DESIGN AND IMPLEMENTATION OF A 2.5KVA HYBRID INVERTER SYSTEM FOR A THREE-BEDROOM APARTMENT

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CERTIFICATION

This is to certify that this project was carried out by ERHUANGA GREAT EHIZOKHAE with matriculation number ENG1805060, UGEH CHIGOZIE COLLINS with matriculation number ENG1805144, OKONONFUA DAVID with matriculation number ENG1805109, ANYAEGBU NJIDEKA with matriculation number ENG1805230 and OSEGHALE GRATEFUL with matriculation number ENG1805123, in partial fulfillment of the requirements of the award of Bachelor of Engineering (B.ENG) degree in Electrical/Electronic Engineering.

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HOD	

DEDICATION

We dedicate this project to everyone involved in this project, who have been a constant source of inspiration, support and encouragement throughout this journey. Their unwavering belief in our abilities and their valuable insights did play a significant role in shaping the outcome of this project.

To our ever supportive supervisor Engr. A. Dauda, your dedication, passion and commitment to excellence have been a source of strength for us.

Finally this project is dedicated to anyone who finds inspiration knowledge, or solace within its pages. May it serve as a source of information, motivation, or reflection, and may it contribute in some small way to the greater good.

ABSTRACT

Energy demand and consumption increase astronomically as the days unfold. This development has made the deployment of natural and renewable energy sources, such as solar, inevitable. They serve as alternative to the inadequate supply of the conventional sources.

It is the increasing need for various homes, institutions and firms to embrace the essence of Photovoltaic (PV) system that necessitated this project study. The research work, titled ‗Design and implementation of a 2.5kVA inverter for a three-bedroom apartment', was aimed at ensuring that the operations and efficiency of a Photovoltaic system, particularly the 2.5kVA type installed in a three-bedroom apartment is well installed and enhanced. To achieve this, a 2.5kVA Hybrid Power Inverter with integrated 50A PWM charge controller which is used to regulate the charging and two 12V batteries of high Depth of Discharge were used, 6 200W solar panels were also used. The batteries and solar panels were connected in series/parallel arrangement for effective utilization. This also involves load sizing, inverter sizing, PV panels sizing and charge controller sizing.

The hybrid Inverter (multi-mode), which produces a pure sine wave in the process, guarantees reliability and cleaner output as expected. At the end of the research, an implementation of a 2.5kVA Solar Home System was actualized

ACKNOWLEDGEMENT

To God: Your divine grace and unwavering presence in our lives have been a constant source of strength and inspiration. We are profoundly thankful for the blessings, wisdom and inner strength that You have provided, guiding us through the journey.

To the Head of Department (HOD), Engr. Prof. K. O Ogbeide. Your leadership encouragement and commitment to academic excellence have been instrumental in shaping our academic and research path. Your guidance and support have helped us navigate the challenges and complexities of this project.

To our supervisor: We extend our sincere appreciation to our supervisor, Engr. Dr. A. Dauda, for his invaluable mentorship, patience and expertise. Your guidance has been instrumental in refining our research skills and shaping the direction of this project. Your dedication to our success has been a driving force behind our achievements.

To our Families: The Erhuanga‘s family, Okononfua‘s family, Ugeh‘s family Anyaegbu‘s family and the Oseghale‘s family for their significant financial contributions, unwavering love, encouragement, and understanding have been the bedrock of our journey.

To our Friends: To our friends who stood by us, listened to our concerns, and provided words of encouragement during the challenging times of this project, your friendship means the world to us. Your belief in our abilities and your willingness to be a pillar of support has been immeasurable.

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LIST OF ABBREVIATIONS/UNITS

Abbreviation	**Meaning**
A	Ampere
AC	Alternating Current
Ah	Ampere per hour
DC	Direct Current
DCB	Deep Circle Battery
DOD	Depth of Discharge
EEE	Electrical and Electronic Engineering
HOD	Head of Department
SHS	Solar Home System
ISC	Current Short Circuit
KVA	Kilo Volt-Ampere
KW	Kilo-Watt
MOSFET	Metal-oxide Field Effect Transistor
MPPT	Maximum Power Point Tracker
OCPD	Over Current Protection Device
PV	Photovoltaic
PWM	Pulse Width Modulation
V	Voltage
VAC	Voltage Alternating Current
VDC	Voltage Direct Current

VOC	Voltage Open Circuit
W	Watt

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUNG OF STUDY

The sun's radiant energy, or solar energy, is an endless, renewable resource that has the potential to meet the growing need for sustainable and clean energy sources. This abundant energy source is captured by photovoltaic (PV) technology, which converts it into easily used power and presents a strong substitute for limited and harmful fossil fuels to the environment. Solar energy is continuously renewed, as opposed to fossil fuels, whose stocks are running low. This ensures longterm supply and allays worries about resource depletion. The production of solar energy results in little to no emissions of greenhouse gases or other air pollutants, which makes a major contribution to the battle against climate change and the preservation of the environment. Solar technology is becoming a more financially viable choice for both individual users and large-scale energy projects as its cost-effectiveness increases.

More energy independence and resilience are fostered at the community and individual levels by solar energy, which facilitates the transition to decentralized energy production systems.

A major step in the direction of a sustainable energy future is the growing use of solar energy. The inherent advantages of solar energy must be acknowledged by governments, businesses, and individual customers alike. To enable its widespread deployment, regulations, technologies, and infrastructure expenditures must be put in place. We can create the conditions for future generations to enjoy a cleaner, healthier, and more secure future by utilizing the infinite potential of solar electricity.

The rapid adoption of solar power has demonstrably shifted its role from a marginal technology to a significant contributor to global energy production. Currently, exceeding 1% of the world's total energy output, solar power demonstrates its growing influence. Further bolstering this trend, projections by the International Energy Agency (IEA) in 2014 suggest that solar energy could account for an impressive 27% of global electricity generation by 2050 (Andreas, 2019).

This substantial projection underscores the immense potential of solar energy and serves as a powerful impetus for increased investment in this burgeoning technology.

1.1.1 ORIGIN OF SOLAR ENERGY

The harnessing of solar energy, far from a recent innovation, possesses a rich and diverse history intertwined with human ingenuity. Its roots stretch back to the seventh century BC, where early civilizations embraced the sun's potent energy in myriad ways. Imagine, if you will, individuals armed with rudimentary magnifying glasses, focusing sunlight to ignite flames – a testament to the human pursuit of manipulating solar power even in its nascent stages.

Fast forward to the present day, and the sun's radiance illuminates our lives in a multitude of forms. Sleek solar panels adorn rooftops, discreetly transforming sunlight into electricity that powers homes and businesses. Futuristic electric vehicles glide silently across city streets, propelled by the sun's captured energy. These contemporary applications stand as a stark contrast to the rudimentary beginnings, yet both exemplify the unwavering human endeavor to tap into the sun's boundless potential.

In 1839, French physicist Alexandre Edmond Becquerel established the foundation for the discipline of photovoltaics with his discovery of the photoelectric effect. He showed how sunlight striking two different metal electrodes submerged in an electrolyte might produce a current. Even though Becquerel's crude "solar cells" had very little efficiency, his discovery laid the groundwork for a revolution in technology.

The absence of sophisticated semiconductor technologies and our imperfect grasp of quantum mechanics were the main causes of the limitations of early solar systems. However, important developments in the field were made possible by advances in semiconductor design and the advent of the transistor. The efficiency of solar cells today is far higher, and future research indicates even higher gains. (Noor, 2016).

1.1.2 HOW DOES SOLAR/PV POWER SYSTEM WORK?

Solar photovoltaic (PV) panels use semiconductor-containing cells to collect solar radiation and transform it into electrical current. Silicon is the most widely used semiconductor material since it is easily obtainable and abundant in sand. When light strikes the semiconductor lattice in the cell, some of its energy is absorbed, pushing out negatively charged electrons and forming positively charged "holes."

PV cells are typically made up of two layers of semiconductor materials: one layer is p-doped (electron-deficient) and the other is n-doped (electron-rich). Direct current (DC) is produced when light irradiation creates an electric field across the p-n junction, which causes electrons to flow from the n-type layer to the p-type layer. External current extraction is facilitated by metallic connections attached to the top and bottom of the cell.

Remarkably, solar photovoltaic panels can generate power even on overcast days; they are not dependent on direct sunshine to function. On the other hand, light intensity directly affects current flow, with direct sunlight often producing higher yields. It's interesting to note that, because of increased sunlight reflection, clouds with modest light scattering can occasionally produce higher energy outputs than perfectly clear skies. (How Do Solar PV Power Systems Work? | EWS Solar, n.d.)

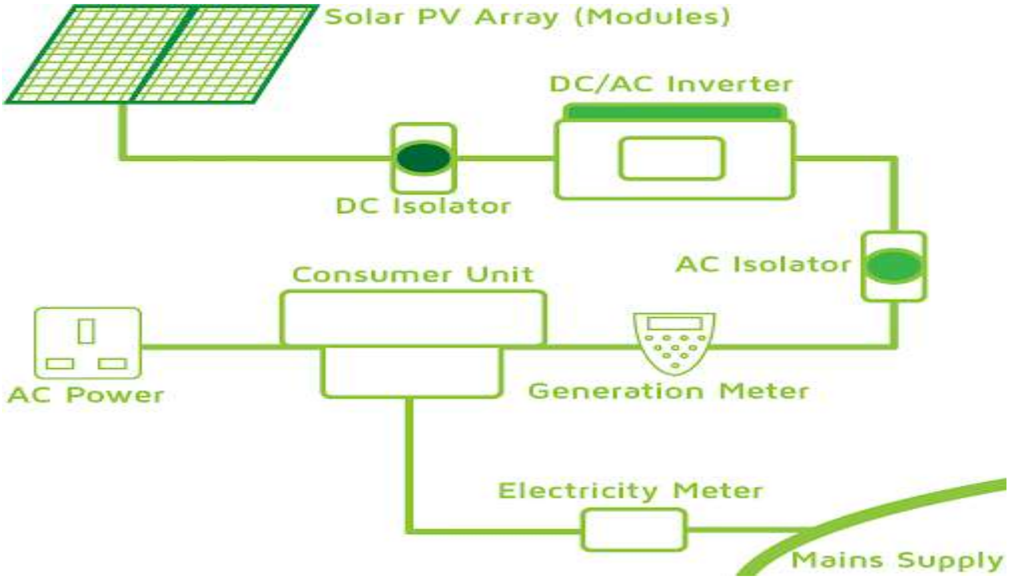

Figure 1.1: A Simple PV System (How Do Solar PV Power Systems Work? | EWS Solar, n.d.)

1.1.3 HOW THE ELECTRICITY IS CONVERTED FOR USE

When exposed to solar radiation, photovoltaic cells function as tiny power plants. They capture the energy contained in photons, or light particles, and transform it into DC electricity. This DC power flows in a single direction, much like a river.

But the enormous networks that run our homes and businesses are powered by alternating current (AC) electricity. Think of AC as a tide that is always rising and falling. Photovoltaic systems use clever devices called inverters to fill this gap. By converting the DC River of electricity into the grid-compatible AC tidal, these inverters function as translators.

1.2 STATEMENT OF PROBLEM

The persistent challenges in Nigeria's power supply sector have given rise to a myriad of issues, significantly impacting the daily lives of residents, businesses, and institutions. The irregular power supply has resulted in an acute shortage of electricity, adversely affecting consumers across the region. In this complex landscape, the typical Nigerian household or business is confronted with a range of difficulties, magnifying the implications of the energy crisis.

Impact on Consumers

At the heart of this issue lies the direct impact on consumers who heavily rely on essential household and business appliances. Refrigerators, indispensable for food preservation, are rendered unreliable due to frequent power outages. Cooling appliances such as fans and air conditioners, critical for maintaining a comfortable living and working environment face continual disruptions. The situation is compounded by the use of electronic devices like televisions, computers, and printers, which are vital for daily activities in both residential and commercial settings. The inefficiencies in the Nigerian power sector directly impede the seamless operation of these devices, affecting the productivity and quality of life for millions.

Rising Electricity Tariffs

Adding to the plight of consumers is the alarming escalation in electricity tariffs. As the costs of power consumption soar, households and businesses find themselves grappling with an additional financial burden. The escalating tariffs, coupled with inconsistent power supply, create a dual challenge that hampers economic activities and standard of living.

