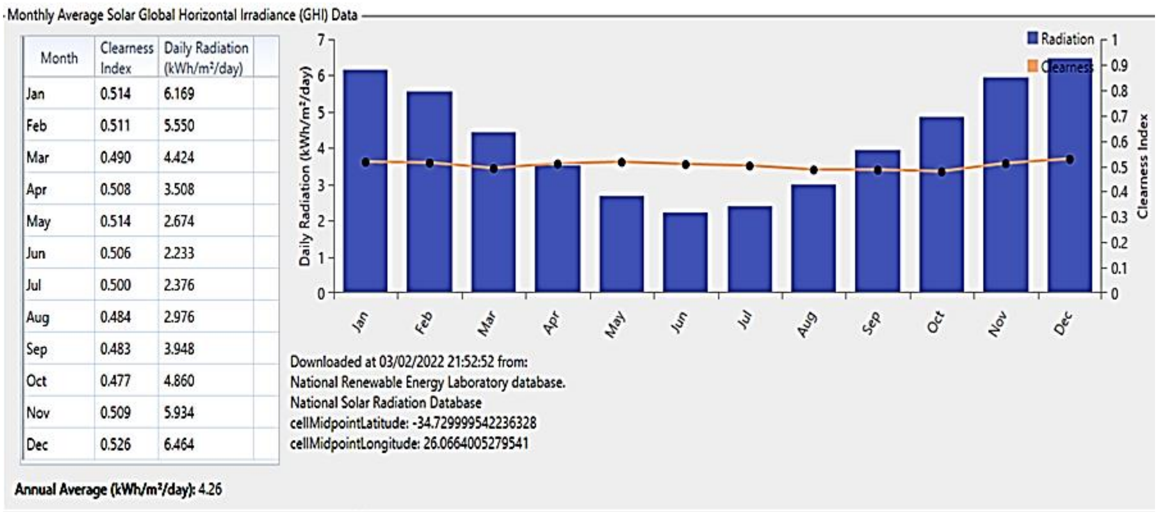
The data that is utilized for the success of this study is acquired from the Ship's technical manuals and HOMER software. The data that is acquired from the Ship's technical manuals is that of the diesel generators that are used onboard the Ship. The Ship uses the diesel generator with specifications as shown in table 3.2. The Ship's dimensions are also in the technical manuals. Therefore, the dimensions of the flag deck and antenna deck are acquired.

Name of Manufacture	AB VOLVO PENTA
Type	VOLVO PENTA NEMA MG1-32
Rated Power (kW)	449.6
Rated Power Factor	0.8
Rated Frequency (Hz)	60
Rated Voltage (V)	450
Rated Current (A)	706
Mass (kg)	3 926
Fuel Consumption (l/hr)	100
RPM	1800
Phase	3

Table 3.2: Ship's Diesel Generator specifications

Solar PV panel's data is acquired from the HOMER software library, and the panel specifications are shown in table 3.1. For the solar panels to generate electricity, they must be exposed to sufficient sun irradiance. The meteorological data for the different locations where the Ship was placed is acquired from National Renewable Energy Laboratory Database and National Solar Radiation Database. Both these database sources are accessible through the HOMER download option during the simulations. For every location where the Ship was placed, the solar radiation profile for that specific location was downloaded and simulates the results for the location. Figure 3.5 below depicts where I placed the Ship in the Port Elizabeth area, and before I simulate I downloaded the solar radiation. The solar radiation that is downloaded is shown in figure 3.6 below.

Figure 3.5: The location where the Ship is placed in Port Elizabeth area



Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.514	6.169
Feb	0.511	5.550
Mar	0.490	4.424
Apr	0.508	3.508
May	0.514	2.674
Jun	0.506	2.233
Jul	0.500	2.376
Aug	0.484	2.976
Sep	0.483	3.948
Oct	0.477	4.860
Nov	0.509	5.934
Dec	0.526	6.464

Figure 3.6: Solar radiation as downloaded from National Renewable Energy Laboratory Database and National Solar Radiation Database

I performed the same data downloads for every location where I placed the Ship. I had to perform this for every location due to the difference in meteorological data for each location, even though the simulations are done in SA's EEZ which is part of two oceans; the Atlantic and the Indian Ocean.

3.3.2 Research equipment

For the purpose of this study and for it to be a success, I chose to use HOMER software for modeling and simulations. HOMER allows for the change of location and enables one to download solar irradiation data for each specific location. Since in this study I used the military Ship, I was able to place it in different locations at Sea in HOMER software. I was also able to model and simulate the Ship's diesel generator. I used SAS DREAKENBERG, a SA Naval supply and support Ship's electrical generation data. The Ship is depicted in figure 3.1.

3.3.3 Analysis and presentation of results

To be able to simulate the modeled system in HOMER software, a whole system must be modeled even though the focus is on solar PV power production. The model includes the battery, Converter, load and solar PVs, as shown in figure 3.2. Therefore, the simulation results show the reaction of all components in the model. Amongst the results are system electrical production per year, Renewable penetration, Battery storage data, and the PV power output profile in a year, the Converter capacity data, and emissions.

For purpose of this study, in these results, I required the system power production per year, System cost which includes capital cost, operation and maintenance cost, and replacement cost in one year. I also required emissions. I also required the diesel generator's power output, fuel consumption, operation and maintenance cost, capital cost as well as emissions. I extracted this data from HOMER software simulated results and presented the data with tables and graphs to be able to compare them and determine if I have achieved the desired results.

3.3.4 Limitations

In the study, I used the military Ship, and as per the approved permission to conduct the study using this Ship. I was only allowed to use the information from the diesel generator up to the main switchboard rooms. The power distribution to the end users within the Ship as well as the power distribution drawings are not used or discussed in the study. However, with the success of this study, permission to further conduct the study using the whole power generation and distribution within the Ship may be requested for future studies, in the perspective of a Ph.D. degree.

With many modeling softwares considered, HOMER was the best for this study. However, it does not have the capability of modeling the GPS-integrated solar power generation system. Hence the Ship was manually moved from one location to another with the continuous sun tracking system.

3.4 SUMMARY

The initial part of this study aided in determining the suitable software to model and simulates the solar PV power output on the Ship as well as the Ship's diesel generator power output to be able to compare both systems' output. This includes acquiring the Ship's load demand, fuel usage, and diesel generator upkeep costs. The complete design of the research is based on simulating solar PV power generation on the Ship to determine that solar PV when installed on the Ship, they can produce sufficient power to serve the Ship's power load.

To achieve that data for a suitable PV panel with relevant rated power had to be identified from the HOMER components library. A diesel generator with similar specifications as the one that is used on the Ship had to be identified for the model. To be able to show that solar PVs can produce power for the Ship, simulation results data had to be analyzed and be presented to be compared with the generator's power. As per any study, there were limitations in this study whereby the HOMER software could not model GPS integrated system, and the only data that was allowed to be used for the Ship limited. However, the results were able to be achieved.

Chapter 4 SIMULATION RESULTS OF THE MODELED DIESEL GENERATOR AND PV POWER GENERATION ON SHIP

This chapter reports on the simulation results of the modeled solar PV power generation on the ship. HOMER application is used for modeling and simulations. The simulation results are used to compare the solar PV power generation at sea in the South African EEZ, which is the mandated area of operation for SA Navy ships. The results of the modeled typical diesel power generation will also be reported. Power output for diesel generators will be compared to solar PV power generation.

Due to the limitation of the HOMER application, i.e. not being able to model and simulate GPS integration in the system, the research had to be based on different zones within SA EEZ. To simulate the movement of the ship at sea, different coordinates around the SA coast line had to be used. The coordinates are separated by areas; Western, Southern, and Eastern of SA. The simulation results are presented and summarized graphically, tabulated, and in charts.

4.1 SHIP'S DIESEL GENERATOR POWER GENERATION

A diesel generator for a ship is modeled in the HOMER application and simulated to learn how much power it produces on a full-load power requirement. Fuel consumption, as well as toxic gas emissions, are also observed. The fuel consumption of the actual generator that is used on the SA Navy ship is also shown. The Ship uses four generators and one emergency generator. As seen in figure 4.1, each actual generator consumes over 100l/hr of fuel at 100% load. Therefore, with four generators running at the same time, over 400 liters will be consumed per hour. Volvo Penta NEMA MG1-32 with power rating 449.6kW, 450V and 60Hz is used onboard the SA Navy ship.

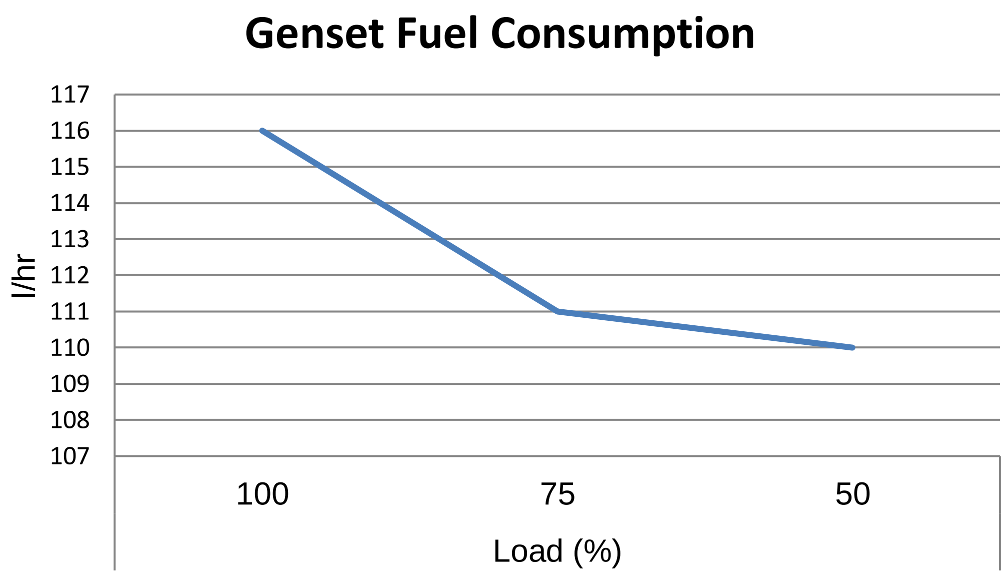


Figure 4.1: Volvo Penta NEMA MG1-32 Diesel generator fuel consumption

In figure 4.2 the research depicts the fuel consumption of a simulated generator. A diesel generator with similar specifications is modeled and simulated. As seen in figure 4.2, the fuel requirement for power generation is calculated on monthly basis use. It is shown that the more power produced the more fuel is required as seen in figure 4.3 which depicts the power generation on monthly basis throughout the year. The results are for only one generator.

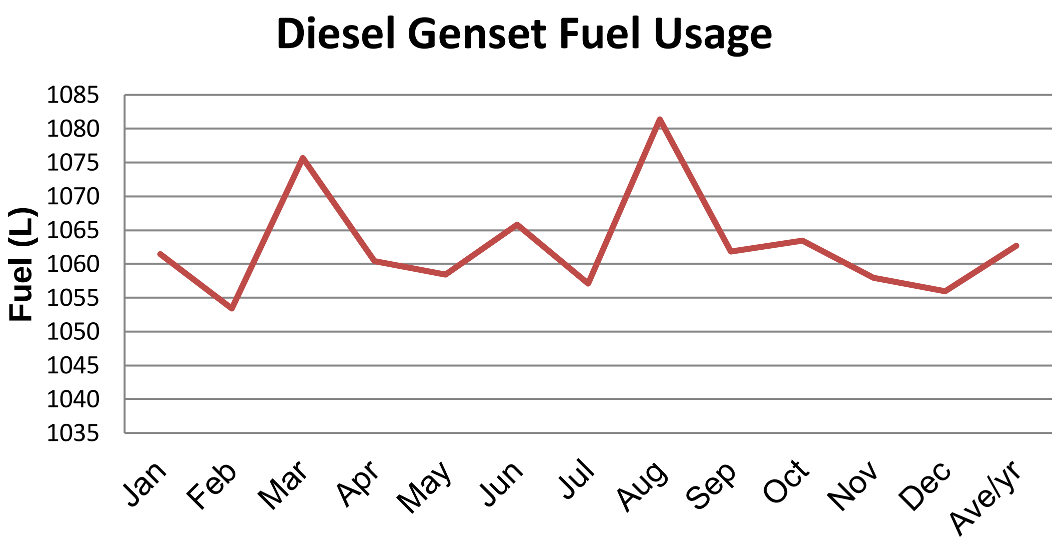


Figure 4.2: Diesel generator simulated fuel usage

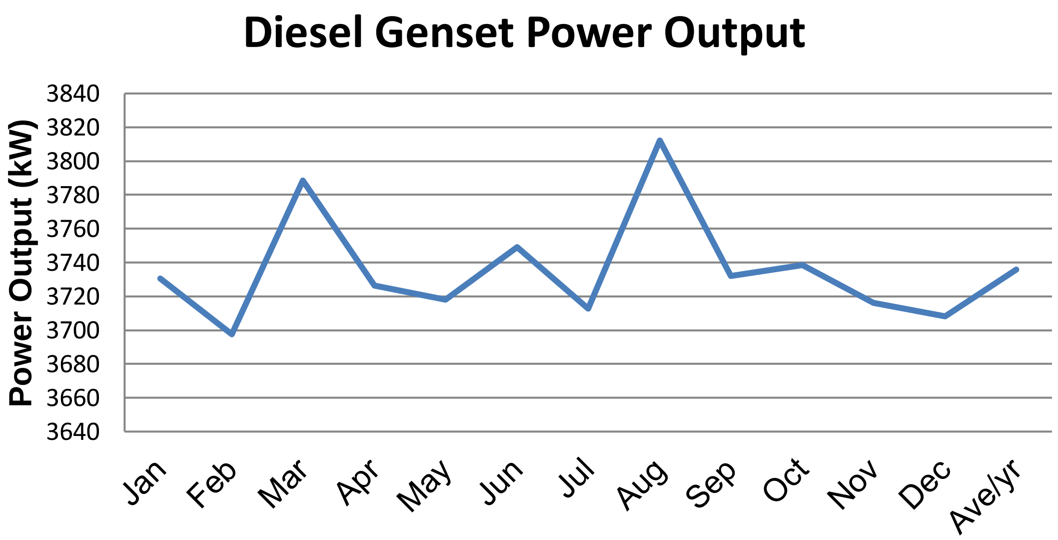


Figure 4.3: Diesel generator simulated power output

Table 4.1 below and figure 4.4 depict the Diesel Generator power production profile. The results in the table are for a generator that would be operated for a year.

Quantity	Value	Units
Hours of Operation	8,760	hrs/yr
Number of Starts	1	starts/yr
Operational Life	1.71	yr

Capacity Factor	34.6	%
Fixed Generation Cost	362	R/hr
Marginal Generation Cost	4.98	R/kWh
Electrical Production	1,363,859	kWh/yr
Mean Electrical Output	156	kW
Minimum Electrical Output	135	kW
Maximum Electrical Output	348	kW
Fuel Consumption	387,970	L/yr
Specific Fuel Consumption	0.284	L/kWh
Fuel Energy Input	3,817,621	kWh/yr
Mean Electrical Efficiency	35.7	%

Table 4.1: Diesel Generator Power production profile

Quantity	Value	Units
Hours of Operation	8,760	hrs/yr
Number of Starts	1.00	starts/yr
Operational Life	1.71	yr
Capacity Factor	34.6	%
Fixed Generation Cost	362	R/hr
Marginal Generation Cost	4.98	R/kWh

Quantity	Value	Units
Electrical Production	1,363,859	kWh/yr
Mean Electrical Output	156	kW
Minimum Electrical Output	135	kW
Maximum Electrical Output	348	kW

Quantity	Value	Units
Fuel Consumption	387,970	L
Specific Fuel Consumption	0.284	L/kWh
Fuel Energy Input	3,817,621	kWh/yr
Mean Electrical Efficiency	35.7	%

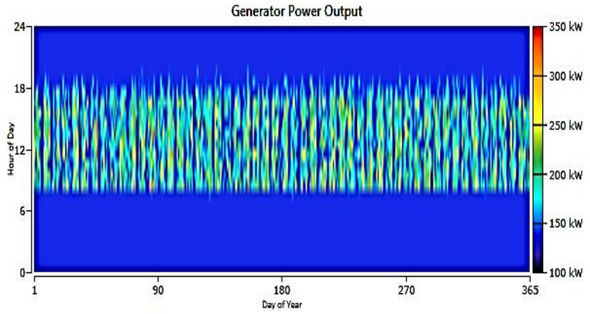


Figure 4.4: Simulated Diesel Generator Power Production

The generated power as shown in table 4.1 and figure 4.4 has to provide power to the load. The load profile that is simulated is depicted in figure 4.5 and further tabled in table 4.2. The load results include AC and DC loads, the deferrable load, excess electricity, unmet electric load, capacity shortage, renewable fraction, and maximum renewable penetration.

Consumption	kWh/yr	%

AC Primary Load	884,852	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	479,007	35.1
Unmet Electric Load	0	0
Capacity Shortage	0	0
Renewable Fraction	0	0
Max. Renew. Penetration	0	0

Table 4.2: Diesel Generator electrical Load profile

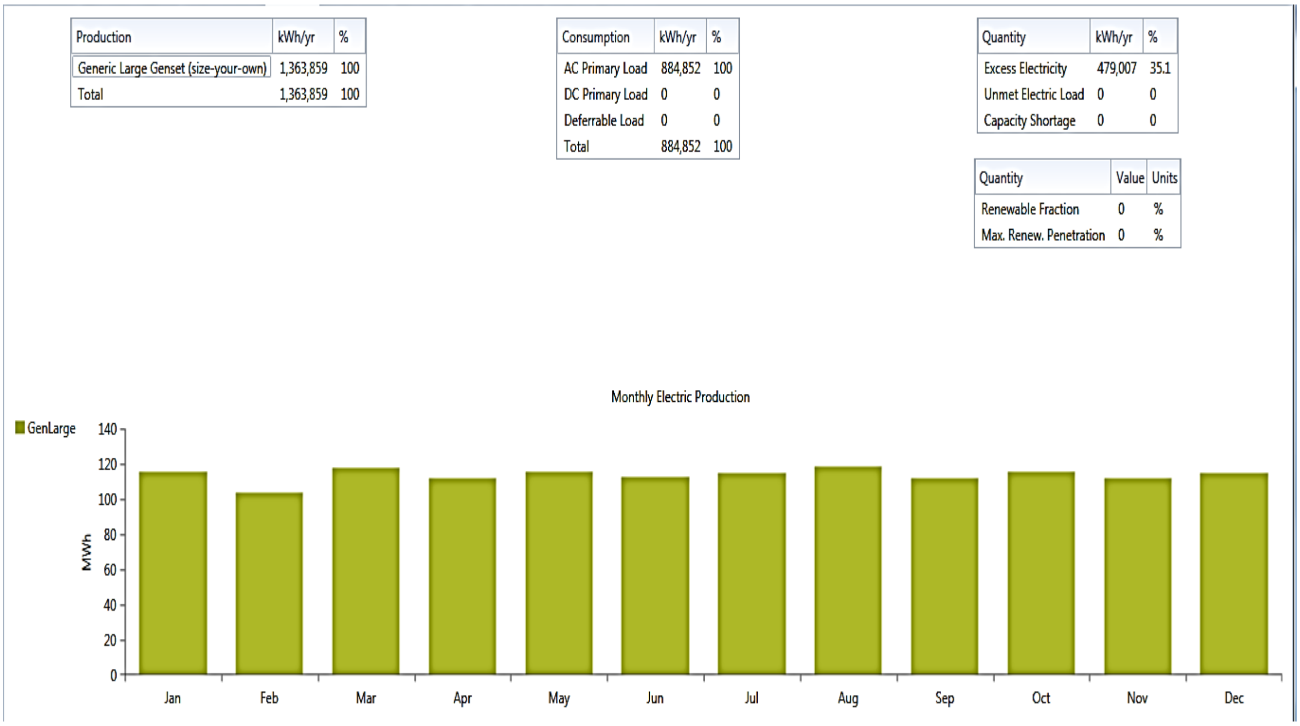


Figure 4.5: Simulated Diesel Generator Electrical Power Production and Load served

Diesel generators use combustion engines that burn diesel to turn the generator that generates electricity. The burned diesel releases toxic gases into the atmosphere. Table 4.3 below depicts the toxic gases that are produced during engine combustion. Simulation results show that a significant amount of CO2 is released into the atmosphere in a year. These toxic gases contribute to air pollution and climate change.

Quantity	Value (kg/yr)

Carbon Dioxide	1,017,344
Carbon Monoxide	5,263
Unburned Hydrocarbons	279
Particulate Matter	45.0
Sulfur Dioxide	2,487
Nitrogen Oxides	1,009

Table 4.3: Toxic gases released to the atmosphere

To ensure that the generators perform to their optimum function, they must be maintained. Since they consist of moving parts; lubricating liquids, bearing and wearings, and servicing kits are necessary to be always available. Figure 4.6 below indicates the simulated fuel consumption of the generator and Figure 4.7 shows the cost to upkeep the generator while operating to its optimum function.

