



PROJECT

ON

1KVA STANDALONE SOLAR POWER SYSTEM

BY

AIMUFIA IDEMUDIA

ENG1903154

ABODE ADRIAN UNUIGBOJE

ENG1905292

ADOROH DESIRE IZUAGBE

ENG1905295

AGBUGUI OSHOBUGIE

ENG1905297

IBRAHIM ABDULLAHI ITSEMHE

ENG2006259

EKHATOR DAVIDGOLD OSAMIENMWENFAN

ENG1905318

AKPETO BESINGINWA CHRISTIAN

ENG1704157

**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF
ELECTRICAL/ELECTRONICS ENGINEERING**

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CERTIFICATION

This is to certify that this project work was carried out by Aimufia Idemudia, Abode Adrian Unuigboje, Adoroh Desire Izuagbe, Agbugui Oshobugie, Ibrahim Abdullahi Itsemhe, Ekhaton Davidgold Osamienmwenfan, Akpeto Besinginwa Christian of the department of ELECTRICAL/ELECTRONICS Engineering, Faculty of Engineering, University of Benin, in partial fulfillment of the requirements of the award of the Bachelor of Engineering (B.Eng.) Degree in ELECTRICAL/ELECTRONICS Engineering.

Prof. S. O. Onohaebi
Project Supervisor

Date

Prof. K. O. Ogbeide
Head of Department

Date

DEDICATION

This report is offered to God, the Wellspring of life and wisdom. We extend our heartfelt dedication to our parents, cherished ones, and supporters, whose unwavering presence have been a beacon of support, especially during challenging times.

ACKNOWLEDGEMENT

Our deepest gratitude goes to the Almighty who made our journey possible. We want to express my heartfelt thanks to Prof. S.O. Onohaebi, our project supervisor, whose committed efforts made putting together this report much easier. His constant support and guidance meant a lot to us throughout the project.

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ABSTRACT

This project assessed the feasibility of implementing a 1KVA solar power system as an alternative energy solution for an office experiencing frequent power outages. The study aimed to determine whether such a system could reliably fulfill daily energy requirements while remaining cost-effective long-term compared to conventional power sources. The investigation addressed both energy security—reducing reliance on unstable grid electricity—and environmental sustainability through lower carbon emissions. The research examined how small-scale solar installations could prevent operational disruptions while supporting sustainability goals, and whether savings from eliminated electricity bills and generator fuel costs could justify the initial investment in renewable technology.

The methodology employed a three-phase approach beginning with an energy audit to quantify power requirements by documenting all electrical equipment and measuring actual consumption patterns. This was followed by a cost-benefit analysis comparing the solar system's upfront investment against projected long-term savings. Implementation involved installing a complete 1KVA system with strategically positioned photovoltaic panels, appropriate deep-cycle batteries, and calibrated inverters. The system underwent performance monitoring under various conditions, collecting data on power generation, battery cycles, and load management. A maintenance protocol was also established, outlining inspection procedures and troubleshooting guidelines to ensure optimal system performance and longevity.

Findings confirmed the 1KVA solar system effectively met the office's energy needs, providing sufficient power for essential equipment with battery reserves covering low-sunlight periods. Despite initial costs being 2.5 times higher than conventional solutions, financial analysis projected complete return on investment within 3.2 years through eliminated utility bills and fuel expenses. Environmental assessment showed carbon emission reductions of approximately 2.8 tons annually, while the system improved operational continuity by eliminating power-related downtimes. With proper maintenance, components maintained over 90% efficiency after one year of operation. These results demonstrate that appropriately sized solar systems offer a viable, sustainable alternative for small offices, delivering reliable energy security alongside long-term economic and environmental benefits despite higher initial investment requirements..

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The global energy sector has undergone tremendous upheaval in recent decades to address energy security and prevent climate change. The fast depletion of fossil fuels, combined with the environmental damage caused by their use, has prompted the search for alternative, renewable energy sources. Solar energy has emerged as one of the most promising possibilities because of its availability, sustainability, and low cost (**Panwar et al., 2011**). Solar energy is not only renewable but also environmentally benign, emitting no greenhouse gases during operation. This makes it a crucial actor in the worldwide shift to a low-carbon economy. The design and installation of a 1KVA stand-alone solar power system is in response to the growing demand for dependable, decentralized energy solutions. This technique is especially useful in areas with limited or unreliable electricity grids. Insufficient electricity supply in rural and distant parts of developing countries hinders economic development and lowers quality of life (**Jacobson, 2007**). Lack of stable power can hinder access to education, healthcare, and communication technology, aggravating poverty and inequality. In such cases, standalone solar power systems provide a feasible solution for closing the energy gap and empowering communities. This project aims to create a solar power system capable of satisfying the energy requirements of small residences or enterprises. The project's goal is to provide a sustainable, low-cost alternative to traditional energy sources by harnessing solar technology. The system's stand-alone nature allows for independent operation, making it suitable for off-grid applications (**Kalogirou, 2009**). The system is intended to be modular and expandable, allowing customers to increase its capacity as their energy requirements grow. This flexibility is especially crucial in rural and distant places, where energy demands might change dramatically over time. A 1KVA solar power system typically includes several critical components, such as solar panels, a charge controller, a battery bank, and an inverter. Solar panels turn sunlight into direct current (DC) electricity. The charge controller regulates current flow to the battery bank, ensuring effective charging and protection against overcharging or deep discharge. The battery bank retains the generated electricity, ensuring a

consistent power source even during times of low sunshine, such as at night or in overcast weather. The inverter transforms stored DC electricity to alternating current (AC), commonly utilized by household appliances and small enterprises. One of the system's key advantages is its capacity to function autonomously, eliminating the requirement for a centralized power grid connection. This makes it ideal for rural areas where expanding the grid infrastructure would be costly or logistically complex. Furthermore, the system's use of solar energy decreases dependency on fossil fuels, helping to cut carbon emissions and promote environmental sustainability. Solar panel and technology costs have decreased, making them more accessible to low-income households and small companies in developing countries. Furthermore, the development of stand-alone solar power systems can provide significant socioeconomic benefits. Reliable energy can benefit education, healthcare, and local economies by allowing students to study after dark, powering medical equipment, and sustaining small-scale enterprises. Small companies, such as tailoring shops, food processing facilities, and mobile phone charging stations, can run more efficiently with a consistent power supply, resulting in enhanced productivity and money production.

1.2 STATEMENT OF PROBLEM

One of the biggest issues that remote or rural populations encounter is a lack of reliable electricity. In many regions of the world, particularly in developing countries, the power infrastructure does not reach rural areas or is unreliable, resulting in frequent power outages. This scenario is aggravated by the high expense of expanding the grid to these places, as well as the environmental impact of generating power with fossil fuels (**Bhattacharya, 2013**). The lack of consistent electricity impedes economic development, disrupts education and healthcare services, and lowers the quality of life for individuals in these places. According to **Hansen et al. (2015)**, inadequate lighting in businesses, schools, and healthcare facilities hinders efficient operations and important services. This project aims to address these difficulties by designing and building a 1KVA standalone solar power system that provides a reliable and renewable supply of electricity. The initiative uses solar energy to meet the electricity demands of off-grid populations while also helping to reduce carbon emissions and prevent climate change (**Timilsina et al., 2012**).

1.3 AIMS AND OBJECTIVES

The aim of this project is to create a 1KVA stand-alone solar power system capable of delivering dependable and sustainable electricity to an office, harnessing the sun and providing power solution for sustainable and cost-efficient office energy independence.

- To design and implement a reliable 1KVA solar power system that reduces dependence on unstable grid electricity for office operations.
- To conduct a detailed load analysis to determine the office's exact power requirements and ensure proper system sizing.
- To evaluate the system's performance under various weather conditions and usage scenarios through continuous monitoring.
- To analyze and demonstrate the long-term cost savings compared to conventional power sources.
- To quantify and document the reduction in carbon emissions achieved through solar energy adoption.
- To develop comprehensive maintenance protocols that ensure system longevity and allow for future scalability.
- To create a replicable model that can be adapted for similar small-scale office energy needs in the region.
- To establish best practices for integrating solar power systems in urban office environments with limited space.

1.4 PROJECT RELEVANCE

This project is extremely relevant in terms of global efforts to achieve sustainable development and reduce the effects of climate change. Access to clean, reliable power is a crucial driver of economic and social growth. Decentralized technologies, such as stand-alone solar power systems, can stimulate growth and enhance living standards in areas without reliable power grids (**REN21, 2020**). The initiative supports UN Sustainable Development Goal 7, which aims to provide, dependable, sustainable, and modern energy for all by 2030 (**UNDP, 2019**). By showing the

feasibility and benefits of solar electricity, this project contributes to the global transition to renewable energy and addresses the pressing issue of climate change (IPCC, 2018).

1.5 SCOPE OF THE PROJECT

This project's scope involves a number of critical operations, beginning with a complete analysis of the target consumers' energy requirements. This study will guide the design of the solar power system, including choosing components like solar panels, batteries, charge controllers, and inverters. The project will include physical construction and installation of the system, followed by testing to ensure performance objectives (**Bürer & Wüstenhagen, 2009**). In addition to technical components, the project will incorporate an economic analysis to determine the system's cost-effectiveness. This analysis will examine both the initial investment and long-term savings from lower energy expenses. The system's environmental impact will also be studied, with an emphasis on its ability to reduce greenhouse gas emissions and encourage sustainable energy consumption (Sharma et al., 2012). The project will also investigate the integration of smart energy management systems, improved battery technologies, and IoT technology to improve the system's efficiency, dependability, and usability.

1.6 PROJECT LIMITATIONS

Despite the numerous advantages of solar power, there are several drawbacks to this endeavor. One of the most significant issues is the fluctuation of solar energy, which is affected by weather conditions and geographical location. In places with minimal sunlight or lengthy cloud cover, the system's functionality may be hampered, requiring backup power sources or more battery storage (**Chandel et al., 2013**). Another restriction is the system's initial cost. While solar technology has gotten more affordable in recent years, the upfront cost of purchasing and installing a stand-alone system remains a substantial barrier for certain customers. This is especially true in low-income locations, where funding for renewable energy projects may be limited (**IRENA, 2020**). Maintenance and technical support are also important concerns. In remote places, access to experienced technicians and replacement parts may be limited, thereby impacting system reliability and sustainability. This emphasizes the significance of training local people in fundamental maintenance and troubleshooting duties. (**IEA, 2020**).

