University of Science and Technology in Zewail City.

Renewable Energy Engineering Program

Design and optimization a hybrid Power supply PV-diesel generator for IPRS

Graduation Project Thesis in Fulfillment of UST Renewable Energy Engineering Bachelor's degree

Under Supervision of

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Abstract

Solar power is considered as one of the most advanced and environmentally friendly forms of renewable energy. To achieve complete independence from the electricity grid, an off-grid solar system is necessary. This thesis introduces a model for an off-grid solar system designed using PVsyst and Sketch up, to develop a sustainable energy solution for intensive fish aquaculture, with the ultimate goal of reducing the farm's high operating costs and carbon footprint. The system includes [128] batteries and [102] PV modules, providing sufficient power to meet the daily energy requirement of the farm consuming [93.2] MWh annually. The system modeling was performed using MATLAB. The design includes the implementation of a maximum power point tracker (MPPT), an Inverter that optimizes the power output from the solar array to match the battery bank. Safety measures, including safety devices, their working principles, and usage methods, are also discussed in the thesis. The results will be valuable in designing off-grid solar systems suitable for remote areas

Gantt chart:

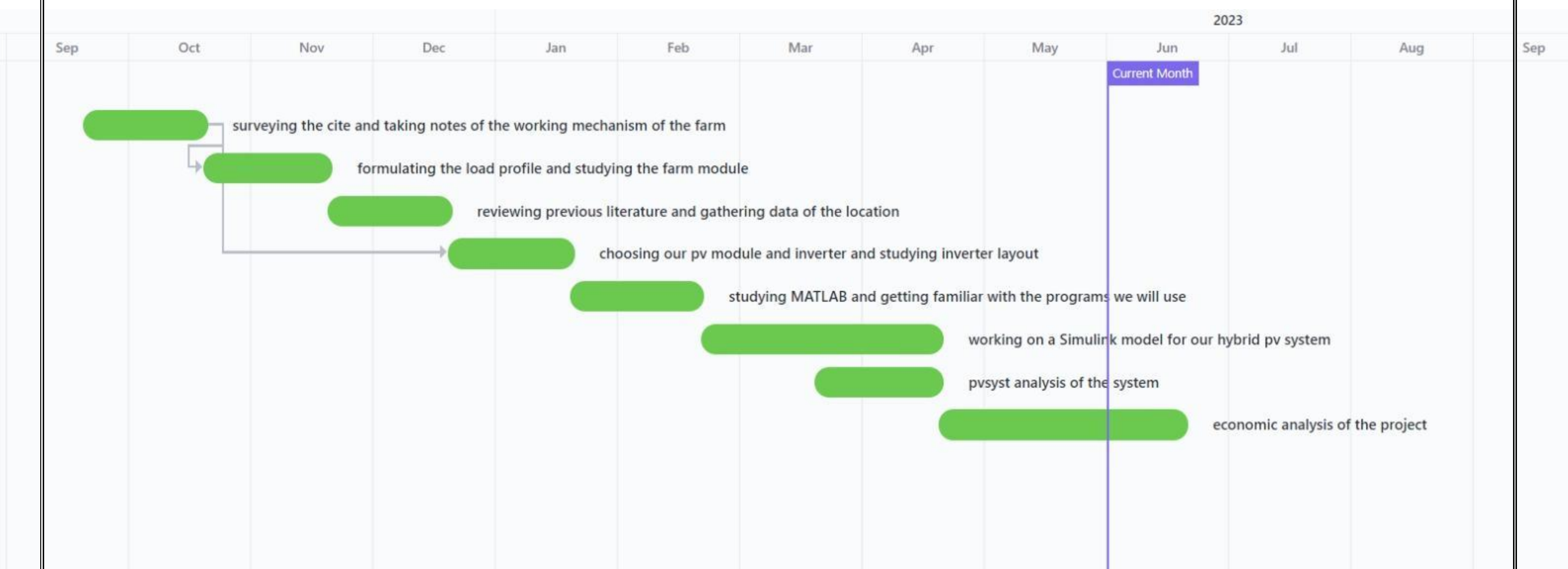

Figure 1 Gantt chart:

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Nomenclature and list of abbreviations

IPRS: In-Pond Raceway System

PV: Photovoltaic

FAO: Food and Agriculture Organization

MPEDA: The Marine Products Exports Development Authority

RAS: recirculating aquaculture systems

BAU: Bangladesh Agricultural University

MT: Million ton

MPPT: maximum power point tracking

DO: Dissolved oxygen

DC: direct current

PERC: Passivated Emitter and Rear Cell or Passivated Emitter and Rear Contact

BOS: Balance of system

PWM: pulse width modulation

Legislation

Legislation	Type
Law No. 102 of the year 1986 establishing the New and Renewable Energy Development and Usage Authority (as amended in 2015)	• Establishes the NREA. • The NREA has the primary role in promoting and developing renewable energy in Egypt.
The Constitution of the Arab Republic of Egypt, 2014 (Article 32)	• To gain optimum benefits from renewable energy, promote its investments, and encourage R&D, in addition to local manufacturing.
Renewable Energy Law (Decree Law 203/2014)	• To support the creation of a favourable economic environment for a significant increase in renewable energy investment in the country.
Cabinet Decree No. 1947 of the year 2014 on Feed-in Tariff	• Establishes the basis for the FIT for electricity produced from renewable energy projects and encourages investment in renewable energy.
Prime Ministerial Decree No. (37/4/15/14) of the year 2015	• Regulations to avail land for renewable energy projects.
New Electricity Law No. 87 of 2015	• To provide legislative and regulatory frameworks needed to realise the electricity market reform targets.
Investment Law No. 72 of the year 2017	• Ensures investment guarantees and amendments as of May 2017. • Establishes a new arbitration centre for settling disputes. • Codifies social responsibility. • Instigates foreign investment in Egypt.

Table 1 Legislation

Introduction

In the year 2100, the protein requirements will increase by 70% because the population will grow rapidly since according to the United Nations Department of Economic and Social Affairs, there will be about 9.7 billion people on earth by 2050 and 11.2 by 2100[2]. Besides that, our current main source of protein is oceans. However, in comparison to what the oceans can sustainably support, the global fishing fleet is 2.5 times greater. Currently, 24% of the world's fisheries are depleted, or undergoing a recovery from collapse, while 52% of them have reached full exploitation [3]. In addition to this, According to the World Wildlife Fund, since 1970, the amount of marine life worldwide has decreased by half [4]. According to another study, 90% of the most frequently caught fish have perished from the ocean since 1950. By this way, we are putting pressure on the ocean and this behavior may destabilize the ecosystem. Thus, one of the solutions to reduce the ocean's pressure is aquaculture fish farming. According to a FAO report from the United Nations, aquaculture has seen an impressive yearly growth rate of 7.4% with rising meat demand and has significantly reduced pressure on global fisheries [5]. This industry is experiencing substantial growth because of some factors that make it worth investment compared to other animals. First, fish is nutritious, delicious, and diversified (over 500 different species of fish). Second, it is economically feasible as it only requires 1.5 pound feed for producing 1 pound fish. In contrast, it requires 8 to 9 pounds of feed and 8000 liters of water for 1 pound meat production from cows. [6]

For operations related to aquaculture, fishing, post-harvest, and product distribution, the fishing sector depends heavily on external sources of energy. It requires a huge amount of electricity to operate the required machines such as compressors, pumps and air conditioners. According to Bord Iascaigh Mhara (BIM) (2017), refrigeration and air conditioning activities account for 15% of all worldwide energy usage. Besides that, the amount of energy and water used in the fish processing sectors does not correspond to the real needs. The processing industries' ineffective use of energy and water management techniques is the cause of that imbalance (The Marine Products Exports Development Authority (MPEDA, 2017). The financial cost of energy and water waste is enormous, and it has a big impact on worker efficiency and profitability. The best approach to this issue must save energy, decrease waste, and thus lower the cost of running the facilities. Currently, the majority of the solutions just call for effective management techniques, such as efficient planning and policy-making, and optimum supply chain management. However, in this report, alternative approaches to solve this problem are discussed such as use of renewable energy and optimization of operating machines.[7]

Solar energy is a viable source of generating electricity, photovoltaic is the direct conversion of the solar energy into electricity. It can be used in a number of applications. Solar Energy is very useful where the climatic conditions are appropriate. This source of renewable energy is a feasible and sustainable source of energy generation in the regions where the Sun is incident on the surface for 6 to 10 hours [1]. This project is about installing an off-grid Hybrid PV system for remote farms. Though the capital cost is high, the operation and maintenance charges of the PV system are very low. System installation and component selection is very critical in this project as it would affect the cost analysis and may prolong the payback period and make the project financially infeasible as well as alternative to the conventional sources of the energy which are affecting the environment.

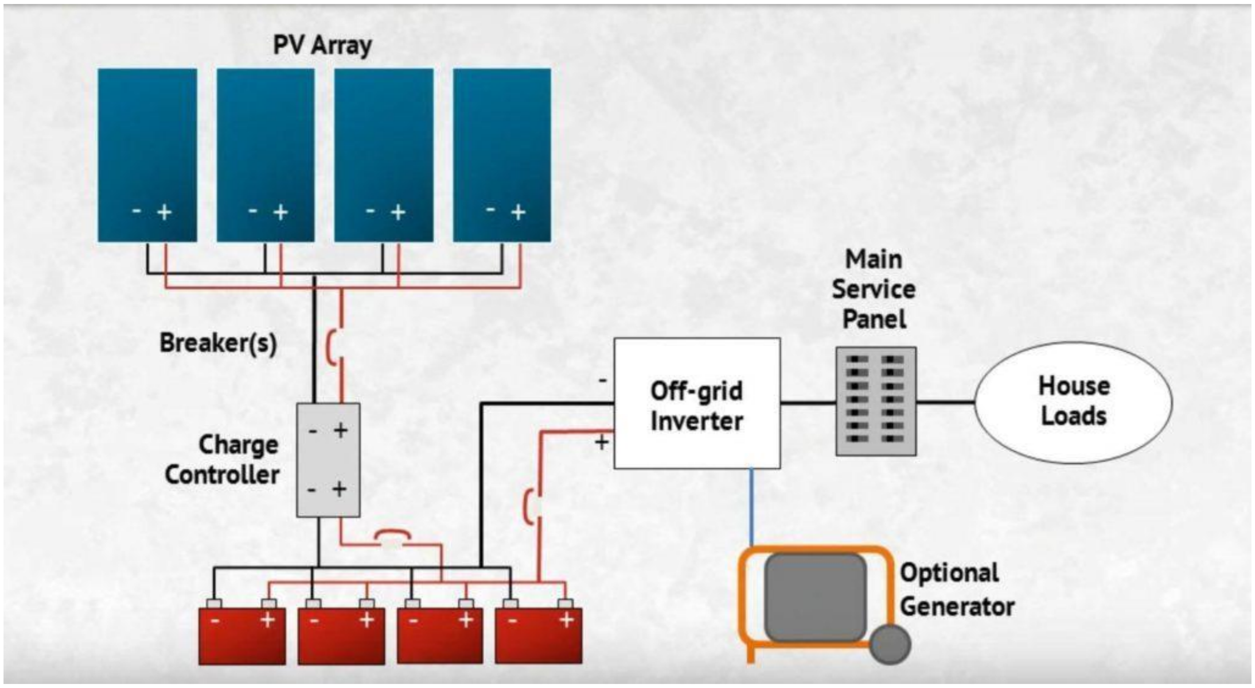


Figure 2 the off-grid solar system schematic diagram

Literature Review

Fish farming or aquaculture is the farming of fish, crustaceans, mollusks, and other aquatic organisms. Aquaculture has been growing rapidly in recent years due to the increasing demand for fish and seafood, and as a result, there has been a corresponding increase in energy use and we will examine the usage of energy in fish farming worldwide.

IPRS is a sustainable and innovative approach to agricultural production that combines aquaculture, hydroponics, and waste management. In this system, fish are raised in tanks or ponds, and the waste generated by the fish is used as a nutrient source for hydroponic plant growth. The plants, in turn, purify the water, which is then returned to the fish tanks. Energy is a crucial input in the operation of IPRS, and its efficient use is essential to achieve sustainability goals. This literature review aims to examine the usage of energy in IPRS.

The fish industry's sustainable use of renewable energy may open up new economic options and decrease the energy gap along the supply chain for seafood. As the fish industry deals with some of the products that are subject to decay, the operations must have a continuous supply of electricity. It cannot rely only on renewable energy sources. Thus, a hybrid system with a backup generator may be set up to have a stable source of electricity.

Energy Usage in Fish Farming

Energy is a vital resource for fish farming, as it is required for various processes, such as water circulation, feeding, heating, and lighting. The energy used in fish farming can be divided into two categories: direct energy and indirect energy. Direct energy refers to the energy used in the production process, such as pumping water, aerating ponds, and operating machinery. Indirect energy refers to the energy used in the production of the inputs used in fish farming, such as fertilizers, feed, and electricity.

Energy usage varies depending on the type of fish farming system used. In general, land-based systems, such as recirculating aquaculture systems (RAS), use more energy than open-water systems, such as net-pen farming. RAS systems require energy for water circulation, filtration, and heating, while net-pen farming relies on natural water currents for water circulation.

Energy Usage in Different Regions

Energy usage in fish farming varies widely depending on the region and the type of fish being farmed. In developed countries, such as the United States, Canada, and Europe, energy usage in fish farming is relatively high due to the use of energy-intensive RAS systems. In contrast, in developing countries, such as China and India, energy usage is relatively low due to the use of low-tech open-water systems.

Energy Usage in IPRS

IPRS is an energy-intensive system, requiring energy for various processes such as water circulation, lighting, heating, and waste treatment. The main sources of energy used in IPRS are electricity and heat. Electricity is required for pumps, aerators, lighting, and monitoring systems, while heat is required for maintaining water temperatures.

The energy required for IPRS varies depending on the size of the system, the species of fish and plants grown, and the location of the system. However, IPRS can be more energy-efficient compared to conventional aquaculture and hydroponic systems due to the integrated nature of the system, which allows for the reuse of waste and the reduction of inputs.

Effect of aeration on fish production

A study was carried out to evaluate the impact of using an air compressor for aeration on the growth and yield of tilapia in an intensive aquaculture system. The study was conducted over a period of five months in six earthen ponds located at BAU campus in Mymensingh. The ponds were divided into two groups: Treatment 1 (T1) consisted of three aerated ponds, while Treatment 2 (T2) had three non-aerated ponds. Both groups had equal stocking density of tilapia. The blower was used for nine hours daily to ensure adequate oxygen supply in the aerated ponds. The growth of fish, water and soil quality parameters were monitored and measured. The DO content in the aerated ponds was consistently higher (7.23 mg/l) compared to the non-aerated ponds (2.33 mg/l) throughout the experiment. Significant differences ($p<0.05$) were observed in DO content between the two treatments at the beginning and end of the experiment. Tilapia in T1 had higher length (15.64±1.56 cm), weight gain (143.36±39.33 gm) and SGR (% per day) (2.54±0.00) compared to T2 (2.42±0.00), with significant differences ($p<0.05$) between the two treatments. T1 also had higher tilapia production (9581.87±0.00 kg/ha/100 days) compared to T2 (6490.80±0.00 kg/ha/100 days). The phytoplankton production was relatively higher in T2, while zooplankton abundance was higher in T1, with no significant differences ($p>0.05$) between the treatments. The water quality parameters were better in the aerated ponds, and the soil quality parameters in both treatments were found to be suitable for fish culture. The study suggests that aeration can be an effective means of improving tilapia growth and production, while also enhancing DO content in pond water and synchronizing other water quality parameters [8].

Energy Efficiency and Conservation

Efforts to improve energy efficiency and conservation in IPRS can help to reduce energy costs and minimize the environmental impact of the system. Various measures can be taken to improve energy efficiency, such as using energy-efficient equipment, optimizing water circulation systems, and improving waste management. In addition, renewable energy sources such as solar and wind power can be used to reduce dependence on fossil fuels.

The main sources of energy used in fish farming in Egypt are electricity and diesel fuel. Electricity is used for water circulation, lighting, and operating machinery, while diesel fuel is used for pumping water and powering generators. The study found that energy use in fish farming in Egypt varies depending on the type of farming system used. Pond-based systems use less energy than cage-based and recirculating systems [9].

Solar power can be a viable option for providing energy to fish farms in Egypt. The study found that solar-powered water pumps and aerators can provide a reliable and cost-effective source of energy, particularly in remote areas where access to the electricity grid is limited [10].

Problem Statement

In Egypt, aqua farming has emerged as the primary contributor to the fish industry, generating 1.7 MT out of 2.2 MT in 2021. However, the intensification of farming in ponds has led to a greater need for aeration, resulting in a shift from natural aeration to the use of air pumps and Paddle Wheel Aerators. This has introduced a new challenge in the form of increased energy consumption, which not only reduces farmers' profit margins but also limits the viability of aqua farming in areas where grid access is unavailable. Therefore, our study aims to address this challenge by developing an off-grid hybrid power supply system for in pond Raceway Systems.

POSSIBILITIES

Sketch Up: a software that enables the creation and design of civil structures while utilizing real location maps. In our study, we employed the Skelion feature to install and configure PV panels, implementing a solar array in the designated location.

PVSYST : a software program that enables the modeling of photovoltaic power plants, while taking into account various factors such as technical, economic, and energy management aspects. In our particular case, we utilized PVSYST to determine the appropriate inverter size and PV power capability for the designated area, based on the software's recommendations.

LIMITATIONS

Power electronics are relatively expensive in Egypt because of the customs fees and the limited number of companies that import power electronics into the country

The location of the site is within an agricultural setting, where there are prevalent high wind speeds. The wind often carries dust and dirt, which can lead to condensation of water during the early morning as a result of dew in the. Such conditions may adversely affect the performance of the PV modules. Additionally, temperatures that exceed the nominal operating temperature can result in a decrease in performance.