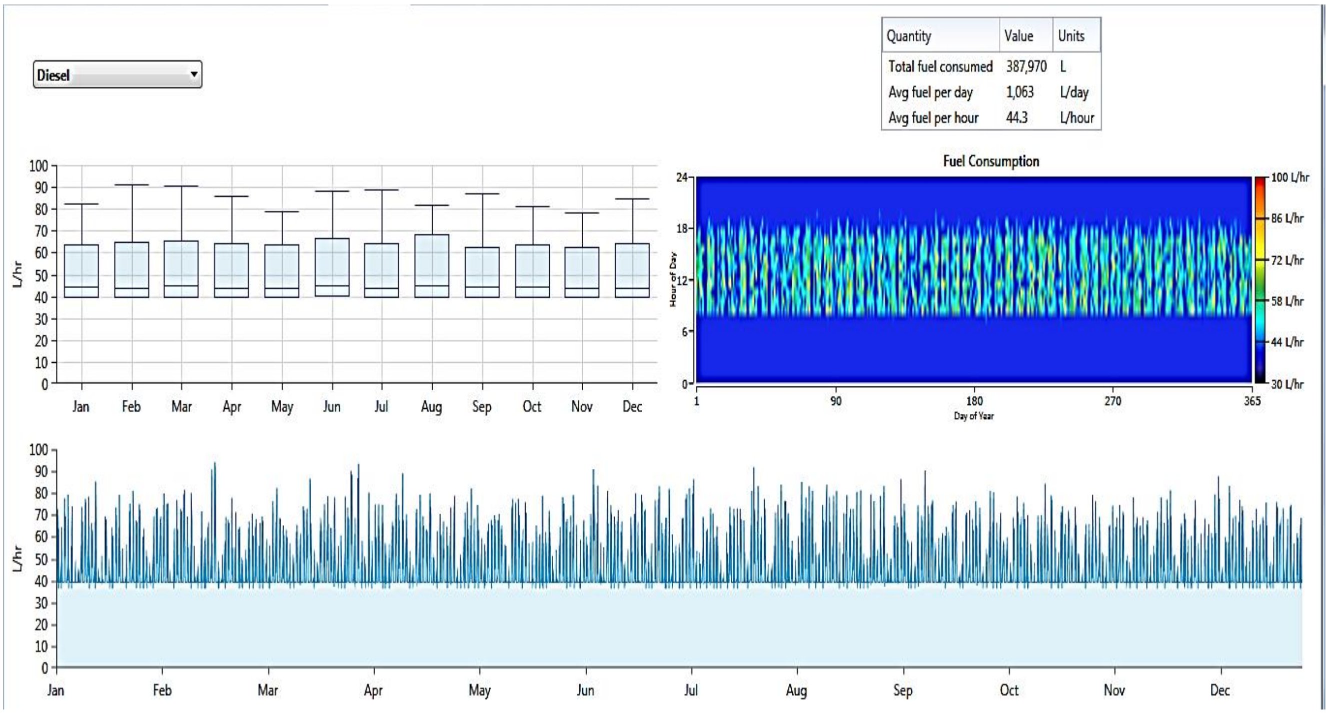
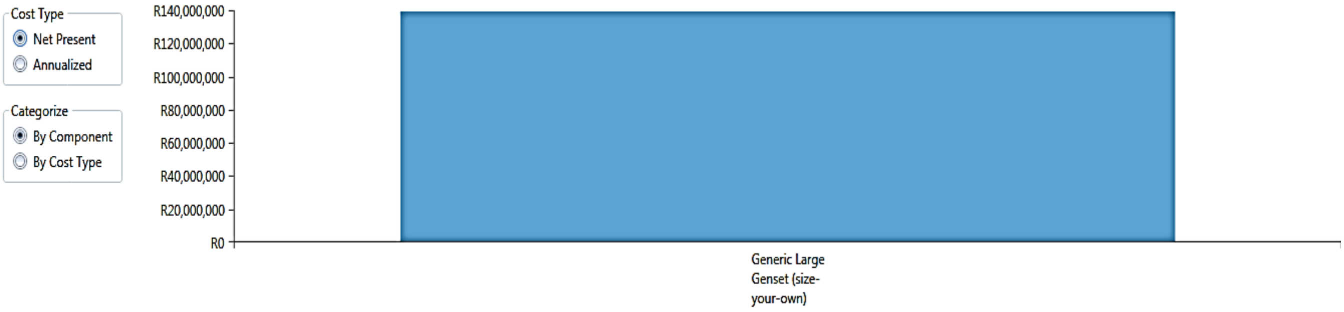


Figure 4.6: Simulated Diesel Generator Fuel Consumption



Component	Capital (R)	Replacement (R)	O&M (R)	Fuel (R)	Salvage (R)	Total (R)
Generic Large Genset (size-your-own)	R3,500,000.00	R25,391,349.52	R8,626,048.19	R102,265,699.30	-R155,712.60	R139,627,384.41
System	R3,500,000.00	R25,391,349.52	R8,626,048.19	R102,265,699.30	-R155,712.60	R139,627,384.41

Figure 4.7: Simulated Diesel Generator System Costs

4.2 SOLAR POWER GENERATION IN THE HARBOR

During the maintenance periods and training of the Ship's personnel, ships spend time in the harbor. Whilst in the harbor, electrical systems are still operating as well as lighting is required. Therefore, the need to have an electricity supply is necessary for the Ship. The Ships can be connected to the grid or generate their electricity through their diesel generators. This means more running hours for the generator and fuel consumption.

The research modeled and simulated the use of solar PV to generate electricity for the ship while it is in the harbor, as shown in figures 4.9 and 4.10. The harbor in which big SA Navy ships are parked is made up of basins as shown in figure 4.4. The ship of interest can be parked at the inner or outer basin depending on what operations are to be performed on it. The results below will depict the performance of the solar PVs when the ship is in the harbor. The results will show the electrical power generation in the outer basin and inner basin.

Figure 4.8: Harbor with Inner and Outer Basins indications

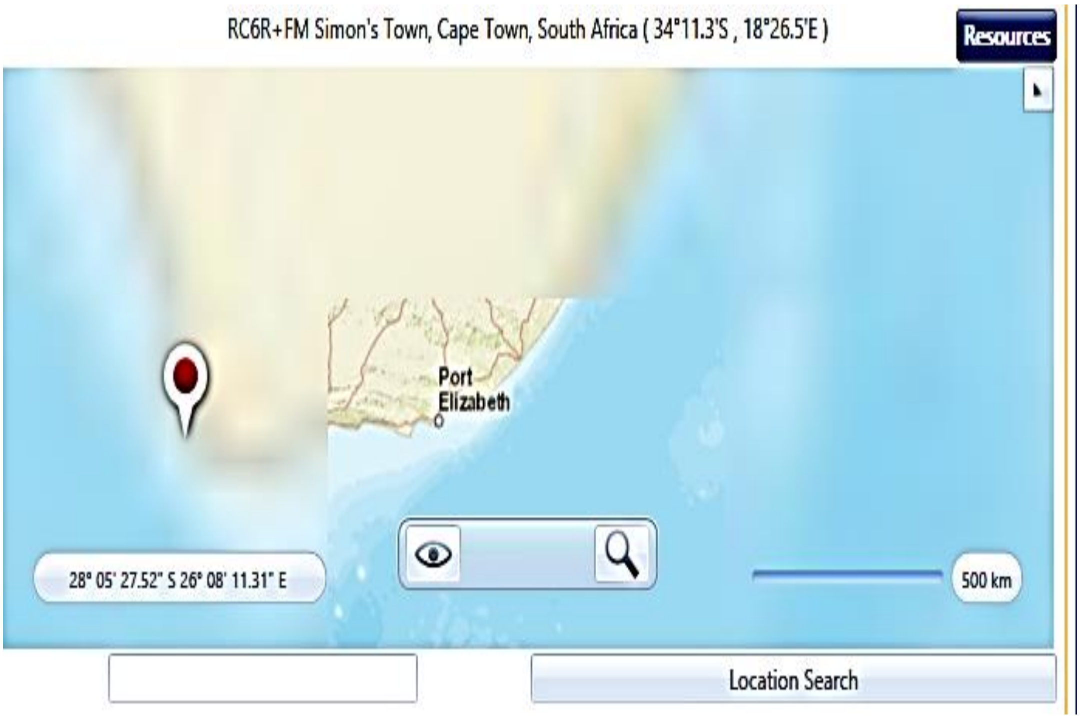


Figure 4.9: Modeled Ship location in Harbor

4.2.1 Inner and Outer basins

Figure 4.10 depicts the modeled and simulated PV power generation on the ship when in the harbor. The output of the PV power is connected to the AC load via a converter and directly to DC loads. To ensure consistent results, the research used a similar electrical load and PV solar panels in simulation for both inner and outer basins. The results of the simulation in the Inner and Outer Basins are tabulated and graphically elaborated.

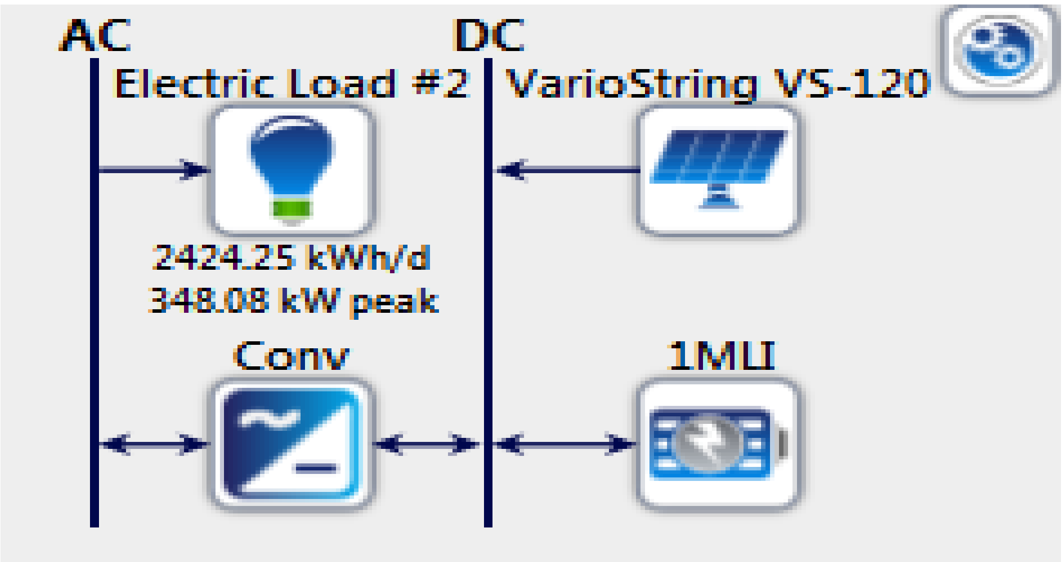


Figure 4.10: HOMER Modelled PV power generation in Harbor

The modeled and simulated Solar PV system costs are depicted in table 4.5 below. The shows the capital amount for components, O&M cost as well as fuel cost for the system.

Components	Capital	O&M	Fuel
Generic 1MWh Li-Ion	R7,000,000.00	R1,659,230.82	R0.00
Studer VarioString VS-120 with Generic PV	R3,000.35	R165.94	R0.00
System Converter	R97,245.31	R0.00	R0.00
System	R7,100,245.67	R1,659,396.76	R0.00

Table 4.4: Simulated Solar PV system costs

Table 4.6 below depicts the amount of toxic gases that would be released into the atmosphere by the solar PV system as compared to that of diesel generators.

Quantity	Value (kg/yr)
Carbon Dioxide	0

Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulfur Dioxide	0
Nitrogen Oxides	0

Table 4.5: Toxic Gases released into the Atmosphere by the Solar PV system

The Solar PV power production profile in the Harbor is shown in figure 4.11 and table 4.7. What is of importance in the table below is the total solar PV power produced by the system. It is to be compared with the electric power that is produced by the diesel generator.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	138	kW
Mean Output	3,312	kWh/d
Capacity Factor	20.3	%
Total Production	1,208,834	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	137	%
Hours of Operation	4,370	hrs/yr
Levelized Cost	0.0002	R/kWh

Table 4.6: Solar PV power production profile in Harbor

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	129	kW
Mean Output	3,107	kWh/d
Capacity Factor	19.0	%
Total Production	1,133,888	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	128	%
Hours of Operation	4,370	hrs/yr
Levelized Cost	0.000213	R/kWh

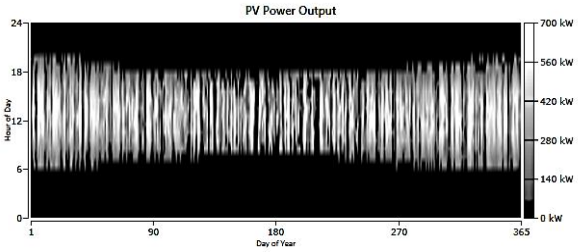


Figure 4.11: Simulated PV Power Production in the Harbor

Table 4.8 depicts the electrical load profile in the Harbor. In the results below, the solar PV that is produced above is sufficient to serve the load and have excess electricity.

Consumption	kWh/yr	%
AC Primary Load	884,350	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	244,989	20.3
Unmet Electric Load	502	0.0567
Capacity Shortage	767	0.0867

Table 4.7: Electrical Load profile in Harbor

The table below 4.9 and figure 4.12 depicts the results of the simulated solar PV power generated during the year at a particular PV cell temperature. The results are broken down into monthly power production throughout the year. The results are also shown graphically in Figures 4.13 and 4.14.

Month	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	137,669	20
Feb	107,163	20

Mar	103,826	20
Apr	86,728	18
May	80,069	17
Jun	72,580	15
Jul	75,108	14
Aug	84,949	14
Sep	88,816	15
Oct	110,742	16
Nov	123,085	17
Dec	138,099	19

Table 4.8: Monthly PV Power Output at a specific PV Cell temperature in Harbor

Figure 4.12: Simulated Monthly PV Power Production and Served Load in the Harbor

From April to August is winter and the days are shorter than in other months. It is also colder in the mornings and afternoons; therefore the power production is lower as seen in figure 4.13. Power production is higher in January and December; it is the hotter days and days a bit longer.

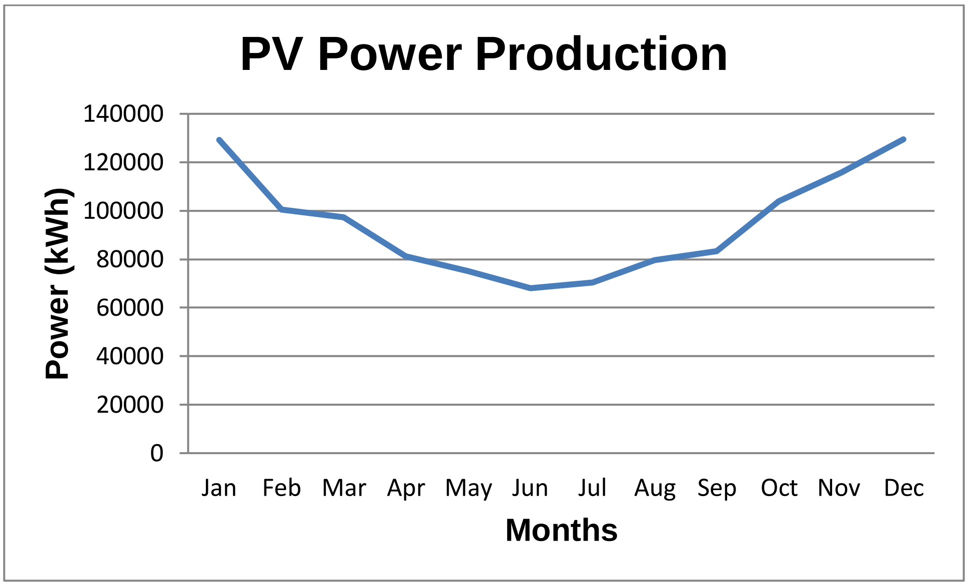


Figure 4.13: PV Power Production in Harbor

Figure 4.14 depicts the temperatures in Simons Town areas throughout the year. Colder temperatures start in April through to the end of August. During this period it's winter and it is normally cloudy and rainy. Between June and August temperatures drops to below 15^{0}C. In this period the power production is reduced.

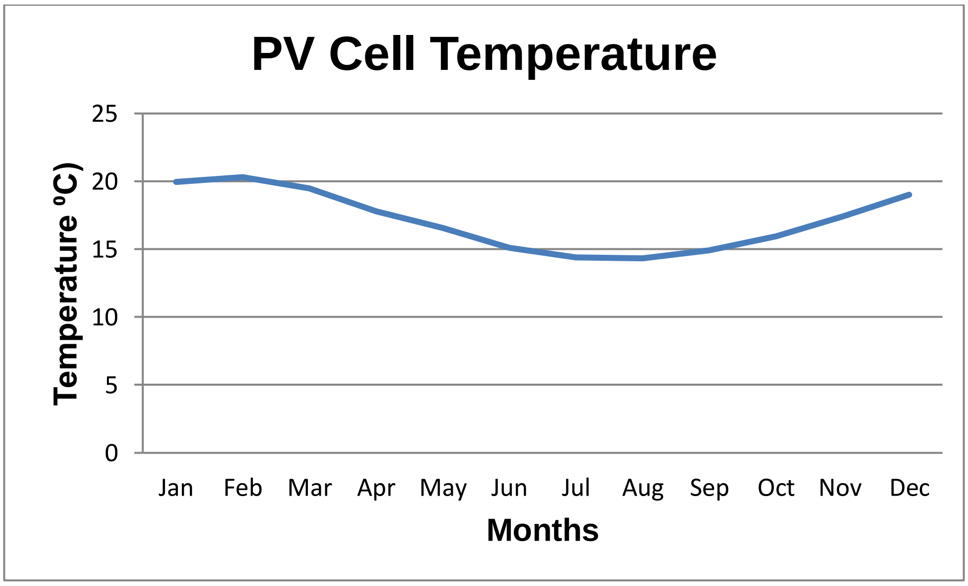


Figure 4.14: PV Cell Temperature in Harbor

4.3 SOLAR POWER GENERATION AT SEA

To ensure the consistency of load requirements, a similar Electrical load profile to one in the harbor was used in all ship's locations. Since the HOMER application does not accommodate the simulation of GPS based PV solar system, the continuous tracking PV solar system is used. Similar PV solar panels are used as well for all simulations as shown in figure 4.9. As the ship's location changes the PV power output changes based on the conditions of the particular location. Even though the locations that are used are around the SA coastline, the weather conditions are not the same and the sun's radiation differs. But at any of the locations, the PV is able to produce power to satisfy the electrical load requirements. The simulation results for the locations where the ship was placed within the SA EEZ (see figure 2.12) are depicted in tables and graphs below. The concentration is focused on power produced at a certain temperature for a particular electrical load.

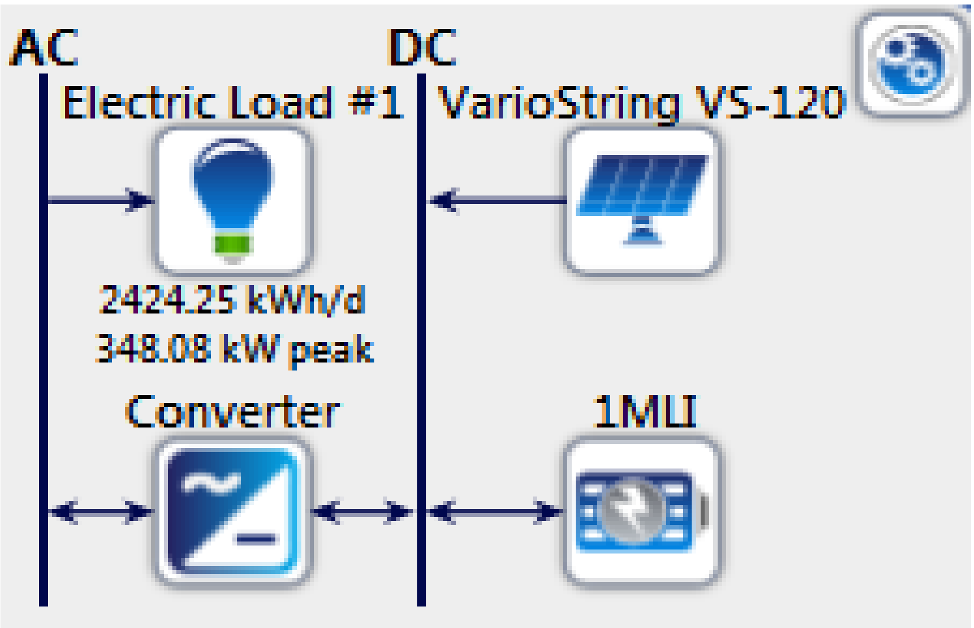


Figure 4.15: Modelled PV power generation at Sea

4.3.1 Western area Namibian border

The figure below depicts the position with coordinates where the Ship is placed at Sea. In this case, the Ship is placed on the Namibian border.

Figure 4.16: Modeled Ship location on Namibian Border

The results of solar PV power generation on a Ship are depicted in table 4.10 below. The table shows the output of the PVs in the Namibian border area, the Western side of SA. The maximum power output of the PV in a year is observed as well as the mean output per day. These are the results of interest since one of the objectives is to determine that solar PV can produce power for the Ship. The results are also shown in figure 4.17 as displayed in the simulation results.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	152	kW
Mean Output	3,640	kWh/d
Capacity Factor	22.3	%
Total Production	1,328,675	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	150	%
Hours of Operation	4,377	hrs/yr
Levelized Cost	0.000144	R/kWh

Table 4.9: Solar PV power production profile on the Namibian border

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	165	kW
Mean Output	3,958	kWh/d
Capacity Factor	24.2	%
Total Production	1,444,597	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	163	%
Hours of Operation	4,377	hrs/yr
Levelized Cost	0.000132	R/kWh

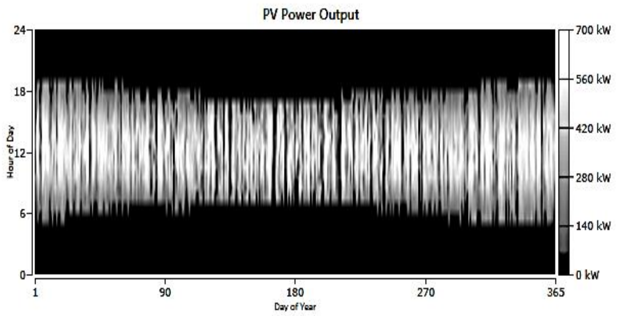


Figure 4.17: Simulated PV Power Production in the NAMIBIAN Border area

The results of the total load served profile are shown below in table 4.11. The total load profile includes excess electricity, unmet electric load as well as capacity shortage.

Consumption	kWh/yr	%
AC Primary Load	884,683	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	366,695	27.6
Unmet Electric Load	169	0.0191
Capacity Shortage	852	0.0963

Table 4.10: Electrical Load profile on the Namibian border

The table below depicts the PV power generation on the Western side of SA, the Namibian border area. In this location, we see that minimum temperatures range between 21 – 23 ^{0}C and highest at 26 – 28 ^{0}C. At lower temperatures, the power generation is 90 748 kWh with maximum temperatures enabling the PV to generate up to 130 029 kWh. PV power generated throughout the year is sufficient to satisfy the minimum load requirement of 2

424.25 kWh/day. The tabulated results are further shown in figure 4.18 and simplified by graphs as shown in figures 4.19 and 4.20.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	129,647	27
Feb	114,975	28
Mar	118,874	27
Apr	104,129	25
May	94,116	23
Jun	89,503	22
Jul	90,748	21
Aug	100,454	21
Sep	107,055	22
Oct	124,039	23
Nov	125,106	24
Dec	130,029	26

Table 4.11: Monthly PV Power Output at a particular PV Cell temperature Western area Namibian border

Figure 4.18 below shows the HOMER simulation results based on the modeled conditions as Sea. The PV power production is shown monthly.

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,444,597	100
Total	1,444,597	100

Consumption	kWh/yr	%
AC Primary Load	884,584	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,584	100

Quantity	kWh/yr	%
Excess Electricity	485,098	33.6
Unmet Electric Load	268	0.0303
Capacity Shortage	835	0.0944

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,091	%

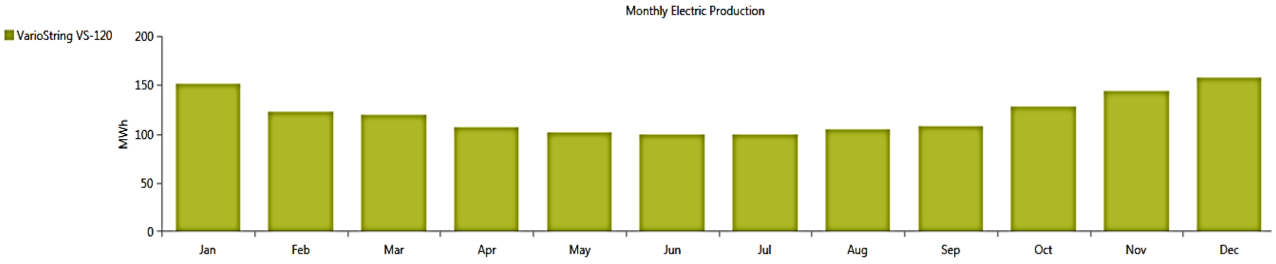


Figure 4.18: Simulated Monthly PV Power Production and Served Load in the Namibian Border Area

Figure 4.19 below depicts the PV power output per month on the Western side of SA, around the Namibian border. The PV power generation reduces to below 100 000 kWh from May to August, due to temperatures getting lower.

