ASSESSMENT OF AN ALTERNATIVE POWER SOLUTION FOR THE DEPARTMENT OF MECHANICAL ENGINEERING

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CERTIFICATION

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DEDICATION

We would like to dedicate this project report to Almighty God who has been our ultimate source of knowledge, strength, and sustenance for his preservation during the five-year period of our B.ENG. We also want to dedicate this report to our parents, friends and course mates who provided for us and were a major support system for us throughout this time.

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We hereby appreciate God almighty for giving us the grace, and strength to complete this project work as well as our bachelor's degree in mechanical engineering.

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ABSTRACT

The study looked at the installation, testing, and assessment of a 3.5kVA solar inverter power system at the Department of Mechanical Engineering, University of Benin, Nigeria. Providing a sustainable and self-sufficient energy source, decreasing dependency on the local power grid, and cutting carbon emissions were the objectives of embarking on this project work. The assessment of solar irradiance, energy generation, battery performance, and system efficiency were among the many performance metrics of the solar inverter system that were evaluated.

Solar panels, a 3.5kVA inverter, 6V 400Ah batteries, a charge controller, and a monitoring system make up the 3.5kVA system. A total of fourteen days' worth of data were gathered, which was then split into two weeks to examine the performance of the system at the location in the Department of Mechanical Engineering, University of Benin in Edo State, Nigeria.

The analysis revealed that solar irradiance significantly impacted the stored power, aligning with typical solar panel operating conditions. During the first week, temperatures ranged from 33.3°C to 38.7°C, with power output varying between 10,523Wh and 10,692Wh, showing how solar irradiation and daily temperatures affect panel performance. The highest energy generation was 10,692Wh on the morning of March 4th, while the lowest was 10,523Wh on the morning of March 5th. On average, the panels produced 10,608Wh per day, meeting around 57% of the department's daily energy needs. The solar inverter system performed as expected, demonstrating its reliability and self-sufficiency. The study highlights the importance of evaluating solar photovoltaic systems to ensure efficient and consistent electricity power supply.

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CHAPTER 1: INTRODUCTION

1.0 INTRODUCTION

Reliable power supply in today's world is an essential tool for smooth running of day-to-day activities. Electricity remains a major driving force as it is highly required in offices, schools, homes, businesses, in the laboratory, offices, in the lecture theatres and for carrying out major and minor works. It is not just for convenience, but also needed for function. A steady power supply would mean comfort, better productivity, and overall give a higher morale for carrying out office and class activities. It is however rather unlucky that in Nigeria, we have been made to see having electricity as a privilege as we still struggle daily with the unstable supply of electricity. Although being unstable, the price for electricity tariffs is on the rise daily and the cost of running a generator with the recent removal of petrol subsidy by the current government has been greatly increased. So therefore, innovative ways to generate energy at a relatively cheaper and being more reliable must be investigated.

1.1 BACKGROUND OF STUDY

The essential task of utilizing energy from sunlight to power equipment is made possible using solar panels and converting the charges from these solar panels between direct current (DC) and alternating current (AC) is performed by an inverter. One of their main responsibilities is to charge batteries so they can store energy, which they can then use as needed. In a solar inverter system, there are multiple steps involved in the charging process. This project is a hybrid system whereby the batteries receive charge from the solar panels and from the inverter. The system first gets AC power from outside sources, such as the grid in this case. A rectifier or converter circuit is used to transform this AC power into DC electricity. The batteries connected to the inverter system are then charged using the DC current. The solar panels produce a DC which is stored in the batteries and converted to AC by the inverter when needed for use.

Despite the increase in electricity tariffs, access to electricity remains unreliable at times, prompting the necessity for this project. Utilizing the inverter power system for daily office and class activities would be more cost-effective compared to the ongoing expenses associated with running the department's diesel generator. Currently, the department possesses a 3.5kVA inverter paired with eight 6V lead-acid batteries boasting a storage capacity of 400Ah each. The department of Mechanical Engineering, University of Benin, Edo State, Nigeria with latitude 6.3998° N, and longitude 5.6009° E being situated in a hot climate region, this solar installation would get a good amount of charge daily which can deliver the required power when needed.

Some benefits of the solar inverter system include:

a. Low maintenance cost
b. Environmentally friendly
c. Economical and saves cost.
d. Conserves energy to a large extent
e. It is very much reliable.

Different types of batteries include lead-acid, lithium-ion, and nickel cadmium batteries and these batteries each have their different depths of discharge. To power appliances or other electrical devices, this usually entails converting DC electricity from the batteries back into AC electricity via the inverter circuits.

Inverter systems can be configured to give preference to using renewable energy sources, such as solar electricity as done in this work. This system runs on solar power and uses solar energy to charge its batteries during the day when there is enough sunlight and on the other hand, the system can use grid power to charge the batteries during times of high energy demand or when there is low sunlight.

A test was carried out on the batteries in the solar inverter power system using a multimeter which indicated a significant drop in the voltage level, and this confirmed the initial thoughts that the batteries were bad as it has been delivering a lower power capacity than usual. This necessitated the urgency for this project to be carried out as the lecture theatres and workshop offices had a need for steady electricity supply. This system powers the workshop offices and two lecture theatres. In the lecture theatres, essential equipment like the projector and light bulbs are used while in the office essentials are charging points for devices such as phones, and light bulbs.

Up until now, this system has been used to power the lecture theatres and only a few offices in the mechanical workshop area but now, all offices in the workshop area are now connected to the solar inverter power grid. This has proven to be productive as an uninterrupted supply of power is now supplied to all offices in the workshop and the lecture theatres as the dead batteries have been replaced, solar panels have been thoroughly cleaned, bad wirings replaced the and the system capacity has also been increased from 10560Wh to 19200Wh which is an over 55% increase in capacity of the system.

1.2 STATEMENT OF PROBLEM

With the ever-increasing cost of electricity tariff despite the continued unavailability of constant power supply to meet the ever-increasing demand for electricity, it is therefore imperative that an innovative solution is put in place to help solve this issue.

1.3 AIM AND OBJECTIVES

- To increase the capacity of the solar inverter power system
- Cost reduction and overall reduced departmental expenses on electricity related issues.
- Energy conservation by means of storing electricity for downtime periods.
- Better performance of the solar inverter power system currently available in the department.
- Better learning and working environment for students and lecturers.

1.4 SIGNIFICANCE OF STUDY

The significance of electrical power supply as being a very vital component of day-to-day activities cannot be overstated, particularly for a department like mechanical engineering department where office activities are carried out daily. As a pioneer in innovation and development, it is crucial for the department to get a stable electrical supply while reducing reliance on traditional diesel/petrol generators mainly due to cost and environmental pollution.

1.5 SCOPE/LIMITATIONS

The scope of the project includes retracement of the power supply line, connecting the offices in the workshop to the solar inverter power grid, replacement of electrical wiring, replacement of bad batteries, development of study on the electrical needs of the mechanical department workshop offices and lecture theatres.

The limitations encountered during the time of working on this project was majorly financial as energy conservation although sounds nice also is not cheap. The total cost needed to ensure a stable supply of power during on and off-peak periods is considerably huge putting into consideration that we are aiming to have a 19200WH capacity solar inverter system. This capacity is only for powering essential loads within the offices and lecture theatres as the issue of cost was a major barrier in having a system capacity that can accommodate the full load.

1.6 METHODOLOGY

The process outlined for this solar energy project showcases a well-thought-out approach that emphasizes both technical precision and financial viability. By meticulously analysing the load requirements and calculating parameters such as cable sizing and system configuration, the project ensures that the solar energy system will be tailored to fit seamlessly into the daily operations of the workshop offices and lecture theatres.

What stands out is the collaborative effort between students and experts, which not only provides a valuable learning experience but also ensures that the project benefits from a diverse range of perspectives and skills. Additionally, the focus on energy storage through battery installation and the utilization of both series and parallel configurations for solar panels demonstrate a thorough understanding of efficient energy management.

The inclusion of a financial analysis to determine the payback period underscores a pragmatic approach to sustainability. It's not just about implementing renewable energy solutions; it's about ensuring that these solutions make financial sense in the long run. This demonstrates a commitment to not only environmental responsibility but also fiscal responsibility.

CHAPTER 2: LITERATURE REVIEW

2.1 CONCEPTUAL REVIEW

2.1.1 SOLAR POWER

Solar power refers to the conversion of sunlight into electricity, either directly through photovoltaic (PV) cells or indirectly using concentrated solar power. PV cells utilize the photovoltaic effect to convert light into electric current, while concentrated solar power systems employ lenses or mirrors with solar tracking mechanisms to concentrate sunlight onto a focal point, often to power a steam turbine (Norman, 2023).

Initially, photovoltaics was primarily used for small to medium-scale applications, such as calculators and off-grid rooftop PV systems for remote homes. Commercial concentrated solar power plants emerged in the 1980s, and as the cost of solar electricity decreased, grid-connected solar PV systems experienced exponential growth. Millions of installations and gigawatt-scale photovoltaic power stations continue to be constructed, with solar accounting for half of new generation capacity in 2021 (Norman, 2023).

In 2022, solar energy contributed 4.5% of the world's electricity, compared to just 1% in 2015 at the signing of the Paris Agreement. Utility-scale solar offers the cheapest levelized cost of electricity for new installations in most countries, and nearly half of the solar power installed in 2022 was rooftop-based (Shankar, 2023; Gerdes, 2023).

The International Energy Agency highlighted the need for greater efforts in grid integration and addressing policy, regulation, and financing challenges in 2022 to combat climate change through increased low-carbon power generation (Gerdes, 2023).

Geographical factors significantly impact solar energy potential, with regions closer to the equator generally receiving higher solar radiation. Sun-tracking capabilities can enhance solar energy potential in areas further from the equator, while time variation and cloud cover affect solar radiation absorption. Land availability is also crucial, as solar panels require suitable and unused land for installation (Gerdes, 2023; Vorrath, 2022).

2.1.2 SOLAR CELLS

A photovoltaic (PV) cell, also known as a solar cell, is a device that utilizes the photovoltaic effect to convert light into electric current. The earliest solar cell was developed by Charles Fritts in the 1880s, and subsequent advancements led to the creation of more efficient solar cells, such as the photocell by Bruno Lange in 1931 and the silicon solar cell by Gerald Pearson, Calvin Fuller, and Daryl Chapin in 1954. These early solar cells were relatively expensive and had efficiencies of 4.5–6%.

A crucial development in solar cell efficiency came in 1957, when Mohamed M. Atalla pioneered the process of silicon surface passivation through thermal oxidation at Bell Labs, which has since played a vital role in enhancing solar cell efficiency.

As of 2022, over 90% of the solar cell market consists of crystalline silicon. A photovoltaic system typically comprises arrays of solar cells that produce direct current (DC) power, which is then converted to alternating current (AC) using inverters. These arrays are connected to form solar panels, which are then wired together to form solar arrays.

In many developed countries, residential PV systems are connected to the grid, and energy storage is optional. However, in applications like satellites, lighthouses, or in developing countries, batteries or additional power generators are often added as backups to create stand-alone power systems that can operate during periods of limited sunlight.

For this work, the system is a hybrid system whereby the batteries receive charge both from the solar arrays and from the local power grid through the inverter.

2.1.3 INVERTER

An inverter is a device that converts direct current (DC) into alternating current (AC). Also known as a power inverter, it takes DC input voltage from a source like a battery and transforms it into AC output voltage at a specified frequency. The input voltage, output voltage, operating frequency, and power handling capacity of an inverter depend on its intended application and design specifications. While inverters change DC into AC, they do not produce electrical power themselves, relying completely on the connected DC source. There are several ways in which an inverter can convert DC to AC. For example, it may be entirely electronic and utilize transistors for the conversion. It may also use a combination of mechanical rotary parts and electronic circuitry to accomplish this conversion (L. Ashok Kumar, 2021).

The operational principle of the inverter resembles that of a switching power supply, employing either an oscillating chip or a specialized circuit to regulate the output oscillating signal, which amplifies to continuously drive the FET to switch. Through adjustments, it can generate AC characteristics akin to a sine wave, mirroring the power grid's output.