Generator Dependence

In response to these challenges, individuals have resorted to the use of mechanical generators as a stopgap measure to bridge the gaps left by the national grid. However, this solution proves to be less than ideal. The operational costs and maintenance requirements of these generators are prohibitively high, exacerbating the financial strain on consumers. The continuous upkeep of various power supply devices has become an increasingly burdensome task, diverting financial resources that could otherwise be allocated to other critical needs.

Environmental Ramifications

Moreover, the prevalent use of conventional electricity sources and generators contributes significantly to environmental degradation. Emissions from these sources contribute to the depletion of the ozone layer, resulting in the greenhouse effect and contributing to climate change. The adverse environmental impact is not limited to global concerns; it permeates local communities, manifesting as air and noise pollution. The environmental hazards posed by these conventional power sources further compound the multifaceted challenges faced by Nigerians.

1.3 AIM

The aim of this study is to design design and implement a 2.5KVA hybrid inverter system for a three-bedroom apartment.

1.4 OBJECTIVES OF THE STUDY

These objectives collectively aim to create a robust, efficient, and sustainable 2.5KVA hybrid inverter system that contributes to the advancement of renewable energy technologies.

The specific objective of the project includes:

I. Design a 2.5KVA hybrid inverter system.

II. To carry out a load survey for the available loads in the home system. Which also includes identification of priority load

III. To analyze the sizing of the PV array

IV. To analyze the battery sizing to be used and its rate of charge.

1.5 METHODOLOGY

1. Research different hybrid inverter models with a 2.5kVA capacity. Considering factors like input voltage range (DC and AC), output voltage and frequency, surge capacity, and efficiency. Then we select an inverter that meets our specific needs and budget.
2. Develop a system diagram showcasing the connection between the inverter, battery bank, solar panels (future installation), and AC and DC loads.
3. Identify all electrical appliances and devices in the home. Then create a list including each appliance's name, wattage rating, and operating time per day.
4. Identify essential appliances needed in a home during a power outage (e.g., lights, fan etc). These essential appliances will be considered priority loads.
5. Sum the wattage ratings of all appliances to determine the total home power consumption.
6. We will find the array size which determines the total kW capacity required for our solar array to meet our daily energy needs. Then we divide the required array size (kW) by the individual solar panel's rated wattage to determine the number of panels needed.
7. Calculate the required battery capacity (Wh) by multiplying the desired backup time (hours) by the total home power consumption (W). Then we divide the required battery capacity (Wh) by the usable battery capacity per battery (Wh) to determine the number of batteries needed.
8. Analyze the inverter's specifications to determine its maximum battery charging current. Then Consider the battery bank's voltage and total Ah capacity to calculate the appropriate charging time based on the inverter's charging current

1.6 SIGNIFICANCE OF THE PROJECT

The sun produces more than enough energy to meet all of the world's energy needs, and unlike finite fossil fuels, it will continue to be a sustainable source of energy for some time to come. Our ability to efficiently and economically transform solar power into energy is the only thing holding it back.

For the majority of typical home users, improving a photovoltaic (PV) system with a 2.5kVA power capacity is crucial since it extends the amount of time that electricity is available for usage by both home and office users. In the long term, it also turns out to be economical. When compared to regular power grid usage, the cost after installing a PV system is minimal. Homeowners can use their electrical appliances whenever they want without having to pay extra.

The optimization component of the project is essential to improving energy efficiency. By carefully adjusting the inverter and charging system, we methodically work to optimize the use of renewable energy sources. This strategic strategy aims to reduce overall energy loss as well as reliance on the conventional grid. In order to achieve increased operational efficiency and support a paradigm shift toward sustainable energy consumption in the academic setting, careful fine-tuning is essential.

1.7 SCOPE OF THE PROJECT

The project focuses on designing, implementing and optimizing a 2.5kVA hybrid inverter for a renewable energy system. The goal is to align the PV system with consumer power requirements, minimize costs, and optimize solar panel output. The integrated solar charger system is implemented to maximize solar energy utilization, ensuring a reliable power supply and minimizing reliance on alternative sources.

CHAPTER TWO
LITERATURE REVIEW

2.1 OVERVIEW OF THE PV TECHNOLOGY:

With the help of Becquerel's 1839 discovery of the photovoltaic effect, Mouchot and other pioneers were able to foresee using their early solar engines for useful purposes. However, bringing this promise to a wider audience was fraught with difficulties, which paved the way for the exciting future growth of solar energy.

Figure 2.1: Charles Fritts installed the first solar panels on New York City rooftop in 1884 (Elizabeth & D.Lawerence, 2019)

An important milestone was reached in 1883 by New York-born American inventor Charles Fritts, who made the first solar cell that could be shown to operate, over a century before the broader environmental consciousness movement. According to Fritts, this experimental device was able to produce a current that was "continuous, constant, and of considerable force" because it was built from a selenium wafer that had been thinly covered with gold. Though Fritts' discovery is of great historical significance, its energy conversion efficiency which ranges from 1 to 2%—falls well short of modern solar devices that boast efficiencies surpassing 15%. It signaled the beginning of photovoltaic research in the US and set the basis for later developments that have brought solar energy to its current prominence as a feasible energy source. (Office, 2023)

At Bell Laboratories, the rapidly developing discipline of photovoltaics underwent a profound paradigm change in the 1950s. Researchers there, including Daryl Chapin, Calvin Fuller, and Gerald Pearson (who was subsequently inducted into the National Inventors Hall of Fame), realized the limits of selenium and succeeded in creating the first silicon solar cell that could be proven to be practically useful. With its remarkable 6% energy conversion efficiency, this ground-breaking discovery served as a vital link between theoretical promise and practical implementation. Nonetheless, the pricing issue continued to be a barrier to wider adoption. The manufacturing of multi-cell panels added to the intrinsic cost of silicon, making the technology unaffordable for the majority of users. Notably, by displaying one of the first structures, the University of Delaware's groundbreaking "Solar One" project from 1973 highlighted the possibilities of solar energy even further. (Office, 2023)

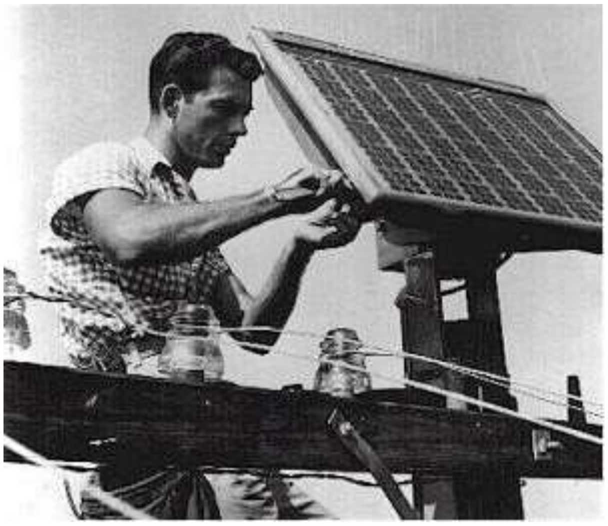

Figure 2.2: Bells laboratory earliest solar panel in the 1950s

2.2 RECENT DEVELOPMENT OF THE SOLAR PANEL

With perovskite research teams in Australia and China leading the way, the race to reinvent solar panels is heating up. This fascinating substance, which has been around since the 1800s, may lead to significant advancements in cost and effectiveness. Because it's getting harder to extract more silicon, as scientists like Thomas White from ANU explain, perovskite's promise is even more appealing. To fully realize the promise of this technology, energy conversion efficiency optimization is still a significant barrier to overcome. Australia is leading the charge to fully realize the promise of perovskite solar cells, which are hailed as a revolutionary development for the solar industry. Recently, the Australian Renewable Energy Agency (ARENA) awarded research and development teams $15 million with the explicit goal of merging silicon with perovskite for greater cost-effectiveness and efficiency.

Prominent entities such as the Australian National University (ANU) and the Chinese conglomerate JinkoSolar have extended their support for this endeavor. The promise of the technique is demonstrated by ANU researchers who have already attained a promising 21.6% efficiency for a bigger perovskite cell.

The superior absorption of light and low production cost of perovskite is its main selling points. But durability is still a big obstacle. Compared to silicon, perovskite crystals have a shorter lifetime because they are more sensitive to heat and moisture. (Gronewold, 2024).

Here we are going to answer the key questions about solar:

i. What are solar panels?
ii. How do solar panels work?
iii. How do solar panels produce electricity?

2.2.1 WHAT ARE SOLAR PANELS?

We see those recognizable blue panels soaking up the sun in quiet rows on roofs and in fields. They're all over the headlines these days, supplying renewable energy to power the future. But have you ever given them any thought as to what they're really composed of? Why do they require so much room, and why are they formed like squares? Let's explore the astonishing science and technology that underpin these solar powerhouses and go behind the scenes, behind the jargon and headlines.

Figure 2.3: Professional technician installing solar panel to metal platform using screwdriver (Benjamin, 2019).

The iconic blue rectangles found on fields and rooftops, known as solar panels, are quietly changing the way we produce power. However, how can these seemingly straightforward panels capture the sun's enormous energy and transform it into the electricity that powers our houses and companies?

Multiple individual solar cells, or tiny powerhouses, make up each solar panel and are what create the magic. Layers of silicon, a semiconductor material, are layered between layers of phosphorus and boron in these cells.

The layers of phosphorus and boron are important because they produce opposite charges: phosphorous produces a negative charge and boron a positive charge. As a result, an electric field is produced inside the silicon "encase."

The electrons in the silicon layer of the solar cell are excited when photons, which are tiny energy packets, made up of sunshine, impact them. A directed flow of current is produced when these excited electrons split off from their atoms and are carried into the electric field. The photovoltaic effect is the name given to these phenomena, which is why solar panels are also known as PV or photovoltaic panels.

Each cell's produced flowing current is then gathered and directed through metal contacts on the panel's outside. To raise the total voltage or current output, many cells on a panel are linked in parallel or series.

Usually, a solar panel consists of 60, 72, or even 90 separate solar cells that combine to transform sunlight into electrical energy that may be used. After that, these panels may be joined in bigger arrays to produce even more energy for use in utility-scale, commercial, and residential settings. (Benjamin, 2019)

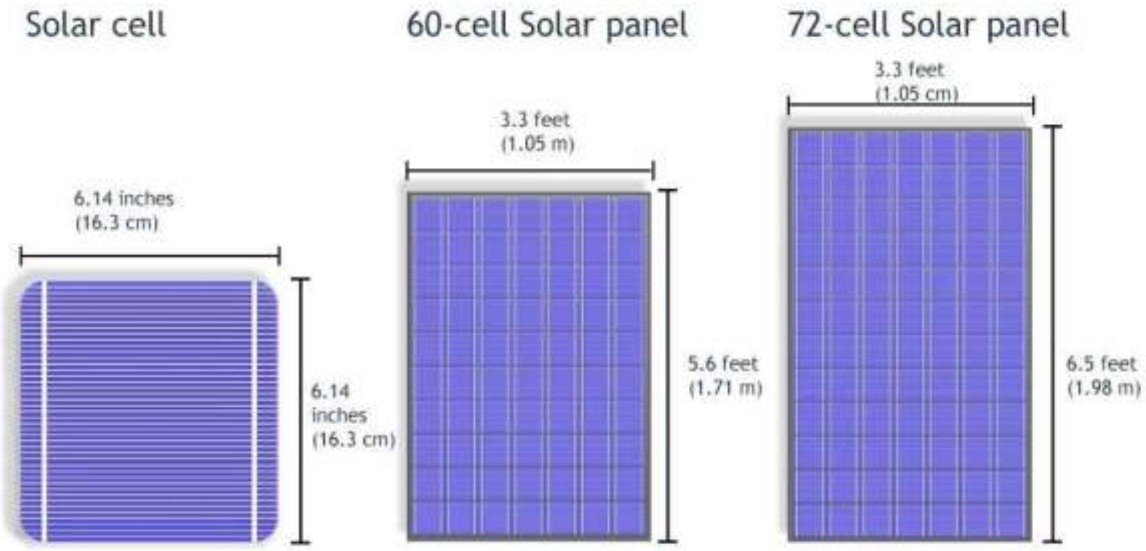

Figure 2.4: Showing the typical classification of solar panel sizes (based on the solar cell size). (THE GREENWATT, 2024)

In the rapidly developing area of photovoltaics, silicon is the most popular material for solar panels. Nevertheless, there is an intriguing diversity in panel technology hidden underneath this crystalline monopoly. We still need to explore a wider range of solar technologies beyond the common monocrystalline and polycrystalline layouts. This investigation explores the four main solar panel archetypes, each of which has a unique material composition, operating principle, and performance attributes. Our mission is to shed light on the complex world of solar energy harvesting technologies, starting with the well-established crystalline leaders and moving on to the up-and-coming thin-film and concentrated photovoltaic competitors.

