DESIGN OF A STAND-ALONE PHOTOVOLTAIC INVERTER SYSTEM FOR SELECTED LOAD CENTRES IN THE FACULTY OF ENGINERING, UNIVERSITY OF BENIN

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CERTIFICATION

This is to certify that this research was carried out by AYOREGA AVWEROSUO, ASAKITIKPI IRORO, ATAVWODA NELSON OGHENERO, ADETUNJI DAVID AYOBAMI, AMADI JEFFERY IKECHUKWU, in the Department of Electrical/Electronic Engineering, University of Benin, in partial fulfillment of the requirements for the award of Bachelor of Engineering (B. Eng) degree in Electrical/Electronic Engineering.

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DEDICATION

This project work is dedicated to God Almighty, who saw us through the period of this project.

ABSTRACT

This study details the design and comprehensive economic analysis of a standalone Photovoltaic (PV) inverter system tailored for selected load centre within the Faculty of Engineering. The primary aim was to devise an optimal, reliable, and sustainable energy solution capable of independently meeting the critical electrical load demands of the facility. This project directly addresses the necessity for a cleaner and cheaper power source in the face of continuous grid rising operational expenses, thereby proposing a resilient renewable energy alternative.

The methodology adhered to a structured process, beginning with load survey to precisely quantify the energy consumption patterns and peak demand. Following this, essential system components including the PV array, battery bank, and inverter were initially sized using fundamental mathematical equations. The technical and economic optimization of the system was then conducted through dynamic simulation using the specialized HOMER Pro(version 64-3.11.2) software, which successfully identified a range of technically feasible solutions. The final critical step involved an in-depth economic analysis, comparing the lifecycle cost of the optimized PV system against the cost of energy supplied by the existing utility grid.

The simulation and economic assessment confirmed the viability and financial advantage of the designed PV inverter system. The Levelized Cost of Energy (LCOE) for the PV inverter system was calculated to be ₦143.47/kWh, demonstrating a significant cost benefit when compared to the utility grid supply's LCOE of ₦209.5/kWh. This result conclusively shows that the PV solution is cheaper and more sustainable over the 25-year project lifetime. With a favorable payback period calculated at 13.4 years, the study concludes that the proposed PV inverter system represents a robust, financially sound, and economically superior investment for guaranteeing continuous power supply to the Centre study details the design and comprehensive economic analysis of a standalone Photovoltaic (PV) inverter system tailored for a selected Centre within the Faculty of Engineering.

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ABBREVIATIONS

1. AC – Alternative Current
2. DC – Direct Current
3. MPPT – Maximum Power Point Tracking
4. DB – Distribution Board
5. PV – Photovoltaic
6. IPCC – Intergovernmental Panel on Climate Change.
7. REN – Renewable Energy Network
8. NERC – Nigerian Electricity Regulatory Commission
9. SoC – State of Charge
10. DoD – Depth of Discharge
11. Li-ion – Lithium-ion
12. LCOE – Levelized Cost of Energy
13. NASA- National Aeronautics and space Administration
14. HOMER- Hybrid optimization of multiple Energy resources.
15. SPD- Surge protection devices
16. MCB- Miniature circuit breaker
17. FORTRAN- Formula Translation
18. NPV- Net present value
19. PERC- Passivated Emitter and Rear contact
20. LCD- Liquid Crystal display
21. PWM- Pulse Width modulation
22. FLA- Flooded lead acid
23. SLA- Sealed lead Acid
24. AGM- Absorbed Glass Mat

25. BMS- Battery management system
26. MOSFETs -Metal oxide semiconductor field effect transistor
27. MCCB -Molded case circuit breaker
28. SCCB- Solid state circuit breaker
29. MOV- Metal oxide varistor
30. GDT- Gas discharge tube
31. UPS- Uninterrupted Power supply.

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CHAPTER ONE

1.1 INTRODUCTION

Energy is the driving force behind social and economic development, influencing almost every aspect of human existence, from health and education to technology, communication, transportation, and industrialization. It is broadly classified into renewable and non-renewable forms. Non-renewable energy sources, such as coal, petroleum, and natural gas, have powered economies for decades but are finite and contribute significantly to environmental degradation through the release of greenhouse gases. Renewable energy, on the other hand, is derived from naturally replenished resources such as solar, wind, hydro, and biomass. It offers cleaner, sustainable alternatives that align with global efforts to mitigate climate change and promote environmental stewardship (Abdallah & Odeleke, 2023).

Renewable energy is derived from sources that naturally replenish themselves, such as sunlight, wind, moving water, and geothermal heat. While most renewable sources are sustainable, some, such as certain biomass sources, may become unsustainable if they are exploited beyond their regenerative capacity. According to the International Renewable Energy Agency (IRENA, 2025), approximately 91% of newly commissioned renewable energy projects are now cheaper than most fossil fuel alternatives, a trend driven by decreasing technology costs, especially for solar and wind, and increasing fossil fuel prices.

In many developing nations, including Nigeria, energy insecurity remains a critical challenge. The national grid suffers from frequent outages, low generation capacity, and inefficient distribution systems. Learning institutions such as universities and polytechnics are particularly vulnerable because they require constant, reliable electricity to power classrooms, laboratories, ICT centres, libraries, and residential facilities. Frequent grid failures disrupt teaching, research, and administrative activities, forcing institutions to depend heavily on diesel-powered generators. This dependency leads to escalating operational costs, air pollution, and budgetary strain, diverting funds from research and infrastructure development (Omeiza et al., 2022).

In Nigeria, renewable energy presents an opportunity to bridge the persistent electricity access gap. Studies by Okonkwo et al. (2021) emphasize that solar photovoltaic (PV) technology is the most abundant and feasible renewable energy source for institutional environments, particularly in southern regions such as Benin City, where solar irradiance is consistently high. The adoption of PV systems offers cleaner, more sustainable power with reduced operational costs in the long term, making them a practical choice for academic institutions with high energy demand.

1.2 PROBLEM STATEMENT

The Faculty of Engineering at the University of Benin, has experienced unreliable power supply due to grid instability and high operational Following the April 2024 increase in electricity tariffs for Band A consumers (NERC, 2024), Therefore, there is a critical need for a reliable, cost-effective, and clean energy solution to support academic and administrative operations, that would not disrupt non-administrate and administrate activities across the faculty of engineering.

1.3 AIM OF THE STUDY

This project aims to design a standalone Photovoltaic (PV) inverter system for a selected load center in the Faculty of Engineering.

1.4 OBJECTIVES OF THE STUDY

To achieve the aim, the following specific objectives are set:

1. To assess the energy demand of selected loads within the Faculty of Engineering through a detailed energy audit.

2. To design and size a standalone PV inverter system for optimal performance and reliability.

3. To simulate and evaluate the system’s technical and economic feasibility using software tools(Homer Pro).

4. To carry out cost-benefit analysis of the PV inverter system

1.5 SIGNIFICANCE OF THE STUDY

This study has significant implications for the energy sustainability and educational development of the University of Benin. The project:

1. Promotes renewable energy adoption in line with Nigeria’s Energy Transition Plan and Sustainable Development Goal 7 (SDG 7).

2. Improves energy security by reducing reliance on the unstable national grid and costly diesel generators.

3. Supports academic continuity by ensuring uninterrupted power supply to critical facilities such as classrooms, laboratories, and staff offices.

4. Fosters technical competence in solar technology by serving as a learning platform for engineering students.

5. Contributes to environmental sustainability by minimizing greenhouse gas emissions from fossil fuels (IPCC, 2021).

1.6 SCOPE OF THE STUDY

The scope of this study is clearly defined to ensure the designed system meets the energy needs of specific equipment and spaces within the Faculty of Engineering, University of Benin, while deliberately excluding high-power-consuming loads. Geographically, the study is limited to the Metallurgical and Material Engineering Department, its laboratory, and the Petroleum Department within the Faculty of Engineering, and therefore will not serve the entire university. The design focuses specifically on the Faculty of Engineering's infrastructure, where the energy demands for academic and administrative activities will be met. The PV inverter system is designed to meet the energy requirements of selected loads, which include lighting circuits used in classrooms, offices, and hallways; ceiling and standing fans used for ventilation in classrooms, offices, and common areas, and socket circuits for low-power devices such as laptops, computers, and mobile chargers found in offices and classrooms. The selection of these load centres is based on a careful assessment of the proposed solar system's power capacity, which limits its ability to supply energy to all possible loads within the faculty; thus, certain high-capacity equipment or areas, such as the air-conditioning system and heavy-duty machines in laboratories, are excluded from the system's supply

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW OF PAST WORKS ON PV SOLAR SYSTEMS

In Nigeria, unreliable electricity supply has continued to affect academic institutions, research centres, households, and commercial buildings. As a result, scholars and engineers have explored standalone solar photovoltaic (PV) systems as a sustainable solution to supplement or replace grid electricity and fossil-fuel generators. Several notable studies have contributed to the understanding of PV design, simulation, and implementation in different contexts, providing a strong foundation for ongoing research in this field.

Okedu and Uhunmwangho (2019) designed and implemented a standalone PV-based power system for the Department of Electrical and Electronics Engineering, University of Port Harcourt. Their project was motivated by frequent interruptions that disrupted laboratory experiments and digital learning. A 3.5 kW PV system was proposed, comprising monocrystalline solar panels, an MPPT charge controller, deep-cycle batteries, and a pure sine wave inverter. Using HOMER Pro for simulation, the system achieved a performance ratio of 79% and covered 90% of the departmental load without generator backup. This case demonstrated the practical viability of faculty-scale PV systems in sustaining academic activities.

Similarly, Ishaq et al. (2013) investigated the design of a standalone PV system for the Faculty of Engineering, Bayero University Kano. The study highlighted the reliance on expensive fossil-fuel generators and proposed solar PV as a cleaner alternative. A load audit revealed an energy demand of 556 kWh/day, though the system was designed to supply only 10% of this as a pilot project. Using FORTRAN-aided computation, the researchers designed a 14 kVA inverter system supported by 96 PV modules, 24 batteries, and 5 voltage regulators. Although the initial cost of ₦2.77 million was high, economic analysis showed a payback period of 3.6 years, reinforcing PV’s long-term viability despite capital challenges.

Further addressing the economic dimension of PV deployment, Okakwu (2025) carried out a techno-economic design of a standalone PV system for the Electrical and Electronics Engineering Department at Olabisi Onabanjo University. With a load profile of 7398 W, the system was sized to include 94 PV panels, 16 batteries, a 100 A charge controller, and a 12.5 kVA inverter. The financial analysis revealed a highly favourable Net Present Value (NPV) of ₦32.83 million and a discounted payback period of just 1.7 years. The calculated cost of energy (₦0.7859/kWh) was significantly lower than the grid tariff of ₦206.80/kWh, demonstrating the superior affordability of solar solutions for institutional loads.

In a residential application, Hamza, Auwal and Sharpson (2018) designed and sized a standalone PV system for a household in Gombe. Their analysis showed a daily demand of 14,904 Wh and a peak load of 3012.5 W. The system design included 31 polycrystalline PV modules, 18 AGM deep-cycle batteries, and three charge controllers. The study concluded that while installation costs may be high, the durability and environmental benefits of PV systems made them attractive for households in solar-rich regions like Gombe.

Expanding to urban housing applications, Ohajianya (2023) simulated a standalone PV system for a housing estate in Abuja. Using computer-aided simulation, the system was designed to meet daily household demands, with results showing both technical and economic viability. Similarly, Ohanu, Egbo and Sutikno (2024) analysed a PV system for a three-bedroom residence in Obollo-Nsukka. Their findings revealed that the system could meet 99.3% of the household’s energy requirements, though economic analysis showed higher levelized costs compared to utility tariffs, highlighting financial barriers to residential adoption.

