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Sonargaon University (SU)
সোনারগাঁও ইউনিভার্সিটি (এসইউ)

Fabrication and Performance Analysis of Hybrid Renewable Energy System (Solar-Wind-Battery) for Rural Electrification

A Thesis

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May, 2026

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SUBMITTED TO THE:
Department of Mechanical Engineering
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In partial fulfillment of the requirement for the award of the degree
Of
Bachelor of Science in Mechanical Engineering

May, 2026

APPROVAL

This is to certify that the project “**Fabrication and Performance Analysis of Hybrid Renewable Energy System (Solar-Wind-Battery) for Rural Electrification**”, By MD.Mahamudul Hasan(ID: ME 2102024334), MD. Sojib Hossen(ID: ME 2201026050), Md Tarikul Islam (ID: ME 2203028336), Md Nadim Hasan Opy (ID: ME 2203028324), Saiful Islam (ID: ME 2203028287) has been carried out under my supervision. The project has been carried out in partical fulfillment of the requirements of the degree of Bachelor of Science (B.Sc.) in Mechanical Engineering of years of 2026 and has been approved as to its style and contents.

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LETTER OF TRANSMITTAL

17 May 2026

To

Ibrahim Khalil Apurba

Department of Mechanical Engineering.

Sonargaon University

Subject: Submission of Project Report.

Dear Sir,

We are pleased to submit the project report on “**Fabrication and Performance Analysis of Hybrid Renewable Energy System (Solar-Wind-Battery) for Rural Electrification** ”. It was a great pleasure to work on such an important topic. This project has been done as per instruction of your supervision and according to the requirements of the Sonargaon University.

We expect that the project will be accepted by the concerned authority we will remain happy to further explanation that you may feel necessary in this regard.

Thank You Sincerely yours,

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DECLARATION

We do hereby solemnly declare that, the work presented here in this project report has been carried out by us and has not been previously submitted to any University/ Organization for award of any degree or certificate

We hereby ensure that the works that has been prevented here does not breach any existing copyright.

We further undertake to indemnify the university against any loss or damage arising from breach of the foregoing obligation.

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ABSTRACT

The increasing demand for electrical energy and the depletion of fossil fuel resources have accelerated the development of renewable energy-based hybrid systems for rural electrification. This project presents the fabrication and performance analysis of a hybrid renewable energy system integrating a 40W solar panel, a vertical axis wind turbine (VAWT), and a 12V, 9Ah battery storage system with IoT-based real-time monitoring. The system was developed using an ESP32 microcontroller, voltage and current sensors, LCD display, and ThingSpeak cloud platform for remote monitoring and data collection. Experimental analysis showed that the solar panel generated an average output power of approximately 24.98W, while the wind turbine produced an average output of 2.53W under available wind conditions, resulting in a combined hybrid output of approximately 27.51W. The battery provided backup support for low-power DC loads and demonstrated stable charging characteristics during hybrid operation. Compared to conventional single-source renewable systems, the proposed hybrid system improved energy reliability and ensured continuous energy availability by combining both solar and wind energy sources. Real-time IoT monitoring enabled continuous observation of voltage, current, and power parameters, improving system analysis and operational efficiency. The proposed system provides a low-cost, environmentally friendly, and portable renewable energy solution suitable for small-scale rural electrification and educational research applications.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Electricity is one of the most important requirements for modern human civilization. It is essential for residential, industrial, agricultural, educational, and healthcare activities. However, many rural and remote areas still suffer from inadequate electricity supply due to the absence of national grid connections, high installation costs, and the shortage of conventional energy resources. As a result, renewable energy technologies are becoming increasingly popular for sustainable and reliable rural electrification.

Renewable energy sources such as solar energy and wind energy are clean, environmentally friendly, and naturally available. Solar energy is produced from sunlight using photovoltaic (PV) panels, while wind energy is generated through wind turbines. Individually, these energy sources are not always reliable because their availability depends on weather conditions. Solar power generation decreases during cloudy weather or nighttime, and wind power generation varies with wind speed. Therefore, combining multiple renewable energy sources in a hybrid system can improve system reliability and energy availability.