Looking at the different types of panels, we would love to only look at two types which are polycrystalline and monocrysatlline. Monocrystalline panels rule the efficiency and lifespan roost. Made from a single, pure silicon crystal (think thin slices!), they pack the most punch per square foot, thanks to their uniform structure and dark black hue. But this top-tier performance comes at a cost. Growing these crystals wastes a lot of silicon, sometimes over half, making them the priciest of the bunch. Polycrystalline panels use melted silicon fragments in place of a single crystal. They are less effective but cheaper (less waste!) using this "crystal confetti" approach. Their disorganized structure results in slower energy flow and poorer absorption of sunlight, requiring more area to produce the same amount of electricity as expensive monocrystalline panels. Moreover, they become even less productive in hot temperatures due to their grumpiness.

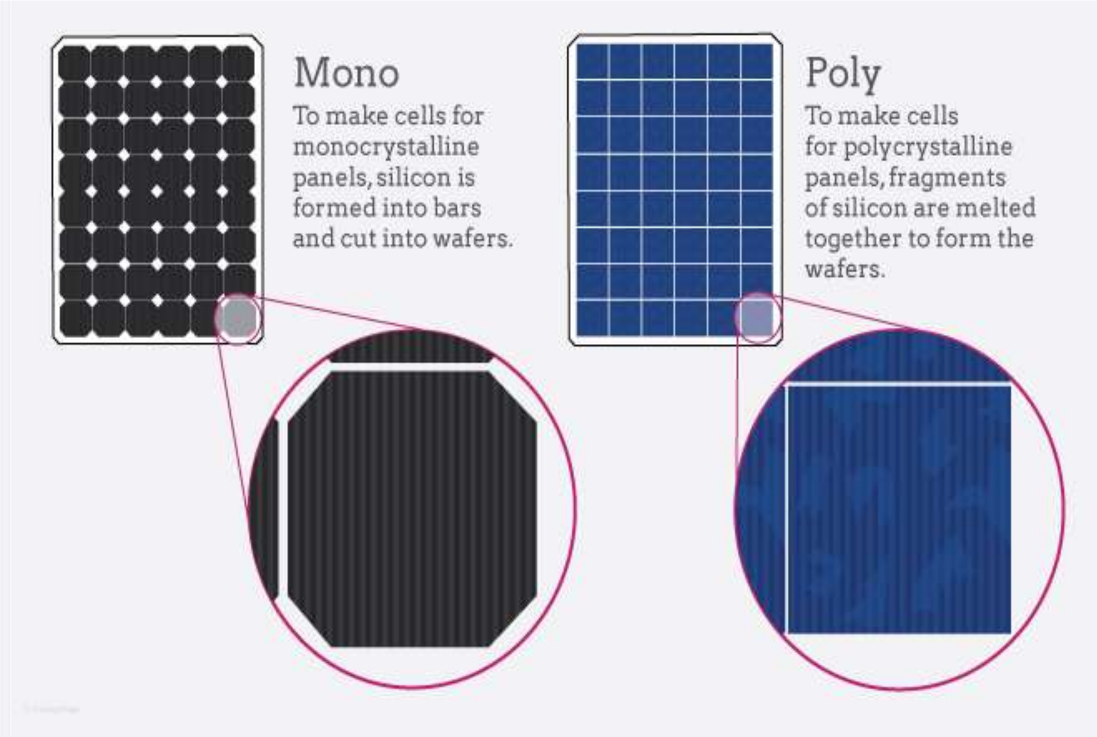

Figure 2.5: Monocrystalline and Polycrystalline solar panel cells (American Solar Energy Society, 2021)

2.2.2 HOW DO SOLAR PANELS WORK?

Picture a little dance taking place inside solar panels. Photons, which are tiny bundles of sunshine, collide with silicon atoms in a way akin to billiard balls having fun. Electrons are propelled forward by this bump, breaking off from their normal location around the atom. Now that they are free and stimulated, these electrons go across the cell's internal electrical highway in an exciting manner. They speed along this electromagnetic field, all going in the direction of a collection point, like surfers riding a wave. They produce a current as they move, which is the same electricity that runs our electronics! Picture a little dance taking place inside solar panels. Photons, which are tiny bundles of sunshine, collide with silicon atoms in a way akin to billiard balls having fun. Electrons are propelled forward by this bump, breaking off from their normal location around the atom. Now that they are free and stimulated, these electrons go across the cell's internal electrical highway in an exciting manner. They speed along this electromagnetic field, all going in the direction of a collection point, like surfers riding a wave. They produce a current as they move, which is the same electricity that runs our devices.

Layers of Solar Cells

Similar to stacked cakes, each layer in solar cells is essential. Specially formulated doped silicon films absorb light and produce minute charged particles. These particles are picked up and sent on their path via metal contacts on both ends. Sunshine is welcomed by a unique coating on top, and the entire stack is shielded from harm by a strong barrier. Our planet is powered by this collaboration, which converts sunlight into electricity. (Novergy April 2020).

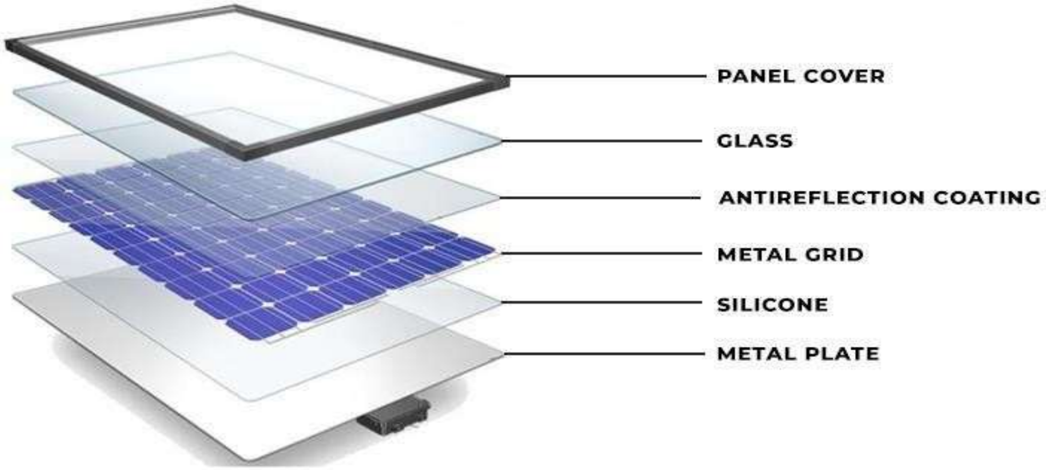

Figure 2.6: Solar Cell (Novergy April 2020).

1. Transparent protective layer

   This is the first layer usually made of glass. The transparent front layer acts as a barrier, letting as much light as possible reach the silicon while shielding the cell from environmental harm.

2. Antireflection coating

   One major obstacle is the intrinsic reflectivity of the silicon layer, which results in around 30% of incident photons being reflected back into the surrounding environment, which has a substantial effect on efficiency. This problem is addressed by the clever anti-reflection coating, which makes use of the destructive interference concept. This effect causes reflected light waves to cancel each other out upon superposition by adjusting their phase and amplitude. The coating's thickness is carefully tailored to be an odd multiple of half the desired wavelength of light in order to achieve this cancellation. In essence, when the reflected waves from the coating's top and bottom surfaces contact with the material, they undergo a precise phase shift that causes destructive interference when the waves recombine.

The anti-reflection coating is purposefully tailored for the green-yellow-red region of the visible spectrum, which is where the majority of solar energy is found, even though sunlight contains a wide range of wavelengths. By reducing reflection in these crucial wavelengths, our improved design efficiently traps more photons inside the silicon layer for energy conversion. But blue light is somewhat more reflective than the optimal range because of the intrinsic wavelength dependency of destructive interference. The distinctive blue color of solar cells is a result of this selective reflection.

3. Silicon

This is usually called the "heart of the cell," or third layer, is a meticulously constructed silicon sandwich. The secret of solar energy conversion—the process of magically converting sunlight into electrical power—lies in this layer. It's not just any silicon, either; two different kinds combine in a carefully planned dance. This two silicon types are called p-type and n-type, they are put together in contact with each other.

The electrons in the silicon layer are energized when sunlight collides with the atoms. Eager as revelers, these stimulated electrons hop from the n-type side to the p-type side, occupying those empty "holes." A little electric current is produced by the electrons moving across the junction.

4. Metal contacts

In order to effectively collect the mobilized electrons created within the silicon layer, the final layer typically consists of a grid of thin metal fingers and busbars arranged in a certain pattern.

By guiding the current towards certain contact sites at the periphery of the cell, these conductors function as highways. The particular metal selections (silver, aluminum) give priority to conductivity, resistance to corrosion, and compatibility with other cell components. (Novergy April 2020)

2.2.3 HOW DO SOLAR PANELS OPERATE?

Now that we are aware of the essential components of a solar cell, what actually occurs inside the silicon? To begin with, we must recognize that silicon is not a material that conducts electricity very well, like metal, nor is it a material that conducts electricity very poorly, like rubber. Rather, silicon falls somewhere in the middle. As a semiconductor, silicon has a low conductivity under normal circumstances and can jump to a much higher conductivity under specific other conditions, like under an applied voltage. This property allows silicon to be used as a switch in integrated circuits, as silicon bonds with four neighboring silicon atoms with its four available electrons. As a result, silicon has no electrons left over to conduct electricity. A little addition of phosphorus, which has five accessible electrons, to silicon essentially, adds one more electron for every additional atom of phosphorus. We refer to this as doping. We refer to this region of silicon as an N-type semiconductor since it is now negatively doped.

With boron, which has one fewer electron than silicon, we can do the same thing. An electron is thereby taken out of the silicon structure. We refer to the consequent lack of an electron—which functions similarly to an effective positive charge—as a hole. We refer to this region of silicon as P-type. Now that we have N-type silicon on top and P-type silicon on bottom, we can make a silicon wafer.

The excess electrons in the N-type silicon rush to merge with the P-type's holes when the two types of silicon come into contact, forming a zone known as the depletion layer that is devoid of both free electrons and holes. The phosphorus atoms now have a net positive charge as a result of losing their fifth electron. Additionally, the boron atoms now have a net negative charge due to their additional electron. Between the two regions, there is an electric field as a result, or more crucially, there is a voltage (voltage is the electric field divided by charge).

Thus, we now have a voltage-producing silicon semiconductor. However, no electron in the depletion layer can travel at all. The voltage will direct them if we can provide them with the energy to travel. Sunlight is the source of that energy.

One way to conceptualize light is as energy packets, or photons, that resemble particles. An electron in the depletion layer is knocked out of place when the right energy photon collides with it, resulting in the (re)creation of an electron-hole pair. The electron moves toward one side of the silicon and the hole toward the other when the voltage is applied.

Currently, when we join a wire or other electrical conductor from one wafer side to the other, the electrons can flow through that conductor (Benjamin, 2019).

2.3 CLASSIFICATION OF PV SOLAR SYSTEMS

Photovoltaic energy systems are typically categorized based on their functional and operational needs, their component setups, and how the equipment integrates with other power sources and electrical loads. The two main categories are grid-tied or utility-interactive systems and off-grid systems. Photovoltaic systems can be engineered to supply DC and/or AC power, can function either interconnected with or separate from the utility grid, and can be linked with other energy sources and storage solutions.