Incorporating a tracking system along with PV panels can significantly enhance power production, as compared to the fixed PV panels. However, the initial investment cost associated with installing the tracking system is significantly higher, making it a challenging option. Moreover, maintenance costs for a tracking system are comparatively higher than of fixed panels. Therefore, in our project, while the installation of a tracking system could lead to a notable increase in capital costs, the profit margin would be relatively small

Objectives and outcomes

The objective of our project is to design a competitive, reliable off grid hybrid PV diesel power supply system that can compete with other available energy sources like diesel generators and power from the grid and can also enable the implementation of IPRS in remote areas.

Constraints

A smart meter was not available to measure the real time electricity consumption of the facility thus the before mentioned assumptions were made following the batten behavior of the pumps operator

The power supplied to the ponds must always be available or the fish might die therefore the diesel generator must be able to support the full load in case of emergency

PV Design flow chart:

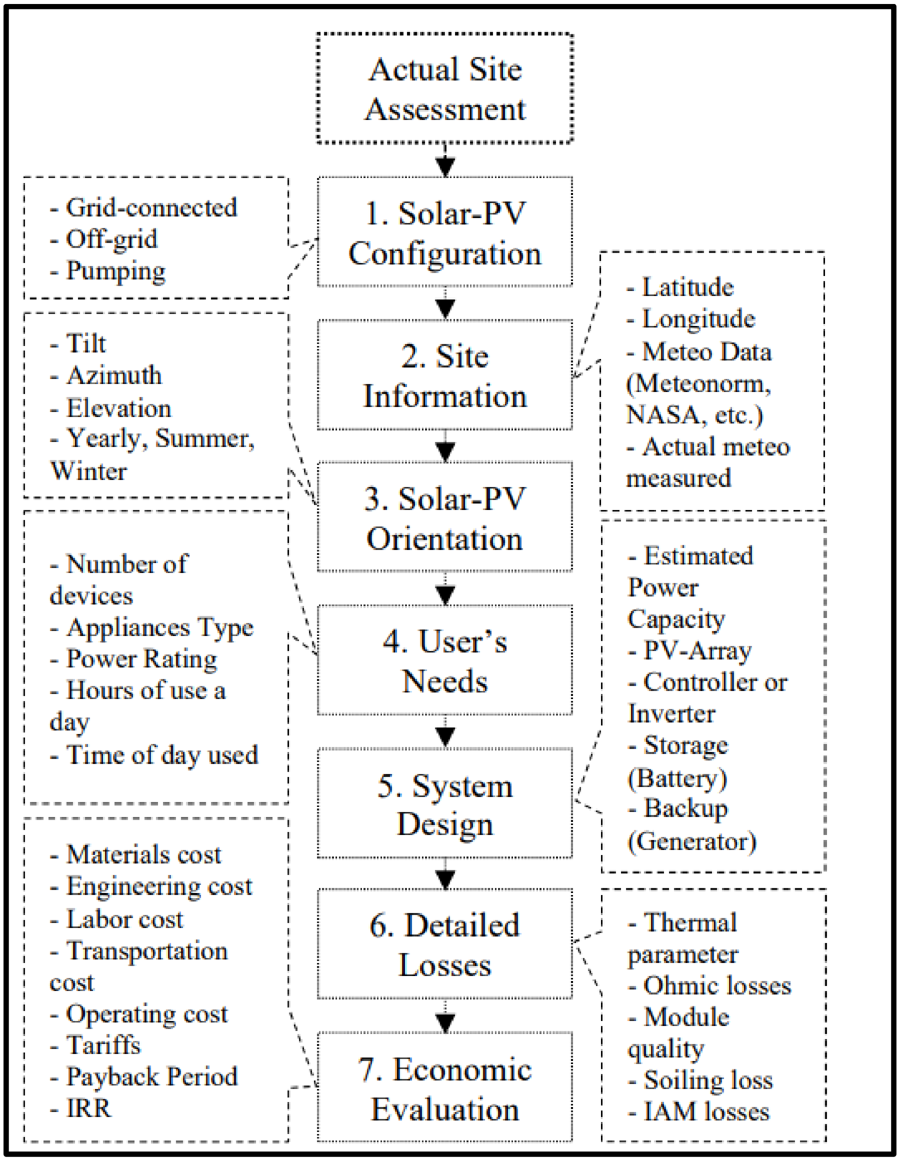


Figure 3 flow chart

Site assessment

For the efficient and sustainable operation of the off-grid solar-PV power system, onsite assessment, face-to face surveys, and focus group discussions (FGD) were conducted. The collected data served as the basis for the design of the off-grid solar-PV power system and as a guide for sustaining its operation. Face-to-face surveys and focus group discussions (FGD) were conducted to determine the residents' demographics and electricity needs. To promote innovation in support of renewable energy, such as the Solar-PV power system, it is necessary to comprehend how individuals and institutions perceive the technology and its application. Recognizing the value of technology, organizational readiness to adopt it, the perception of how it could work, the capacity to manage it, and the perception of obstacles and opportunities to its long-term use are all crucial

The following data collected from the site:

- **Location:** Latitude, Longitude (30.5492055806186, 31.738647896306475) El Tal El Kebeer, EG Egypt
- **The power usage pattern:**
    - ❖ In winter from 15th of April till 15th of October.
    - ❖ Day power usage is 10 HP
    - ❖ In summer from 16th of October till 14th of April.
    - ❖ Day power usage is 20 HP full load.

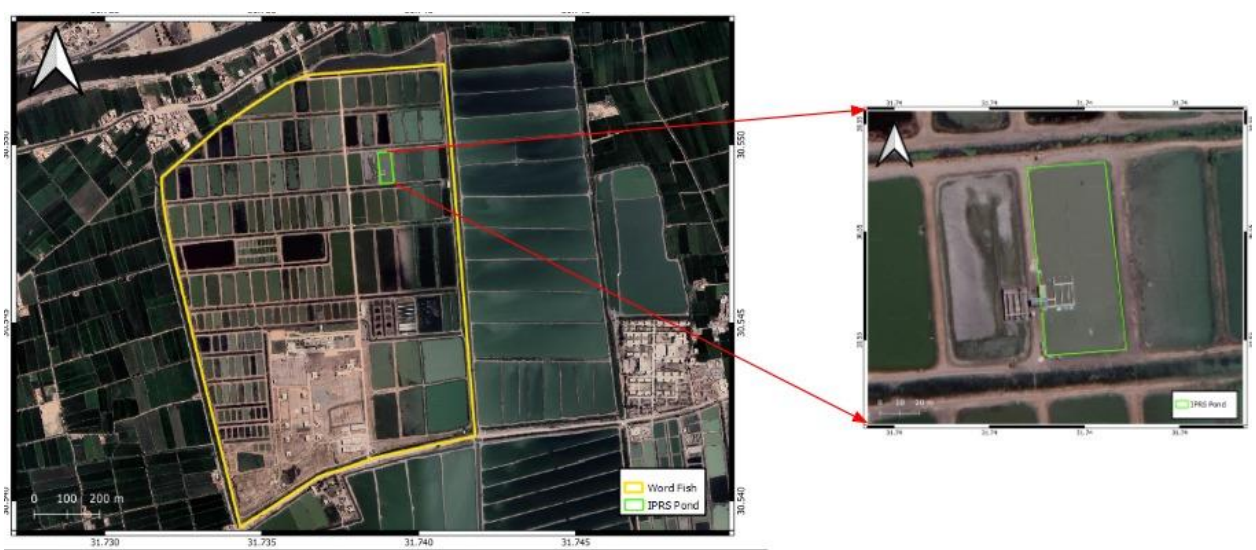


Figure 4 site satellite image

Solar PV configuration

Solar pumping

Solar pumping is a technology that uses solar energy to power water pumps. Solar pumping systems consist of solar panels, a pump controller, and a water pump. Solar panels convert sunlight into electricity, which is then used to operate the pump. Solar pumping systems can provide a reliable and sustainable source of water for irrigation, drinking, and other purposes.

Solar pumping has many advantages over conventional water pumping methods. Solar pumping does not require fuel or grid electricity, which reduces operational costs and environmental impacts. Solar pumping can also increase water availability and crop productivity in rural areas where access to water is limited or unreliable. Solar pumping is easy to install and maintain, and can last for more than 20 years with proper care.

Solar pumping also has some disadvantages and challenges. Solar pumping depends on the availability and intensity of sunlight, which can vary depending on the season, weather, and location. Solar pumping may require water storage tanks or batteries to ensure water supply during cloudy days or at night. Solar pumping systems can be expensive to purchase and may be vulnerable to theft or vandalism. Solar pumping requires careful design and sizing to match the water demand and the solar resource.

Hybrid off grid photovoltaic and diesel generator

Hybrid power systems that combine photovoltaic and diesel generator technologies have gained significant attention in recent years as they offer a sustainable, reliable, and cost-effective source of energy. Various studies have been conducted to evaluate the technical, economic, and environmental feasibility of such hybrid systems.

The hybrid system can reduce diesel fuel consumption by 32% and resulted in cost savings of up to 20% compared to a standalone diesel generator.

The main advantages of hybrid power systems:

1. Reduced fuel consumption: Hybrid systems can reduce the amount of fuel needed to generate electricity, which can result in cost savings and lower emissions.
2. Improved energy security: A hybrid system can provide a more reliable power supply than a standalone diesel generator, as it is less vulnerable to fuel shortages or mechanical failure.
3. Reduced emissions: By incorporating PV panels into the system, a hybrid system can reduce greenhouse gas emissions and other pollutants associated with diesel generators.
4. Increased efficiency: A well-designed hybrid system can optimize the use of both PV and diesel power sources, resulting in higher overall efficiency and lower operating costs.

5. Flexibility and scalability: Hybrid systems can be designed to meet a wide range of energy demands, from small-scale off-grid applications to large-scale grid-connected systems.

Load Profile

Hourly User's needs

Annual needs	**93.2**	MWh
Average load	**10.64**	kW
Maximal load	**22.37**	kW

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
6985	6285	7737	8208	8670	8264	8514	8447	8110	8241	6808	6978	93247	kWh

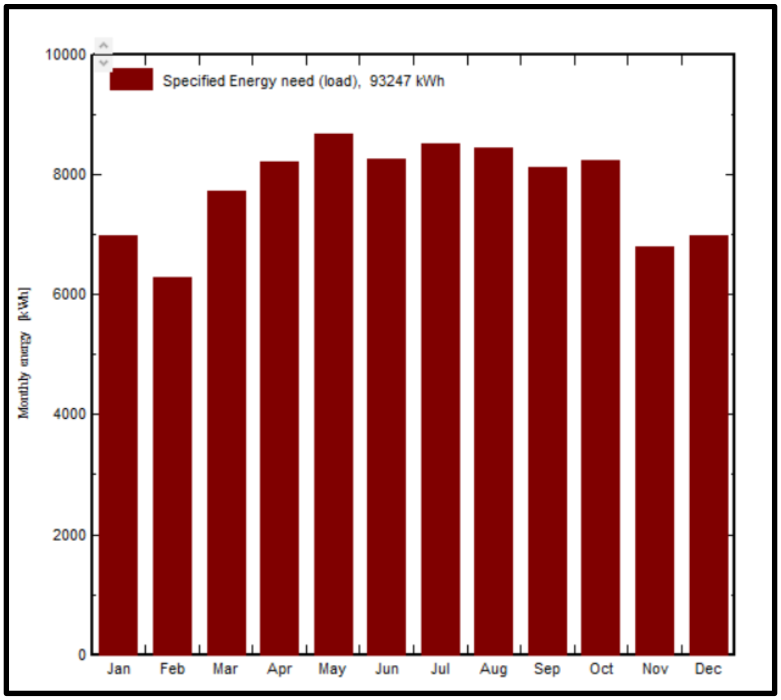


Figure 5 Load Profile

System components' overview

PV modules

PV modules are devices that use photovoltaic cells to convert sunlight into electricity. PV cells are made of semiconductor materials that release electrons when they absorb light. The electrons flow through a circuit and produce direct current electricity, which can be used to power various devices or be stored in batteries. PV modules are also known as solar panels, solar cell panels, or solar electric panels, PV modules can be connected together in groups called arrays or systems to increase the power output. A photovoltaic system consists of one or more PV modules

Cell material

Organic

Organic solar cells are a type of photovoltaic technology that uses organic materials, such as carbon-based polymers or small molecules, to absorb light and convert it into electricity. Unlike conventional silicon-based solar cells, organic solar cells are flexible, lightweight, and can be printed on various substrates using low-cost methods. Organic solar cells have the potential to be integrated into windows, walls, clothing, and other applications that require transparency or flexibility.

However, organic solar cells also face some challenges, such as low efficiency, stability, and durability compared to silicon solar cells. The efficiency of organic solar cells depends on the band gap and molecular structure of the organic materials, as well as the morphology and interface of the active layer. The stability and durability of organic solar cells are affected by environmental factors, such as oxygen, moisture, and temperature, which can degrade the organic materials and reduce their performance over time.

Non organic

Non-organic photovoltaic (PV) modules, which are based on inorganic materials such as silicon, perovskite, copper indium gallium selenide (CIGS) and cadmium telluride (CdTe). Non-organic PV modules have several advantages over organic PV modules, such as higher efficiency, stability, scalability and compatibility with existing PV technologies. However, they also face some limitations and drawbacks, such as high cost, toxicity, scarcity of raw materials and environmental impact

Silicon

Silicon PV modules are the most widely used type of solar technology, accounting for more than 90% of the global PV market.

1. Monocrystalline Solar Panels

Monocrystalline solar panels are a type of solar panel that use solar cells made from a single crystal of silicon. These panels have a high efficiency rating, meaning they can produce more electricity from the same amount of sunlight. Monocrystalline solar panels are also known for their black color and sleek appearance. However, these panels are also more expensive than other types of solar panels, and they may lose some efficiency in

Figure 6 Monocrystalline solar panel

high temperatures. Monocrystalline solar panels are suitable for homes and businesses that have limited roof space or want to maximize their energy production.

2. Polycrystalline Solar Panels

Polycrystalline solar panels are a type of photovoltaic (PV) panels that are made from multiple silicon crystals. Unlike monocrystalline solar panels, which are cut from a single crystal, polycrystalline solar panels are formed by melting and pouring silicone into a mold. This process makes them cheaper and easier to produce, but also less efficient and durable. Polycrystalline solar panels have a bluish hue and a speckled appearance due to the different orientations of the crystals. They are suitable for applications where space is not a constraint and cost is a priority

Figure 7Polycrystalline solar panel

Non silicon

Non-silicon solar panels are an alternative to the conventional silicon-based solar panels that dominate the market. These panels use different materials and technologies to capture and convert solar energy into electricity. Some of the advantages of non-silicon solar panels are lower costs, higher flexibility, and better performance in low-light conditions. However, they also have some drawbacks, such as lower efficiency, shorter lifespan, and environmental concerns.

Module technology

PERC

PERC stands for Passivated Emitter and Rear Cell or Passivated Emitter and Rear Contact. It is a technology that improves the efficiency and performance of solar cells by adding a thin layer of dielectric material on the back surface of the cell. This layer reduces the recombination of electrons and holes, which increases the amount of electricity generated by the cell. PERC modules also have lower temperature coefficients, which means they perform better in high temperatures. PERC modules are becoming more popular in the solar industry because they offer higher power output and lower costs compared to conventional modules.

Half cut

Figure 8 Half cut solar panel

Half cut module technology of solar panels is a technique that involves cutting the solar cells in half and arranging them in a way that reduces the electrical resistance and increases the power output. By cutting the cells in half, the current flowing through each cell is halved, which reduces the resistive losses and improves the efficiency. Additionally, by using a split junction box and two separate strings of cells, the shading effect and the hot spot risk are minimized. Half cut module technology of solar panels is a promising innovation that can lower the cost and increase the performance of solar energy systems. [19]

Quarter cell

Quarter cell module technology is a new innovation in the field of solar panels that aims to increase the efficiency and reliability of photovoltaic systems. Quarter cell modules are made by cutting standard solar cells into four equal pieces and rearranging them in a compact layout. This reduces the electrical losses due to shading, mismatch, and resistance, and also improves the thermal performance of the modules. Quarter cell modules can generate more power per unit area than conventional modules, and are also more resilient to partial shading and hot spots. Quarter cell module technology is expected to lower the cost of solar energy and make it more accessible and sustainable for various applications. [20]

N-type and P-type

N-type cells have a silicon base that is infused with phosphorus, which has one more electron than silicon (making the cell negatively charged). The top layer of n-type cells is infused with boron, which has one less electron than silicon (making the cell positively charged). This creates a p-n junction that allows electrons to flow from the n-type layer to the p-type layer when exposed to sunlight.

P-type cells have a silicon base that is infused with boron, which has one less electron than silicon (making the cell positively charged). The top layer of p-type cells is infused with phosphorus, which has one more electron than silicon (making the cell negatively charged). This creates a n-p junction that allows electrons to flow from the p-type layer to the n-type layer when exposed to sunlight [21]

Bifacial

Bifacial Module technology of Solar Panels is a type of photovoltaic technology that can generate electricity from both sides of a solar panel. Unlike conventional solar panels that only capture sunlight from one side, bifacial modules can also utilize the reflected and scattered light from the rear side, increasing the overall energy output. Bifacial modules can be installed on various surfaces, such as rooftops, ground-mounted systems, carports, or floating structures. Depending on the installation conditions and the albedo of the surface, bifacial modules can achieve up to 30% more power generation than nonofficial modules. [22]

Inverter

Inverters for solar panels are devices that convert the direct current (DC) electricity generated by the solar panels into alternating current (AC) electricity that can be used by most appliances and devices in homes and businesses. Inverters are essential components of a solar power system, as they enable the utilization of solar energy.