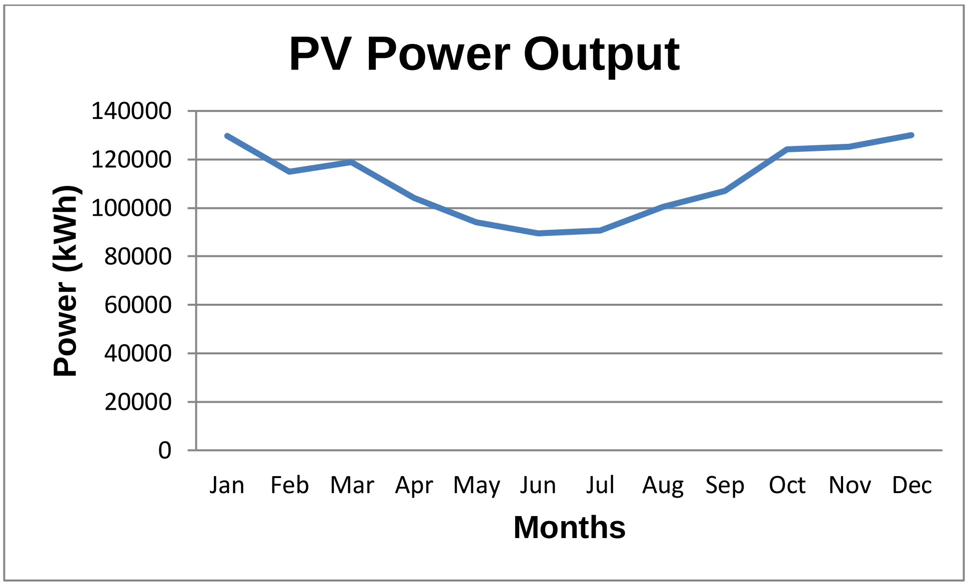


Figure 4.19: PV Power Output per month Western area Namibian border

PV Cell temperature depends on the solar radiation on the cell in a particular area. We see below in figure 4.20, the temperatures start to gradually reduce from March to August, and then increase again from September as the seasons change.

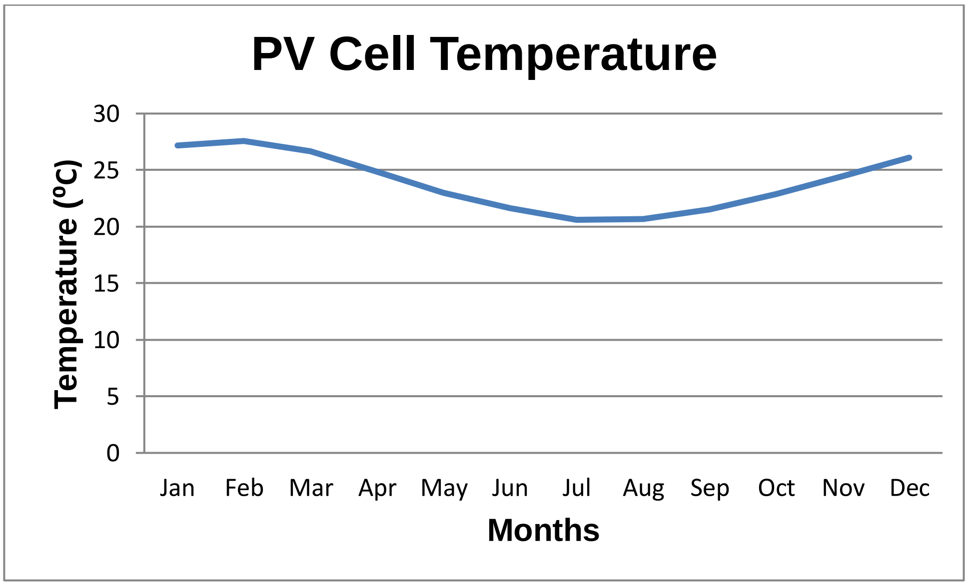


Figure 4.20: PV Cell Temperature per month Western area Namibian border

4.3.2 Western side of SA

As required by the study, the Ship should be moving at Sea changing locations. The figure below shows the location where the Ship is placed to model the movement from the Namibian border to the next location on the Western side of SA.

Figure 4.21: Modeled location on the Western side of SA

The results depicted in table 4.13 below are the solar PV power generation output when the Ship is placed on the Western side of SA. The power output results are presented yearly. The results are also depicted in figure 4.22 below.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	159	kW
Mean Output	3,826	kWh/d
Capacity Factor	23.4	%
Total Production	1,396,522	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW

Maximum Output	680	kW
PV Penetration	158	%
Hours of Operation	4,371	hrs/yr
Levelized Cost	0.000173	R/kWh

Table 4.12: Solar PV power production profile on the Western side of SA

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	159	kW
Mean Output	3,826	kWh/d
Capacity Factor	23.4	%
Total Production	1,396,522	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	158	%
Hours of Operation	4,371	hrs/yr
Levelized Cost	0.000173	R/kWh

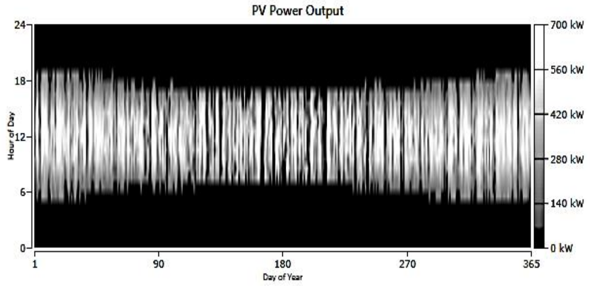


Figure 4.22: Simulated PV Power Production on the Western Side of SA

The total AC load served by the produced solar PV power is shown in table 4.14 below. As simulated, the results also show Excess electricity, Unmet electric load, and capacity shortage.

Consumption	kWh/yr	%
AC Primary Load	884,544	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	435,013	31.1
Unmet Electric Load	308	0.0348
Capacity Shortage	364	0.0412

Table 4.13: Electrical Load profile on the Western side of SA

The table below depicts the PV power output at a particular temperature. The results are simulated with the ship placed in different areas within the western side of SA. In all the positions that the ship was placed the temperature was the same and the power produced was similar. The PV is able to output a maximum of 159 782 kWh of power at the temperature of 27 ^{0}C in warmer months.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	150,602	27
Feb	124,043	27
Mar	117,442	25
Apr	98,938	23
May	92,908	22
Jun	90,691	21
Jul	90,790	20
Aug	99,325	20
Sep	103,110	21
Oct	125,424	23
Nov	143,467	25
Dec	159,782	27

Table 4.14: PV Power Output at a particular PV Cell temperature Western side of SA

To depict the results as outputted in the HOMER simulation, figure 4.23 shows the PV output in a year monthly.

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,396,522	100
Total	1,396,522	100

Consumption	kWh/yr	%
AC Primary Load	884,544	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,544	100

Quantity	kWh/yr	%
Excess Electricity	435,013	31.1
Unmet Electric Load	308	0.0348
Capacity Shortage	364	0.0412

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,167	%

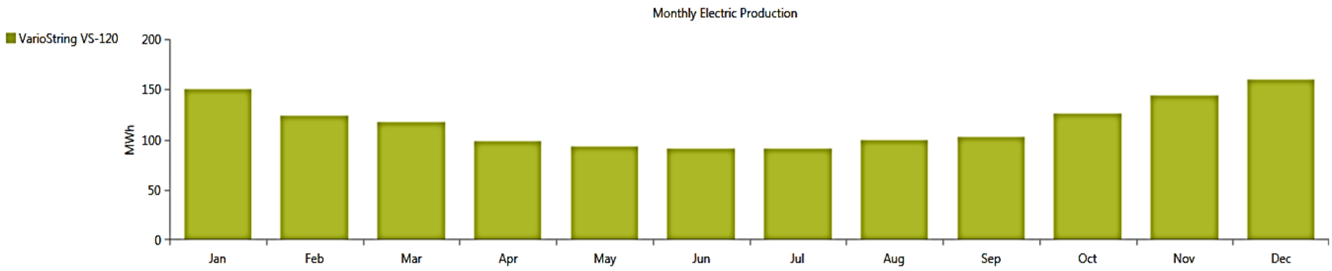


Figure 4.23: Simulated Monthly PV Power Production and Served Load in the Western Side of SA

The power output of the PV is graphically depicted in figure 4.24 below. The graph gives a clear indication of how much power is generated in a month throughout the year. In March power generation starts to gradually decrease until to the lowest in May to July. It then starts to increase from August to December.

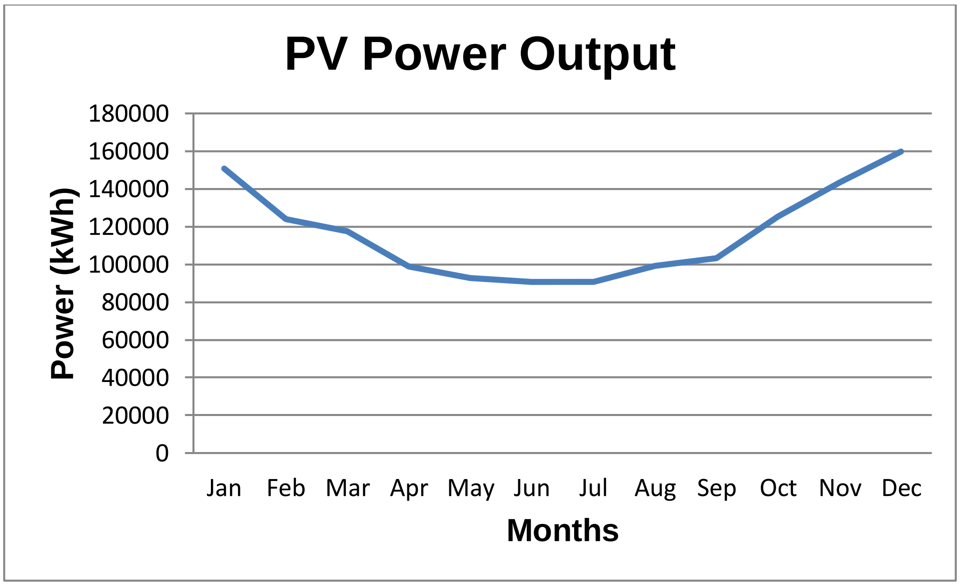


Figure 4.24: PV Power Output per month Western side of SA

The temperature on the western side of the SA area varies from 27 ^{0}C to 20 ^{0}C. The graph below depicts the temperature change monthly, we see lower temperatures from May to September. However, as seen in figure 4.25 the power can still be produced.

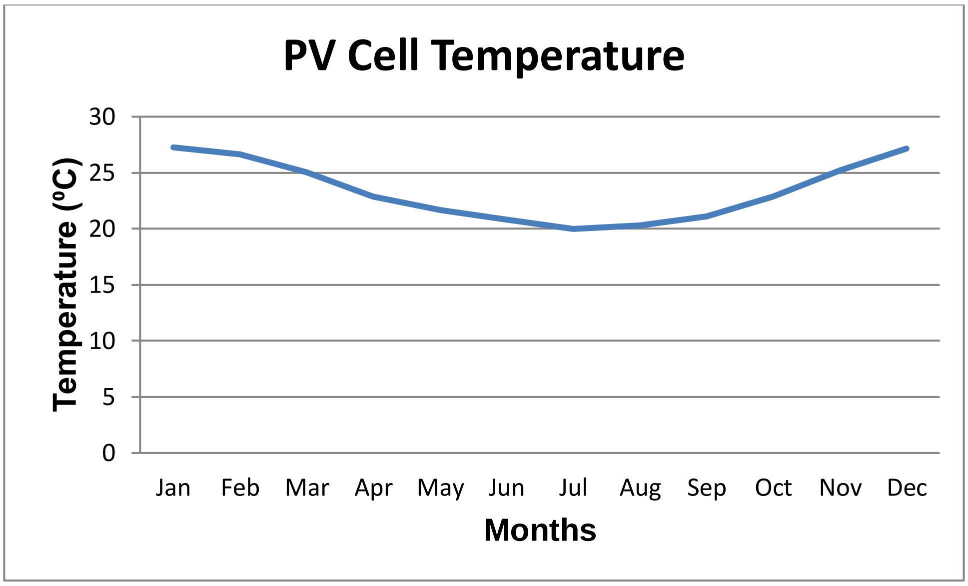


Figure 4.25: PV Cell Temperature per month Western side of SA

4.3.3 Western area of SA False Bay area

Figure 4.26: Modeled Ship location in False Bay area

When the simulation was done with the Ship placed in the False Bay area, on the Western side of SA as shown in figure 4.26 above, the solar PVs were able to produce the power as depicted in table 4.16 below. The power output is observed over a year, hence the results are yearly.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	149	kW
Mean Output	3,586	kWh/d
Capacity Factor	22	%
Total Production	1,308,785	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	148	%
Hours of Operation	4,371	hrs/yr
Levelized Cost	0.000185	R/kWh

Table 4.15: Solar PV power production profile in False Bay

Figure 4.27 below shows the simulated results of the solar PV power production in HOMER results to further explain the results in the table above.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	149	kW
Mean Output	3,586	kWh/d
Capacity Factor	22.0	%
Total Production	1,308,785	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	148	%
Hours of Operation	4,371	hrs/yr
Levelized Cost	0.000185	R/kWh

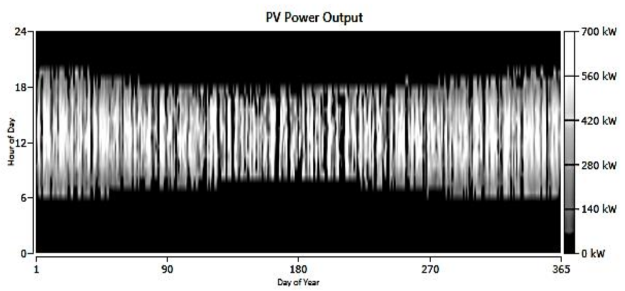


Figure 4.27: Simulated PV Power Production in the False Bay Area

The results of the total load served by the PV power output in the False Bay area are shown in table 4.17 below.

Consumption	kWh/yr	%
AC Primary Load	884,634	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	347,257	26.5
Unmet Electric Load	218	0.0247
Capacity Shortage	481	0.0544

Table 4.16: Electrical Load profile in False Bay

The results of the simulations in the False Bay area are tabulated in table 4.18 below. The table shows the PV power output at a certain temperature. The results are further elaborated in graphs as shown in figures 4.13 and 4.14.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	147,047	29
Feb	116,507	28
Mar	111,347	26
Apr	94,089	23
May	88,726	21
Jun	80,410	18
Jul	80,748	17
Aug	92,652	18
Sep	96,131	19
Oct	119,083	22
Nov	134,592	25
Dec	147,452	28

Table 4.17: PV Power Output at a particular PV Cell temperature Western area of SA False Bay area

As tabulated above, the simulation results are further depicted in figure 4.28 below.

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,308,785	100
Total	1,308,785	100

Consumption	kWh/yr	%
AC Primary Load	884,634	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,634	100

Quantity	kWh/yr	%
Excess Electricity	347,257	26.5
Unmet Electric Load	218	0.0247
Capacity Shortage	481	0.0544

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,083	%

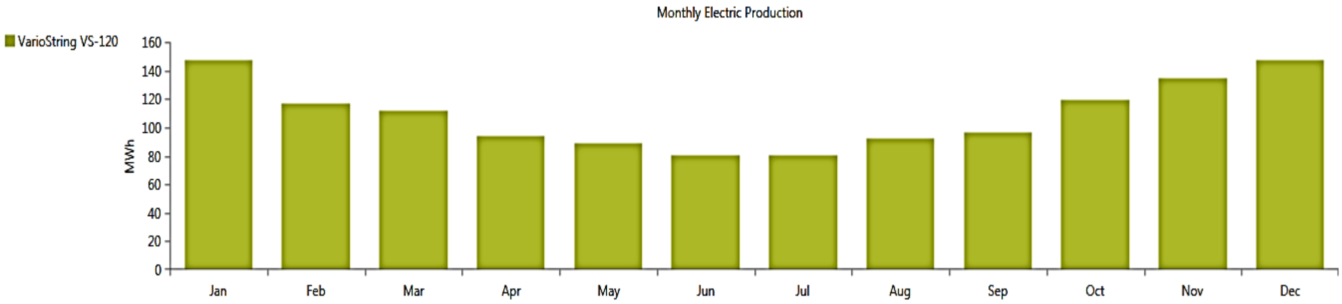


Figure 4.28: Simulated Monthly PV Power Production and Served Load in the False Bay Area

Figure 4.29 below depicts the PV power output throughout the year and shows the power produced per month. The graph shows that in June and July less power was produced as compared to other months. In January and December, most power is produced.

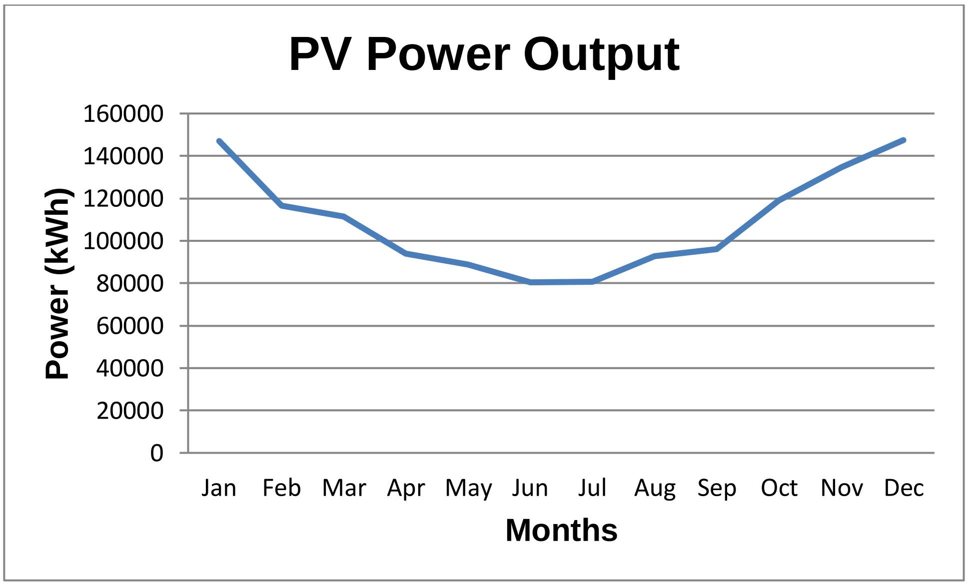


Figure 4.29: PV Power Output Western area of SA False Bay area

The figure below shows the temperature behavior in the area of False Bay, It maximizes at 29 ^{0}C and the minimum is at 17 ^{0}C. The lowest temperature is in July and the highest in January. The graph shows that the temperatures start to decrease to below 25 ^{0}C in March and go back to above 25 ^{0}C in November.

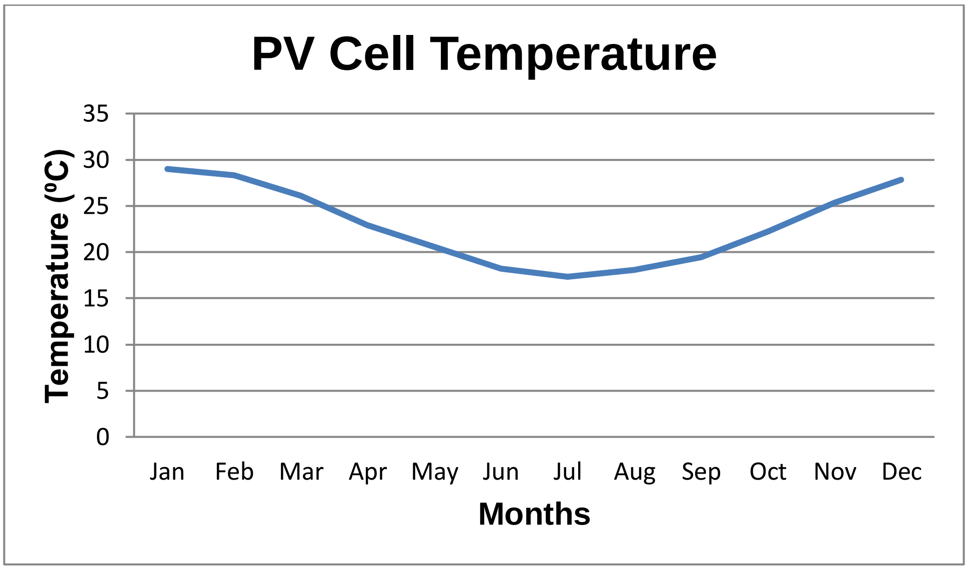


Figure 4.30: PV Cell Temperature Western area of SA False Bay area

4.3.4 Western area of SA Cape Point area

The Ship is now shifted to the other position which is in the Cape Point area on the Western side of SA. The position of the Ship is shown buy the location marker as shown in figure 4.31 below.

Figure 4.31: Modeled Ship Location in Cape Point Area

The solar PVs produced the power as depicted in the table below when the Ship is placed in the Cape Point area, Western side of SA. As shown in the table the solar PVs were able to produce 3 406 kWh per day, which is sufficient to serve the 2 425 kWh load per day.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	142	kW
Mean Output	3,406	kWh/d
Capacity Factor	20.9	%
Total Production	1,243,331	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	141	%
Hours of Operation	4,372	hrs/yr
Levelized Cost	0.000195	R/kWh

Table 4.18: Solar PV power production profile in the Cape Point area

The HOMER simulated results of the Ship in the Cape Point area are depicted in figure 4.32 below. The figure amplifies the results that are displayed in the table above.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	142	kW
Mean Output	3,406	kWh/d
Capacity Factor	20.9	%
Total Production	1,243,331	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	141	%
Hours of Operation	4,372	hrs/yr
Levelized Cost	0.000195	R/kWh

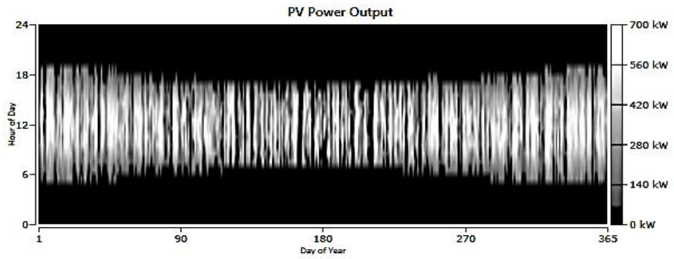


Figure 4.32: Simulated PV Power Production in the Cape Point Area

The solar PVs produced sufficient power to satisfy the total load of 884 724 kWh as shown in the simulation results in table 4.20 below. The results show that with this sufficient power there is excess electricity of 277 154 kWh.

Consumption	kWh/yr	%
AC Primary Load	884,724	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	277,154	22.3
Unmet Electric Load	128	0.0145
Capacity Shortage	170	0.0192

Table 4.19: Electrical Load profile in the Cape Point area

Tabled below in table 4.21 is the PV power output in the Cape Point area, the southern side of SA. The table depicts the PV power output in relation to the particular temperature. In the table, we see that the minimum power produced was in June due to lower temperatures in that month. The simulation results are further explained and shown in figures 4.33, 4. 34, and 4.35.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	176,226	30
Feb	141,333	29
Mar	133,322	27
Apr	101,079	24
May	89,027	22
Jun	78,677	21
Jul	80,943	20
Aug	102,229	21
Sep	117,689	22
Oct	145,282	24
Nov	169,501	27
Dec	182,585	29

Table 4.20: PV Power Output at a particular PV Cell temperature Western area of SA Cape Point area

The figure below depicts the simulated results of solar PV power production per month in a year as the temperatures changes.