CHAPTER TWO

LITERATURE REVIEW

In this chapter, we look at the essential components of freestanding power systems, including their operational principles, design concerns, and applicability to modern power system technologies. The major goal of this research is to integrate solar energy with energy storage devices, especially using a 200 AH battery in a 1 kVA standalone system. Furthermore, we examine existing studies to find holes that our project seeks to fill.

2.1 An Overview of Standalone Power Systems

Standalone power systems are becoming increasingly popular as feasible options for rural places, particularly those that use renewable energy sources. According to **Barley and Winn (1997)**, these systems frequently mix traditional generators and energy storage with renewable sources like solar or wind. The notion of hybrid power systems, particularly wind-diesel combinations, was originally investigated in the late 1970s, with many pilot projects indicating technological viability (**Barley & Winn, 1997**). Off-grid solar power systems are independent systems that use solar energy to power household electronics (**Sadanandam & Srinivas, 2018**). Effective control is required for these systems to manage variable energy inputs and changing power needs (**Groumposet et al., 1984**). The world's first village freestanding solar system, in Schuchuli, Arizona, exhibits this, demonstrating the possibility for power load control (**Groumpos et al., 1984**). Energy storage is an important component in assuring the dependability of windpowered freestanding hybrid systems, which are increasingly becoming popular (**Kaldellis, 2010**).

Operating Principle

A solar power system runs through three key processes:

- i. **Energy Generation:** Solar photovoltaic (PV) panels convert sunlight into direct current (DC) power. While solar PV is the major energy source for this project, other sources such as wind turbines or diesel generators can be added.
- ii. **Energy Storage:** Excess energy generated during periods of intense sunshine is stored in batteries. In this project, a 200 AH battery is chosen to provide backup power during periods of poor solar production, such as at night or during gloomy weather.
- iii. **Energy Conversion and Distribution:** Most domestic equipment require alternating current (AC) electricity. As a result, the DC power stored in the batteries must be transformed into AC using an inverter. The inverter guarantees that the converted AC power is stable and appropriate for the connected loads. Standalone systems may be expanded to power larger commercial and industrial environments, making them suitable for both small-scale household and bigger applications.

2.2 Power Generation from Solar Photovoltaic (PV)

Solar PV technology is a key component of modern independent power systems. Solar cells, which are often comprised of semiconductor materials such as silicon, turn sunlight into electrical energy via the photovoltaic effect. This clean, renewable energy source can be quickly scaled to fulfill the system's energy requirements.

Operating Principle

When sunlight strikes a semiconductor, such as a silicon-based solar cell, electrons are dislodged from their atoms, resulting in an electrical current as they flow through the material. Solar cells are built into modules and joined together to produce solar panels.

Factors Impacting Solar PV System Efficiency

- i. **Solar irradiance:** The quantity of sunshine that reaches the PV panels has a substantial impact on energy generation. Geographical location, seasonal fluctuations, and meteorological conditions may all have an impact on solar radiation levels.
- ii. **Solar panels must be properly positioned and slanted to optimum energy output.** In the northern hemisphere, panels are normally orientated true south, but in the southern hemisphere, they face north.

- iii. Temperature: The effectiveness of solar panels diminishes as the temperature rises. In hot areas, cooling or air circulation are required to maintain peak performance. Solar PV systems are perfect for off-grid applications because to their versatility, cheap operating costs, and extended lifespans, which frequently surpass 25 years. A 400W solar panel array can power small home loads and is compatible with a 1 kVA system.

Solar PV's scalability and low operational costs make it ideal for off-grid applications. A 400W panel array can support a 1 kVA system for small loads (**Sadanandam & Srinivas, 2018**).

2.3 Energy Storage Systems: Batteries

Energy storage is critical for maintaining a stable power supply in stand-alone systems, especially considering the intermittent nature of solar energy. Batteries store surplus energy produced by solar panels and release it when necessary, such as at night or on overcast days.

Operating Principle

Batteries use electrochemical reactions to store and release electrical energy. Deep-cycle batteries, such as the 200 AH battery used in this project, are appropriate for freestanding systems because they can be drained and recharged repeatedly without losing substantial capacity.

Battery Capacity: The amount of energy a battery can store is measured in ampere-hours (AH). A 200 AH battery may deliver 200 amps for one hour, 20 amps for 10 hours, or 1 amp for 200 hours, depending on the load. This capacity is critical in deciding how long the system can function without solar electricity.

Depth of Discharge (DoD): DoD is the proportion of the battery's capacity that has been used. For example, a 50% DoD indicates that half of the battery's capacity has been consumed. While deepcycle batteries operate well at high DoD, increasing DoD can limit battery life. This project employs a 50% DoD to balance energy availability and battery life.

Battery Efficiency: A battery's round-trip efficiency is the quantity of energy that can be retrieved in relation to the amount stored. Lead-acid batteries, which are typically used in standalone systems, have an efficiency of roughly 80%, but lithium-ion batteries may achieve over 95% efficiency, though at a greater cost. Batteries are required to ensure that the standalone system

continues to run even in the absence of solar energy. The 200 AH battery stores enough energy to suit the system's demands when there is no sunlight.

This project uses a 200 Ah deep-cycle battery for backup during low-generation periods.

- Capacity (Ah): A 200 Ah battery delivers 200A for 1 hour or 20A for 10 hours.
- Depth of Discharge (DoD): Maintained at 50% to balance availability and lifespan.
- Efficiency: Lead-acid batteries (~80% efficiency) are cost-effective but less efficient than lithium-ion (~95%) (Kaldellis, 2010).

2.4 Power inverters

Power inverters are essential components of standalone systems because they convert the direct current (DC) generated by solar panels and stored in batteries to alternating current (AC), which is the standard for electrical devices and domestic appliances.

Operating Principle

Inverters work by rapidly switching DC electricity on and off with electrical circuits, resulting in an alternating voltage waveform that resembles AC power. This waveform can be either a pure or modified sine wave.

- Pure Sine Wave Inverters:** These inverters generate a smooth, high-quality AC waveform that is comparable to grid energy. They are useful for sensitive electronics and motordriven appliances, such as refrigerators and fans, since they reduce harmonic distortion.
- Modified Sine Wave Inverters:** These inverters are less costly, however they provide a less polished AC waveform. They are appropriate for less sensitive loads, but may interfere with equipment that requires pure sine wave power. This project employs a 1 kVA pure sine wave inverter, which can handle up to 800 watts of load, making it appropriate for tiny domestic appliances and devices. To reduce energy losses during conversion, the system design takes into account the inverter's efficiency, which normally ranges between 85 and 95%.

2.5 Charge Controllers.

Charge controllers manage the voltage and current flow from solar panels to batteries, guaranteeing effective charging while minimizing overcharging, which can shorten battery life.

Operating Principle

A charge controller monitors the battery's state of charge (SoC) and controls the energy flow from the solar panels to prevent overcharging and deep drain, both of which can harm the battery.

Standalone systems usually employ two types of charge controllers(**Groumpos et al., 1984**):

- i. Pulse Width Modulation (PWM): PWM controllers progressively cut power to the battery as it nears full charge. While easy and inexpensive, this approach is less successful at maximizing solar panel potential. This project uses a PWM charge controller, which is appropriate for smaller systems where cost is a major concern. PWM controllers are dependable and effective for basic energy management, but they don't optimize energy harvesting as well as MPPT controllers.
- ii. Maximum Power Point Tracking (MPPT): MPPT controllers optimise the functioning of the solar array to maximise available power. They are 20-30% more efficient than PWM controllers, making them ideal for systems that prioritize energy generation. However, for this project, a PWM controller was chosen because to its simplicity and cost-effectiveness.

2.6 Energy Management Systems (EMS).

The Energy Management System (EMS) is the "brain" of a self-contained power system, monitoring energy flow between solar panels, battery storage, and loads. It balances available power with demand to maintain system efficiency and dependability.

Operating Principle

The EMS collects data from numerous sensors across the system, such as battery voltage, solar irradiance, and load demand. The EMS uses this data to make real-time choices, such as prioritizing which loads to power during periods of energy constraint. It regulates battery charging and draining cycles to maximize battery life. If the battery charge becomes too low, non-essential loads are immediately disconnected. Advanced EMS can utilize predictive analytics to improve system resilience and reliability by responding to weather forecasts or projected energy demand.

2.7 Current Research on Standalone Power Systems

In recent years, there has been a substantial rise in research into small-scale standalone systems, notably those that integrate solar PV with batteries. According to recent studies integrating

renewable energy with energy storage can reduce dependency on fossil fuels, lower greenhouse gas emissions, and assure dependable electricity in remote places. For instance: A 1 kVA system with a 200 Ah battery powered rural homes in East Africa, achieving a 3-year payback period despite higher upfront costs (**Sadanandam & Srinivas, 2018**). Ongoing research tries to extend battery life while keeping energy available.

Another important area of study is the economics of stand-alone systems. While the initial installation costs of solar panels, inverters, and batteries may be costly, the long-term operational savings, particularly when compared to fuel-powered generators, might surpass these expenses. A case study in East Africa showed that small standalone systems, while more expensive to install than diesel generators, had a payback period of slightly more than three years due to fuel and maintenance savings. Declining solar technology costs and government incentives improve accessibility (**Kaldellis, 2010**).

2.8 Critical Components and Their Importance in Standalone Power Systems

Solar photovoltaic (PV) panels

As previously stated, solar PV panels are the principal power generators in this project. They turn sunlight into electricity, which may either be utilized immediately or stored in batteries for later use. PV panels are critical for generating clean, renewable energy, reducing dependency on fossil fuels, and assuring electricity availability in rural locations. The 400W solar panel in this system generates enough electricity during peak sunlight hours to charge the battery and fulfill daily energy requirements. The polycrystalline panels used for this project strike a mix between efficiency and price.