In the educational sector, Akinsanmi, Omodunbi and Ayeoribe (2023) designed a 3.5 kVA standalone PV system for the Federal University Oye-Ekiti. The system, optimized with appropriate tilt angles and battery sizing, successfully powered the university's broadcasting station. Likewise, Ikechukwu and Chibueze (2022) applied HOMER software to evaluate a PV system for Michael Okpara University of Agriculture, Umudike. Their design produced excess energy beyond demand, with 100% renewable fraction achieved, although the cost of energy remained relatively high.

Institutional-scale designs have also been evaluated in other contexts. Oladeji, Balogun and Aliyu (2017) designed a PV system for the National Centre for Hydropower Research and Development (NACHRED), targeting office loads. Their results showed PV systems could effectively replace diesel generators for essential services. Similarly, Ishaq, Ibrahim and Abubakar (2013) developed an off-grid PV system for Government Technical College, Wudil. With 72 modules and 20 batteries, the system achieved a payback period of just 2.8 years, further proving the financial attractiveness of solar power.

Rural electrification studies also underscore PV's significance. Ozogbuda and Iqbal (2021) developed and simulated a PV-battery-generator hybrid for a household in Edo State. Their dynamic simulation confirmed efficient maximum power point tracking and reliable coordination between PV, storage, and generator backup. Likewise, Oton and Iqbal (2021) designed a PV system for Uyo High School, Akwa Ibom State. Their optimized configuration of a 42.2 kW PV array and 60 batteries demonstrated strong technical and economic performance, ensuring nearly uninterrupted supply for school operations.

Finally, Omorogiuwa et al. (2021) designed a 2.5 kW PV system for classrooms at the University of Benin. Incorporating lithium-ion storage and MPPT-based control, the project emphasized load prioritization and low-maintenance design, further validating PV's adaptability in educational contexts.

Taken together, these studies highlight the growing body of work on PV deployment across Nigeria. They consistently reveal that while capital costs remain a barrier, standalone PV systems are technically viable and, in many cases, economically competitive compared to grid electricity and fossil-fuel generators. These insights directly support the relevance of designing standalone PV inverter systems for specific load centres in Nigerian universities.

2.2 Literature of Components

An off-grid photovoltaic (PV) inverter system is designed to operate independently of the utility grid, supplying power to specific loads by harnessing solar energy and storing it for use when sunlight is unavailable. Unlike on-grid systems, off-grid systems need a more complete set of components to provide continuous, reliable, and independent power. Each component, ranging from solar panels and battery banks to inverters, charge controllers, and protective devices, plays a vital role in energy conversion, storage, regulation, and safety.

To design a standalone solar system, some basic components/materials would be needed to perform the design. Some of the major components used for the design are highlighted below;

1. **Photovoltaic solar panel**

2. Solar charge controllers.

3. Batteries.

4. Inverters.

5. Circuit breakers.

6. Mounting Structures.

7. Surge protection devices.

8. Lightning Arrestors.

9. Cables.

10. Change-over switches.

2.2.1 Solar Panels

Solar panels are devices that convert sunlight directly into electricity using the photovoltaic effect. This technology plays a central role in the global transition to clean and renewable energy. As fossil fuel reserves continue to deplete and concerns about global warming intensify, PV systems are becoming vital components of sustainable energy systems (IEA, 2021). Since the development of the first practical PV cell in 1954 by Bell Laboratories, the photovoltaic industry has advanced rapidly. Today, PV panels are widely used across residential rooftops, commercial buildings, and utility-scale power plants due to declining costs and rising energy demand (Green, 2020).

The operation of a photovoltaic panel is based on the photovoltaic effect, first discovered by Edmond Becquerel in 1839. When sunlight hits the surface of a semiconductor material, such as silicon, it transfers energy to electrons, freeing them to move and generate an electric current (Razykov et al., 2011). Each PV cell typically comprises two semiconductor layers—a negatively charged (n-type) and a positively charged (p-type) layer. The interface between these layers forms a p-n junction that creates an electric field, which drives the movement of freed electrons, producing direct current (DC) electricity (Fraunhofer ISE, 2021).

There are several types of PV panels available in the market. Each differs in material composition, efficiency, cost, and application. Monocrystalline PV panels are produced from a single crystal structure of silicon, giving them a uniform black appearance and high purity. These panels are among the most efficient solar technologies, achieving 15–22% efficiency (Green, 2020). They are particularly suitable for installations where space is limited, such as rooftops, due to their high-power output per square meter. However, they are also more expensive due to the complex manufacturing process involved (IEA, 2021). Polycrystalline panels are manufactured by melting several silicon fragments together, resulting in a bluish and grainy appearance. Their production is simpler and more environmentally friendly compared to monocrystalline panels (Kurtz, 2012). While their efficiency is slightly lower, typically around 13–17%, they are a cost-effective option for large-scale projects where space is not a constraint (Fraunhofer ISE, 2021).

Thin-film solar panels are created by depositing thin layers of photovoltaic material onto substrates like glass or metal. Common materials include amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS) (Razykov et al., 2011). These panels are flexible, lightweight, and more aesthetically pleasing, making them ideal for architectural applications. However, their efficiency ranges from 10–12%, and they generally require more surface area to generate the same power as crystalline panels (Green, 2020). PERC technology is an advancement over traditional crystalline silicon cells. It adds a rear-side passivation layer that reflects unused sunlight into the cell, improving light absorption and enhancing efficiency (Fraunhofer ISE, 2021). With efficiencies reaching up to 23%, PERC panels offer a good balance between cost and performance, especially in areas with high temperatures or low-light conditions (IEA, 2021). Bifacial PV panels can absorb light from both their front and rear sides, capturing reflected light from the ground or nearby surfaces. This design can increase energy output by 5–15%, especially in reflective environments such as snow-covered areas or concrete roofs (Kurtz, 2012). These panels are becoming increasingly popular for commercial and utility-scale installations, especially when installed with reflective ground surfaces to maximize performance (Razykov et al., 2011).

The choice of PV panel depends on factors such as efficiency requirements (Mono-Si and PERC are most efficient), budget constraints (Poly-Si and Thin-Film are more affordable), installation space (Mono-Si is suitable for limited space), and environmental conditions (Bifacial works best in reflective areas). Understanding these options allows users to make informed decisions that optimize energy production and cost-effectiveness (IEA, 2021).

Fig 2.1 A photovoltaic (PV) panel

2.2.2 CHARGE CONTROLLER

A charge controller, also known as a solar charge regulator, is a critical component in solar photovoltaic (PV) systems. Its primary function is to regulate the voltage and current coming from the solar panels to the battery, ensuring safe and efficient battery charging. Without a charge controller, batteries are at risk of overcharging, deep discharging, or damage, which can significantly shorten their lifespan (Razykov et al., 2011). As solar systems become more common in both on-grid and off-grid settings, the demand for advanced charge controllers has increased, especially with the development of smarter energy storage and higher-efficiency panels (IEA, 2021).

A charge controller sits between the solar panel array and the battery bank. When solar energy is harvested and converted into electricity, the controller monitors battery voltage and charging current to prevent overcharging and excessive discharging. It operates by disconnecting the panels from the batteries when a certain voltage threshold is reached and reconnecting them when the voltage drops below a defined level (Green, 2020). Modern charge controllers also include features such as load control, which prevents the battery from being excessively discharged, temperature compensation that adjusts charging based on ambient or battery temperature, and real-time monitoring, which displays system performance via LCD screens or apps.

There are two main types of charge controllers used in solar systems: Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). PWM controllers regulate the battery charging process by sending short pulses of energy to the battery rather than a continuous stream. The width of these pulses decreases as the battery becomes charged. With an efficiency around 75–80%, a relatively low cost, and best use in small off-grid systems with minimal power needs, PWM controllers are simple, reliable, and effective for low-cost installations, but they are less efficient when the solar panel voltage is much higher than the battery voltage (Kurtz, 2012).

MPPT charge controllers are more sophisticated and are designed to optimize the energy harvest from solar panels by constantly tracking the maximum power point, the point at which the panel operates most efficiently (Fraunhofer ISE, 2021). With an efficiency of 95–98%, they cost more than PWM controllers and are best used in large-scale and high-voltage PV systems. These controllers convert excess panel voltage into additional current, making them particularly efficient when panels operate at higher voltages than batteries.

Charge controllers play a crucial role in maintaining the health and efficiency of solar power systems, especially in off-grid setups. Their key benefits include battery protection by preventing overcharging and deep discharging, system safety by avoiding overheating and electrical faults, improved efficiency as MPPT models extract more power from panels, and system longevity by reducing battery wear and enhancing performance. For systems using expensive lithium-ion or deep-cycle batteries, a charge controller is essential to avoid performance degradation over time (Green, 2020).

2.2.3 Deep Cycle Batteries

A battery is a crucial energy storage component in off-grid or hybrid photovoltaic (PV) systems. It consists of multiple batteries connected to store electrical energy produced by solar panels for use during periods of low or no solar generation, such as at night or on cloudy days (Green, 2020). By providing a continuous and reliable power supply, batteries are particularly vital in areas without grid access or where the utility grid is unreliable. As solar power systems become more advanced and cost-effective, battery banks are increasingly deployed across residential, commercial, and industrial renewable energy applications (IEA, 2021).

A battery operates by storing the direct current (DC) electricity generated by the PV panels. During the day, any excess solar energy charges the batteries via a charge controller. When the panels are not producing electricity, the system automatically draws power from the battery bank to meet the load demand (Razykov et al., 2011). The total capacity of a battery is determined by its design and the configuration of the batteries. A series connection is used to increase voltage, while a parallel connection is used to increase current, which boosts the amp-hour capacity. Proper design and sizing are critical to ensure that the battery meets the system's power requirements and maintains overall reliability.

Several types of batteries are commonly used in solar systems, each offering a distinct set of advantages, limitations, and maintenance requirements. Flooded Lead-Acid (FLA) batteries are a traditional and widely used option due to their relatively low cost. However, they require regular maintenance, including electrolyte top-ups and terminal cleaning, and need to be housed in a well-ventilated area. With a lifespan of 4–8 years and an efficiency of 80–85%, they are best suited for stationary off-grid systems where users are capable of routine maintenance (Kurtz, 2012). Sealed Lead-Acid (SLA) batteries, which include Absorbent Glass Mat (AGM) and Gel types, are a more modern, maintenance-free alternative. They are sealed and safer for indoor use, with a longer lifespan of 5–10 years and higher efficiency of 85–90%. SLA batteries are a popular choice for residential systems and mobile units. The most advanced option is Lithium-Ion (Li-ion) batteries. They are gaining rapid popularity due to their high energy density, longer lifespan of 10–15 years or more, and a superior efficiency of 95–98%. Despite their higher initial cost, their deep discharge capacity and lightweight design make them ideal for modern smart energy systems where space and performance are critical (Fraunhofer ISE, 2021).

Proper design, configuration, and management are essential for the safe and optimal performance of a battery bank. Designing a battery bank involves calculating the total daily energy load (kWh/day), the desired days of autonomy, the depth of discharge (DoD), and the required battery voltage and capacity. Additionally, battery banks must be carefully managed to prevent damage and ensure longevity. This includes preventing overcharging or deep discharging, regulating temperature, and balancing battery voltage, especially in series or parallel setups. For lithium-ion batteries, using a dedicated Battery Management System (BMS) is crucial to ensure their safety and optimal performance. Regular inspections and maintaining proper ambient conditions are also key to extending the lifespan of the battery bank (Razykov et al., 2011).