Grid-tied or utility-interactive PV systems are designed to function in conjunction with and be connected to the electric utility grid. The main component in these systems is the inverter or power conditioning unit (PCU). The PCU transforms the DC power generated by the PV array into AC power that matches the voltage and quality standards of the utility grid, and it automatically ceases power supply to the grid when the utility grid is not active. A bi-directional interface connects the PV system's AC output circuits to the electric utility network, typically at an on-site distribution panel or service entrance. This connection allows the AC power generated by the PV system to either supply on-site electrical loads or feed excess power back into the grid when the PV system output surpasses the on-site load demand. During nighttime or other times when the electrical load exceeds the PV system's output, the additional power needed is supplied by the electric utility. This safety feature, required in all grid-connected PV systems, ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for maintenance or repairs. (Sherri, 2021)

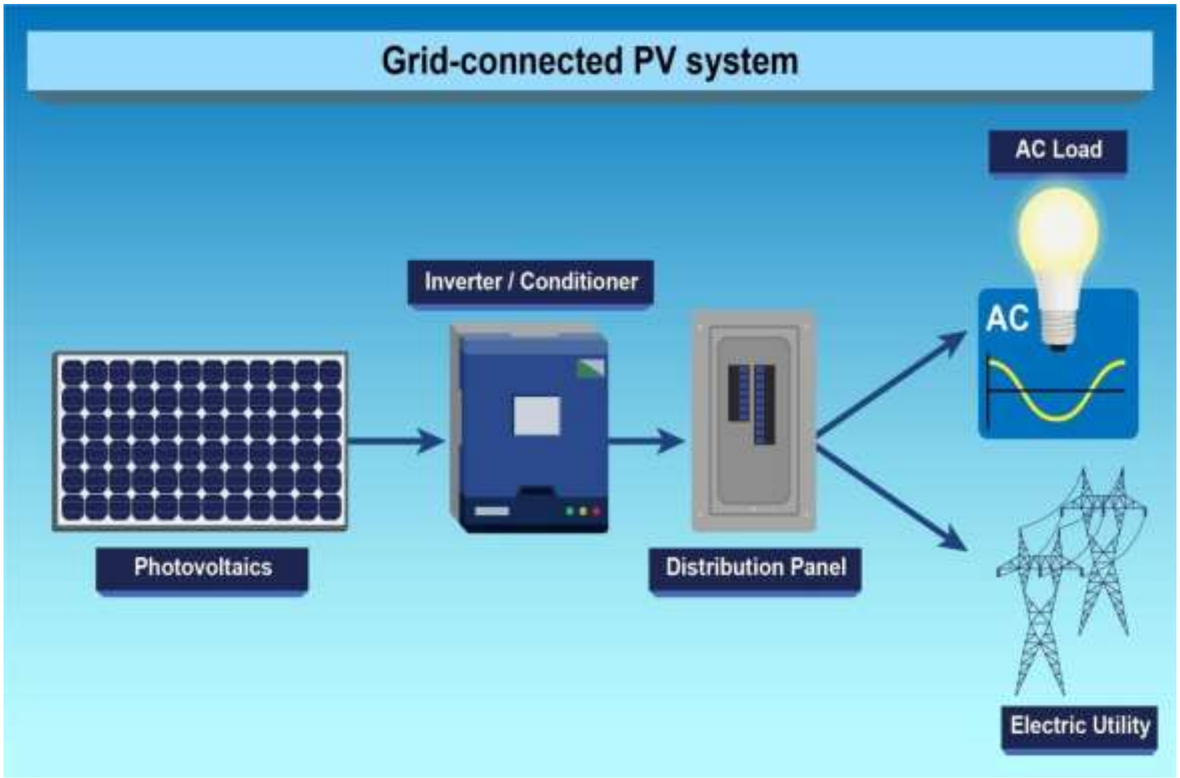

Figure 2.7: Grid-connected PV system (Sherri, 2021)

Stand-alone PV systems are engineered to function independently of the electric utility grid and are typically designed and sized to supply specific DC and/or AC electrical loads. These systems may be powered solely by a PV array or may incorporate wind, an engine-generator, or utility power as an auxiliary power source in a PV-hybrid system. The simplest form of a stand-alone PV system is a direct-coupled system, where the DC output from a PV module or array is directly connected to a DC load. As direct-coupled systems lack electrical energy storage (batteries), the load operates only during daylight hours, making these designs suitable for applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the electrical load's impedance to the PV array's maximum power output is a crucial aspect of designing an efficient direct-coupled system. For specific loads, such as positive-displacement water pumps, an electronic DC-DC converter known as a maximum power point tracker (MPPT) is used between the array and the load to optimize the utilization of the array's maximum power output. (Sherri, 2021)

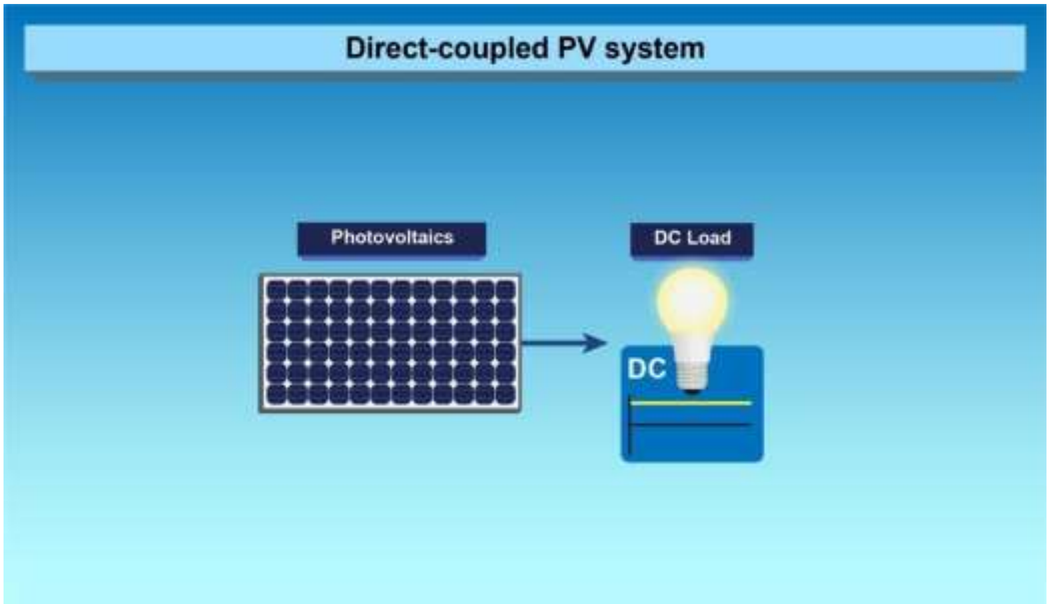

Figure 2.7: Direct-coupled PV system (Sherri, 2021)

In many stand-alone PV systems, batteries are used for energy storage. The figures below show two possible configurations. . Fig 2.8 below shoes the diagram of a Stand-alone PV system with battery storage powering DC and AC loads while Fig 2.9 shows an Hybrid PV system.

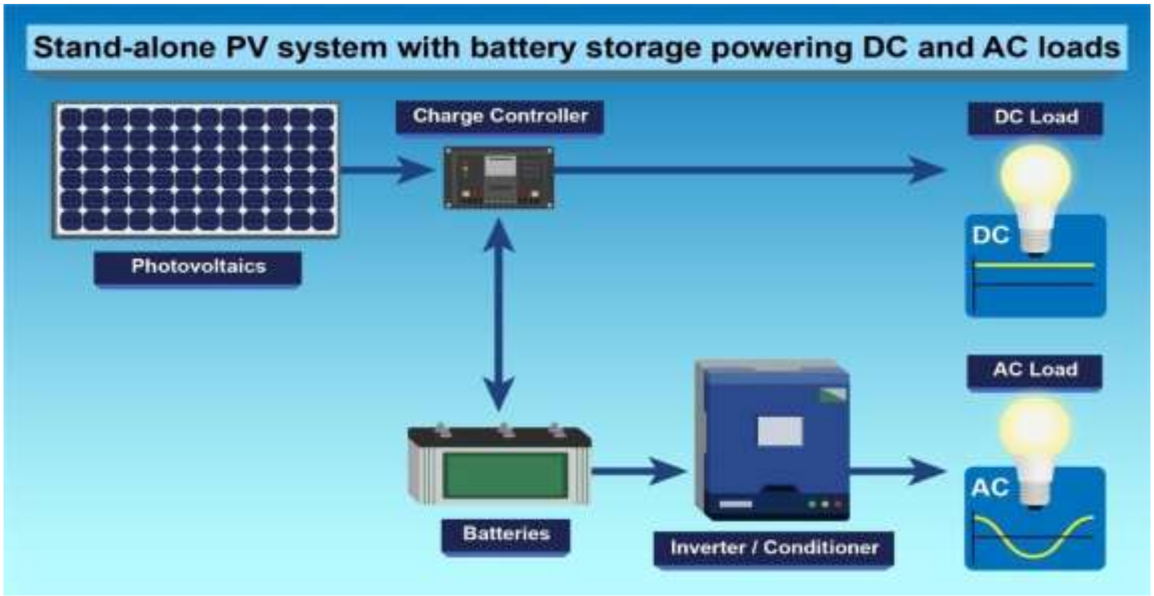

Figure 2.8: Stand-alone PV system with battery storage powering DC and AC loads (Sherri, 2021).

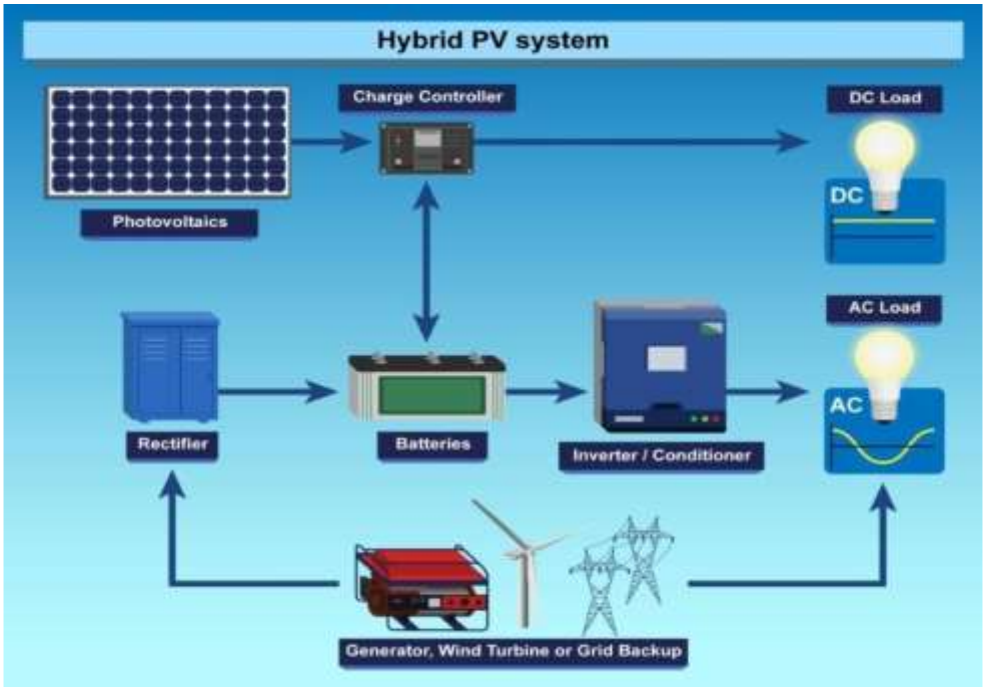

Figure 2.9: Hybrid PV system (Sherri, 2021).

2.4 ESSENTIAL PARTS OF A STAND-ALONE SOLAR SYSTEM

As was previously said, a standalone PV system can be built to power DC loads only or to power both AC and DC loads. Since it is the kind of system that this project is built for, the latter is the system that is of importance here. Additionally, it has been determined that such a system is made up of four fundamental parts, which are as follows:

1. The PV array
2. A battery bank
3. Charge controller
4. An inverter

2.4.1 THE PHOTOVOLTAIC ARRAY

Photovoltaic cells are electrically connected in series and/or parallel circuits to generate higher voltages, currents, and power levels. PV modules, which consist of PV cell circuits enclosed in an environmentally protective laminate, serve as the fundamental building blocks of PV systems. Photovoltaic panels comprise one or more PV modules assembled into a pre-wired, field-installable unit. A photovoltaic array is the entire power-generating system, made up of multiple PV modules and panels.