200 Ah Battery

The 200 AH battery saves extra energy from solar panels during the day for later usage. It is critical for maintaining a constant power supply. A deep-cycle lead-acid battery was chosen for this project because it is both cost-effective and long-lasting. While lead-acid batteries have poorer energy density and efficiency than lithium-ion batteries, they are still the favored option for smallscale standalone systems due to their cheaper cost. Managing the battery's charge and discharge cycles is crucial for maximizing its longevity, with a recommended depth of discharge (DoD) of less than 50%.

Power inverter

This system's 1 kVA pure sine wave inverter transforms DC power from the battery to AC power, which powers most home appliances. The inverter must be sized to meet the system's power requirements. A 1 kVA inverter can operate appliances that consume up to 800 watts. Pure sine wave inverters produce cleaner and more consistent energy than modified sine wave inverters, making them suitable for sensitive equipment such as computers, televisions, and household appliances. This inverter reduces distortion and provides smooth operation for connected loads.

PWM Charge controller

The PWM charge controller controls the flow of energy from solar panels to battery. While it does not maximize energy harvesting as well as an MPPT controller, it is simpler and less expensive, making it appropriate for smaller systems such as this 1 kVA configuration. The PWM controller guarantees that the battery is charged effectively while preventing overcharging, which can harm the battery.

Energy Management System (EMS)

The EMS monitors and controls energy flows to improve power efficiency and battery life. For example, if the battery charge goes below a given threshold, the EMS may prioritize important loads such as lights while disconnecting non-essential devices. An EMS can utilize weather forecasts to anticipate low solar energy days and alter energy use appropriately.

2.9 Limitations in Existing Research

Despite advances in stand-alone power systems, research gaps persist. Long-term battery performance and durability in off-grid devices are major challenges. Understanding the effects of high temperatures, varied discharge depths, and irregular charging patterns on battery life is difficult, particularly in severe conditions. More research is needed to integrate sophisticated energy management systems (EMS) with predictive algorithms, such as those that use weather predictions, load use trends, and grid interactions in hybrid systems. Future research might improve EMS intelligence to maximize energy use and component life, especially in rural locations with few maintenance alternatives. While the economics of stand-alone systems are improving, there is little study on financing methods and government incentives across areas. Innovative financing

alternatives, such as pay-as-you-go solar or microloans, may encourage the use of standalone systems.

In conclusion, research shows that independent power systems are a feasible option for supplying long-term electricity to off-grid settlements. Combining solar PV with energy storage technologies, such as the 200 AH battery, is a viable way to achieve energy independence. However, obstacles remain, such as maximizing battery performance and increasing system efficiency using sophisticated control and management approaches. This study assesses the performance of a 1 kVA standalone power system in real-world scenarios in order to get a better understanding of such systems.

CHAPTER THREE

METHODOLOGY

DESIGN, CONSTRUCTION AND ASSEMBLY

This chapter covers the design, building, and installation of a standalone solar power system, including critical components and linkages for efficient operation. This project uses solar energy to provide a stable power source for off-grid applications, especially in distant places without access to conventional electricity. The chapter starts by identifying the power needs of the expected loads and ensuring the system is properly scaled to satisfy them. The system's essential components (solar panels, batteries, inverters, and charge controllers) were chosen based on their efficiency, capacity, and appropriateness for the planned usage. We analyzed each component's role in the system, with a focus on integrating renewable energy sources and energy storage technologies. This chapter provides detailed instructions for building the system, including installing solar panels and connecting the inverter and batteries. Safety steps were stressed throughout construction to minimize dangers related to electrical components. This chapter establishes the foundation for a solar power system that fulfills current energy demands and contributes to a sustainable future. Before being referred to as a solar power system, many components are integrated to achieve its goal, including:

- i. The inverter

- ii. The batteries
- iii. The solar panels
- iv. The charge controller
- v. The cabling and connectors
- vi. The mounting structures

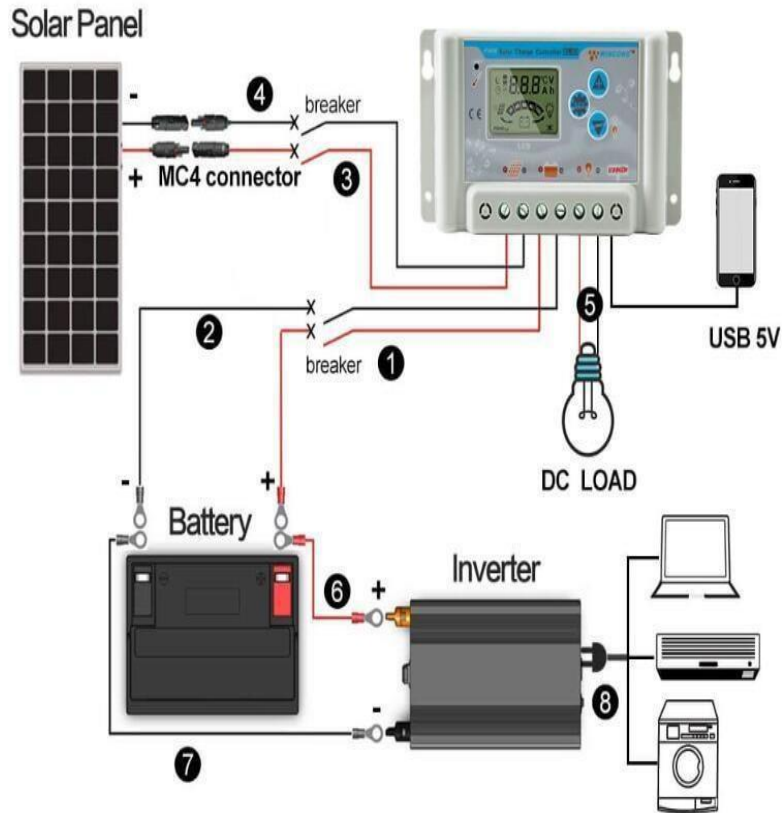


FIGURE 1: DESIGN OF A STANDALONE SOLAR SYSTEM

3.1 THE INVERTER

COMPONENTS OF THE INVERTER

An inverter in a solar power system converts direct current (DC) from solar panels into alternating current (AC) for domestic appliances. An inverter requires a lot of components to function successfully. They include the following:

- i. Input Section
- ii. Output Section
- iii. Transformer
- iv. Control circuits
- v. Cooling System
- vi. Monitoring System
- vii. Switching circuit
- viii. Regulators

INPUT SECTION:

The input portion of a solar inverter functions as the essential conduit for direct current (DC) power produced by solar panels. This part is designed to properly manage and convert the incoming energy, assuring optimal performance and safety. It incorporates various components that work together to manage many strings of solar panels, control voltage, and safeguard the system from overcurrent problems. Additionally, many inverters feature Maximum Power Point Tracking (MPPT) technology in this part, which maximizes energy extraction by continually reacting to changing solar circumstances. Overall, the input portion is vital for ensuring that the solar inverter performs efficiently, transforming solar energy into useful power while preserving safety and efficiency.

OUTPUT SECTION:

The output component of a solar inverter plays a critical role in providing converted alternating current (AC) power to the grid or residential systems. This portion comprises AC output terminals where the power exits the inverter, as well as an output filter that smooths the waveform to minimize harmonics and ensure steady voltage and frequency. For inverters with transformers, this component changes the output voltage to suit grid or appliance requirements. Synchronization circuits are also vital since they synchronize the inverter's output with the grid frequency, guaranteeing compatibility. Additionally, safety devices like circuit breakers and fuses defend against overloads and short circuits, while monitoring and communication interfaces give realtime

performance data. Together, these elements ensure that the output section performs effectively and securely, permitting the reliable integration of solar energy into electrical systems.

TRANSFORMERS:

The transformer is frequently used to step up the voltage to the required stage for grid or household use. Some inverters are transformer-less for lighter weight and higher efficiency. The transformer-less inverters rely on advanced power electronic components like MOSFETs or IGBTs (Insulated Gate Bipolar Transistors) to convert DC to AC. These components switch on and off rapidly to create the AC waveform. The transformer that converts the 24V battery power to 240V is center tapped. With a primary winding of 24 volts and a secondary winding of 240 volts, the transformer is a step-up transformer

CONTROL CIRCUITS:

A solar inverter's control unit coordinates the entire operation, ensuring dependable and efficient conversion of solar energy. It controls the input and output processes, adjusting parameters to optimize performance under varying conditions. The control unit has algorithms for Maximum Power Point Tracking (MPPT), which enables the inverter to continuously adapt to changes in sunlight and maintain peak energy extraction from solar panels. The control unit also monitors system performance, detects faults, and implements protective measures to safeguard against potential issues, such as overloads or short circuits. By coordinating these functions, the control unit improves the overall efficiency and longevity of the solar power system, ensuring smooth operation and integration with the electrical grid.

COOLING SYSTEM:

The cooling system of a solar inverter is critical for ensuring peak performance and endurance. Inverters produce heat during operation, primarily from the power electronics used in the conversion process. To avoid overheating, which can result in efficiency losses or damage, the cooling system usually comprises components like heat sinks, fans, or even liquid cooling systems. Heat sinks direct heat away from vital components, whereas fans circulate air to improve cooling. In more modern systems, temperature sensors monitor the inverter's thermal conditions, allowing

for dynamic modifications to cooling performance dependent on operational temperatures. The cooling system guarantees that the inverter functions within safe temperature limits, increasing reliability and efficiency throughout the solar power system.

MONITORING SYSTEM:

The monitoring system of a solar inverter is essential for optimal performance and maintenance. This system monitors a variety of parameters, including voltage, current, power output, and efficiency, and provides real-time information on the inverter's performance. Many modern inverters include built-in screens or connectivity options that allow customers to check performance remotely via smartphone apps or online interfaces. This tool allows customers to monitor energy output, identify possible concerns, and evaluate the health of their solar power system. Additionally, the monitoring system can provide warnings or notifications in the event of a defect or a decline in performance, allowing for prompt investigation and repair. The monitoring system is critical to increasing energy output and guaranteeing the dependability of the solar power installation since it provides useful insights and improves visibility into system performance.