A battery is a crucial energy storage component in off-grid or hybrid photovoltaic (PV) systems. It consists of multiple batteries connected to store electrical energy produced by solar panels for use during periods of low or no solar generation, such as nighttime or cloudy weather (Green, 2020). Batteries provide a continuous and reliable power supply, particularly in areas without grid access or where grid electricity is unreliable.

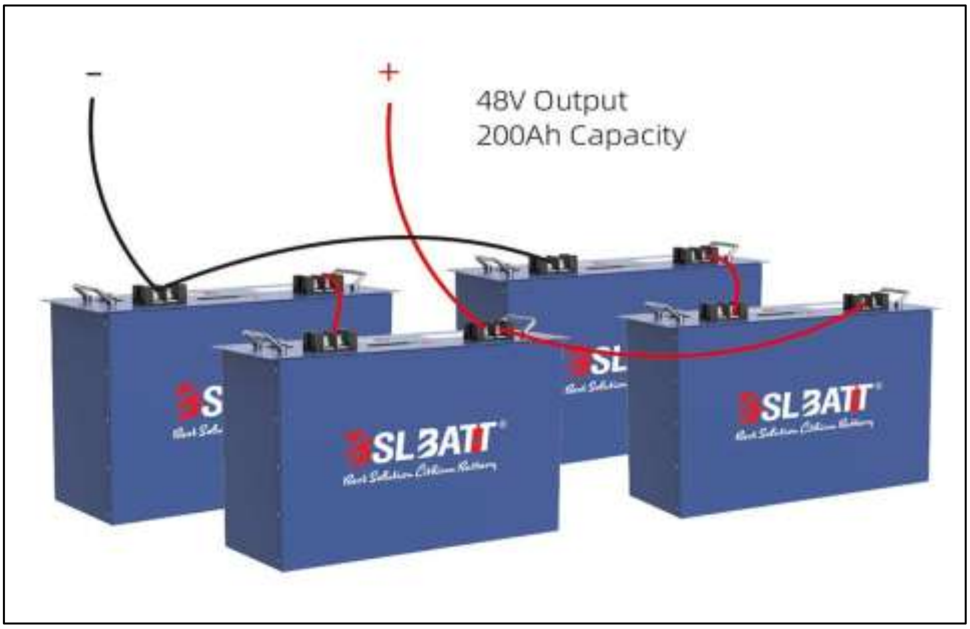


Fig 2.2: Battery of 48V Output 200Ah Capacity

2.2.4 SOLAR INVERTER

A solar inverter is a core and indispensable component of any solar photovoltaic (PV) system. It functions as a critical energy conversion device, transforming the direct current (DC) generated by solar panels or stored in batteries into the alternating current (AC) used by most household appliances and grid-connected systems (Green, 2020). Without this crucial device, a PV system would be limited to powering only a narrow range of DC loads or simply charging batteries, severely restricting its utility. Inverters have evolved significantly to meet the demands for more reliable and autonomous energy systems, now integrating advanced functions such as real-time monitoring, grid interaction, and power quality regulation (IEA, 2021).

The working principle of an inverter is based on electronic switching. While solar panels and batteries produce electricity in DC form, which is not compatible with standard AC appliances, the inverter solves this problem by using sophisticated switching circuits. These circuits convert the DC input into a sinusoidal AC voltage with the appropriate frequency and voltage level, typically 50 Hz or 60 Hz, depending on the country (Fraunhofer ISE, 2021). The basic operation involves a four-step process: receiving DC input from the PV array or battery bank; performing a DC-to-AC conversion using components like transistors or MOSFETs; filtering the output to ensure a smooth waveform; and finally, supplying the power to the connected load or utility grid. Advanced inverters are also programmed to synchronize with the utility grid, continuously monitor system parameters, and provide essential protection against overloads, short circuits, or reverse current.

Modern PV installations utilize several types of inverters; each designed for a specific application. Standalone (off-grid) inverters are specifically for systems with no utility power, converting DC from solar panels or batteries for local use. Grid inverters are used in on-grid PV systems, synchronizing with the grid and feeding solar energy directly into it. They are equipped with anti-islanding protection to ensure the system safely disconnects when the grid is down. Hybrid inverters are a more versatile option that can manage energy flows between solar panels, battery storage, the grid, and local loads, combining the functions of both off-grid and grid-tied systems. Microinverters are small devices installed on each solar panel, converting DC to AC at the panel level, which can improve system performance and simplify troubleshooting.

Beyond their fundamental role in energy conversion, modern inverters serve as intelligent energy managers for the entire system. They perform crucial functions such as Maximum Power Point Tracking (MPPT), which ensures that solar panels operate at their highest possible efficiency to maximize power output. They also provide comprehensive monitoring and diagnostics, tracking power production and overall system health, which is essential for maintenance. Furthermore, inverters play a vital role in safety and grid compliance, ensuring the system meets utility and electrical safety standards. In off-grid or hybrid systems, they can also perform load management, prioritizing essential loads when power is limited (Kurtz, 2012).

Fig 2.3 *Felicity Solar 5kva 48v Hybrid Inverter with Inbuilt 6000W MPPT Controller*

2.2.5 Circuit Breakers

Circuit breakers are indispensable safety components within solar photovoltaic (PV) systems, serving a critical role in protecting the entire installation from electrical faults. Their primary function is to guard against the dangers of overcurrent and short circuits. Unlike fuses, which are single-use devices, circuit breakers can be reset after tripping, providing a reusable and reliable means of system protection. In a solar PV system, these breakers are strategically placed throughout the electrical path—between components such as the panels, inverters, and batteries—to ensure that power can be safely and instantly disconnected in the event of a fault. This ability to isolate a faulty section of the system is vital for preventing equipment damage and, most importantly, fire hazards.

The working principle of circuit breakers in a PV system is complicated by the nature of direct current (DC). Unlike alternating current (AC), which naturally drops to zero periodically, DC remains constant, making the suppression of an electrical arc a significant challenge. For this reason, circuit breakers designed for PV applications must be specifically rated for DC and feature enhanced arc-extinguishing capabilities (EE Times, 2025). The breaker operates by detecting abnormal current levels and then triggering a mechanical or electronic mechanism to interrupt the current flow, thereby protecting the system's wiring and equipment from overheating and potential fires.

There are several types of circuit breakers tailored for different PV applications. DC-rated miniature circuit breakers (MCBs) are a common choice for small to medium-sized systems. They are specifically engineered to handle DC arcs with increased contact separation. For larger-scale solar installations, molded case circuit breakers (MCCBs) are utilized. These offer higher current ratings and a more robust level of protection, often designed to withstand harsh environmental conditions (Chint Global, 2024). A more modern solution, the solid-state circuit breaker (SSCB), offers superior performance. These breakers use semiconductor technology to provide extremely fast tripping speeds and eliminate arcing entirely, making them highly reliable for sensitive, high-speed applications (Rubino et al., 2017).

Selecting the appropriate circuit breaker is a crucial step in system design. The choice depends on several factors, including the system's voltage, current rating, operating temperature range, and environmental conditions. Additionally, the type of installation (rooftop, off-grid, hybrid, etc.) must be considered. Beyond initial selection, proper maintenance is essential for ensuring the system remains safe and functional. Many modern breakers include monitoring features that allow for remote diagnostics and predictive maintenance, helping to identify potential issues before they become a hazard (Tongou, 2024).

Fig.2 4 A DC Miniature Circuit Breaker

2.2.6 Mounting Structures

Solar photovoltaic (PV) mounting structures are fundamental to the effective operation of any solar energy system. Beyond simply providing mechanical support for solar panels, these structures are responsible for securely positioning them at the correct tilt and orientation to maximize exposure to sunlight. A well-designed and properly installed mounting system is crucial for maximizing energy yield, safeguarding panels against physical damage, and enhancing the overall durability of the installation (Nijmeh et al., 2022). The specific choice of mounting system is determined by a variety of factors, including the installation location, system size, and prevailing environmental conditions.

The most common mounting systems are categorized by their location. Roof-mounted structures are a popular choice for residential and small commercial applications, as they efficiently utilize existing space. These can be categorized as fixed tilt, where panels are held at a constant angle; flush mounts, which keep panels parallel to the roof surface; or tilt-up mounts, which allow for seasonal angle adjustments to optimize performance. While roof-mounted systems reduce land use and are cost-effective, their viability can be limited by the roof's orientation or potential shading from nearby objects (PV Education, 2023).

For larger installations, two other types of structures are often employed. Ground-mounted systems are frequently used in utility-scale and large off-grid projects. These offer several advantages, including superior airflow for panel cooling, flexible spacing and orientation, and easier installation and maintenance. However, ground mounts require a significant amount of land and may necessitate civil engineering work like concrete foundations (Rahman et al., 2022). Pole-mounted structures, on the other hand, are typically reserved for standalone or remote PV systems, such as for street lighting or water pumps. They can be mounted on top of a pole or on the side, and often include tracking systems that follow the sun's path to significantly improve energy capture.

The materials used for these structures are also a key consideration, as they must withstand various environmental conditions. Galvanized steel is widely favored for its strength, corrosion resistance, and affordability. Aluminum is another option, valued for its lightweight nature and corrosion resistance, though it comes at a higher cost. Stainless steel provides the highest level of durability and is primarily used in harsh environments like marine or coastal applications where it must resist salt spray (Nijmeh et al., 2022). The selection of material is a critical aspect of ensuring the longevity and structural integrity of the entire PV system.

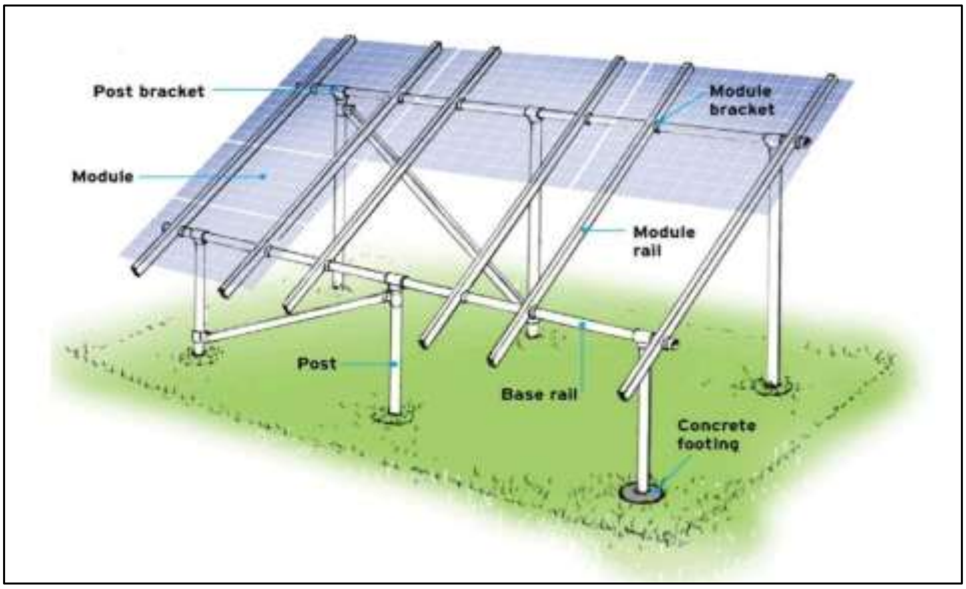


Fig 2.5 Well labeled view of component part of a mounting structure (Burdick, J., Schmidt, P.,2017)

2.2.7 Surge Protectors

Surge protectors, also known as surge protective devices (SPDs), are another critical safety component in solar photovoltaic (PV) systems. Their primary function is to protect electrical equipment from transient overvoltage, which is often caused by lightning strikes, grid disturbances, or switching operations (Khan et al., 2022). These devices are especially important in areas prone to thunderstorms or where sensitive electronics like inverters and controllers are installed.