There are different types of inverters for solar panels, each with its own advantages and disadvantages. The main types are [23]:

String inverters

These are centralized inverters that connect multiple solar panels in a series, or "string". They are the simplest and most cost-effective type of inverters, but they can suffer from power losses if one panel is shaded or damaged, as they operate at the lowest performing panel's level. They also do not allow individual panel monitoring or optimization.

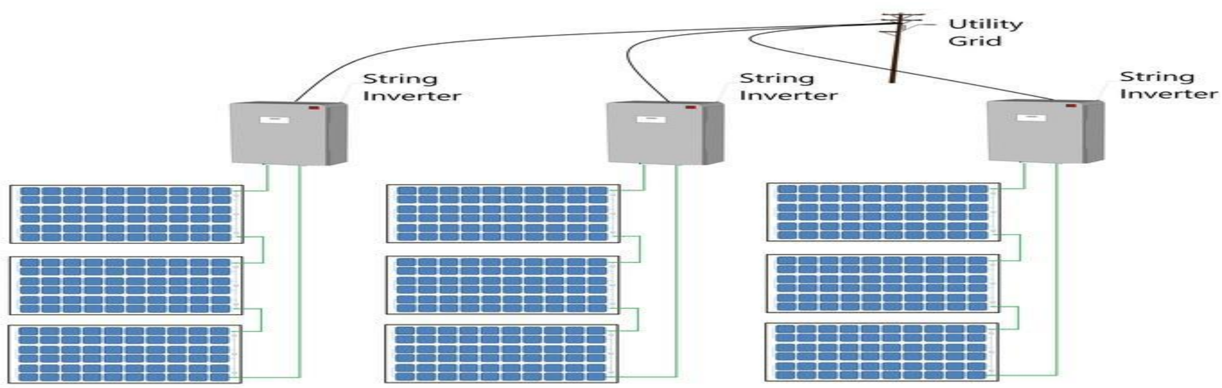


Figure 9 String inverters connection

Micro inverters

These are small inverters that are attached to each individual solar panel. They convert DC to AC at the panel level, which means that each panel can operate independently and optimally, regardless of shading or damage to other panels. They also enable panel-level monitoring and troubleshooting. However, they are more expensive and complex to install than string inverters.

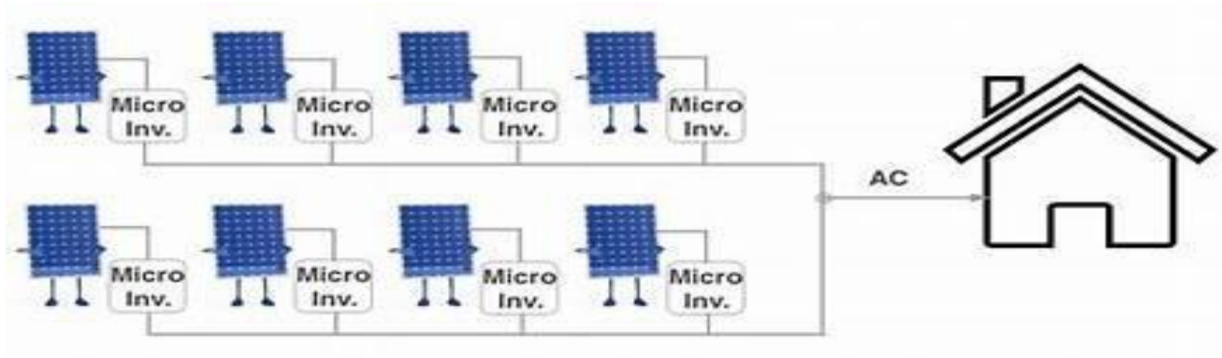


Figure 10 Micro inverter connection

Central inverters

Central inverters are suitable for large-scale solar power plants that have multiple strings of connected solar panels. Central inverters have some advantages and disadvantages compared to other types of inverters, such as string inverters or micro inverters. Some of the advantages are lower cost, easier maintenance, and higher efficiency. Some of the disadvantages are lower flexibility, higher losses, and higher sensitivity to shading or faults.

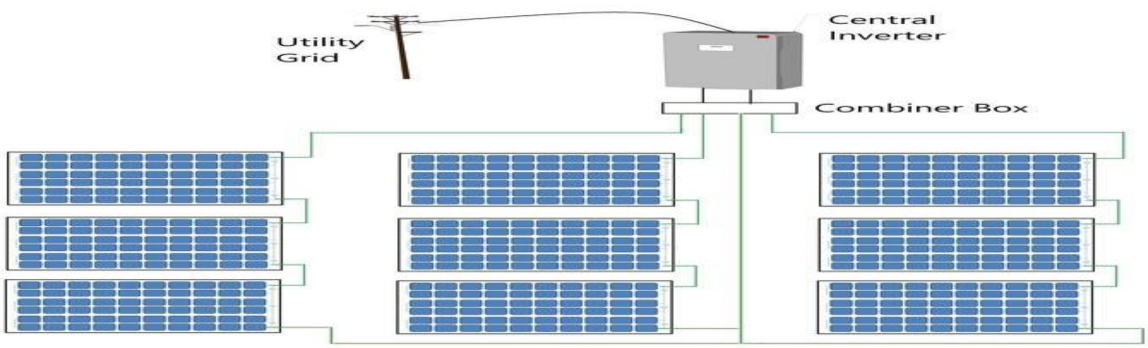


Figure 11Central inverter connection

Choosing the right type of inverter for solar panels depends on several factors, such as the size, design, orientation, and location of the solar power system, as well as the budget and preferences of the owner. In general, string inverters are suitable for simple and uniform systems with minimal shading issues, while micro inverters and power optimizers are better for complex and irregular systems with varying shading conditions.

Charger controller

A charger controller is a device that regulates the voltage and current coming from the solar panels to the batteries. It prevents overcharging and protects the batteries from damage. A charger controller is an essential component of a solar system, as it ensures the optimal performance and longevity of the batteries. A charger controller can be either PWM (pulse width modulation) or MPPT (maximum power point tracking), depending on the efficiency and complexity of the system. [24]

Maximum Power Point Tracking MPPT

MPPT charge controllers can adjust their input voltage to match the optimal voltage of the solar panels, which varies depending on the level of sunlight, temperature, and other factors. This allows them to extract the maximum power from the solar panels and increase the efficiency of the system. It convert voltage input to battery voltage When voltage drop it it increases the current

Pulse Width modulator PWM

PWM charge controllers simply switch on and off the connection between the solar panels and the batteries at a fixed frequency. This means that they cannot adapt to the changing voltage of the solar panels and may waste some power. PWM charge controllers are cheaper and simpler than MPPT charge controllers, but they are also less efficient and suitable for smaller systems with low power demand , PWM has direct connection from solar panel to battery and the Voltage of panel is pulled down to battery voltage

Direct coupling

A direct coupling charger controller It connects the solar panel directly to the battery, without any intermediate converter or inverter. The direct coupling charger controller monitors the battery voltage and adjusts the current flow from the solar panel accordingly. The advantages of a direct coupling charger controller are simplicity, low cost, and high efficiency. However, there are also some drawbacks, such as limited flexibility, lack of protection features, and dependence on the solar panel characteristics

Battery

Batteries are an essential component of any solar system that needs to store energy for later use. Batteries allow solar panels to produce electricity during the day and store it for use at night or during cloudy weather. There are different types of batteries used in solar systems, such as lead-acid, lithium-ion, nickel-cadmium, and flow batteries. Each type has its own advantages and disadvantages in terms of cost, performance, lifespan, and environmental impact. Choosing the right battery for a solar system depends on several factors, such as the size of the system, the load demand, the climate, and the budget.[25]

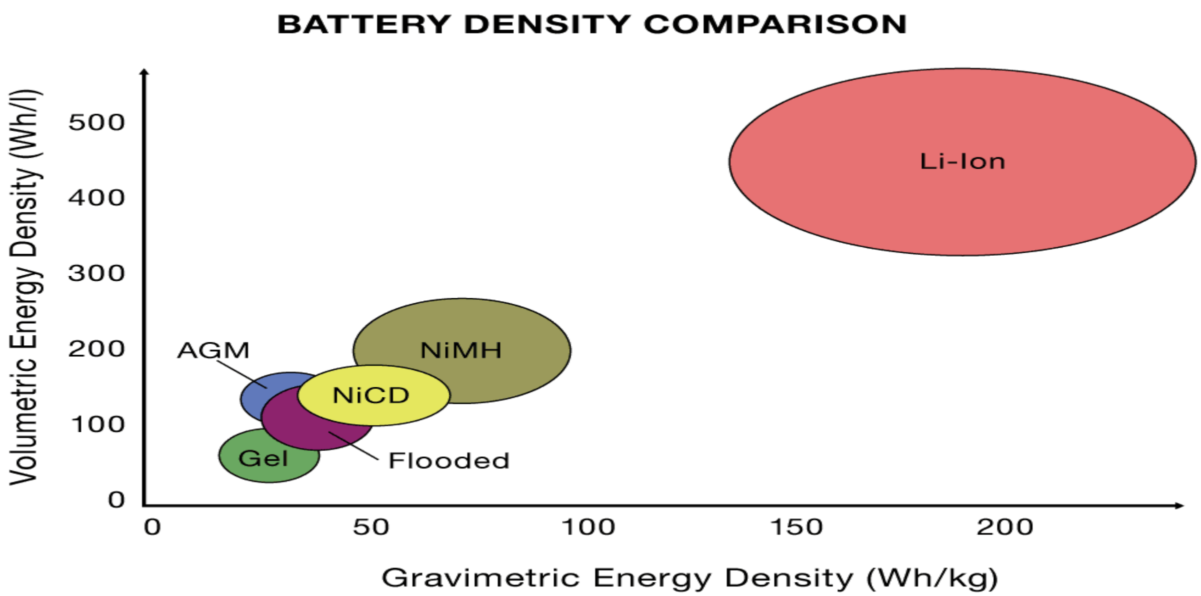


Figure 12 Different types f batteries

Lead Acid

Lead acid batteries are a type of rechargeable battery that can store electrical energy produced by solar photovoltaic (PV) systems. They are based on a simple chemical reaction between lead, sulfuric acid, and water. Lead acid batteries have been used for over 160 years and are still popular because they are robust, reliable, and cheap to make and use.

However, lead acid batteries also have some drawbacks for solar PV applications. They have a low energy density, which means they take up a lot of space and weight. They also suffer from sulfation, which is a permanent loss of capacity caused by over-discharging or under-charging. To prevent sulfation, lead acid batteries must be kept at a certain level of charge and not be drained more than half of their total capacity.

Flooded lead acid

Flooded lead acid batteries are the oldest and cheapest type of lead acid battery. They have liquid electrolyte that needs to be refilled regularly and vented to prevent gas buildup. They also need to be placed in a well-ventilated area and protected from freezing temperatures.

Sealed lead acid

Sealed lead acid batteries are similar to flooded lead acid batteries, but they have a valve that prevents gas from escaping. They do not need to be refilled or vented, but they still need to be kept at a certain level of charge and temperature.

Absorbed glass matt

AGM batteries are a type of sealed lead acid battery that have a glass mat between the plates that absorbs the electrolyte. They have a higher energy density, lower self-discharge rate, and better resistance to vibration and shock than flooded or sealed lead acid batteries. They also do not need to be placed upright and can operate in a wide range of temperatures.

Gelified electrolyte

Gelified electrolyte lead acid batteries are a type of sealed lead acid battery that use a gel-like substance instead of liquid acid as the electrolyte. They are commonly used in solar systems because they have several advantages over other types of batteries. Some of these advantages are [24]:

- They are maintenance-free and do not require water refilling or venting.

- They have a longer cycle life and can withstand deep discharge and overcharge better than flooded or AGM batteries.

- They have a lower self-discharge rate and can operate in a wider temperature range.

- They are more resistant to shock, vibration and leakage.

However, gelified electrolyte lead acid batteries also have some drawbacks, such as:

- They are more expensive and heavier than flooded or AGM batteries.

- They require a special charger and a lower charging voltage to prevent gas formation and damage to the plates.

- They have a lower power density and capacity than flooded or AGM batteries.

- They are sensitive to over-discharge and may suffer from irreversible sulfation if left in a discharged state for too long.

Lithium ion

Lithium ion batteries are a type of rechargeable batteries that can store excess solar energy produced by solar panels. They are usually made of lithium iron phosphate (LiFePO4), which is a safe and efficient material for energy storage. Lithium ion batteries have many advantages over other types of batteries, such as lead acid batteries, for solar applications. They have a longer lifespan, can store more energy per unit weight, and have a higher efficiency of charge and discharge. They can also be used in different voltage levels and capacities depending on the size and needs of the solar system.

Lithium ion batteries are widely used in grid-scale energy storage systems, which play an essential role in balancing power generation and utilization. They can provide various grid services, such as frequency regulation, peak shifting, integration with renewable energy sources, and power management. They can help stabilize the electric power systems by smoothing out the fluctuations caused by the intermittent nature of solar energy. They can also reduce the dependence on fossil fuels and lower the carbon emissions of the power sector.

Lithium ion batteries are considered to be the best energy storage option for solar systems because of their high performance, reliability, and environmental benefits. However, they also face some challenges, such as high cost, limited availability of raw materials, safety issues, and recycling problems.

Diesel generator

Diesel generators are devices that use diesel engines and electric generators to produce electrical energy. Diesel generators are widely used as backup power sources in places without connection to a power grid, or as an emergency power supply if the grid fails. They can also be used for more complex applications such as peak-lopping, grid support, and export to the power grid. Diesel generators can be classified according to their size, cooling system, and use and purpose [12][14].

There are various types of diesel generators based on different criteria, such as size, design, application, fuel injection system, cooling system and exhaust system. Some of the common types are:

- Portable diesel generators: These are small and lightweight generators that can be easily transported and installed. They are suitable for temporary or occasional use, such as camping, recreational activities, construction sites and remote areas. They usually have a power output range of 1 to 10 kW and run on diesel or biodiesel fuel [12].

- Standby diesel generators: These are large and heavy-duty generators that are permanently installed and connected to the main power grid. They are used to provide backup power in case of power outage or failure. They typically have a power output range of 10 to 2000 kW and run on diesel or natural gas fuel [12].

- Prime diesel generators: These are medium-sized and continuous-duty generators that are used as the main or sole source of power. They are often installed in places where grid power is unreliable, unavailable or expensive, such as rural areas, islands, military bases and industrial plants. They usually have a power output range of 10 to 500 kW and run on diesel or biodiesel fuel [12].

According to their size, diesel generators can range from 8 kW (11 kVA) to 2,000 kW (2,500 kVA) or more. The smaller generators are suitable for homes, small shops, and offices, while the larger ones are used for industrial complexes, factories, and other large facilities. A 2,000 kW generator can be housed in a 40 ft. ISO container with all the necessary equipment to operate as a standalone power station or as a standby backup to grid power. These units are called power modules and can be combined to form a small power station or a large synchronized power plant [12] [14].

According to their cooling system, diesel generators can be either water-cooled or air-cooled. Water-cooled generators have a radiator and wear-resistant pipes that allow water to flow through the engine when it is running. They require regular checks of the water level and more routine maintenance than air-cooled generators. Air-cooled generators rely on air to keep the machine's operating temperature within an acceptable range. They have a built-in special system that helps increase the intake air volume to the required level [12] [14].

According to their use and purpose, diesel generators can be either industrial or domestic. Industrial diesel generators are used in industries and at construction sites and large settings. They produce more output power and have higher efficiency and durability than domestic generators. Domestic diesel generators are used at home or in small settings as a stopgap measure in case of a power outage. They produce less output power and have lower efficiency and reliability than industrial generators [12] [14].

Balance of system

Balance of system (BOS) is a term that refers to all the components of a photovoltaic system other than the solar panels. It includes wiring, switches, mounting systems, inverters, batteries, charge controllers, and other accessories that are needed to make the system work properly. The BOS is important because it affects the performance, reliability, and cost of the photovoltaic system.

The BOS can be divided into three subsystems: the power generation subsystem, the power use subsystem, and the power management subsystem. The power generation subsystem consists of the solar panels that convert sunlight into DC electricity. The power use subsystem consists of the loads that consume the electricity generated by the solar panels. The power management subsystem consists of the devices that regulate, convert, store, and distribute the electricity between the power generation and power use subsystems.

The BOS can account for a significant portion of the total cost of a photovoltaic system, depending on the type, size, and complexity of the system. Therefore, it is important to optimize the design and selection of the BOS components to achieve the best performance and efficiency at the lowest cost. Some factors that influence the BOS design are:

- The location and climate of the site

- The availability and quality of sunlight

- The type and size of the load

- The type and size of the solar panels

- The type and size of the batteries

- The type and size of the inverter

- The safety and environmental standards

The BOS is an essential part of any photovoltaic system. It ensures that the solar energy is captured, converted, stored, and delivered in a safe and reliable manner. By choosing the right BOS components and designing them properly, one can maximize the benefits of solar energy and minimize its drawbacks.