In stand-alone solar systems catering to AC loads, an inverter, acting as a power conversion device, becomes essential. The determination of the appropriate inverter size hinges significantly on the preset DC voltage. Inverter outputs are typically divided into two categories: DC and AC. Referred to as a converter for DC output, the inverter facilitates voltage transformation from DC to DC, thereby supplying the required voltage for various DC load operations (Utmel Rose, 2022).

When considering AC output from the inverter, apart from power and voltage, it's crucial to address waveform and frequency. Pay attention to the inverter's DC voltage requirements and its tolerance for input surge voltage fluctuations.

The gate drive circuit of the power switch tube can be controlled by various means, such as a logic circuit, dedicated control chip, single-chip microcomputer, or DSP chip. This setup allows for voltage regulation capability in the inverter output. For instance, in a bridge inverter, the AC bus's rated voltage should typically be 10%–20% lower than the DC bus's rated voltage to ensure stability.

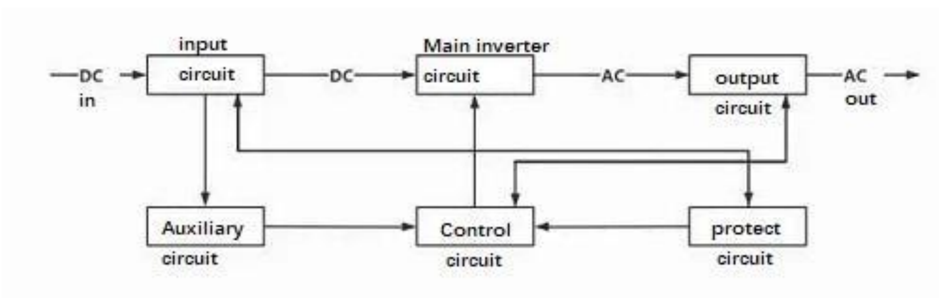

Figure 2.1: Inverter basic structure

Controlled by PWM, the inverter provides an adjustable margin, typically varying from 10% to 20%, by adjusting the PWM on-duty ratio. The input DC voltage fluctuation range can be from 15% to 20%, depending on the device's withstand voltage. Boosting is necessary when the battery or solar cell output voltage is low, achieved either through a circuit booster or the DC charge pump method.

Efficiency considerations are vital, aiming for an inverter mode where the DC input voltage matches the transmission line voltage, minimizing conversion loss. Typically, inverter efficiency exceeds 90%, with losses mainly manifesting as heat in the power tube

and transformer. Proper heat dissipation methods, like radiators or fans, are necessary to maintain device performance and safety. Inversion loss consists of conduction loss and switching loss, with MOSFETs offering high switching frequencies and significant on-resistance, and IGBTs featuring lower conduction voltage drop and moderate switching losses at lower frequencies. Reducing switching loss is paramount, often achieved through novel resonant switching methods,
which capitalize on zero-crossing points of voltage or current to minimize loss during turn-on and turn-off operations.

2.2 ELECTRICITY SITUATION IN NIGERIA

The rapid global population growth, coupled with current industrial growth and lifestyles, has led to a significant disparity between energy demand and supply. This disparity underscores the urgent need for a substantial increase in clean, stable, and dependable energy sources. Relying heavily on dwindling fossil fuels to meet daily energy needs is exacerbating environmental degradation and adversely impacting human health. Access to reliable energy remains elusive for many developing nations, posing a formidable obstacle to economic, social, and agricultural progress, as well as overall living standards. The economies of the world are overwhelmingly energy-dependent, and the Nigerian situation is not a different one. Electricity is one of the major forms of energy; its importance cannot be over-emphasized given the essential role it plays in the economic development of any country.

Over the past few decades, electricity has become an essential tool of technological innovation and advancement. Human development will be impaired without access to electricity, given that basic household activities are carried out with the aid of electricity

(OECD/IEA, 2016; Tully, 2006). There must be access to electricity for any meaningful development opportunity in this era. Electricity supports education by facilitating research; the vehicle through which economic ideas are transformed into profitable ventures. In addition, access to electricity is the linkage between Africa and the Global economy grid (Latham & Watkins Africa Practice, 2016).

According to Kri-zanic (2007), the standard of living in real terms is a function of access to electricity. It is an indispensable source of food that is required for human survival across the globe. Therefore, access to electricity is a catalyst for the growth and development of an economy. Nevertheless, despite being fully aware of the role of energy in the economy and blessed with abundant energy sources, such as coal, oil, gas, hydropower and other renewable energy sources, Nigeria still faces a serious problem of energy poverty. Particularly, the Power Africa Summit 2017 reported that fifty-five percent of Nigerians lack access to electricity, while the forty-five per cent connected, suffer constantly from power failure. The estimated yearly electricity usage per capita in Nigeria was about 150kWh; one of the lowest in Africa. In the same vein, only 3500-5000 MW of the 12.5 GW installed generation capacity, is typically accessible (United States Agency for International Development [USAID], 2017). One (2006) reported that the increasing demand for electricity has outgrown its supply and the rate of new connections is lower than the rate of new household formation due to population growth. Undoubtedly, the lack of access to electricity remains one of the biggest challenges to the development of Nigeria. Many people who do not have access to electricity are living in extreme poverty and use toxic, harmful, and unsustainable energy sources for illumination, and cooking.

In 2012, the International Research Centre for Energy and Economic Development (ICEED) stated that about 72% of the Nigerian population is still depending on firewood for cooking, utilising the traditional three stone fires. This has contributed to the indiscriminate felling of trees and its attendant environmental degradation and increasing desertification (Babanyara, Usman, & Saleh, 2010). This was further corroborated by the World Bank's estimate of an average annual deforestation rate of 4.12 per cent between 2000 and 2015 in the country.

Consequently, it has resulted in increased impoverishment, health diseases, poor access to social services, dampened women's prospects, and hampered sustainability of the environment at local, national, and global levels (Legroset al., 2009). According to (Carvallo, Shaw, Avila, & Kammen, 2017), the incessant power outage has impaired the growth of sub-Sahara’s economy and frustrated her efforts to actualise several development goals. Thus, the electricity crisis in Nigeria threatens to weaken regional and global market competition, obstruct job creation, and reduce the rate of growth of the economy.

2.3 THEORETICAL BACKGROUND

This section introduces the theoretical framework underlying solar photovoltaic (PV) systems. It begins with an exploration of the solar resource, followed by an overview of photovoltaic systems. Additionally, the conventions utilized to describe the solar position are elucidated.

2.3.1 THE SOLAR RESOURCE

The solar resource serves as the essential foundation for the operation of photovoltaic systems in solar power generation. The key aspects concerning the solar resource as it relates to photovoltaic systems are:

1. SOLAR RADIATION: Photovoltaic cells directly convert sunlight, or solar radiation, into electricity. The amount of solar radiation reaching a specific location on Earth's surface is the primary determinant of the solar resource potential. Solar radiation levels vary based on factors such as time of day, season, latitude, weather conditions, and atmospheric phenomena. Determining the sun's location relative to an observer on Earth's surface is a crucial parameter for modelling the performance of photovoltaic (PV) systems. The position of the sun is typically defined according to the convention illustrated in Figure 2.1 (Masters, 2004).

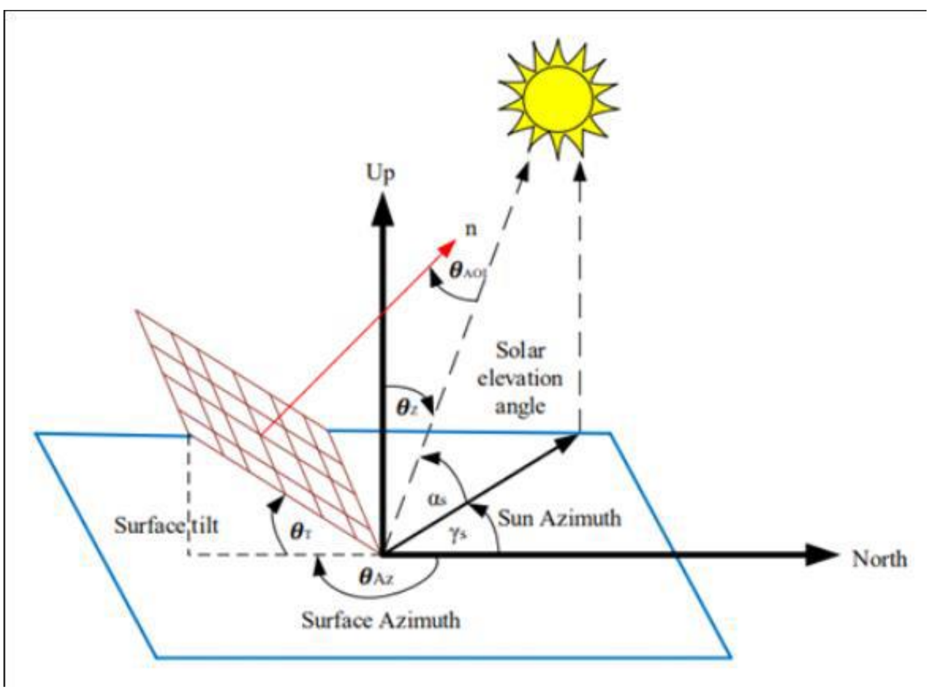

Figure 2.2: Solar Radiation

2. IRRADIANCE AND INSOLATION: Irradiance denotes the instantaneous rate of solar radiation received per unit area, usually expressed in W/m^2. Insolation refers to the total solar radiation received over a specified period, commonly measured in kilowatt-hours per square meter (kWh/m^2) (Sandia National Laboratories, 2014).

The solar radiation received by the PV cell or module initiates the process of generating electrical energy. In contrast, insolation quantifies the total solar energy accumulated on a surface area during a specific time period.

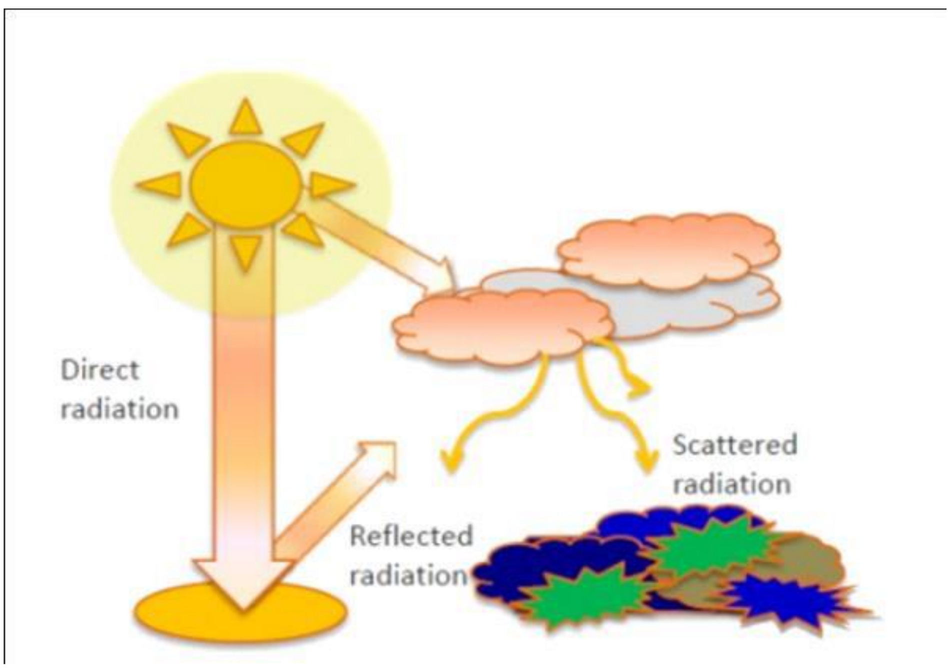

Figure 2.3: Direct, reflected and diffuse radiation

Understanding the solar resource is vital for designing and evaluating photovoltaic systems, as it directly determines the amount of energy that can be captured and converted into electricity.

2.4 EMPIRICAL REVIEW

Multiple studies have assessed the efficiency of solar power plants globally, including in Iran, through theoretical modeling and practical experimentation. For instance, Dai et al. (2003) analyzed a solar chimney power plant in China, while Makkiabadi et al. (2021) highlighted the worldwide increase in electricity generation from renewable sources like solar, wind, heat, and ocean waves. Makkiabadi et al. also noted Iran's potential for solar energy due to its geographical location.