The purpose of SPDs is to prevent severe damage to PV system components, such as inverter failure, data corruption, and fire hazards. They work by creating a short path to ground for high-voltage transients, diverting the excess voltage away from sensitive devices. They often utilize components like Metal Oxide Varistors (MOVs), Gas Discharge Tubes (GDTs), and Transient Voltage Suppression (TVS) diodes to achieve this. SPDs are strategically placed at various points in a PV system, including the DC side between the PV array and the inverter, the AC side between

the inverter and the distribution board, and on communication lines to protect monitoring and control systems (Kumar and Deb, 2021). This proper placement ensures that all components are shielded from both internal and external surge sources.

Fig 2.6 An AC Surge Protector (2P 20-40KA/275V)

2.2.8 Lightning Arrestors

Lightning arrestors are protective devices used to safeguard solar photovoltaic (PV) systems from high-voltage transients caused by lightning strikes. These devices operate by diverting surge energy safely to the ground, preventing electrical equipment damage, fire outbreaks, and system failures (Obayomi et al., 2023). In grid-connected or standalone PV systems—especially those deployed in lightning-prone regions—lightning arrestors form a first line of defense, complementing surge protective devices (SPDs) and grounding systems. Their primary purpose is to intercept and divert lightning surges, clamping voltage peaks to safe levels to protect sensitive components like inverters, batteries, charge controllers, and monitoring systems. They act within nanoseconds providing a low-impedance path to earth when the system detects a voltage surge above the breakdown voltage threshold (Daut et al., 2022).

Fig 2.7: 33kV-Lightning-Arrester.

Lightning arrestors are typically installed between conductor lines (AC or DC) and earth ground. When lightning-induced voltage exceeds a certain threshold, the arrestor conducts, shunting the current away from the circuit. Common materials used include Zinc oxide (ZnO) varistors, Silicon carbide, and spark gaps. Once the surge is discharged, the arrestor returns to its non-conductive state, allowing normal system operation to continue without interruption (Kumar & Rajeev, 2021). Lightning arrestors play a crucial safety role in PV installations, especially in areas with high lightning density. When combined with proper grounding and SPDs, they ensure system longevity, user safety, and equipment protection. Their installation should be guided by site-specific risk assessments, national codes, and international standards to ensure effective protection of the solar infrastructure

Fig 2.8 Solar cable 6mm² 2 in 1 cable (Zeus Electrical Limited brand)

2.2.9 Cables

Cables are essential for safely and efficiently transmitting electricity between components such as PV modules, inverters, batteries, and the grid. A poor cable choice can lead to significant power loss, overheating, and fire hazards (Sundaram & Narayanan, 2022). Various types of cables are used in PV systems, each with a specific function. DC cables connect the PV panels to the inverter and must be UV-resistant, weatherproof, and double-insulated, with ratings up to 1000−1500V DC. AC cables carry alternating current from the inverter to the load or grid and are typically 3-core or 5-core copper or aluminum cables rated for 230/400V AC. Earth cables are used to ground metal frames to prevent electric shock and safely carry fault currents, while communication cables (e.g., RS485, Ethernet) transmit monitoring and control data. Proper cable selection is critical and depends on several factors, including the required current capacity and limits on voltage drop (typically <2% for DC and <3% for AC).

2.2.10 Change-Over Switches

A changeover switch is a device that transfers electrical loads between two power sources, such as the utility supply and a generator, either manually or automatically. It enables quick switching during power failures, ensures proper isolation of power sources, and protects utility workers from electrical accidents. The main advantage is safe, fast, and efficient load transfer. Changeover switches are widely used, from simple home setups to complex industrial systems with multiple generators and grid connections.

2.2.11 Load Separation

Load separation is the practice of dividing electrical loads into groups (e.g., essential vs. non-essential, critical vs. non-critical, or by function). This improves reliability, safety, and efficiency by ensuring that vital loads can be backed up (with generators, batteries), non-essential loads can be shed during shortages, and circuits can be safely managed and optimized.

2.2.12 Total Connected Load

The total connected load refers to the sum of the power ratings of all electrical appliances and equipment intended to be powered by the system. It represents the theoretical maximum load assuming all devices operate simultaneously. Based on the load audit conducted for the Faculty of Engineering, the total connected load was found to be 75.66 kW. This value represents the cumulative power requirement of all identified loads within the system and serves as the initial reference point for further analysis.

2.2.13 Diversity Factor

The diversity factor (Df) accounts for the practical reality that not all electrical appliances or systems operate at the same time. It is defined as the ratio of the total connected load to the maximum demand and helps to adjust the theoretical load to a more realistic operational scenario. A higher diversity factor indicates that load usage is spread out over time, reducing the likelihood of simultaneous operation. For this project, a diversity factor of 0.98 was adopted. This value reflects the operational pattern of academic environments where various loads may overlap during peak hours but seldom run concurrently at full capacity.

2.2.14 Load Factor

The load factor (Lf) is the ratio of the average load to the peak load over a specific period. It indicates how effectively electrical energy is utilized within the system. A low load factor signifies uneven or intermittent use of power, while a higher value reflects more consistent and efficient utilization. Although the load factor was not directly employed in computing the design peak load, it played a supporting role in verifying the estimated load consistency derived from the load audit data.

2.2.15 Loss Allowance (Derating Factor)

In practical PV systems, some portion of energy is lost due to several factors such as cable resistance, inverter inefficiencies, temperature effects, and connection losses. To account for these, a 2.5% loss allowance (also known as a derating factor) was introduced into the design. This adjustment ensures that the system can maintain optimal operation despite unavoidable technical losses.

2.2.16 PV (Photovoltaic) combiner box

A PV (Photovoltaic) combiner box is an essential component in a solar power system that serves to combine the outputs of multiple solar panel strings into a single main output fed to a charge controller or inverter. It is primarily a safety and system management device that simplifies the wiring of a large solar array.

2.2.17 Operation Modes

In photovoltaic (PV) inverter systems, operation modes define how power flows between the solar array, batteries, the grid or generator, and connected loads. In grid-connected mode, the inverter supplies local loads and exports excess energy to the grid, while in stand-alone mode it operates independently, often supported by batteries or a generator. The hybrid mode integrates multiple sources, prioritizing solar before switching to stored or external power. Additionally, the inverter may enter battery charging or discharging modes to manage storage, while in emergency mode only essential loads are supplied. These modes collectively enhance the reliability, efficiency, and flexibility of PV systems in both on-grid and off-grid applications.

CHAPTER 3

DESIGN ANALYSIS

3.1 Introduction

This chapter presents a detailed design analysis of a standalone photovoltaic (PV) inverter system developed to supply electrical power to a selected load centre within the Faculty of Engineering. The analysis outlines the systematic procedures adopted to determine the appropriate sizes and capacities of the key system components, namely, the solar PV array, charge controller, battery storage, and inverter unit. Each of these components was carefully analyzed in terms of its functional role, efficiency, and compatibility to ensure the overall system performs optimally under local operating conditions.

The design process commenced with a comprehensive load assessment of the selected load centre. This involved identifying some electrical appliances (Light, Socket, and Fan), recording their respective power ratings, and estimating their daily usage to be 8hours (8 am-4 pm). From this data, the total daily energy demand was computed, which served as the foundation for sizing the PV array, battery bank, inverter, and charge controller. System losses and derating factors were also incorporated to enhance accuracy and reliability under real-world operating conditions.

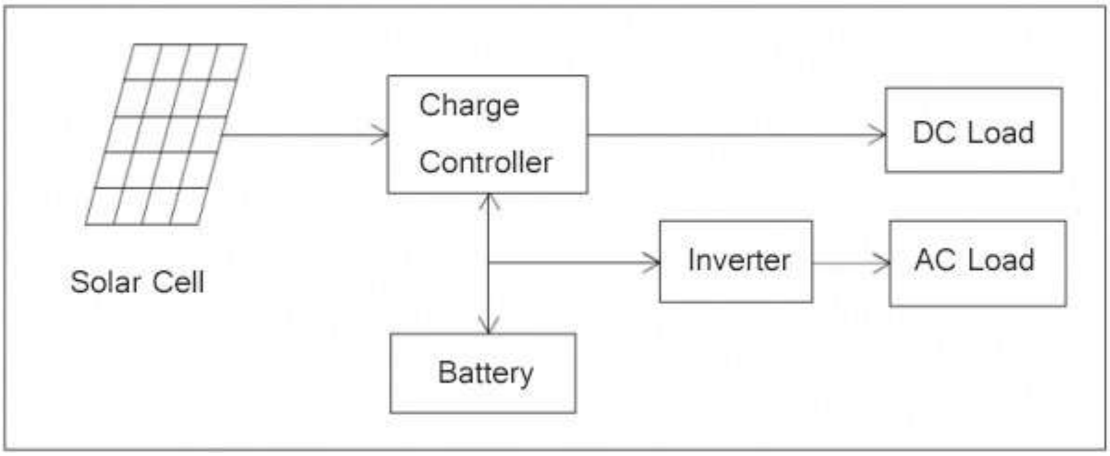


Fig 3.1: The Block Diagram of the system

3.1.1 Peak Load Estimation

After considering all influencing parameters, the peak load for the selected load centre was determined using the following relationship:

$$P_{peak} = P_{connected} \times Diversity\ Factor \times (1 + Loss\ Allowance)$$

Substituting the known values:

$$P_{peak} = 75.66 \times 0.98 \times (1 + 0.025) P_{peak} = 75.66 \times 1.0045 = 76.0\ kW$$

Therefore, the design peak load for the Faculty of Engineering load centre was calculated to be approximately 76.00 kW. This value serves as the primary basis for sizing the PV array, inverter, and battery bank components of the standalone PV inverter system.

In designing the standalone PV system, it was calculated that the total power consumption of the selected load centre was 76,000watts and it was to be operated for 8 hours daily, then the daily energy demand is given as:

$$E = P\ x\ t$$

Where:

E = Energy consumed (in watt-hours, Wh/day)

P = Power rating of the appliance (in watts, W)

t = Average hours of use per day

$$Energy\ demand = 76000\ x\ 8 = 608 kWh/day$$

The selected load centre requires approximately 608 kWh of energy per day.

3.2 Inverter Sizing

Inverter sizing is essential to ensure that the system can meet the total load demand efficiently and reliably. The inverter must be capable of handling the total connected load, surge (starting) power, and operational efficiency of the system. The rated capacity of the inverter should typically be 25–30% higher than the total load demand to account for transient surges and to ensure continuous operation under variable loading conditions.

The inverter capacity (P_{inv}) can be determined using the following relation:

$$P_{inv} = P_{load} \times F_s$$

where:

P_{inv}= inverter rated power (kW)

P_{load}= total load demand (kW)

F_s= safety factor (1.25–1.30)

For this design, the total connected load is 76 kW, and a safety factor of 1.25 is used to accommodate surge power and inverter losses. Thus:

$$P_{inv} = 76 \times 1.25 = 95\ kW$$

Hence, the required inverter capacity is approximately 95 kW. However, to ensure robustness and future expansion, a 100 kW inverter is recommended

Key specifications for inverter selection include:

A pure sine wave inverter is use in this design because it provides a high-quality AC output waveform that is compatible with sensitive electronic devices, motors, and inductive loads. It also ensures reduced harmonic distortion, higher efficiency, and longer equipment lifespan.