Combiner Box

A combiner box is a device that combines the output of multiple solar strings into a single cable that connects to the inverter. A combiner box helps to protect and manage the solar power system by providing overcurrent and overvoltage protection, disconnecting switches, surge protection devices, and monitoring devices. A combiner box is usually placed between the solar modules and the inverter, and it can be customized according to the number of strings, voltage, and current of the system. A combiner box is an essential component for any solar power system that has more than one string

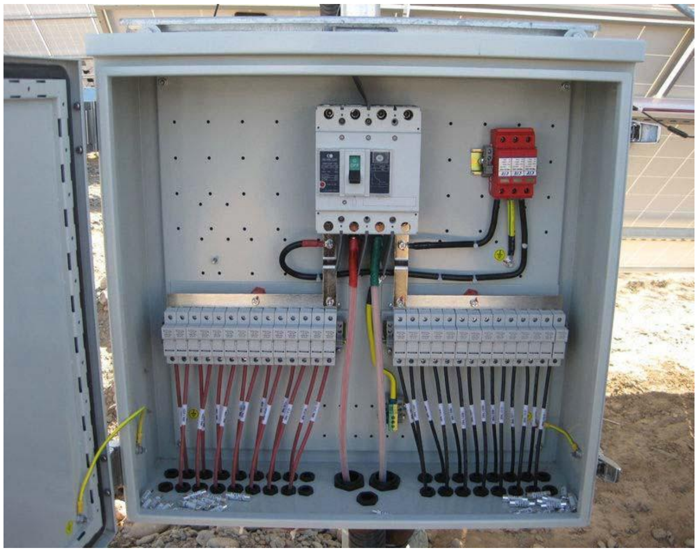


Figure 13Combiner Box

AC and DC cables

AC and DC cables are essential components of a solar system. They have different functions and characteristics that affect the performance and efficiency of the system.

In a solar system, AC cables are used to connect the inverter to the grid or to the appliances. AC cables have a lower carrying capacity than DC cables, which means that they can carry less current for a given cross-sectional area. This also means that they have more energy loss due to resistance and heating.

DC cables are used to connect solar panels to batteries or to the inverter. DC cables have a higher carrying capacity than AC cables, which means that they can carry more current for a given cross-sectional area. This also means that they have less energy loss due to resistance and heating. However, DC cables also have some drawbacks, such as higher voltage drop and more susceptibility to interference.

The choice of AC and DC cables for a solar system depends on several factors, such as the size and layout of the system, the distance between components, the voltage and current ratings, the environmental conditions, and the safety and quality standards. It is important to select the appropriate cables for each part of the system to ensure optimal performance and efficiency.

Formula for calculating cross sectional of the Capel:

$$A = \frac{2I\rho L}{V}$$

Where A is cables' minimum cross-sectional area, I is the current in cable, ρ is resistance of the conductor, L is cable length and V is the voltage drop across the cable.

Fuses

Fuses are devices that protect electrical circuits from overcurrent by breaking the circuit when the current exceeds a certain limit.

Fuses in solar systems have several functions and benefits. First, they can prevent damage to the solar panels and other components from short circuits, overloads, or reverse currents. Short circuits can occur when two wires touch each other accidentally, creating a low-resistance path for the current. Overloads can occur when the current exceeds the capacity of the wires or components, causing them to overheat and melt. Reverse currents can occur when the solar panels produce less electricity than the load demands, causing the current to flow in the opposite direction.

Second, fuses can isolate faulty parts of the solar system from the rest of the system, allowing the system to continue operating normally. For example, if one solar panel is damaged by hail or debris, a fuse can disconnect it from the rest of the system, preventing further damage and reducing power loss. Similarly, if one battery is defective or overcharged, a fuse can isolate it from the rest of the battery bank, preventing fire or explosion.

Circuit breakers

A switch can be used to manually disconnect or isolate a circuit, or it can be used to open and disconnect a circuit automatically in the event of a short circuit or a surge in current. In combiner boxes, circuit breakers are typically single-pole, meaning they only have one set of contacts for use with a single incoming wire

MC4

MC4 connectors are a type of electrical connector commonly used in photovoltaic (PV) systems. They are designed to allow for quick and easy connection and disconnection of PV modules, while ensuring high performance and reliability. MC4 connectors consist of a male and a female part, which can be snapped together by hand or with a special tool. The connectors have metal contacts that are sealed inside plastic housings, which protect them from dust, water and corrosion. MC4 connectors can handle high currents and voltages, and are compatible with different types of PV cables and modules. MC4 connectors are widely used in PV systems because they offer several advantages, such as:

Mounting structure

A mounting structure is a structure that supports and secures solar panels on a surface, such as a roof, a facade, or the ground. Mounting structures can vary in design, material, and installation method depending on the type and location of the solar photovoltaic system [23].

Pole mount

A pole mount is a type of mounting structure used on a single vertical pole that is connected to the ground via a base and supporting plates. Pole mounts are common in public areas where the system is space constrained and require flexible positioning for maximum production. Pole mounts can also allow easy adjustment of the tilt angle and potential use for dual axis tracking. Some advantages of pole mounts are cooler module temperature, easy access for maintenance/troubleshooting, and no roof penetration/liability. Some disadvantages are higher cost, higher wind load, and limited space for modules.

Figure 14pole mount structure

Ground mounting

Ground mounting structures can be designed to suit different terrain, climate and load conditions, and can be made of steel or aluminum. Ground mounting structures have some advantages over roof-mounted systems, such as more space, better orientation and tilt, easier access and maintenance, and higher efficiency. However, they also have some drawbacks, such as higher installation costs, land use, environmental impact and security issues. Ground mounting structures can use different types of foundations, such as ramming, drilling, screwing or ballasting, depending on the soil characteristics and project requirements. Ground mounting structures can also use tracking mechanisms to follow the sun across the sky and increase the energy output of the PV system.

Figure 15Ground mounting

Roof Mount

Roof mounts can be classified into two main categories: fixed and adjustable. Fixed roof mounts are designed to hold the solar panels at a fixed angle and orientation, while adjustable roof mounts allow the tilt and azimuth of the panels to be changed according to the sun's position and the optimal energy output. Roof mounts can also vary in terms of the materials, shapes, sizes and installation methods. The choice of roof mount depends on several factors, such as the roof type, slope, load capacity, aesthetics, budget and local codes and regulations.

Figure 16Roof mounts

Shadow analysis

When attempting to harvest solar radiation, it is also important to consider shade. Solar-PV panels are susceptible to solar radiation intensity variations. A slight variation in intensity on a Section of solar-PV panels due to shading will reduce their overall efficiency. There are a variety of possible shading types. Constantly obscuring the sun's rays, dense cloud cover is the most prevalent form of shade. In addition, nearby trees, buildings, and other structures can significantly reduce the output and efficiency of a solar-PV energy system.

First, the peak sun hours is needed to perform the shadow analysis, from SolarGIS, it is clear that the peak sun hours is approximately **5** hours

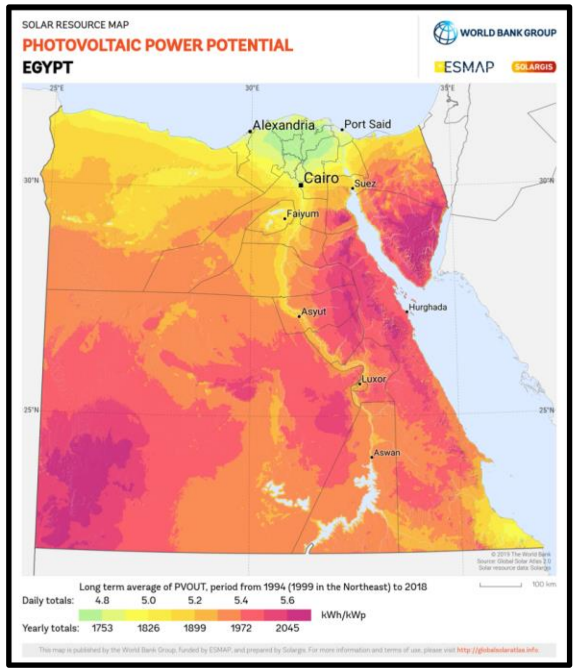
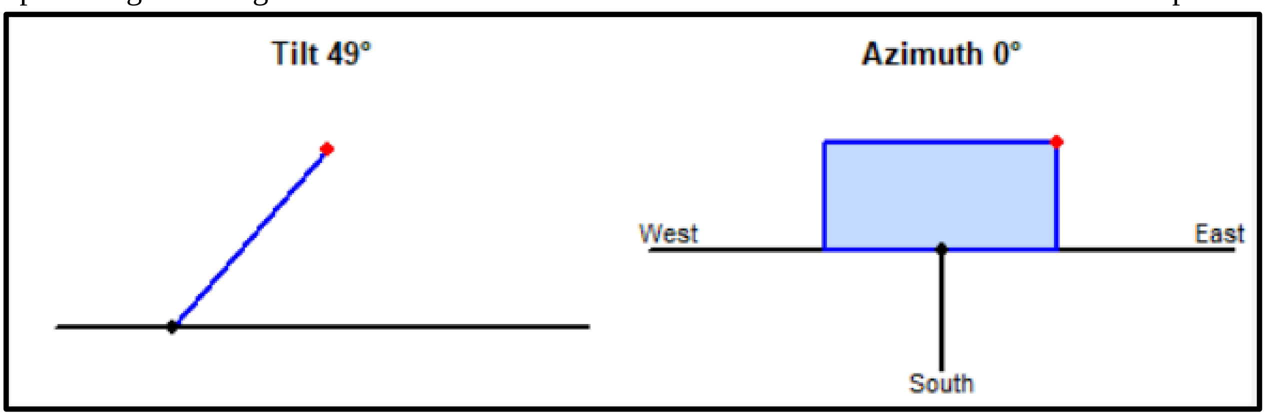
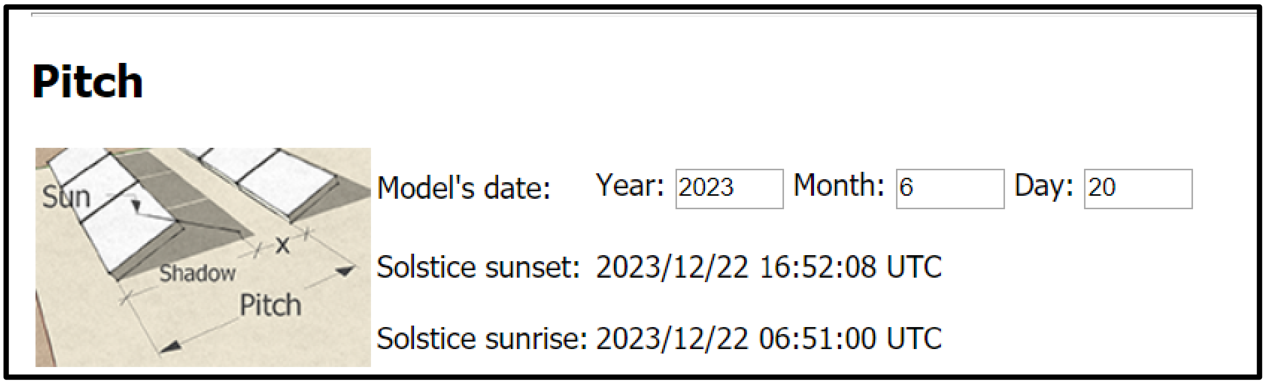


Figure 17Solar Map

Second, the tilt and azimuth angle: The tilt is optimized based on the worst case (winter season) using PVsyst which gives **49** degrees while the azimuth is measured from the location on sketch up which gives 0 degrees that means the location is on true south as it is in the northern hemisphere.



The shadow analysis is done on sketchup software to determine the spacing between panels and to observe any obstacles in the site that will cause the shadow. The spacing between panels is optimized based on the worst pitch at the winter season on **22/12** which is **4** meters in total area of **1495.79 m²** of the placement of the required number of panels **102** panels.



Sketch up model:

To build and simulate the photovoltaic system, a 3D model of the PV power plant and its surroundings was created using Sketch up Pro 2023 program:

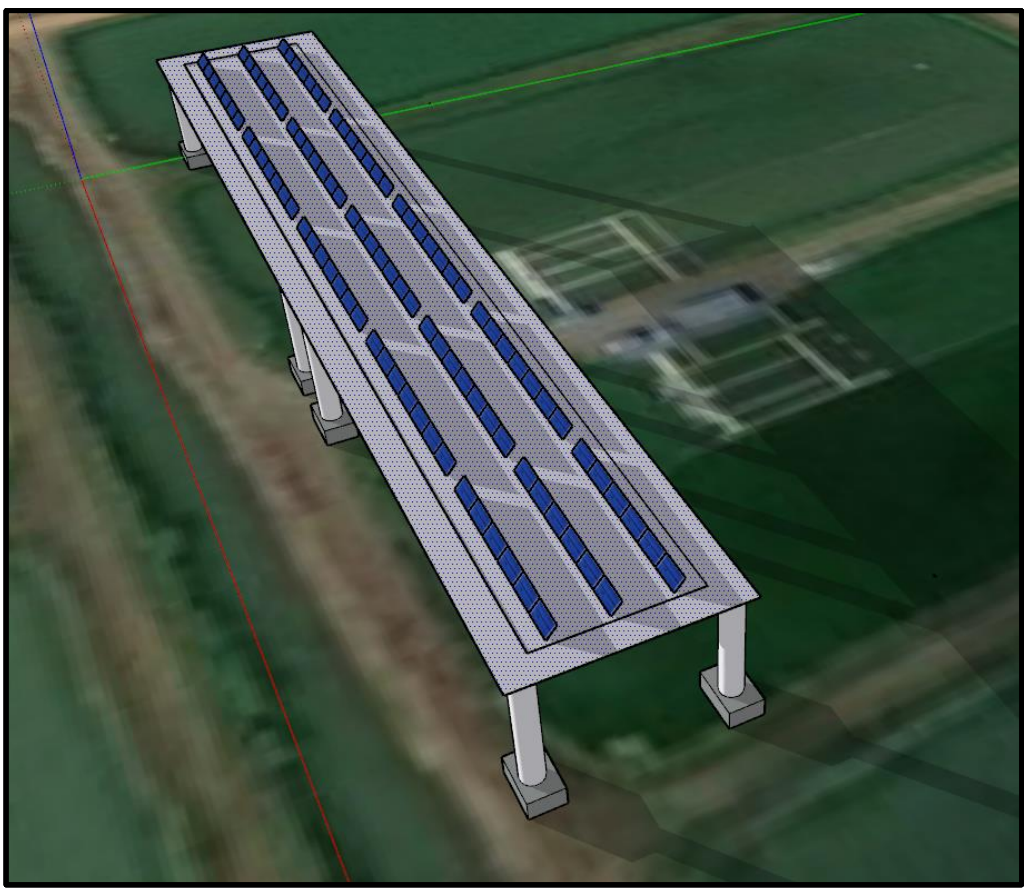


Figure 18 3D model of the PV power plant

PV module sizing

To design the PV modules to meet the required load and charge the batteries. The following approach is adapted:

<u>First, the following values is defined:</u>

- The total Energy Required from the load profile is 93247 KWh/year
- The DC system voltage chosen to be 48 Volt as the load demand is 15 KW which is greater than 5KW
- The average solar radiation of the site is 6.2 Wh/m2/day

<u>Second, design procedures:</u>

1. **Daily energy demand for array sizing (output of PV panels)**

$$E_d = \frac{E}{\eta_{all}}$$

Where E is the total average energy demand per day and the overall efficiency is

$$\eta_{all} = \text{battery eff.} \times \text{inverter eff.} \times \text{charge cont. eff.}$$

$$E_d = \frac{93247/365}{0.85*0.85*0.97} = 364.53 \text{ KWh/day}$$

2. **Needed array power**

$$P_{array} = \frac{E_d}{R}$$

Where R is the average daily solar radiation on the site

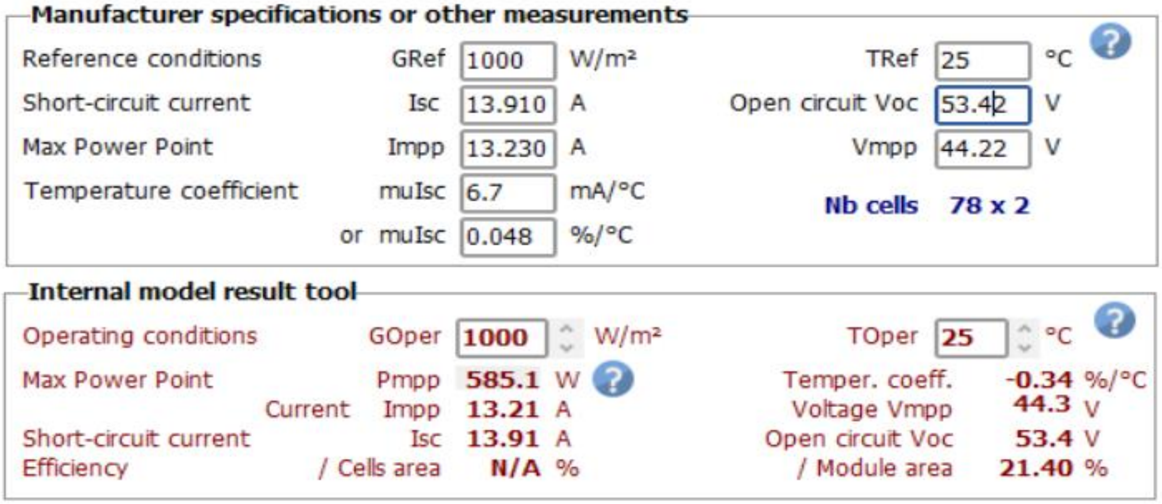
$$P_{array} = \frac{364.53 * 10^3}{6.2} = 58{,}795.2 \text{ W}$$

3. **Panels selection :**

The suggested module is 585 watt (silicon mono crystalline) JKM585M-7Rl4 solar panel from Junko

Figure 19 JKM585M-7Rl4 Module

Panel specifications from PVsyst:



4. Panels connection :

$$N_{Ps} = \frac{\text{System DC voltage}}{\text{Voltage at P}_{\text{max}}} = \frac{V_{DC}}{V_{max}}$$

$$N_{ps} = \frac{48}{44.2} = 1.08 \sim 2 \text{ Panels in series}$$

$$N_{Pp} = \frac{\text{Total no. of panels}}{\text{No. of series panels}} = \frac{N_{Pt}}{N_{Ps}}$$

$$N_{Pt} = \frac{P_{\text{array}}}{\text{panel power}}$$

$$N_{Pp} = \frac{\frac{58{,}795.2}{585}}{2} = 50.25 \sim 51 \text{ Panels in parallel}$$

Total number of panels is 102

Inverter sizing

When sizing and choosing the off grid inverter the following should be considered:

- Frequency
- Voltage
- Surge capacity
- Peak Load power

The off grid inverter size should be higher than the total power required to ensure handling the demand at peak time. Thus, a factor of safety is considered using the following formula:

$$\text{Size of inverter} = \text{Power required} \ * \text{correction factor of safety}$$

This correction factor is 1.25 to 1.3 .Thus, the inverter size for our system is:

$$\text{Size of inverter} = 15\ \text{KW} \ * 1.25 = 20\ \text{KW}$$

The input voltage is 48 volt and output AC voltage 220 volt with frequency 60HZ. The max hp for the components in the system is 3hp.