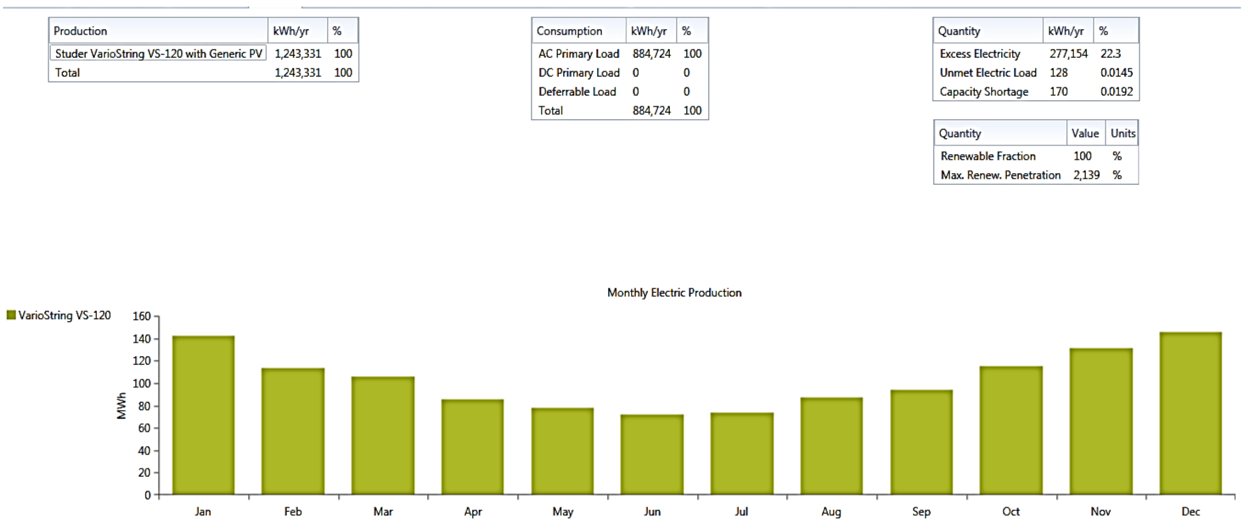


Figure 4.33: Simulated Monthly PV Power Production and Served Load in the Cape Point Area

Figure 4.34 below further shows the pattern in which the PV power was produced during a particular month. The slope shows that lower power is produced in mid-year months and higher PV power is produced at the beginning and at the end of the year due to higher temperatures.

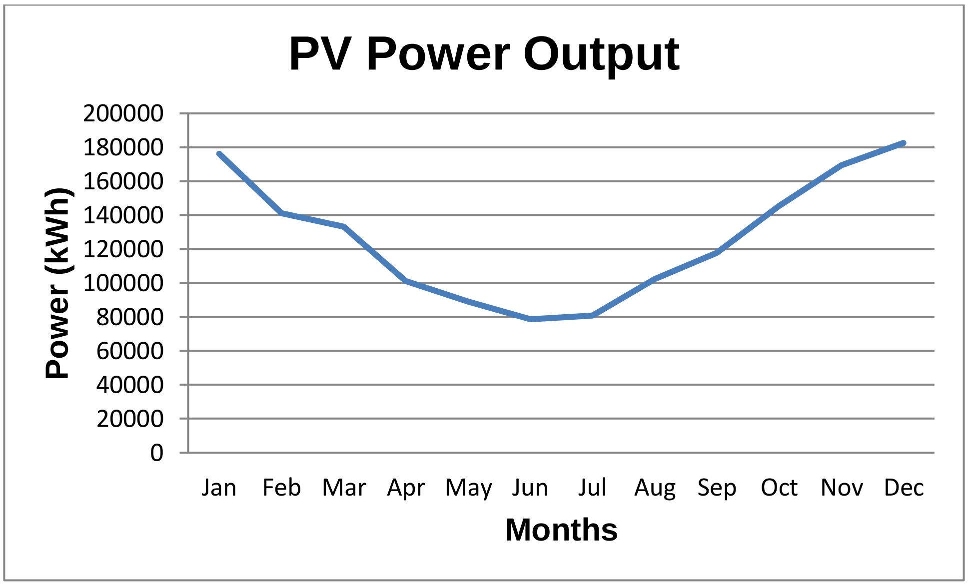


Figure 4.34: PV Power Output Western area of SA Cape Point area

The PV cell temperature is shown in figure 4.35 below. The figure indicates that the temperatures vary throughout the year due to changes in seasons in SA. In July temperatures reach below 20 ^{0}C and in January and December reaches around 30 ^{0}C.

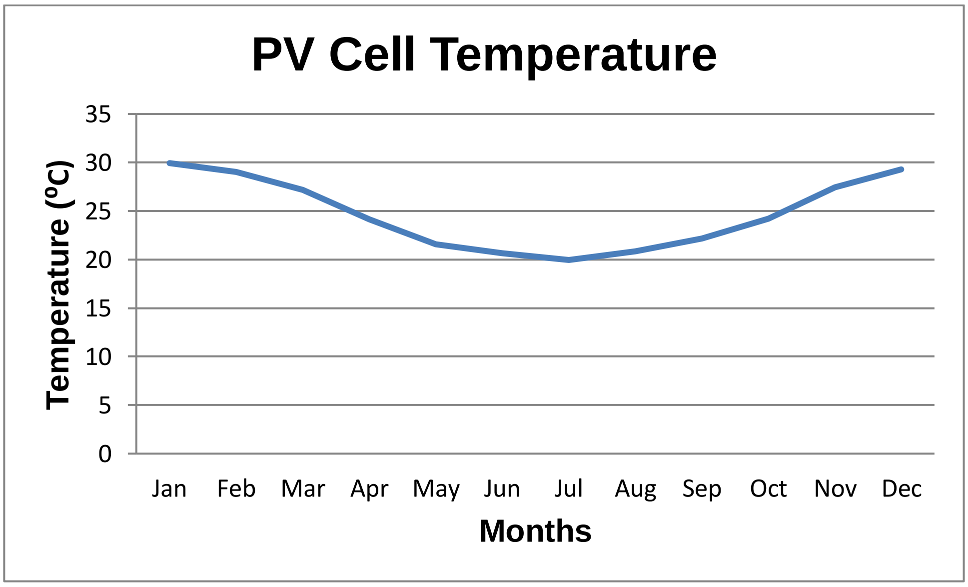


Figure 4.35: PV Cell Temperature Western area of SA Cape Point area

4.3.5 Southwest of the SA area

Figure 4.36 depict the location where the Ship is placed in the Southwest area of SA. The location marker shows where the Ship is placed.

Figure 4.36: Modeled Ship Location in the Southwest of SA

The power output of the solar PV when the Ship is placed in the Southwest area of SA is depicted in table 4.22 and figure 4.37 below. The figure shows the PV power production as resulted in the simulation

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	140	kW
Mean Output	3,351	kWh/d
Capacity Factor	20.5	%
Total Production	1,223,204	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	138	%
Hours of Operation	4,392	hrs/yr

Levelized Cost	0.000198	R/kWh

Table 4.21: Solar PV power production profile in Southwest of SA

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	140	kW
Mean Output	3,351	kWh/d
Capacity Factor	20.5	%
Total Production	1,223,204	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	138	%
Hours of Operation	4,392	hrs/yr
Levelized Cost	0.000198	R/kWh

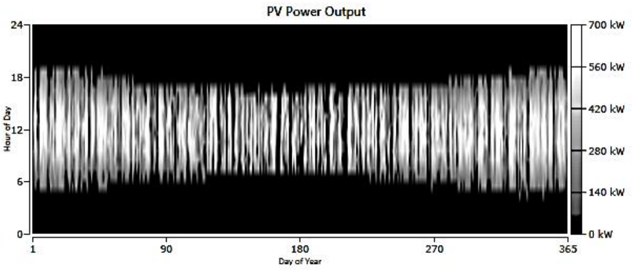


Figure 4.37: Simulated PV Power Production in the Southwest Area of SA

Table 4.23 below depicts the simulation results of the load that is served by the solar PV-produced power. In the results, it is observed that there was excess electricity of 256 194 kWh/year as the produced power was more than the electrical load demand. Also shows the unmet electrical load, due to PV not producing power at some period of the year.

Consumption	kWh/yr	%
AC Primary Load	884,764	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	256,194	20.9
Unmet Electric Load	88	0.0099
Capacity Shortage	158	0.0178

Table 4.22: Electrical Load profile in Southwest SA

The table below depicts the PV power generation in Southwest of SA at a particular temperature with the electrical load that is served. In this area, the Ship is placed in different locations to simulate its movement. Temperatures in this area range from 19 ^{0}C to 27 ^{0}C. We see the PV power output ranges from 72 065kW to 144 498 kW.

Months	PV Power Output (kWh)	PV Cell Temp (^oC)
Jan	140,238	28
Feb	10,9843	27
Mar	102,222	25
Apr	83,301	23
May	76,800	21
Jun	72,065	20
Jul	72,702	19
Aug	84,186	20
Sep	92,123	21
Oct	115,744	23
Nov	129,480	25
Dec	144,498	27

Table 4.23: PV Power Output at a particular PV Cell temperature Southwest of the SA area

The total solar PV power production results for when the Ship is placed in the Southwest area are shown below in figure 4.38. The results are shown on monthly basis for a year.

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,223,204	100
Total	1,223,204	100

Consumption	kWh/yr	%
AC Primary Load	884,764	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,764	100

Quantity	kWh/yr	%
Excess Electricity	256,194	20.9
Unmet Electric Load	88.0	0.00990
Capacity Shortage	158	0.0178

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,149	%

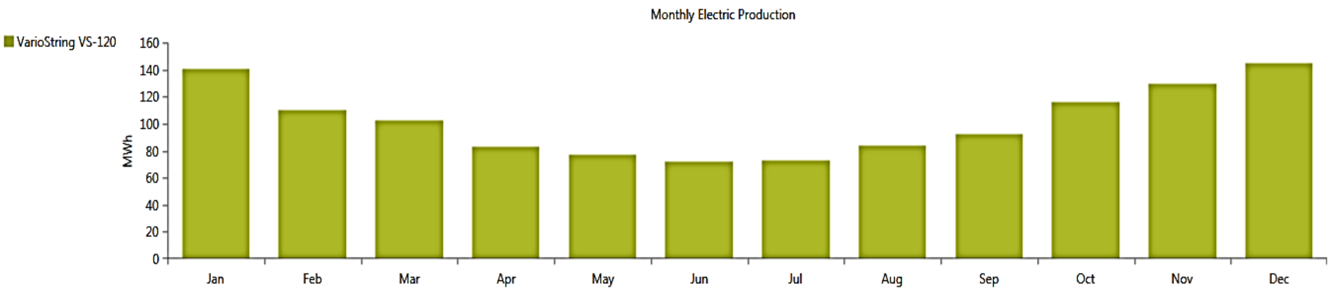


Figure 4.38: Simulated Monthly PV Power Production and Served Load in the Southwest Area of SA

Figure 4.39 below depicts the PV power output as the temperature changes from January to December. Lower PV power generation is observed from May to August.

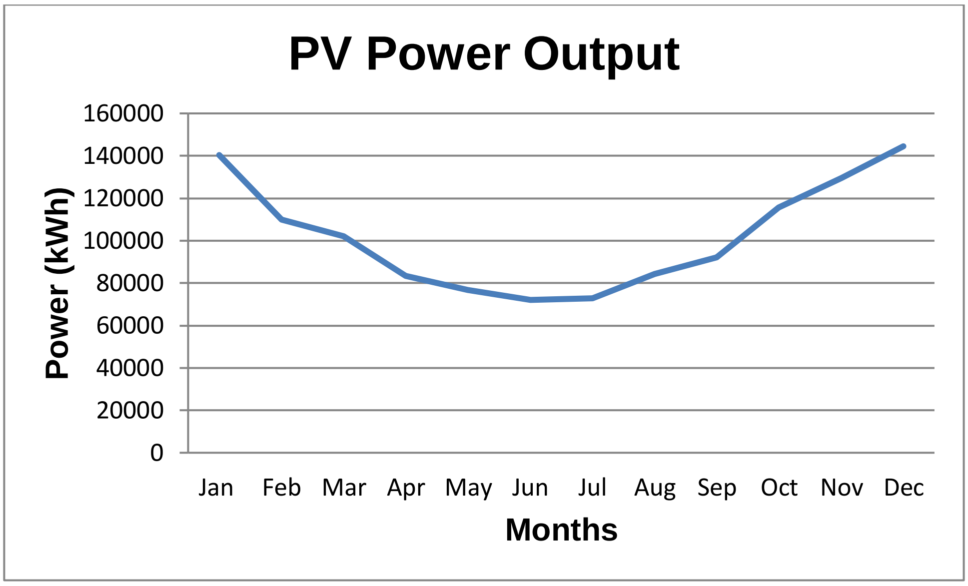


Figure 4.39: PV Power Output Southwest of SA area

In the Southwest area of SA, the temperatures are lower in July and higher in January and December as seen in figure 4.40.

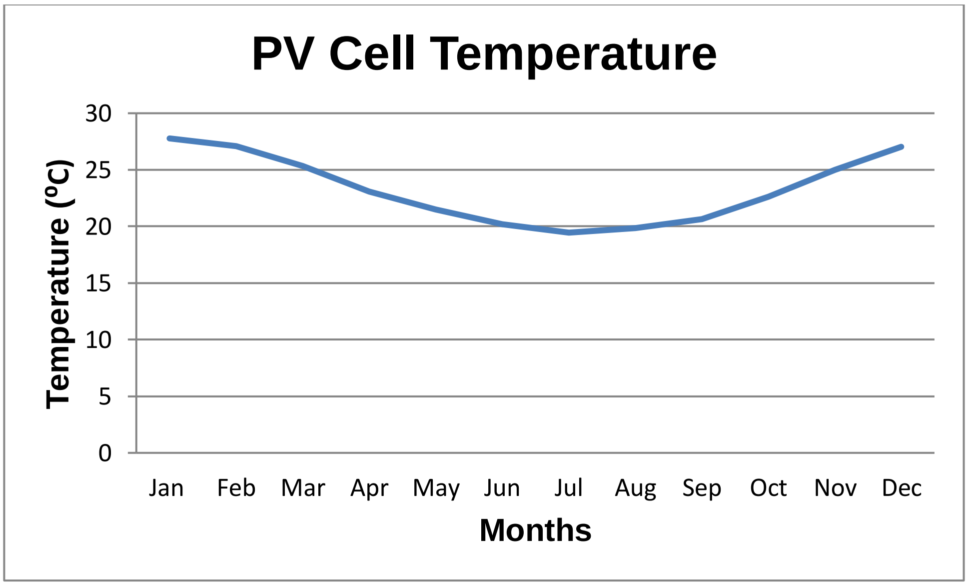


Figure 4.40: PV Cell Temperature Southwest of SA area

4.3.6 Southern side area of SA

Figure 4.41 below depicts the Ship's location in the Southern area of SA as indicated by the location marker.

Figure 4.41: Modeled Ship location in the Southern area of SA

The results of the solar PV power production in the Southern area of SA. The Ship is placed in this area, which is more out to Sea, to determine the production of solar PV. Table 4.25 and figure 4.42 below show that the solar PVs produced a total power of 1 109 404 kWh a year. Within this period, there was a time when the solar PV output was less than zero which resulted in no power production. Therefore, the PV produced power for only 4 380 Hours in a year.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	127	kW
Mean Output	3,039	kWh/d
Capacity Factor	18.6	%
Total Production	1,109,404	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW

PV Penetration	125	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.000218	R/kWh

Table 4.24: Solar PV power production profile on the Southern side of SA

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	127	kW
Mean Output	3,039	kWh/d
Capacity Factor	18.6	%
Total Production	1,109,404	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	125	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.000218	R/kWh

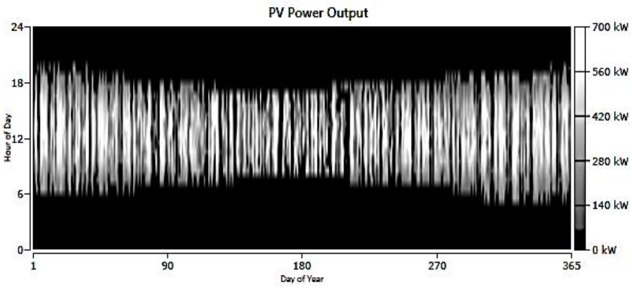


Figure 4.42: Simulated PV Power Production in the Southern Area

The electrical load profile that was served by the solar PV-produced power is depicted in table 4.26 below. The electrical load that was served is 884 852 kWh per year. The DC load is zero as the DC power is directed to the batteries.

Consumption	kWh/yr	%
AC Primary Load	884,852	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	141,532	12.8
Unmet Electric Load	0	0
Capacity Shortage	0	0

Table 4.25: Electrical Load profile on the Southern side of SA

Table 4.27 below depicts the PV power output on the South side of SA with the temperature change as well as the electrical load served. The results are graphically elaborated to indicate the change in PV power generation with the temperature change. Also in figure 4.43, the simulated results are displayed to indicate the power output.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	123,746	28
Feb	99,666	28
Mar	91,220	26
Apr	78,824	24
May	73,177	23
Jun	64,365	21
Jul	68,178	21
Aug	81,113	21
Sep	84,626	22
Oct	100,524	23
Nov	117,788	26
Dec	126,177	27

Table 4.26: PV Power Output at a particular PV Cell temperature Southern side area of SA

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,109,404	100
Total	1,109,404	100

Consumption	kWh/yr	%
AC Primary Load	884,852	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,852	100

Quantity	kWh/yr	%
Excess Electricity	141,532	12.8
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,733	%

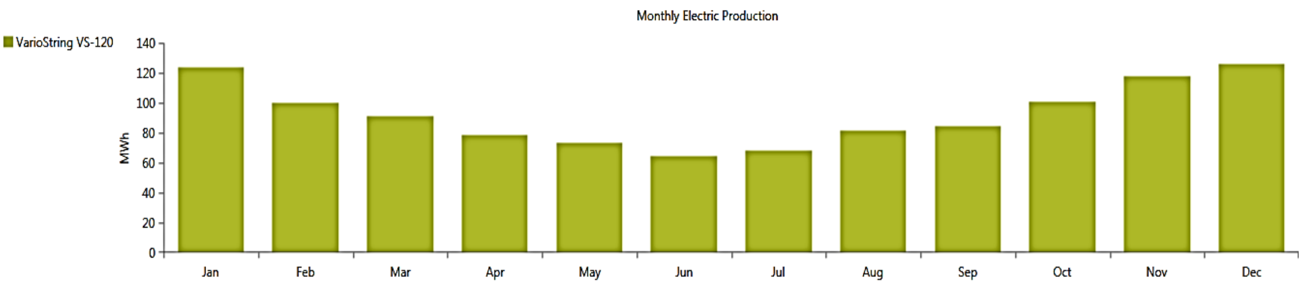


Figure 4.43: Simulated Monthly PV Power Production and Served Load in the Southern Area

PV Power output is depicted in figure 4.44 below. In July just above 60 000 kWh is produced and in January and December over 120 000 kWh of PV power is generated.

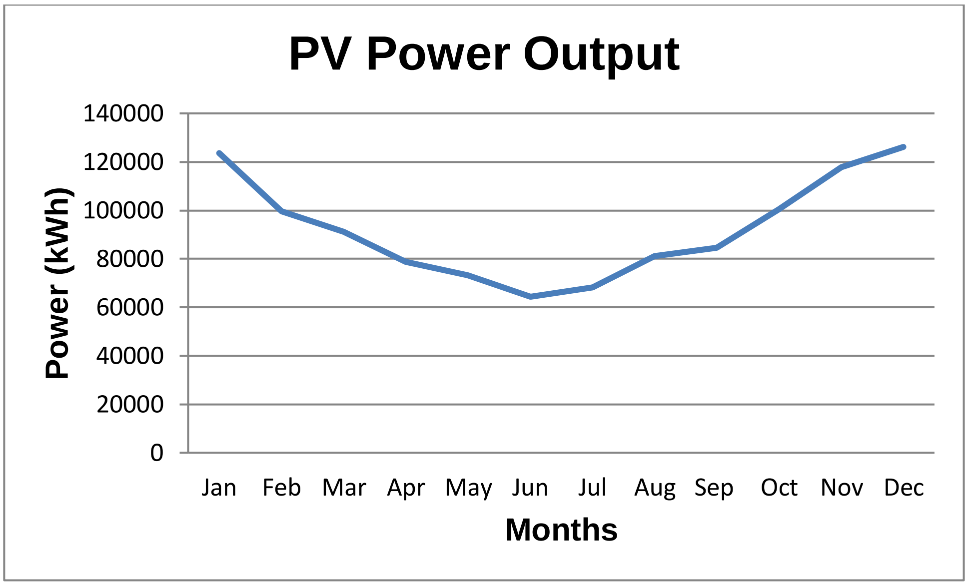


Figure 4.44: PV Power Output per month Southern side area of SA

The figure below shows the temperature of the PV Cells. Temperatures range between 28 ^{0}C and 21 ^{0}C. Lower temperatures are observed from May through to August.