For a system of this capacity, a three-phase inverter configuration is ideal to distribute the load evenly and minimize current imbalance. The inverter should also include protection features such as overload protection, short-circuit protection, low-voltage disconnection, and over-temperature shutdown.

Parameter	Symbol	Value	Unit
Total Load Demand	P_{load}	76	kW
Safety Factor	F_s	1.25	–
Inverter Capacity	P_{inv}	95	kW
System DC Voltage	V_{DC}	240	V
AC Output Voltage	V_{AC}	230/400	V
Frequency	f	50	Hz
Inverter Type	–	Pure Sine Wave	–
Efficiency	η_{inv}	≥ 0.9	–

Table 3.1: Inverter Specification

It is also important to select an inverter that matches the system DC voltage. Since the battery would operate at 48 V DC, the inverter should have a compatible DC input of 48 V and an AC output of 230/400 V at 50 Hz, suitable for standard electrical loads.

Hence, the required inverter capacity is approximately 100 kW. However, to ensure robustness and future expansion ten (10) FELICTY 10KVA pure sine wave inverter 48V was selected for the design to be connected in parallel to meet the required power, and it has an efficiency of 95%. Price for each unit is #1,500,000, totaling #15,000,000 for 10 units.

Therefore, for this standalone PV system, a 100kW pure sine wave, three-phase inverter operating at 48V DC input and 240V AC output is used to ensure efficient energy conversion, stability, and reliability for the 76 kW load centre in the Faculty of Engineering.

3.3 Battery Sizing

The total battery capacity required depends on the daily energy demand(E_{load}), the system voltage (V_{sys}), the depth of discharge (DOD), the battery efficiency (η_{bat}), and the days of autonomy (D_{aut})that is, the number of days the system should operate without sunlight.

The general equation for sizing the battery capacity is given by:

$$C_{bat} = \frac{E_{load} \times D_{aut}}{V_{sys} \times DOD \times \eta_{bat}}$$

where:

- C_{bat}= required battery capacity (Ah)
- E_{load}= daily energy demand (Wh)
- D_{aut}= days of autonomy (days)
- V_{sys}= DC system voltage (V)
- DOD= depth of discharge (fraction)
- η_{bat}= battery efficiency (fraction)

3.3.1 Design Parameters

For this design, the following parameters were extracted from the Felicity battery datasheet:

Parameter	Symbol	Value	Unit
Daily Load Demand	E_{load}	608,000	Wh/day
Days of Autonomy	D_{aut}	1	days
System Voltage	V_{sys}	48	V
Depth of Discharge	DOD	0.95	–
Battery Efficiency	η_{bat}	0.85	–

Table 3.2: Felicity Battery Datasheet

3.6.3 Substitution into the Formula

Substituting the above values into the battery sizing equation:

$$C_{bat} = \frac{608{,}000 \times 1}{48 \times 0.95 \times 0.85} C_{bat} = \frac{608{,}000}{38.76} = 15{,}686.27\ Ah$$

Therefore, the total required battery capacity is approximately 15,700 Ah at 48 V DC.

3.3.2 Determining the Number of Batteries

With the use of the selected 48V, 250 Ah Felicity deep-cycle batteries

To achieve the required capacity of 15,700 Ah, the number of parallel strings is:

$$N_{parallel} = \frac{15{,}700}{250} = 62.8 \approx\ 63\ numbers$$

Hence, the total number of batteries required is:

$$N_{total} = 63\ batteries$$

Hence, the Felicity 48V 250AH battery is used for the design with a lifecycle of less than or equal to 6000. Each unit of this battery costs #2,600,000, totaling #163,800,000 for the required 63 units.

3.3.3 Design Summary

Parameter	Symbol	Value	Unit
Required Energy Storage	$E_{load} \times D_{aut}$	608,000	Wh
System Voltage	V_{sys}	48	V
Battery Capacity	C_{bat}	15,700	Ah
Battery Rating	–	48 V, 250 Ah	–
Battery Product		Felicity	–
Parallel Strings	$N_{parallel}$	63	–
Total Batteries	N_{total}	63	–
Recommended Type	–	Deep-cycle LiFePO4	–

Table 3.3: Battery Specification

3.3.4 Battery Charge Modeling for 3-Hour Full Charge

To model the system, we first need to calculate the battery and MPPT changing inefficiencies.

$$E_{bat,input} = \frac{E_{load}}{\eta_{bat}\ x\ \eta_{MPPT}} = \frac{608}{0.85\ x\ 0.95} = 752.94kWh$$

$$E_{bat,input} = P_{load}\ x\ t_c\ = 76\ x\ 3 = 228kWh$$

Accounting for inverter losses (to supply AC load):

$$E_{load,eff} = \frac{E_{load,3h}}{\eta_{inv}} = \frac{228}{0.95} = 240kWh$$

Total PV energy required over the 3 hours

Sum battery charging energy + load energy

$E_{bat,input} + E_{load,eff}$ = 752.94 + 240 = 992.94kWh

To get the required PV power in kW

$$P_{PV} = \frac{E_{load}}{H_s \times \eta_{sys}} = \frac{992.94}{4.66\ x\ 0.85} \approx\ 250.7kW$$

The system required $250.7kW$ to fully charge in 3 hours while the 76kW load was running.

The computed PV capacity is approximately $250.7kW$, which is rounded up to $251kW$ to ensure adequate energy generation and to allow for possible system losses, dust accumulation, and component aging.

Therefore, the PV array capacity required to meet the 952.82 kWh/day energy demand is 303 kW.

To determine the number of PV modules required, the capacity of each panel must be considered. Wth the use of 500 W (0.5 kW) rated PV modules, the number of panels needed is calculated as:

$$Number\ of\ panels = \frac{251}{0.5} = 502\ panels$$

Hence, a total of 502 PV panels rated at 500 W each will be required to supply the load demand effectively under the given site conditions. Selecting Jinko 500W Solar Panel with a unit cost of #120,000. 502 panels total #60,240,000.

3.4 Charge Controller Sizing

The charge controller is an essential component in a standalone photovoltaic (PV) system. It regulates the flow of electrical energy between the PV array and the battery bank, ensuring that the batteries are charged efficiently and protected from both overcharging and deep discharging. Proper sizing of the charge controller is critical for maintaining system reliability and extending battery life.

The charge controller's current rating must be sufficient to handle the maximum current produced by the PV array under peak sunlight conditions. The required charge controller current capacity can be calculated using the relation:

$$I_C = \frac{P_{PV}}{V_{system}}$$

where:

I_C= rated current of the charge controller (A)

P_{PV}= total power output of the PV array (W)

V_{system}= nominal DC system voltage (V)

Given the PV array capacity of 251 kW (251,000 W) and assuming a DC system voltage of 48V, the charge controller current is calculated as:

$$I_C = \frac{251{,}000}{48} = 5229.17\ A$$

Therefore, the charge controller must be capable of handling at least 5229.17 of current. However, it is standard engineering practice to include a safety margin of 25% to account for possible current surges due to variations in sunlight intensity and system efficiency losses. Applying this factor gives:

$$I_{C(rated)} = 1.25 \times\ 5229.17 = 6536.46\ A$$

Hence, a charge controller rated at approximately$6536.46\ A$ is selected for this system.

120A MPPT charge controller would be paralleled to arrive at this value;

$6536.46\ A/120$ A = 54.47 units = approximately 55 units

Fifty-five (55) 120A Felicity MPPT charge controllers would be paralleled to safely and efficiently supply the system's required current. Each unit costs #230,000 with a total cost of #12,650,000

This ensures efficient energy transfer from the PV array to the battery bank, protects the batteries from overcharging and deep discharging, and contributes to the overall stability and reliability of the standalone PV system.

3.5 System Configuration in HOMER Pro

The standalone PV system was modeled in HOMER Pro software with these components: 303kW PV array, 15,700AH 48V battery, 100 kW inverter, and a 76 kW load. The system was simulated using NASA solar data with 4.66 kWh/m²/day irradiance. Optimization was performed to evaluate system performance, cost, and reliability.

3.6 Protection Devices

To ensure safe and reliable operation, several protection devices were integrated into the photovoltaic (PV) hybrid power system. These devices guard the system against short circuits, overcurrent, and voltage surges that could cause equipment failure or power interruption. All DC circuits especially the PV array and battery lines use DC-rated breakers and fuses, while AC-rated devices protect the inverter output.

3.6.1 PV Combiner to MPPT DC Breaker

A DC circuit breaker was installed between the PV combiner box and the MPPT charge controller. This breaker protects both the PV trunk cable and the MPPT input from overcurrent. The total current from the PV array was calculated as 5229A, and by applying a 25% safety margin, the breaker current rating became 6536. A. Hence, a 50 A DC circuit breaker was selected. This provides effective protection and allows safe isolation of the PV array during maintenance.

3.6.2 Inverter DC Breaker (Battery to Inverter)

Inverter DC breaker was placed between the battery bank and the inverter to protect the DC cables and enable easy disconnection when needed. The inverter’s DC input current was found to be 129.63 A. After applying a 25% safety factor, the calculated rating was 162.04 A. Therefore, a 200A DC breaker was chosen as the standard size to ensure safe operation of the inverter circuit.

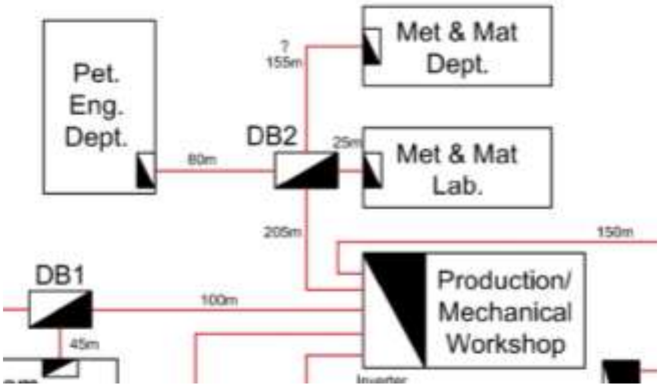


Fig.3.2: Block Diagram of the load distribution to the various centres

3.6.3 AC-Side Breaker (Inverter Output)

On the AC side, the inverter produces 100 kVA at 220 V as we used ten (10) 10kVA Felicity Inverters, corresponding to an output current of 454.55 A 500A AC miniature circuit breaker (MCB) was therefore selected to protect the inverter’s output and connected loads from overcurrent or short-circuit faults. Therefore, the incomer breaker of DB2 as seen in fig 3.1 was set as 500A.

The incoming circuit breaker of the three (3) DB’s at the three centres were sized with the equation below;

For Met. and Mat. Department:

Load = 32,325W at 220V supply

Current = 32,325/220 =146.9A

Including safety factor of 1.45, 146.9* 1.45 =213A

The size of circuit breaker chosen was a 250A Schneider Electric 4-pole circuit breaker with a unit cost of #51,800.

For Met and Mat Laboratory:

Load = 22,068V at 220V supply

Current = 22,068/220 =100.3A

Including safety factor of 1.45, 100.3 * 1.45 = 145A

The size of circuit breaker chosen was a 150A Suntree 3-pole circuit breaker with a unit cost of #43,629

For Petroleum Department:

Load = 32,325W at 220V supply

Current = 21,267/220 =96.7A

Including safety factor of 1.45, 96.7* 1.45 =140A

The size of circuit breaker chosen was a 150A Suntree 3-pole circuit breaker with a unit cost of #43,629.