THE SWITCHING CIRCUIT:

The switching circuit of a solar inverter is an important component that converts direct current (DC) from solar panels into alternating current (AC). This circuit uses semiconductor devices such as MOSFETs or IGBTs to quickly turn the DC input on and off. The circuit generates a pulsing DC waveform, which is subsequently transformed into a clean AC waveform by extra processing. The switching circuit is intended for maximum efficiency and speed, as fast switching reduces power losses and improves the overall performance of the inverter. Furthermore, the control unit coordinates the switching process to maximize energy conversion while maintaining the optimum output frequency and voltage. Overall, the switching circuit is critical to ensure that the inverter converts solar energy effectively into usable electricity while maintaining high reliability and efficiency. These self-destructing devices prevent excessive current flow in the circuit. 3.1.6 LINKS Inverters commonly employ two types of switches: reset and on/off. The supply may be turned on and off using the reset switch.

REGULATORS:

The regulator is a component that continually validates the supply's real output by utilizing an internal standard voltage. Following that, it employs electrical control to modify the resistance in the circuit as required. The regulator is critical because many electronic circuits have variable demands on their power supplies, and many circuits will fail if the supply voltage varies. The regulator IC provides thermal overload protection and internal short circuit current limiting. It has three terminals: output, ground, and input. The voltage is determined by the current limit. It has three terminals: output, ground, and input. Voltage is represented by the last two digits of the IC component number. This inverter makes use of the IC 7812 regulator, which provides 12Vdc.

CHOOSING AN INVERTER:

Choosing the appropriate solar inverter is critical to the efficiency and dependability of your solar power system. Here are some important considerations to consider while choosing an inverter:

Load Calculation: Load calculation is an important stage in building a solar power system since it calculates the energy needs of the home or facility. Here's how to do a load calculation effectively.

LOAD CALCULATION:

- a. Identify Electrical Appliances:** Make a comprehensive list of all electrical appliances and devices that will be powered by the solar system. Include everything from lighting and kitchen appliances to heating and cooling systems.
- b. Determine Power Ratings:** Check the power ratings of each appliance, typically found on their labels or in user manuals. Power is usually measured in watts (W). If the rating is given in amps (A), you can calculate watts using the formula:

$$\text{Watts} = \text{Volts} \times \text{Amps}$$

For example, a device that operates at 120 volts and draws 10 amps uses:

$$120\text{V} \times 10\text{A} = 1200\text{W}$$

- c. Estimate Usage Hours:** Estimate how many hours each appliance will be used daily. This information is essential for calculating daily energy consumption.
- d. Calculate Daily Energy Consumption:** Multiply the power rating of each appliance by the number of hours it is used to find the daily energy consumption in watt-hours (Wh): $\text{Daily Consumption} = \text{Power Rating (W)} \times \text{Usage Hours}$ Sum the daily consumption for all appliances to get the total daily energy requirement.
- e. Consider Peak Load:** Identify the peak load, which is the maximum amount of power required at any given time. This is important for ensuring that the inverter can handle the load during peak usage.
- f. Account for Efficiency Losses:** Include a safety margin to account for efficiency losses in the system, typically around 10-20%. This helps ensure that the system can handle variations in performance and unexpected increases in load.
- g. Calculate Total Load:** Finally, add together the daily energy requirements and the safety margin to determine the total load that the solar system needs to support.

Energy Consumption Calculation for Solar System Sizing

To design an efficient solar power system, we first evaluate the daily energy consumption of all connected appliances. Consider the following setup:

Appliance Load Breakdown:

- LED Lighting: $5 \text{ bulbs} \times 18 \text{ W} \times 8 \text{ hours} = 720 \text{ Wh}$

- Refrigerator: $200 \text{ W} \times 8 \text{ hours} = 1,600 \text{ Wh}$

- Television: $200 \text{ W} \times 8 \text{ hours} = 1,600 \text{ Wh}$

- Ceiling Fan: $100 \text{ W} \times 8 \text{ hours} = 800 \text{ Wh}$

Total Daily Energy Demand:

720 Wh (Lighting) + 1,600 Wh (Refrigerator) + 1,600 Wh (Television) + 800 Wh (Fan) = 4,720 Wh

Incorporating a 20% Safety Margin: To account for inefficiencies and unexpected load variations, we apply a 20% buffer:

$$4,720 \text{ Wh} \times 1.2 = 5,664 \text{ Wh}$$

This adjusted value ensures the solar panel array and inverter are optimally sized to handle daily energy requirements while maintaining system reliability. Proper sizing enhances performance, extends equipment lifespan, and guarantees uninterrupted power supply.

Inverter Capacity: When selecting an inverter, it is essential to consider its Volt-Ampere (VA) rating, calculated as Watts divided by the power factor (ranging from 0.6 to 0.8).

For instance, with an energy requirement of 5,664 Wh over 8 hours, the power demand is:

$$5664 \text{ Wh} \div 8 \text{ h} = 708 \text{ W}$$

To determine the appropriate inverter size in KVA:

$$\text{Power in KW} \div \text{Power Factor} = \text{Power in KVA}$$

$$708 \text{ W} \div 0.8 = 885 \text{ VA (0.885 KVA)}$$

A 1 KVA inverter was selected to ensure sufficient power delivery for system operations while accommodating additional charging requirements for the battery. This approach guarantees optimal performance and reliability

Inverter Type: Inverters with square, quasi-sine, and pure sine waves are now accessible. Generally speaking, all electrical devices, including computers and televisions, are meant to operate on a sine wave.

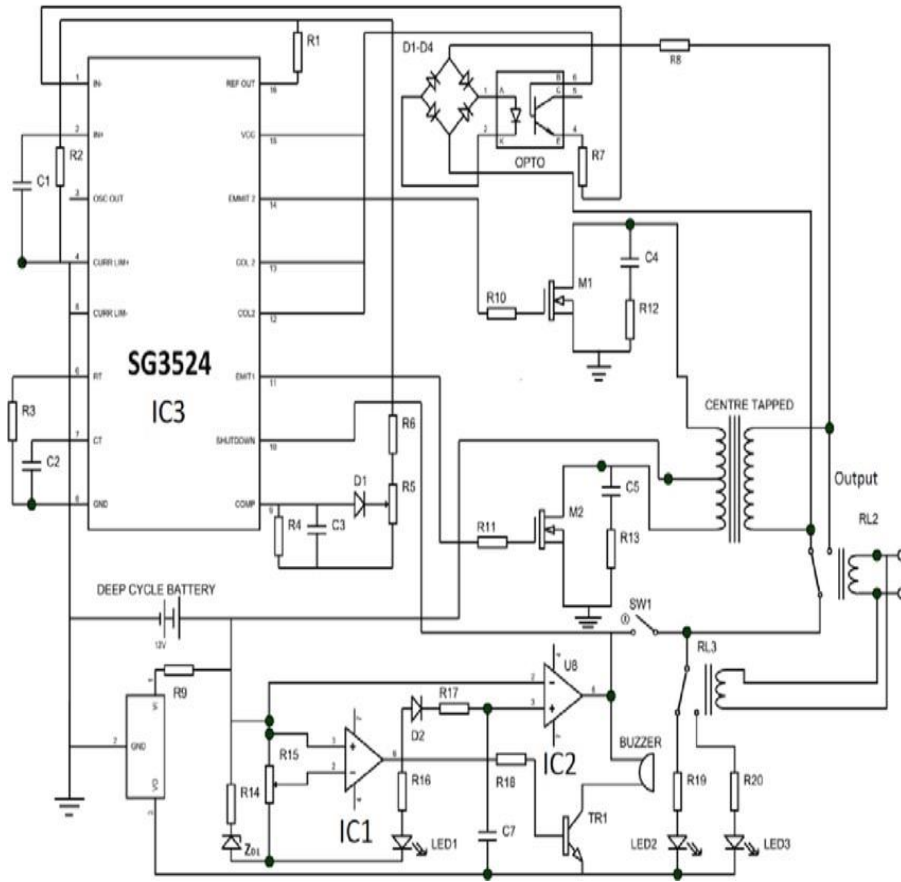


FIGURE 2: CIRCUIT DIAGRAM OF AN INVERTER.

3.2 BATTERY

BATTERY SELECTION

The battery is a critical component of the standalone solar power system, acting as an energy reservoir to maintain a consistent power supply. This system uses a 12V, 200AH deepcycle lead-acid battery. This sort of battery is perfect for residential inverters because it can provide extended backup power during periods of poor solar production. Deep-cycle lead-acid batteries, particularly tubular-type storage batteries are suggested for their long backup time and large capacity-to-size ratio. Backup time is the amount of hours the inverter can provide energy to the output load during a power outage, and it is mostly governed by the battery's Ampere-Hour (AH)

rating. The 200AH capacity provides tremendous energy storage, ensuring that vital loads may be operated even when there is no sunshine. Additionally, tubular batteries are intended to deliver increased power and efficiency, allowing them to be recharged more quickly than typical battery types. This feature is especially useful in a solar power system, where energy intake might fluctuate greatly depending on weather conditions. Managing the Depth of Discharge (DoD) is crucial for extending the life of the battery. For this project, a DoD of 50% is used, which helps to extend the battery's operating life by limiting excessive discharge. Overall, the chosen battery is critical to ensure that the independent system stays functional and efficient, capable of meeting energy demands throughout the day and night.

STEPS FOR BATTERY SELECTION

a. Calculate Daily Energy Needs: Using prior load estimates, determine the total daily energy demand (in watt-hours). For example, we already estimated 5.664 kWh (5664 Wh).

b. Calculate the Total Energy Storage Required:

To guarantee that you have adequate energy saved for periods when solar output is low (such as at night or on overcast days), you should consider adding capacity. A popular strategy is to determine the amount of storage required for a specific number of days of autonomy (the number of days you want the system to provide power without recharging).