This project focuses on the fabrication and performance analysis of a hybrid renewable energy system that integrates solar energy, wind energy, and battery storage for rural electrification. The generated energy from the solar panel and wind turbine is used to charge a 12V battery through a solar charge controller. The stored energy can supply electrical loads when renewable generation is low.

An ESP32 microcontroller is used for monitoring system parameters such as voltage, current, and power generation. Voltage and current sensors collect real-time data from both solar and wind sources. The measured data is displayed on an LCD with I2C module and uploaded to the ThingSpeak IoT platform for remote monitoring and analysis.

The main objective of this project is to develop an efficient, low-cost, and eco-friendly hybrid energy solution suitable for rural areas. The system ensures continuous power availability, improves renewable energy utilization, and reduces dependency on fossil fuels, thereby contributing to sustainable development and environmental protection.

1.2 Proposed Method / System

The proposed system is a hybrid renewable energy system that combines solar energy, wind energy, and battery storage for efficient rural electrification. The system is designed to provide continuous and reliable electrical power by integrating multiple renewable energy sources. Solar panels convert sunlight into electrical energy, while a wind turbine generates electricity from wind energy. Both energy sources are connected to a solar charge controller that regulates charging and protects the battery from overcharging and deep discharge.

A 12V sealed lead-acid battery is used to store the generated electrical energy. The stored energy supplies power to rural electrical loads when solar radiation or wind speed becomes insufficient. The hybrid configuration improves system reliability because power can still be generated even if one energy source becomes unavailable.

An ESP32 microcontroller is used as the main control and monitoring unit of the system. Voltage sensors and current sensors measure the electrical parameters of both solar and wind systems. The collected data is processed by the ESP32 to calculate voltage, current, and generated power. A 16×2 LCD with I2C module displays real-time system information locally.

For remote monitoring and performance analysis, the ESP32 uploads data to the ThingSpeak IoT platform using WiFi communication. The proposed system is low-cost, environmentally friendly, energy-efficient, and highly suitable for rural electrification applications.

1.3 Objectives

- To construct a portable Solar-Wind hybrid system.
- To implement IoT-based real time monitoring system.
- To perform analysis for rural electrification.

1.4 Organization of book

This book is structured to provide a comprehensive understanding of the study and construction of a purified water cooling and heating system using Peltier modules. It is organized into the following chapters:

- **Chapter 1: Introduction** – Covers the background, objectives, and scope of the project.
- **Chapter 2: Literature Review** – Discusses existing water purification and thermoelectric temperature control technologies.
- **Chapter 3: System Design** – Details the components, design specifications, and working principles of the proposed system.
- **Chapter 4: Implementation and Construction** – Describes the step-by-step process of building the system, including materials used.
- **Chapter 5: Experimental Results and Discussion** – Presents test results, performance analysis, and system efficiency.
- **Chapter 6: Conclusion and Future Work** – Summarizes findings and suggests improvements for further research.

Each chapter builds upon the previous one, ensuring a logical flow of information that aids in understanding the principles, design, and execution of the project. This organization ensures clarity and provides a structured approach to comprehensively studying the system's development and application.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The rapid growth of energy demand and the depletion of conventional fossil fuel resources have increased the importance of renewable energy systems worldwide. Rural areas in many developing countries still face major challenges in obtaining reliable and affordable electricity. To overcome this problem, researchers and engineers have focused on renewable energy technologies such as solar and wind power for sustainable rural electrification.

Solar energy systems convert sunlight into electrical energy using photovoltaic (PV) panels. These systems are environmentally friendly, noiseless, and easy to install. However, solar power generation depends heavily on sunlight availability and becomes unavailable during nighttime or cloudy weather conditions. Similarly, wind energy systems generate electricity using wind turbines, but their performance depends on wind speed and environmental conditions.

Previous studies show that standalone renewable systems often suffer from instability due to the intermittent nature of renewable resources. To solve this issue, hybrid renewable energy systems combining solar and wind energy with battery storage have been developed. Hybrid systems provide better reliability, improved efficiency, and continuous power generation compared to single-source systems.

Recent research has also integrated Internet of Things (IoT) technologies for real-time monitoring and performance analysis of renewable energy systems. Microcontrollers such as ESP32 are widely used because of their built-in WiFi capability, low power consumption, and low cost. IoT platforms like ThingSpeak allow remote monitoring of voltage, current, and power generation data.