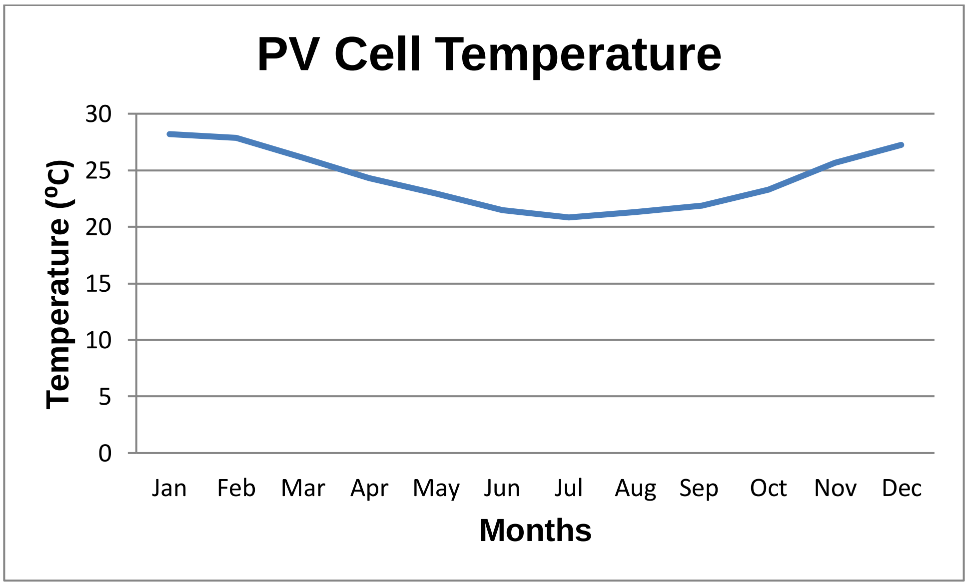


Figure 4.45: PV Cell Temperature Southern side area of SA

4.3.7 Southern area of SA Gqeberha area

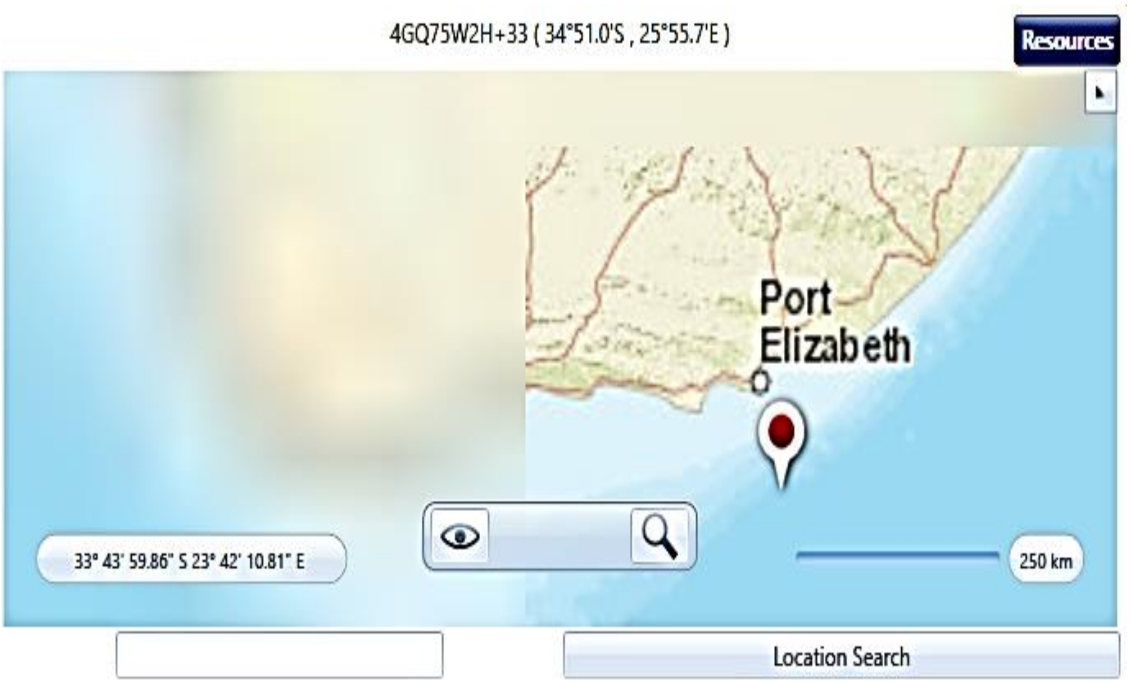


Figure 4.46: Modeled Ship location in the Gqeberha area

The Ship is now placed in the Gqeberha area, which is on the Southern side of SA as shown in figure 4.46 above. In this area, the solar PV was able to produce a mean power of 128 kW, which is 3 065 kWh per day, and a maximum power of 1 118 853 kWh per year as shown in table 4.28 below. Simulation results are further depicted in figure 4.47 to show the solar PV power output.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	128	kW
Mean Output	3,065	kWh/d
Capacity Factor	18.8	%
Total Production	1,118,853	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	126	%

Hours of Operation	4,378	hrs/yr
Levelized Cost	0.000216	R/kWh

Table 4.27: Solar PV power production profile in the Gqeberha area

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	128	kW
Mean Output	3,065	kWh/d
Capacity Factor	18.8	%
Total Production	1,118,853	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	126	%
Hours of Operation	4,378	hrs/yr
Levelized Cost	0.000216	R/kWh

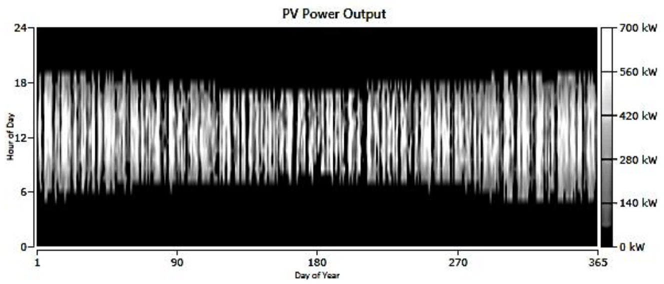


Figure 4.47: Simulated PV Power Production in the Gqeberha Area

Table 4.29 below depicts the electrical load profile that was served by the produced solar PV power.

Consumption	kWh/yr	%
AC Primary Load	884,610	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	151,393	13.5
Unmet Electric Load	242	0.0274
Capacity Shortage	461	0.0521

Table 4.28: Electrical Load profile in the Gqeberha area

On the South side of SA, in the Gqeberha area, it is observed that the temperatures are above 20 ^{0}C and more PV power is produced per month as shown in table 4.30 below. This is displayed graphically in figures 4.21and 4.22. The graphs show the slopes of power produced, i.e. the lower and the highest PV power that is produced in this area at a particular temperature. To illustrate the monthly solar PV power production within a year further, simulation results are further shown in figure 4.48.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	118,298	29
Feb	97,070	29
Mar	91,858	27
Apr	82,614	26
May	79,624	25
Jun	71,491	23
Jul	74,302	22
Aug	80,823	22
Sep	85,486	23
Oct	97,544	24
Nov	113,846	26
Dec	125,897	28

Table 4.29: PV Power Output at a particular PV Cell temperature Southern area of SA Gqeberha area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,118,853	100
Total	1,118,853	100

Consumption	kWh/yr	%
AC Primary Load	884,610	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,610	100

Quantity	kWh/yr	%
Excess Electricity	151,393	13.5
Unmet Electric Load	242	0.0274
Capacity Shortage	461	0.0521

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,614	%

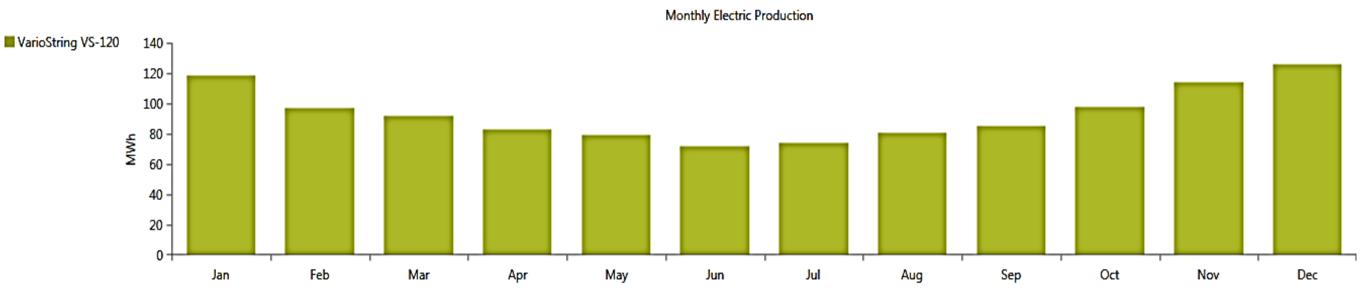


Figure 4.48: Simulated Monthly PV Power Production and Served Load in the Gqeberha Area

Figure 4.49 below depicts the PV power output in the South of SA in the area of Port Elizabeth. When the ship is placed in this area, Solar PVs can produce a minimum of 71 491 kWh and a maximum of 125 897 kWh of power. The minimum power is produced from May to July which are the months when temperatures are lower.

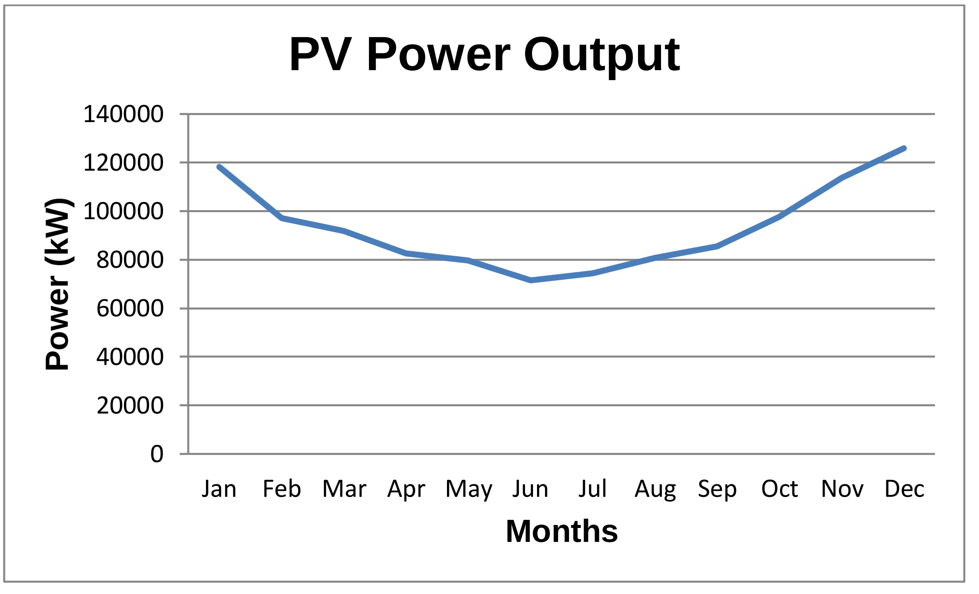


Figure 4.49: PV Power Output Southern area of SA Gqeberha area

As depicted in figure 4.50, the temperature in the South area of SA, in the Port Elizabeth area is warmer as compared to the previously observed temperatures on the Western and Southern sides of SA. A minimum of 22 ^{0}C is observed with a maximum of 29 ^{0}C observed.

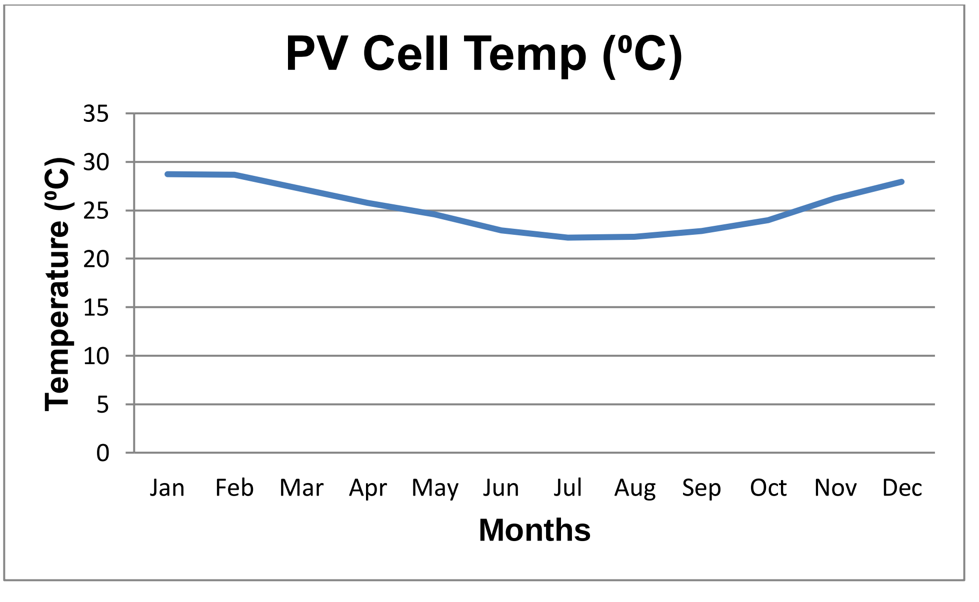


Figure 4.50: PV Cell Temperature Southern area of SA Gqeberha area

4.3.8 Southeast of SA East London area

Figure 4.51: Modeled Ship location in the East London area

When the Ship is placed in the East London area as shown by the location marker in figure 4.51 above, which is also on the Southern side of the SA, the solar PVs were able to produce a maximum power of 1 080 500 kWh per year. It produced this power in 4 377 hours of the year where the PV array output was more than zero as depicted in table 4.31 below. Figure 4.52 further depicts the simulated results of solar PV power production.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	123	kW
Mean Output	2,960	kWh/d
Capacity Factor	18.1	%
Total Production	1,080,500	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW

PV Penetration	122	%
Hours of Operation	4,377	hrs/yr
Levelized Cost	0.000224	R/kWh

Table 4.30: Solar PV Power production profile in the East London area

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	123	kW
Mean Output	2,960	kWh/d
Capacity Factor	18.1	%
Total Production	1,080,500	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	122	%
Hours of Operation	4,377	hrs/yr
Levelized Cost	0.000224	R/kWh

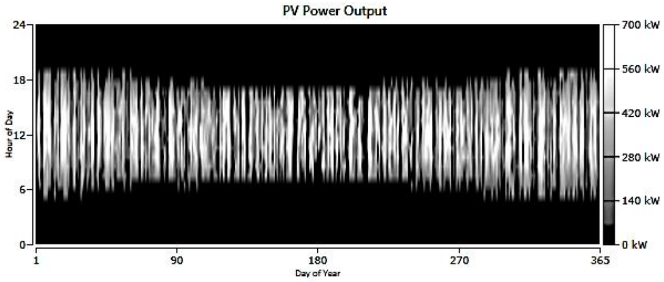


Figure 4.52: Simulated PV Power Production in the East London Area

Depicted in table 4.31 below is the load profile of the simulated results when the Ship is placed in the East London area. The total load of 884 443 kWh per year was served by the produced solar PV power. The solar PV produced more power for the said load, hence the excess power of 112 342 kWh per year.

Consumption	kWh/yr	%
AC Primary Load	884,443	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	112,342	10.4
Unmet Electric Load	409	0.0462
Capacity Shortage	637	0.072

Table 4.31: Electrical Load profile in the East London area

The table below depicts the PV power output and PV cell temperature in the East London area. This area also has warmer temperatures and less cloudy days. The solar PVs produced a maximum of 115 079 kWh in a month and a minimum of 73 285 kWh. As seen in figure 4.53, solar PV produced power in all the months of the year with the change in temperature in this area.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	111,294	29
Feb	91,485	29
Mar	88,363	28
Apr	79,481	27
May	80,457	26
Jun	73,285	24
Jul	76,503	23
Aug	82,568	24
Sep	84,995	24
Oct	94,092	25
Nov	102,897	26
Dec	115,079	28

Table 4.32: PV Power Output at a particular PV Cell temperature Southeast of SA East London area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,080,500	100
Total	1,080,500	100

Consumption	kWh/yr	%
AC Primary Load	884,443	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,443	100

Quantity	kWh/yr	%
Excess Electricity	112,342	10.4
Unmet Electric Load	409	0.0462
Capacity Shortage	637	0.0720

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,434	%

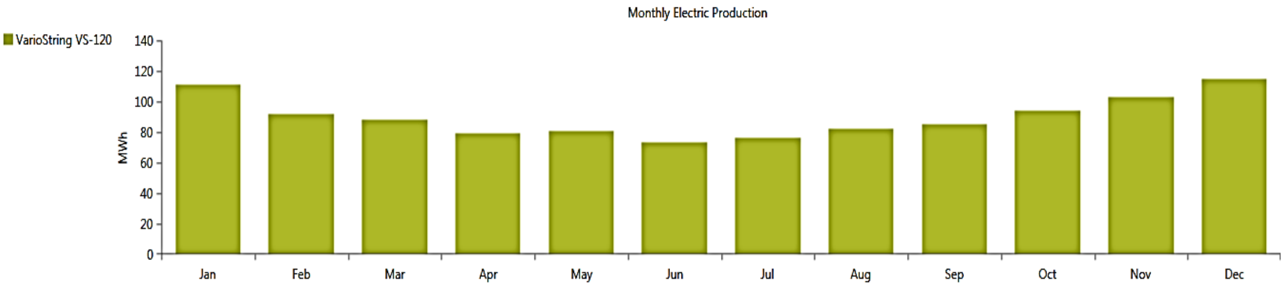


Figure 4.53: Simulated Monthly PV Power Production and Served Load in the East London Area

Figure 4.54 below shows the PV power output in the Southeast of SA, in the East London area. The maximum power is produced in December and the minimum power is in June. The power production decreases due to the temperature change towards the mid-year months as shown by the graph.

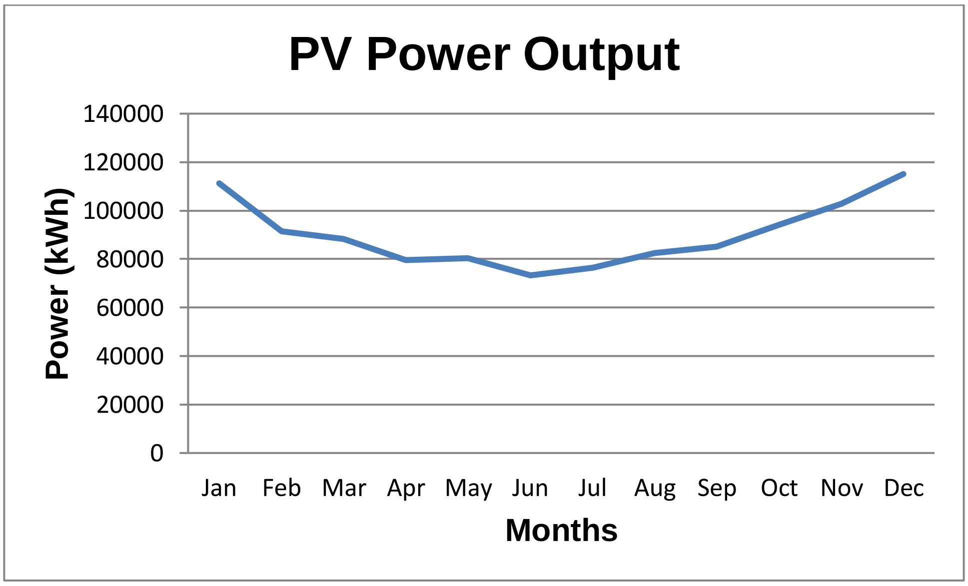


Figure 4.54: PV Power Output Southeast of SA East London area

PV cell temperature is depicted in figure 4.55 below. The graph shows that the temperatures change between the beginning of the year and the end of the year. Higher temperatures are observed in January and February then start to gradually decrease from March to a minimum in June then start to increase again from September to the maximum in December.

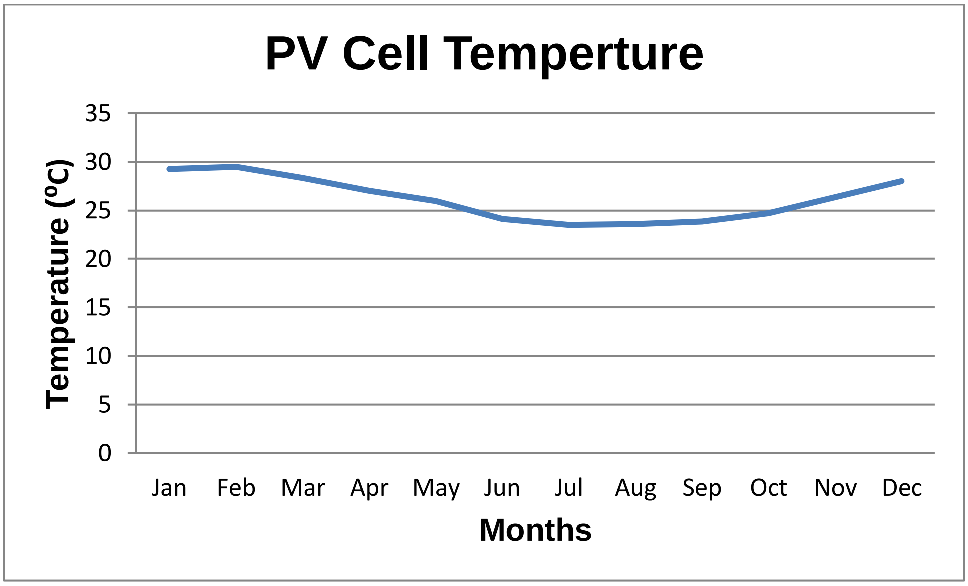


Figure 4.55: PV Cell Temperature Southeast of SA East London area

4.3.9 Southeast of Africa area

Figure 4.56: Modeled Ship Location in the Southeast area

In table 4.34 and figure 4.57 below, the solar PV power output is shown. The results show that when the Ship is placed in the area of Southeast of Africa as depicted in figure 4.56

above, the solar PVs that would be installed on the Ship can produce the power to supply the Ship. In a year, the solar PVs produced a maximum of 1 092 837 kWh. That means in a day they produced 2 994 kWh as depicted in the table below.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	125	kW
Mean Output	2,994	kWh/d
Capacity Factor	18.3	%
Total Production	1,092,837	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	124	%
Hours of Operation	4,375	hrs/yr
Levelized Cost	0.000222	R/kWh

Table 4.33: Solar PV Power production profile in the Southeast of Africa area

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	125	kW
Mean Output	2,994	kWh/d
Capacity Factor	18.3	%
Total Production	1,092,837	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	124	%
Hours of Operation	4,375	hrs/yr
Levelized Cost	0.000222	R/kWh

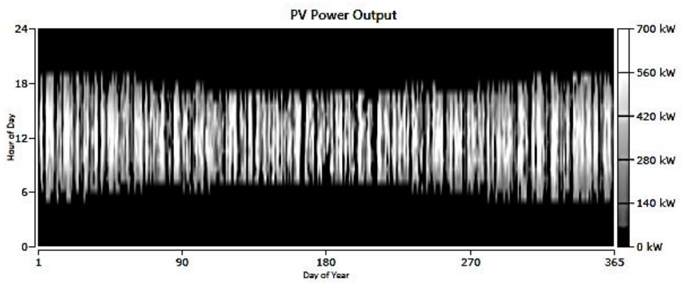


Figure 4.57: Simulated PV Power Production in the Southeast Area

Table 4.35 below depicts the load profile of the Southeast area. The total load that was served by the produced solar power is 884 356 kWh per year. The results also show the Dc primary load, deferrable load, and excess electric load as well as the capacity shortage.

Consumption	kWh/yr	%
AC Primary Load	884,356	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	124,685	11.4
Unmet Electric Load	496	0.056
Capacity Shortage	875	0.0989

Table 4.34: Electrical Load profile in the Southeast of Africa area

As the ship moves towards the east of SA, the temperatures start to increase, so the PV power output is increased as seen in table 4.36 below. As seen in figure 4.58 and table 4.36 below, the PV power produced starts to reach 133 595 kWh in a month and the minimum being 80 117 kWh in the coldest month.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	133,595	30
Feb	109,528	30
Mar	111,611	29
Apr	90,842	27
May	95,586	26
Jun	80,117	24
Jul	86,256	24
Aug	98,389	24
Sep	105,382	25
Oct	116,204	26
Nov	126,594	27
Dec	142,940	29

Table 4.35: PV Power Output at a particular PV Cell temperature Southeast of the African area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,092,837	100
Total	1,092,837	100

Consumption	kWh/yr	%
AC Primary Load	884,356	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,356	100

Quantity	kWh/yr	%
Excess Electricity	124,685	11.4
Unmet Electric Load	496	0.0560
Capacity Shortage	875	0.0989

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,489	%

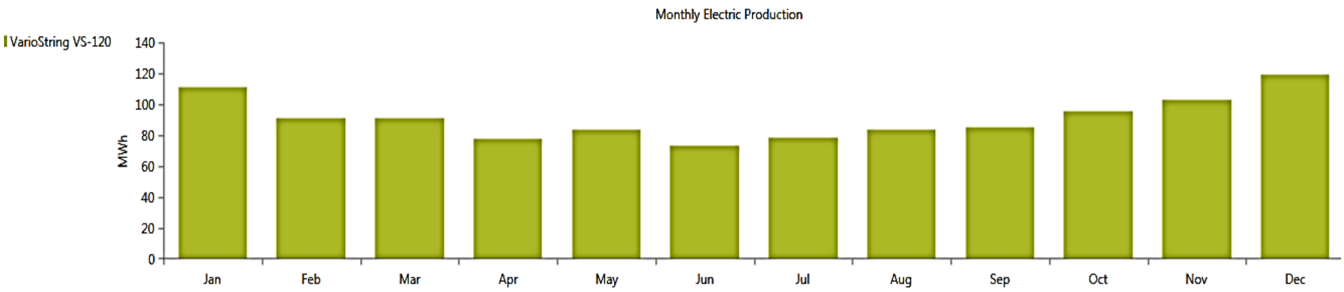


Figure 4.58: Simulated Monthly PV Power Production and Served Load in the Southeast Area

The PV power output in the Southeast of Africa area is depicted in figure 4.59 below. The graph shows that a minimum of 80 117 kWh was produced in June and gradually increased to a maximum of 142 940 kWh in December.