Inverter selection:

Thus, for the available inverters in the market to meet the design criterion: two inverters are chosen of model PV3500 TLV each of 10 KW rated power with surge rating 30000VA, capable of starting electric motors up to 5 HP, output voltage 220 volt and input voltage 48 Volt.

Battery bank sizing

To determine the capacity of the battery bank, the following formula is used:

$$C_B = \frac{E \times DOA}{V_B \times DOD}$$

DOA: Number of autonomy days (days that have almost radiation is diffuse) which is set to 1 day.
VB: Nominal voltage of each battery in the battery bank.
DOD: Depth of discharge allowable limit
E: Daily average energy demand from the user

Battery selection:

The suggested battery is lead acid (sealed gel) with the following specifications:

Basic parameters

Nb of elements in Series	6	
Nominal voltage	12.0	V
Capacity at C10	209.00	Ah
Internal resistance @ ref. temp.	11.48	mΩ
Reference temperature	25.0	°C
Coulombic efficiency	97.0	%

$$C_B = \frac{(93247/365) * 10^3}{12 * 0.8} = 26611.6 \text{ Ah}$$

$$N_{Bs} = \frac{V_{DC}}{V_B}$$

$$N_{B_S} = 48/12 = 4 \text{ batteries in series}$$

$$N_{Bp} = \frac{N_{Bt}}{N_{Bs}}$$

$$N_{Bt} = \frac{\text{Capacity of battery bank}}{\text{Capacity of one battery}} = \frac{C_B}{C}$$

$$N_{B_p} = \frac{(93247/365) * 10^3}{209} = 31.8{\sim}32 \text{ batteries in parallel}$$

Charger controller sizing

Charger controller is set to regulate the current and voltage from the PV models. Thus, it should be designed to be able to withstand the max current from the PV modules or from the loaf.
We will use MPPT Charger controller type Thus, its size can be done from the following formula in terms of its rated current:

$$I_{cc} = N_{Pp} \times \text{Panel short circuit current} \times \text{safety factor}$$

$$I_{cc} = 51 * 13.91 * 1.25 = 887 \text{ A}$$

$$V_{oc_{controller}} = N_{P_s} * \text{Panel open circuit voltage} * \text{ safety factor}$$

$$V_{oc_{controller}} = 2 * 53.4 * 1.25 = 133.5 \text{ Volt}$$

A controllers of 48 volt, 900 A, max operating voltage of 140 Volt is chosen

Cables sizing

When accurate sizing of the cables is done, this improves the reliability of the system. The copper conductor is used in this system. Voltage drop calculations are needed to optimize the design to not exceed the voltage drop limit of 3 to 5%.(we used online tool to measure the voltage group accurealty) .

$$V_d(DC) = \frac{2 * L_{cable} * I_{mp} * \rho}{A_{cable}}$$

$$\text{Voltage drop (in percentage)} = \frac{V_d}{V_{batt}} \times 100$$

- **L_CABLE:** Route length of cable in KM.
- **Imp:** Current of Pv modules at maximum power
- **ρ:** resistivity of the wire in ohm/m/mm2
- **A_CABLE:** cross sectional area of cable in mm^2 .

- **Vbatt :** the nominal voltage of the battery which is the dc system voltage
- **P.f:** Power factor
- **R:** Resistance per Km

The voltage drop between:

1. Combiner box and input of charger controller

Route length is 10 meter

Cross section area mm2	Resistance ohm/km	Voltage drop volt	Volatge drop %
1.5	15.5	5.126625	10.68046875
2.5	9.48	3.13551	6.5323125
4	5.9	1.951425	4.06546875
6	3.94	1.303155	2.71490625
10	2.34	0.773955	1.61240625
16	1.47	0.4862025	1.012921875
25	0.93	0.3075975	0.640828125
35	0.671	0.22193325	0.462360938
50	0.495	0.16372125	0.341085938

Table 2 Vd between Combiner box and input of charger controller

2. Charger controller and battery

Route length is 1 meter

Cross section area mm2	Resistance ohm/km	Voltage drop volt	Volatge drop %
1.5	15.5	0.5126625	1.068047
2.5	9.48	0.313551	0.653231
4	5.9	0.1951425	0.406547
6	3.94	0.1303155	0.271491
10	2.34	0.0773955	0.161241
16	1.47	0.04862025	0.101292
25	0.93	0.03075975	0.064083
35	0.671	0.022193325	0.046236
50	0.495	0.016372125	0.034109

Table 3 Vd between Charger controller and battery

3. Battery and inverter

Route length 2 meter

Cross section area mm2	Resistance ohm/km	Voltage drop volt	Volatge drop %
1.5	15.5	1.025325	2.136094
2.5	9.48	0.627102	1.306463
4	5.9	0.390285	0.813094
6	3.94	0.260631	0.542981
10	2.34	0.154791	0.322481
16	1.47	0.0972405	0.202584
25	0.93	0.0615195	0.128166
35	0.671	0.04438665	0.092472
50	0.495	0.03274425	0.068217

Table 4 Vd between Battery and inverter

4. Inverter and the load

Route length 4 meter and power factor 0.9

Cross section area mm2	Resistance ohm/km	Voltage drop volt	Volatge drop %
1.5	15.5	1.845585	3.844969
2.5	9.48	1.1287836	2.351633
4	5.9	0.702513	1.463569
6	3.94	0.4691358	0.977366
10	2.34	0.2786238	0.580466
16	1.47	0.1750329	0.364652
25	0.93	0.1107351	0.230698
35	0.671	0.07989597	0.16645
50	0.495	0.05893965	0.122791

Table 5 Vd between Inverter and the load

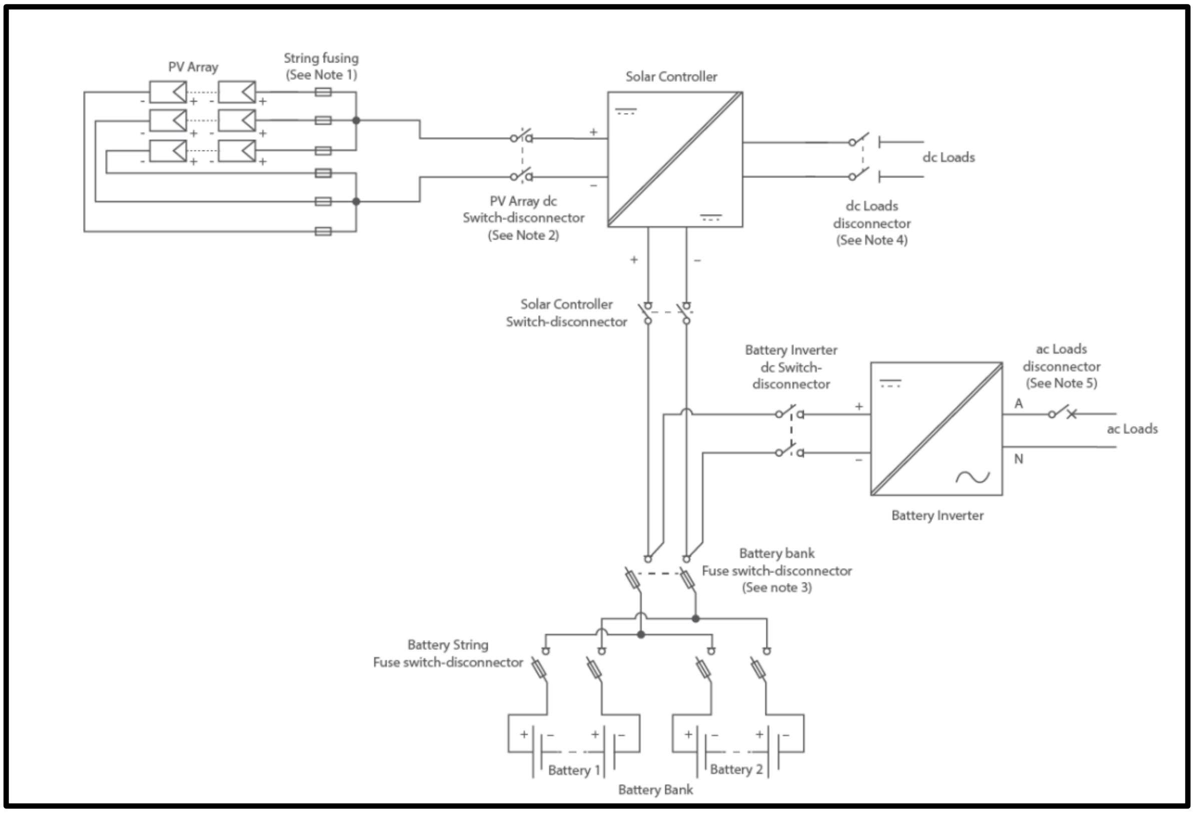
5. PV modules and combiner box

Route length average of 45 meter

Cross section area mm2	Resistance ohm/km	Voltage drop volt	Volatge drop %
1.5	15.5	23.0698125	48.06211
2.5	9.48	14.109795	29.39541
4	5.9	8.7814125	18.29461
6	3.94	5.8641975	12.21708
10	2.34	3.4827975	7.255828
16	1.47	2.18791125	4.558148
25	0.93	1.38418875	2.883727
35	0.671	0.998699625	2.080624
50	0.495	0.736745625	1.534887

Table 6 V d Between PV modules and combiner box

Protection devices



<u>Between panels and charger:</u>

The fuses should have the following ratings:

$$1.5 \text{ x } I_{sc\ of\ module} < I_{TRIP} < 2.4 \text{ x } I_{sc\ of\ module}$$

- **<u>I_sc :</u>** Module short circuit current
- **<u>I_TRIP:</u>** Rated trip current of the fuse

$$1.5 * 13.91 < I_{trip} < 2.4 * 13.91$$
$$20.865 < I_{trip} < 33.384$$

<u>The chosen fuse is 25 A</u>

For combined strings, the circuit breaker should have the following ratings:

$$1.25 * 13.91 * 51 < I_{trip} < 2.4 * 13.91 * 51$$
$$886.76 < I_{trip} < 1702.584$$

<u>The chosen is 900 A</u>

<u>Between battery and charger:</u>

$$\text{Fuse ratings} = 1.25 * \text{controller ratings}$$

$$\text{Fuse ratings} = 1.25 * 900 = 1225 \text{ A}$$

<u>The chosen fuse is 1250 A</u>

<u>Between battery and inverter:</u>

$$\text{Circuit breaker ratings} = 1.25 * \frac{P_{inverter}}{V_{system}}$$

$$\text{Circuit breaker ratings} = 1.25 * \frac{10{,}000}{48} = 260.4 \text{ A}$$

<u>The chosen circuit breaker is 280 A</u>

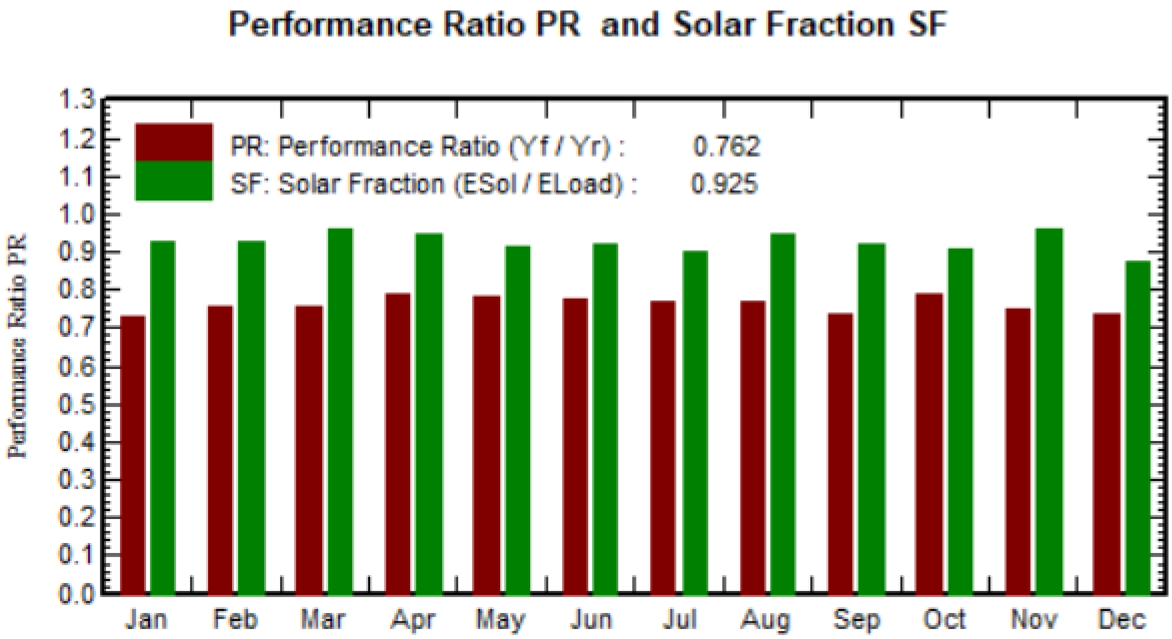
Diesel Generator:

The generator in our project is a standby generator, so we will choose a generator with a minimum load capacity of 6 HP.

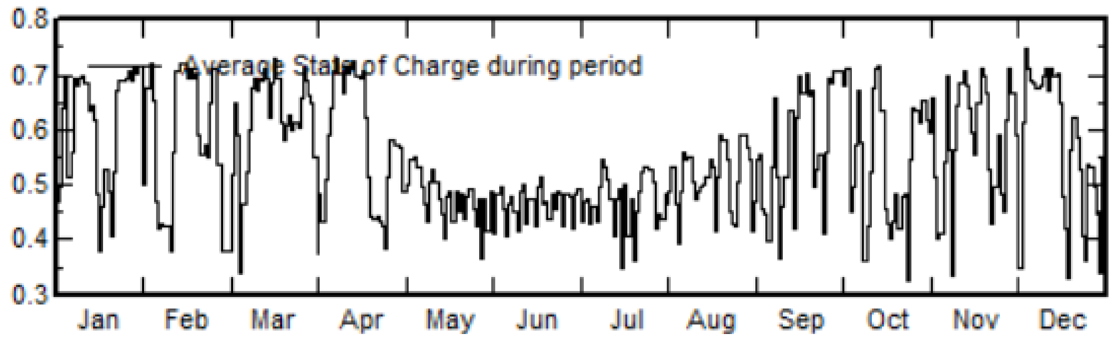
Figure 20 5KW diesel Generator

System simulation

System performance



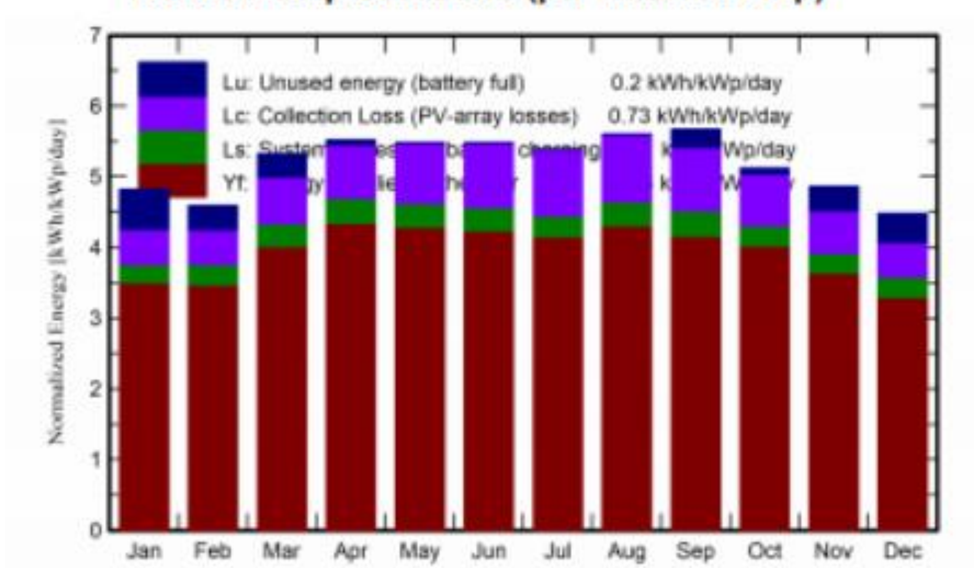
State of charge daily distribution



Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	95.6	144.7	7697	1028	6982	6985	0.929
February	101.9	124.2	6601	566	6283	6285	0.924
March	150.1	158.8	8294	599	7734	7737	0.961
April	177.0	158.4	8177	111	8205	8208	0.949
May	210.1	161.4	8198	0	8670	8670	0.916
June	222.5	155.5	7806	0	8264	8264	0.919
July	218.7	158.3	7875	0	8514	8514	0.903
August	198.6	165.4	8244	0	8446	8447	0.946
September	162.3	163.1	8212	449	8106	8110	0.919
October	129.3	153.1	7804	144	8239	8241	0.904
November	99.2	141.5	7341	605	6805	6808	0.959
December	87.4	134.8	7117	754	6975	6978	0.876
Year	1852.6	1819.4	93366	4258	93224	93247	0.925

Normalized productions (per installed kWp)



System losses

Array losses

Array Soiling Losses
Loss Fraction 2.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 0.66 mΩ
Loss Fraction 0.5 % at STC

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.8 % at STC

LID - Light Induced Degradation
Loss Fraction 2.0 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Soiling losses: The quantity of solar energy that reaches PV modules can be decreased if they become soiled or coated in dust or other particulates. Based on empirical data from simulations, PVSyst predicts these losses.