This project is based on these modern renewable energies and IoT technologies to develop an efficient hybrid energy solution for rural electrification.

2.2 Literature Review

Renewable energy systems have become one of the most significant research areas in modern electrical and energy engineering due to the continuously increasing global demand for electricity, depletion of fossil fuel resources, and rising environmental concerns such as

greenhouse gas emissions and climate change. According to Duffie and Beckman [1] and Goswami et al. [9], solar photovoltaic (PV) systems are among the most widely used renewable energy technologies because they directly convert solar radiation into electrical energy using semiconductor materials, offering clean, silent operation and low maintenance requirements. Singh [3] further explains that PV systems are highly suitable for both small and large-scale applications; however, their performance is highly dependent on solar irradiance, atmospheric conditions, and diurnal variations, which significantly reduce their reliability during cloudy weather and at night. Similarly, wind energy systems are another important renewable source where wind turbines convert kinetic energy of wind into electrical power. Khan [2] highlights that wind energy is an essential non-conventional energy resource that supports sustainable development, but its intermittent nature due to continuous variations in wind speed limits its ability to provide stable and consistent power output under all operating conditions.

To address the limitations of standalone renewable energy systems, researchers have extensively studied hybrid renewable energy systems that combine multiple energy sources such as solar and wind along with energy storage units. Dincer and Rosen [8] emphasize that energy storage systems play a crucial role in maintaining energy balance by storing excess energy during high generation periods and supplying power during low generation or demand peaks, thereby improving system reliability and stability. The International Energy Agency (IEA) [15] also reports that hybrid renewable energy systems are highly effective for rural electrification, remote areas, and off-grid applications due to their ability to provide continuous and more reliable power supply compared to single-source systems. Furthermore, Wadhwa [4] discusses the challenges of integrating renewable energy sources into conventional power systems, particularly issues related to stability, load balancing, and system design. Studies such as the U.S. Department of Energy guidelines [12], heat transfer performance in copper tubing systems [14], and low-cost solar water heater development research [16] indicate that proper system design, efficient material selection, and cost-effective implementation strategies significantly enhance overall system performance, efficiency, and affordability, especially in developing regions.

In recent years, the integration of smart monitoring, automation, and IoT-based technologies into renewable energy systems has gained significant attention. IoT platforms such as ThingSpeak [6] enable real-time data acquisition, cloud storage, visualization, and remote monitoring of system performance parameters, making energy systems more intelligent and

manageable. Research on IoT-based smart energy monitoring systems [11] demonstrates that real-time monitoring improves system efficiency, enhances fault detection capability, and supports predictive maintenance strategies. Embedded systems based on ESP32 microcontrollers [5], [19] are widely used in such applications due to their low cost, built-in Wi-Fi connectivity, multiple analog/digital input capabilities, and suitability for sensor interfacing in real-time environments. Arduino-based development platforms [7] are also commonly used for rapid prototyping and system implementation in embedded applications. Additionally, sensor technologies [17] play a critical role in measuring key electrical and environmental parameters such as voltage, current, power, and temperature, which are essential for performance evaluation and system optimization. Power electronics design principles discussed by Billings and Morey [18], along with microcontroller-based system design approaches [13], further contribute to efficient energy conversion, regulation, and automated control of hybrid renewable energy systems.

Based on the reviewed literature, it is evident that although significant advancements have been made in renewable energy technologies and IoT-based monitoring systems, there still exists a gap in developing low-cost, efficient, and fully integrated hybrid systems suitable for rural electrification in developing countries. Therefore, integrating solar and wind energy sources with battery storage and ESP32-based IoT monitoring provides a practical and effective solution to achieve improved energy reliability, real-time monitoring capability, and overall system efficiency for sustainable energy applications

2.3 Summary

Hybrid renewable energy systems combining solar and wind power with battery storage provide a reliable solution for rural electrification. Previous studies show improved efficiency, stability, and sustainability using IoT-based monitoring and control systems like ESP32 for real-time energy performance analysis.

