

**DESIGN OF HYBRID RENEWABLE ENERGY SYSTEMS USING
SOLAR AND WIND ENERGY**



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A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY. IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF A BACHELOR OF ENGINEERING (B. ENG) IN ELECTRICAL AND ELECTRONIC ENGINEERING

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CERTIFICATION

This is to certify that this project work was carried out by **AGBONKHESE EHIMHANRE DUKE** with Matriculation Number **ENG1704152**, a student of the DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING, UNIVERSITY OF BENIN, in partial fulfillment of the requirements for the award of the BACHELOR OF ENGINEERING DEGREE in ELECTRICAL/ELECTRONICS ENGINEERING; under the supervision of Prof. Sunday Onohaebi.

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Date

DEDICATION

This project work is dedicated to Almighty God and also dedicated to all whose mission is to see the world make maximum use of Hybrid Renewable Energy Systems Using Solar and Wind.

ACKNOWLEDGEMENT

My biggest thanks goes to God Almighty for giving me the strength to start and finish my bachelor's degree in Electrical and Electronic Engineering, University of Benin. With his help, I was able to start and finish this project despite the obstacles encountered.

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Special thanks go to my parents and guardians for their encouragement and support throughout my stay in the university. Without them I wouldn't have made it this far. Thank you to my friends who helped during my time of need. Their loving support saw me through the hurdles I faced.

Finally, thank you to everyone in the Electrical and Electronic Engineering Graduating class of 2021/2022 session. The journey was not a smooth one, but we made it to the end. Congratulations!!!

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ABSTRACT

This project involves the design of a hybrid renewable energy system using solar and wind for residential areas and to use the system to generate sustainable electricity for household consumption, independent of fluctuations in the weather.

A review of previous works was carried out, radiation (solar) and wind data (speed) was collected using Northern part of Nigeria as a case study and then load listing for a typical household was done. The subsystem of the Hybrid Renewable system was organized in a block diagram and then each of the subsystem was designed. The Design Calculation (result and finding) was that a typical household requiring 11KW per day. Each Subsystem requires a PV subsystem requires with 6 solar panels of 1000w connected in series, Wind subsystem with rotor blade Radius/Length of 5m is required with 11kw 24V Turbine, an Energy storage subsystem of 24V, 13000AH which is 10 (1300AH) batteries in series and an Inverter required is 15KW 24V inverter.

Overall, this research provides a comprehensive framework for the design of a hybrid renewable energy system that combines the strengths of solar and wind resources. The proposed system offers a reliable and environmentally friendly solution to meet the increasing energy demands while reducing greenhouse gas emissions, ultimately contributing to a cleaner and more sustainable energy in the future.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In today's interconnected global economy, energy security is increasingly important. Nations aim for energy independence, yet rising demand pressures limited oil supplies. Developing countries like China, Brazil and India need oil to sustain rapid economic growth. However, fossil fuel reserves are dwindling while burning oil and gas harms the environment. These factors drive the search for alternative energy sources and change consumer views on energy use.

Renewable energy sources have enormous potential to meet and even exceed current global energy demands, enhancing supply diversity and sustainability. Renewables can also reduce emissions, provide cost-effective energy services especially in developing regions, create jobs, and enable local manufacturing. However, despite commercially available options, most renewables remain at an early stage technically. Ongoing research, development and demonstration can improve technologies and cut costs through innovation and scaled production. Currently, few renewables can compete economically with conventional fuels without subsidies except in niche markets. But further technological advances and wide deployment can make renewables more cost-competitive, closing the price gap with traditional energy. Realizing the full promise of renewables requires continuing to mature technologies, build production capacity, and drive market adoption.

Hybrid renewable energy systems, combining multiple clean energy technologies, provide a promising approach to maximize renewable power generation.

Renewable sources like solar, wind, biomass, hydro, tidal, wave, and geothermal energy offer naturally replenished energy and are seen as crucial components of future more electrified energy systems. Hybrid systems generate power for direct use rather than grid integration, supplying electricity to industries or residences. This proposed hybrid design will rely primarily on solar and

wind, which are freely available renewable sources requiring minimal infrastructure compared to alternatives like hydro power.

The main goal is phasing out fossil fuels like coal, oil and gas from the industry to reduce pollution. The planned hybrid system aims to provide clean, economical energy with low maintenance requirements.

In summary, integrating solar and wind power in a hybrid renewable energy system can potentially provide sustainable, low-cost electricity while minimizing reliance on dirty energy sources.

1.2 STATEMENT OF THE PROBLEM

A single solar panel or wind turbine can generate ample electricity for a home during summer months, but their efficiency drops when energy demands rise in winter. Installing a hybrid system that integrates both solar and wind renewable sources may provide a better solution.

The intermittent nature of the sun and wind presents challenges in maintaining a consistent power supply. Most hybrid systems require batteries to store excess energy for use when solar and wind conditions are low. However, batteries add monitoring costs and typically last only a few years before needing replacement. Researchers indicate battery lifespan needs to improve substantially to make them economically viable for home hybrid systems.

Supplementing the renewable sources with a diesel generator or fuel cell that provides steady power regardless of weather could help stabilize fluctuations in supply. These technologies aren't dependent on sunshine or wind patterns to generate electricity.

1.3 AIMS AND OBJECTIVES

The aim of this work is to design a hybrid renewable energy system using solar and wind for residential areas.

The specific objectives are to:

1. Collect and analyze data from the renewable systems
2. design a hybrid renewable energy system for residential areas
3. use the system to generate sustainable electricity for household consumption, independent of fluctuations in the weather.
4. enhance the reliability of power generation systems and to reduce the cost/rate of energy consumption

1.4 SCOPE

The project entails designing a hybrid renewable energy system that uses solar and wind energy as was already mentioned. This suggests that the project will initially be split into two sections, the first of which will be the design of a wind turbine to capture wind energy and the second of which will be the design of a solar power system. In the hybrid systems, a charge controller (Hybrid System Control Unit) is also present. The battery charging process is controlled by this circuit, which receives the two direct current (DC) outputs from the solar and wind energy systems and outputs a DC voltage that is just right to charge the battery. This controller also prevents overcharging by supplying the precise amount of voltage required. Also incorporated in the system is an inverter that converts the battery's DC voltage to alternating current (AC). As a result, the inverter's output can be used to power AC loads like ceiling fans and incandescent light bulbs. On the other hand, DC loads can be connected directly to the battery's output terminal.

1.5 METHODOLOGY

In this section, an overview of the procedures that would be utilized in achieving the aim and objectives is discussed;

1. A review on previous work done on hybrid renewable energy system noting the challenges faced and how to improved them
2. Analyzing data related to hybrid renewable energy system, including wind speed and direction, energy output, radiation of the sun,etc on different weather conditions using Nigeria North as a case study
3. The hybrid renewable energy system will be designed for a house, sofor a typicalhousehold electrical load listing will be done.
4. The hybrid renewable energy system components will be organized in a block diagram
5. Design of the hybrid energy system
6. The findings of this project will be discussed and interpreted and a literature comparison will be provided.
7. Draw conclusions, emphasize contributions to the field, and summarize the key discoveries. Identify research gaps and existing restrictions.

CHAPTER TWO

LITERATURE REVIEW

2.0 CONCEPT OF ENERGY

In science, energy is commonly defined as the capacity to do work or cause change. Work involves moving or altering something, which requires energy to be transferred from one place or form to another. Energy comes in many forms, categorized as either potential (stored) or kinetic (in motion). For instance, heat comprises kinetic energy since it arises from particles vibrating when heated. Meanwhile, nuclear energy represents potential energy stored in atomic nuclei.

2.1 SOURCES OF ENERGY

Energy sources can be classified into two primary categories: renewable and non-renewable

2.2 RENEWABLE ENERGY

Renewable energy comes from natural sources that replenish over time. Growing industrialization and populations have increased the need for renewable resources. Major renewable energy types include:

Solar power harnesses sunlight using panels that transform solar radiation into electricity for buildings. Wind turbines capture kinetic energy from wind, converting it into electrical power. Hydropower utilizes the movement of water in rivers and oceans to spin turbines that generate electricity. Geothermal power taps into the Earth's interior heat to produce steam and run turbines. Biomass energy derives from burning organic matter like wood, crops, and waste to provide heat or make biofuels. Tidal power generates electricity from tidal flows through turbines.