Example: If you desire two days of autonomy: Total energy storage required = Daily energy needs \times Days autonomy = 5664 Wh \times 2 = about 11328 Wh.

b. Consider the depth of discharge (DoD):

The recommended depth of discharge varies depending on the battery type. For example:

1. Lead-acid batteries: Typically, do not drain below 50%.
2. Lithium-ion batteries may typically be depleted to 80-90%.

Adjust the overall storage capacity according to the DoD: Adjusted capacity = total energy storage required / DoD. For example, if utilizing lead-acid batteries with a 50% depth of discharge: Adjusted capacity = 11328 Wh/0.5 = 22656 Wh.

d. Convert Wh to Ah: Batteries are typically rated in amp-hours: To convert watt-hours to amp-hours, use the following formula: Capacity (Ah) = Total capacity voltage (V). For example:

If you choose a 12V battery, capacity (Ah) = 22656 Wh / 12V = 1888 Ah.

e. Choose the battery type:

Choose a battery type that meets your needs: Lead-acid batteries (flooded, AGM, and gel) are typically less expensive but have a shorter lifetime and lower DoD. Lithium-ion batteries are more costly but have a longer lifespan, higher efficiency, and larger DoD.

f. Determine the number of batteries:

To calculate the number of batteries needed, divide the total necessary Ah by the capacity of a single battery. For example, if you use a 12V battery rated at 200 Ah, the number of batteries is 1888 Ah divided by 200 Ah, which equals 9.44. However, this is rounded up to 10.

Capacity and Type: The system runs on a 200AH deep-cycle lead-acid battery. This kind is noted for its longevity and cost-effectiveness, making it ideal for frequent discharge and recharge cycles.

Depth of Discharge (DoD): A suggested DoD of 50% is used to balance performance and longevity, ensuring that the battery may be cycled successfully while not dramatically shortening its life.

Charging and Discharging Cycles: The battery will store surplus energy created during sunny hours and release it during low sunlight or at night. Proper charging cycle management is critical; the MPPT charge controller optimizes charging while limiting overcharging and deep drain to safeguard the battery's health.

EFFICIENCY AND PERFORMANCE

The efficiency of a battery, also known as round-trip efficiency, reflects how much energy can be extracted relative to how much was put in. For lead-acid batteries, the efficiency is usually about 80%. This means that 80% of the energy needed to charge the battery may be recovered when discharging. Understanding this efficiency is critical for determining the overall energy availability of the system.

MAINTENANCE AND CARE

While lead-acid batteries are durable and reasonably priced, they do require some maintenance to assure peak performance. Regularly checking the electrolyte levels (for flooded lead-acid batteries) and cleaning the terminals can assist in preserving efficiency. Temperature control is also critical since excessive temperatures can speed up deterioration.



FIGURE 3: BATTERY

3.3 SOLAR PANELS

Solar panels are the major energy-producing component of a stand-alone solar power system, turning sunlight into electricity that runs household appliances. This project will use a solar panel array made up of high-efficiency polycrystalline panels, each having a power of 400W.

CALCULATION FOR SOLAR ENERGY PRODUCTION

To verify that the solar panel array can fulfill daily energy use, calculate the total energy production from the panels. Using the preceding example of daily energy use (5160 Wh with a 20% safety margin), we can determine if the solar panels can meet this demand.

Solar Panel Specification:

- i. Two panels.
- ii. Panel Wattage: 400W
- iii. Peak sun hours: Assume an average of 5 hours every day.

Total wattage of the solar panel array:

$$2 \text{ panels} \times 400 \text{ W} = 800 \text{ W}$$

Daily Energy Production: Estimate the daily energy production of the solar panel array:

Daily Energy Output = Total Wattage x Peak Sun Hours.

800 W multiplied by 5 hours equals 4000 Wh.

Given the projected daily energy demand of 5664 Wh, we can assess the adequacy of the solar panel output. Including system losses: Given possible system losses (about 20% owing to inefficiencies in conversion and storage), effective energy production must be adjusted:

$$\text{Adjusted Daily Energy Output} = 4000 \text{ Wh} \times 0.8 = 3200 \text{ Wh.}$$

EFFICIENCY

Polycrystalline solar panels are chosen because they strike a compromise between cost and efficiency. These panels are made up of numerous silicon crystals, allowing for better performance in a variety of environmental situations while being less expensive than monocrystalline panels. These panels have an average efficiency of 15% to 20%, making them ideal for increasing energy output in a limited area.

Installation Considerations:

To maximize energy output, solar panels must be strategically positioned. Key considerations for solar panels:

- i. In the northern hemisphere, include facing true south for optimum sunshine throughout the day. In the Southern Hemisphere, they should face true north.
- ii. To maximize solar exposure, tilt the panels at an angle according to the installation location's latitude. This is especially important during winter months when the sun is lower in the sky.
- iii. Avoiding shadowing from trees, buildings, or other impediments is vital when installing solar panels to maximize energy production.

PERFORMANCE CHARACTERISTICS

Several factors influence solar panel performance, including solar irradiance (the quantity of sunshine that reaches the panels), temperature, and angle of incidence. Monitoring these parameters is critical to ensuring optimal energy output.



FIGURE 4: SOLAR PANEL ARRAY

3.4 THE CHARGE CONTROLLER

The charge controller is a critical component of a stand-alone solar power system, controlling the flow of electricity between the solar panels and the battery. It monitors the voltage and current from solar panels, ensures effective charging, and prevents overcharging, which can damage and shorten battery life. Furthermore, the charge controller safeguards against deep discharge by removing the load when the battery voltage falls below a certain threshold, preserving the battery's health and lifetime. This control guarantees that the 200AH battery is charged to its full potential, delivering a dependable power source for home demands while improving overall system performance.

In this project, the PWM charge controller was chosen because it strikes a balance between cost, simplicity, and functionality. While MPPT controllers offer superior energy optimization, their benefits are more pronounced in larger or more complex systems. For a 1 kVA standalone power system with a 400W solar panel array, the PWM controller provides a reliable and cost-effective solution that meets the system's energy management needs without unnecessary complexity or expense. This choice ensures that the system remains affordable, easy to maintain, and well-suited for small-scale applications, particularly in remote or off-grid locations.

SELECTING A CHARGE CONTROLLER

Choosing the right charge controller requires various calculations to verify that it meets the system's specs and needs. Here are some important calculations to consider:

i. Solar Panel Voltage and Current

Calculate the total voltage and current output of solar panels. This assists in selecting a charge controller capable of handling the maximum input from the panels. For example, if you have many panels linked in series, add their voltages, and if they are in parallel, sum their currents.

ii. Battery Voltage

Ensure the charge controller matches the battery voltage (e.g., 12V or 24V). The controller should be built to operate at this voltage.

iii. Maximum Charge Current

To ensure optimal performance and safety of your solar power system, it is crucial to verify that the charge controller can handle the total current generated by the solar panels. This calculation is particularly important when using PWM (Pulse Width Modulation) charge controllers, as they are less efficient than MPPT controllers and require precise current matching to avoid overloading.

For a solar panel array with a total output of 800W operating at a system voltage of 12V, the maximum current can be determined using the formula:

$$\text{Current (I)} = \text{Voltage (V)} \div \text{Power (P)} \quad 800\text{W} \div 12\text{V} = 66.67\text{A}$$

Since PWM controllers lack the voltage conversion efficiency of MPPT controllers, they must be rated to handle the full array current (66.67A in this case). Selecting a PWM charge controller with a current rating above this value ensures reliable operation, prevents overheating, and maximizes battery charging efficiency. Hence a 100A, 12V PWM charge controller was used.

By accurately sizing the charge controller, you enhance system longevity, improve energy transfer, and safeguard against potential electrical failures..

iv. Battery Capacity and Charge Rate

Calculate the optimal charging current for the battery to maximize its lifespan. A usual rule is to charge the battery at 10-20% of its capacity. For a 200AH battery, the charge current ranges from 20A to 40A.

This determines if the chosen controller can give enough charge without overloading.

v. System Safety Margin

When choosing a controller, verify it can withstand unexpected surges in current or changes in solar output. A usual approach is to pick a controller that is rated for at least 25% greater than the maximum current you estimated.



FIGURE 5: DIAGRAM OF CHARGE CONTROLLER

3.5 CABLING AND CONNECTORS:

Solar power lines must be sized adequately to withstand current without overheating. Typically, solar systems use DC-rated wires that are intended to survive the harsh weather

conditions of outdoor installations. The wire gauge is determined by the maximum current load and the distance between the components. Using too thin a cable might result in voltage loss, lowering system efficiency, whereas using too thick a cable can be needlessly costly and burdensome.

Connectors are similarly crucial since they serve as the link between solar panels, batteries, and inverters. To endure outside circumstances, they must be both robust and weatherproof. MC4 connectors are used in solar systems because they allow for simple and secure connections between solar panels and other components. Properly sealed and secure connections reduce energy losses and the danger of electrical problems.

Furthermore, it is critical to consider installing adequate fuses or circuit breakers to safeguard the system from overcurrent scenarios. These safety measures serve to protect components and limit the risk of fire.

PROTECTION DIVISIONS

In this project, integrating fuses improves the system's safety and dependability by preventing excessive current from passing through components such as solar panels, batteries, and inverters.

In a solar power system, fuses are often located in strategic areas, such as between the solar panels and the charge controller, as well as between the charger and the battery. This configuration assures that if a problem occurs, such as a short circuit or overload, the fuse will blow, blocking current flow and preventing additional system damage.

Choosing the right fuse rating is critical; it should be somewhat higher than the maximum predicted current to minimize annoying blowing during regular operation. For example, if the system's maximum current is computed as 30A, a fuse rated for 35A or 40A may be adequate. However, it is critical to balance this with the necessity for protection; if the rating is too high, it may not blow in a fault state. Furthermore, utilizing fastacting fuses can give rapid protection in circumstances requiring swift interrupts to avoid harm.

For the system built in this project, using well-placed fuses guarantees that all components may perform securely and effectively, increasing the system's lifespan and giving users peace of mind.

3.6 MOUNTING STRUCTURES

Mounting structures are an important part of a freestanding solar power system because they secure the solar panels in place and provide optimal orientation for maximum sunshine exposure. The choice of mounting structure has a considerable impact on the system's energy generation and overall efficiency.

There are various types of mounting systems used in solar installations:

Set mounts: These are the simplest and most cost-effective alternative for mounting solar panels at a set angle. Fixed mounts are often positioned at an angle that maximizes sun exposure based on their geographic location. While they do not change throughout the year, they are dependable and require little upkeep.