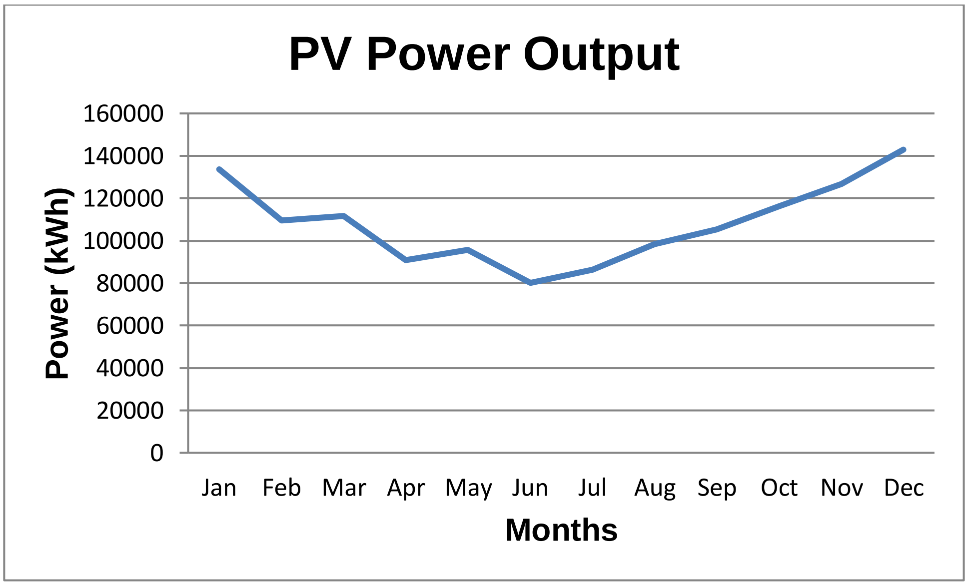


Figure 4.59: PV Power Output Southeast of Africa area

The figure below shows the PV cell temperatures in the Southeast Africa area. In this area, the temperatures are higher than in the above simulated areas. The minimum temperature is 24 ^{0}C and the maximum is 30 ^{0}C, already it can be observed that more PV power is produced due to the higher temperatures.

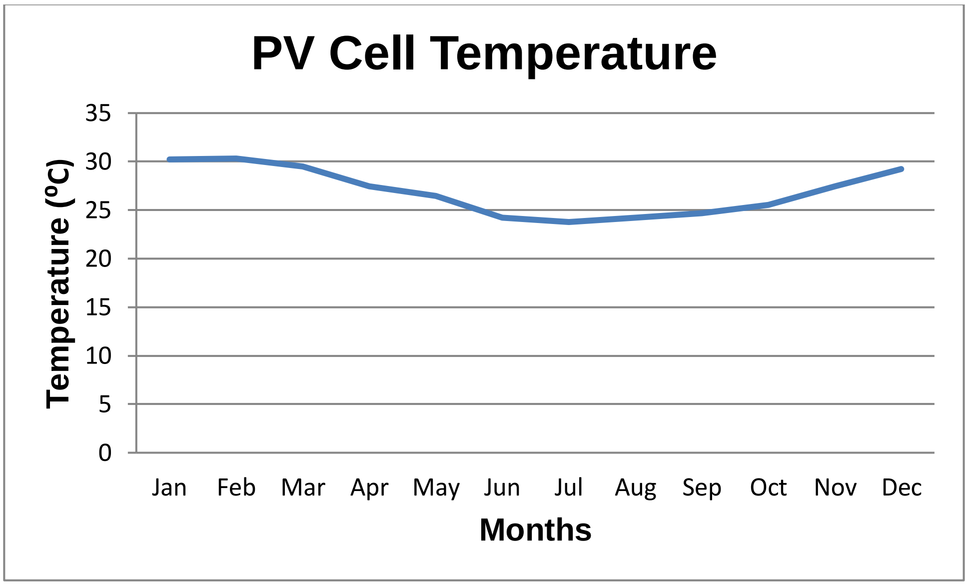


Figure 4.60: PV Cell Temperature Southeast of Africa area

4.3.10 Eastern side of the SA Durban area

Figure 4.61: Modeled Ship location in the Durban area

The Ship is now placed in the Durban area as seen in figure 4.61. This area on the Eastern side of SA has warmer temperatures which range from 25 ^{0}C to 32 ^{0}C. On the days of the year, there are fewer cloudy days, which enabled solar PVs to be able to produce more power. As shown in the simulation results in table 4.37 and figure 4.62, the solar PVs produced a mean power of 132 kW, which is 3 166 kWh a day and 1 155 529 kWh a year. This power was produced in the hours of operation of solar PV in a year.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	132	kW
Mean Output	3,166	kWh/d
Capacity Factor	19.4	%
Total Production	1,155,529	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	131	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	0.00021	R/kWh

Table 4.36: Solar PV Power production profile in the Durban area

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	132	kW
Mean Output	3,166	kWh/d
Capacity Factor	19.4	%
Total Production	1,155,529	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	131	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	0.000210	R/kWh

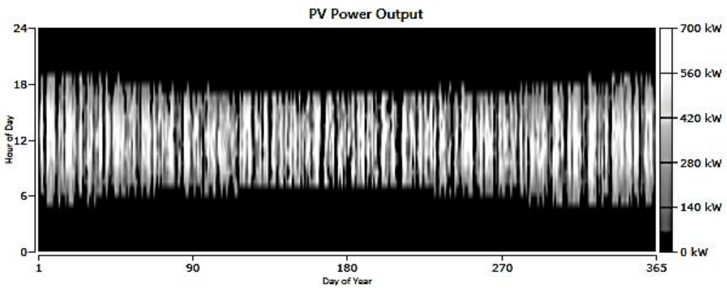


Figure 4.62: Simulated PV Power Production in the Durban Area

Table 4.38 below depicts the electrical load profile of the load that was served by the produced solar power. Results depict that there was a 188 854 kWh/yr excess electric load as solar PV had produced more than enough power to serve the load.

Consumption	kWh/yr	%
AC Primary Load	884,618	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	188,854	16.3
Unmet Electric Load	234	0.0265
Capacity Shortage	290	0.0328

Table 4.37: Electrical Load profile in the Durban area

Table 4.39 below depicts the PV power output at a particular temperature in the Durban area, Eastern side of South Africa. The PV power output and PV cell temperature are graphically explained below and further depicted in figure 4.63.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	116,681	32
Feb	98,045	32
Mar	98,713	31
Apr	86,880	29
May	90,627	28
Jun	78,620	26
Jul	86,242	25
Aug	86,708	25
Sep	86,980	26
Oct	96,781	27
Nov	108,953	29
Dec	120,300	30

Table 4.38: PV Power Output at a particular PV Cell temperature Eastern side of SA Durban area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,155,529	100
Total	1,155,529	100

Consumption	kWh/yr	%
AC Primary Load	884,618	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,618	100

Quantity	kWh/yr	%
Excess Electricity	188,854	16.3
Unmet Electric Load	234	0.0265
Capacity Shortage	290	0.0328

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,660	%

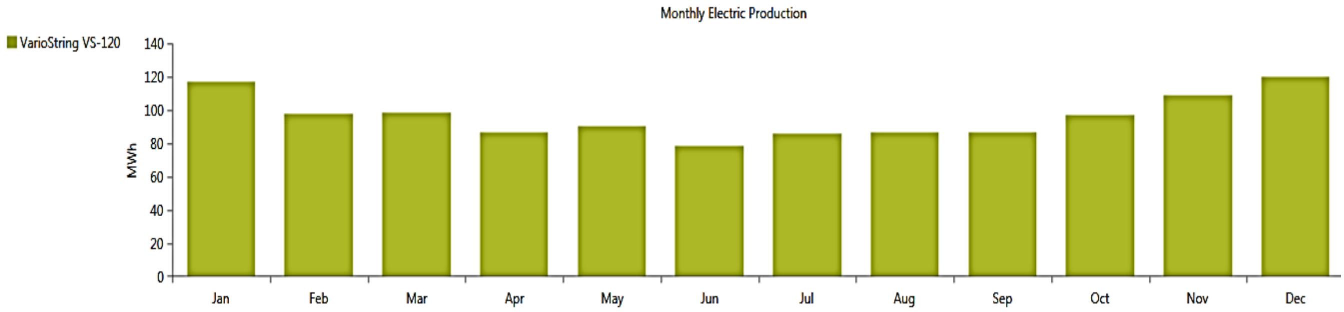


Figure 4.63: Simulated Monthly PV Power Production and Served Load in the Durban Area

The PV power output is depicted in figure 4.64 below. From the graph, it is observed that in this area higher PV power is produced. The minimum power that is produced is 78 620 kWh and the maximum is 120 300 kWh. From February to November, the produced power ranges between 100 0000 kWh and 80 000 kWh.

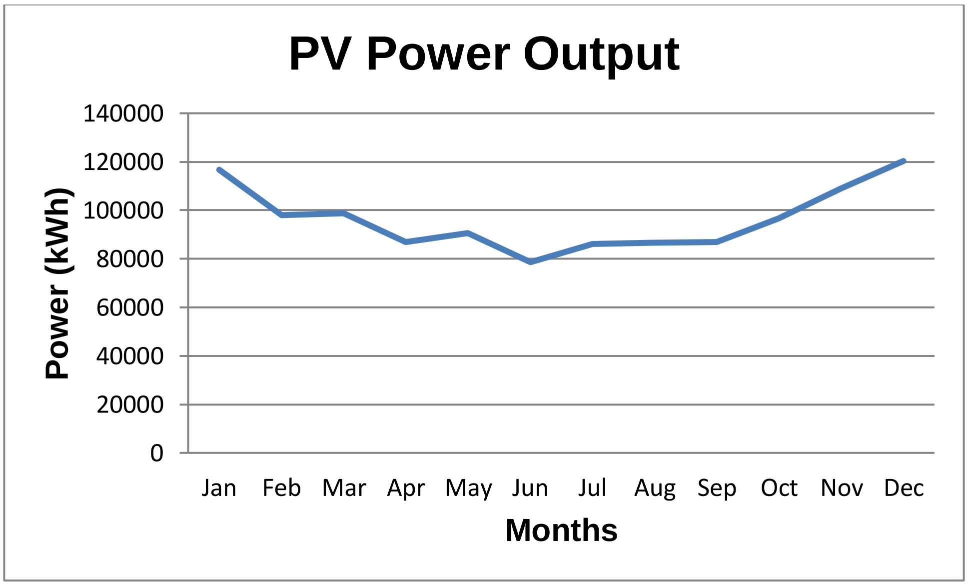


Figure 4.64: PV Power Output Eastern side of SA Durban area

The temperatures in this area are higher as compared to the Western and Southern sides. The minimum temperature observed is 25 ^{0}C and the maximum is 32 ^{0}C as seen in figure 4.65 below.

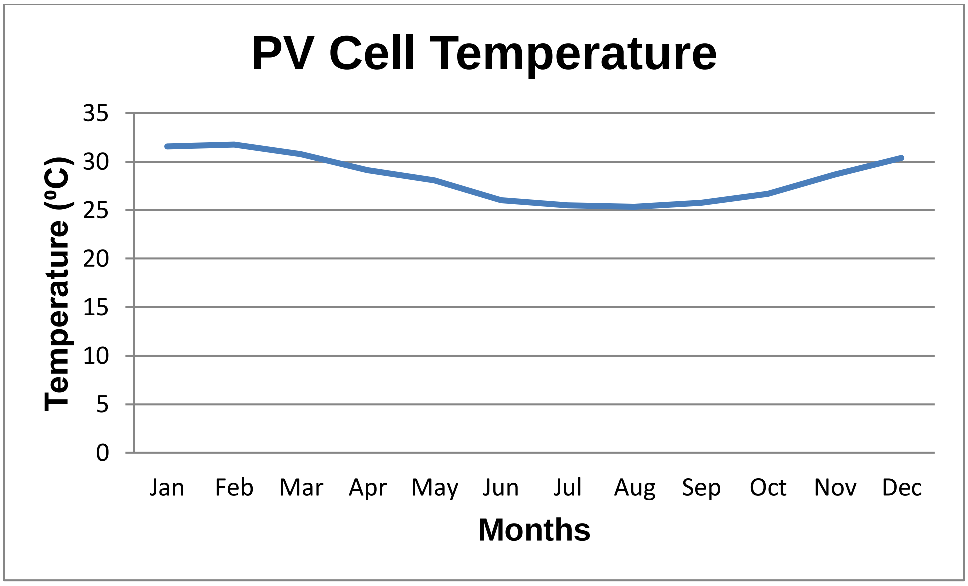


Figure 4.65: PV Cell Temperature Eastern side of SA Durban area

4.3.11 Eastern side of SA Maputo area

Figure 4.66: Modeled Ship location in the Maputo area

The Ship is placed in the Maputo area as depicted in figure 4.66, which is on the Eastern side of SA. In this area, the temperatures are even higher than in the Durban area. Solar PVs produced a mean power of 145 kW, which is 3 470 kWh per day and 1 266 494 kWh per year as depicted in table 4.40 below.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	145	kW
Mean Output	3,470	kWh/d
Capacity Factor	21.3	%
Total Production	1,266,494	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	143	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	0.000191	R/kWh

Table 4.39: Solar PV Power production profile in the Maputo area

The results of the solar PV power production in the Maputo area are also depicted in figure 4.67 below to further show the power production in this area as simulated.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	145	kW
Mean Output	3,470	kWh/d
Capacity Factor	21.3	%
Total Production	1,266,494	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	143	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	0.000191	R/kWh

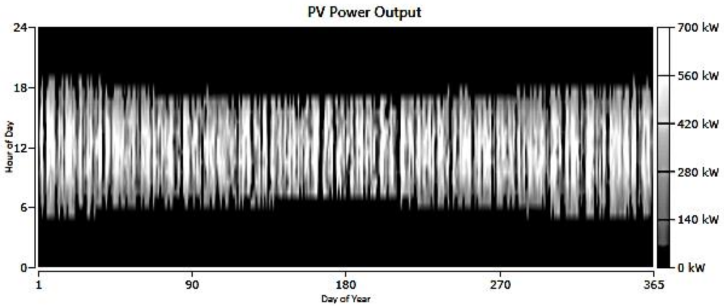


Figure 4.67: Simulated PV Power Production in the Maputo Area

Depicted in table 4.41 below is the load profile of the load that was served by the solar PVs that produced power in the Maputo area. The results show that the load of 884 682 kWh/yr was served by solar power while the Ship was in the Maputo area. This resulted in an excess electric load of 302 302 kWh/yr.

Consumption	kWh/yr	%
AC Primary Load	884,682	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	302,302	23.9
Unmet Electric Load	170	0.0193
Capacity Shortage	217	0.0245

Table 4.40: Electrical Load profile in the Maputo area

Table 4.42 below shows the PV power output at the particular temperature per month in the Maputo area, Eastern side of SA. The results are further elaborated graphically in figures 4.29 and 4.30 as well as in figure 4.68.

Months	PV Power Output (kWh)	PV Cell Temp (^0C)
Jan	125,614	33
Feb	105,512	33
Mar	104,277	32
Apr	94,903	31
May	98,447	29
Jun	88,935	28
Jul	95,390	27
Aug	102,873	27
Sep	100,439	28
Oct	110,053	29
Nov	115,383	31
Dec	124,669	32

Table 4.41: PV Power Output at a particular PV Cell temperature Eastern side of SA Maputo area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,266,494	100
Total	1,266,494	100

Consumption	kWh/yr	%
AC Primary Load	884,682	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,682	100

Quantity	kWh/yr	%
Excess Electricity	302,302	23.9
Unmet Electric Load	170	0.0193
Capacity Shortage	217	0.0245

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	1,983	%

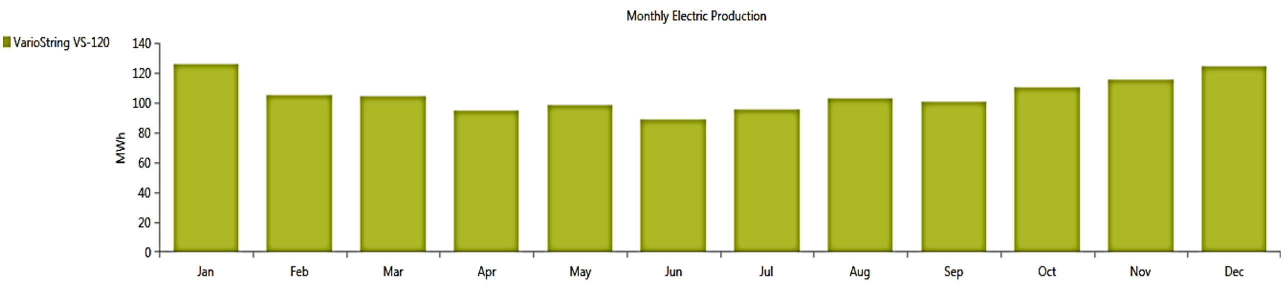


Figure 4.68: Simulated Monthly PV Power Production and Served Load in the Maputo Area

PV power output per month is depicted in figure 4.69 below. The figure graphically shows the PV power that is produced in the area of Maputo. Temperatures in this area are higher, thus there is more PV power that is produced. A maximum of 125 614 kWh and a minimum of 88 935 kWh is observed.

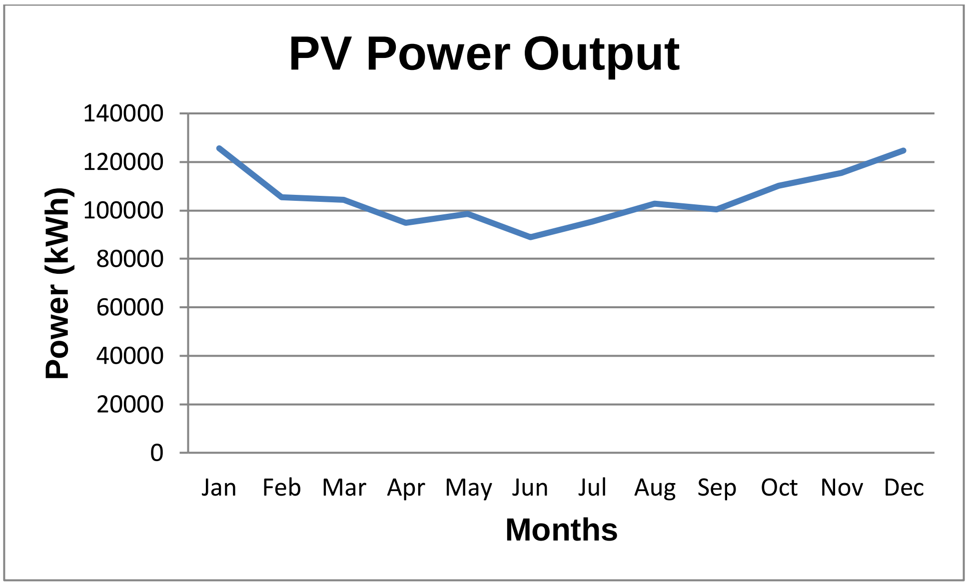


Figure 4.69: PV Power Output Eastern side of SA Maputo area

PV cell temperatures are shown in figure 4.70. The graphs show that in this area it is hotter than the areas that are simulated above. The temperature ranges from a minimum of 27 ^{0}C which is the maximum temperature in other areas. A maximum of 33 ^{0}C is observed which doubles other areas' temperatures.

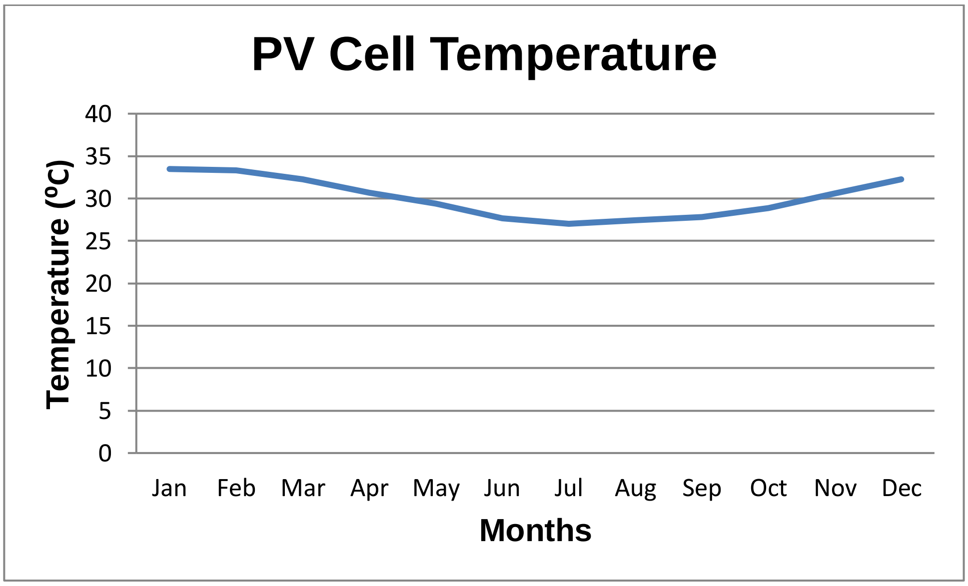


Figure 4.70: PV Cell Temperature Eastern side of SA Maputo area

4.3.12 Eastern side of Africa MOZAMBIQUE area

Figure 4.71: Modeled Ship location in the MOZAMBIQUE area

Table 4.43 and figure 4.72 below depict the solar PV power production in the Mozambique area, this is the area that is on the Eastern side of Africa, outside of SA EEZ as depicted in figure 4.71. When the Ship is placed in this area, the solar PVs were able to produce power to supply the Ship as per the modeled electric load. The solar PVs produced 144 kW, which is 3 461 kWh per day and 1 263 323 kWh in a year. The results as shown in the table show that with the rated power of 680 kW, the solar PVs capacity factor is 21.1 %.

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	144	kW
Mean Output	3,461	kWh/d
Capacity Factor	21.2	%
Total Production	1,263,323	kWh/yr
Dedicated converter	680	kW
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	143	%

Hours of Operation	4,373	hrs/yr
Levelized Cost	0.000192	R/kWh

Table 4.42: Solar PV Power production profile in the MOZAMBIQUE area

Quantity	Value	Units
Rated Capacity	680	kW
Mean Output	144	kW
Mean Output	3,461	kWh/d
Capacity Factor	21.2	%
Total Production	1,263,323	kWh/yr
Dedicated converter	680	kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	680	kW
PV Penetration	143	%
Hours of Operation	4,373	hrs/yr
Levelized Cost	0.000192	R/kWh

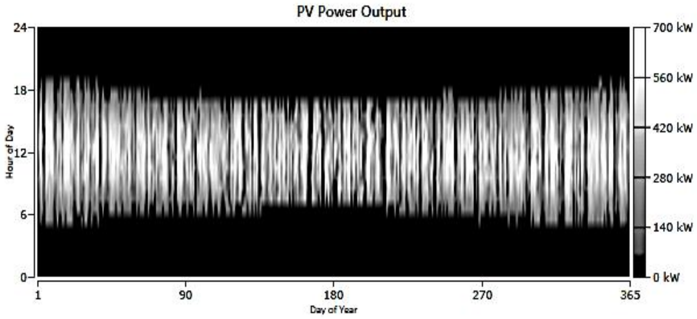


Figure 4.72: Simulated PV Power Production in the MOZAMBIQUE Area

The electrical load that was served by the produced power is 884 587 kWh/yr as depicted in table 4.44 below. The results indicate that there was an excess of 281 795 kWh/yr and an unmet electric load of 265 kWh/yr.