CHAPTER 3

HARDWARE ANALYSIS

3.1 Required Components

Table 1: Required Components

S/L	Component	Quantity
1	ESP-32 Microcontroller	1
2	Battery 12V	1
3	Current Sensor	2
4	Voltage Sensor	2
5	LCD (16x2) With I2C	1
6	Connecting Wires	Multiple
7	Buck Converter	1
8	Breadboard/PCB	1
9	Solar Charge Controller	1
9	Resistors and Capacitors	As needed
10	Switches/Connectors	As needed

3.2 ESP-32 Microcontroller

The ESP32 is a powerful and low-cost microcontroller developed by Espressif Systems for embedded systems and Internet of Things (IoT) applications. It is widely used in modern electronic and renewable energy projects because of its built-in WiFi and Bluetooth communication features, high processing speed, and low power consumption.

In this project, the ESP32 acts as the main control and monitoring unit of the hybrid renewable energy system. It collects real-time data from voltage and current sensors connected to the solar panel and wind turbine. The analog sensor signals are processed by the ESP32 to calculate voltage, current, and generated power. The processed data is then displayed on the LCD module and uploaded to the ThingSpeak IoT platform through WiFi communication.



Figure 3.1: ESP-32 Microcontroller

The ESP32 microcontroller contains a dual-core processor operating at up to 240 MHz, which provides fast and efficient data processing capability. It also includes multiple GPIO pins, analog-to-digital converter (ADC) channels, PWM outputs, serial communication interfaces, and low-power operating modes. These features make it suitable for sensor interfacing, automation, and remote monitoring systems.

One of the major advantages of the ESP32 is its integrated wireless communication capability, which eliminates the need for external WiFi modules. This reduces circuit complexity and system cost. The ESP32 supports programming through the Arduino IDE using Embedded C/C++ language, making it easy for students and researchers to develop IoT-based applications.

Due to its compact size, high performance, reliability, and low power consumption, the ESP32 is an ideal microcontroller for renewable energy monitoring and smart rural electrification systems.

3.3 Battery 12V

The 12V 9Ah battery is an important component of the hybrid renewable energy system. It is used to store electrical energy generated from the solar panel and wind turbine for later use. In this project, the battery acts as an energy storage device and provides backup power when renewable energy generation becomes insufficient due to low sunlight or low wind conditions.



Figure 3.2: Battery 12V

A 12V 9Ah sealed lead-acid (SLA) rechargeable battery is commonly used because of its low cost, simple maintenance, reliability, and easy availability. The battery stores direct current (DC) electrical energy produced by the renewable sources through the charge controller. The stored energy can then be supplied to electrical loads whenever required.

The battery capacity is measured in ampere-hour (Ah). A 9Ah battery means it can theoretically supply 9 amperes of current for one hour or smaller currents for longer durations. The battery output voltage is 12 volts DC, which is suitable for small renewable energy systems, lighting systems, and low-power rural electrical applications.

In this project, the battery is charged using both solar and wind energy through a charge controller. The charge controller protects the battery from overcharging, deep discharge, and reverse current flow, which helps increase battery life and improve system safety. The ESP32 microcontroller monitors the battery charging condition and controls the load automatically.

The battery plays a significant role in maintaining continuous power supply and improving system stability. During daytime or high wind conditions, excess energy is stored in the battery. During nighttime or low energy generation periods, the stored energy supplies electrical power to the load.

Therefore, the 12V 9Ah battery improves the reliability, efficiency, and uninterrupted operation of the hybrid renewable energy system for rural electrification.

3.4 Solar Charge Controller

The solar charge controller is an essential component of the hybrid renewable energy system. It is used to regulate and control the charging process of the battery from the solar panel and wind turbine. The main function of the charge controller is to protect the battery from overcharging, deep discharging, and reverse current flow, thereby improving battery life and system safety.



Figure 3.3: Solar Charge Controller

In this project, the solar charge controller manages the electrical energy generated from the renewable energy sources and safely transfers it to the 12V battery. When the solar panel and wind turbine produce electrical energy, the charge controller ensures that the battery receives the correct charging voltage and current. It prevents excessive voltage or current from damaging the battery.