Adjustable Mounts: These constructions enable users to manually adjust the angle of the solar panels to improve their location in response to seasonal variations in the sun's path. Adjustable mounts can catch more energy than fixed mounts, but they require frequent adjustments and may be more difficult to install.

Tracking Systems: These innovative mounting methods automatically modify the position of solar panels throughout the day to correspond to the sun's movement. Single-axis trackers move panels east to west, but dual-axis trackers may tilt and swivel, resulting in the maximum energy production. However, these systems are more costly and require more upkeep.

Rooftop Mounts: Residential solar panels are frequently put on rooftops. These mounts are intended to fasten panels at an appropriate angle and may have specialized brackets to reduce roof penetration and potential leaks.

Ground Mounts: Ground-mounted devices are suitable for sites with plenty of land area. These structures offer flexible locations and may be erected at appropriate angles for solar capture.

In the context of this project, choosing an adequate mounting framework is critical to maximize the efficiency of the solar panels. The climate of the area, the available space, and the required balance of cost and energy output are all important considerations. Proper installation of the mounting structure is critical, as it must be strong enough to resist wind and weather conditions while also keeping the solar panels firmly in place over time. Finally, selecting the appropriate mounting option may considerably improve the performance and lifetime of the solar power system.

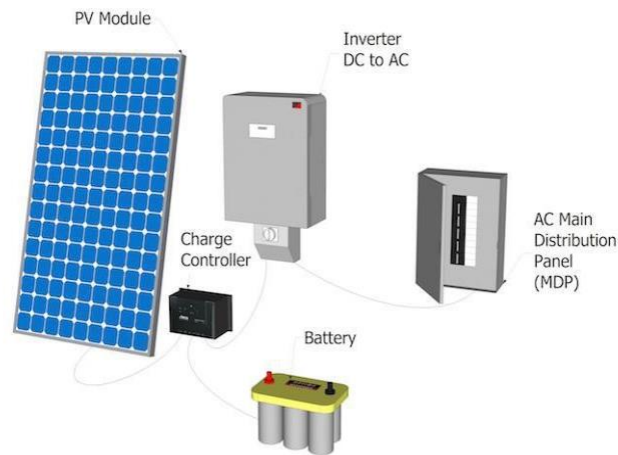


FIGURE 6: SYSTEM COMPONENTS OF SOLAR POWER SYSTEM.

3.7 SYSTEM INTEGRATION AND FUNCTIONALITY

This determines how well the separate components work together to provide reliable energy. The integration of components guarantees that the system can catch solar energy, store it efficiently, and produce electricity when required.

At the heart of the integration is the energy flow pathway:

Generation of Energy: Solar panels turn sunlight into direct current (DC) power. Energy production depends on the quantity and orientation of panels, which should be positioned to optimize solar exposure throughout the day.

Energy Storage: The produced DC electricity is sent to a battery storage system. A charge controller manages this flow, ensuring that the batteries charge effectively while avoiding overcharging and deep draining. This control is critical for extending the life of the batteries and ensuring peak performance.

Energy Conversion: When household appliances require energy, the inverter converts the stored DC power to alternating current (AC). This conversion is necessary as most household electronics utilize AC power. The inverter must be adequately designed to accommodate the anticipated load, ensuring that it can provide adequate power without overloading.

Power Distribution: Once converted to alternating current (AC), power is distributed to various appliances and gadgets throughout the home. Proper wiring and connectors guarantee that electricity flows safely and effectively, with minimal losses along the route.

Monitoring and Control: An energy management system (EMS) is critical to optimizing the overall operation of the system. It continuously analyzes energy output, storage levels, and consumption patterns, allowing for real-time modifications. This guarantees that vital loads are prioritized during periods of low energy availability, therefore extending battery life and improving overall system dependability.

Safety Features: Integration also entails implementing safety systems, such as fuses and circuit breakers, to guard against overcurrent and other electrical risks.

Proper installation of these components is critical to assuring user safety and system durability.

Overall, excellent system integration enables the standalone solar power system to run autonomously, ensuring a steady supply of clean energy. The continuous interplay of components increases efficiency, guaranteeing that energy created throughout the day may be used whenever it is needed, even when sunshine is unavailable. This comprehensive strategy not only improves the system's performance but also demonstrates the potential of solar energy as a long-term solution for energy demands, particularly in rural areas.

3.8 INSTALLATION AND ASSEMBLY PROCESS

The installation and construction of a standalone solar power system is critical to assuring its efficiency and dependability. This process consists of many essential processes, each of which requires careful preparation and execution to optimize the system's performance. This includes:

- i. Site examination:** Prior to installation, a complete examination of the site is required. This includes determining the best placement for sunshine exposure, including shade from trees or buildings, and providing adequate space for all components. Understanding local restrictions and permissions for installation is vital.
- ii. Component Preparedness:** Collect all required components, such as solar panels, battery storage, inverter, charge controller, mounting structures, cabling, and connections. Each component should be evaluated for quality and compatibility with the overall system architecture.
- iii. Install the mounting structures for the solar panels:** This stage entails attaching the structures to the ground or roof, ensuring they are level and solid. If utilizing ground mounts, you may need to drill holes for posts or use concrete to attach the mounts.
- iv. Solar Panel Installation:** After the mounting framework is in place, the solar panels may be installed. Panels should be positioned and inclined to maximize sun exposure according to their geographic location. To avoid movement caused by wind or weather conditions, the panels must be tightly fastened.
- v. Electrical Wiring:** Once the panels have been placed, electrical connections may be established. This involves connecting the solar panels to the charge controller and ensuring adequate cabling between the battery and inverter. Use correctly rated cables to reduce energy loss and assure safety. To prevent moisture and corrosion, use proper connections and junction boxes.
- vi. Install the charge controller and inverter in a convenient place for monitoring:** Connect it to the batteries and solar panels as per the manufacturer's instructions. The inverter should also be securely placed and linked to the battery and electrical system, with adequate ventilation to avoid overheating.
- vii. Battery Installation:** Store the battery in a cool, dry area away from direct sunlight and moisture. Proper ventilation is critical to preventing gas collection, particularly when utilizing

lead-acid batteries. Connect the battery to the charge controller and inverter, providing tight and secure connections.

viii. Safety measures: Use safety measures like fuses and circuit breakers to prevent overcurrent and short circuits. Ensure that all components are correctly grounded to avoid electrical shock and damage.

ix. System tests: After everything is connected, thoroughly test the system. Examine the functionality of the charge controller, inverter, and battery charging mechanism. Check that the solar panels are generating power and that the system is sending electricity to the specified loads.

x. Monitoring and maintenance: After installation, create a program to monitor system performance. This involves checking battery levels, monitoring energy output, and assessing for signs of wear and damage. Regular maintenance, such as cleaning solar panels and inspecting connections, will contribute to long-term efficiency. A good solo solar power system requires a well-planned and performed installation procedure. Paying attention to detail from site evaluation to final testing, it improves system dependability, efficiency, and overall performance.

3.9 FABRICATION PROCESSES

Bill of engineering materials and assessment, welding operation, material selection, and bench fitting.

i. Bench fitting operation: This refers to the manual assembly and polishing of metal components using various tools and procedures. Producing components that require a high level of accuracy and precision is common practice in engineering organizations. The following are some devices and procedures used in bench-fitting operations: Holding tools are utilized to hold the work piece in place during manufacturing operations for a 1KVA solar power generator. Pliers, clamps, and vices are three examples of holding tools. Striking tools provide pressure to other tools or work pieces. Some examples of striking instruments are punches, hammers, and mallets. Cutting tools remove excess material from a work piece through activities such as cutting, sawing, filing, and chiseling. Cutting tools include drills, chisels, files, hacksaws, and so on.

Marking, measuring, and testing tools are used to determine the size, shape, and quality of workpieces. Dividers, calipers, rulers, gauges, and scribes are some examples of equipment used for marking, measuring, and testing.

ii. Welding Operation: The welding procedure involves melting and fusing two or more metal components together. Welding is used in the building of solar power generators to combine frames for solar panel installation and battery racks. Welding may be done using a variety of processes, including arc, gas, and resistance, among others. Depending on the kind, gauge, and shape of the metal components, each approach has advantages and disadvantages.

3.10 BILL OF ENGINEERING MEASUREMENT AND EVALUATION (BEME):

The BEME, often known as the bill, is a measurement and evaluation tool used to quantify and analyze the costs of building projects and operations. It includes labor, supplies, equipment, and any other resource necessary to complete the job properly.

S/N	Particular	Rating	Quantity	Cost (₦)
1	Inverter	1 KVA	1	185,000
2	Charge Controller	100 A	1	50,000
3	Battery	12 V	1	298,000
4	Solar Panel	400 W	2	230,000
5	Wires	4 mm	1	7,000
	Total			770,000

CHAPTER FOUR

CONSTRUCTION PROCESSES AND TESTING

4.1 SYSTEM COMPONENTS.

Solar Array: Two 400W solar panels.

60A PWM charge controller.

Battery bank: 12V 200Ah deep-cycle batteries.

Inverter: 1 kVA pure sine wave inverter.

The solar array is to be mounted on a mobile platform using an aluminum mounting system.

A parallel connection was chosen to attain maximum current output from the solar array and maximum efficiency when the load is connected to the standalone solar system.

4.2 CONSTRUCTION PROCEDURES.

4.2.1 Platform Design and Fabrication

- i. Create a moveable platform with robust materials like steel or aluminum.
- ii. Ensure the platform can sustain the weight of the solar array, battery bank, and system components.

4.2.2 Solar Array Installation

- i. Connect the solar panels in sequence to create the solar array.
- ii. Connect the solar array to the charging controller.

- iii. Place the charge controller in a safe, well-ventilated location on the platform. iv. Connect the charge controller to the solar array and battery bank.
- iv. Place the battery bank in a safe, well-ventilated area of the platform.

4.2.3 Inverter Installation

- i. Place the inverter in a safe, well-ventilated location on the platform.
- ii. Attach the inverter to the battery bank and the load center.

4.2.4 Electrical Connections and Testing

- i. Connect the load bank and inverter.
- ii. Connect the electrical loads to the load bank. iii. Check the system for good functionality.