Despite this potential, Iran's utilization of solar energy remains relatively low compared to global standards. In 2020, Iran generated only 900 MW of its electricity demand from solar sources, significantly below the global average. However, certain provinces, such as Yazd, Fars, and Kerman, are leading Iran's solar energy production. Additionally, Iran has vast expanses of unused land suitable for constructing solar power plants.

The study delves into Iran's solar energy generation capacity, including an economic and technical analysis of a proposed 10 MW solar power plant in Sirjan. The findings indicate that such a plant could be constructed in the Sirjan region with an initial investment of $16.14 million, with the capital recouped within approximately four years. Simulations conducted using Homer software suggest that peak power generation occurs in July.

Sangi (2012) evaluated the efficiency of solar chimney power plants in several cities of Iran and estimated the electricity they could generate. Their results indicated that a solar chimney power plant with a 350 m chimney height and 1000 m collector diameter could produce an average of 1–2 MW of electric power monthly over a year.

Onyango and Ochieng (2006) conducted a study on using a solar chimney power plant to generate electricity in rural areas, finding that it could provide electricity for approximately fifty households in rural regions.

Nizetic et al. (2008) focused on assessing the electrical energy capacity in Mediterranean countries, including estimating the value and price of electricity generation from solar energy.

Labti et al. (2010) examined the viability of a solar chimney power plant to supply remote villages in Algeria. Their findings showed that such a plant could produce between 140 to 200 kW of electricity, enough to meet the needs of isolated areas. They also suggested that the solar collector could potentially be repurposed as a greenhouse for agricultural use.

Pasumarthi and Sherif (1998) investigated various parameters affecting the performance of a solar chimney plant, including air velocity, temperature, moisture, and geometric factors.

Hosseini et al. (2005) compared six configurations for power plants in Yazd city, Iran, suggesting that an integrated solar combined cycle system with 67 MWe would be the most suitable as Iran's first solar power plant. They demonstrated the potential savings in fuel consumption and reduction in CO2 emissions over 30 years, highlighting the environmental benefits of such a system.

Solar power plants play a crucial role in addressing both electricity needs and environmental concerns, particularly in reducing CO2 emissions (Hirbodi et al., 2020). Wang et al. (2016) investigated the economic and technical aspects of low-medium temperature solar energy plants, demonstrating their potential for enhancing power generation while reducing CO2 emissions. Similarly, studies like those by Obeng et al. (2020) have delved into the technical and economic analyses of solar power plants.

In the United States, Vasilis et al. (2020) conducted a theoretical analysis of photovoltaic (PV) coupled with compressed air energy storage (CAES) and concentrating solar power

(CSP) plants. Their analysis suggested that large-scale solar power plants could be built to produce 3800 TWh of electricity by 2050, potentially replacing fossil fuels and enabling the production of electrolytic hydrogen.

In Indonesia, Fathoni et al. (2014) evaluated the technical and economic potentials of solar energy applications, considering the country's unique geography with thousands of islands.

Countries situated near the equator, like those in the southern hemisphere, receive the highest levels of solar radiation. Consequently, the construction of various types of solar power plants has been rapidly expanding in these regions (Makkiabadi et al., 2021).

Shafiey et al. (2022) conducted modeling and optimization of wind/PV/battery/diesel hybrid systems for different cities in Iran. Their results indicated varying optimal costs based on different environmental conditions, including solar irradiance, wind availability, and ambient temperature ranges.

Additionally, Bayareh (2017) performed numerical modeling of a solar chimney power plant in the southern region of Iran, while Taner (2017) presented an economic analysis of a solar power plant in Aksaray city, Turkey, demonstrating its significant potential for electricity production.

Trabelsi et al. (2016) focused on simulating a power plant with a parabolic collector for the southern region of Tunisia. Their study examined various climatic conditions and evaluated the electrical, thermal, and economic efficiency of the power plant with both warm and dry cooling systems.

Eljrushi and Zubi (1995) conducted an economical, technical, and comparative analysis of photovoltaic (PV) power plants intended for installation in the southern region of Libya. Similarly, Ehtiwesh et al. (2019) and Zhang et al. (2013) explored Concentrated

Solar Power (CSP) plants in countries like Iran, Turkey, and Iraq, providing insights into different solar collector types and variations in solar irradiation flux.

Pelay et al. (2017) investigated CSP plants with storage systems to identify key factors influencing the development of this technology for efficient and cost-effective electricity production. Sarvghad et al. (2018) proposed utilizing CSP at higher temperatures than currently employed to enhance capacity and reduce the cost of power production.

Kreith et al. (1990) compared CO2 emissions from fossil fuel and solar power plants in the United States, highlighting the environmental benefits of solar energy. In recent years, life cycle assessments (LCA) of solar energy systems have become more common, with researchers like Guillén-Lambea (2021) analyzing the environmental impacts of solar power plants on both human life and nature.

The adoption of solar power plants is gaining momentum globally, with European, African, and Asian countries increasingly using them for various purposes, including building, agriculture, and industrial applications (Ding et al., 2021).

In the context of rural electrification, Akanksha and Tara (2010) conducted assessments and evaluations of PV-based decentralized rural electrification. They emphasized that PV technology has been widely adopted globally to meet the basic electricity needs of rural areas lacking grid connectivity.

Bhubaneswari et al. (2011) provided a comprehensive review of photovoltaic technology, covering its power generation capabilities, various light-absorbing materials utilized, environmental aspects, and diverse applications. They also discussed performance and reliability evaluation models, sizing and control techniques, grid connection, and distribution aspects of photovoltaic systems.

Ahmed et al. (2011) emphasized the significance of solar photovoltaic technology for developing countries like Mauritania and Senegal, where it can address the lack of electricity services in many villages, thereby improving living conditions.

Obeng et al. (2009) examined the intersectoral linkages of solar PV electrification in Ghana, focusing on its impact on education, health, information acquisition, agriculture, and micro-enterprises. They also addressed sustainability-related issues such as costs, market barriers, subsidies, stakeholder involvement, and policy implications, proposing a framework to understand how solar PV electrification affects energy poverty and quality of life in rural and peri-urban areas.

Jack (2010) developed an assessment tool based on a lifecycle sustainability framework and applied it to evaluate Solar Home System (SHS) projects in rural Vanuatu. They conducted case studies at three SHS project sites, assessing them during and after completion to determine best practices for rural SHS projects. The study highlighted the importance of rural-specific SHS component selection, design, and economic considerations, emphasizing factors like technical design accuracy and system robustness for longevity and effectiveness. Recommendations included modifications to the assessment tool for better relevance under SHS project contexts.

Klunne (2002) highlighted the issue of poor maintenance and vulnerability to criminal activity in solar photovoltaic (SPV) systems. This emphasizes the importance of proper maintenance and security measures to ensure the long-term functionality and effectiveness of such systems.

Rizwan et al. (2010) assessed SPV systems using artificial neural networks (ANN) and VHDL (VHSIC Hardware Description Language). They utilized meteorological data, such as temperature and daily solar irradiance, from various Indian stations to evaluate the performance of SPV systems. The ANN model was trained using inputs of daily total irradiance and mean average temperature, with outputs representing the current and voltage generated by the system. They implemented the neural network in VHDL based on saved weights and biases, enabling efficient prediction of electrical energy output from the SPV system using only meteorological parameters.

Barhdadi and Zakey (2010) employed the PVGIS (Photovoltaic Geographical Information System) method to assess the performance of the first grid-connected PV Micro-power plant in Africa. PVGIS provides an analysis of in-site solar energy resources and accurately predicts the potential electricity production of PV systems. Their findings indicated that the annual total power generation of the micro-power plant slightly exceeded initial expectations and measured values. While yearly predicted and measured power production aligned closely (about 2% difference), monthly production values could vary more significantly. Their work also integrated new components, such as predictions from the radiation scheme in the ICTP-Regional Climate Model (RegCM), enhancing the accuracy of performance predictions for PV systems.

Khalil (2022) conducted a comprehensive analysis of existing global solar radiation (GSR) models applicable to various locations worldwide. This involved evaluating 400 sunshine based GSR models on a horizontal surface using meteorological data spanning 40 years from selected sites in Egypt. The data was split into two subsets: one from 1980 to 2019 for developing empirical correlation models between monthly average daily global solar radiation fraction (H/H0) and meteorological parameters, and another from 2015 to 2019 for model validation. The derived models were assessed against each other and experimental data from the second subset using statistical error indicators like RMSE, MBE, MABE, MPE, and correlation coefficient (R), with all models showing strong correlation (R > 0.92). Notably, models M 272, M 261, M 251, and M 238 exhibited the smallest t-Test values. Further evaluation employing ten statistical indicator tests and the Global Performance Indicator (GPI) ranked the Rietveld model (Model 272) as the most accurate in predicting GSR on horizontal surfaces, followed by the Katiyar et al. model (Model 251) and the Aras et al. model (Model 261).

Allouhi et al. (2016) designed a grid-connected PV system installed on a school building, comparing the technology, energy output, and economic performance of poly and mono solar panels. Poly panels demonstrated higher monthly yield compared to mono panels, but system reliability was not assured due to potential failure of either type. To address this, they incorporated an off-grid solar PV system, utility power supply, and a petrol-driven generator as backup alternatives in case of failure.

Previous research indicates that renewable energy offers a potential solution to Nigeria's longstanding energy crisis, which has persisted for over twenty years. Studies such as Shaaban and Petinrin (2014) highlight the severe electricity deficit in the country and propose that renewable energy adoption can address this crisis by narrowing the gap between demand and supply while enhancing living conditions, particularly in rural areas. Ohunakin (2010) discusses the current and future prospects of renewable energy in Nigeria, noting the high and continuously increasing energy demand due to population growth and recommending the exploitation of available renewable resources to diversify the energy supply. Anumaka (2012) emphasizes the need for private and foreign investment in renewable energy integration to improve electricity access, given the limitations of government funding. Similarly, Mohammed et al. (2013) stresses the potential of renewable energy to alleviate energy poverty in rural areas and advocate for its utilization to compensate for the country's energy deficit amid rapid population growth.

Sanusi et al. (2011) investigated the impact of ambient temperature on the performance of an Amorphous Silicon Photovoltaic System (ASPS) in the Ogbomosho area of Nigeria. Their findings reveal a direct correlation between system power output and ambient temperature, as evidenced by the correlation coefficient (R) values. They underscore the importance of considering ambient temperature in ASPS design and performance prediction, particularly in Nigeria's tropical regions. Additionally, efforts have been made in recent years to provide electricity to rural communities in South Africa through photovoltaic (PV) systems. While PV systems have been successfully installed in various schools and clinics, post-installation experiences have been mixed.

Agbo and Oparaku (2006) conducted an assessment to explore the current state and future potential of solar water heating (SHW) in Nigeria. Despite extensive research and development of SHW systems within the country, the adoption rate remains low across various sectors such as households, health, agriculture, education, and industry. They highlighted the significant untapped potential of SHW technology and emphasized the need for bold initiatives from both the public and private sectors, financial institutions, and international agencies to address existing limitations and promote widespread dissemination of SHW systems. They underscored the benefits that such initiatives would bring to citizens, the economy, and the environment.

Ismail et al. (2012) emphasized the importance of solar photovoltaic (PV) systems in providing reliable electricity access, particularly in rural areas of developing countries like Nigeria. Despite the installation of PV systems in some Nigerian villages, the expected benefits have not been fully realized. Their study focused on assessing the performance of a solar PV system installed in Oke-Agunla, Akure local government of Ondo State. Through visits to the village, examination of equipment, interviews with residents, and evaluation of energy demands, they identified several challenges including inadequate PV facilities, lack of trained technicians, and poor maintenance practices. Their assessment revealed that only a small fraction of the installed solar PV capacity was utilized due to significant malfunctions and deterioration in performance, highlighting inefficiencies resulting from poor maintenance and technical expertise, as well as inadequate consideration of these factors during the installation process.

Oparaku (2002) highlighted the potential of solar photovoltaic (PV) systems as reliable sources of power, especially for small loads in remote and rural areas. The paper extensively discussed the status and potential of photovoltaics in Nigeria, emphasizing their ability to produce electricity directly from the sun without environmental harm.