In summary, renewables like solar, wind, hydro, geothermal, biomass and tidal offer sustainable energy alternatives by utilizing continuously available natural processes. Technology allows capturing these clean sources to produce electricity, heat, or fuel. The renewable resources provide options to reduce fossil fuel dependence.

2.3 NON-RENEWABLE ENERGY

Non-renewable energy comes from sources that decay or deplete over time and cannot be readily replenished. The main non-renewables are fossil fuels - coal, oil, and natural gas. Fossil fuels formed from ancient plant matter, earning them the name "fossil" fuels. Today, fossil fuels provide most of the world's energy needs.

India possesses substantial coal reserves, around 361 billion tonnes as of 2022. Coal generates nearly half of India's commercial energy. The country's estimated oil reserves stand at 603 million tonnes, though India's annual oil consumption of 194 million tonnes relies over 80% on imports.

Burning fossil fuels causes significant environmental pollution. As non-renewables take millions of years to form, reserves are finite and will eventually be exhausted.

In summary, coal, oil and natural gas are non-renewable legacy energy sources that release pollutants when burned. While fossil fuels currently dominate energy use, their finite, non-replenishing nature leads to concerns about long-term sustainability and environmental impacts.

2.4 SOLAR ENERGY

The sun provides sunlight - a clean, renewable form of energy. Solar power is considered sustainable since the sun radiates energy to Earth on a near-daily basis. Unlike finite resources such as coal and gas, the sun's energy cannot be depleted. There is growing interest in utilizing renewable "green" energy sources like solar, wind and geothermal instead of unsustainable fossil fuels.

Solar energy already has many uses including natural lighting, drying clothes and crops, and heating. But its potential applications are far greater. With innovations in technology, solar could one day power electricity generation, water heating, cooking, transportation and more aspects of our lives through this unlimited natural resource.

2.4.1 ADVANTAGES OF SOLAR ENERGY

The disadvantages of solar energy are:

1. Abundant resource - Sunlight provides a renewable, plentiful energy supply.
2. Non-polluting - Solar generates electricity without air/water pollution.
3. Zero emissions - Using solar energy produces no greenhouse gases that cause climate change.
4. Energy independence - Solar allows self-sufficiency, avoiding unpredictable fossil fuel politics and pricing.
5. Eco-friendly - Solar power does not damage forests and ecosystems like extracting fossil fuels does.

2.4.2 DISADVANTAGES OF SOLAR ENERGY

The disadvantages of solar energy are:

1. Inconsistent supply - Solar depends on sunny weather, so generation varies by season and climate.
2. High upfront costs - Large solar installations require significant initial investments.
3. Limited nighttime output - Solar only produces energy during daytime, requiring batteries to store surplus electricity.
4. Storage challenges - Current solar storage technology has not achieved full potential.
5. Bulkiness - Traditional silicon solar panels have large, heavy profiles compared to new thin-film options.

2.5 WIND ENERGY

Wind is the natural movement of air over land and water. This kinetic energy can be harnessed by wind turbines, whose rotating blades turn a shaft connected to a generator that produces electricity. India has estimated wind power generation potential of around 302,251 megawatts (MW) based on suitable wind conditions exceeding 200 watts per square meter at 80 meter hub heights with 2% land availability.

As of October 2021, India had installed wind power capacity of 39,990 MW, making it the world's 4th largest. The private sector owns 95% of India's wind farms. Through continued growth in wind energy, India aims to utilize this renewable resource to meet rising power demands in a sustainable manner.

2.5.1 ADVANTAGES OF WIND ENERGY

The advantages of wind energy are:

1. Eco-friendly - Wind energy does not cause air or water pollution like fossil fuels. It is a clean, renewable source.
2. Abundant supply - Wind is a freely available resource that can be harnessed for electricity generation.

2.5.2 DISADVANTAGES OF WIND ENERGY

The disadvantages of wind energy are:

1. High capital costs - Constructing large wind farms requires substantial upfront investment.
2. Intermittent supply - Wind speeds vary over time and location, leading to inconsistent electricity generation.

2.6 HYBRID RENEWABLE ENERGY SYSTEMS

Hybrid systems, as the name implies, combine two or more methods of electricity generation, typically leveraging renewable energy sources such as solar photovoltaic (PV) panels and wind turbines. By integrating various generation technologies, hybrid systems enhance energy security. To further enhance the reliability and security of the power supply, storage devices like batteries or fuel cells are often integrated.

With advancements in renewable energy technology and the escalating cost of petroleum products, hybrid renewable energy systems are increasingly being adopted as independent power systems for providing electricity in remote areas. A hybrid energy system, also referred to as hybrid power, generally consists of two or more renewable energy sources working together to optimize system efficiency and ensure a balanced power supply.

One of the primary drawbacks of relying solely on individual renewable energy sources is their intermittent availability. To overcome this limitation, solar and wind energy can be combined. This way, if one source experiences downtime, the other can step in to maintain power generation. In this proposed system, both sources can be used concurrently, or one can serve as a backup unit to ensure continuous power generation, thereby enhancing system reliability. While the initial cost is relatively high, this approach offers reliability, reduced emissions, lower maintenance costs, an extended system lifespan, and increased efficiency.

2.6.1 ADVANTAGES OF HYBRID RENEWABLE ENERGY SYSTEMS

The advantages of hybrid renewable energy systems are:

1. These systems leverage the complementary characteristics of various energy sources, enhancing the system's overall efficiency and performance, including power quality and reliability.
2. Hybrid renewable energy systems can be strategically designed to optimize the utilization of renewable resources, leading to reduced emissions and a more eco-friendly operation.

3. The design of hybrid energy systems allows for the achievement of desired attributes at the most cost-effective levels, a crucial factor in gaining market acceptance.

2.7 DISTRIBUTED GENERATION

The term "distributed generation" pertains to the process of generating electricity in proximity to the point of consumption, as opposed to sourcing it from centralized facilities like power plants.

Various technologies, such as solar panels and combined heat and power systems, fall under the umbrella of "distributed generation." They produce electricity at or near the location where it will be used. Distributed generation can serve the energy needs of a single structure, whether it's a residential house or a commercial establishment, or it can be integrated into a microgrid. A microgrid is a smaller-scale grid connected to a larger electrical delivery system. Examples of microgrids include large industrial complexes, military installations, and university campuses.

Distributed generation, when integrated into the lower voltage distribution lines of the electric utility, can play a crucial role in delivering clean and reliable power to a broader customer base while also reducing losses associated with transmitting electricity over long-distance transmission and distribution lines.

2.7.1 BENEFITS AND APPLICATION OF DISTRIBUTED GENERATION

Distributed generation offers numerous advantages and applications:

1. **Localized Energy Production:** Distributed systems generate electricity in close proximity to consumption, significantly reducing transmission losses and improving overall system efficiency. This approach grants communities, businesses, and institutions greater control over their energy supply.
2. **Grid Resilience and Reliability:** Communities with distributed systems can enhance the resilience of their grid, thereby reducing the risk of extensive power outages. Localized

energy sources can continue to operate during disruptions, ensuring a reliable electricity supply to critical infrastructure, emergency services, and residential areas.

3. **Renewable Energy Integration:** Distributed generation paves the way for the seamless integration of renewable energy sources, such as solar panels, wind turbines, and small-scale hydroelectric systems. This integration optimizes the utilization of clean energy resources and supports the transition toward a more sustainable and environmentally friendly energy mix.