Consumption	kWh/yr	%
AC Primary Load	884,587	100
DC Primary Load	0	0
Deferrable Load	0	0
Excess Electricity	281,795	22.6
Unmet Electric Load	265	0.0299
Capacity Shortage	459	0.0519

Table 4.43: Electrical Load profile in the Mozambique area

Table 4.45 below depicts the PV power output and PV cell temperature in the Mozambique area, on the Eastern side of Africa. The table indicates that in this area almost double the load power requirement is produced. This can also be witnessed in figure 4.73, as the figure shows the power production monthly with the temperatures changing throughout the year.

Months	PV Power Output (kWh)	PV Cell Temp (^{0}C)
Jan	160,386	35
Feb	134,200	35
Mar	133,019	34
Apr	118,374	32
May	114,102	30
Jun	94,318	28
Jul	104,088	27
Aug	116,789	28
Sep	121,918	29
Oct	131,529	30
Nov	151,548	33
Dec	152,880	34

Table 4.44: PV Power Output at a particular PV Cell temperature Eastern side of Africa Mozambique area

Production	kWh/yr	%
Studer VarioString VS-120 with Generic PV	1,263,323	100
Total	1,263,323	100

Consumption	kWh/yr	%
AC Primary Load	884,679	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	884,679	100

Quantity	kWh/yr	%
Excess Electricity	298,812	23.7
Unmet Electric Load	173	0.0195
Capacity Shortage	840	0.0949

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,066	%

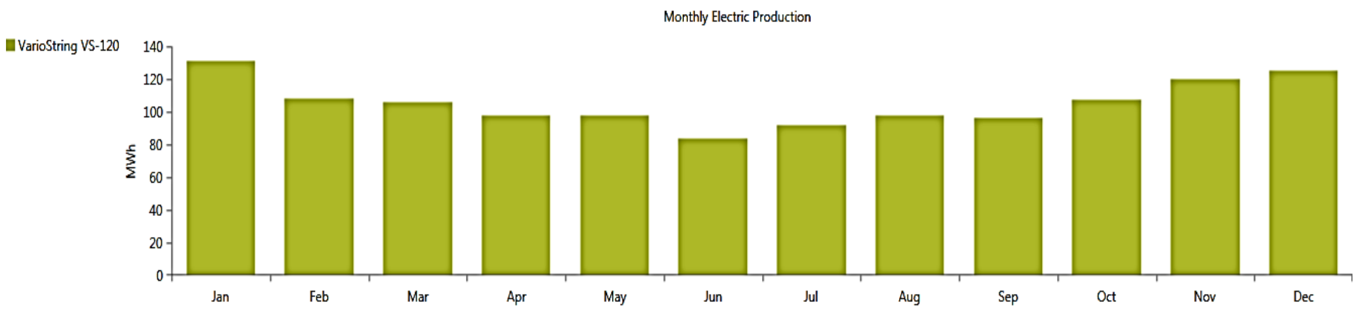


Figure 4.73: Simulated Monthly PV Power Production and Served Load in the MOZAMBIQUE Area

PV power output in the Mozambique area is displayed in figure 4.74 below. Due to the higher temperature in this area, observation is made that PV can produce more power throughout the year. With the minimum power produced being 94 318 kWh and a maximum above 150 000 kWh.

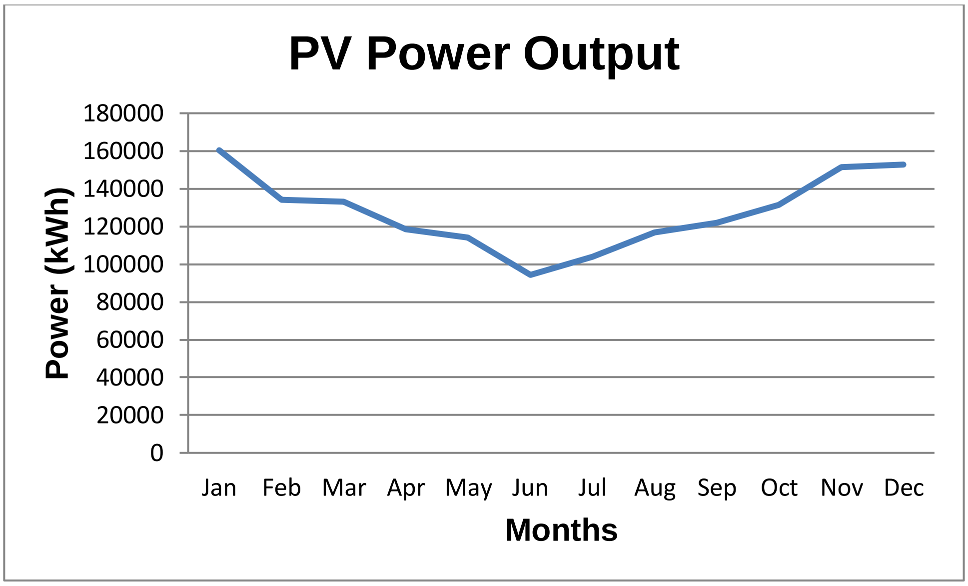


Figure 4.74: PV Power Output Eastern side of Africa Mozambique area

In this area, the temperatures are higher. As shown in figure 4.75 below, it is observed that the minimum temperature is 27 ^{0}C and the maximum is 35 ^{0}C. Even in the months that are usually the cold month in SA, the temperatures are still above 20 ^{0}C.

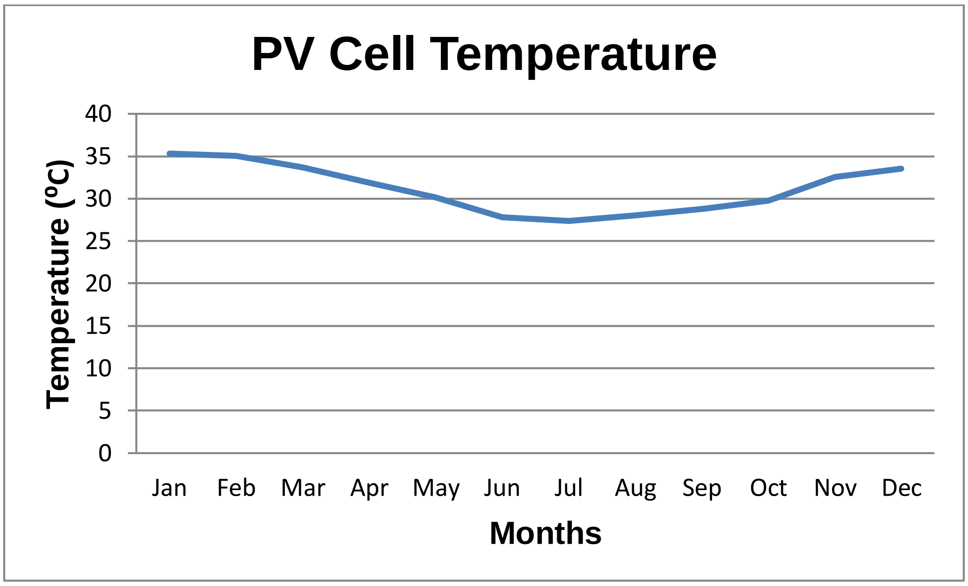


Figure 4.75: PV Cell Temperature Eastern side of Africa Mozambique area

4.4 SUMMARY

The diesel Generator of the Ship is modeled and simulated to determine its electrical power production, Fuel consumption, and toxic gas emissions. Solar PV power production when the panels are installed on the Ship is modeled and simulated with the Ship placed in the harbor and different locations at Sea. Simulation results for the diesel generator and solar PVs are shown. The results of the solar power production for when the Ship is at Sea are shown according to each location where the Ship is placed. The full results of the simulations as per the HOMER application are depicted in the appendices per the Ship's positions at Sea.

Chapter 5 DISCUSSION

This chapter will discuss the simulated results in chapter 4. The results will be evaluated, interpreted, and deliberated in depth. To accommodate the limitation of the HOMER application that is used to simulate the production of PV power on a moving ship; the ship is simulated in different areas around SA and within the SA's EEZ. As simulated in chapter four, the locations are divided into Western, Southern, and Eastern areas in the SA's EEZ. These areas are chosen because are the areas of operation for SA Naval Ship to safe keep the South African marine resources.

The results of the simulations are displayed in the tables and graphs. Specifically, the PV power output, PV cell temperature, and electrical load are the results of interest. Therefore, these results will be discussed in this chapter. The results of each location will be discussed independently as each location produced different output from the others. In the results in chapter 4, the PV power output, PV cell temperature, and electrical load are simulated on a monthly basis. Therefore the average temperature per month is used. The chapter will start the discussion with the results of the simulated diesel generator in the Ship, followed by the results of the simulation of the Ship in the harbor, and lastly when the ship is at Sea.

5.1 SHIP'S DIESEL GENERATOR POWER GENERATION

The design of the Ship requires it to be able to generate its electricity. SA Navy ships use diesel generators to generate their electricity while at Sea and when it is alongside in Harbor. The ship that is used for the purpose of the study uses five diesel generators including one for emergencies. Each diesel generator has the following specifications; voltage of 450 V 60 Hz and a power rating of 449.6 kW. These are Volvo Penta NEMA MG1-32. Each diesel generator consumes over 100l/hr of diesel at 100% load. Therefore, when the ship is operating all four diesel generators same time as required at Sea, over 400 liters of diesel are consumed in an hour. This is depicted in figure 4.1 in the results chapter.

Already with the high cost of diesel in SA, SA Navy will have to spend a lot of money on diesel to be able to fully operate the Ship. The price of a liter of diesel is just above R25 at the time of this simulation in SA and could increase as time goes by. This means SA Navy will spend just over R60 000 in a day and over R1.8m per month and close to R45m a year on diesel should it require to use the diesel generator only. This excludes the operation and maintenance costs as well as the replacement costs should there be a need to replace the generator. Looking into the period in which a typical operation would take out at Sea, the Ship can be deployed for six months, this means SA Navy will spend over R11m on diesel only. The simulation results as shown if figure 4.6, also shows that in a day the generator would consume an average of 1 063 liters and 387 990 liters in a year.

Since these generators have moving parts, maintenance is critical to ensure that they can still operate to their maximum capacity. Therefore, the lubrication, cooling, bearings, and wear rings as well as the servicing kits will have to be budgeted for. This amounts to even more money to be spent on generators. Since generators use combustion to turn the engines that turn the generator, toxic gases are produced and released into the atmosphere. Four generators turning at the same time could result in a great amount of gases being emitted into the atmosphere. Meaning SA Navy will also be greatly contributing to the emission of toxic gases which affect the climate.

A diesel generator with similar specifications is modeled and simulated in the HOMER application. It is simulated with the typical load that a Ship will have. In the simulations, the fuel requirement for electrical power generation is calculated monthly. In the simulation results, it is shown that the more electrical power to be produced more diesel will be consumed. As shown in Figures 4.2 and 4.3, to produce 3 816 kW of electrical power, 1 082 liters of diesel would be consumed. The simulation is done on only one generator, therefore when taking the use of four generators into account, about 4 328 liters would be consumed.

The results also showed the amount of toxic gases that are released into the atmosphere as the generators are operating. As depicted in table 4.3, over 1 million kg of Carbon Dioxide, 5 263 kg of Carbon Monoxide, 279 kg of unburned Hydrocarbons, 45.0 kg of Particulate Matter, and 2 487 kg of Sulfur Dioxide, and 1 009 kg of Nitrogen Oxide are released to the air in a year. This significant amount of toxic gases that can be produced by only one diesel generator in a year can create great damage to the climate. One can just imagine the danger that more generators can create.

To upkeep, a diesel generator costs a lot of money. To ensure that it is operating at its optimum function, the operation and maintenance will have to be kept at a high standard. Simulation results in figure 4.7 shows how much it costs to upkeep the generator; it is observed that O&M costs over R8.5m, To replace or complete overhaul it cost close to R25m, and over R1.2m for diesel over the generator life span. The next section will discuss Solar PV power generation in Harbor.

5.2 SOLAR POWER GENERATION IN THE HARBOR

When the Ships are not out at Sea, they are alongside in the harbor to undergo maintenance and training for personnel. Electrical systems are still operational at this state. Therefore, the need to generate electricity for the Ship is still needed. Even though the Ships connect to the grid power that is available on the quays, an alternative electrical power generation is still needed. Hence the Ships will have the diesel generators on standby should a need for alternative power arise. But having generators operating adds to O&M and fuel costs and toxic gas emissions. Among the objectives of the research, one is to indicate that Solar PV can produce sufficient power for the Ship.

A modeled Solar PV power generation on the Ship is simulated with the Ship placed in two positions in the harbor. The inner and outer basins are the areas where the Ship that is used for the research is mostly placed. Areas are shown in figures 4.8 and 4.9. The results of the simulations in both areas will be discussed below.

5.2.1 Inner and Outer basins

The simulations in these areas show that there is sufficient solar radiation to allow the solar PV to produce power for the ship. The temperatures that hit the PV panels reach the maximum of 20 ^{0}C from January to March. They then start to reduce due to the change in seasons in SA. From April to early September temperatures are low, and it is mostly rainy and cold. However, even with the decrease in temperature, Solar PVs were still able to produce electrical power for the ship. The minimum power that the PVs produced is 68

057 kWh, which is in June, the rainy month. The load that is used in simulations requires 2 424.25 kW/h per day. The solar PVs were able to produce a minimum of 2 269 kWh a day in June.

In the results, solar PVs produced a maximum of 129 475 kWh in one month, which means they produced 4 177 kWh per day. The ship's highest load demand requires at least 320 kW per day which is 7 680 kWh per day. This requirement applies when the Ship is operating a crane, which demands more power. As shown in table 4.7 and figure 4.7, the solar PV system that is used in the model has a rating capacity of 680 kW with a mean output of 138 kW. In the simulation results, the solar power produces a mean output of 3 312 kWh per day. In a year solar PV produces 1 208 834 kWh. Looking at the electrical load which is 884 350 kWh per year, the solar PV power is sufficient to power it and have excess electricity. In the modeled solar PV power system, it costs just over R7.1m and about R1.6m for maintenance and operation. It costs R0 for diesel as shown in table 4.5.

In these areas, the ship remains stationary and always facing one direction. Therefore, it allows maximum solar irradiation on the solar PVs and keeps them facing the sun. Solar PVs are tracking the sun in one trajectory. It could be an east-west trajectory or a south-north trajectory. The tracking is much easier in this situation as only the PVs are moving to track the sun. However, the following section where the PVs will be tracking while the ship is moving can present a challenge. Hence the GPS-integrated tracking system is considered.

5.3 SOLAR POWER GENERATION AT SEA

When the Ship is at sea it becomes an island, there is no other support it can get but to be able to support itself. Likewise, with its electricity, it must produce its own. Traditionally diesel generators are used onboard Ships to generate electricity. The operating of diesel generators comes with costs involved as well as the toxic gases produced in the atmosphere. In this section of the chapter, the use of solar PVs to produce electricity for the Ship at sea will be discussed as per the simulated results in chapter 4.

Modeled solar PVs as installed on the Ship are simulated and gave results as per the conditions that the ship is placed. The HOMER application is used to simulate solar PV power production. The simulation intends to simulate solar tracking PVs installed on a Ship, with integration to the GPS to allow consistent exposure to the sun arrays while the Ship is moving. Due to the limitation of the application to simulate the GPS integration and movement of the Ship, The Ship is placed in different locations within the SA's EEZ divided into Western, Southern, and Eastern areas of the SA coastline. A continuous tracking system is used in the simulations, this allows for enough sun arrays on the PVs as the locations are changing. The simulation results in these areas are discussed below.

5.3.1 WESTERN SIDE OF SA

This area is divided into four sub-sections and the Ship is placed in these sub-sections to simulate the solar PV power generation according to the temperature in these areas. The PV power generation on the Namibian border will be discussed first then followed by Cape Point, False Bay, and then the Western area of SA, which is further out to the Sea.

5.3.1.1 Namibian Border

The Ship is placed in this area to observe solar PV power production. With the continuous tracking system on the Ship, The results indicate that PV can produce enough power to certify the total electrical load. With the power being able to be produced, it indicates that the temperatures in this area are sufficient. The lowest temperature observed in the results is 21 ^{0}C and the highest is 28 ^{0}C. However, the temperatures changes with the months throughout the year. Therefore the power produced by solar PVs also changes.

The highest solar PV power of 130 029 kWh is produced in December with a temperature of 26 ^{0}C. The minimum power that solar PVs produced is 89 503 kWh in June at a temperature of 22 ^{0}C. In the results, it shows that throughout the year the power that is produced is above 100 000 kWh except from May to July as table 4.12 and figure 4.18 depicts. Even though less power is produced in these months it is still sufficient to serve the electrical load. In a year the solar PVs can produce a maximum of 1 328 675 kWh, this power can serve a load of 884 683 kWh per year as shown in tables 4.10 and 4.11 as well as figure 4.17.

5.3.1.2 Cape Point

The Ship is placed in the Cape Point area to determine the solar PV power output in this area. The temperatures in this area maximize at 30 ^{0}C and the lowest being 20 ^{0}C. The results in table 4.21 and figure 4.33 showed that at the lowest temperature, the solar PVs can produce 80 943 kWh per month and at the maximum temperature, they produce between 141 00kWh and 182 585 kWh per month as shown in table 4.20. This indicates that even in the months that have low temperatures the PVs can still produce sufficient power to supply the ship. In a year the PVs can produce 1,243,331 kWh which is sufficient to power an 884,724 kWh electrical load.

The rated capacity for the solar PV is 680 kW, in this area, it produced a mean output of 142 kW which is 3 406 kWh per day. The electrical load that was required to be satisfied was 2 423 kWh per day. Solar PV produced more than enough power for the load requirement. When the Ship is sailing in this area and needs electrical power for its systems, it can be supplied by Solar PV power alone and be fully functional. Even in the winter months, there will still be power generated by solar PVs.

The capacity factor of the PV output which is the average power output of the PV array divided by its rated power is observed to be 20.9%. In the results as shown in table 4.19 as well as figure 4.32, it shows that there is 141 % of PV penetration, whereby the PV average power output of the array is divided by the average primary load. The number of hours whereby the PV array output was greater than zero is observed to be 4 372 hrs/yr. This is the period when the PVs were producing the power. In the simulation, the AC load is simulated whilst the DC load is used as a battery. Hence the DC primary load is 0 kWh/yr. The system has no deferrable load. With the maximum power of 1 243 331 kWh/yr produced to serve an 884 724 kWh/yr, the excess electricity results at 277 154 kWh/yr. throughout the year there is a time when not sufficient power was produced by the solar PVs, hence the results of 128 kWh/yr of unmet electric load. The system had a 170 kWh/yr capacity shortage, where the system could not satisfy the load requirement.

5.3.1.3 False Bay

The Ship is now placed in the False Bay area which is closer to the harbor. The temperatures in this area are lower as compared to that of Cape Point above. This is the area that is commonly used by the Ships during trials and training. The power demand in this area is essential as the systems must always be available. The results in table 4.18 and figure 4.28 indicates that the minimum power that is produced at the lower temperature is 80 410 kWh in a month and the maximum at the highest temperature is 147 452 kWh in a month as shown in table 4.17. In the table, the results show that from June to September the temperatures are below 20 ^{0}C and from January to May as well as October to December are above 20 ^{0}C. Even with the variation of the temperatures in this area, the solar PVs can produce enough power to serve the load.

As it is shown in table 4.16 and figure 4.27 the mean output for the solar PVs in this area is 149 kW, which is 3 586 kWh per day. The total production in a year is 1 308 785 kWh. The total electrical AC load that the produced power had to serve is 884 634 kWh. This means that solar PVs produced enough power to serve the load as required. The solar PVs produced this power per year when they were operational for 4 371 hrs. This is the period where the produced power was above 0 kWh. In this area, the PV penetration is 148 %. Similar to the Cape Point area results, the DC load and Deferrable load are 0 kWh. In the results, the excess electricity is observed to be 347 257 kWh per year. This confirms that the solar PVs were able to produce more than sufficient power for the load. The capacity factor of 22% for the system is observed, this is the average power output of the PV array divided by its rated power. There is a time when there was no power that was produced by the solar PVs in a year, hence the system has an unmet electric load of 218 kWh and a capacity shortage of 481 kWh

5.3.1.4 Western area

In this area, the Ship is placed further out to Sea, further to the shoreline. The average temperatures per month in this area are relatively higher than the areas that are closer to the shoreline in the Western area of SA. Most of the temperatures are above 20 ^{0}C except in July and August when the temperature averages at exactly 20 ^{0}C. Even the solar PV power that is produced per month in this area is relatively higher than the power that is produced in Cape Point and False Bay areas. The minimum power that is produced per month in this area is 90 790 kWh and the maximum is 159 782 kWh.

The results indicate that solar PV produced a total production of 1 396 522 kWh per year in this area. The solar PVs produced a mean output of 159 kW, which is 3826 kWh per day. The capacity factor of the PV output which is the average power output of the PV array divided by its rated power is observed to be 23.4 %. Hours in which the solar PV power production was above 0 kWh are observed to be 4 371 hrs. At the time when there was no power produced, the unmet electricity load was 308 kWh, with a capacity shortage of 364 kWh. The total electrical load that was to be served by the produced power was 884 544 kWh and the total DC and deferrable loads were 0 kWh. Excess electricity was 435 013 kWh, this is the excess electricity that was produced by the solar PVs and the load did not require.

5.3.2 SOUTHERN SIDE OF SA

This is the area in the SA's EEZ that is on the Southern side of SA. In the simulations, this area is divided into sub-areas; the Southern area which is further out to Sea, the Southwest area, the Gqeberha area, the East London area, and the Southeast area. The Ship is placed in these different areas to determine if the solar PVs could be able to produce power for the Ship in these areas. The results are discussed below in accordance with the area temperatures and PV power output.

5.3.2.1 Southern area

The solar PV power production is simulated in this area to determine if enough power can be produced for the Ship. This area is further out to the Sea south of SA. The average temperatures per month in this area are between 21 to 28 ^{0}C. This means there are enough sun rays for solar PVs to generate electricity. Simulation results indicate that solar PVs are producing a minimum of 64 365 kWh per month and a maximum of 126 177 kWh. From April to July the lower power is produced which is below 80 000 kWh, however, from January to March and August to December is above 80 000 kWh. The maximum power is produced in January and December these are the months with warmer temperatures.

Solar PVs produced mean power of 127 kW, which is 3 039 kWh per day. With a rated capacity of 680 kW and a mean power of 127 kW, the capacity factor of the system is 18.6 %. The period in a year where the solar PV output was above zero is 4 380 hrs and with the solar PV penetration of 125 %, the solar PV was able to produce a total power of 1 109 404 kWh in a year. In that year the electrical load that the solar PV was able to serve was 884 852 kWh. The DC primary load and deferrable load were 0 kWh. The amount of power that was produced by the system was enough to serve the load, hence the system has excess electricity of 141 532 kWh in that year. As shown in table 4.24. The system had no unmet electric load and therefore the capacity shortage is zero.

5.3.2.2 Southwest area

This is the area between the South and the West side of SA. The Ship is placed around this area to show that the solar PVs can produce power for the Ship when it is sailing around this area. The sun rays in this area are strong enough to give temperatures that average to the lowest of 19 ^{0}C per month and are maximized at 28 ^{0}C. Table 4.23 shows the power that was produced by the solar PV per month. The power varies with the change in the temperature in a particular month. In the mid-year months, the power that is produced is lower. During these months the temperatures are lower as it is the winter season in SA. At the beginning of the year and end of the year, it is observed that the solar PV power is higher. These are the summer and spring months which have warmer temperatures and fewer clouds.