Adesina et al. (2023) argued that solar panels, which convert sunlight into electricity, are essential for various applications. They presented a detailed design, implementation, and performance analysis of an off-grid solar power system for a Nigerian household. The study utilized solar irradiance data from the Nigerian Meteorological Agency to design the system components and assess load demands. Results showed that the system provided uninterrupted power supply for 24 hours with a specified load, reducing dependency on the grid and enhancing user satisfaction.

Ghenaia and Bettayebb (2019) proposed a hybrid solar PV system for university buildings, combining grid-tied solar PV with fuel cells to meet building loads while minimizing greenhouse gas emissions. However, the study found that the percentage of emissions from the fuel cell system was still significant, unlike in the new design, where emissions were reduced to 5%.

Gerard (2020) analyzed the application of renewable energy to power a faculty building in a Nigerian university, comparing solar panels/battery systems, conventional utility supply, and a generator set. The analysis revealed that the generator set was cost-effective over 25 years but raised concerns about environmental pollution due to gas emissions.

Chaudhry and Iqbal (2021) designed an off-grid solar PV plant for small-scale applications, finding it more costly than conventional electricity supply over time. However, they noted a lack of provision for maintenance and repairs.

Michael (2012) conducted a study on an off-grid solar system for DC loads in Pakistan, showing its cost-effectiveness compared to conventional power, although it was designed solely for DC loads.

Adoghe et al. (2023) emphasized the crucial role of effective electric power generation and distribution in boosting overall economic efficiency. Despite Nigeria's vast renewable energy potential, the country heavily relies on natural gas for power generation, resulting in significant electricity access challenges. The study aims to assess the growth of Nigeria's power sector over time by evaluating government-enacted reforms and reviewing existing research on the sector's strengths, weaknesses, opportunities, and threats. Identified challenges include energy user issues, financial constraints, and energy losses, with proposed solutions including distributed generation, smart meters, and smart grid implementation. Additionally, the authors suggest tapping into viable renewable energy sources in each state to promote self-reliance and contribute to the national power generation pool, ultimately fostering economic, social, and technological benefits.

Ogbekwe (2010) developed a 3-kVA hybrid power supply system for a computer laboratory experiment, incorporating a 560 W, 24 V solar panel and PWM charge controller. While enhancing power reliability compared to traditional electricity supply, the system faced challenges due to mismatches between load estimates and battery capacity, leading to insufficient daily charging. Additionally, the selected PWM controller struggled to convert over-voltages to equivalent current.

Diemuodeke et al. (2021) highlighted the significant number of rural households globally lacking electricity access and the potential of distributed energy systems, particularly solar photovoltaic (PV), for rural electrification. Their study assessed the status of solar PV in Nigeria and discussed strategies for aggressive PV penetration, especially in rural areas. Despite policy targets, distributed PV penetration remains low, indicating a gap between policy intent and reality. The study also analyzed solar resource potential across Nigeria's geopolitical zones, showing better potential in northern zones. While PV for rural lighting is more affordable than fossil-fueled alternatives, effective fiscal and energy policies are crucial for market creation and realizing the potential of PV systems for rural electrification and climate change mitigation.

Ajayi et al. (2016) assessed the solar and wind resources' potential in Northern Nigeria and affirmed that solar photovoltaic technology offers a feasible pathway to achieve sustainable development goals. Akimbami (2001) conducted an analytical review of renewable energy policies in Nigeria, concluding that leveraging renewable energy resources could decentralize energy supply and enhance energy security. Akuru et al. (2017) underscored the renewable energy potential in Nigeria, suggesting that achieving a 100% renewable energy supply is feasible with significant financial investment, drawing on successful precedents from other regions.

Chanchangi et al. (2022) highlighted the adverse socio-economic consequences of Nigeria's population growth and heavy reliance on fossil fuels, emphasizing the urgent need for clean energy solutions. They advocated for photovoltaic technology as a viable clean energy alternative to advance Nigeria's progress towards Sustainable Development Goal 7, noting its economic and environmental benefits despite challenges such as efficiency limitations.

According to reports by Dodondawa (2019) and Daily Trust (2019), the Managing Director of Shell Nigeria Exploration and Production Company (SNEPCO), Mr. Bayo Ojulari, estimated that Nigeria would need between USD 40 billion to USD 200 billion to bridge the energy gap and achieve a generation capacity of 30 gigawatts (GW) to 175 GW. However, the breakdown of this estimation does not specify whether the generation capacity would be from renewable sources.

Aliyu et al. (2015) reviewed Nigeria's primary renewable energy sources and advocated for their integration into the energy supply mix. Ikem et al. (2016) provided an overview of Nigeria's national electricity grid, highlighting gaps in information flow regarding renewable energy and recommending the implementation of renewable energy policies to enhance reliable and stable energy supply.

Ajayi et al. (2016) assessed the solar and wind resources' potential in Northern Nigeria and affirmed that solar photovoltaic technology offers a feasible pathway to achieve sustainable development goals in the country.

This research by Ajayi et al. suggests that renewable energy, particularly solar PV, presents a viable solution to address the longstanding energy challenges faced by Nigeria. The researchers concluded that solar PV technology can help Nigeria make progress towards its sustainable development goals.

The prominent Nigerian researcher, Ajayi, affirmed that renewable energy, and specifically solar PV, offers a feasible solution to address Nigeria's persistent energy problems and support the country's sustainable development.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This section of the report describes the design of the 3.5KVA solar system.

3.2 DESCRIPTION OF A GRID-CONNECTED SOLAR INVERTER SYSTEM

A grid-connected solar inverter system is connected to the electrical grid in the locality as shown in the figure 3.1 below. This type of system with an inverter has access to power from the local electrical grid if the solar PV panels cannot generate the amount of electricity needed to meet the load requirements on the solar inverter system such as in cases or times when there is insufficient amount of sunlight received by the solar PV panels. The two major components of the grid-connected solar inverter system are the inverter and the solar PV panels.

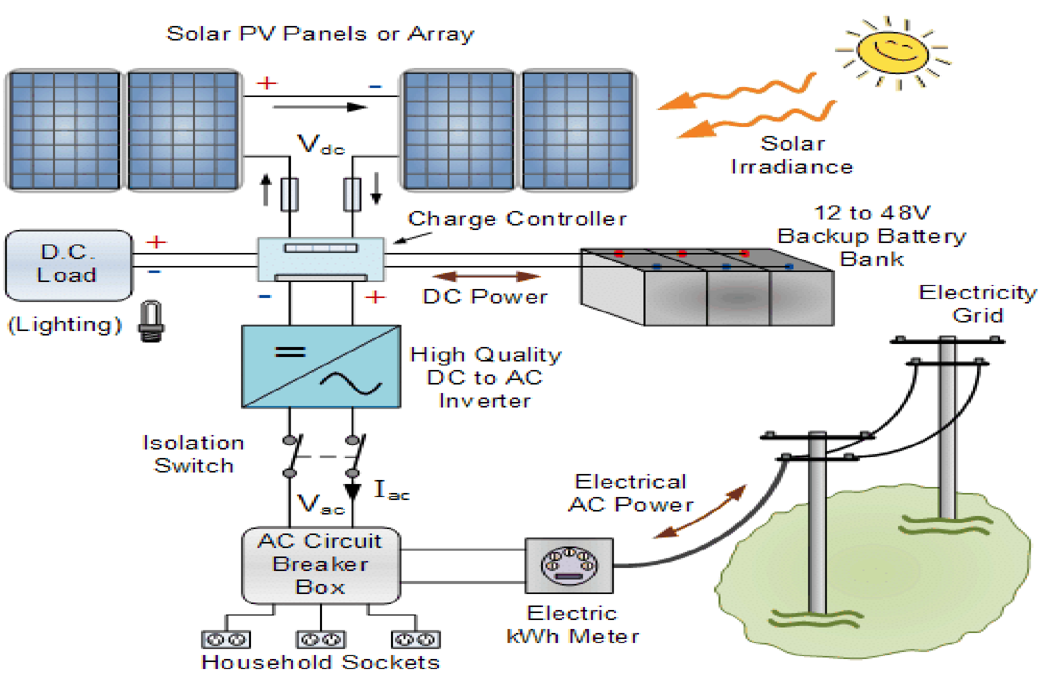

Figure 3.1: A grid-connected solar inverter system

The solar inverter system comprises of several components. The main components are the inverter and solar PV panels. Other components are the charge controller, ac circuit breaker box, electric utility meter, battery bank, and isolation switch.

3.3 ELECTRICAL LOAD ESTIMATION

For this project work, we focused on the departmental lecture theatres and workshop offices. The load refers to the equipment which utilizes the power generated by the solar inverter system. The load in this project includes office and lecture theatre equipment such as laptops, refrigerators, light bulbs, fans, projectors, phones etc. To accurately size the system and be sure that the new batteries we were installing would be able to effectively sustain the system, a load estimation was carried out which was then used to calculate the total power required per day. The table below shows the electricity load estimation for the areas covered by the solar inverter system.

LOAD	QUANTITY	WATTAGE RATING (W)	TOTAL WATTAGE (W)	HOURS IN A DAY (Hr.)	TOTAL ENERGY IN WATT HOUR (WH)
ROOM 1					
Bulb	1	15	15	8	120
Standing fan	0	50	0	8	0
Laptop	1	60	60	8	480
Small printer	0	300	0	0.5	0

Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 2					
Bulb	1	15	15	8	120
Standing fan	0	50	0	8	0
Laptop	0	75	0	8	0
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	0	80	0	5	0
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 3					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	0	80	0	5	0

Phone	1	33	3	3	99
Router	0	10	0	8	0
ROOM 4					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 5					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0

ROOM 6					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 7					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 8					
Bulb	1	15	15	8	120

Standing fan	0	50	0	8	0
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 9					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	1	300	300	0.5	150
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 10					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600

Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 11					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	1	300	300	0.5	150
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 12					
Bulb	1	15	15	8	120
Standing fan	0	50	0	8	0
Laptop	0	75	0	8	0
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515

Refrigerator	0	80	0	5	0
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 13					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	1	300	300	0.5	150
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99
Router	0	10	0	8	0
ROOM 14					
Bulb	1	15	15	8	120
Standing fan	1	50	50	8	400
Laptop	1	75	75	8	600
Small printer	1	300	300	0.5	150
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	1	80	80	5	400
Phone	1	33	33	3	99

Router	0	10	0	8	0
ROOM 15					
Bulb	1	15	15	8	120
Standing fan	0	50	0	8	0
Laptop	1	75	75	8	600
Small printer	0	300	0	0.5	0
Air Conditioning Unit	1	1103	1103	5	5515
Refrigerator	0	80	0	5	0
Phone	1	33	33	3	99
Router	0	10	0	8	0
400 Level Lecture Hall					
Bulb	4	45	180	12	2160
Bulb	2	15	30	12	360
Ceiling fan	4	50	200	12	2400
Laptops/Loading points	8	75	600	12	7200
Air Conditioning Unit	2	1103	2206	10	22060
LT2					
Bulb	9	45	405	12	4860
Bulb	6	15	90	12	1080

Ceiling fan	4	50	200	12	2400
Projector	1	60	60	4	300
Laptops/Loading Points	18	75	1350	12	16200
Sound Amplifier	1	300	300	5	1500
Microphone Receiver	1	90	90	5	450
Air Conditioning Unit	4	1103	4412	10	44120
Total					207780
Estimated Total for Implementing the solar inverter system					18655

3.4 SIZING THE SOLAR INVERTER SYSTEM

The solar inverter system was dimensioned to determine the requisite number and type of solar panels, the battery capacity for energy storage, and the specifications for other system components like the charge controller, power inverter, and Balance-of-System (BOS) elements. To ensure system reliability, the duration of autonomy was set at 12 hours, or half a day which is typically what would be required of the system on an average day given that major school activities do not go on for complete 24 hours daily. The design approach factored in the department's energy demands to size the standalone photovoltaic system components in a manner that strikes a balance between cost and reliability.

Various calculation methods exist to ensure reliability at minimal expense, yet many rely on statistical solar radiation data that are often lacking in numerous regions.

Consequently, a straightforward approach known as the "Watt-Hour (WH) method" was suggested for this project. This method computes the system dimensions to ensure effective operation even during periods of high energy demand surpassing available solar energy. System reliability was addressed by establishing the maximum number of days it can operate without solar radiation, relying solely on the battery bank for energy supply. The selection of the maximum autonomy days (N) was influenced by the climate at the Department of Mechanical Engineering's location and the installation type. It was recognized that a higher N would necessitate more components or investment. Therefore, a duration of 12 hours, equivalent to half a day, was deemed suitable.