3.6.4 Surge Protection Devices (SPDs)

To safeguard the system against lightning and switching surges, surge protection devices were installed at key points. On the PV side, a Type II DC SPD rated between 100 V and 150 V DC with a minimum surge capacity of 10 kA was mounted at the PV combiner box. On the battery side, an optional DC SPD was added near the battery bank to protect sensitive electronics. On the AC side, a Type II AC SPD rated 230/275 V AC with a surge capacity of 10–20 kA was installed at the inverter output or main distribution board. These SPDs collectively ensure comprehensive protection against transient overvoltage.

3.7 Cable Sizing for DC Circuits

Proper cable sizing minimizes voltage drop, power loss, and heating in DC circuits. The required cross-sectional area of each cable was calculated using the standard voltage-drop formula:

Cable size can be calculated using the following formula:

$$A = \frac{I \; x \; L \; x \; \rho \; x \; 2}{k \; x \; Vd}$$

Where A = cross-section (mm²), I = current (A), L = length (m), ρ = 0.0175 Ω·mm²/m (resistivity of copper)*, Vd = allowable voltage drop (V).*

3.7.1 PV Trunk Cable (Combiner to MPPT)

For the PV trunk line, the total array current is 38 A, with a one-way distance of 10 m and an allowable voltage drop of 2.22 V. Substituting into the formula gives: A = (2 × 10 × 38 × 0.0175) / 2.22 = 5.99 mm². To provide additional margin and reduce heating, a 10 mm² PV-rated copper cable was selected. This size also meets the mechanical robustness and outdoor durability requirements of IEC 62548 and NEC 690 standards.

3.7.2 Battery Cable (MPPT to Battery)

The cable connecting the MPPT to the battery bank carries approximately 116.67 A of charging current over a 2 m one-way distance, with an allowable voltage drop of 0.72 V. The required cross-sectional area was calculated as: A = (2 × 2 × 116.67 × 0.0175) / 0.72 = 11.34 mm².

Summary of Selected Components

Location	Device	Rating	Type/Specification	Installation Point
PV Combiner → MPPT	DC Breaker	50 A	PV-rated	Between combiner and MPPT
Battery → Inverter	DC Breaker	200 A	Battery-rated	On battery positive line
Inverter Output	AC Breaker	500A	AC MCB	Inverter output
PV Array	SPD (DC)	100–150 V DC, 10 kA	Type II	Combiner box
Battery Bank	SPD (DC)	Optional	Type II	Near battery
AC Distribution	SPD (AC)	230/275 V AC, 10–20 kA	Type II	Distribution board
PV Trunk Cable	Cable	10 mm²	PV-rated Copper	Combiner → MPPT
Battery Cable	Cable	16 mm²	Flexible Tinned Copper	MPPT → Battery

Table 3.4: Cable Specification

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

In designing any solar power system, it is very important to estimate the total electrical load that the system will supply. Load estimation helps to determine how much energy is needed daily and guides the proper sizing of components such as the inverter, batteries, and solar panels.

In this project, the load estimation was carried out for three main areas within the Faculty of Engineering: the Metallurgical and Materials Engineering Department, the Metallurgical and Materials Engineering Laboratory, and the Petroleum Engineering Department. The equipment considered includes lighting, 13A sockets, and ceiling fans, which are the major electrical loads used in these locations.

Fig 4.1: Geographical Location of the Study Area

Each load category was analyzed based on the quantity, rated power (in watts), and load factor to calculate the total power consumption in watts. The total load for each section was then converted to an equivalent current value at 220 V, which represents the normal supply voltage for the building.

This analysis provides a clear understanding of the total energy demand and forms the basis for sizing the solar PV components appropriately in the later stages of the system design.

S/N	MET & MAT DEPARTMENT	QTY	RATINGS	LOAD FACTOR	CONSUMPTION
1	Lightings	172	40	0.9	6,192.00
2	13A Sockets	146	200	0.6	17,520.00
3	Fans	58	165	0.9	8,613.00
	Subtotal Met & Mat Dept				32,325.00
	Load @ 220V				**146.93**

Table 3.5: Load audit for Metallurgical and Materials Engineering Department

S/N	MET & MAT LABORATORY	QTY	RATING	LOAD FACTOR	CONSUMPTION
1	Lightings	154	40	0.9	5544
2	13A Sockets	108	200	0.6	12,960
3	Fans	24	165	0.9	3,564
	Subtotal Met & Mat Lab				22,068.00
	Load @ 220V				**100.31**

Table 3.6: Load audit for Metallurgical and Materials Engineering Laboratory

S/N	PETROLEUM DEPARTMENT	QTY	RATINGS	LOAD FACTOR	CONSUMPTION
1	Lightings	87	40	0.9	3,132
2	13A Sockets	114	200	0.6	13,680
3	Fans	30	165	0.9	4,455
	Subtotal Petroleum				21,267.00
	Load @ 220V				**96.67**

Table 3.7: Load audit for Petroleum Department

S/N	SUBTOTAL	CONSUMPTION(Watts)
1	Subtotal Met & Mat Dept	32,325.00
2	Subtotal Met & Mat Lab	22,068.00
3	**Subtotal Petroleum**	21,267.00
	Total	75,660

Table 3.8: Summarizing of the load analysis

In designing the standalone PV system we calculated the total power consumption of the selected load centre to be 76,000watts and its operation to be 8 hours daily.

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.582	5.430
February	0.555	5.490
March	0.516	5.350
April	0.485	5.060
May	0.467	4.750
June	0.425	4.230
July	0.356	3.570
August	0.348	3.570
September	0.370	3.820
October	0.439	4.380
November	0.529	4.990
December	0.575	5.240

Annual Average (kWh/m²/day): 4.66

Downloaded at 22/10/2025 11:26:11 from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 96185
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 6.5
CellMidpointLongitude: 5.5

Scaled Annual Average (kWh/m²/da: 4.66

Fig 4.2: Monthly Average Solar Global Horizontal Irradiance (GHI) Data

The design of a reliable standalone Photovoltaic (PV) system relies fundamentally on the Monthly Average Solar Global Horizontal Irradiance (GHI) data for the site $(Lat\ 6.5°N, Lon\ 5.5°\ E)$. The location demonstrates a strong overall resource with an annual average GHI of $4.66kWh/m^2/day$, confirming system viability.

However, the system's year-round reliability is constrained by seasonal variations. The critical design month is August, which registers the lowest Daily Radiation (or Peak Sun Hours, PSH) at just $3.570kWh/m^2/day$. This minimum PSH value shows the system battery would be charged up to 89.25% of the total capacity during this month which is still good for the system.

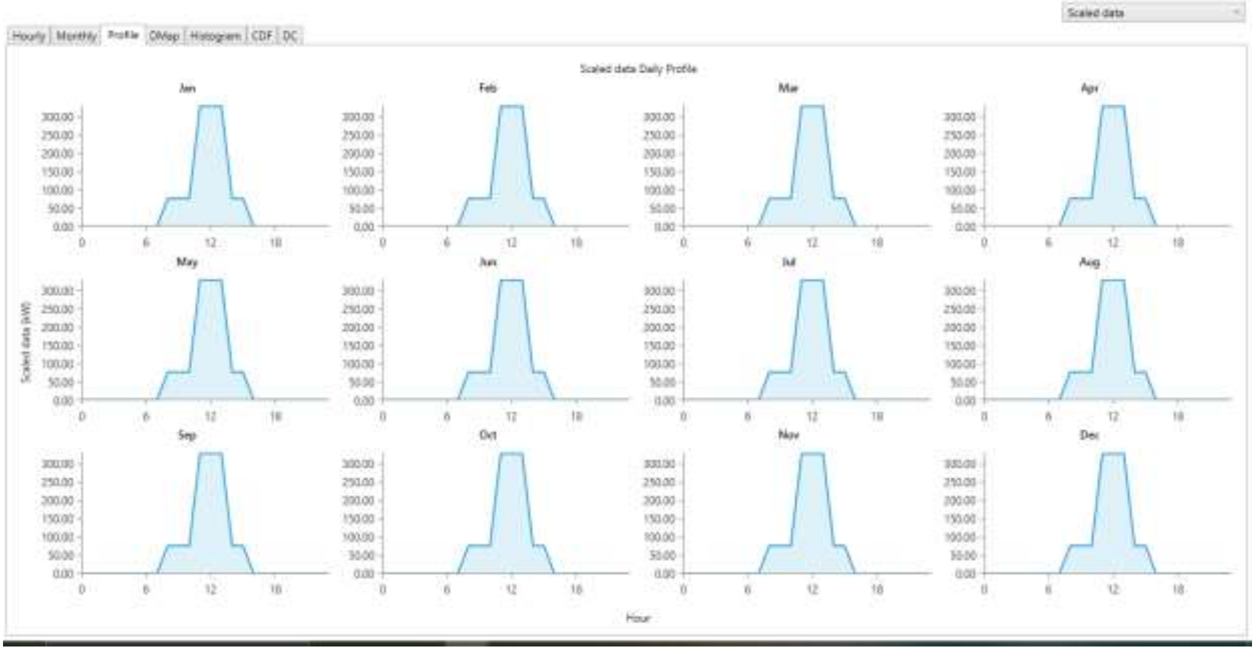


Fig 4.3: Time Series Detail Analysis

The image titled "Time Series Detail Analysis" presents a grid of twelve plots, one for each month from January to December, showing daily profiles of scaled data across 24 hours.

Name: Electric Load #1

January Profile

Hour	Load (kW)
6	0.000
7	0.000
8	76.000
9	76.000
10	76.000
11	328.000
12	328.000
13	328.000
14	76.000
15	76.000
16	0.000

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 0.2

Timestep (%): 0.1

Peak Month: **None**

Metric	Baseline	Scaled
Average (kWh/d)	1,364	1,364
Average (kW)	56.83	56.83
Peak (kW)	330.43	330.43
Load Factor	.17	.17

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost (₦): 0

Lifetime (yr): 10

Scaled Annual Average (kWh/d): 1,364.00

Fig 4.4: Electric Load

This image provides a comprehensive overview of the electric consumption pattern for a device or system labelled "Electric Load", using four distinct visualizations that span different time scales: hourly, daily, monthly, and yearly

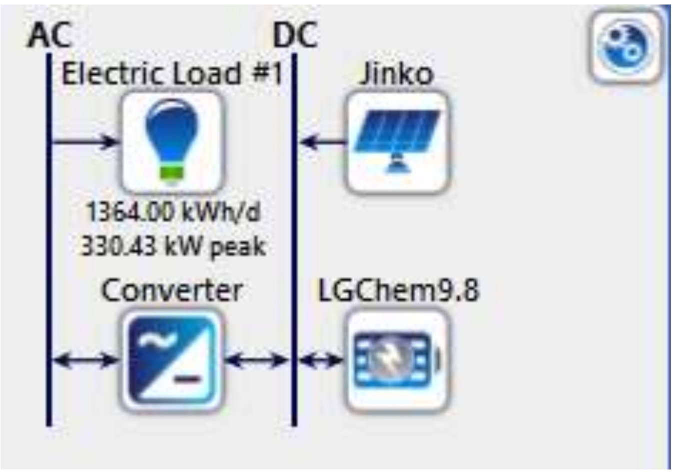


Fig 4.5: Schematic diagram

The schematic diagram illustrates the configuration and energy flow of the standalone photovoltaic (PV) inverter system designed for the selected load centre within the Faculty of Engineering. It highlights how solar energy is generated, stored, converted, and utilized to supply electrical power independently of the national grid.

On the DC side, the Jinko solar panels capture solar radiation and convert it into DC electricity, which is then stored in LGChem9.8 batteries for continuous power availability, even during periods without sunlight.