The performance of PV modules and arrays is typically rated based on their maximum DC power output (watts) under Standard Test Conditions (STC). STC is defined by a module (cell) operating temperature of 25°C (77°F), an incident solar irradiance level of 1000 W/m², and an Air Mass 1.5 spectral distribution. Since these conditions do not always reflect real-world operations, the actual performance of PV modules and arrays is generally 85 to 90 percent of the STC rating.

Modern photovoltaic modules are exceptionally safe and reliable, exhibiting minimal failure rates and expected service lifetimes of 20 to 30 years. Most leading manufacturers provide warranties of 20 years or more, ensuring the maintenance of a high percentage of the initial rated power output. When choosing PV modules, review the product listing (UL), qualification testing, and warranty details in the manufacturer's specifications. (University of Central Florida | FSEC, 2024)

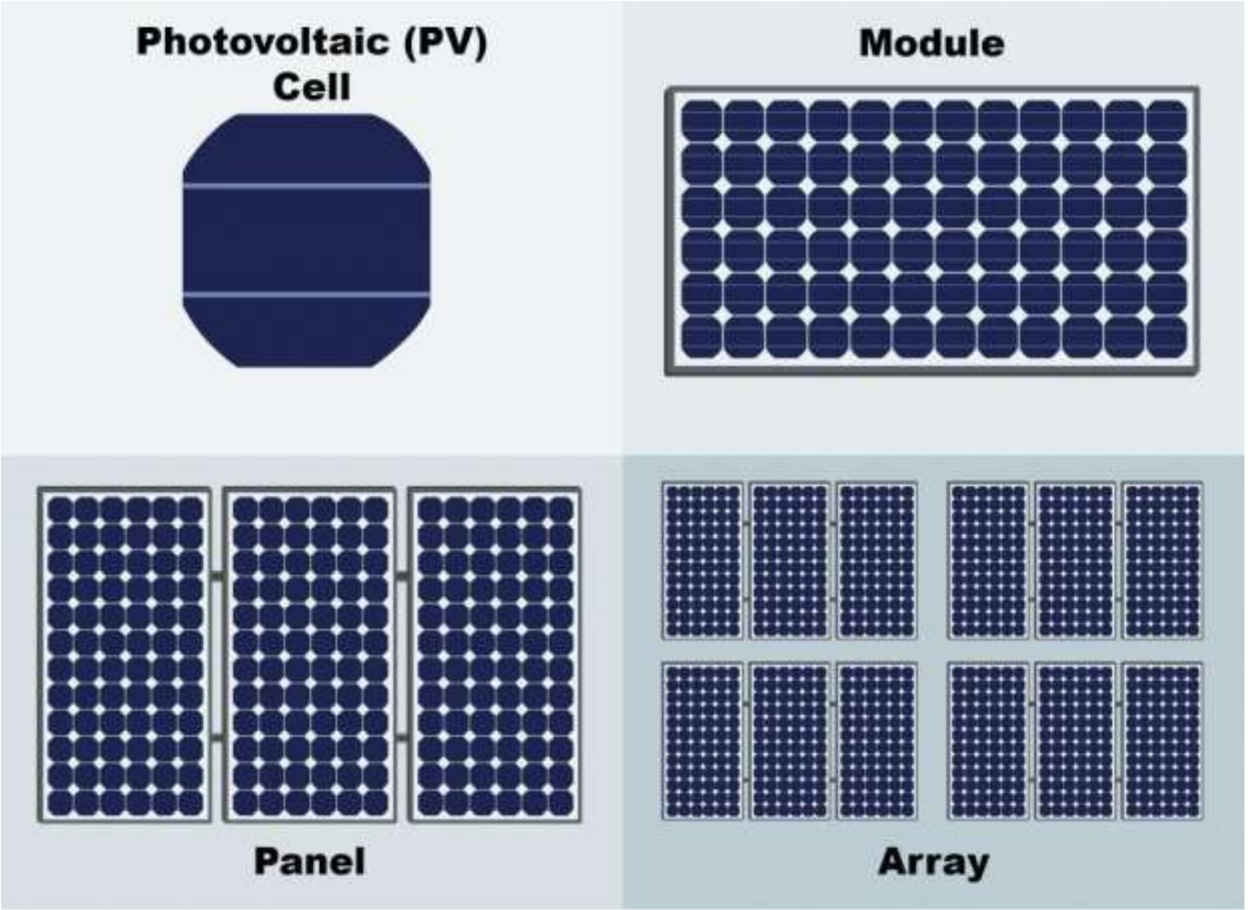

Figure 2.10: A Photovoltaic Solar Array (University of Central Florida | FSEC, 2024)

2.4.2 BATTERY BANK

The battery bank comprises multiple batteries connected in parallel and series configurations, forming an energy storage unit. This bank stores solar energy from the solar panels and supplies electricity to loads through a DC-AC inverter. As the central component for energy storage, the battery bank is essential in a solar power system.

Generally, there are two major application of industrial battery : standby use and cycle use. (Lighten World Industry co.,Ltd, 2017).

1) Standby use – emergency power backup for UPS, telecom base station, and security system.

   This battery remains fully charged and in a standby state as a power backup, used only during grid power failures. During a blackout, the battery supplies AC loads via a DC-AC inverter.

This type of battery, technically termed "discharged," is utilized only a few times a year, spending most of its time on standby. When employed as a power backup, the battery typically does not undergo deep discharge. The emphasis is more on its "standby life" rather than its "cycle life."

2) Deep Cycle use – power source for e-scooter, e-mobility, e-bike and renewable energy

   The battery is used daily as a power source, and a "cycle" refers to the process of fully charging and then deeply discharging the battery once. This type of battery, intended to provide maximum power to extend usage time, is typically deeply discharged. The focus is on its "cycle life" rather than its "standby life." Batteries designed for such deep cycle applications are known as deep cycle batteries. (Lighten World Industry Co., Ltd, 2017).

Clearly, in a solar power system, the battery charges during the day using sunlight and discharges on cloudy days or at night. The battery functions as a solar energy storage unit, storing power during sunny periods and supplying power during rainy times or at night. Consequently, the solar battery is consistently fully charged and deeply discharged. Therefore, for the battery bank of a solar power system, a deep cycle battery should be selected.

It depends on how much AC loads, which are usually home electric appliance and how long they will be powered by batteries. For example, if you have 1500W AC loads and need to be powered by batteries for 3 hours. The calculation is : 1500W x 3 hours = 4500Wh, which means you need 4500Wh battery capacity If we use 12V 150Ah gel deep cycle battery, (Gel link) The single battery capacity is 12V x 150Ah = 1800Wh 4500Wh / 1800Wh
= 2.5, so we need at least 3 pcs battery to support AC loads. (Lighten World Industry co.,Ltd, 2017)).

2.4.3 A CHARGE CONTROLLER

A charge controller, also known as a charge regulator, is essentially a device that manages voltage and/or current to prevent batteries from overcharging. It controls the voltage and current flowing from the solar panels to the battery. Since most "12 volt" panels output around 16 to 20 volts, unregulated charging could damage the batteries due to overcharging. Typically, batteries require approximately 14 to 14.5 volts to achieve a full charge.

Do I always need a charge controller?

Usually, but not always. Generally, a charge controller is unnecessary for small maintenance or trickle charge panels, like those ranging from 1 to 5 watts. A general guideline is that if the panel produces around 2 watts or less per 50 battery amp-hours, a charge controller is not needed.

For instance, a typical flooded golf cart battery has about 210 amp-hours. To maintain or store a series pair of these batteries (12 volts), you would need a panel around 4.2 watts. The commonly used 5-watt panels are sufficient and do not require a controller. If you are maintaining AGM deep cycle batteries, like the Concorde Sun Xtender, a smaller panel of 2 to 2.5 watts will suffice (Gates, n.d.).

Using High Voltage (grid tie) Panels with Batteries

Almost all PV panels rated above 140 watts are not standard 12-volt panels and should not be used with standard charge controllers. The voltages on grid-tie panels vary significantly, typically ranging from 21 to 60 volts. While some are standard 24-volt panels, the majority are not.

Using standalone controller

Standard charge controllers (excluding MPPT types) can often work with high-voltage panels as long as the maximum input voltage of the controller is not exceeded. However, this can result in a significant power loss, ranging from 20% to 60% of the panel's rated capacity. Charge controllers regulate the panel's output and feed current to the battery until it is fully charged, usually around 13.6 to 14.4 volts. A panel can only supply a certain number of amps; thus, even if the voltage is reduced from 33 volts to 13.6 volts, the panel's current output remains at its rated amps. For example, a 175-watt panel rated at 23 volts/7.6 amps will only deliver around 7.6 amps at 12 volts to the battery. According to Ohm's Law, power (watts) is the product of volts and amps, so a 175-watt panel will only supply about 90 watts to the battery.

Using an MPPT controller with high voltage panels

To extract full power from high-voltage grid-tie solar panels, an MPPT controller is necessary. For detailed information on MPPT charge controllers, refer to the link above. Most MPPT controllers can handle up to 150 volts DC on the solar panel input side, with some models accommodating up to 600 VDC. This capability allows you to connect two or more high-voltage panels in series, reducing wire loss and enabling the use of smaller wire. For instance, with the 175-watt panel mentioned earlier, connecting two in series would provide 46 volts at 7.6 amps to the MPPT controller, which would then convert it to approximately 29 amps at 12 volts. (Gates, n.d.)

The Two Primary Charge Controller Types

Charge controllers may be found in many different forms, costs, and power ratings, but they can be broadly classified into two types: PWM (pulse-width modulation) and MPPT (maximum power point tracking).

i. PWM regulators function similarly to series regulators, but they utilize a transistor instead of a relay to control the array. By switching the transistor at a high frequency with varying pulse widths, they maintain a constant voltage. The PWM regulator adjusts itself by altering the pulse widths (lengths) and speeds sent to the battery. Unlike on/off charge controllers that instantly stop power transfer to prevent battery overcharging, PWM regulators operate as rapid on/off controllers continuously.

Like series regulators, the transistor in a PWM regulator can be placed in either the positive or negative line, allowing for use in both positive and negative ground systems. The key difference between series regulators and PWM regulators lies in the modulation width of the transistor. When the modulation width is 100% or 0%, the regulator behaves like a series regulator. The variation in modulation width enables the PWM regulator to maintain a constant voltage to the battery, unlike the on/off action of a series regulator. The figure below illustrates a PWM regulator operating with a 70% on and 30% off duty cycle.

When the width is at 100%, the transistor is fully ON, allowing the solar array to charge the battery. When the width is at 0%, the transistor is OFF, creating an open circuit to prevent any current flow to the fully charged battery.

Some PWM regulators can be converted to series (on/off) regulators. This feature is useful for sensitive loads that may be affected by the noise generated by the PWM frequency. Because PWM charge controllers rely on transistors, they are always solid-state, which can lead to heat dissipation issues, especially with larger solar arrays.

As with series regulators, PWM regulators control voltage by opening the array at high frequency during regulation. If you measure the array voltage during this time, it can range between the battery voltage and the open circuit voltage, depending on the charging stage. If the array voltage drops below the battery voltage during normal operation, this indicates a problem. (SUNWIZE fueled by challenge, 2024)

Figure 2.11: PWM charge controller (SUNWIZE fueled by challenge, 2024)

ii. The Maximum Power Point Tracking (MPPT) charge controller enhances the capabilities of a PWM controller by allowing the array voltage to differ from the battery voltage. By adjusting the array input, the MPPT controller can determine the point where the solar array generates maximum power. Here's how the MPPT process works: suppose you have a battery at a low 12 V. An MPPT controller takes 17.6 volts at 7.4 amps and converts it to provide the battery with 10.8 amps at 12 volts. MPPT controllers take the DC input from the solar panels, convert it to high-frequency AC, and then convert it back to a different DC voltage and current. This ensures the voltage meets the battery's requirements precisely.