Diode losses: Internal diodes in PV modules normally stop reverse current passage through the module. Because of their voltage drop, these diodes may result in some energy loss.

Mismatch losses: Due to manufacturing tolerances and shading, PV modules may have various current ratings or characteristics. These variations can cause mismatch losses, in which the energy output of the array is decreased as a result of variations among the modules.

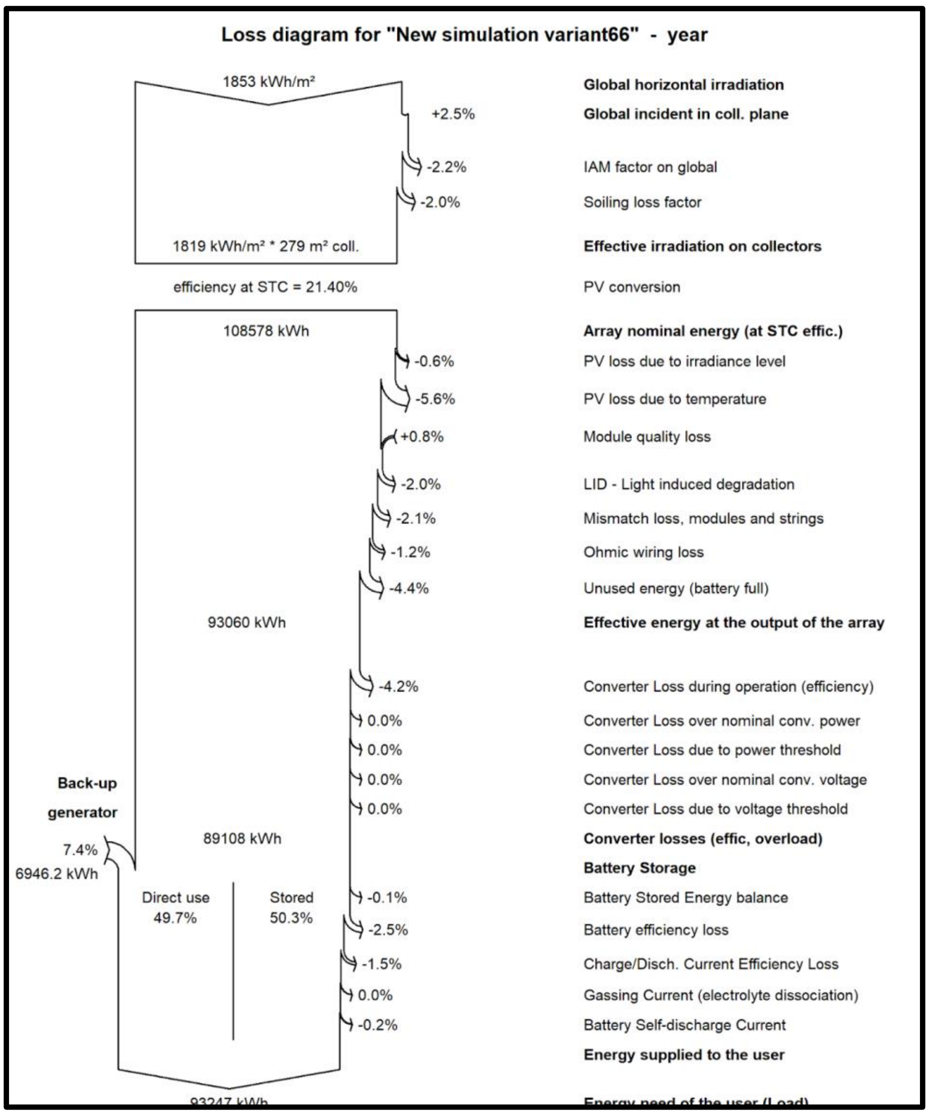
Thermal losses: PV modules decrease in efficiency as their temperature increases, this is affected by ambient temperature, wind speed, solar intensity and other factors. The temperature coefficient of the PV module is used by PVSyst to simulate temperature losses. And this quantifies how much the module's efficiency declines as the temperature rises, which is specified by the manufacturer.

Module quality loss: PV modules may perform more or less better than expected, Based on the manufacturer's recommendations and additional elements like temperature and shade, PVSyst estimates this.

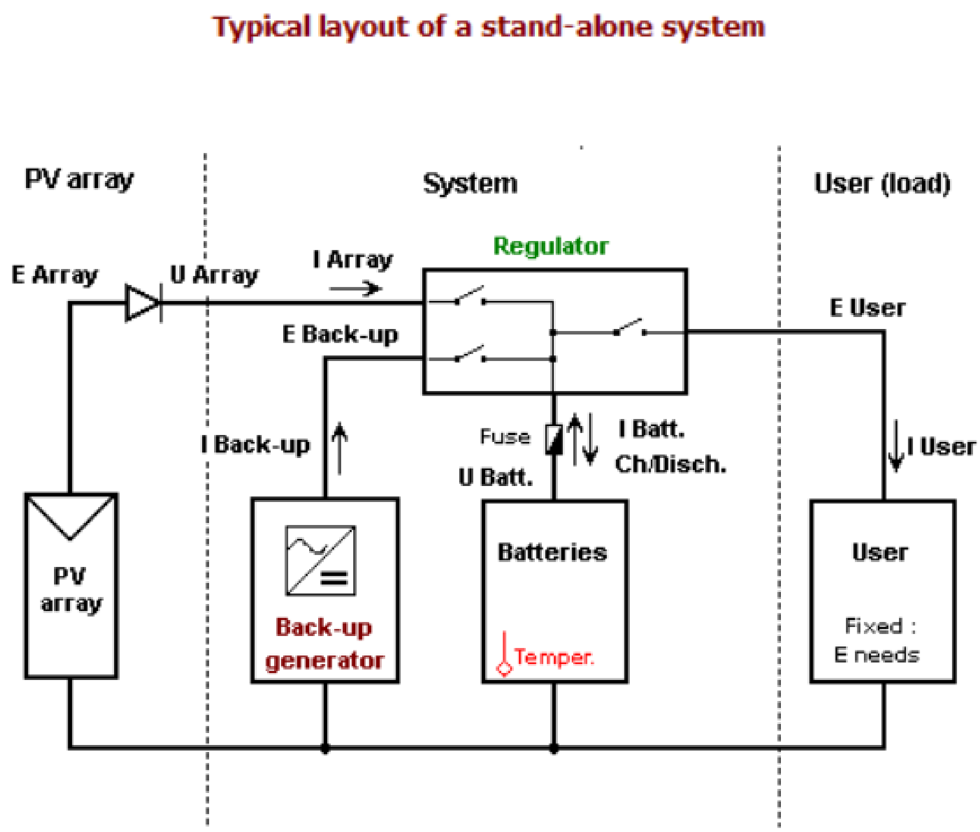
IAM losses: (Incidence Angle Modifier) losses describe the decrease in solar irradiance that reaches the solar module as a result of the angle at which sunlight is incident. The solar module's effective area decreases when the angle of incidence of sunlight is not perpendicular to it, which lowers the quantity of solar energy that can be used to generate electricity. The angle of incidence, the type of solar module, and the wavelength of the solar radiation are among the variables that affect the amount of IAM losses.

LID losses: The silicon material used in the PV module has boron-oxygen imperfections which cause LID. The defects become active when the material is exposed to sunlight, decreasing the module's efficiency. The LID effect can cause a drop in energy output of up to 5% and is most noticeable in the first few hours or days of exposure to sunshine.

Dc wiring losses: These losses are due to the DC voltage drop in cables connecting PV modules through inverter. By taking into consideration the size and length of the cables used in the PV array, PVSyst calculates DC wiring losses. The programme estimates the voltage drop and energy loss in the system by calculating the resistance of the cables and connectors.

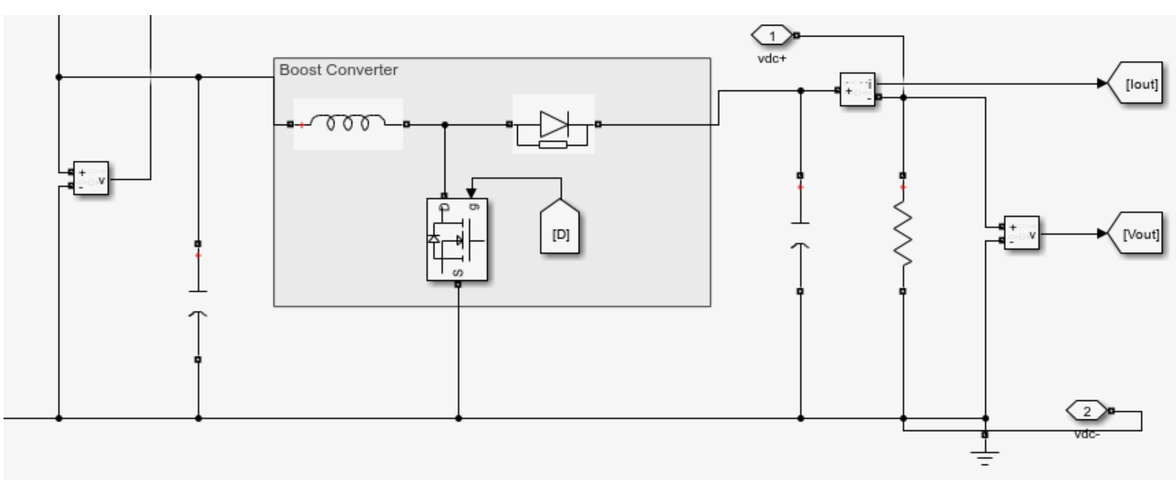


Layout



Matlab Simulink analysis

DC-DC BOOST CONVERTER:



$$V\_out = V\_in / (1 - D)$$

P_in=P_out=(V_out^2)/R V_out =V_in /(1-D)

R = (V_out^2)/P_out

The minimum Inductor value can be determined by

L_min = (D(1 − D)^2 R)/(2f_s)

Forf_s = 10kHz , R = 1.125 ohm

L_min=1.812μH

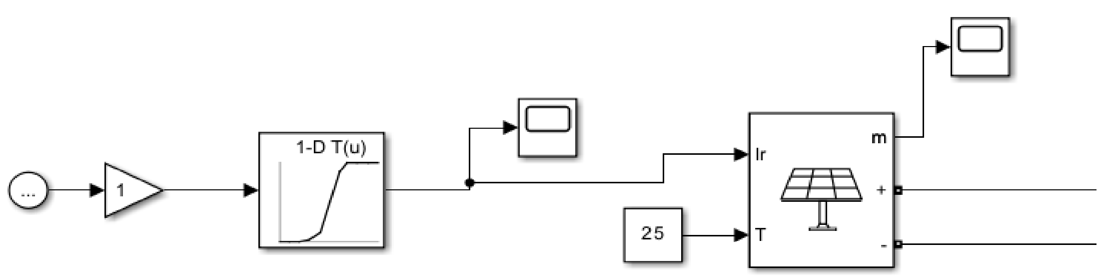
The minimum capacitor value can be determined by

C_min = D/(Rf_s (ΔV_0)/V_0)

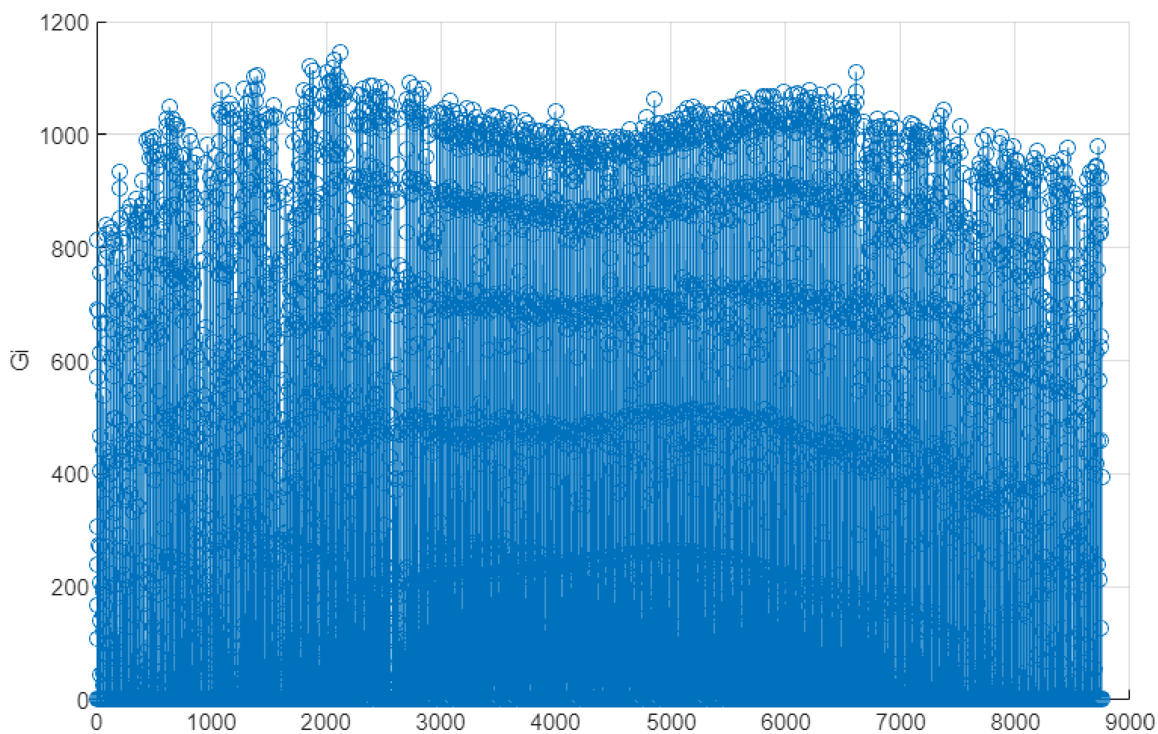
Assuming a voltage ripple,(ΔV_0)/V_0 = 0.5%

C_min=2151.11μF

PV_MODULE

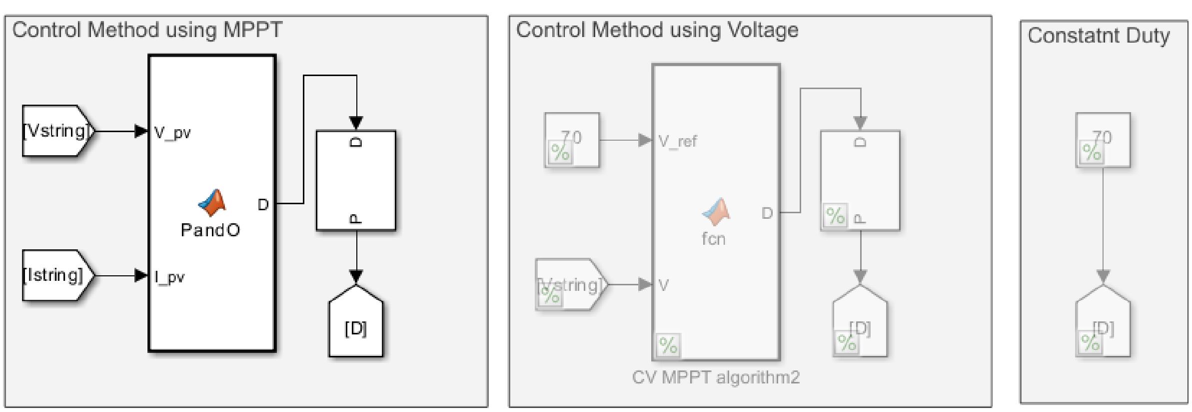


Irradiance:



MPPT

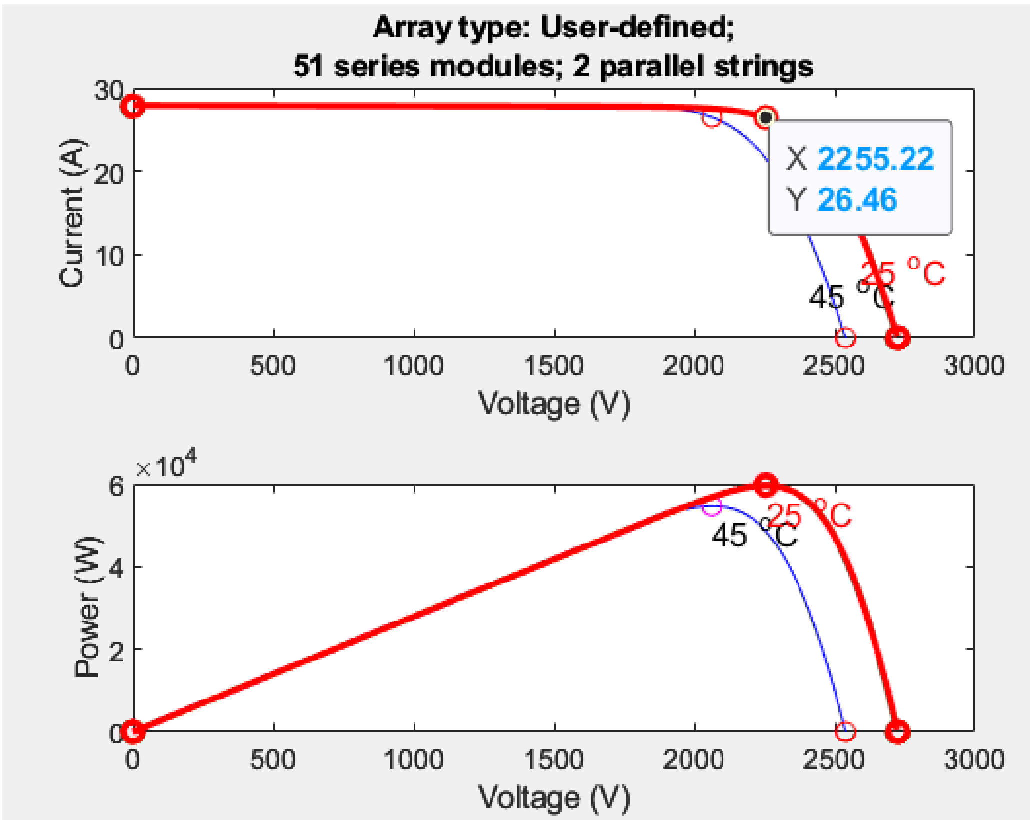
Two MPPT techniques were used to operate the PV modules in optimal conditions