In sizing the solar inverter system, we determine the load requirement for the system, then do load shedding to determine the more vital loads which needs to be powered and determine the inverter rating to be used. The number of batteries which is required for such loading demand is also determined while taking losses into consideration and giving reasonable load allowance. Final step is to determine the number of solar panels as well as the configuration which would be able to generate the specified amount of voltage for the required days of autonomy.

3.5 SOLAR PANEL FAILURES AND INEFFICIENCIES

There are several factors that can contribute to the failure and low efficiency of solar panels in a typical solar installation. Some of the common modes of failure and inefficiencies include:

1. Dust and debris accumulation: Over time, dust, dirt, leaves, and other debris can accumulate on the surface of solar panels, blocking sunlight and reducing their efficiency. Regular cleaning and maintenance are necessary to ensure optimal performance.

2. Shading: Even partial shading of a solar panel can significantly reduce its output. Trees, buildings, or other obstructions that cast shadows on the panels can cause localized hotspots and decrease overall efficiency.

3. Inverter failure: The inverter is a crucial component of a solar installation that converts the DC electricity generated by the panels into usable AC electricity for your home. If the inverter fails, the entire system may shut down or operate at reduced efficiency.

4. Weather damage: Extreme weather conditions such as hail, high winds, or heavy snowfall can damage solar panels, reducing their efficiency or causing them to fail altogether. Proper installation and regular maintenance can help mitigate these risks.

5. Corrosion: Over time, exposure to moisture and other environmental factors can cause corrosion on the connectors and wiring of solar panels, leading to performance degradation. Regular inspections and maintenance can help prevent this issue.

6. Poor installation: Improper installation of solar panels can lead to a variety of issues, including poor alignment, insufficient mounting, and inadequate wiring. These factors can all contribute to reduced efficiency and potential failure of the system.

3.6 CAUSES OF FAILURE OF INVERTER BATTERIES

Lead-acid batteries are commonly used in solar installations to store excess energy generated by solar panels for use during times when there is little or no sunlight. However, these batteries can experience several failure modes and low efficiency issues that can impact the performance of the solar system. Some causes of inverter battery failure include.

1. Improper Installation: A primary cause of inverter malfunctions stems from improper installation. This often occurs when individuals select inappropriate cable types, gauges, or inline fuses, or when they neglect the guidance outlined in the user manual. Ensure accurate installation following the manufacturer's instructions to prevent such issues.

2. Capacitor Degradation: Inverters rely on capacitors to maintain consistent power output across fluctuating current levels. However, electrolytic capacitors, essential for this function, have a finite lifespan and degrade faster compared to dry components.

Temperature Influence: Capacitors are sensitive to temperature variations. Operating beyond specified temperature limits can significantly reduce their lifespan.

Mitigating Wear and Tear: Timely replacement of capacitors and regular maintenance practices help minimize wear-related issues, ensuring optimal inverter performance.

3. Overutilization: In some cases, process managers neglect to consider the limitations of inverters. Exceeding their operational capacity due to negligence or lack of awareness can lead to inverter bridge failure.

4. Fluctuations in Input Voltage: Instability in the input voltage can cause erratic behaviour or complete failure of the inverter. This instability may arise from unreliable power sources, such as inconsistent grid supply or fluctuations in generator output. Although, poor electrical connections are a common culprit behind inverter malfunctions.

5. Overcharging and Undercharging: Proper battery management is crucial for maintaining battery life. Both overcharging and undercharging can damage inverter batteries, reducing their lifespan.

6. Terminal corrosion and loose connections can both have an impact on how well a battery performs. Battery terminals should be routinely inspected and cleaned to avoid corrosion and guarantee tight connections.

7. Manufacturing Defects: Occasionally, batteries may contain flaws from the manufacturing process, leading to premature failure.

8. Age: Inverter batteries have a finite lifespan, much like regular batteries. The battery's ability to store and release energy is facilitated by chemical interactions that deteriorate with time, eventually resulting in reduced performance and failure.

9. Physical Damage: Cracks, leaks, or other physical damage to the battery can reduce its capacity to store a charge and eventually cause it to fail.

10. Sulfation: This occurs when a battery is not consistently fully charged, leading to the formation of lead sulfate crystals. These crystals diminish the battery's ability to hold a charge and thereby resulting in an event of battery failure.

11. Deep Discharge: The battery may also sustain harm if it is discharged too far. While inverter batteries are meant to last through blackouts, frequent and significant discharges can cause lasting harm.

3.7 LIFE CYCLE OF INVERTER BATTERIES

Ensuring reliable backup power hinges significantly on the longevity of inverter batteries. There are various aspects of inverter battery life.

1. Run Time: The duration a battery or battery pack can operate between charges is its run time, which varies based on connected appliances. An essential factor is the Depth of Discharge (DoD), indicating the percentage of energy drawn from the battery before

recharge. For most lead-acid batteries, a minimum DoD of 80% is recommended, often managed automatically by inverters and chargers to prevent excessive discharge.

2. Shelf Life: Battery shelf life denotes the duration an inactive battery can be stored before losing functionality. As batteries undergo constant chemical reactions, active compounds are gradually consumed by parasitic processes. Proper storage practices by dealers or users significantly impact shelf life.

3. Cycle Life: The number of charge-discharge cycles a battery can endure before experiencing a noticeable capacity decline is its cycle life. Typically, lead-acid batteries offer 500–1000 cycles. Tubular batteries commonly used in inverters boast a lifespan of three to four years. For extended lifespans, lithium-ion batteries are preferred due to their longer Cycle lifetimes.

4. Maintenance: Regular maintenance is crucial. For flooded lead-acid batteries, monitoring water levels, inspecting connections, and ensuring cleanliness are imperative. Avoiding deep discharges and overcharging is essential to prolong battery life.

5. Replacement: When a battery's performance visibly declines, replacement becomes necessary. To maximize lifespan, assess your power requirements and choose the appropriate battery type accordingly.

3.8 SOLAR INVERTER SYSTEM OVERVIEW

The 3.5kVA solar inverter system comprised of the following components:

Solar panels: 8 solar panels, each having a capacity of 300W installed on the rooftop of the departmental building. They convert sunlight into electricity by the photovoltaic process whereby electrons are emitted from metal surface when hit by sunlight.

Figure 3.8.1: Solar panels

Inverter: A power inverter converts the direct current (DC) electricity generated by solar panels into alternating current (AC) electricity suitable for use by majority of equipment available in the workshop offices and lecture theatres. Three waveform output types exist: Square wave, Modified sine wave, and Pure or true sine wave. Despite its higher cost, the Pure Sine wave inverter was used in this system due to its ability to produce waveforms identical to utility grid power. A 3.5kVA inverter was employed in this system.

Figure 3.8.3: Inverter

Batteries: The batteries used in this system were 6 volts 400 ampere-hour batteries for the purpose of storing the current from the solar panels and inverter. There are a total of 8 batteries in this system. Specifically, four pairs of 6V 400AH AGM batteries were used to store the excess charge in the system which is then used during periods of low sunlight.

Charge Controller: It keeps the battery from overcharging by regulating the voltage and current which gets into the battery from the solar panels and inverter. Controlling the amount of charge getting into the battery helps to prolong the battery life.

Monitoring System: A solar inverter monitoring platform combines satellite and solar resource data to estimate solar energy production via a computer model. In this system, a monitoring system was set up to monitor and log various aspects of the solar system's performance, such as energy output, battery status, and system efficiency.

3.9 TESTING METHODOLOGY

Inverters play a crucial role in numerous electric products and machines, housing intricate circuitry that demands meticulous testing to guarantee optimal operation. To evaluate the system performance, the following tests were conducted:

1. Functionality Testing:

Validate the inverter's capability to convert DC power from various sources, such as solar panels, batteries, or other DC sources, into AC power suitable for residential, commercial, or industrial use. Assess the inverter's performance under different input voltage and current conditions to ensure accurate conversion and output regulation.

2. Voltage and Frequency Regulation:

Conduct tests to verify the inverter's ability to maintain stable output voltage and frequency within specified tolerances, even amidst fluctuations in input power or changes in load conditions. Measure output voltage and frequency across different load levels, from no-load to full-load conditions, ensuring compliance with standards and specifications.

3. Grid Connection Testing:

Evaluate the inverter's synchronization with the utility grid and its ability to inject power safely and efficiently when connected in grid-tied mode. Test compliance with grid codes and regulations, including anti-islanding protection, power factor control, and voltage and frequency ride-through capabilities. Assess response to grid disturbances like voltage sags or swells and verify reconnection after a grid outage.

4. Islanding Detection:

Verify the inverter's detection of islanding conditions, where it disconnects from the utility grid to prevent safety hazards for workers and equipment. Evaluate sensitivity and response time of the islanding detection mechanism across various load and grid conditions.

5. Communication Protocols:

Ensure proper functioning of communication interfaces like Wi-Fi, Ethernet, or Modbus for remote monitoring, control, and data logging. Test reliability and security of communication protocols, including data transfer rates, error handling, and encryption (if applicable).

6. Fault Response:

Evaluate response to fault conditions such as overvoltage, overcurrent, short circuits, and ground faults, ensuring protection for the inverter and connected devices. Test fault detection and isolation mechanisms, as well as built-in protection features like fuses or circuit breakers.

7. Performance Under Environmental Conditions:

Subject the solar panels and the other system components to environmental conditions like temperature extremes, humidity, altitude, and others to assess real-world performance and reliability. Conduct accelerated life testing to simulate long-term operation under harsh conditions and identify potential failures or degradation.

8. Efficiency Testing:

Measure efficiency across different load levels to ensure effective energy conversion and minimal losses. Evaluate the impact of factors like input voltage, temperature, and power factor on efficiency.

9. Durability and Reliability Testing:

Conduct stress tests and long-term operation tests to assess durability and reliability over the expected lifetime. Perform accelerated life testing, thermal cycling, and other stress tests to identify weaknesses or failure modes.

3.10 PROBLEMS AND SOLUTIONS OF THE SOLAR INVERTER SYSTEM

3.10.1. OVERLOADING

Overloading is a common challenge faced with inverter systems, occurring when the combined power demand from connected loads exceeds the maximum rated capacity of the inverter. This issue can lead to various problems and requires proper understanding and mitigation strategies.

Symptoms of Overloading:

- Sudden shutdown or automatic tripping of the inverter
- Audible warning signals or alarms indicating an overload condition
- Malfunctioning or complete failure of connected appliances or devices

Causes of Overloading:

- Connecting too many appliances or devices with high power requirements simultaneously
- Sudden power surges or spikes during the startup of certain appliances (e.g., refrigerators, air conditioners)

- Exceeding the maximum continuous power rating specified for the inverter

By addressing overloading issues promptly and implementing preventive measures, users can ensure the safe, efficient, and uninterrupted operation of their inverter systems, minimizing the risk of damage and power supply disruptions.

Solutions:

1. Load Reduction: Disconnect non-essential appliances or devices to reduce the overall power demand, especially during peak usage periods. Prioritize critical loads and avoid simultaneous operation of high-power appliances.

2. Inverter Capacity Upgrade: If the existing inverter's capacity is consistently insufficient, consider upgrading to a higher-capacity inverter that can handle the combined power requirements of all connected loads.

3. Power Distribution and Load Balancing: Utilize power strips or surge protectors with built-in circuit breakers to regulate power draw from individual outlets. Distribute loads evenly across multiple outlets or circuits to prevent overloading any single outlet or circuit.

Preventive Measures:

1. Appliance Compatibility Check: Regularly verify the power ratings of connected appliances and ensure they are within the inverter's capacity. Avoid connecting devices with power demands exceeding the inverter's capabilities.

2. User Education and Awareness: Educate users on the operational limitations of the inverter and the importance of preventing overloading to maintain optimal performance and extend the system's lifespan.

3. Load Management Strategies: Implement load shedding or prioritization techniques during periods of high-power demand to proactively mitigate overloading risks. This may

involve temporarily shutting off non-critical loads or staggering the operation of high-power appliances.