MPPT controllers use the negative line as a reference and switch the positive line, meaning they can only be used in negative ground systems. It's important to note that voltage is a potential difference, referring to the difference between ground potential and another potential. This reference point is crucial for understanding voltage regulation.

MPPT charge controllers can adjust the charge current to the battery, enabling them to function as multi-stage chargers with bulk, absorption, and float settings. They are always solid-state, which can lead to heat dissipation issues, particularly with larger solar arrays. MPPT controllers are typically step-down converters, so the array voltage must always be higher than the battery voltage. Therefore, if the array voltage is lower than the battery voltage during normal operation, it indicates a problem. (SUNWIZE fueled by challenge, 2024)

Figure 2.12: MPPT charge controller (SUNWIZE fueled by challenge, 2024)

2.4.4 INVERTER

In many small electronic projects, converting DC voltage to AC voltage is a common challenge. While circuits are often designed to convert AC input to DC output, converting from DC to AC requires a DC to AC converter circuit, also known as an inverter. Inverters are essential in situations where direct DC to AC conversion is not feasible.

The typical inverter technology used in electronics involves converting a voltage source from a battery into an AC signal. These inverters usually operate at 12 volts and are commonly used in automotive, lead-acid technology, photovoltaic cells, and other applications.

A basic inverter circuit consists of a transformer coil system and a switch. The transformer is connected to the DC signal's input through a switch to quickly alternate the current flow, generating an AC output.

Due to the current flow in bi-directional in the primary coil of the transformer, an alternating current signal is an output throughout the secondary coils.

DC to AC Converter

Below is the circuit diagram for a DC to AC Converter Circuit using Transistors. The primary function of an inverter circuit is to generate oscillations with a specified DC voltage and apply them to the primary winding of the transformer, increasing the current. This main voltage is then stepped up to a higher voltage based on the number of turns in the primary and secondary coils.

A circuit diagram for a 12V DC-to-220V AC converter can be constructed using simple transistors. This circuit can power lamps up to 35 watts, but it can be designed to drive more powerful loads by using additional MOSFETs. (Agarwal, 2019)

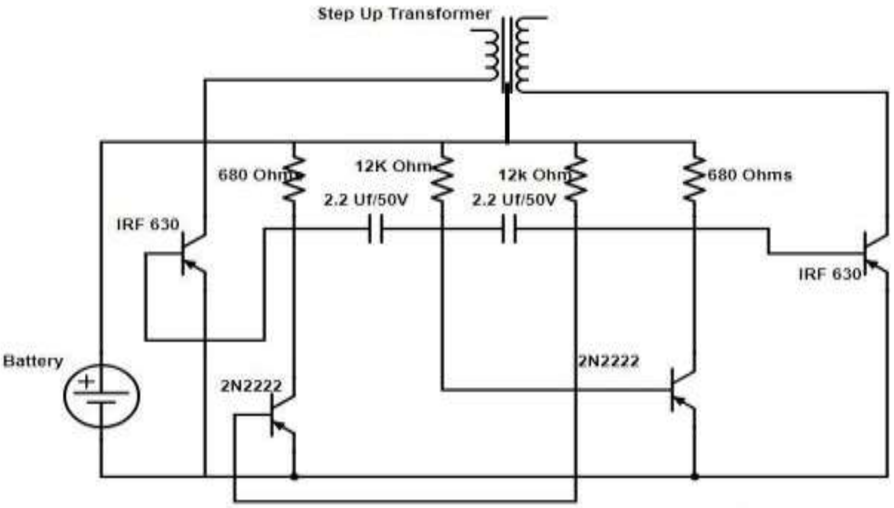

Figure 2.13: DC to AC Conversion Circuit using Transistors (Agarwal, 2019)

The inverter implemented in this circuit produces a square wave, suitable for devices that do not require a pure AC sine wave.

The necessary components for building the DC to AC circuit include a 12V battery, 2N2222 transistors, two MOSFET IRF 630s, two 2.2μF capacitors, twelve 12k resistors, two 680 ohm resistors, and a center-tapped transformer for step-up functionality.

The DC to AC circuit can be divided into three main sections: the amplifier, transistor, and oscillator. Since the AC supply frequency is 50Hz, a 50Hz oscillator is used. This is achieved by designing an astable multivibrator that generates a 50Hz square wave signal. The oscillator is created using resistors (R1, R2, R3, R4), capacitors (C1, C2), and transistors (T2, T3).

Each transistor produces square waves (inverting), with the frequency determined by the resistor and capacitor values. The frequency formula for the square wave generated by the astable multivibrator is F = 1/(1.38 * R2 * C1).

The oscillator's inverting signals are amplified by the two power MOSFETs (T1, T4), and these signals are then sent to the step-up transformer via its center tap connected to 12V DC.

Types of Solar Inverters

1. String inverters
2. Power optimizers
3. Micro inverters

String inverters are currently the most cost-effective option for inverters in the United States. Traditionally, these inverters were recommended for roofs with limited shading and facing a single direction. However, recent advancements in hardware and software have made string inverters suitable for a wider range of circumstances.

In a string inverter setup, solar panels are grouped into "strings," which are then connected to a centralized inverter. This inverter converts the DC electricity produced by the panels into usable AC electricity for homes or businesses.

Although string inverters have been used for decades and are known for their reliability, they may not be ideal for installations prone to shading. Unlike microinverters and power optimizers, which optimize power output at the individual panel level, string inverters can only optimize at the string level.

If shading is a concern, alternatives like power optimizer systems and microinverters may be more suitable. Power optimizers condition the DC electricity at the panel level and send it to a string inverter for conversion, offering improved efficiency in shaded conditions. Microinverters, on the other hand, convert DC to AC electricity at each panel, maximizing performance and offering panel-level monitoring.

Both power optimizers and microinverters reduce the impact of shading on system performance and are increasingly popular for residential solar panel systems.

CHAPTER 3

MATERIALS AND METHOD

3.1 MATERIALS

In this section we will be discussing the different components used in the construction of this project.

I. Batteries.
II. Hybrid Inverter (Charge controller included)
III. Solar Panels.
IV. Cables.

3.2 METHOD

The optimization of an independent solar microgrid for a three bedroom apartment is the focus of this project. In this project, we examined the power consumption of an average Nigerian home (three bedroom apartment) and a load survey, system sizing in order to ascertain the load survey component ratings, did an analysis on the rate of charge of the batteries and the discharging time and breakdown of the cost analysis of solar power.

3.3 SOLAR SYSTEM DESIGN

Accurate sizing of the different components of the stand-alone PV system is necessary for the system to be designed correctly. To achieve this, the following processes were be carried out:

i. Load profiling
ii. Sizing of the battery bank
iii. Inverter sizing
iv. PV array sizing

3.3.1 LOAD PROFILE

In electrical engineering the fluctuation in the electrical load versus time is referred to as a load profile. Temperature, holiday seasons and client type (residential, commercial, and industrial are common examples) will all affect the load profile. Utilizing these data, producers may forecast the amount of energy they will need to supply at any particular moment.

The following information must be captured in a load profiling

I. The power usage of each appliance in the house or place of business where the solar system will be placed.
II. The energy usage of each particular device in the house or workplace
III. How many hours a day are spent using different appliances?
IV. The overall energy usage of every appliance and gadget in the the house or workplace.
V. A list of all appliances in the house or workplace that use electricity.

Carrying out a load profile varies for the different types of scenario, lets look at two kinds of scenario.

3.3.1.1 LOAD PROFILE OF AN AVERAGE HOME THREE BEDROOM FLAT FOR SOLAR HOME SYSTEM

Table 3.1: Load Profile of an Average Home Three Bedroom Flat For (SHS)

Appliances	Rating Watt(W)	Numbers	Total Watt (W)	Hours (h)	Energy (Wh)
Lights	35	13	455	8	**3640**
Fan	70	4	280	8	2240
Laptop	100	2	200	8	1600
Phone	5	5	25	8	200
TV	120	1	120	10	1200
Decoder	22	1	22	10	2200
TOTAL			**1102**		**11080**
LET US ADD INDUCTIVE LOADS AND SEE THE TOTAL					
Fridge	140	1	140	24	3360
Bore hole	746	1	746	2	1492
TOTAL			**1988**		**15932**

3.3.2 INVERTER SIZING

In systems that require AC power output, an inverter is employed. The overall wattage of the appliances should always exceed the input rating of the inverter. Your battery‘s nominal voltage and the inverter‘s voltage must match.

The inverter wattage rating should sufficiently cover all load at full load excluding inductive loads. The inverter‘s rating should be 25-30% larger than the appliances combined wattage. If the type of appliance is a motor or compressor, the inverter rating needs to be at least three times the size of those appliances. In addition, the inverter capacity needs to be increased in order to withstand surge current at startup.

Table 3.2: Inverter Sizing

SPECIFICATIONS	
Model	GREEN kapital 2500
Power Rating	2.5Kva
Inbuilt Charge controller	50Amp PWM
OUTPUT	
AC Voltage Regulation	230 VAC ±5%
Efficiency	100%
Surge Power	10000VA for 5 sec
Wave Form	Pure Sine Wave

Looking at the load rating in table 3.1 our total power for both scenario is 1102W and 1988W respectively but the inverter rating is in VA, we need to convert the total Watt load to VA in order to determine the inverter sizing.

Watt is used for real power i.e. power consumed by the resistive load; whilst VA is used for apparent power, which is the combination of real power and the effect of reactive load like capacitor and inductor.

Conversion of Watt to VA:

$$\text{Power (VA)} = \frac{Watt}{pf} \quad \text{......} \quad \text{Eqn 3.1}$$

Where pf is the power factor = 0.8

Therefore, VA = $\frac{1988}{0.8}$ =2485VA ~2.5kVA >>>>>>>>> ***for all loads***

Therefore, VA = $\frac{1102}{0.8}$ =1377.5VA ~1.4kVA >>>>>>>>> ***excluding inductive loads***

Considering the capacity of the inverter we will be knocking off the inductive loads so as to allow the inverter accommodate the loads and also the surge power of the loads.

3.3.3 BATTERY SIZING

Deep cycle batteries are the recommended battery type for use in solar PV systems. Deep cycle batteries are made specifically to be quickly recharged after being fully depleted to a low energy level, or to be charged and discharged repeatedly over the course of years. To determine the battery size, we used the following calculation:

I. Calculate total Watt-hours per day used by appliances.
II. Divide the answer obtained in (i) above by the nominal battery voltage.
III. Multiply the answer obtained in (ii) above with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Watt-hour capacity of deep-cycle battery.

Battery capacity (Wh) = Total Watt-hours per day × Days of autonomy……. Eqn 3.2

Table 3.4: Battery Sizing

SPECIFICATIONS	
Rating	12V, 200Ah
Type of Battery	**Depth of Discharge**
Lead Acid	50%
Mercury	80%
Lithium	100%

From the load profile of the three-bedroom flat above we can see that we have a total of **15932Wh** for all the loads in the house with inductive loads inclusive and a total of **11080Wh** without inductive load

FOR TOTAL LOADS IN THE HOUSE

Days of Autonomy = 11hrs = 0.46days

Battery Bank Capacity = 15932 × 0.46 = 7328.72Wh

Considering Depth of Discharge = 80%

$$\text{Number of Batteries} = \frac{\text{Battery Bank Capacity}}{\text{A Battery capacity in Wh} \times \text{Depth of discharge}} \ldots\ldots\ldots\ldots\text{Eqn 3.3}$$

$$= \frac{7328.72\text{Wh}}{12\text{V} \times 220\text{Ah} \times 0.8} = 3.47 \sim 4 \text{ Batteries}$$

EXCLUDING INDUCTIVE LOADS

Days of Autonomy = 9 hrs = 0.375days

Battery Bank Capacity = 11080 × 0.375 = 4155Wh

Considering Depth of Discharge = 80%

$$\text{Number of Batteries} = \frac{\text{Battery Bank Capacity}}{\text{Battery capacity in Wh} \times \text{Depth of discharge}}$$

$$\frac{4155\text{Wh}}{12\text{v} \times 220\text{Ah} \times 0.8} = 1.967 \sim 2 \text{ Batteries}$$

3.3.4 PV ARRAY SIZING

In order for us to find the total power and energy consumption of all loads that the solar PV system must supply is the first stage in building a solar PV system. In this stage we:

I. Determined the total Watt-hours utilized by each appliance each day. To determine the total Watt-hours per day that must be supplied to the appliances, we added the Watt-hours required for each appliance collectively.