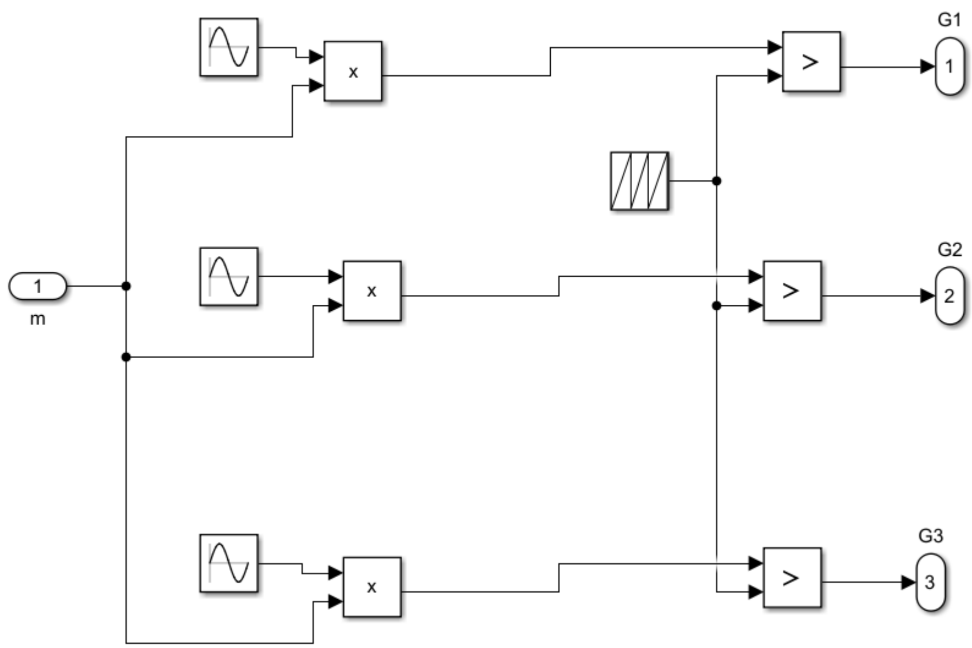
1-incremental inductance: this method of control uses the duty ratio of the converter to change the voltage on the solar panel modules which is lower or increased following a matlab code provided in the appendix

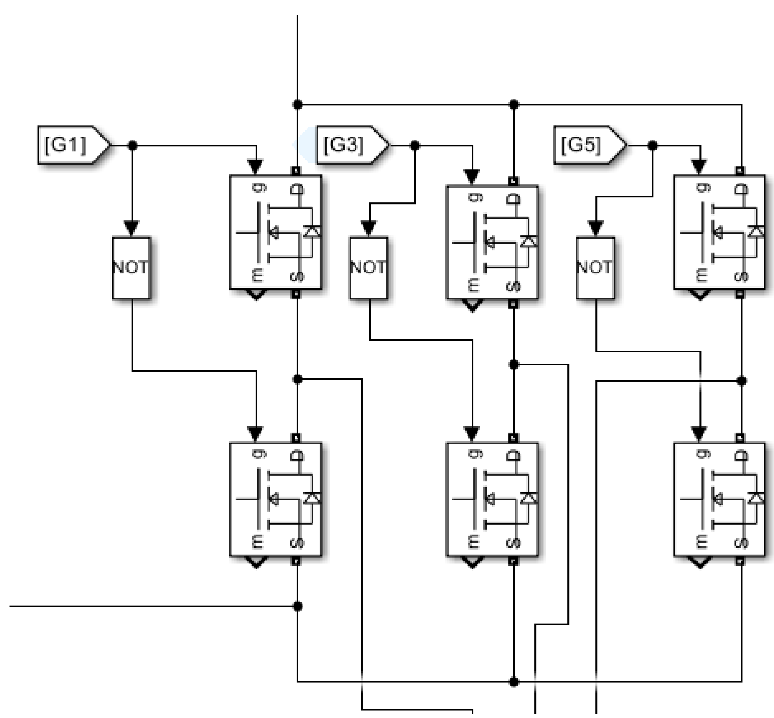
2- Constant Voltage: in this technique a constant voltage of 2255.22v is maintained on the solar panel modules as it is the voltage of MPP at 1000w/m^2 irradiance

Power output at different voltage levels:



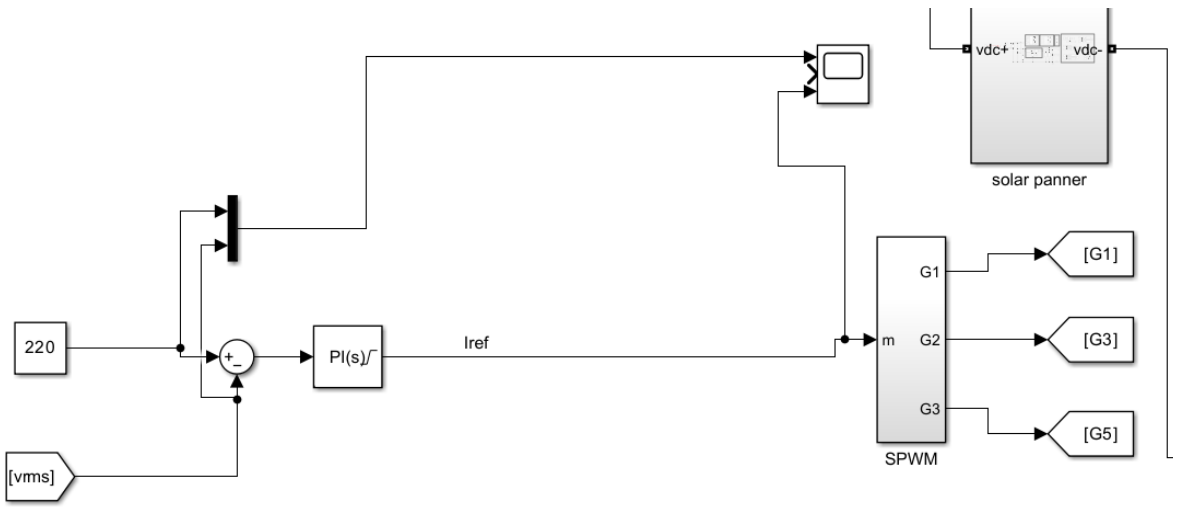
DC-AC inverter





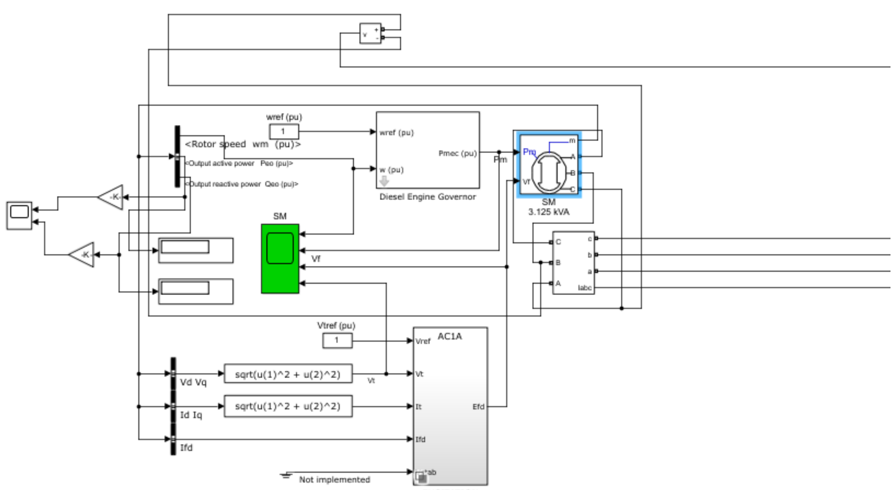
The inverter is constructed out of three pairs of mosfets and a control system that uses three sine wave signals as inputs and of frequency of 5kh changes the direction of the input current to maintain an output of the same frequency and shape of the sine wave input signal

DC AC inverter voltage control:



A PI controller is used to control the rms voltage and maintain it around 220 volt

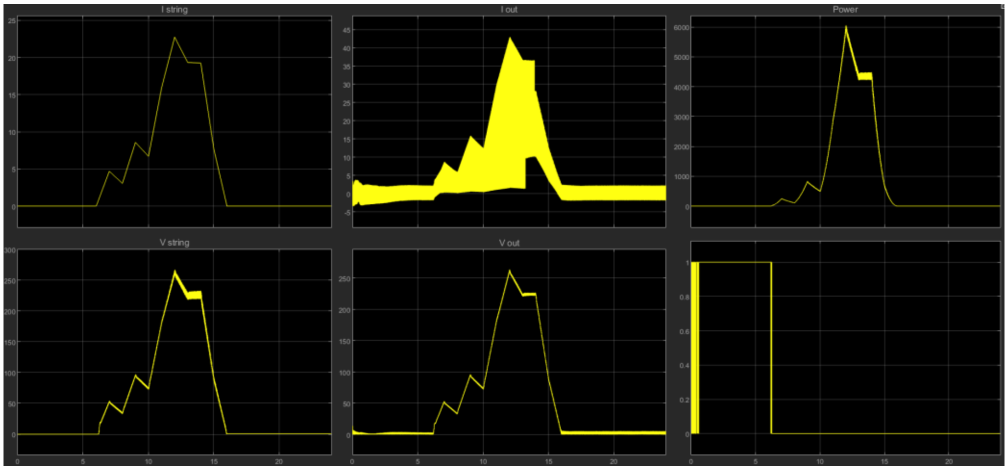
Generator



In this model excitation is used instead of a minor to provide torque and reference voltage to the generator the limit of the torque provided to the generator is [0 1.1] while a reference rotor speed of 1pu maintain the operation of the generator at rated power

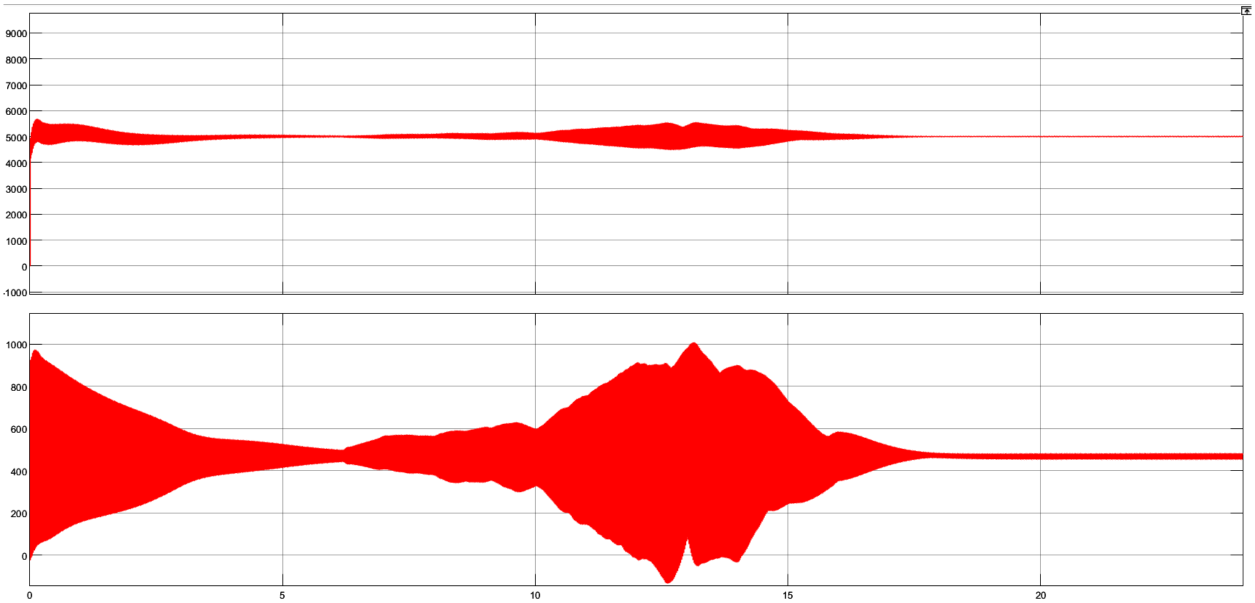
Simulation results

PV:



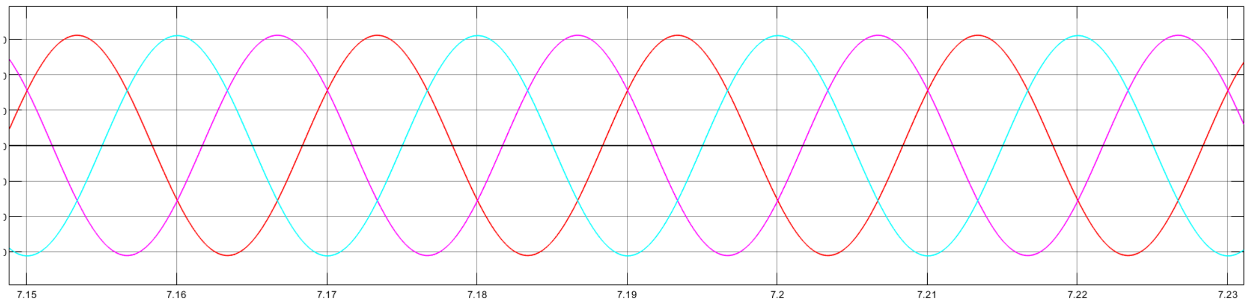
In the simulation the output voltage and power of PV yielded satisfactory results yet the flicker in the output current was huge yet it did not affect the output voltage

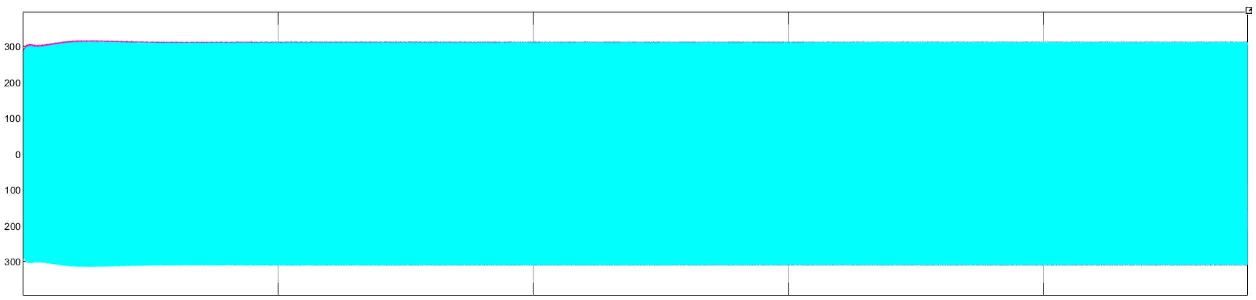
Generator simulation results:



The generator maintained a roughly constant power output with a noticeable increase in reactive power output at the start of operation and at peak PV power output

Load voltage





According to the extracted graphs the voltage supplied to the load remained roughly at rms value of 220v with noticeable change over the simulation course

Economic Analysis

Calculation of CAPEX and OPEX at different solar friction to choose the design model:

Solar fraction 92.53%:

Output power from the PV system equals 59.7 KW

Solar PV System (92.53%)								
		Detailed Quantitiy						
Component	Specifications	Cad length	Additional length(building heigth)	Total length	Unit	Unit Price(EGP)	Total Price(EGP)	life time
DC cables	4mm2	17	0	17	m	30.006	510.102	25
AC Cables	16mm2	45	0	45	m	60.012	2700.54	25
		Quantity	Spare	Total Quantity				
PV Panels	JKM585M-7RL4-V	102	7	109	PC	4680	269708.4	25
Inverter	PV35-12048 TLV	2	0	2	PC	32447.31	104894.62	20+5
MC4	202				Pair	32	6464	25
Mounting Structure					per KW	2200	126786	25
COMBINER BOX					PC	9000		25
Installation					per KW	2000	115260	25
					Total 59.7 KWp system price	$868,857.80	Total Price per KWp	14553.73203
DIESIL COST	$45,385.20	BATTERY	123594.24	GENERATOR	64,554.70			

Table 7Solar fraction 92.53%:

Solar fraction 72.93%:

Output power from the PV system equals 44.5KW

Solar PV System (72.93%)								
		Detailed Quantitiy						
Component	Specifications	Cad length	Additional length(building heigth)	Total length	Unit	Unit Price(EGP)	Total Price(EGP)	life time
DC cables	4mm2	17	0	17	m	30.006	510.102	25
AC Cables	16mm2	45	0	45	m	60.012	2700.54	25
		Quantity	Spare	Total Quantity				
PV Panels	JKM585M-7RL4-V	76	7	83	PC	4680	200959.2	25
Inverter	PV35-12048 TLV	2	0	2	PC	32447.31	104894.62	20+5
MC4	150				Pair	32	4800	25
Mounting Structure					per KW	2200	94468	25
COMBINER BOX					PC	9000		25
Installation					per KW	2000	85880	25
					Total 44.5 KWp system price	$881,504.63	Total Price per KWp	14765.57161
DIESIL COST	$164,905.22	BATTERY	123594.24	GENERATOR	64,554.70			

Table 8Solar fraction 72.93%:

Solar fraction 57.30%:

Output power from the PV system equals 35.1KW

Solar PV System (57.30%)								
		Detailed Quantitiy						
Component	Specifications	Cad length	Additional length(building heigth)	Total length	Unit	Unit Price(EGP)	Total Price(EGP)	life time
DC cables	4mm2	17	0	17	m	30.006	510.102	25
AC Cables	16mm2	45	0	45	m	60.012	2700.54	25
		Quantity	Spare	Total Quantity				
PV Panels	JKM585M-7RL4-V	60	7	67	PC	4680	158652	25
Inverter	PV35-12048 TLV	1	0	1	PC	32447.31	52447.31	20+5
MC4	118				Pair	32	3776	25
Mounting Structure					per KW	2200	74580	25
COMBINER BOX					PC	9000		25
Installation					per KW	2000	67800	25
					Total 35.1 KWp solar system price	$991,607.19	Total Price per KWp	16609.8356
DIESIL COST	$362,491.59	BATTERY	123594.24	GENERATOR	129109.4			

Table 9Solar fraction 57.30%

Solar fraction 0%:

Output power from the PV system equals 0 KW

full diesel								
					Total system price	$977,448.16	Total Price per KWp	$16,372.67
DIESIL COST	$609,126.10	BATTERY	0	GENERATOR	368322.06			

Table 10Solar fraction 0%:

Comparison between the different solar fractions:

Solar fraction	PV(kWh)	Generator (kWh)	Battery 48V	COST(LE)/KWP	TOTAL COST (LE)
57.30%	53431	39935	6688AH	16609.84	991607.19
72.93%	68009	25238	6688AH	14765.57	881,504.63
92.53%	86420	6946	6688AH	14553.73	868,857.80
0%	0	93224	0	16372.67	977,448

Table 11 Comparison between the different solar fractions:

Cconclusion :

This project aimed to design an off-grid solar system for fish farming sector using PVsyst and SketchUp software. We also developed a control model of the system using MATLAB and simulated the results and output. We considered different solar fractions and performed cost analysis for each scenario. We also discussed the safety devices and methodology for the protection of each component of the system. The project demonstrated the feasibility and benefits of using solar energy for fish farming, which is an approach towards sustainable renewable energy.

Recommendations:

It will be good approach towards the solar energy this project has potential applications in regions that receive high amounts of solar radiation and face water scarcity. For example, the Western Desert of Egypt, along the northern coast, is an ideal location for this model. The land is below sea level, which facilitates the access to groundwater or seawater. The solar radiation is also very high, as shown by the Global Solar Atlas. This combination of factors makes this region suitable for implementing this project.

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Appendixes

Inverter specifications catalog:

MODEL		PV35-8048 TLV	PV35-10048 TLV	PV35-12048 TLV
Nominal Battery System Voltage		48VDC	48VDC	48VDC
INVERTER OUTPUT	Rated power	8.0KW	10.0KW	12.0KW
	Surge rating	24000VA	30000VA	36000VA
	Capable of starting electric motor	4HP	5HP	6HP
	Waveform	Pure sine wave / same as input (bypass mode)		
	Nominal output voltage RMS	100V/110V/120V/200V/220V/240V		
	Output frequency	50Hz / 60Hz ± 0.3Hz		
	Inverter effciency(peak)	>88%		
	Line mode efficiency	>95%		
	Power factor	1.0		
	Typical transfer time	20ms(max)		
AC INPUT	Voltage	220V/230V/240V		
	Selectable voltage range	90-280 VAC (APL)		
	Frequency range	50Hz / 60Hz		
BATTERY	Low battery voltage cutoff	40-48VDC for 48VDC mode		
	Low battery voltage recover	42-50VDC for 48VDC mode		
	High battery voltage cutoff	60VDC for 48VDC mode		
	High battery voltage recover	57VDC for 48VDC mode		
	Idle consumption-search mode	< 60W when power saver on		

Table 12 Inverter specifications catalog:

Cables specifications characteristics:

TABLE A.3 Characteristics of copper conductors, hard drawn, 97.3% conductivity

Size of Conductor		Number of Strands	Diameter of Individual Strands (inches)	Outside Diameter (inches)	Breaking Strength (pounds)	Weight (pounds per mile)	Approx Current Carrying Capacity* (amps)	Geometric Mean Radius at 60 Hz (feet)	r_a Resistance (Ohms per Conductor per Mile)								x_a Inductive Reactance (ohms per conductor per mile at 1 ft spacing)			x'_a Shunt Capacitive Reactance (megohms per conductor per mile at 1 ft spacing)		
									25°C (77°F)				50°C (122°F)									
Circular Mils	AWG or B & S								dc	25 Hz	50 Hz	60 Hz	dc	25 Hz	50 Hz	60 Hz	25 Hz	50 Hz	60 Hz	25 Hz	50 Hz	60 Hz
1 000 000		37	0.1644	1.151	43 830	16 300	1 300	0.0368	0.0585	0.0594	0.0620	0.0634	0.0640	0.0648	0.0672	0.0685	0.1666	0.333	0.400	0.216	0.1081	0.0901
900 000		37	0.1560	1.092	39 510	14 670	1 220	0.0349	0.0650	0.0658	0.0682	0.0695	0.0711	0.0718	0.0740	0.0752	0.1693	0.339	0.406	0.220	0.1100	0.0916
800 000		37	0.1470	1.029	35 120	13 040	1 130	0.0329	0.0731	0.0739	0.0760	0.0772	0.0800	0.0806	0.0826	0.0837	0.1722	0.344	0.413	0.224	0.1121	0.0934
750 000		37	0.1424	0.997	33 400	12 230	1 090	0.0319	0.0780	0.0787	0.0807	0.0818	0.0853	0.0859	0.0879	0.0888	0.1739	0.348	0.417	0.226	0.1132	0.0943
700 000		37	0.1375	0.963	31 170	11 410	1 040	0.0308	0.0836	0.0842	0.0861	0.0871	0.0914	0.0920	0.0937	0.0947	0.1759	0.352	0.422	0.229	0.1145	0.0954
600 000		37	0.1273	0.891	27 020	9 781	940	0.0285	0.0975	0.0981	0.0997	0.1006	0.1066	0.1071	0.1086	0.1095	0.1799	0.360	0.432	0.235	0.1173	0.0977
500 000		37	0.1162	0.814	22 510	8 151	840	0.0260	0.1170	0.1175	0.1188	0.1196	0.1280	0.1283	0.1296	0.1303	0.1845	0.369	0.443	0.241	0.1205	0.1004
500 000		19	0.1622	0.811	21 590	8 151	840	0.0256	0.1170	0.1175	0.1188	0.1196	0.1280	0.1283	0.1296	0.1303	0.1853	0.371	0.445	0.241	0.1206	0.1005
450 000		19	0.1539	0.770	19 750	7 336	780	0.0243	0.1300	0.1304	0.1316	0.1323	0.1422	0.1426	0.1437	0.1443	0.1879	0.376	0.451	0.245	0.1224	0.1020
400 000		19	0.1451	0.726	17 560	6 521	730	0.0229	0.1462	0.1466	0.1477	0.1484	0.1600	0.1603	0.1613	0.1619	0.1909	0.382	0.458	0.249	0.1245	0.1038
350 000		19	0.1357	0.679	15 590	5 706	670	0.0214	0.1671	0.1675	0.1684	0.1690	0.1828	0.1831	0.1840	0.1845	0.1943	0.389	0.466	0.254	0.1269	0.1058
350 000		12	0.1708	0.710	15 140	5 706	670	0.0225	0.1671	0.1675	0.1684	0.1690	0.1828	0.1831	0.1840	0.1845	0.1918	0.384	0.460	0.251	0.1253	0.1044
300 000		19	0.1257	0.629	13 510	4 891	610	0.01987	0.1950	0.1953	0.1961	0.1966	0.213	0.214	0.214	0.215	0.1982	0.396	0.476	0.259	0.1296	0.1080
300 000		12	0.1581	0.657	13 170	4 891	610	0.0208	0.1950	0.1953	0.1961	0.1966	0.213	0.214	0.214	0.215	0.1957	0.392	0.470	0.256	0.1281	0.1068
250 000		19	0.1147	0.574	11 360	4 076	540	0.01813	0.234	0.234	0.235	0.235	0.256	0.256	0.257	0.257	0.203	0.406	0.487	0.266	0.1329	0.1108
250 000		12	0.1443	0.600	11 130	4 076	540	0.01902	0.234	0.234	0.235	0.235	0.256	0.256	0.257	0.257	0.200	0.401	0.481	0.263	0.1313	0.1094
211 600	4/0	19	0.1055	0.528	9 617	3 450	480	0.01668	0.276	0.277	0.277	0.278	0.302	0.303	0.303	0.303	0.207	0.414	0.497	0.272	0.1359	0.1132
211 600	4/0	12	0.1328	0.552	9 483	3 450	490	0.01750	0.276	0.277	0.277	0.278	0.302	0.303	0.303	0.303	0.205	0.409	0.491	0.269	0.1343	0.1119
211 600	4/0	7	0.1739	0.522	9 154	3 450	480	0.01579	0.276	0.277	0.277	0.278	0.302	0.303	0.303	0.303	0.210	0.420	0.503	0.273	0.1363	0.1136
167 800	3/0	12	0.1183	0.492	7 556	2 736	420	0.01559	0.349	0.349	0.349	0.350	0.381	0.381	0.382	0.382	0.210	0.421	0.505	0.277	0.1384	0.1153
167 800	3/0	7	0.1548	0.464	7 366	2 736	420	0.01404	0.349	0.349	0.349	0.350	0.381	0.381	0.382	0.382	0.216	0.431	0.518	0.281	0.1405	0.1171
133 100	2/0	7	0.1379	0.414	5 926	2 170	360	0.01252	0.440	0.440	0.440	0.440	0.481	0.481	0.481	0.481	0.222	0.443	0.532	0.289	0.1445	0.1205
105 600	1/0	7	0.1228	0.368	4 752	1 720	310	0.01113	0.555	0.555	0.555	0.555	0.606	0.607	0.607	0.607	0.227	0.455	0.546	0.298	0.1488	0.1240
83 690	1	7	0.1093	0.328	3 804	1 364	270	0.00992	0.699	0.699	0.699	0.699	0.765				0.233	0.467	0.560	0.306	0.1528	0.1274
83 690	1	3	0.1670	0.360	3 620	1 351	270	0.01016	0.692	0.692	0.692	0.692	0.757				0.232	0.464	0.557	0.299	0.1495	0.1246
66 370	2	7	0.0974	0.292	3 045	1 082	230	0.00883	0.881	0.882	0.882	0.882	0.964				0.239	0.478	0.574	0.314	0.1570	0.1308
66 370	2	3	0.1487	0.320	2 913	1 071	240	0.00903	0.873				0.955				0.238	0.476	0.571	0.307	0.1537	0.1281
66 370	2	1		0.258	3 003	1 061	220	0.00836	0.864				0.945				0.242	0.484	0.581	0.323	0.1614	0.1345
52 630	3	7	0.0867	0.260	2 433	858	200	0.00787	1.112				1.216				0.245	0.490	0.588	0.322	0.1611	0.1343
52 630	3	3	0.1325	0.285	2 359	850	200	0.00805	1.101				1.204				0.244	0.488	0.585	0.316	0.1578	0.1315
62 630	3	1		0.229	2 439	841	190	0.00745	1.090		Same as dc		1.192		Same as dc		0.248	0.496	0.595	0.331	0.1656	0.1380
41 740	4	3	0.1180	0.254	1 879	674	180	0.00717	1.388				1.518				0.250	0.499	0.599	0.324	0.1619	0.1349
41 740	4	1		0.204	1 970	667	170	0.00663	1.374				1.503				0.254	0.507	0.609	0.339	0.1697	0.1415
33 100	5	3	0.1050	0.226	1 505	534	150	0.00638	1.750				1.914				0.256	0.511	0.613	0.332	0.1661	0.1384
33 100	5	1		0.1819	1 591	529	140	0.00590	1.733				1.895				0.260	0.519	0.623	0.348	0.1738	0.1449
26 250	6	3	0.0935	0.201	1 205	424	130	0.00568	2.21				2.41				0.262	0.523	0.628	0.341	0.1703	0.1419
26 250	6	1		0.1620	1 280	420	120	0.00526	2.18				2.39				0.265	0.531	0.637	0.356	0.1779	0.1483
20 820	7	1		0.1443	1 030	333	110	0.00468	2.75				3.01				0.271	0.542	0.651	0.364	0.1821	0.1517
16 510	8	1		0.1285	826	264	90	0.00417	3.47				3.80				0.277	0.554	0.665	0.372	0.1862	0.1552

*For conductor at 75°C, air at 25°C, wind 1.4 miles per hour (2 ft/sec), frequency = 60 Hz

Table 13Cables specifications characteristics:

Fuse characteristics:

Electrical Characteristics

CASE SIZE	CATALOG NUMBER			AMPERE RATING (A)	VOLTAGE RATING (V)	INTERRUPTING RATING	MINIMUM BREAKING CAPACITY (A)	MELTING (PRE-ARC) I^2T (A^2S)	TOTAL CLEARING I^2T (A^2S) AT RATED VOLTAGE	WATTS LOSS AT 100% RATED CURRENT (W)	AGENCY CERTIFICATION
	FLUSH METRIC (FL)	BOLTED BLADE (UB)	DIN BLADE (DB)		DC	DC			DC		cURus
NH 1XL	PSX1XLFL0080	PSX1XLUB0080	PSX1XLDB0080	80	1500	250 kA	800 A	2048	8720	16.4	•
	PSX1XLFL0100	PSX1XLUB0100	PSX1XLDB0100	100	1500	250 kA	1000 A	3540	15485	19.1	•
	PSX1XLFL0125	PSX1XLUB0125	PSX1XLDB0125	125	1500	250 kA	1250 A	7091	35720	19.6	•
	PSX1XLFL0160	PSX1XLUB0160	PSX1XLDB0160	160	1500	250 kA	1600 A	13704	55490	24.6	•
	PSX1XLFL0200	PSX1XLUB0200	PSX1XLDB0200	200	1500	250 kA	2000 A	18016	77240	34.6	•
	PSX1XLFL0250	PSX1XLUB0250	PSX1XLDB0250	250	1500	250 kA	2500 A	36552	156450	38.5	•
	PSX1XLFL0280	PSX1XLUB0280	PSX1XLDB0280	280	1500	250 kA	2800 A	36552	156450	48.7	•
	PSX1XLFL0315	PSX1XLUB0315	PSX1XLDB0315	315	1500	250 kA	3150 A	56940	212400	53.6	•
	PSX1XLFL0350	PSX1XLUB0350	PSX1XLDB0350	350	1500	250 kA	3500 A	86623	332050	51.8	•
	PSX1XLFL0400	PSX1XLUB0400	PSX1XLDB0400	400	1500	250 kA	4000 A	116271	352600	64.4	•
	PSX1XLFL0450	PSX1XLUB0450	PSX1XLDB0450	450	1500	250 kA	6750 A	149336	540850	69.3	•
	PSX1XLFL0500	PSX1XLUB0500	PSX1XLDB0500	500	1500	250 kA	7500 A	250109	774600	71.5	•
	PSX1XLFL0550	PSX1XLUB0550	PSX1XLDB0550	550	1500	250 kA	8250 A	276650	924967	83.1	•
	PSX1XLFL0630	PSX1XLUB0630	PSX1XLDB0630	630	1500	250 kA	9450 A	276650	924967	127.3	•
NH 3XL	PSX3XLFL0450	PSX3XLUB0450	PSX3XLDB0450	450	1500	250 kA	4500 A	57143	194500	146.3	•
	PSX3XLFL0500	PSX3XLUB0500	PSX3XLDB0500	500	1500	250 kA	5000 A	98570	333900	132.5	•
	PSX3XLFL0550	PSX3XLUB0550	PSX3XLDB0550	550	1500	250 kA	5500 A	142790	451600	136.7	•
	PSX3XLFL0630	PSX3XLUB0630	PSX3XLDB0630	630	1500	250 kA	6300 A	205617	650304	150.9	•
	PSX3XLFL0700	PSX3XLUB0700	PSX3XLDB0700	700	1500	250 kA	7000 A	305720	1003650	164.5	•
	PSX3XLFL0800	PSX3XLUB0800	PSX3XLDB0800	800	1500	250 kA	8000 A	335493	1150000	209.6	•
	PSX3XLFL0900	PSX3XLUB0900	PSX3XLDB0900	900	1500	250 kA	9000 A	403262	1308500	266.9	•
	PSX3XLFL1000	PSX3XLUB1000	PSX3XLDB1000	1000	1500	250 kA	10000 A	484792	1791500	335.0	•
	PSX3XLFL1100	PSX3XLUB1100	PSX3XLDB1100	1100	1500	250 kA	11000 A	656719	2201250	341.0	•
	PSX3XLFL1250	PSX3XLUB1250	PSX3XLDB1250	1250	1500	250 kA	12500 A	995376	3003500	346.9	•
	PSX3XLFL1400	PSX3XLUB1400	PSX3XLDB1400	1400	1500	250 kA	14000 A	1395828	4228250	361.9	•

Table 14Fuse characteristics