4. Regular Monitoring and Maintenance: Periodically monitor the power consumption of connected loads and adjust as necessary. Perform regular maintenance checks and ensure proper ventilation and cooling for the inverter system.

3.10.2. BATTERY DRAINAGE

Battery drainage is a frequent challenge in inverter systems, particularly in off-grid or backup power setups. This issue arises when connected batteries discharge too rapidly, leading to diminished battery life and potential power interruptions. Let's explore this problem in detail:

Symptoms:

- Inverter shuts off unexpectedly or fails to deliver power.
- Reduced runtime of connected appliances during power outages.
- Batteries necessitate frequent recharging or replacement.

Causes:

- Excessive power consumption by connected appliances or devices.
- Inefficient charging or discharging processes within the batteries.
- Overuse of the inverter without adequate monitoring or maintenance.
- Aging or damaged batteries incapable of retaining a charge effectively.

Solutions:

1. Reduce Power Consumption: Identify and rectify sources of high-power consumption, such as inefficient appliances, standby power usage, or excessive reliance on high-power devices.

2. Optimize Battery Charging: Ensure batteries receive proper and efficient charging. Utilize appropriate charging methods and parameters recommended by the battery manufacturer (e.g., bulk, absorption, float).

3. Monitor Battery Health: Regularly assess the state of charge (SoC) and overall health of batteries using dedicated monitoring systems. Early detection of issues enables proactive maintenance.

4. Avoid Deep Discharges: Mitigate deep discharges of batteries, which can diminish battery life and capacity over time. Implement low-voltage cutoff limits on the inverter to prevent excessive discharge.

5. Invest in High-Quality Batteries: Utilize batteries of superior quality with adequate capacity and performance characteristics suitable for the application. Consider factors like battery chemistry, capacity, cycle life, and temperature tolerance.

6. Implement Energy Management: Deploy energy management strategies to prioritize essential loads, optimize usage patterns, and curtail unnecessary power consumption, particularly during peak demand periods.

7. Perform Regular Maintenance: Conduct routine maintenance tasks such as cleaning battery terminals, inspecting electrolyte levels (for flooded lead-acid batteries), and securing connections to ensure optimal battery performance.

Preventive Measures:

1. User Education: Educate users on proper battery maintenance and usage practices to minimize drainage and extend battery lifespan.

2. Battery Health Monitoring: Invest in battery health monitoring systems to track performance metrics and identify potential issues early.

3. Energy-Efficient Appliances: Invest in energy-efficient appliances and devices to lower overall power consumption and alleviate strain on batteries.

4. Proper Battery Sizing: Ensure that the battery bank is adequately sized to meet the expected power demands and runtime requirements, considering factors like load profiles, autonomy time, and depth of discharge.

5. Environmental Control: Maintain optimal environmental conditions for battery storage, such as temperature, humidity, and ventilation, to prevent premature degradation and maximize battery life.

6. Regular Battery Replacement: Plan for periodic replacement of batteries based on their expected lifespan and usage patterns, as batteries degrade over time and lose capacity.

3.10.3 OVERHEATING

Overheating is a prevalent issue that can adversely affect the performance and lifespan of inverters, particularly during prolonged usage or when subjected to high load conditions. This problem arises when the internal components of the inverter generate excessive heat, potentially leading to performance degradation, permanent damage, or even complete failure of the device. Understanding the symptoms, causes, and appropriate countermeasures is crucial to mitigating the risks associated with overheating.

Symptoms of Overheating:

- Automatic shutdown or activation of thermal protection mode by the inverter to prevent further damage.
- Noticeable heat emanating from the casing or external surfaces of the inverter.
- Gradual reduction in efficiency, output power, or overall performance of the inverter over time.
- Warning indicators or alarms related to high internal temperatures.

Causes of Overheating:

- High ambient temperatures, especially in poorly ventilated or confined spaces with limited airflow.
- Sustained operation at maximum or near-maximum load capacity, exceeding the inverter's continuous power rating.
- Accumulation of dust, dirt, or debris within the inverter enclosure, hindering airflow and heat dissipation.
- Presence of faulty or worn-out internal components, such as cooling fans, heat sinks, or thermal interface materials.
- Inadequate cooling system design or insufficient heat management provisions for the inverter.

Solutions to Address Overheating:

1. Ensure Proper Ventilation: Position the inverter in a well-ventilated area with ample airflow to facilitate effective heat dissipation. Avoid enclosing the inverter in tight spaces or obstructing airflow with objects.

2. Load Management: Refrain from running the inverter at maximum load capacity for prolonged durations. Distribute the load evenly across multiple outlets or circuits to minimize heat generation and stress on the inverter components.

3. Temperature Monitoring: Keep track of ambient temperatures surrounding the inverter. Install temperature sensors or utilize external monitoring devices to detect overheating conditions promptly and take corrective actions.

4. Routine Maintenance: Regularly clean both the exterior and interior of the inverter to eliminate dust, dirt, and debris that may impede airflow and hinder heat dissipation. Utilize compressed air or soft brushes to clean vents, cooling fans, and heat sinks.

5. Cooling Enhancements: Consider integrating additional cooling fans, larger heat sinks, or liquid cooling systems to enhance heat dissipation and thermal management, especially in environments prone to high temperatures or during periods of heavy usage.

6. Thermal Protection: Ensure the inverter is equipped with robust thermal protection mechanisms, automatically powering off or reducing output power when internal temperatures surpass safe thresholds to prevent damage.

7. Cooling Periods: If the inverter becomes excessively hot during operation, allow it to cool down adequately before resuming use. Minimize the load by turning off non-essential appliances or devices to mitigate heat accumulation.

Preventive Measures:

1. Optimal Positioning: Position the inverter in a well-ventilated location, away from direct sunlight and other heat sources, with adequate clearance around the device for proper airflow.

2. Regular Maintenance Schedule: Establish and adhere to a routine maintenance schedule for the inverter, including cleaning vents and filters, checking fan functionality, and monitoring internal temperatures.

3. Load Management Strategies: Implement load management strategies to avoid overloading the inverter and ensure connected appliances remain within the rated capacity of the device.

4. Temperature Monitoring Systems: Consider installing comprehensive temperature monitoring and alarm systems to provide early warnings of potential overheating issues, enabling timely intervention and preventive actions.

5. Periodic Component Replacement: Plan for periodic replacement of critical components, such as cooling fans and heat sinks, based on their expected lifespan and usage patterns, as these components can degrade over time.

3.10.4 OUTPUT VOLTAGE FLUNCTUATIONS

Output voltage fluctuations in inverters can lead to instability and unreliable operation of connected appliances and devices, potentially causing malfunctions, damage, or even complete failure of sensitive equipment. This issue demands careful attention and proactive measures to mitigate its impact and ensure smooth operation of the inverter system.

Symptoms of Output Voltage Fluctuations:

- Flickering lights or intermittent power supply experienced by connected appliances.
- Inconsistent performance or malfunctions observed in sensitive electronic devices such as computers, audio/video equipment, or medical devices.
- Appliances prone to overheating or sustaining damage due to voltage spikes or drops.
- Warning indicators or alarms related to voltage instability or irregularities.

Causes of Output Voltage Fluctuations:

- Inadequate battery capacity or improper charging voltage, resulting in fluctuations in the input voltage supplied to the inverter.
- Overloading of the inverter, causing voltage drops when the aggregate power demand exceeds the inverter's rated capacity.
- Poor quality, aging, or damaged internal components within the inverter affecting voltage regulation, such as faulty voltage stabilizers or control circuits.
- External factors such as fluctuations in the grid power supply or sudden changes in load conditions when operating in grid-tied mode.
- Loose or corroded electrical connections within the inverter or associated wiring, leading to voltage instability.

Solutions to Address Output Voltage Fluctuations:

1. Check Battery Capacity and Charging: Ensure that the batteries connected to the inverter are appropriately sized and maintained at the recommended state of charge to provide a stable input voltage. Regularly monitor battery health and adjust charging parameters as needed to prevent input voltage fluctuations.

2. Reduce Load and Optimize Load Distribution: Distribute the load evenly across multiple outlets or circuits and disconnect non-essential appliances to avoid overloading the inverter, maintaining stable output voltage during operation.

3. Inspect, Maintain, and Upgrade Components: Regularly inspect the inverter for signs of damage or wear, clean and tighten electrical connections, replace aging or damaged components, and perform firmware updates as needed to improve voltage regulation and overall performance.

4. Use Voltage Stabilizers or Regulators: Install external voltage stabilizers or regulators between the inverter and sensitive appliances to smooth out voltage fluctuations, ensuring a consistent voltage supply and protecting equipment from damage.

5. Monitor Grid Power Quality: If operating in grid-tied mode, monitor the quality and voltage levels of the grid power supply to identify potential issues affecting the inverter's output voltage. Consider installing power conditioning equipment or filters to enhance grid stability and mitigate voltage fluctuations.

6. Implement Power Management Strategies: Prioritize essential loads and prevent sudden changes in power demand by implementing power management strategies. Utilize timers, load shedding devices, or intelligent control systems to control consumption during peak periods and maintain stable voltage levels.

Preventive Measures:

1. Regular Maintenance and Inspection: Establish and adhere to a regular maintenance and inspection schedule for the inverter and associated battery system to ensure optimal performance and voltage regulation.

2. User Education and Load Management: Educate users on proper load management practices, the importance of avoiding overloading the inverter, and the potential consequences of voltage instability on connected equipment.

3. Install Monitoring and Protection Devices: Implement voltage monitoring and protection devices, such as surge protectors or voltage regulators, to detect and mitigate voltage fluctuations before they can affect connected appliances.

4. Upgrade or Replace Aging Components: Plan for periodic upgrades or replacements of critical components, such as voltage regulators, control circuits, or batteries, based on their expected lifespan and usage patterns, as aging components can contribute to voltage instability.

- COMPONENT FAILURES

Component failures pose a significant risk to the performance and reliability of inverters, potentially resulting in malfunctions, power interruptions, or complete failure of the system. This issue demands vigilant monitoring and proactive measures to mitigate its impact and ensure the uninterrupted operation of the inverter.

Symptoms of Component Failures:

- Complete failure to power on or provide output from the inverter.

- Detection of unusual noises, smells, or visible signs of damage or overheating.

- Erratic behaviour or inconsistent performance of connected devices and appliances.

- Display of error codes, fault indicators, or warning messages on the inverter's control panel or monitoring interface.

- Reduced efficiency or output power capacity of the inverter.

Causes of Component Failures:

- Age-related degradation of electronic components over time, leading to wear and tear.
- Exposure to environmental factors like extreme temperatures, high humidity, dust, or corrosive elements.
- Voltage spikes, surges, or electrical noise from the input power source, stressing internal components.
- Overloading or excessive stress on internal components due to high load conditions or frequent cycling.
- Manufacturing defects, quality control issues, or improper assembly of components during production.
- Physical damage or impact to the inverter casing or internal components.

Solutions to Address Component Failures:

1. Diagnose Faulty Components: Employ diagnostic tools like multimeters, oscilloscopes, or thermal imaging cameras to pinpoint failed components. Conduct visual inspections for signs of damage, discoloration, or abnormal behavior.
2. Replace Failed Components: Upon identification of faulty components, replace them with compatible replacements meeting the original specifications, ratings, and quality standards.
3. Perform Repairs: Where feasible and cost-effective, repair or re-solder damaged connections, traces, or components on the circuit board. Adhere to safety protocols and electrostatic discharge (ESD) precautions when handling electronic components.

4. Update Firmware and Software: Check for and apply firmware or software updates released by the manufacturer to address known issues, vulnerabilities, or performance enhancements that may contribute to component failures or instability.
5. Improve Cooling and Ventilation: Enhance cooling mechanisms within the inverter to alleviate thermal stress on internal components. Install additional cooling fans, heat sinks, or improve ventilation systems as necessary.
6. Implement Surge Protection: Utilize surge protectors, transient voltage suppressors, or power conditioning equipment to shield the inverter from voltage spikes, surges, or electrical noise originating from the input power source.
7. Perform Regular Maintenance: Conduct periodic inspections and maintenance checks to detect and address potential issues before they escalate into component failures. Clean internal components, check for loose connections, and verify cooling system operation regularly.