II. Determined how many Watt-hours the PV modules must provide daily. To calculate the total Watt-hours per day that the panels must supply, we multiplied the total Watt-hours per day of appliances by 1.3, which represents the energy wasted in the system.

III. Considered the PV module size knowing that PV modules of varying sizes will yield varying power outputs. To determine the PV module's sizing, we determined the entire peak wattage required.

IV. Determined how many PV panels the system needs. We did that by Determining the total Watt-peak rating that PV modules require, Divided by the Watt-peak rated output of the PV modules that you have access to. The calculation's outcome is the bare minimum of PV panels. Increased PV module installation will increase system performance and extend battery life. Reduced utilization of PV modules will shorten battery life and perhaps prevent the system from operating at all during overcast spells.

Table 3.4: PV Array Sizing

SPECIFICATIONS	
Voltage (V)	**Power (W)**
12	250

FOR ALL TOTAL LOADS

Peak Sun Hours = 4h

Battery Storage Capacity for 4 Batteries = 4(12V×220Ah) = 10560Wh

$$\text{Array Peak power} = \frac{\text{Battery Storage Capacity}}{\text{Peak Sun Hours}} = \frac{10560Wh}{4} = 2640\text{W} \ldots\ldots\ldots\ldots\ldots\ldots.. \text{Eqn 3.5}$$

$$\text{Number of Solar Panels} = \frac{\text{Array Peak Power}}{\text{Watt Per Panel}} = \frac{2640\text{W}}{250\text{W}} = 10.56 \sim 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\text{Eqn 3.6}$$

EXCLUDING INDUCTIVE LOADS

Peak Sun Hours = 4h

Battery Storage Capacity for 2 Batteries = 2(12V×220Ah) = 5280Wh

$$\text{Array Peak Power} = \frac{\text{Battery Storage Capacity}}{\text{Peak Sun Hours}} = \frac{5280\text{Wh}}{4\text{h}} = 1320\text{W}$$

$$\text{Number of Solar Panels} = \frac{\text{Array Peak Power}}{\text{Watt Per Panel}} = \frac{1320\text{W}}{250\text{W}} = 5.28 \sim 6$$

Table 3.5: Charge Controller Sizing

Solar Charger Type	PWM
Maximum PV Array Voltage Open Circuit	45VDC
Maximum PV Array Power	1800W
Maximum Solar Charge Circuit	50A
Maximum AC Charge Current	50A
Maximum Charge Current	50A
Battery	
Battery Voltage	24VDC

Battery Storage Capacity = 5280Wh

Total Solar Array Watt = 250W × 6 = 1500W

Time to Completely Charge $= \frac{5280Wh}{1500W} = 3.52h$

Battery Bank Capacity Considering Depth of Discharge = 5096.8Wh

Total Solar Array Watt = 250W × 6 = 1500W

Time to Completely Charge $= \frac{5096.8Wh}{1500W} = 3.397h$

CHAPTER FOUR

RESULTS AND DISCUSSSION

4.1 RESULTING SYSTEM DESIGN

From the design calculations and the rate of charge analysis, the following have been determined:

4.1.1 INVERTER RATING

2.5KVA/24V line diagram connection of each component of 2.5kVA system in Fig 4.1

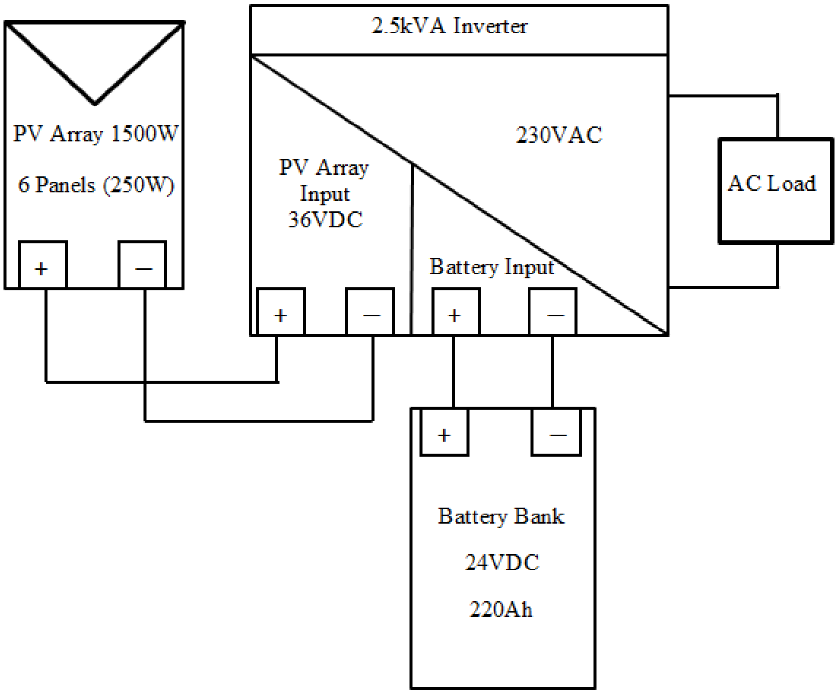

Figure 4.1: Line diagram connection of each component of 2.5kVA system

4.1.2 PV ARRAY:

The Panels used are 6 in total with nominal voltage 12V, 200W with a charge controller of 45VDC, 50A PV array VOC. The PV panels were connected 2 PV panels in series and 2 series string in parallel. For PV array arrangement greater than 2 parallel strings OCPD are used in case a panel shorts. The PV array connection diagram is in Fig 4.2

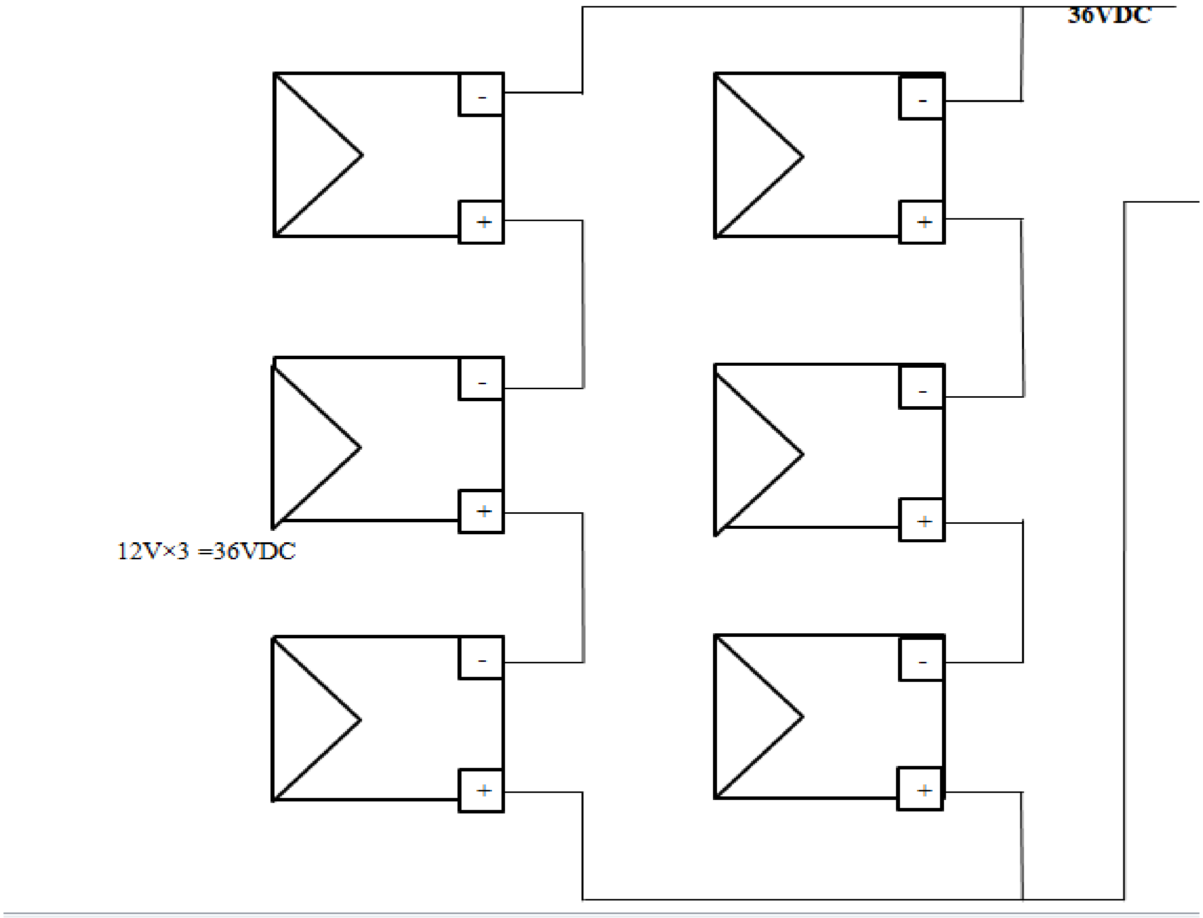

Figure 4.2: The PV array connection diagram

4.1.3 BATTERY BANK:

The battery used is 2 in total with nominal voltage of 12V; 220Ah due to the voltage output from the charge controller 24V the batteries were connected in series. Diagram of battery connection is in Fig 4.3.

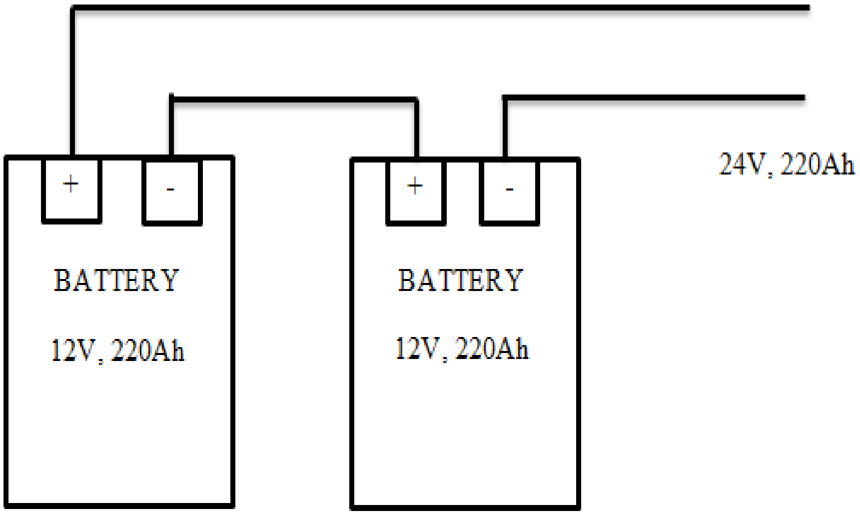

Figure 4.3: Diagram of battery connection

4.1.4 CHARGE CONTROLLER

The charge controller used is inbuilt in the Hybrid Inverter with charging rate of 24V, 50A and PV array VOC of 45VDC, 50A

4.1.5 RATE OF CHARGE ANALYSIS

In a PV (photovoltaic) system, rate of charge analysis measures how quickly the solar panels charge the battery bank. The system must be designed and optimized with this analysis in mind to guarantee effective energy use and long battery life. Below is a summary of the main elements and factors to take into account

Table 4.1 Open circuit testing results

TIME	Voc BATTERY A	Voc BATTERY B	Voc CHARGING VOLTAGE	CHARGING CURRENT	BATTERY VOLTAGE
9:00AM	13.5	13.6	25.5	6.0	25.0
10:00AM	13.5	13.6	26.0	5.8	25.4
11:00AM	13.5	13.6	26.9	5.6	26.1
12:00NOON	13.5	13.6	27.0	4.7	26.4
1:00PM	13.5	13.6	29.0	3.9	26.8
2:00PM	13.5	13.6	32.2	2.7	27.0
3:00PM	13.5	13.6	29.1	2.4	27.1
4:00PM	13.5	13.6	27.1	3.0	27.2
5:00PM	13.5	13.6	26.1	3.5	27.2