The solar PVs can produce a total power of 1 223 204 kWh in a year to serve the electrical load of 884 764 kWh in that year. In a day they produced a mean output of 3 351 kWh from the mean output power of 140 kW with a capacity factor of 20.5 %. The results indicate that the system has 138 % of PV penetration. The hours of operation in a year where the solar PV output was greater than zero are 4 392 hrs. With the total electric load that was served by the solar PVs, the amount of the excess electricity is 256 194 kWh/yr, this is the power that had to be dumped since it could not be used on the load. As the solar PVs were not fully generating power in a year where the output was 0 kWh, the unmet electric load was 88 kWh/yr, which yielded a capacity shortage of 158 kWh/yr. The system's DC electric and deferrable load was 0 kWh/yr.

5.3.2.3 Gqeberha area

This is on the Southern side of the SA and close to the shoreline. The Ship is placed in this area as well. In this area, the temperatures are warmer than in the Southwest area. They average at a minimum of 22 ^{0}C in a cold month and maximize at 29 ^{0}C in a hotter month. Like in other areas in the Western and the Southern area, the temperatures are lower in mid-year months. As seen in table 4.30, from June to September the temperatures are between 22 ^{0}C and 23 ^{0}C. But at the beginning and the end of the year are between 24 ^{0}C and 29 ^{0}C. Likewise with the solar PV power output, in the mid-year months, the produced power is lower than the power that is produced at the beginning and the end of the year.

From April to September the solar PV power produced is between 71 491 kWh and 85 486 kWh and from January to March as well as from October to December is between 91 858 kWh and 125 897 kWh. Solar PVs produced mean power of 128 kW, which is 3 065 kWh per day. The solar PV-rated power is 680 kW, with a mean power of 128 kW resulting in an 18.8 % power factor. The total solar PV power produced in a year in this area is 1 118 853 kWh. To generate this power, the solar PV array output was greater than zero for 4 378 hours in that particular year, with a PV penetration of 126 %. The total load that was served is 884 610 kWh, with DC primary and deferrable load being 0 kWh. As for the DC load, the DC output of the system is only connected to the battery.

The excess electricity energy that had to be dumped since it could not be used to serve a load was 151 393 kWh. Since the solar PVs were not producing power 100 % of the time in a year, there is an unmet electric load of 242 kWh, which is a capacity shortage of 461 kWh.

5.3.2.4 East London area

From the Gqeberha area, the Ship was moved to the East London area which is around 140 nautical miles from Gqeberha. In this area, the temperatures are warmer as compared to the temperatures in the Gqeberha area. The minimum temperature is 23 ^{0}C and the maximum is 29 ^{0}C in a particular month. Even in the months that are normally cold in SA, in the East London area temperatures are warmer. Solar PVs can produce power in this area as shown in table 4.33. The lower solar PV power is produced in June and July. 73 285 kWh and 76 503 kWh was produced in these months respectively. Higher solar PV power was produced in January, November, and December. 111 294 kWh, 102 897 kWh, and 115 079 kWh was produced in the above-mentioned months respectively. From February to May and August to October between 79 481 kWh and 94 092 kWh were produced.

As depicted in table 4.31, the solar PVs were able to produce mean power of 123 kW, which amounts to 2 960 kWh per day. With a rated capacity of 680 kW and a mean output power of 123 kW, the system has a capacity factor of 18.1 %. The capacity factor is calculated by dividing the average PV power output by its rated capacity. In a year the solar PVs produced a total of 1 080 500 kWh. PV penetration, which is the average PV array output divided by the average load that it served, is 122 %. The period during the year when the solar PV array output was greater than zero was 4 377 hrs. The system served a load of 884 443 kWh in a year with 0 kWh for DC and deferrable load. The system produced more power than the served load required, therefore resulting in excess electricity of 112 342 kWh. Since the solar PVs were only producing power in 4 377 hrs of the year, there was an unmet electric load of 409 kWh/yr which was the 637 kWh capacity shortage.

5.3.2.5 Southeast area

This area is out towards the Sea between the South and East side of SA, but still within 200 Nautical Miles of SA EEZ. From the East London area, the Ship was now placed in this area. As observed in table 4.36, the solar PV power that gets produced in a month in this area is getting higher as compared to production in the months of the East London area. In the mid-year months, the produced power is above 80 000 kWh which is high as compared to mid-year production in the East London area. The highest power produced in a month is 142 204 kWh. This simply indicates that in this area there are enough sun rays that strike the solar PV. This area also has higher temperatures, with a minimum of 24 ^{0}C and a maximum of 30 ^{0}C.

The solar PV generated an output of 2 994 kWh per day from the mean output of 125 kW. The rated power of solar PV is 680 kW. Therefore, the capacity factor of the system is

18.3. The system produced a total production of 1 092 837 kWh in a year with a PV penetration of 124 %. The output of the solar PV array was greater than zero for a period of 4 375 Hrs in a year. The total AC load that was served by the produced power is 884 356 kWh in that particular year. That resulted in an excess electric load of 124 685 kWh. The system has no DC load, instead, the produced DC power is sent to the batteries, hence the DC load and deferrable load is 0 kWh. The unmet electricity load is 496 kWh. This is the result of solar PV not producing power for the entire year but in the hours where the output was greater than zero, hence the 875 kWh capacity shortage.

5.3.3 EASTERN SIDE OF SA

This section discusses solar PV power production in the Eastern area of SA. This is the area that is on the east side of the SA's EEZ. The Ship is placed in different places in this area to confirm that there are enough sun rays and sufficient temperatures to enable the solar PV arrays to generate electricity. The area is divided into three areas where the Ship is placed. These areas are the Durban area, Maputo area which is towards the Mozambique border, and the Mozambique area, where the SA Navy Ships operate. The solar PV power production in these areas is discussed below as per the production in each area. The temperatures in this area are higher, even in the winter months. In the Durban area, the minimum temperature is 25 ^{0}C and the maximum is 32 ^{0}C. In the Maputo area temperatures ranges from 27 ^{0}C to a high of 33 ^{0}C. And in the Mozambique area temperatures are even higher, with a minimum of 27 ^{0}C and a maximum of 35 ^{0}C. All these temperatures are averages per month.

5.3.3.1 Durban area

This section discusses the PV power production in the Durban area as the results are depicted in chapter 4. With a minimum temperature of 25 ^{0}C and a maximum of 32 ^{0}C, the solar PVs with a power rating of 680 kW were able to produce a mean output of 132 kW, which is 3 166 kWh per day. At 132 kW produced the system has a 19.4 % capacity factor. In a year solar PV produced 1 155 529 kWh. On a monthly basis, the solar PV produced between 78 620 kWh and 120 300 kWh. The PV arrays were not producing power for the entire period of the year, it was producing power for 4 374 hours of the year.

This is the time when the PV array output was greater than zero. The PV penetration of the array was 131 %.

The maximum AC load that was served by the produced solar PV power was 88 618 kWh, with a DC load of 0 kWh. The power that was produced is more than the served load requirement, hence there is excess electricity of 188 854 kWh. Since solar PVs produced power for almost half of the whole year’s hours, there is an unmet electric load of 234 kWh, which is a capacity shortage of 290 kWh.

5.3.3.2 Maputo area

This section discusses solar PV power generation in the Maputo area. As stated above, the temperatures in this area are warmer. This implies that there are also sufficient sun rays that would strike the solar arrays to generate the power. With the Ship placed in this area, the solar PVs can produce mean power of 145 kW, which gives 3 470 kWh per day as resulted in table 4.40 depicted. The rated power for the PV is 680 kW; therefore, with the mean power output of 145, it gives a capacity factor of 21.3 %. In a year the solar PVs produced 1 266 494 kWh when the Ship is in this area. The average electric load that is served by the produced power is 884 682 kWh. Therefore this gives the system a PV penetration of 143 %. Solar PVs produced power for 4 374 hours per year. This is the period during the year when the PV array output was greater than zero.

With 69 % of the produced power serving the electrical load, excess electricity of 302 302 kWh is observed as shown in table 4.41. This shows that the solar PVs produced more power than what the load demanded. Since the solar PVs were not generating power during some hours of the year, it resulted in an unmet electrical load of 170 kWh/yr, which is a 217 kWh/yr capacity shortage.

5.3.3.3 Eastern side of Africa Mozambique area

The Mozambique area is outside the SA EEZ, however, it is the common area of operation for the SA Navy. Therefore, while in this area the Ship must still be able to produce its power. Should the produced solar power be sufficient and be able to sustain the Ship’s required power, means that SA Navy will still be able to save on fuel, and O&M coats and reduce toxic gas emissions. This area has more sun throughout the day with high temperatures. They are higher even in the moths that have cold days in the Western and Southern sides of SA.

As observed in table 4.43, solar PVs can produce a mean power of 144 kW, which is 3 461 kWh per day. The capacity factor of the system is 21.2 %, as the rated power of the solar PV is 680 kW. In a year the solar PVs produced a maximum of 1 263 323 kWh. The number of hours in a year when solar PV was producing power is 4 373 Hours. This is the period where the PV array output was greater than zero. The total load that was served by the produced power is 884 587 kWh/yr, with this much load the PV penetration of the system is 143 %. The system has excess electricity of 281,795 kWh. Due to the period in which the solar PVs were not producing sufficient power, the unmet electric load is 265 kWh/yr. This resulted in a capacity shortage of 459 kWh per year.

5.4 SUMMARY

The results of the modeled and simulated Ship's diesel generator solar PV for the Ship were discussed in this chapter. The discussions were based on the results that are shown in chapter four. Tables and figures displayed the system upkeep costs, the location of the Ship, and the power generation for both diesel generator and solar PVs.

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of the study will be presented in this chapter. The conclusions will be firstly presented and then followed by the recommendations. The paper is based on research on the implementation of a sun-tracking system of solar power on Military ships, which is rare in this era. The modeling and simulation approach was used in this paper to determine the results. HOMER application was used for modeling and simulating the results. However, due to the limitations of the application, the integration of GPS could not be modeled. But the movement of the Ship was determined by moving the Ship to different locations at Sea in the South African Economic Exclusive Zone and the common areas of operation. A Continuous Tracking system was used in the modeling since it could provide the results as the Ship changes locations. The desired results were achieved, hence the following conclusions were reached.

6.1 CONCLUSIONS

The areas within the SA EEZ are divided into three sides, Western, Southern, and Eastern sides for the purpose of the study. The Ship is placed in different locations within these areas and also place in the harbor to determine if the solar panel could produce power for the Ship's load demand. Placing the Ship in various locations at Sea is to model the movement of the Ship out at Sea. A continuous sun-tracking solar panel with a power rating of 680 kW is used in the model. The minimum load requirement was 2 424 kWh per day. A diesel generator on the Ship was also modeled to determine the amount of fuel that would be consumed during the operation, the amount of toxic gases that the diesel generator emits into the atmosphere as well as the operation and maintenance costs.

In the results, the amount of fuel that is consumed by the generator in a year is significant. Therefore, the fuel costs are directly proportional to fuel usage. A significant amount is spent on fuel for the generator. Taking into consideration the operation and maintenance of the generator also add to the already high cost of fuel. To operate one generator for the Ship, in a year cost a lot of money. Considering that the Ship uses four generators, the costs are four times higher. The generators generate a huge amount of toxic gases in a year, as shown in the results. This is a huge contribution to CO2 emissions to the atmosphere and damage to the climate. This leads to climate change impact.

When the Ship is placed in the harbor, the solar PV produced enough power to satisfy the load as modeled. The simulation results showed that solar PV power can sustain the Ships electrical requirement in a year while in the harbor. Even though the power production varies monthly, and daily, the minimum load requirement was met. Therefore in the harbor, the Ship could depend entirely on the produced solar PV power and the generators switched off or placed on standby in case of solar power loss due to faults or defects.

As the Ship is required to generate its electrical power when out at Sea. The Ship is placed in different locations on the Western side of SA, in The SA's EEZ. Solar PV power is modeled to determine that when installed on the military Ship, it will produce the power to support the Ship's power demand requirement. In the different locations within the Western side of SA, the solar PV produced enough power to satisfy the electrical load as modeled in the HOMER application. The produced power is sufficient that there is an excess electrical power to the load. Hence the solar PVs can produce the power for the Ship's load demand on the Western side of SA. This implies that the Ship can use solar power to power its electrical systems while out at Sea and reduce greatly on the use of diesel generators. A continuous tracking system allowed for consistent sun rays on the solar panels.

The Ship is now moved to the Southern side of SA, in different locations like on the Western side to determine the PV power output in these areas followed. The Ship is moved into Gqeberha, East London, Southwest, Southeast areas, and in the Southern area out to Sea. In all these areas, the solar PVs produced sufficient power to fulfill the load demands as modeled. The tracking system was able to track the sun and kept the sun rays perpendicular to the solar panels for maximum power production. Simulation results confirm that the Ship can be supplied by solar power solely and have the diesel generator on standby.

Lastly, the Ship is moved to the Eastern side of SA with the EEZ and one location outside the SA's EEZ. This is location is in the Mozambique area. The continuous tracking solar system produced sufficient power in these different locations within the Eastern side of SA. The daily load requirement of 2 424 kWh as modeled is fulfilled by the produced power. The yearly produced power was sufficient to serve a yearly load. This implies that solar power is reliable to power the Ship for the duration of its operation period.

As the Ship is still in the harbor, the solar PVs produced an average of 1 208 834 kWh per year to serve the load of 884 350 kWh per year. When the Ship is at Sea, moving from the Western to the Eastern sides of the SA, the solar PVs produced an average power of 1 215 621 kWh per year to serve an average load of 811 617 kWh per year. The power is produced with 0 kg of toxic gases being produced and emitted to the atmosphere and 0 liters of diesel being consumed. The cost to install the solar system as simulated is R7.1m and operation and maintenance are R 1.7m/yr. However, the diesel generator on the other hand for the Ship it would cost over R3.5M to install and around R667 262 for operation and maintenance. With the price of diesel increasing gradually in SA in this era, it will require around R7.9m per year for fuel only. Installing the solar PVs on the military Ship for electrical power supply would save a lot on the cost of upkeep of the generators. The continuous tracking system enabled the solar panels to produce enough power to serve the Ship's load.

6.2 RECOMMENDATIONS

The research is relatively new to the integration of renewable energy into the military Ship, especially in the SA Navy. None of the Ships uses any form of renewable energy to power their electrical power. Taking into consideration the cost of fuel and the amount of toxic gases these diesel generators emit into the atmosphere, Engineers in the military environment must look into venturing into renewable energy for the Ships. The study was conducted on the supply and support Ship with sufficient space to install solar panels. The experiments are conducted employing modeling and simulated results on the HOMER application. The experiment may be physically conducted by physically installing the solar panels on the Ship's superstructure and exposing them to the conditions at Sea. The Ship's GPS is connected to the Inertia Navigation System which provides the behavioral movement of the Ship. Therefore, in future research, the researcher may consider connecting the solar PV system to the Ships navigation system to allow it to track the sun as the Ships movement changes.

Future research on integrating renewable energy such as solar or wind power into combat Ships can be conducted. This type of Ships has many electronic weapon systems which require more power than the support Ships. Even the space on the superstructure is limited due to the installations on the upper decks. However, considering the integration of solar panels could be a viable option. Other modeling applications may be used in future research to indicate the power production of renewable energy systems on the Ships.

REFERENCES

Aijjou A., L. Bahatti, Raihani A., and De Mohammedia E. 2019. Influence of Solar Energy on Ship Energy Efficiency: Feeder Container Vessel as Example.

Adnanes A. K. 2003. Maritime Electrical Installation and Diesel Electric Propulsion.

Anish. 2021. How is power generated and supplied on a Ship?. Marine Electrical. https://www.marineinsight.com/marine-electrical/how-is-power-generated-and-supplied-on-a-ship/ [11-07-2021]

Atkinson G. M. 2016. Analysis of marine solar power trials on Blue Star Delos. Journal of Marine Engineering and Technology, 15(3): 115-123.

Altayeb M., Abdalla S. and Mustafa A. H. 2018. Dual Axis Solar Sun Tracking System Based on GPS Satellite Receiver and Embedded System. 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE). Khartoum.

Cheng P., Liang N., Li R., Lan H. and Cheng Q. 2020. Analysis of Influence of Ship Roll on Ship Power System with Renewable Energy.

Chartier A. How does solar energy work for you in your Home?. Household Improvements.com. https://za.pinterest.com/pin/438326976225812464/ [17/05/2022]

Carlson. O. and Nilsson P. 2015. Development and Demonstration of New Technology for the use of Wind Turbines on Ships - Phase 2. Wind Turbine on Ships. https://www.google.com/search?q=wind+electrical+power+generation+on+ships&sxsrf=ALiCzsbcYmGDG2_chZeWjPvKTdhqQ90bwg:1651146249497&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiAq7GN17b3AhWSTcAKHZy9BH0Q_AUoAXoECAEQAw&biw=911&bih=438&dpr=1.5#imgrc=CKSt3oDuqJ-MCM [28/04/2022]

Corr A. Q. 2010. Nuclear Energy Explained. https://www.google.com/search?q=nuclear+electrical+power+generation+on+ships&tbm=isch&hl=en&chips=q:nuclear+electrical+power+generation+on+ships,online_chips:diag

ram:9h76SvxXn5o%3D&sa=X&ved=2ahUKEwitwePc2rb3AhVBxhoKHaKqAQMQ4lYoAXoECAEQIA&biw=899&bih=427#imgrc=gwzTLT1fEx1_YM [09/05/2022]

Clynch J. R. 2001. A Short Overview of Differential GPS. https://www.oc.nps.edu/oc2902w/gps/dgpsnote.html [24/03/2022]

Edward. 2017. Typical Power Supply Schemes for Standby and Production Generator sets. Electrical Engineering Portal. https://electrical-engineering-portal.com/standby-production-generator-sets-schemes [23/05/2022]

Eco Marine Power. Technologies. https://www.ecomarinepower.com/en/technologies [14/04/2022]

Federal Aviation Administration. Satellite Navigation - How it works. https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/gps/howitworks [24 /03/2022]

Office of Energy Efficiency and Renewable Energy, How do wind turbines work?. https://www.energy.gov/eere/wind/how-do-wind-turbines-work [18/03/2022]

HOMER Software. https://www.homerenergy.com/products/pro/index.html [18/06/22]

Kozak P. A. 2014. Effects of unsteady Aerodynamics on Vertical-Axis wind Turbine Performance. Simulation of wind turbine Aerodynamics. https://www.google.com/search?q=hawt+wind+turbine&tbm=isch&hl=en&chips=q:hawt+wind+turbine,g_1:diagram:3QHwmG0Jn28%3D,online_chips:vertical:GVsx0XjeYtc%3D&sa=X&ved=2ahUKEwiepaa31Mb3AhWI34UKHdr-BIMQ4lYoAHoECAEQIQ&biw=899&bih=427#imgrc=Pv5ER89vuVQNgM [13/05/2022]

Kuttybay N., Saymbetov A., Mekhilef S. and Nurgaliyev M. 2020. Optimized Single-Axis Schedule Solar Tracker in Different Weather Conditions.

Kurniawan A. 2016. A review of solar-powered boat development. IPTEK, The Journal for Technology and Science. 27(1).

Lan H., Bai Y., Wen S., Yu D. C., Hong Y., Dai J. and
Cheng P. 2016. Modeling and stability analysis of hybrid PV/Diesel/Ess in ship power system.

Marineregions.org. Marine Gazetteer Placedetails. https://marineregions.org/gazetteer.php?p=details&id=8396 [28/07/2022]

Ma Z., Zhang Y. and Li H. 2019. Energy efficiency analysis of inland ship PV system based on PVSyst. 4th International Conference on Energy Equipment Science and Engineering. *Earth and Environmental Science. Wuhan. IOP.*

Operation Phakisa. Marine Spatial Planning. The four Marine Planning Areas of South Africa https://www.operationphakisa.gov.za/operations/oel/msp/Pages/default.aspx [24/03/2022]

Olmer N., Comer B., Roy B., Mao X, and Rutherford D. A. N. 2017. "GREENHOUSE GAS EMISSIONS FROM GLOBAL SHIPPING, 2013 – 2015.

Paulson M. and Chacko M. 2019. Marine Photovoltaics: A Review Of Research And Developments, Challenges And Future Trends. 8(09).

Peralta C. O. P., Vieira G. T. T., Meunier S., Vale R. J., Salles M. B. C., and Carmo B. S. 2019. Evaluation of the CO 2 Emissions Reduction Potential of Li-ion Batteries in Ship Power Systems, pp. 1–19.

Qiu Y., Yuan C., Tang J. and Tang X. 2019. Techno-economic analysis of PV systems integrated into ship power grid: A case study. Energy Convers.

Salgaonkar K., Shirodkar A., Yedurkar A, and Mohite A. 2017. Automated Dual Axis Solar Tracking System using LDR Sensors. 6(07).

SA Naval Ship SAS DRAKENSBERG https://www.google.com/search?q=sas+drakensberg+dimensions&source=lmns&bih=4

38&biw=911&hl=en&sa=X&ved=2ahUKEwinn6_S9Zn5AhUJlRoKHQcqCvQQ_AUoAHoECAEQAA [27/07/2022]

Seme S., Štumberger B. and Hadžiselimovi M. 2020. Solar Photovoltaic Tracking Systems for Electricity Generation: A Review.

South African Maritime Safety Authority. South African National Workshop on Implementation of MARPOL Annex VI On 0.50 % Sulphur Limit Regulation Report. Pretoria. SAMSA.

Solar Reviews. 2022. What is a Solar tracker and is it worth investment?. https://www.google.com/search?q=single+axis+solar+tracker&sxsrf=APq-WBs9vnVBQv_sLVhhvpKpXJEtifd_UA:1648159981011&source=lnms&tbm=isch&sa=X&ved=2ahUKEwikws2x4t_2AhXOVsAKHdsSDdcQ_AUoAXoECAEQAw&biw=911&bih=438&dpr=1.5#imgrc=bwpF4wqT77fOzM [24/03/2022]

Shi Y. and Wei Luo M.S. 2018. Application of photovoltaic power generation system in maritime vessels and development of maritime tourism. *POLISH MARITIME RESEARCH Special Issue.* 25(98): 176-181.

The Economic Times News. 2017. INS SARVEKSHAK goes green: Installs solar power system. 12 Feb. https://economictimes.indiatimes.com/news/defence/ins-sarvekshak-goes-green-instals-solar-power-system/articleshow/57110554.cms?from=mdr [24/05/2022]

Visa I., Cotorcea A., Neagoe M. and Moldovan M., 2016. Adaptability of solar energy conversion systems on ships. IOP Conference Series: Material Science and Engineering. *7th International Conference on advanced Concept in Mechanical Engineering*. Romania. IOP

Whavale S. and Dhavalikar M. A review of Adaptive solar tracking for performance enhancement of solar power plant.

World Nuclear Association. 2021. Nuclear-Power Ships. https://world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx [25/04/2022]

World Nuclear Association. 2021. Nuclear-Power Ships| Nuclear Submarines. https://www.google.com/search?q=nuclear+electrical+power+generation+on+ships&tbm=isch&hl=en&chips=q:nuclear+electrical+power+generation+on+ships,online_chips:diagram:9h76SvxXn5o%3D,online_chips:submarine:BtXS6U2Iino%3D&sa=X&ved=2ahUKEwi1x4rt2rb3AhUU_IUKHRZhAlcQ4lYoAXoECAEQIw&biw=899&bih=427#imgrc=eoqITenS1QbPEM [25/04/2022]

Wu Z. and Xia X. 2018. Tariff-driven demand side management of green ship.

Zhang Y. and Yuan C. 2021. Effect of marine environment on electrical output characteristics of PV module. *Journal of Renewable and Sustainable Energy*.