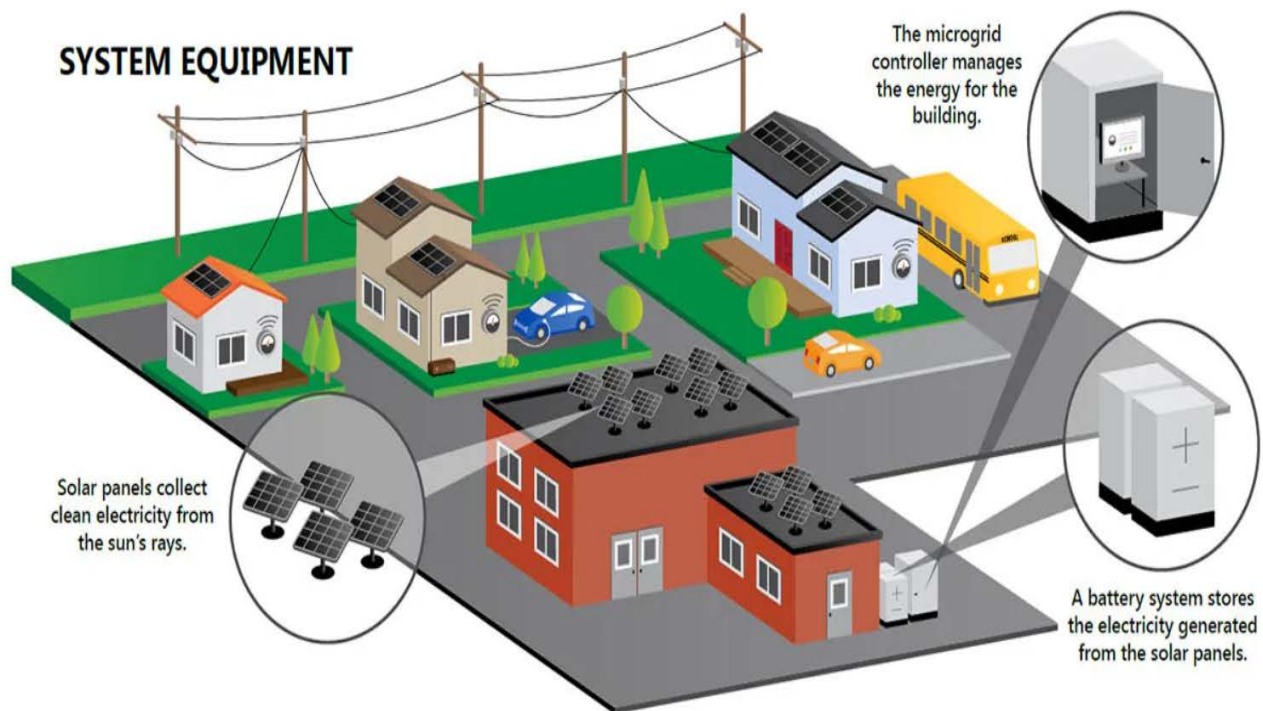


Figure 1: Showing Distributed Generation

2.8 REVIEW ON RELATED WORKS

J. Godson (2013) emphasized the significance of renewable energy sources, including solar, wind, biomass, hydro power, geothermal, and ocean resources, as viable technological options for generating clean energy. While energy production from solar and wind sources lags behind fossil fuels, there has been a substantial increase in electricity generation through PV cells and wind turbines in recent years.

The paper introduces a Solar-Wind hybrid Power system designed to harness the renewable energies provided by the sun and wind to generate electricity. This system relies on microcontrollers for effective control, ensuring optimal resource utilization, thereby enhancing efficiency when compared to individual modes of generation. Furthermore, it enhances reliability and reduces dependence on a single energy source. This hybrid solar-wind power generation system is well-suited for both industrial and residential applications.

Ali Diabat (2014) highlights that among the numerous challenges our world faces today, there exists a global consensus that greenhouse gas (GHGs) emissions have the most substantial negative impact on our environment. GHGs encompass carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. These gases play a crucial role in maintaining the Earth's temperature at levels conducive to sustaining life. A reduction in GHG levels could lead to temperatures that are too low for human survival.

Conversely, because GHGs allow sunlight to penetrate the atmosphere while trapping heat radiated from the Earth's surface, an increase in these emissions would result in a rise in the planet's temperature—a phenomenon known as global warming. Such elevated temperatures could have dire consequences for living organisms. Moreover, many scientists argue that the surge in natural disasters can be attributed to climate change, as shifts occur in atmospheric and oceanic patterns in response to the Earth's rising temperatures.

Karim Mousa (2014) noted that while solar and wind energy stand out as two of the most promising renewable energy sources, there has been limited research on simultaneously harnessing both of these resources to leverage their complementary characteristics. Their study focuses on devising an optimal design for a hybrid solar-wind energy plant. The variables subjected to optimization encompass the number of photovoltaic modules, wind turbine height, the quantity of wind turbines, and turbine rotor diameter, all aimed at minimizing costs. Through simulation studies and sensitivity analysis, the research demonstrates that the hybrid plant effectively capitalizes on the complementary nature of these two energy sources, delivering reliable energy throughout the year.

In his work, Medugu (2014) developed a hybrid power system that combines PV-arrays and wind turbines along with energy storage (battery banks) and power electronic devices. The primary objective of this system is to generate and utilize electrical energy from multiple sources, with the condition that at least one of these sources is renewable. The power electronic device designed for this system exhibits an efficiency of approximately 95% for capacitive loads and 73% for resistive loads.

The integration of this hybrid system was aimed at providing electricity to a residential house and its vicinity, with the ultimate goal of reducing reliance on fossil fuels, thereby promoting a more sustainable power supply. This approach has proven to be both technologically and economically feasible, particularly for rural electrification.

Vaibhav J. Babrekar and colleagues (2017) emphasize that in the 21st century, energy is an essential necessity. Renewable energy resources are gaining significant attention due to their ready availability and cost-effectiveness. However, these individual energy sources have inherent limitations, including unpredictability and intermittent availability. These challenges can be effectively addressed through the implementation of hybrid energy systems, which combine multiple renewable energy resources. Such hybrid systems offer improved stability in the face of voltage and frequency fluctuations, harmonics, and power-related issues that standalone systems may encounter.

Hybrid power systems also contribute to reducing complexity, maintaining lower unit costs, mitigating energy fluctuations due to deficiencies in power supply probability (DPSP), and enhancing overall performance through careful design, swift response mechanisms, optimized operation, and effective control. The paper provides a comprehensive review of hybrid solar and wind power systems, highlighting their technical feasibility within a given load demand range. It also includes an economic evaluation of standalone PV, standalone wind, and PV-wind hybrid systems, supported by a detailed model.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This chapter demonstrates the intricate design of a hybrid renewable energy system combining solar and wind power. As outlined in chapter one, a step-by-step approach is followed. Solar radiation and wind speed data were collected for the case study location in northern Nigeria. Energy load listing was conducted for a typical household. The subsystems of the hybrid renewable system were organized in a block diagram, and the role of each subsystem was explained.

Table 1: ELECTRICAL LOAD LISTING FOR A TYPICAL HOUSEHOLD 1

Appliance	No of Appliance	Type	Power(W)
Pressing iron	1	Dry iron	1200
Blender	1	Medium	450
Water heater	1	50Litre	1500
Cooker	1	4 Plate	4500
Fan	4	Standing	$70 \times 4 = 280$
Refrigerator	1	Large	250
Air conditioner	2	Small(1hp)	$746 \times 2 = 1492$
Television	1		75
Water pump	1	Small(1hp)	746
Washing Machine	1	With spinning	600
Light bulb	20	Energy saving	$15 \times 20 = 300$

Total Power Demand=11KW

This is the total power required per day.

3.1 SOLAR (RADIATION) AND WIND (SPEED) DATA

Nigeria is a sub-Saharan country strategically located on the equator, which results in high solar radiation that is evenly distributed. Investigations into Nigeria's solar energy potential have estimated the country receives a daily average of total solar radiation ranging from about 12.6 MJ/m²/day (3.5 kWh/m²/day) along the coast to about 25.2 MJ/m²/day (7.0 kWh/m²/day) in the far north. This amounts to approximately 17,459,215.2 million MJ/day (17.439 TJ/day) of solar energy falling on Nigeria's 923,768 sq km land area. With such abundant sunlight, Nigeria has significant potential for solar photovoltaic (PV) energy, especially in the semi-arid northern regions.

Nigeria can be divided into three solar radiation zones, each with different levels of radiation that impact PV project selection and sizing. The northeast states fall under Zone 1, which receives the highest levels of radiation. The Nigeria north region is used as a case study in the design.