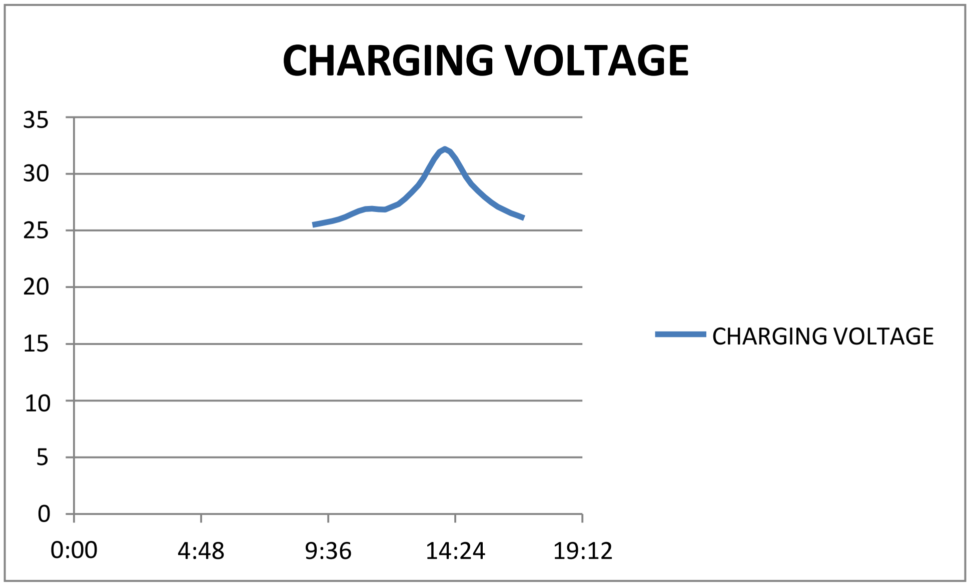

Figure 4.4 Graph of charging voltage against time

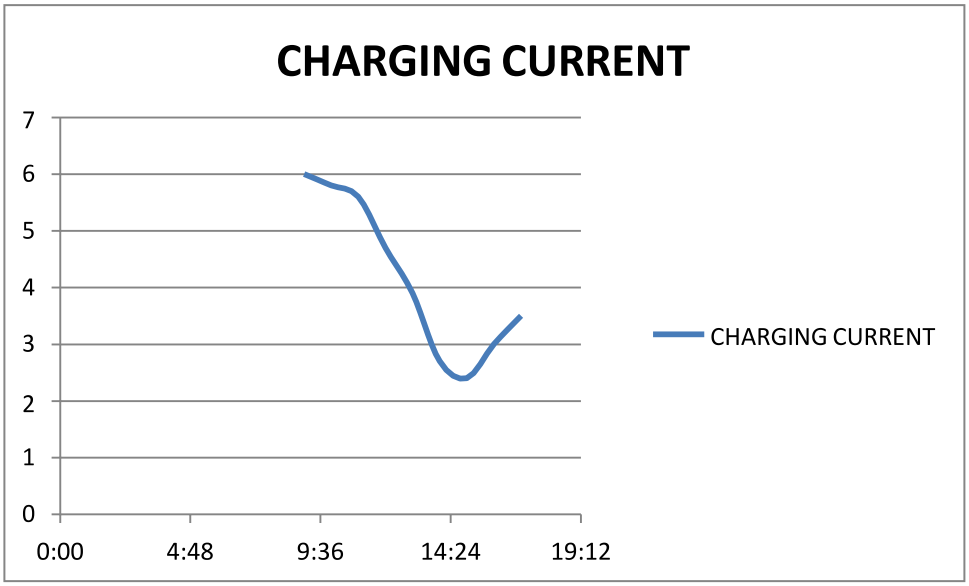

Figure 4.5 Graph of charging current against time

4.1.5.1 LOAD TEST (BATTERY RUN-TIME TESTING)

Theoretical approach:

$$\text{Discharging time} = \frac{\text{Battery Capacity} \times \text{Battery voltage}}{\text{Device Watt}}$$

Battery capacity = 220Ah

Battery voltage = 27.2V

Device Watt = 1102W

Therefore Discharging time $= \frac{220 \times 27.2}{1102} = 5.43 \sim 5$hours

Theoretically this battery should last for 5hours

In practice after connecting an equivalent 1102W load to the system the battery took 4.5hrs to run down completely.

4.2 DISCUSSION

We would be discussing on the implementation of a 2.5KVA PV system in a three-bedroom flat, and enhancement of the PV systems in general

4.1.4 IMPLEMENTATION AND ENHANCEMENT OF 2.5KVA PV SYSTEM

I. In implementing the PV array we implored the use of a solar racking system in order to acquire maximum power output from the panels, and to get as much sun as possible. Also knowing that the array is to be placed somewhere without shadows we placed the PV array on the south side of the structure. This would enable the panels to generate more energy in the evening when more people are using appliances and are at home. When electricity is most needed, it is readily available, counteracting the decline in overall production.

The distance between the grid and the place of usage is another factor we took consideration when assembling our microgrid. There is a greater chance of power loss the farther away you go and the hotter it becomes, putting this into account we also set up the grid in the best possible way to reduce the distance between the grid and the place of usage.

Lastly in the series and parallel connection of the panel we were careful of the polarity so as not to cause damage to the panels and put our lives at risk.

In enhancing this system solar trackers should also be used, particularly in areas with limited space. By tracking the path of the sun, the trackers generate 40% more electricity. Since they are so costly, it is preferable to install more solar panels because they are less expensive.

II. In installing the solar battery system we did the following:

- We kept the solar batteries in a spot that's not too hot or cold to make them last longer and work better.
- We ensured the place we choose for our solar battery has good air flow. This stops it from getting too warm and helps it run smoothly.
- We also put our solar battery somewhere easy to get to.
- We were safety conscious: We did this by installing our solar battery away from anything flammable. Also we did not make the positive and negative terminal of a battery come in contact as it can cause short circuit which can also lead to explosion of the battery.

From the load test we saw that the theoretical time and actual time were different with 30minutes, this is due to battery losses or better put the depth of charge of the batteries, in order to enhance the system we can use batteries that have a higher depth discharge. For instance, lithium batteries may be continuously charged and drained for years, and they have a 100% discharge rate. Their primary use is in solar batteries and cell phones. Also if one is to use mercury batteries use the wet cell which enables the change of electrolyte instead of total replacement.

Also we can double the battery system configuration and connect them in parallel this will increase the ampere hour of the system and increase the battery run-time.

III. In implementing the inverter ensure that the desired load is not up to the rating of the inverter, so as not to cause overloading and to give room for surge voltage.

When it comes to enhancement as we have done here we use a hybrid inverter that has an inbuilt charge controller in it. This is cost efficient also it can integrate utility grid/generator to charge the batteries.

4.1.5 ENHANCEMENT OF PV SYSTEMS IN GENERAL.

Solar is the cheapest and clean way to generate electricity and makes business sense but if solar is so great, why don‘t we rely on it much more and just switch off all the dirty power plant. But solar has this one big problem STORAGE.

Lithium-ion batteries have revolutionized the storage of energy but for a couple of hours. We might want to opt in to longer-term storage in order to distribute to areas with lesser sunshine

Enhancement of storage at Industrial Scale

Optimization of renewable energy is at its peak but the problem of storage is a major concern. The best battery storage holds battery for about 4 days and starts degrading these as fuel up the innovation of more efficient and longer lasting means of storage of which most are in the development stages.

i. Flow Batteries: Another type of battery called a flow battery separate the charge outside a cell, that has two advantages it can store more energy and for longer. The problem is they are relatively expensive.

ii. Pumped Hydro Storage: This is already in use quite a bit. You need two lakes and one of them needs to be on a hill. During the day you use solar energy to pump water from the lower lake to the upper lake when you need energy at night you can just let it run through a turbine. But for that you need to find a lake and a hill.

iii. Gravity Base Storage: Another solution using gravity comes for a Swiss company (Energy Vault) has developed a six-arm crane to lift 5,000 concrete blocks weighing 35tons in total up and down 33 storey high, which store gravitation potential energy when they are raised and releases it as they are lowered and its 50% cheaper than battery storage technology.

iv. Hydrogen: And there‘s also the option of using solar to produce hydrogen which can be conducted by two processes: water electrolysis using solar generated electricity and direct water solar splitting and with the hydrogen produced you could do a number of things like fuel cars or even make steel but the process is still costly.

Other storages include thermo-storage, compressed air etc.

A forecast according to Jenny Chase head of solar analyst at research firm Blumberg NEF that solar power will supply about 23% or higher of global electricity by 2050 (Matte, 2021).

4.3 BILL OF ENGINEERING MEASUREMENTS AND EVALUATION (BEME)

In all engineering projects, it is essential to determine the anticipated construction cost, which is known as the estimated cost. The Bill of Engineering Measurement and Evaluation (BEME), also known as the 'Bill,' is a tool used before, during, and after construction to evaluate and assess the cost of construction works. This encompasses the cost of materials, labor, equipment, and any other necessary resources for the successful completion of a construction project, based on predetermined scope and specifications.

In order to fully execute the implementation of this design the following cost was accrued in the process

Table 4.2: 3 BILL OF ENGINEERING MEASUREMENTS AND EVALUATION (BEME)

Item	Unit Price	Quantity	Sub-Total
Inverter	290000	1	290000
Batteries	280000	2	560000
250W/12V monocrystalline Solar Panel	90000	6	540000
Cables	50,000		50,000
Batteries refill	100,000	2	200,000

GRAND TOTAL	**N1,640,000**

Given the cost of the solar microgrid as #1640000 for a battery runtime of 4.5 hours

Let’s calculate the cost of PHCN grid for that same time. Using a prepaid billing method.

1unit = 1KWh = #26.31

Recall our KWh is 11.080KWh

Therefore 11.080KWh = 26.31 × 11.080 = #291.5

Recall that our battery run-time is 4.5 hours, therefore we will us the same time for our calculation.

For 4.5 hours the total cost is = #291.5 × 4.5 = #1311.8.

The solar system duration most times is dependent on the lifetime of the batteries, and for a battery the average lifespan of the wet cell is 4 years. Therefore we can say that the cost of installing the system covers power for 4 years.

Therefore the total cost of PHCN billing in this comparison will cover for 4 years

#1311.8 × 2920days = #3830456

Comparing both costs we will have:

3,830,456 – 1,640,000 = #2,190,456

Looking at this result we will observe that implementation of the solar system is cost intensive but over time when compared with PHCN it proves to be cheaper.

4.4 IMPLEMENTATION HIGHLIGHTS

Figure 4.6: Battery arrangement/connection of the PV system

Figure 4.7: Inverter system connection

Figure 4.8: Solar panel arrangement during testing

Figure 4.9: Rear view of the inverter showing connection of the battery, PV array and output.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

At the end of the project, the following factors, in accordance with the objectives of the study, were actualized:

i. An implementation of a 2.5kVA PV system for a three bedroom-flat apartment
ii. The load surveys of the three bedroom-flat, were obtained.
iii. Suitable battery bank, inverter, charge controller and PV array were ascertained.
iv. Accurate number of batteries and solar panels for the needed installation were duly determined via corresponding calculations.
v. The cost used to implement the design was obtained
vi. We carried out a charge rate analysis to show when the panels receive more power to charge the batteries.

5.2 RECOMMENDATIONS

This research work is recommended to passionate researchers on Power System Engineering for further findings in respect of advance enhancement that could lead to better efficiency and effectiveness of PV systems, especially 2.5kVA Solar Home System, which was fundamentally the area of interest of this very study.

We also recommend policymakers, political leaders, investors, concerned institutions, and energy personnel, among others, to support any work or activity targeted to promote solar power systems by taking the necessary actions and steps towards ensuring that more people would acquire electricity from the Sun in the near future, thereby harnessing the full potential of solar power for our common good.

All levels of government should, among other things, implement policies that will:

i. Encourage environmental and energy sustainability.

ii. Promote workforce development and training in the area of power systems.

iii. Raise public awareness of the usage of solasr energy systems through media jingles, seminars, workshops, public lectures, and symposiums.

iii. Eliminate altogether or drastically cut the excise tax paid on solar-powered equipment.

v. Establish the necessary safeguards and an atmosphere that encourages investme

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