Preventive Measures:
1. Follow Manufacturer Recommendations: Adhere to maintenance intervals, operating guidelines, and procedures recommended by the manufacturer to minimize the risk of component failures and ensure optimal performance.
2. Avoid Overloading: Operate the inverter within its rated capacity and specifications to reduce stress on internal components and prevent premature failures.
3. Monitor Operating Parameters: Implement monitoring systems to track input and output voltages, temperatures, load levels, and other parameters to detect abnormalities indicative of potential component failures.

4. Invest in Quality Components and Systems: Opt for high-quality inverters and components from reputable manufacturers with proven reliability and durability records.

5. Provide Adequate Ventilation and Cooling: Ensure that the inverter is installed in a well-ventilated area with sufficient airflow and cooling provisions to prevent overheating and component degradation.

6. Implement Redundancy and Backup Systems: In critical applications, consider implementing redundant inverter systems or backup power sources to minimize downtime in the event of component failures.

- INVERTER FAN ISSUES

Inverter fans are vital for maintaining optimal operating temperatures by dissipating heat generated during operation. However, issues with these fans can lead to overheating, reduced efficiency, and potential damage to internal components.

Symptoms:

- Audible noise or unusual vibrations from the inverter fan during operation.
- Inconsistent fan operation, such as intermittent spinning or failure to start.
- Overheating indicators or alarm codes displayed on the inverter's control panel.
- Reduced cooling performance or increased internal temperatures.

Causes:

- Accumulation of dust, dirt, or debris obstructing the fan blades or impeding airflow.
- Mechanical wear or damage to the fan motor, bearings, or blades.

- Electrical issues such as faulty wiring, connections, or control circuitry affecting fan operation.
- Environmental factors such as high temperatures, humidity, or exposure to moisture.

Solutions:

1. Clean Fan and Vents: Remove dust, dirt, or debris from the fan blades and surrounding ventilation openings to ensure proper airflow and cooling performance.
2. Inspect Fan Motor: Check the fan motor, bearings, and blades for signs of wear, damage, or obstruction. Replace damaged components or lubricate bearings as needed.
3. Test Fan Operation: Manually spin the fan blades to verify free rotation and check for any unusual resistance, noise, or vibration indicating mechanical issues.
4. Verify Electrical Connections: Inspect wiring connections, terminals, and control circuitry associated with the fan for damage or loose connections. Ensure proper voltage supply.
5. Replace Faulty Components: If the fan motor or associated components are faulty, replace them with new, compatible replacements rated for the inverter's operating conditions.
6. Improve Ventilation: Provide adequate clearance space around the inverter and avoid obstructing ventilation openings. Install additional cooling fans or ventilation systems if needed.
7. Monitor Temperature: Use temperature monitoring devices to track internal temperatures and implement automatic shutdown or cooling strategies to prevent overheating.

Preventive Measures:

1. Regular Maintenance: Clean and inspect inverter fans and ventilation openings periodically to prevent dust buildup and obstruction.
2. Schedule Maintenance Checks: Verify fan operation during routine maintenance checks and address any issues promptly.
3. Monitor Ambient Temperatures: Keep track of environmental conditions to ensure optimal cooling performance and prevent overheating.

By promptly addressing fan issues and implementing preventive maintenance measures, users can ensure optimal cooling performance, prolong inverter lifespan, and minimize the risk of component damage.

CHAPTER 4: DISCUSSION OF FINDINGS AND IMPLICATION OF RESULTS

4.1 INTRODUCTION

In this study, results from power quality observations obtained at a grid connected solar inverter site - Department of Mechanical Engineering, University of Benin, Edo State, Nigeria with latitude 6.3998° N, and longitude 5.6009° E, measurements from the solar inverter system were recorded over a period of 14 days. The analysis of data gathered from the site of the grid-connected solar inverter undergoing testing has been conducted. It was evaluated to observe both the overall efficiency of the system and the impact of solar irradiance on the operation of the tested grid-connected systems. The analysis examined two scenarios: one with typical ("average") solar radiation levels, and another with diminished ("low") radiation. The study looked at how the amount of solar irradiance impacts power quality measurements.

Additionally, the study conducted a series of performance test scenarios to evaluate the 3.5kVA solar system installed at the Department of Mechanical Engineering, University of Benin, Nigeria. This assessment focused on the following key performance metrics:

1. Solar Irradiance
2. Energy Generation
3. Battery Performance
4. System Efficiency

Table 4.1 presents the collected data about the performance of the system, including relevant parameters such as date, time, ambient temperature, output voltage, output current, and generated power. This data forms the basis for the subsequent analysis and evaluation of the system performance and reliability under different operating conditions and scenarios.

Table 4.1: Data collected during a two week span of using the Solar Inverter System under loading conditions.

Date	Time	Temperature	Voltage (V)	Power (Wh)
WEEK ONE				
04/03/2024	8:00 am- 6:00 pm-	33.3ºC 38.2ºC	46.70v 46.70v	10692 10627
05/03/2024	8:00 am- 6:00 pm-	33.7ºC 38.7ºC	46.91v 46.78v	10523 10649
06/03/2024	8:00 am- 6:00 pm-	33.8ºC 38.0ºC	47.02v 46.84v	10648 10637
07/03/2024	8:00 am- 6:00 pm-	34.2ºC 38.1ºC	47.02v 46.75v	10624 10625
08/03/2024	8:00 am- 6:00 pm-	33.4ºC 36.1ºC	47.04v 46.89v	10657 10631
09/03/2024	8:00 am- 6:00 pm-	33.1ºC 35.9ºC	46.96v 45.78v	10636 10625
10/03/2024	8:00 am- 6:00 pm-	34.3ºC 38.0ºC	47.02v 46.73v	10625 10625
WEEK TWO				
11/03/2024	8:00 am- 6:00 pm-	35.8^{0}C 37.1^{0}C	46.97v 46.90v	10625 10644
12/03/2024	8:00 am- 6:00 pm-	33.5^{0}C 38.7^{0}C	47.02v 46.72v	10643 10647
13/03/2024	8:00 am- 6:00 pm-	34.0^{0}C 38.1^{0}C	47.00v 46.73v	10648 10653
14/03/2024	8:00 am- 6:00 pm-	33.9^{0}C 38.2^{0}C	46.89v 46.74v	10627 10651
15/03/2024	8:00 am- 6:00 pm-	33.5^{0}C 36.3^{0}C	46.65v 46.58v	10639 10692
16/03/2024	8:00 am- 6:00 pm-	33.5^{0}C 36.6^{0}C	47.00v 46.57v	10651 10631
17/03/2024	8:00 am- 6:00 pm-	33.6^{0}C 36.7^{0}C	47.01v 46.55v	10652 10648

4.2 PERFORMANCE ANALYSIS OF THE 3.5KVA SOLAR INVERTER SYSTEM

4.2.1 SOLAR IRRADIANCE DATA ANALYSIS

Solar irradiance data refers to measurements of the amount of solar radiation energy received on a given surface area over a period. This data captures how much of the sun's radiant energy, in the form of electromagnetic radiation, reaches and strikes a particular location on Earth. Solar irradiance is measured in units of watts per square meter (W/m²). Higher values indicate more intense sunlight hitting that area. This data is influenced by factors like time of day, season, latitude, elevation, atmospheric conditions, and obstructions like clouds or shade. The figure 4.1 below shows the graph of voltage against power for the first week and the figure 4.2 shows the graph of voltage against power for the following week.

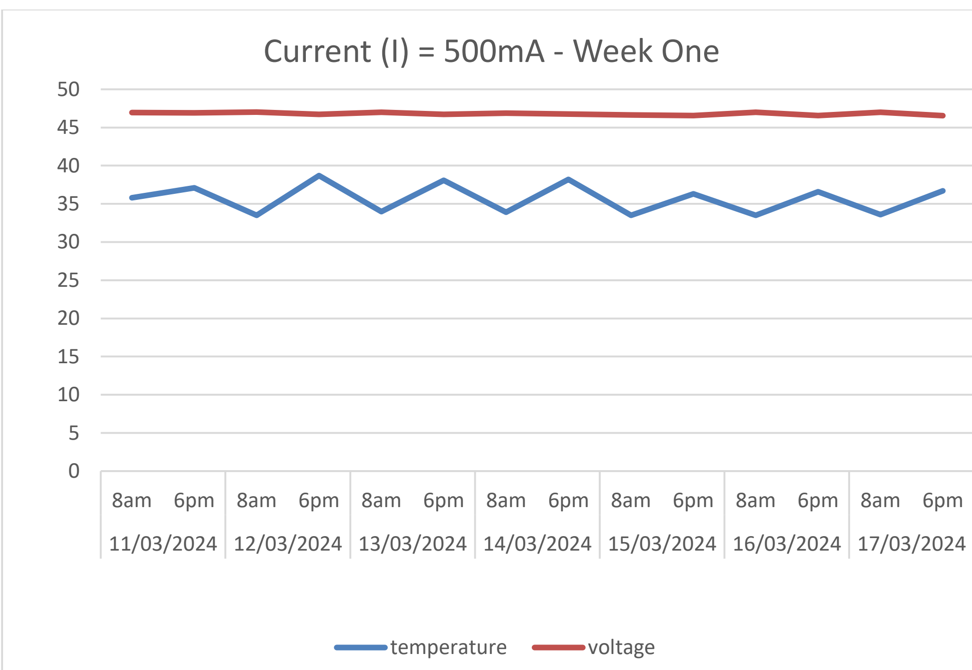

Figure 4.1: Graph of voltage against power for week on

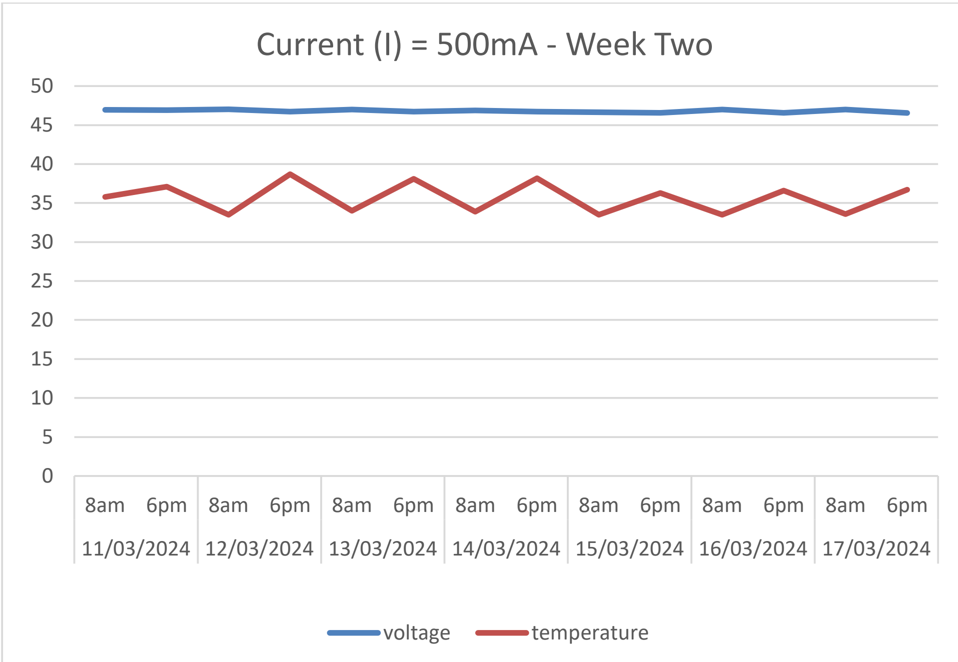

Figure 4.2: Graph of voltage against power for week two

Figure 4.2 is a graph showing the relationship between the voltage against power where the blue line represents the power, and the red shows the voltage obtained from the solar inverter system for a period of seven days. The concept of more solar irradiance equals more power is well shown in the graph whereby we peak periods on the graph showing times of high solar irradiance and this thereby satisfies the working condition of a normal working solar panel. Also, Figure 4.2 shows the relationship between the voltage against power where the blue line represents the voltage, and the red shows the power obtained from the system for the second week of collecting this data.

4.2.2 ENERGY GENERATION DATA ANALYSIS

Analysing solar inverter data includes gathering and processing information to monitor system performance, predict power production, perform financial evaluations, aid in research and development, ensure adherence to regulations, and compare technologies to enhance solar photovoltaic systems and progress the solar energy sector. The table 4.2

below shows the amount of power generated for the two weeks period of noting this data at 6am and 8pm daily. The graph corresponding to this data is also represented below in figure 4.3 below.