Nigeria experiences sunny conditions daily, averaging about 6.25 hours of sunshine ranging from 3.5 hours along the coast to 9 hours in the north. The mean daily solar radiation is approximately 5.25 kWh/m²/day, spanning 3.5 kWh/m²/day in coastal areas to 7 kWh/m²/day in the north. Given Nigeria's high solar resource, PV represents a viable alternative energy supply, especially for rural electrification.

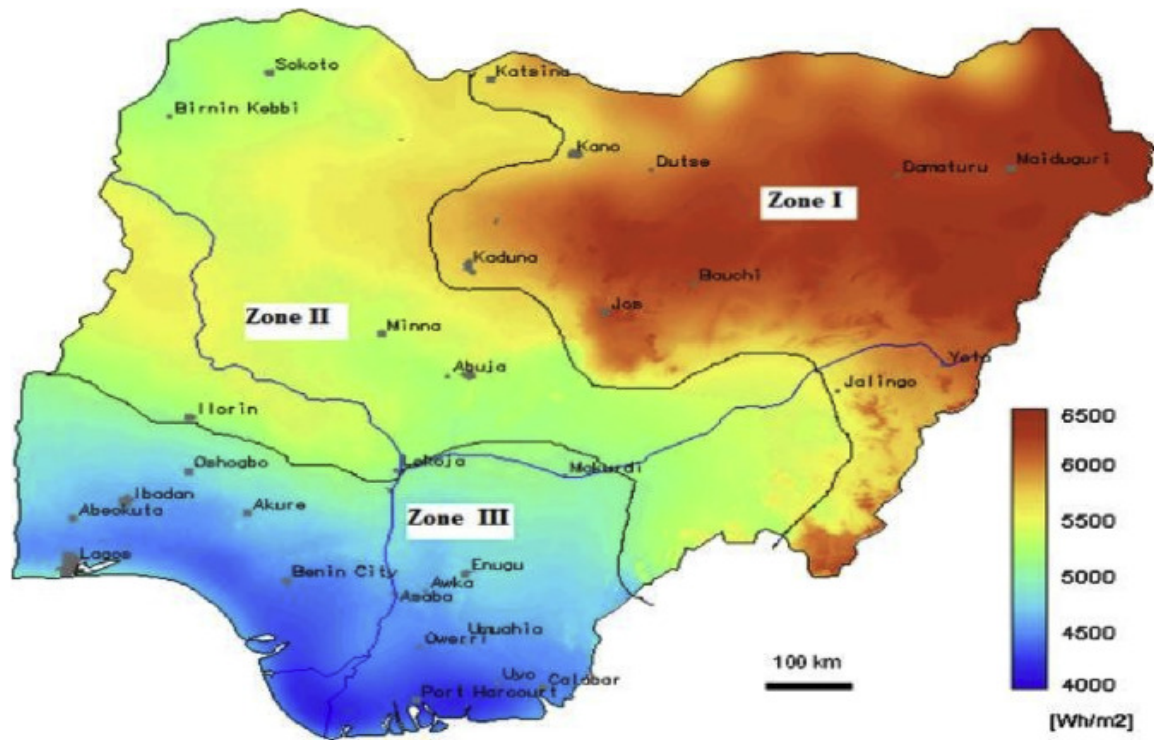


Figure 2: Solar Radiation Map Of Nigeria

Table 2. Solar radiation zones (global horizontal irradiation) [16].

Zones	kWh/m ²	h/d	kWh/m ² /yr	States
Zone I	5.7–6.5	6.0	2186	Borno, Yobe, Jigawa, Kano, Kaduna, Bauchi, Gombe, Adamawa, Plateau and Katsina
Zone II	5.0–5.7	5.5	2006	Sokoto, Zamfara, Kebbi, Niger, Abuja, Nassarawa, Taraba, Kwara, some section of Plateau and Katsina
Zone III	<5.0	5.0	1822	Oyo, Osun, Ekiti, Kogi, Benue

Figure 3: Solar Radiation Zones

The northern region of Nigeria experiences average wind speeds of 4 to 6 meters per second, making wind power a viable energy generation option that could be used for small-scale telecom applications. Figure 2 illustrates the potential for wind power plants across Nigeria. The highest wind potentials are concentrated in the far north. By harnessing Nigeria's significant wind resource, progress could be made toward national electrification goals while also enabling wireless connectivity critical for economic development.