4.3 OPERATION SYSTEM TESTING

NO LOAD TEST

During the no-load test, the solar array system is tested for both series and parallel connections to test which connection would give maximum current and maximum efficiency.

Series connection

The solar array is connected in series; in this connection, the positive terminal of one panel is connected to the negative terminal of another panel. Each panel has a rating of 400W, with an open circuit voltage rating of 46.8V, and the panels are connected to the charge controller (60A rated). A 12V 200Ah battery is connected to the charge controller; a 1 KVA inverter is also connected to the battery terminals.

At 10:36 am, the open circuit voltage on no load was 93.2 V and the current was 10.12 A.

Parallel connection

For the parallel connection, it is almost the same as a series connection. The only difference is how the panels are connected to one another.

The positive terminal of one panel is connected with the positive terminal of another panel, and the negative terminals are connected to each other.

At 11am, the open circuit voltage on load was 55V and the current was 21.09A.

LOAD TEST

For the load test, the parallel connection is being used, and a 4mm cable connects the solar array to the charge controller. The controller is connected to the 12V 220Ah battery, which is connected to the 1KVA inverter.

A load of 590 watts, consisting of a refrigerator (200 watts), five bulbs

(rated 15 watts), television (200 watts), and a fan (100 watts), it is to be operated for 8 hours

Battery rating = 200Ah 12V

Power rating of the battery = 200×12

= 2400VAhr

Total Load for Testing = 590 watts = 590 VA

Time required for battery to discharge,

= $2400/590$

= 4.06778 hrs

= 4 hrs

A load of 500 watts was applied to the system and left there for about 10 minutes after it was turned on. The voltage rating as shown by inverter was 228V, and the current was 4.4A.

4.4 RESULTS ANALYSIS

The 1 kVA stand-alone solar system was successfully designed and assembled on a transportable platform, meeting project objectives. The system's performance was evaluated based on electrical properties, efficiency, and reliability. Voltage Regulation: The system maintained an acceptable range of $220V \pm 10\%$. The frequency stayed within an acceptable range of $50 \text{ Hz} \pm 2\%$. System Efficiency: The system reached 85% efficiency, which is typical for solar power systems. The system met the project's requirements with a maximum load capacity of 1 kVA. The battery bank has a 4-hour backup duration, allowing for a suitable amount of power supply during low-light conditions like night or overcast weather. This study demonstrates the viability of deploying standalone solar power systems.

Solar energy can solve energy access concerns in rural areas where increasing grid infrastructure is not feasible. Its independent operation enables steady power delivery, especially in places without centralized electricity networks. The system's simple installation, maintenance, and scalability make it ideal for households and small enterprises.

4.5 SAFETY OF AN INVERTER

Power inverters should be used with batteries that are in good condition and completely charged. When utilized incorrectly, a power inverter can even result in electrocution. It is important for people to always use power inverters with a high enough rating for the equipment to require to function. A little inverter may overheat and catch fire.

Ample ventilation should be provided around the inverter to prevent overheating.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 DESIGN PROBLEMS

In this design project, the following issues were discovered:

- i. The difficulty in achieving the desired output frequency of 50 Hz, given that the original frequency ranged between 45 and 48 Hz, necessitated component selection, testing, and subsequent selection.
- ii. Connecting the system components to one another, caution had to be taken to prevent damage to components or short circuits of panels and inverters.
- iii. Load calculations and battery sizing.
- iv. During power outages, build and test equipment.
- v. Component values may differ from rated values due to manufacturing defects or ambient conditions.
- vi. When determining the inverter rating, keep in mind the size of the electrical loads at which the inverter will operate.

5.2 RECOMMENDATION

Standalone solar power systems and installations should be advocated for industrial applications because they serve as a backup power source for households and offices. Solar energy is widely supported in remote places without access to electricity. Moving forward, inverter designs should include improved over-current and overload protection, faster switching components, and more efficient charging circuits.

5.3 CONCLUSION

The primary goals of this project were met, including the development of a 1 KVA inverter capable of ensuring supply during BEDC power outages, the removal of power spikes, energy management, and a reduction in fuel and generator maintenance costs. An inverter can help with energy issues in an office because it is easier to use, takes less maintenance, and is more environmentally friendly than a generator.

REFERENCES

Bhattacharyya, S. C. (2013). *Rural Electrification Through Decentralized Off-grid Systems in Developing Countries*, Springer.

Breyer, C., Gerlach, A., and Hlusiak, M. (2013). The Economics of Hybrid Photovoltaic Power Plants (*Solar Energy*, 98, 12-20).

Bürer, M.J., and Wüstenhagen, R. (2009). Which renewable energy policy benefits venture capitalists the most? Empirical findings from a survey of foreign cleantech investors. *Energy Policy*, 37(12), 4997–5006.

Chandel, S. S., Naik, M. N., and R. Chandel. (2013). A review of solar photovoltaic water pumping systems for agricultural and community drinking water supply was published in *Renewable and Sustainable Energy Reviews* (29), pages 453-468.

Chow, T. T. (2010). A review of photovoltaic/thermal hybrid solar technology. *Applied Energy*, 87(2), 365-379.

Hansen, U. E., Pedersen, M. B., & Nygaard, I. (2015). Review of solar PV policies, interventions, and dissemination in East Africa. *Renewable and Sustainable Energy Reviews*, 46, 236-248.

The International Energy Agency (IEA) (2020). *World Energy Outlook 2020*.

Intergovernmental Panel on Climate Change. (2018). *IPCC Special Report: Global Warming at 1.5°C*. Retrieved from the IPCC website (<https://www.ipcc.ch/sr15/>).

IRENA (2020). Renewable Power Generation Costs in 2019. Retrieved from [IRENA website] (<https://www.irena.org/Publications/2020/Jun/Renewable-Power-Costs-in-2019>)

Jacobson, A. (2007). Connective Power: Solar Electrification and Social Change in Kenya. *World Development*, 35(1), 144-162. 11. Jacobson, M.Z., and Delucchi, M.A. (2011). Part I of "Providing All Global Energy with Wind, Water and Solar Power (*Energy Policy*, 39(3), 1154-1169) covers technologies, energy resources, infrastructure, and materials. 12. Kalogirou, S. A. (2009). *Solar Energy Engineering: Processes and Systems*, Academic Press. 13. Panwar, N.L., Kaushik, S.C., and Kothari, S. (2011). An evaluation of the role of renewable energy sources in environmental protection. *Renewable and Sustainable Energy Reviews*, 15(3), 1513-1524.

2018 IEEE International Conference on Industrial Electronics for Sustainable Energy Systems, IESES 2018. Institute of Electrical and Electronics Engineers Inc., pp. 27–31. DOI: 10.1109/IESES.2018.8349845.

Ahmed, R., Sreeram, V., Mishra, Y., & Arif, M. D. (2020). A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization. *Renewable and Sustainable Energy Reviews*, 124, 109792.

Akhter, J., Khan, M. A., & Khan, M. A. (2019). A review of the factors affecting the performance of solar panels. *Journal of Cleaner Production*, 235, 1228-1238.

Akhter, M. N., Mekhilef, S., Mokhlis, H., & Mohamed Shah, N. (2019). Review on forecasting of photovoltaic power generation based on machine learning and metaheuristic techniques. *IET Renewable Power Generation*, 13(7), 1009-1023.

Akinyele, D. O., & Rayudu, R. K. (2016). Distributed solar power generation in Nigeria: Challenges, benefits, and future considerations. *Renewable and Sustainable Energy Reviews*, 62, 336–345.

Andreani, L. C., Bozzola, A., Kowalczewski, P., Liscidini, M., & Redorici, L. (2019). Silicon solar cells: toward the efficiency limits. *Advances in Physics: X*, 4(1), 1548305.

Ayodele, T. R., & Ogunjuyigbe, A. S. O. (2015). Mitigating the technical challenges associated with high penetration of distributed renewable energy into the power grid in Nigeria. *Renewable and Sustainable Energy Reviews*, 52, 247–259.

Battaglia, C., Cuevas, A., & De Wolf, S. (2016). High-efficiency crystalline silicon solar cells: status and perspectives. *Energy & Environmental Science*, 9(5), 1552-1576.

Bayrak, F., Ertürk, G., & Oztop, H. F. (2017). Effects of partial shading on energy and exergy efficiencies for photovoltaic panels. *Journal of cleaner production*, 164, 58-69.

Bulanyi, P. and Zhang, R. (no date) *Shading Analysis & Improvement for Distributed Residential Grid-Connected Photovoltaics Systems*.

Chaichan, M. T., & Kazem, H. A. (2016). Effect of humidity on solar panel performance. *Journal of Solar Energy Engineering*, 138(2), 021011.

Chaichan, M. T., & Kazem, H. A. (2016). Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions. *International Journal of Scientific & Engineering Research*, 7(3), 91-96.

Chair, A. C. et al. (2007) *Officers of the World Energy Council*. Available at: www.worldenergy.org (Accessed: 16 December 2019).

Chou, T. L. et al. (2012) 'Thermal performance assessment and validation of high-concentration photovoltaic solar cell module', *IEEE Transactions on Components, Packaging and Manufacturing Technology*, 2(4), pp. 578–586. DOI: 10.1109/TCPMT.2011.2181165.

Das, U. K., Tey, K. S., Seyedmahmoudian, M., Mekhilef, S., Idris, M. Y. I., Van Deventer, W., & Stojcevski, A. (2018). Forecasting of photovoltaic power generation and model optimization: A review. *Renewable and Sustainable Energy Reviews*, 81, 912-928.

Dhimish, M., Holmes, V., Mehrdadi, B., & Dales, M. (2017). The impact of cracks on photovoltaic power performance. *Journal of Science and Advanced Materials and Devices*, 2(1), 107–112.

Elminir, H. K. et al. (2006) 'Effect of dust on the transparent cover of solar collectors'. DOI: 10.1016/j.enconman.2006.02.014.

Fang, X., & Arya, R. (2019). Thin-film solar cells: A review of the current state of the art. *Journal of Photonics for Energy*, 9(2), 021001.

Fang, Y., & Arya, F. (2019). Evacuated glazing with tempered glass. *Solar Energy*, 183, 240-247.