Table 4.2: Data collected in two weeks for energy generated.

Date	**Time**	**Power (Wh)**
	WEEK ONE	
4/3/2024	8:00 AM 6:00 PM	10692 10627
5/3/2024	8:00 AM 6:00 PM	10523 10649
6/3/2024	8:00 AM 6:00 PM	10648 10637
7/3/2024	8:00 AM 6:00 PM	10624 10625
8/3/2024	8:00 AM 6:00 PM	10657 10631
9/3/2024	8:00 AM 6:00 PM	10636 10625
10/3/2024	8:00 AM 6:00 PM	10625 10625
	WEEK TWO	
11/3/2024	8:00 AM 6:00 PM	10625 10644
12/3/2024	8:00 AM 6:00 PM	10643 10647
13/03/2024	8:00 AM 6:00 PM	10648 10653
14/03/2024	8:00 AM 6:00 PM	10627 10651
15/03/2024	8:00 AM 6:00 PM	10639 10692
16/03/2024	8:00 AM 6:00 PM	10651 10631
17/03/2024	8:00 AM 6:00 PM	10652 10648

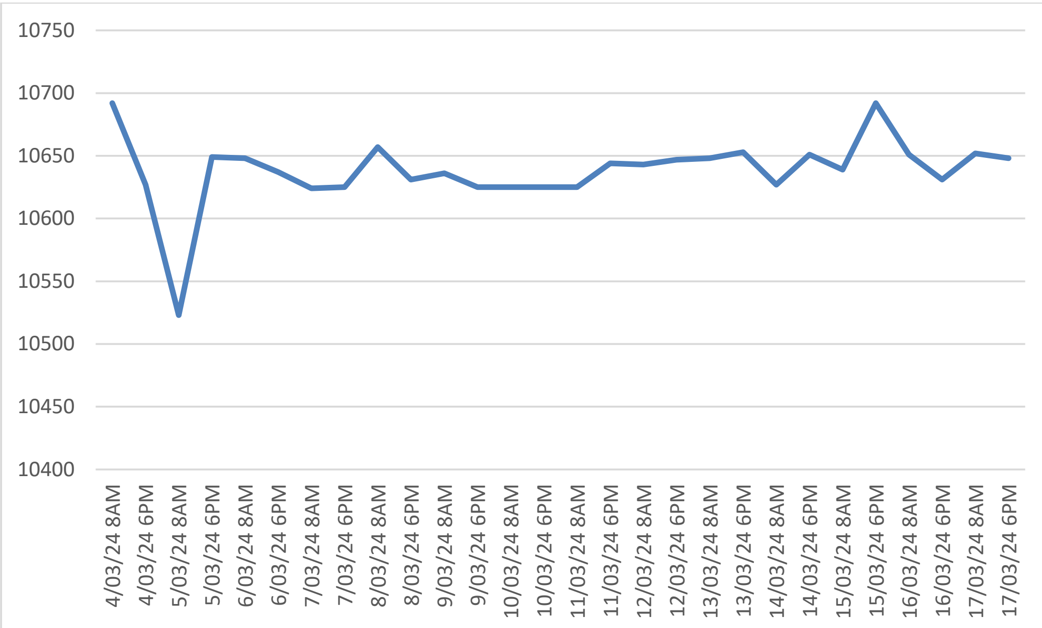

Figure 4.3: Graph of power generated over the period of data collection.

From the data shown so far, we see that maximum power was generated on the morning of Monday March 4th, 2024, which was in fact the first day of this testing and the least power generated was on the morning of the next day Tuesday March 5th 2024. The power generated on an average daily throughout the two weeks period of this testing was 10628Wh per day and this combined with the power delivered also from the local electricity grid through the inverter in the system meeting over 60% of the daily power requirements for the workshop offices and lecture theatres.

4.2.3 BATTERY PERFORMANCE DATA ANALYSIS

The energy capacity of solar batteries is expressed in kilowatt-hours (kW), as opposed to battery size, which is expressed in kWh. Therefore, the term "kWh" in this study refers to the total energy utilized. The rate of electricity usage is expressed in kW. Additionally, the power rating of a battery is the quantity of kW that the solar system can produce at any given time. At the Department of Mechanical Engineering, University of Benin, more office equipment can run simultaneously when there is a higher battery power rating. Higher power, however, means that the stored energy will run out more quickly. Illustrating the average performance of the solar + battery system combined power to enable total self-sufficiency within this specific time frame. The only times grid imports are needed are when the battery runs out of power and then it can be recharged by the solar panels and power from the local electricity grid through the inverter.

The accompanying figure 4.4 below is an example for the period of March 4th to March 17th, 2024, illustrating the average performance of how the solar inverter and battery system work together in enabling total self-sufficiency during that specific time frame.

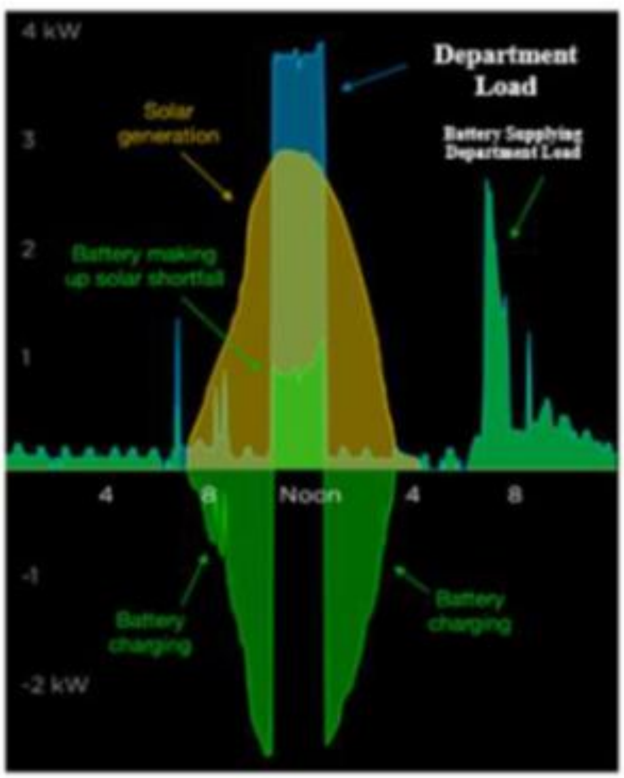

Figure 4.4: Average power flow from 4th March to 17th March, 2024

4.2.4 SYSTEM EFFICIENCY ANALYSIS

Referring to the data collected by testing the solar inverter system over a period of two weeks and tabulated in Table 4.1, The research sheds light on the intricate interplay between environmental conditions and the performance of photovoltaic (PV) systems. One of the key findings highlights the significant impact that low levels of solar irradiance can have on the quality and consistency of the power output from this system. The primary objective of this test caried out was to delve into the complex interrelationships between ambient temperature fluctuations and varying solar radiation intensities, and their combined effects on the overall efficiency and productivity of PV installations. Interestingly, the data collected during this two-week period in typical operating conditions, characterized by normal daily cycles with load on the system, exhibited a strong alignment with the expectations, validating the robustness of this experimental approach.

Perhaps one of the most remarkable findings of this study is the calculation of the overall system efficiency, which stood at an impressive 60%. This figure underscores the remarkable achievement of the solar panels in successfully utilizing 60% of the energy gotten from sun rays. To put this into perspective, the solar panels generated an average daily output of 289 watts, a substantial contribution that met approximately 60% of the daily energy demands of the workshop offices and lecture theatres the system is meant to power.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The research study undertook a comprehensive analysis of the testing and performance evaluation of a 3.5kVA solar photovoltaic (PV) system installed at the Department of Mechanical Engineering, University of Benin, Nigeria, as part of a sustainable energy initiative aimed at reducing the department's dependence on the traditional power grid and minimizing carbon emissions. The analysis focused on examining in detail various aspects of the 3.5kVA solar system's operational performance, including solar irradiance measurement, energy generation, battery performance, and system efficiency. Specifically, the study examined the solar irradiance levels incident on the PV panels, which significantly impact the system's energy generation capability. Additionally, the analysis assessed the performance of the battery bank, including its capacity, charging, and discharging characteristics, and overall efficiency in storing and supplying energy to meet the department's energy demands.

The 3.5kVA solar system comprises several essential components: eight solar panels, each with a 300W capacity, installed on the rooftop of the departmental building; a 3.5kVA inverter responsible for converting the DC power generated by the solar panels into AC power; a set of deep-cycle batteries with a total capacity of 400Wh to store excess energy produced during the day; a charge controller integrated into the system to regulate the charging and discharging of the batteries; and a monitoring system to track and record the system's performance, including energy generation, battery status, and overall efficiency. The study gathered comprehensive data on the performance of the 3.5kVA solar system installed at the Department of Mechanical Engineering, University of Benin, Edo State, Nigeria, located at latitude 6.3998° N and longitude 5.6099° E. The data collection spanned a period of 14 consecutive days and focused on four key performance metrics: Solar Irradiance Measurement, which assessed the amount of solar power per unit area received from the Sun, directly impacting the energy generation capability of the solar panels; Energy Generation, measuring both electrical and thermal energy generated by the solar panels under various operating conditions; Battery Performance, evaluating the battery bank's usage cycles, including charging and discharging patterns, and overall efficiency in storing and supplying energy; and System Efficiency, representing the portion of incoming sunlight energy successfully converted into electrical energy by the solar cells, considering various system losses and inefficiencies.

The results have been analysed for two different scenarios, labelled "Week One" and "Week Two." The collected data demonstrates that higher levels of solar irradiance led to increased power storage, aligning with the expected behaviour of a properly functioning solar panel system.

During Week One, temperatures varied from 33.3°C to 38.7°C, with power output ranging from 10692Wh to 10523Wh. This indicates the influence of solar irradiance on the solar panel's performance, as power output depends on the temperature on the day the reading was taken. The data also reveals instances of lower and higher voltage output at different points in time, further reinforcing the principle that higher irradiance results in greater power storage, meeting the requirements of a standard solar panel.

Similarly, in Week Two, temperatures ranged from 33.5°C to 38.7°C, with power output ranging from 10692Wh to 10625Wh, further supporting the notion that solar irradiation affects the solar panel's performance based on the previous day's temperature.

Regarding energy generation, data shows that the morning of March 4th, 2024, saw the highest energy generated at 10692Wh, while the evening of March 5th, 2023, recorded the least at 10523Wh. Moreover, the solar panels generated an average of 10608Wh per day, meeting approximately 57% of the department's daily energy demand, which is commendable.

In terms of battery performance, at its peak, the solar system generated 19200Wh compared to the total consumption of the department's offices and lecture theatres, which amounted to 18655Wh.

Regarding overall system efficiency, the solar system exhibited good alignment with expectations. Solar irradiation indeed impacts solar cells, with an overall efficiency calculated at 60%, indicating successful utilization of 60% of the energy generated by the solar panels.

5.2 RECOMMENDATIONS

Based on the conclusions drawn from this report, the following recommendations are proposed.

1. Implement a comprehensive monitoring and data acquisition system: Install sensors and monitoring devices to track the performance of the solar photovoltaic system in real-time, enabling proactive maintenance and optimization.
2. Develop a detailed maintenance and inspection plan: Establish regular checks and preventive maintenance tasks for all system components based on manufacturer recommendations and industry best practices to ensure long-term reliability.
3. Explore energy storage solutions: Investigate integrating energy storage systems to enhance system flexibility, mitigate intermittency, and provide backup power during grid outages.

4. Consider implementing backup power solutions: Evaluate options such as generators or grid tie-ins to provide additional resilience during periods of low solar irradiance or battery depletion.

5. Adhere to electrical safety rules and regulations: Ensure total compliance with electrical safety standards during installation to safeguard technicians, system components, and end-users.

6. Conduct periodic performance evaluations: Regularly assess the system's performance against expected targets, identifying deviations and taking corrective actions as necessary to maintain efficiency.

7. Encourage community engagement and education: Promote awareness of solar energy benefits and engage in educational initiatives to foster broader adoption of renewable energy solutions within the local community.

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