At the centre of the system, a converter (inverter) transforms the stored DC energy into AC power, making it suitable for use by conventional electrical equipment.

On the AC side, the generated power is supplied to the selected load centre, represented as *Electric Load*, with an estimated daily energy consumption of 1364.00 kWh and a peak demand of 330.43kW.

This configuration demonstrates a reliable, efficient, and renewable energy solution capable of meeting the faculty’s energy needs while promoting sustainability and reducing dependence on the conventional power grid.

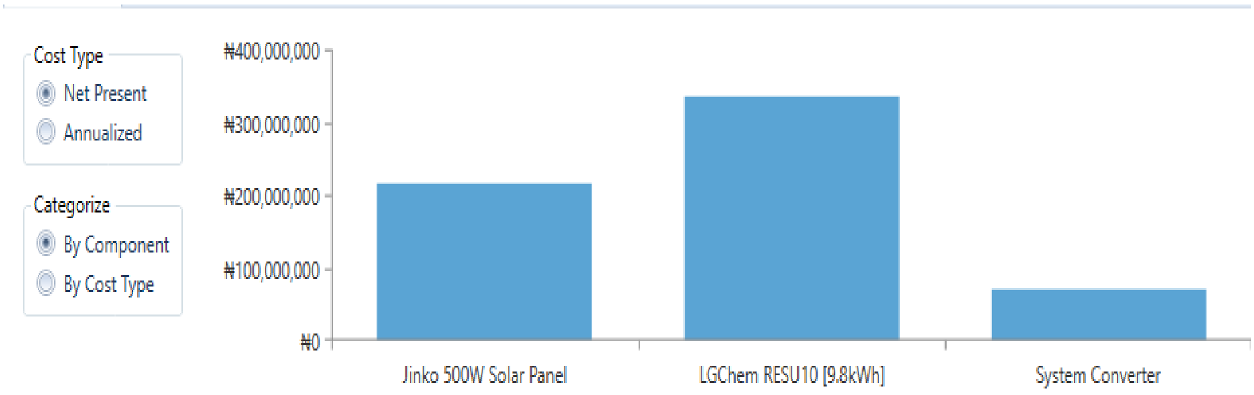
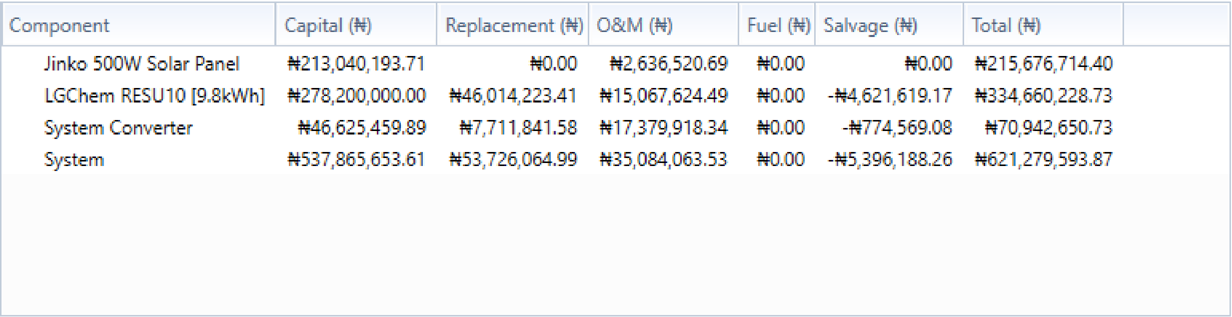


Fig 4.6: The Summary of the System Cost by Component

The bar chart provides a financial breakdown of three key components in a solar power system, helping to visualize their relative costs in Nigerian Naira (₦). It compares both **Net Present Cost** and **Annualized Cost** for each item, offering insight into both upfront investment and long-term financial impact.



Component	Capital (₦)	Replacement (₦)	O&M (₦)	Fuel (₦)	Salvage (₦)	Total (₦)
Jinko 500W Solar Panel	₦213,040,193.71	₦0.00	₦2,636,520.69	₦0.00	₦0.00	₦215,676,714.40
LGChem RESU10 [9.8kWh]	₦278,200,000.00	₦46,014,223.41	₦15,067,624.49	₦0.00	-₦4,621,619.17	₦334,660,228.73
System Converter	₦46,625,459.89	₦7,711,841.58	₦17,379,918.34	₦0.00	-₦774,569.08	₦70,942,650.73
System	₦537,865,653.61	₦53,726,064.99	₦35,084,063.53	₦0.00	-₦5,396,188.26	₦621,279,593.87

Total NPC: ₦648,349,800.00

Levelized COE: ₦143.47

Operating Cost: ₦12,171,830.00

Fig 4.7: Economic Evaluation and Payback Period Analysis

This section presents the economic evaluation and period analysis of the designed hybrid solar power system. It evaluates the capital cost, replacement cost, operation and maintenance (O&M) cost, and salvage value of the major components. Based on these financial parameters, the payback period, return on investment (ROI), and cost-s payback having strategies are presented.

Cost Breakdown Summary

Component	Capital (₦)	Replacement (₦)	O&M (₦)	Salvage (₦)	Total (₦)
Jinko 500W Solar Panel	213,040,193.71	0.00	2,636,520.69	0.00	215,676,714.40
System Converter	46,625,459.89	7,711,841.58	17,379,918.34	-774,569.08	70,942,650.73
LGChem RESU10 [9.8kWh]	278,200,000.00	46,014,223.41	15,067,624.49	-4,621,619.17	334,6609,228.73
Total System Cost	537,865,653.61	53,726,064.99	35,084,063.53	-5,396,188.26	621,279,593.87

Table 4.1: Cost Breakdown Summary

The total system cost is estimated at ₦621,279,593.87 which includes the capital, O&M, and replacement costs after considering the salvage value.

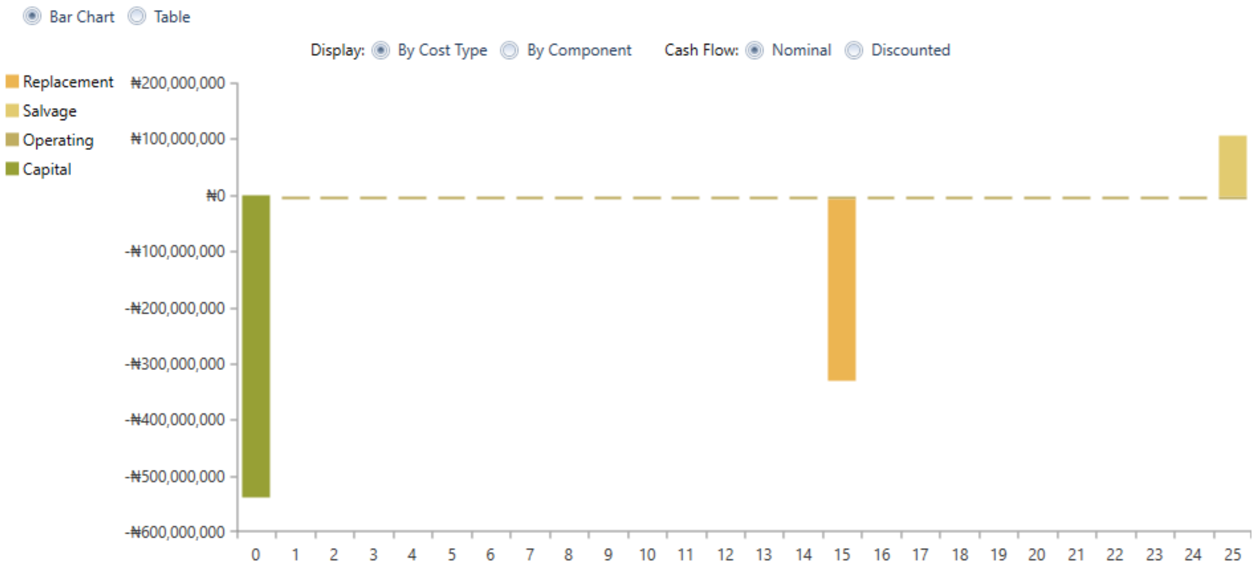


Fig 4.8: Cost analysis over 25years

Payback Period Estimation

The payback period is the time required for the total savings generated by the solar system to equal the initial investment. The calculation is based on the daily and annual energy consumption and the current grid electricity rate.

Daily energy consumption = 608 kWh

Annual energy consumption = 608 × 365 = 221,920 kWh/year

Electricity rate = ₦209.67/kW

Annual Cost per year (at ₦209.50/kWh) = 221,920 × ₦209.50 = ₦46,520,240

Total System Cost   ₦621,279,593.87

Payback Period = ₦621,279,593.87 ÷ ₦46,520,240 ≈ = 13.4 years

25-Year ROI

Total 25-year savings = 46.52M × 25 = ₦1,163 million

Net gain = 1,163M – 621,279,593.87 = ₦541,720,406.13

ROI = (1,163M ÷ 621,279,593.87) × 100 ≈187.19%

ROI ≈ 187.19% over 25 years

Therefore, the system has a payback period of approximately 13.4years, indicating a rapid return on investment and strong financial feasibility.

Return on Investment (ROI)

If the system operates for 25 years with annual savings of ₦46,520,240 million, the total savings will be ₦541,720,406.13.

The levelized cost of energy using the PV system is ₦143.47, which is lower than the cost of the utility grid of ₦209.5. This represents an ROI of over 187.19%, demonstrating that the project is both sustainable and economically rewarding.

Summary of Findings

This study presented the design, economic evaluation, and performance analysis of a 76-kW standalone photovoltaic (PV) solar power system designed to supply electricity to selected load centres within the Faculty of Engineering. The system was developed to meet a total daily energy demand of 929.15 kWh, covering the combined load requirements of the Mechanical/Materials (Met & Mat) and Petroleum Engineering Departments.

The load assessment revealed that the Met & Mat Department consumed approximately 32.33 kWh, the Met & Mat Laboratory consumed 22.07 kWh, and the Petroleum Department consumed 21.27 kWh, resulting in the total estimated load of 76.58 kW. These values formed the basis for sizing the PV array, battery storage, and converter systems.

Economic analysis of the system was carried out using updated cost data for the Jinko 500W solar panels, Trojan SAGM 12-105 batteries, and a system converter, leading to a total system cost of approximately ₦621,279,593.87 When evaluated under the Band A electricity tariff of ₦209.50/kWh, the system achieves annual savings of about ₦541,720,406.13. Consequently, the simple payback period was calculated to be approximately 13.4 years, indicating a highly attractive financial return.

Further analysis of the system's lifetime performance over 25 years shows a net gain of ₦1.163 billion and an overall Return on Investment (ROI) of over 187.19%, and the levelized cost of energy using the system achieves a much lower rate with a difference of confirming that the system is not only technically feasible but also economically superior to grid electricity in the long term.

Technically, the system demonstrates high efficiency through proper component selection, appropriate cable sizing, and the inclusion of protective devices. The DC subsystem ensures effective solar energy capture and storage, while the AC subsystem provides stable and clean energy to connected loads. The system also emphasizes sustainability, reliability, and cost-effectiveness, aligning with Nigeria's renewable energy development goals.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The design and analysis of the 76-kW standalone PV solar system proved that renewable energy technologies can effectively bridge the power supply gap in academic institutions. The results show that solar energy is a valuable alternative to grid electricity and diesel-powered generators, offering substantial savings in operational costs, zero carbon emissions, and improved energy reliability.

The system's short payback period and high ROI demonstrate that the project is both technically sound and financially sustainable. It supports uninterrupted academic and research activities while reducing the institution's dependency on the national grid. The project also serves as a model for implementing similar renewable energy systems in other faculties and universities across Nigeria.