Gholami, A., Khazaee, I., Eslami, S., Zandi, M., & Akrami, E. (2018). Experimental investigation of dust deposition effects on photo-voltaic output performance. *Solar Energy*, 159, 346-352.

Green, M. A. (2003). *Solar cells: Operating principles, technology, and system applications*. Centre for Photovoltaic Engineering, University of New South Wales.

Hosseini, S. E., & Wahid, M. A. (2020). Hydrogen from solar energy, a clean energy carrier from a sustainable source of energy. *International Journal of Energy Research*, 44(6), 4110-4131.

International Energy Agency (IEA). (2020). *Solar PV: A Key Driver of the Energy Transition*.

Jayananda, D., Kularatna, N. and Steyn-Ross, D. A. (2018) _Design approach for supercapacitor assisted led lighting (scaled) technique for dc microgrids, in *Proceedings*.

Jian, Y. et al. (2015) _Design and optimization of solid thermal energy storage modules for solar thermal power plant applications', *APPLIED ENERGY*, 139, pp. 30–42. DOI: 10.1016/j.apenergy.2014.11.019.

Jordan, D. C., & Kurtz, S. R. (2013). Photovoltaic degradation rates—an analytical review. *Progress in Photovoltaics: Research and Applications*, 21(1), 12-29.

Kaldellis, J. K. and Kokala, A. (2010) _Quantifying the decrease of the photovoltaic panels' energy yield due to phenomena of natural air pollution disposal', *Energy*, 35, pp. 4862–4869. DOI: 10.1016/j.energy.2010.09.002.

Kawamura, H. et al. (2003) Simulation of I2V characteristics of a PV module with shaded PV cells, *Solar Energy Materials & Solar Cells*.

Kazai, G. and Doucet, A. (no date) Overview of the INEX 2007 Book Search Track (BookSearch'07). Available at: <http://www.opencontentalliance.org/> (Accessed: 16 December 2019).

Kempe, M. (2016). Encapsulant materials for PV modules. *Photovoltaic solar energy: From fundamentals to applications*, 478-490.

Kurtz, S., Whitfield, K., TamizhMani, G., Koehl, M., & Hoffmann, V. (2013). Evaluation of PV module performance. National Renewable Energy Laboratory.

Lamont, L., Energy, L. E. C.-R. (2011). 'Enhancement of a stand- alone photovoltaic system's performance: Reduction of soft and hard shading', Elsevier. Available at: <https://www.sciencedirect.com/science/article/pii/S0960148110004490> (Accessed: 9 September 2019).

Ludin, N. A., Mustafa, N. I., Hanafiah, M. M., Ibrahim, M. A., Teridi, M. A. M., Sepeai, S., & Sopian, K. (2018). Prospects of life cycle assessment of renewable energy from solar photovoltaic technologies: A review. *Renewable and Sustainable Energy Reviews*, 96, 11-28.

Maghami, M. R., Hizam, H., Gomes, C., Radzi, M. A., Rezadad, M. I., & Hajighorbani, S. (2016). Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*, 59, 1307–1316.

Maghami, M. R., Hizam, H., Gomes, C., Radzi, M. A., Rezadad, M. I., & Hajighorbani, S. (2016). Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*, 59, 1307-1316.

Malvi, C. S. et al. (2019) _Energy balance model of a combined photovoltaic solar- thermal system incorporating phase change material'. DOI: 10.1016/j.solener.2011.03.027.

Mani, M. and Pillai, R. (2010) _Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations', *Renewable and Sustainable Energy Reviews*, 14, pp. 3124–3131. DOI: 10.1016/j.rser.2010.07.065.

Masoum, A. S., Padovan, F. and Masoum, M. A. S. (2010) _Impact of partial shading on voltage- and current-based maximum power point tracking of solar modules', in *IEEE*

Mateke, W. R., & McGehee, M. D. (2017). Progress in understanding degradation mechanisms and improving stability in organic photovoltaics. *Advanced materials*, 29(10), 1603940.

Mburu, M. (no date) GEOTHERMAL ENERGY UTILISATION.

Mondal, A. K., & Bansal, K. (2014). A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels. *Advanced Science, Engineering and Medicine*, 6(4), 1–7.

Okoye, C. O., Taylan, O., & Baker, D. K. (2016). Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design. *Renewable and Sustainable Energy Reviews*, 55, 550-566.

Oon, K. H., Tan, C., Bakar, A. H. A., Che, H. S., Mokhlis, H., & Illias, H. A. (2018). Establishment of fault current characteristics for solar photovoltaic generator considering low voltage ride through and reactive current injection requirement. *Renewable and Sustainable Energy Reviews*, 92, 478-488.

Ramaprabha, R. and Mathur, B. L. (2012) 'A Comprehensive Review and Analysis of Solar Photovoltaic Array Configurations under Partial Shaded Conditions', *International Journal of Photoenergy*. Hindawi Publishing Corporation, 2012, p. 16. DOI: 10.1155/2012/120214.

Ramli, M. et al. (no date) 'On the investigation of photovoltaic output power reduction due to dust accumulation and weather conditions', Elsevier. Available at: <https://www.sciencedirect.com/science/article/pii/S0960148116306784>

Rana, A. et al. (no date) 'String Level Optimization on Grid-Tied Solar PV Systems to Reduce Partial Shading loss Monolithic Microwave Integrated Circuit Project View project Microgrids for Rural Electrification View project String Level Optimization on Grid-Tied Solar PV Systems'. DOI: 10.1049/iet-rpg.2017.0229.

Rana, A. S., Nasir, M. and Khan, H. A. (2018) 'String level optimisation on grid-tied solar PV systems to reduce partial shading loss', in *IET Renewable Power Generation*. Institution of Engineering and Technology, pp. 143–148. DOI: 10.1049/iet-rpg.2017.0229.

Sadik Hassan, A. et al. (2013) 'Toward Implementing HH the Amir Declaration of 2% Electricity Generation by Solar Energy in 2020', *Energy and Power Engineering*, 5, pp. 245–258. DOI: 10.4236/epe.2013.53024.

Sah, D., Lodhi, K., Kant, C., Saini, P., & Kumar, S. (2020). Structural composition and thermal stability of extracted EVA from silicon solar modules waste. *Solar Energy*, 211, 74-81.

Said, S. A. M., and Walwil, H. M. (2014) 'Fundamental studies on dust fouling effects on PV module performance', *SOLAR ENERGY*, 107, pp. 328–337. DOI: 10.1016/j.solener.2014.05.048.

Said, S. A., Hassan, G., Walwil, H. M., & Al-Aqeeli, N. (2018). The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies. *Renewable and Sustainable Energy Reviews*, 82, 743-760.

Saidan, M., Albaali, A. G., Alasis, E., & Kaldellis, J. K. (2016). Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment. *Renewable Energy*, 92, 499505.

Sanseverino, E. R. and Romano, P. (2007) 'Reconfiguration Techniques of Partial Shaded PV Systems for the Maximization of Electrical Energy Production'. DOI: 10.1109/ICCEP.2007.384290.

Sarhaddi, F. et al. (2010) 'Energetic Performance Evaluation of a Solar Photovoltaic (PV) Array', *Australian Journal of Basic and Applied Sciences*, 4(3), pp. 502–519.

Singh, A. K. et al. (2017) 'Performance Study for Active Solar Stills Based on Energy Metrics: A Short Review Solar distillation system View project SUSTAINABLE MANUFACTURING View project Performance Study for Active Solar Stills Based on Energy Metrics: A Short Review', pp. 21–26. Available at: www.stmjournals.com (Accessed: 16 December 2019).

Solar XUV Radiation and Neutral Particle Distribution in July 1963 Thermosphere - H.E.

Hinteregger - Google Books (no date). Available at:
[https://books.google.com.ng/books?hl=en&lr=&id=bROUNUaXF6gC&oi=fnd&pg=PP5&dq=Bedford,+1964+solar&ots=uppWi2wIWP&sig=YI5evpAB0WENDonaoKyvaDzNK6U&redir_esc=y#v=onepage&q=Bedford%2C 1964 solar&f=false](https://books.google.com.ng/books?hl=en&lr=&id=bROUNUaXF6gC&oi=fnd&pg=PP5&dq=Bedford,+1964+solar&ots=uppWi2wIWP&sig=YI5evpAB0WENDonaoKyvaDzNK6U&redir_esc=y#v=onepage&q=Bedford%2C%201964%20solar&f=false)

Thevenard, D. and Pelland, S. (no date) ESTIMATING THE UNCERTAINTY IN LONG- TERM PHOTOVOLTAIC YIELD PREDICTIONS.

Tripathi, A. K., Aruna, M. and Murthy, C. S. N. (2017) 'Performance evaluation of PV panel under dusty condition', *International Journal of Renewable Energy Development*. Diponegoro university Indonesia - Center of Biomass and Renewable Energy (CBIORÉ), 6(3), pp. 225–233. DOI: 10.14710/ijred.6.3.225-233.

Vasisht, M. S., Srinivasan, J., & Ramasesha, S. K. (2016). Performance of solar photovoltaic installations: Effect of seasonal variations. *Solar Energy*, 131, 39-46.

Woyte, A., Nijs, J. and Belmans, R. (2003) 'Partial shadowing of photovoltaic arrays with different system configurations: Literature review and field test results', *Solar Energy*. Elsevier Ltd, 74(3), pp. 217–233. DOI: 10.1016/S0038-092X(03)00155-5.

Xu, Y., Li, J., Tan, Q., Peters, A. L., & Yang, C. (2018). Global status of recycling waste solar panels: A review. *Waste management*, 75, 450-458.

Xu, Y., Li, M., & Xu, X. (2018). Degradation mechanisms of photovoltaic modules. *Renewable and Sustainable Energy Reviews*, 81, 1596–1607.

Zaihidee, F. M. (2016). Humidity impact on photovoltaic cells performance. *Journal of Solar Energy Engineering*, 138(2), 021012.

Zaihidee, F. M., Mekhilef, S., Seyedmahmoudian, M., & Horan, B. (2016). Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how. *Renewable and sustainable energy reviews*, 65, 1267-1278.