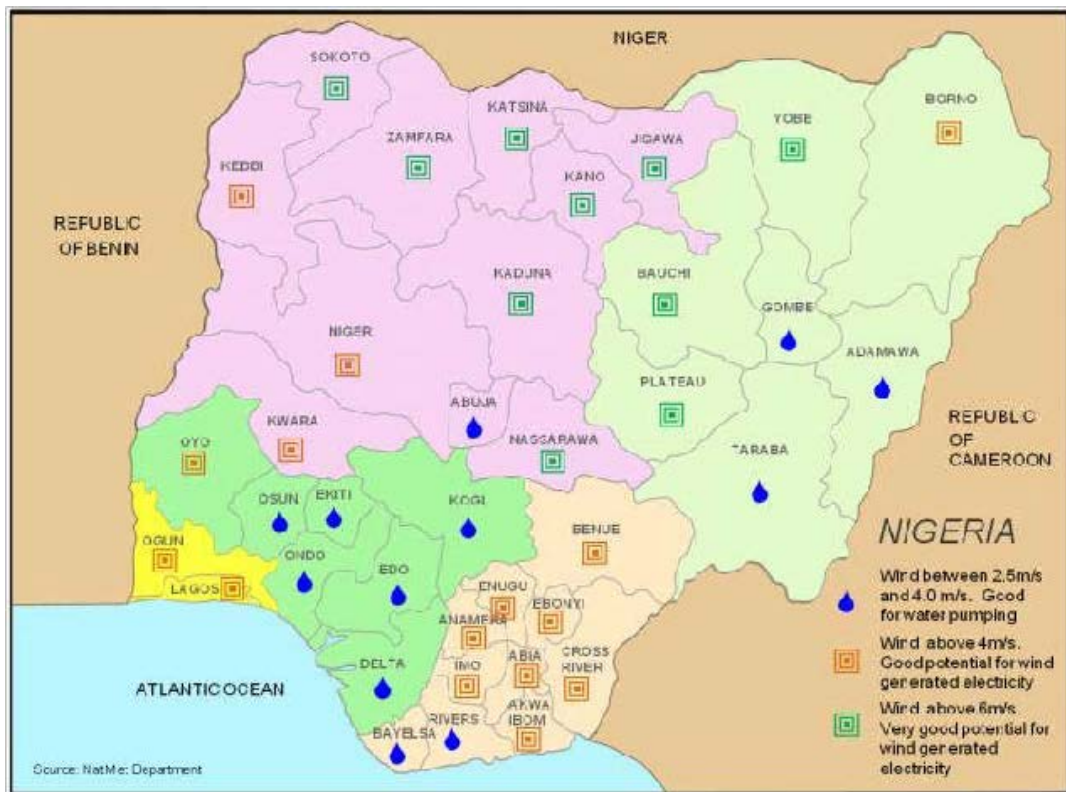


Figure 4: Map Of Nigeria Showing Wind speed in Different Region

3.2 BLOCK DIAGRAM OF HYBRID RENEWABLE ENERGY SYSTEMS

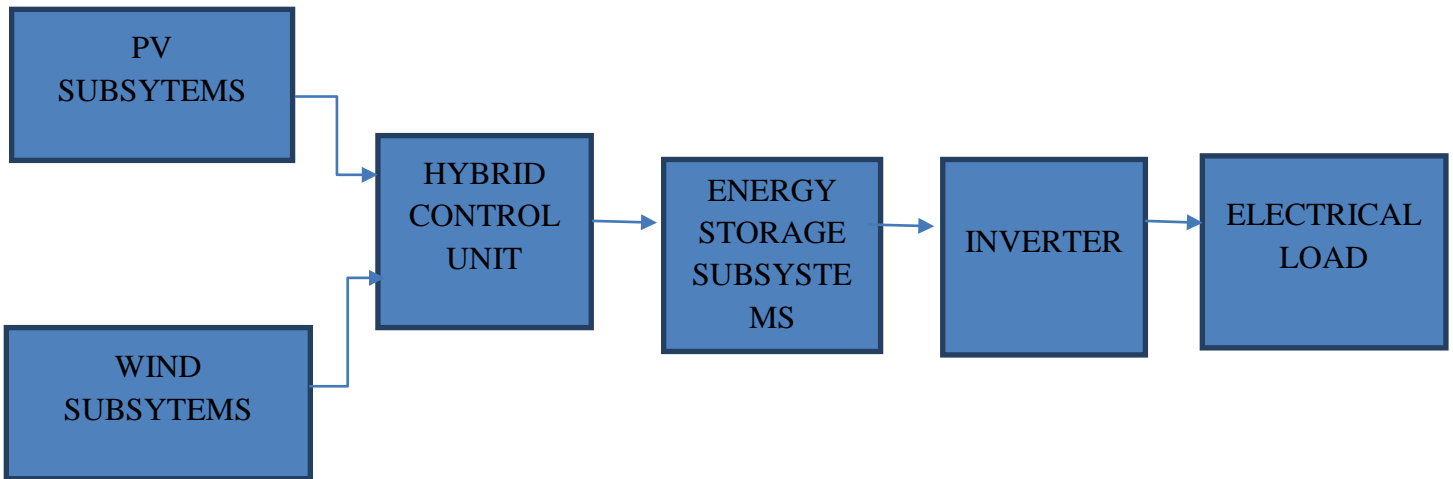


Figure 5: Block Diagram Of Hybrid Renewable Energy Systems

Figure 5 shows the block diagram of the hybrid renewable energy system using wind and solar power. This block diagram includes the following blocks:

1. PV subsystem
2. Wind energy subsystem
3. Energy storage subsystem
4. Power converters(inverter)
5. Hybrid system control unit(charge controller)

3.3 DESIGN ARCHITECTURE

This section will provide an understanding of the various subsystems and explains their roles in the design of hybrid renewable energy using solar and wind.

3.4 PV SUBSYSTEM

Solar panels are composed of photovoltaic (PV) cells that convert sunlight directly into electricity. Sunlight contains particles called photons that carry energy. When these photons strike the semiconductor material in a PV cell, they transfer their energy to electrons in the cell, causing the electrons to flow and generate a DC electric current. The photovoltaic effect enables individual PV cells to turn the radiant energy in sunlight into usable electrical energy. Multiple PV cells are interconnected and encapsulated to form larger PV modules, which are further connected in arrays to create solar panels. By collecting and converting the abundant solar resource, PV panels provide clean, renewable electricity that can be used to power anything from small electronics to large grid-tied systems. With solar panel technology becoming increasingly efficient and cost-competitive, photovoltaics are poised to play a major role in the global transition to sustainable energy.

3.4.1 Solar Panel System

A solar panel system consists of an array of interconnected photovoltaic (PV) cells that convert sunlight into electricity. The energy output of a solar panel is measured in volts or watts, and varies based on the PV cell technology used. Each solar panel, also called a PV module, contains a number of PV cells encapsulated in a metal frame, typically 60, 72, or 96 cells per module. By interconnecting multiple PV modules into an array, a solar panel system can be sized and designed to match electrical load requirements. Modular solar panel technology enables scalable and customizable renewable energy generation for homes, businesses, and utility applications.



Figure 6: Solar Panel System

3.4.2 Types of Solar Panel

1. **Monocrystalline Solar Panels (Mono-SI):** Monocrystalline solar panels are made from a single crystal structure, giving them a high level of efficiency and a sleek black appearance. They are known for their excellent performance in converting sunlight into electricity, making them a popular choice for residential and commercial solar installations.
2. **Polycrystalline Solar Panels (Poly-SI):** Polycrystalline solar panels are made from multiple silicon fragments, which results in a less uniform appearance compared to monocrystalline panels. While they are slightly less efficient than monocrystalline panels, they are more cost-effective and widely used in various solar applications.
3. **Amorphous Silicon Solar Cell (A-Si):** Amorphous silicon solar cells are known for their thin and flexible design. They can be integrated into various applications, such as portable solar chargers and solar-powered calculators. However, their efficiency is lower compared to crystalline silicon solar panels.

4. **Thin-Film Solar Cells (TFSC):** Thin-film solar cells use various materials, such as cadmium telluride (CdTe) or copper indium gallium selenide (CIGS), to create thin and lightweight solar modules. They are more adaptable and cost-effective but generally have lower efficiency compared to crystalline silicon panels.

These different types of solar panels offer various options for harnessing solar energy, allowing consumers to choose the most suitable option based on their specific needs and budget.

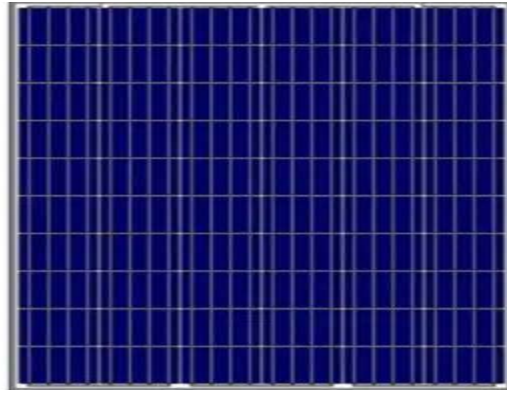


Figure 7: Monocrystalline Solar Panels (Mono-SI)

Figure 8: Polycrystalline Solar Panels (Poly-SI)

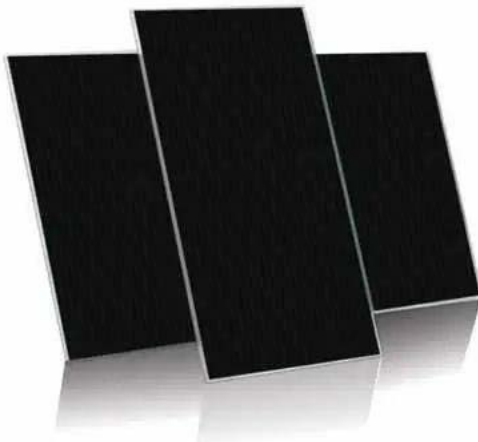


Figure 9: Amorphous Silicon Solar Cell (A-Si)

Figure 10: Thin-Film Solar Cells (TFSC)

3.4.3 How To know Type Of Solar Panel To Use

Choosing the right solar panel type depends on your specific property conditions and project goals. Each panel technology has advantages and disadvantages. Some key considerations are:

If you have ample roof space, polycrystalline silicon panels may be the most economical choice. Though they are slightly less efficient than monocrystalline, their lower cost per watt can maximize energy output given sufficient area.

For limited roof real estate, high-efficiency monocrystalline panels can produce more power. Despite their higher cost, you can offset more loads.

For large commercial rooftops, thin-film panels may be suitable. While less efficient, their flexibility enables alternative mounting configurations. Their lower cost can balance out their reduced output.

Local climate factors like temperature, cloud cover, and snow also impact performance. Optimal solar solutions balance efficiency, durability, and cost.

For this particular project, I will select polycrystalline silicon panels. Their competitive pricing helps meet the budget constraints of the project. And the ample roof space allows me to achieve the targeted system size despite the marginally lower efficiency per panel. By taking this balanced approach, I can deliver the most value and performance for the investment.

3.5 WIND ENERGY SUBSYSTEM

Wind turbines harness the kinetic energy of wind to generate electricity. The basic principle involves converting the mechanical power of wind into rotational motion to drive an electrical generator.

Wind turns the angled blades of a wind turbine's rotor similar to the way airflow generates lift on an airplane wing or helicopter rotor. As wind passes the blades, the airflow on one side has a

lower pressure than the other. This pressure differential creates lift and drag forces that cause the rotor to spin. The rotor connects to a shaft and gearbox which increase the rotational speed to the level required by the generator. The generator then converts this mechanical rotation into electrical energy.

Compared to old fashioned windmills that used wind for mechanical work like pumping water or grinding grain, today's wind turbines utilize advanced aerodynamic blade designs and power electronics to efficiently harvest wind energy and feed usable electricity into the grid on a large scale. By tapping into the free and abundant power of the wind, wind turbines provide a sustainable source of renewable energy without producing greenhouse gas emissions. With many windy locations still unutilized, wind power has great potential for further expansion globally.