Overall, this research confirms that solar power systems, when properly designed and maintained, can serve as long-term, cost-effective, and environmentally friendly solutions for institutional energy needs.

5.2 Recommendations

Based on the technical and economic findings of this study, the following recommendations are made:

1. Adoption of Standalone PV Systems for Institutional Power Supply: The faculty should adopt the designed Standalone PV system as a primary power source, as it provides a rapid payback and reliable energy supply.

2. Preventive and Scheduled Maintenance: Routine maintenance, such as cleaning of solar panels, battery inspection, and inverter checks, should be conducted regularly to sustain high system efficiency and extend component lifespan.

3. Provision for Component Replacement: To ensure long-term reliability, provisions should be made for battery and converter replacement around their mid-life (typically 10–12 years) as part of a preventive maintenance plan.

4. Expansion and Replication: The success of this project should encourage the university management to replicate similar solar installations in other departments and administrative units to achieve full energy independence.

5. Smart Monitoring and Energy Management: Incorporating digital monitoring systems will enable real-time tracking of power generation, battery health, and load consumption. This will improve maintenance scheduling and system performance.

6. Training and Capacity Building: Local technicians and engineering students should be trained in the operation, maintenance, and troubleshooting of PV systems to build institutional expertise and reduce outsourcing costs.

7. Encouragement of Public–Private Partnerships (PPP): The government and private investors should collaborate with universities to expand renewable energy deployment, using such systems as models for sustainable campus electrification,

REFERENCES

A. A. Abdallah & O. B. Odeleke., 2023. *Energy Security in Nigeria: Challenges and Prospects" Journal of Arid Zone Economy 1(1):101 – 111.*

Akinsanmi, O., Omodunbi, B. & Ayeoribe, O.P., 2023. *Design and implementation of a standalone 3.5 kVA solar PV system. International Journal of Electrical and Electronics Research, 11(2), pp.45–56.*

Akinyele, D.O., Rayudu, R.K., and Folly, K.A., 2020. *A review of energy storage technologies for renewable energy systems. Renewable and Sustainable Energy Reviews, 67, pp.935–951.*

Burdick, J. And Schmidt, P. (2017), Install your own solar panels: designing and installing a photovoltaic system to power your home, Storey [online], Available at https://www.storey.com/freshpicks [Accessed 25 June 2025].

Charles, O. And Edeko, F.0. (2016) Design and implementation of a solar charge controller with variable output

Chint Global, 2024. *Explore the Best HV MCCB for PV Power Plants. [online].*

Daut, I., Ibrahim, H., Irwan, Y.M., and Adzman, M.R., 2022. *Lightning Protection for Large-Scale Photovoltaic Power Plants: Design and Review. Renewable Energy, 198, pp.1147–1155.*

De Rooij, D., n.d. *Circuit Breakers in PV Systems. [online] Sinovoltaics. Available at: https://sinovoltaics.com/learning-center/system-design/circuit-breakers-in-pv-systems/.*

EE Times, 2025. *Circuit protection design for photovoltaic power systems. [online].*

Fraunhofer ISE, 2021. *Photovoltaics Report. [online] Available at: https://www.ise.fraunhofer.de [Accessed 7 Aug. 2025].*

Gonçalves, J.M., Lopes, J.A. and Pinto, M.G., 2021. *Design methodology for standalone PV systems with battery storage. Energy Reports, 7, pp.612–626.*

Green, M.A., 2020. *Photovoltaic technology and visions for the future. Progress in Energy, 2(1), p.012002.*

Hamza, H.A., Auwal, Y.M. and sSharpson, M.I., 2018. *Standalone PV system design and sizing for a household in Gombe, Nigeria. International Journal of Interdisciplinary Research and Innovations, 6(1), pp.96–101. Available at: http://www.researchpublish.com [Accessed 22 September 2025]*.

Ikechukwu, I.F. and Chibueze, P., 2022. *Techno-Economic Viability Assessment of Standalone Solar PV System for Rural Electric Power Supply. Journal of Applied Sciences and Environmental Management, 26(2), pp.287–294. Doi:10.4314/jasem.v26i2.17.*

Intergovernmental Panel on Climate Change (IPCC), 2021. AR6 Climate Change 2021: The Physical Science Basis. [online] Available at: https://www.ipcc.ch/report/ar6/wg1/ [Accessed 8 Aug. 2025].

International Energy Agency (IEA), 2021. *Trends in Photovoltaic Applications. [online] Available at: https://www.iea.org [Accessed 7 Aug. 2025]*.

International Renewable Energy Agency (IRENA), 2025. *91% of new renewable energy projects are cheaper than fossil fuels*. Reuters, 22 July. Available at: https://www.reuters.com/business/energy/around-90-renewables-cheaper-than-fossil-fuels-worldwide-irena-says-2025-07-22 [Accessed 23 Jul. 2025].

Ishaq, M., Ibrahim, U.H., Abubakar, H. and Baba, A.A., 2013. *Computer-aided design of a stand-alone photovoltaic system: A case study of Faculty of Engineering, Bayero University Kano. Academic Research International, 4(3), pp.322–331.*

Khan, A., Wang, Y., and Lin, T., 2022. *Protection of solar PV systems against transient overvoltages using advanced surge protective devices. IEEE Transactions on Power Delivery, 37(1), pp.168–176.*

Kumar, R. and Deb, A., 2021. *A study on the effectiveness of surge protection systems in residential photovoltaic setups. Renewable Energy, 179, pp.1020–1030.*

Kumar, R. and Rajeev, P., 2021. *Comparative Performance Analysis of Surge and Lightning Arrestors in Solar PV Systems. IEEE Access, 9, pp.76450–76459.*

Kurtz, S., 2012. *Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Industry. National Renewable Energy Laboratory (NREL).*

Nigerian Electricity Regulatory Commission (NERC), 2024. Tariff Review for Band A Customers. [online] Available at: https://nerc.gov.ng/news-updates/band-a-tariff-review-april-2024 [Accessed 23 Jul. 2025].

Nijmeh, S., Hassan, H., and Aldabbas, H., 2022. *Structural considerations for PV mounting systems in urban installations. Renewable Energy, 187, pp.567–575.*

Obayomi, J., Agboola, A.O. and Olorunfemi, J., 2023. *A Review of Lightning Protection Systems for Renewable Energy Installations in Tropical Regions. Energy and Power Engineering, 15(3), pp.85–98.*

Ohajianya, A.C., 2023. *Design and techno-economic simulation of a standalone PV solar power plant for a typical housing estate in Owerri, Nigeria. International Journal of Research and Innovation in Applied Science (IJRIAS), 8(12), pp.60–68.*

Ohajianya, A.C., 2023. *Simulation and Analysis of a Standalone PV Solar Power Plant for a Housing Estate in Abuja, Nigeria. IOSR Journal of Electrical and Electronics Engineering (IOSR-*

JEEE), 18(2), pp.1–8. Available at: https://www.iosrjournals.org/iosr-jeee/papers/Vol18-Issue2/Ser-1/A1802010108.pdf [Accessed 22 September 2025].

Ohanu, C.P., Egbo, G.N. & Sutikno, T., 2024. *Sizing and analysis of a standalone photovoltaics system for a three-bedroom residence in Nigeria. Indonesian Journal of Electrical Engineering and Computer Science, 33(1), pp.1–9. Doi:10.11591/ijeecs.v33.i1.pp1-9.*

Okakwu, I.K., 2025. *Design and Economic Analysis of a Stand-alone Photovoltaic System for a University Building in Nigeria. Electrical and Electronics Engineering Department, Olabisi Onabanjo University.*

Okedu, K. and Uhunmwangho, R., 2019. *Design and simulation of a solar PV system for engineering laboratories. Nigerian Journal of Solar Energy, 30(1), pp.18-27.*

Okonkwo, C.C., Edoziuno, F.O., Adediran, A.A., Nwosu, O.I. and Atumah, C.A., 2021. *Renewable energy in Nigeria: Potentials and challenges. Journal of Southwest Jiaotong University, 56(2), pp.1–14. https://doi.org/10.35741/issn.0258-2724.56.2.924*

Okundamiya, M.S., Emagbetere, J.O., and Ogujor, E.A., 2021. *Design and implementation of a standalone photovoltaic power system for a remote location. Renewable Energy, 145, pp.2375–2386.*

Oladeji, S.O., Balogun, O.S. and Aliyu, M. (2017) *Use of Standalone Photovoltaic System for Office Building: A Case Study of National Centre for Hydropower Research and Development (NACHRED). FUTA Journal of Engineering and Engineering Technology (FUJEET), 11(1), pp. 154–160.*

Oluwatosin, A.O., Choji, D.S. & Silas, A.F. (2025) *Techno Economic Assessment of a Standalone Solar PV System for Residential Electrification: A Case Study of Fadele Estate, Osogbo,* *Nigeria. International Journal of Engineering and Modern Technology (IJEMT), 11(6), pp.65–76. Doi:10.56201/ijemt.vol.11.no6.2025.pg65.76*

Omeiza et al, 2022.

Omorogiuwa, E., Oduwa, I. and Iyasele, J., 2021. *Performance Analysis of a PV Inverter System for University Classrooms. International Journal of Renewable Energy Research, 11(3), pp.1452–1460.*

Oton, C. and Iqbal, T., 2021. *Load Analysis and Design of a Stand-alone Solar PV Power System for a Secondary School in Nigeria. Department of Electrical and Computer Engineering, Memorial University of Newfoundland, St. John's, Canada.*

Ozogbuda, J.C. and Iqbal, M.T., 2021. *Dynamic Simulation of an Off-Grid Photovoltaic System with Backup Battery and Generator for a Remote House in Nigeria. Proceedings of the 30th IEEE NECEC Conference, St. John's, NL, 18 November 2021. Memorial University of Newfoundland.*

Pérez, A., Sánchez, R. and Ortega, M., 2023. *Comparative analysis of SPD types for solar PV applications. Solar Energy Materials & Solar Cells, 248, p.112038.*

PV Education, 2023. Mounting Structures for Residential Solar. [online] Available at: https://www.pveducation.org/mounting-structures [Accessed 7 Aug. 2025].

Rahman, M.M., Rahman, M.T. and Khan, S.H., 2022. *Structural Optimization of Solar Panel Mounts for Large-Scale PV Plants. International Journal of Renewable Energy Research, 12(2), pp.580–588.*

Razykov, T.M., Ferekides, C.S., Morel, D.L., Stefanakos, E.K., Ullal, H.S. and Upadhyaya, H.M., 2011. *Solar photovoltaic electricity: Current status and future prospects. Solar Energy, 85(8), pp.1580-1608.*

REN21 (2023) Renewables 2023 Global Status Report. Paris: REN21 Secretariat. Available at: https://www.ren21.net/reports/global-status-report/ (Accessed: 8 August 2025).

Rubino, L. et al., 2017. *Smart Solid-State Circuit Breaker for Photovoltaic Power Plants. International Review of Electrical Engineering, 12(5), pp.410–.*

Samlex Solar. (2014). 30A Solar Charge Controller SCC-30AB: Owner's Manual. Samlex America Inc.

Sundaram, S. and Narayanan, M., 2022. *Evaluation of Cable Losses and Safety Measures in PV Power Plants. Journal of Solar Energy Engineering, 144(6), p.061007.*

Tongou, 2024. *Navigating the Intricacies of DC MCBs for Enhanced Solar PV System Safety. [online] Available at: https://www.tongou.com [Accessed 7 Aug. 2025].*