Wind turbines come in two main configurations namely:

Horizontal-axis turbines have propeller-style blades that spin on an axis parallel to the ground, like airplane propellers. They typically have three blades for optimum aerodynamic efficiency. Turbine height and blade length correlate with power output - utility-scale horizontal-axis turbines stand up to 300 feet tall with blade spans exceeding 150 feet. This design dominates the wind industry today.

Vertical-axis turbines have blades attached at the top and bottom of a vertical rotor shaft. The most common type is the Darrieus model with egg-beater looking blades. Vertical-axis turbines reach up to 100 feet tall and 50 feet wide, though they are far less prevalent than horizontal axis due to lower efficiency.

For small wind generation projects, horizontal-axis turbines are generally the preferred technology. Their aerodynamic design makes them inherently more efficient at converting wind into rotary motion.

For this particular research application, I will utilize a small horizontal-axis wind turbine

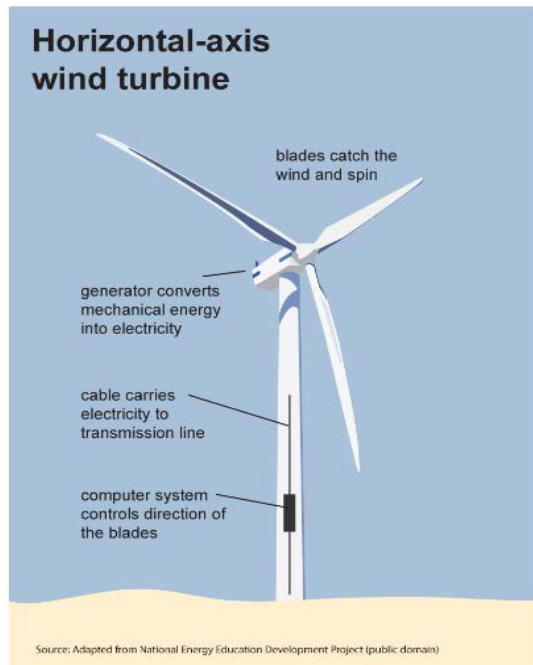


Figure 11: Types Of Wind Turbines

3.6 ENERGY STORAGE SUBSYSTEM

Energy storage systems allow the capture of energy when it is generated so that it can be utilized when needed. Batteries are a key storage technology, especially for intermittent renewable energy sources like solar and wind. The energy can be stored in the battery when supply exceeds demand, and discharged later when required, enabling consistent power availability.

Lead-acid batteries are a mature, inexpensive battery type well-suited for renewables storage. They work by chemical reactions involving lead and lead dioxide electrodes immersed in an electrolyte solution. When the battery discharges, the electrode reactions produce an electric current. These reactions can be reversed during charging to replenish the battery's chemical energy.

Though heavier and less energy-dense than lithium-ion, lead-acid batteries remain practical for small to medium scale renewables storage, back-up power, and off-grid uses. Their commercial availability and low cost make them accessible.

For this research project, lead-acid batteries will provide energy storage to complement the solar photovoltaic and wind subsystems. By selecting appropriately sized lead-acid batteries, I can store excess renewable generation and discharge the batteries during low light or wind conditions to meet the electric load demands. This will demonstrate essential energy storage concepts within the project's budget limitations.

3.6.1 Terms Used In Energy Storage Subsystem

The terms used in energy storage subsystem are:

- 1. **Connecting batteries in parallel:** Increases amp-hour capacity while maintaining system voltage.

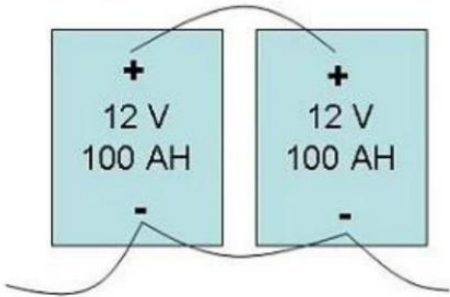


Figure 12: Battery Connection in Parallel

- 2. By connecting two 12V, 100Ah batteries in series, a 24V battery bank with 100 amp-hours of capacity is created.
- 3. **Connecting Batteries in Series;** Connecting batteries in series increases system voltage and maintains the same amp-hour capacity.

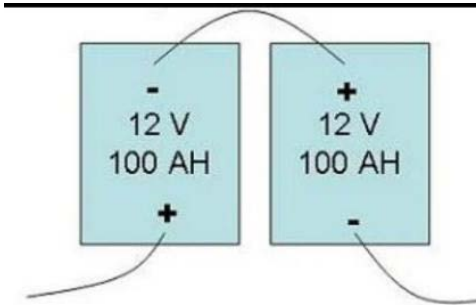


Figure 13: Battery Connection in Series

4. When two 12V, 100Ah batteries are connected in series, a 24V battery bank of 100 amp-hours is formed.
5. **Connecting Batteries in Parallel and Series:** A mix of parallel and series connections boosts both the amp-hour capacity and the voltage of the bat

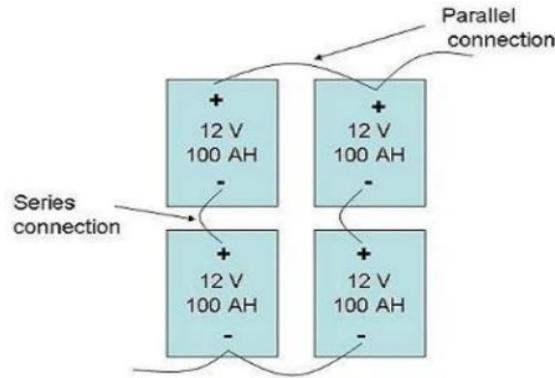


Figure 14: Battery connection in parallel and series

6. Connecting four 12V, 100Ah batteries in parallel and series results in a 24V battery bank with a capacity of 200 amp-hours
7. **Efficiency of Battery:** A key performance metric for comparing battery chemistries is round-trip efficiency. This refers to the amount of energy retained when charging and discharging the battery. Lead-acid batteries have an efficiency of approximately 75%. This means 25% of the energy is lost, primarily as heat, during each charge and discharge cycle. In contrast, lithium-ion batteries can achieve much higher efficiencies around 98%. They have lower internal resistance and less parasitic side reactions. This minimizes wasted energy during cycling and allows lithium-ion batteries to retain nearly all of their inserted energy.
8. **Days of Autonomy (days) :** Days of autonomy refers to the number of days a renewable energy system can continue providing power without any generation input. For solar PV systems, autonomy time allows for periods when insufficient sunlight is available such as due to cloudy weather or storms. Even on sunny days, a solar system may only have around 5 hours of peak generation, but household energy use continues around the clock. By building

in days of autonomy, the battery storage can discharge as needed to meet the 24 hour load demand. Sizing battery capacity to support multiple days of autonomy prevents power interruptions during prolonged overcast or rainy periods.

9. **Depth Of Discharge:** Depth of discharge (DoD) refers to the portion of a battery's capacity that is discharged relative to its maximum rated capacity. It is expressed as a percentage. For example, if a 100Ah lead-acid battery is discharged by 50Ah, it has been cycled to a 50% depth of discharge. The remaining 50Ah represents the unused battery capacity. Shallower discharges are generally better for battery lifespan. Deep cycling to 80% or 100% DoD can accelerate deterioration in lead-acid batteries. Limiting the discharge depth provides a safety buffer to prevent over-depletion.

A common recommended maximum DoD for lead-acid batteries is 50%. This balances usable energy storage capacity with extended cycle life. By preventing excessively deep discharging, the battery will retain its performance for more cycles before needing replacement.

3.7 POWER CONVERTERS (INVERTERS)

Inverters play several important roles in renewable energy systems:

1. Converting the DC electricity from solar PV modules and wind turbines into usable AC power.
2. Ensuring the AC output is pure sine wave at the required frequency, typically 60 Hz.
3. Regulating voltage and optimizing the AC waveform for compatibility with appliances.
4. Providing safety features and protection against abnormal conditions.

Inverters come in two main types:

Grid-tied inverters feed synchronized AC directly into the utility grid. They are designed specifically for grid exports and have advanced functions for power quality and fault response.

Off-grid inverters produce stand-alone AC power for off-grid sites. They incorporate battery charging and MPPT to maximize renewable energy utilization. Off-grid inverters are typically outdoor-rated.

For solar PV systems, inverter sizing is based on the total wattage of the PV array at standard test conditions. It must be able to handle the maximum power output. The inverter's voltage specifications must also match the array design, such as 12V or 24V nominal. By selecting the properly rated inverter, the system can operate at optimal efficiency and deliver the highest energy yield.

3.7.1 Classification Of Inverters

Inverters are categorized into several types but based on their output characteristics; we will discuss them according to this criterion.

1. **Square Wave Inverter:** The output voltage waveform of a square wave inverter is a square wave. It is the least commonly used type of inverter due to the fact that most appliances are designed to operate with a sine wave power source. When a square wave is sent to an appliance designed for a sine wave, it can potentially cause damage or result in significant performance losses. Square wave inverters are cost-effective but find limited application and are typically suitable for basic tools equipped with universal motors.

2. **Sine Wave Inverter:** Sine wave inverters produce a voltage output waveform that closely resembles a sine wave. This inverter type is highly regarded for its ability to provide an output similar to the utility supply. The significant advantage of a sine wave inverter is its compatibility with the majority of electronic devices, as they are designed to operate with sine wave power. Despite being relatively more expensive, sine wave inverters are commonly used in both residential and commercial applications.

3. **Modified Sine Wave Inverter:** A modified sine wave inverter is more complex to manufacture than a basic square wave inverter but simpler than a pure sine wave inverter. The output of a

modified sine wave inverter is a hybrid waveform, neither a clean sine wave nor a square wave. It is essentially a combination of two square waves, resulting in a waveform that does not precisely replicate a pure sine wave but closely resembles its shape.

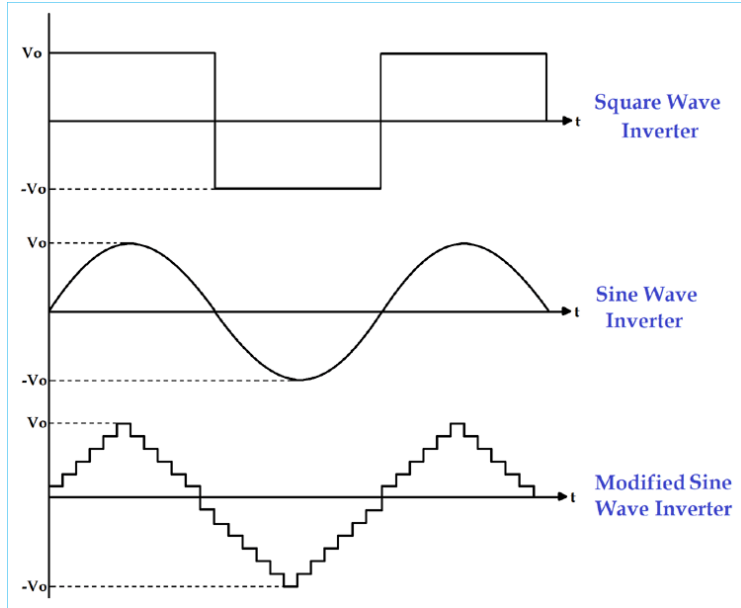


Figure 15: Diagram Of Classification Of Inverters Based On Output

3.7.2 Terms Used In Inverters

1. **Efficiency of Inverter** – Typical inverters, including both normal inverters and solar inverters, generally exhibit an efficiency range of 80-95%. In contrast, high-frequency string inverters are known to achieve an impressive efficiency level of 100%.
2. **Safety Factor:** A commonly accepted guideline recommends that the inverter should possess a minimum power rating of 125% of the total load.

3.8 HYBRID SYSTEM CONTROL UNIT

The wind/solar hybrid controller stands as an intelligent control device capable of simultaneously managing wind turbines and solar panels. It's meticulously designed for top-tier wind/solar hybrid systems while also being well-suited for wind/solar hybrid power setups and monitoring systems. Its primary role is to ensure the safe and efficient charging of batteries by regulating both wind generators and solar panels. With its sleek design, user-friendly operation, visual LCD display, and comprehensive protective functions, this device excels in achieving high charge efficiency and minimizing no-load losses.

Recognized as the cornerstone of off-grid power generation systems, the wind/solar hybrid controller wields significant influence over the system's overall lifespan and stability, particularly with regards to the battery banks.



Figure 16: Wind/solar hybrid controller

CHAPTER FOUR

DESIGN CALCULATIONS

4.0 INTRODUCTION

This chapter shows the design and the calculations involved in the various subsystems which are PV subsystems, Wind subsystems, Energy storage subsystems, and power converters (inverters).

4.1 PV SUBSYSTEM DESIGN

Table 2: Appliances power ratings

Appliance	Power(W)	Operating Time(hrs)	Total Energy (Wh)
Pressing iron	1200	1	1200
Blender	450	1	450
Water heater	1500	4	6000
Cooker	4500	4	18000
Fan	280	6	1680
Refrigerator	250	6	1500
Air conditioner	1492	3	4476
Television	75	3	225
Water pump	746	1	746
Washing Machine	600	1	600
Light bulb	300	6	1800

Total Power Required Per Day=11KW

Total Energy Required Per Day=37KWh

$$\text{Power Required from PV subsystem} = \frac{\text{TotalEnergyRequiredfromPVSubsystem}}{\text{Effectivesuns hinc hours} \times \text{SystemEfficiency}}$$

System Efficiency= battery efficiency × inverter efficiency × others efficiency

Battery Efficiency= Assume 90%

Inverter Efficiency= Assume 95%

Others Component(Charge controller, cables) Efficiency= Assume 85%

System Efficiency= 0.9 × 0.95 × 0.85=0.73

Effective Sunshine hours=9hrs

$$\text{Power Required from PV subsystem} = \frac{37}{9.0 \times 0.73} = 5631 = 6000\text{W}$$

$$\text{Number of Solar Panels Required} = \frac{\text{PowerRequiredFromSolarPanel}}{\text{OutputPowerOfsolarPanel}}$$

Assuming Output power of solar panel=1000W

$$\text{Number of Solar Panels Required} = \frac{6000}{1000} = 6 \text{ solar panels of } 1000\text{w in series}$$

4.2 WIND ENERGY SUBSYSTEM DESIGN

The quantity of power transferred to a wind turbine is directly proportional to the area swept out by the rotor to the density of the air and the cube of the wind speed. The power in the wind turbine (P_w) can be determined using equation;

$$P_w = \frac{1}{2} \times \rho \times A_w \times v^3$$

Where,

P is power in watts (W)

ρ is the air density in kilograms per cubic meter (kg/m^3)

A_w is the swept area by air in square meters (m^2)

V is the wind speed in meters per second (m/s).

$$A_w = \pi r^2$$

Where r = Rotor blade Radius (m)

P(W)=11KW, $\rho=1.225 \text{ kg}/\text{m}^3$, V=6m/s

$$A_w = \frac{2 \times P}{\rho \times V^3} = \frac{2 \times 11000}{1.225 \times 6^3} = 83 \text{ m}^2$$

$$r^2 = \frac{A_w}{\pi} = \frac{83}{\pi} = 26.419$$

$$r = \sqrt{26.419} = 5 \text{ m}$$

Which means for a load of 11kw a rotor blade Radius/Length of 5m is required with 11kw 24V Turbine.

4.3 ENERGY STORAGE SUBSYSTEM DESIGN

$$\text{Total Required Battery Capacity(AH)} = \frac{\text{Total Backup Energy Required Per day} \times \text{Day Of Autonomy}}{\text{Battery Voltage} \times \text{Depth of discharge} \times \text{Battery Efficiency}}$$

Battery Voltage = 24v

Depth Of Discharge = 0.5

Battery Efficiency = 0.75

Days Of Autonomy = 3 days

$$\text{Total Required Battery Capacity(AH)} = \frac{37 \times 3}{24 \times 0.5 \times 0.75} = 13000 \text{AH}$$

$$\text{Number Of Batteries} = \frac{\text{Required Battery Capacity (AH)}}{\text{Required AH of Battery}}$$

Required AH of Battery = 24V , 1300AH

$$\text{Number Of Batteries} = \frac{13000}{1300} = 10 \text{ batteries in series}$$

4.4 POWER CONVERTERS(INVERTERS) DESIGN

$$\text{Required Inverter Power} = \frac{\text{Total Power Required Per Day} \times \text{Safety Of Factor}}{\text{Inverter Efficiency}}$$

$$\text{Required Inverter Power} = \frac{11000 \times 1.25}{0.95} = 15 \text{KW}$$

which means 15KW 24V inverter is required.

CHAPTER FIVE

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Cost Analysis

The total number of solar panels, wind turbines, batteries employed will determine the overall anticipated price of the solar-wind hybrid energy system. Consequently, the following is the total price:

Total price = (No. of Wind Turbine \times price of single Wind Turbine) + (No. of Solar Panels \times price of single Solar Panel) + (No. of Batteries used in Battery Bank \times price of single Battery) + (Price of Inverter)

$$TP = (NT \times PWT) + (NP \times PSP) + (NB \times PB) + (PI)$$

Where,

Total Price (TP) is expressed in Naira.

The price in Naira of a single wind turbine is known as the PWT.

PSP is the price of single solar panel in Naira

PB is the price of single Battery in Naira

PI is the price of inverter in Naira

NT is the number of wind turbine used

NP is the number of solar panels used

NB is the number of Batteries used in Battery Bank

Solar-wind hybrid energy systems require only an initial investment but can compete effectively with conventional energy sources when considering the reduced or avoided utility costs over their lifetime. The overall cost of such a system depends on several factors, including the specific system chosen, the wind resource available at the site, electricity costs in the area, and the capacity of the battery bank required. To minimize the cost of a Wind-Solar Hybrid system, it is essential to increase the utilization of non-conventional energy sources. This approach will boost the production of both solar and wind power, ultimately leading to a reduction in the overall system cost.

Overall Discussion

Hybrid power generation systems represent an excellent and efficient solution for power generation, surpassing conventional energy resources. These systems boast higher efficiency and the ability to provide electricity to remote areas inaccessible to government infrastructure. By generating power where it's needed, they reduce transmission losses and associated costs. Cost-effectiveness can further be enhanced by scaling up equipment production. Encouraging people to adopt non-conventional energy resources is paramount. Moreover, hybrid systems are environmentally friendly, producing no emissions or harmful waste products typical of conventional energy sources. They stand as a cost-effective solution with minimal initial investment requirements and an extended lifespan. In summary, they present a dependable, sustainable, and affordable approach to electricity generation.

5.2 LIMITATIONS

1. The initial investment is very high
2. Due to variation in wind speed, wind turbine can not operate with full efficiency in these areas.
3. More space required to install entire system

5.3 RECOMMENDATIONS

Larger rotor radius (blades) allow wind turbines to sweep more area, capture more wind, and create more power, increasing efficiency. Even in locations with little wind, a turbine with longer blades will be able to capture more of the available wind than one with shorter blade.

REFERENCES

1. Ashish S. Ingole*, Prof. Bhushan S. Rakhonde, “Hybrid Power Generation System Using Wind Energy and Solar Energy” International Journal of Scientific and Research Publications, Volume 5, Issue 3, March 2015.
2. Karim Mousa¹, Hamzah AlZu’bi², Ali Diabat³, “Design of a Hybrid Solar-Wind Power Plant Using Optimization”
3. Medugu, D. W. & Michael, E., “Integrated Solar – Wind Hybrid Power Generating System for Residential Application”, Global Journal of Researches in Engineering: F Electrical and Electronics Engineering, Volume 14 Issue 4 Version 1.0 Year 2014.
4. Rashid Al Badwawi, Mohammad Abusara & Tapas Mallick, “A Review of Hybrid Solar PV and Wind Energy System”, Smart Science Vol. 3, No. 3, pp. 127-138(2015).
5. Rashid Al Badwawi^{1,*}, Mohammad Abusara¹ and Tapas Mallick¹, “A Review of Hybrid Solar PV and Wind Energy System”, Smart Science Vol. 3, No. 3, pp. 127-138(2015).
6. R. Chedid, “A DECISION SUPPORT TECHNIQUE FOR THE DESIGN OF HYBRID SOLAR-WIND POWER SYSTEM”, IEEE Transactions on Energy Conversion, Vol. 13, No. 1, March 1998.
7. Sandeep Kumar¹, Vijay Kumar Garg², “A HYBRID MODEL OF SOLAR-WIND POWER GENERATION SYSTEM”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 8, August 2013.
8. Vaibhav J. Babrekar, Shraddha D. Bandawar, Ashwini R. Behade, “Review Paper on Hybrid Solar-Wind Power Generator”, International Journal of Computer Applications (0975 – 8887) Volume 165 – No.5, May 2017

9. Chandragupta Mauryan.K.S, Nivethitha.T, Yazhini.B, Preethi.B, “Study on Integration of Wind and Solar Energy to Power Grid”, Nivethitha.T et al Int. Journal of Engineering Research and Application, Vol. 4, Issue 5(Version 1), May 2014.
10. V. K. Gajbhiye¹, Prof. A. A. Kanaskar², Prof. S. S. Jawre, “Solar Wind Hybrid System- A Review”, International Journal of Research in Advent Technology, Vol.5, No.5, May 2017.
11. Energy consumption of domestic appliances (2020) Ikeja Electric. Available at: <https://www.ikejaelectric.com/energy-consumption-domestic-appliances/> (Accessed: 12 September 2023).
12. Yousef et al. (2022) Types of solar panels: Types, working, application with (PDF), The Engineers Post. Available at: <https://www.theengineerspost.com/solar-panel-types/> (Accessed: 12 September 2023).
13. U.S. Energy Information Administration - EIA - independent statistics and analysis (no date) Types of wind - U.S. Energy Information Administration (EIA). Available at: <https://www.eia.gov/energyexplained/wind/types-of-wind-turbines.php> (Accessed: 12 September 2023).
14. Distributed generation in the energy industry (2023) WTS Energy. Available at: <https://www.wtsenergy.com/glossary/distributed-generation/> (Accessed: 12 September 2023).
15. Agbossou, K., Kolhe, M., Hamelin, J., & Bose, T. K. (2004). Performance of a stand-alone renewable energy system based on energy storage as hydrogen. IEEE Transactions on energy Conversion, 19(3), 633-640.
16. Bartolucci, L., Cordiner, S., Mulone, V., Rocco, V., & Rossi, J. L. (2018). Hybrid renewable energy systems for renewable integration in microgrids: Influence of sizing on performance. Energy, 152, 744-758.

17. Mustapa, S. I., Leong Yow, P., & Hashim, A. H. (2010, 2-4 June 2010). Issues and challenges of renewable energy development: A Malaysian experience. Paper presented at the Proceedings of the International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010)
18. Negi, S., & Mathew, L. (2014). Hybrid renewable energy system: a review. *International Journal of Electronic and Electrical Engineering*, 7(5), 535-542
19. Sen, S., & Ganguly, S. (2017). Opportunities, barriers and issues with renewable energy development–A discussion. *Renewable and Sustainable Energy Reviews*, 69, 1170-1181
20. Valente, L. C. G., & de Almeida, S. C. A. b. (1998). Economic analysis of a diesel/photovoltaic hybrid system for decentralized power generation in northern Brazil. *Energy*, 23(4), 317-323.
21. Gipe, P., *Wind Energy Comes of Age* , John Wiley & Sons, 1995
22. Vikaspedia domainsVikaspedia. Available at: <https://vikaspedia.in/energy/energy-basics/sources-of-energy> (Accessed: 12 September 2023).
23. Kavita Sharma, Prateek Haksar “Designing of Hybrid Power Generation System using Wind Energy- Photovoltaic Solar Energy- Solar Energy with Nanoantenna” *International Journal of Engineering Research And Applications (IJERA)* Vol. 2, Issue 1,Jan-Feb 2012, pp.812-815 .
24. Sandeep Kumar, Vijay Kumar Garg, “A Hybrid model of Solar-Wind Power Generation System”, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)*, Vol. 2, Issue 8, August 2013, pp. 4107-4016.