The charge controller also disconnects the load automatically when the battery voltage becomes too low. This protection mechanism prevents deep discharge, which can reduce battery efficiency and lifespan. Similarly, when the battery becomes fully charged, the controller limits or stops charging to avoid overheating and overcharging.

There are mainly two types of solar charge controllers: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking). PWM controllers are simple and low-cost, while MPPT controllers provide higher efficiency by extracting maximum power from the solar panel. In this project, a standard 12V solar charge controller is used for safe and stable battery charging.

The solar charge controller improves the overall efficiency and reliability of the hybrid renewable energy system. It maintains stable power flow between the renewable sources, battery, and electrical load. The controller also ensures safe operation under varying environmental conditions.

Therefore, the solar charge controller plays a vital role in energy management, battery protection, and uninterrupted power supply for rural electrification applications.

3.5 Current Sensor

A current sensor is an essential component in this solar power management system, used to measure the flow of electric current from the solar panel to the load and battery. In this project, the ACS712 Current Sensor Module is utilized due to its accuracy, compact size, and ease of integration with microcontrollers like the Arduino UNO. This sensor operates based on the Hall Effect principle, which detects the magnetic field generated by the current flowing through a conductor and converts it into a proportional voltage output.

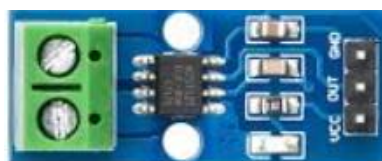


Figure 3.4: Current Sensor

The ACS712 module can measure both AC and DC current, making it suitable for hybrid systems. It provides an analog output voltage centered around 2.5V when no current flows. As current increases in either direction, the output voltage deviates proportionally above or below this midpoint. The Arduino reads this analog signal through its ADC (Analog-to-Digital Converter) and calculates the actual current using calibration factors such as sensitivity and offset voltage.

In this system, the current sensor is connected in series with the load or power source, allowing real-time monitoring of energy consumption. This information is crucial for system efficiency, as it helps determine power usage, detect overload conditions, and protect components from damage. Additionally, the measured current is displayed on the LCD, enabling users to monitor system performance easily.

Overall, the current sensor enhances the reliability and safety of the solar power system by providing continuous feedback. It plays a vital role in energy management, ensuring optimal utilization of solar energy and preventing excessive current flow that could harm the system.

3.6 Voltage Sensor

A voltage sensor is a crucial component in this solar power management system, used to measure the electrical potential difference of both the solar panel and the battery. In this project, a DC Voltage Sensor Module is employed due to its simplicity, affordability, and compatibility with the Arduino UNO. The module works on the principle of a voltage divider, which scales down higher voltages (up to 25V) into a safe range (0–5V) suitable for the Arduino's analog input pins.

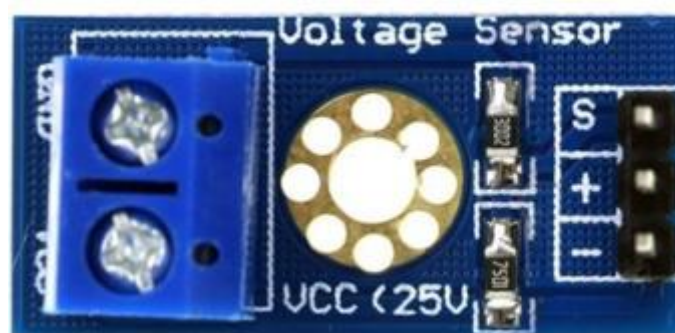


Figure 3.5: Voltage Sensor

The voltage sensor module typically consists of precision resistors that divide the input voltage proportionally. The reduced voltage is then fed into the Arduino's analog-to-digital converter

(ADC), which converts the analog signal into a digital value. Using a predefined calibration factor, the Arduino calculates the actual voltage of the solar panel and battery. This allows accurate monitoring of system conditions in real time.

In this system, two voltage sensors are used—one for the solar panel and another for the battery. Monitoring the solar voltage helps determine whether sufficient sunlight is available for power generation, while battery voltage measurement is essential for assessing the charge level and preventing overcharging or deep discharge. These readings are continuously displayed on the LCD for user awareness.

The voltage sensor plays a key role in decision-making within the system. Based on voltage levels, the Arduino controls relay switching between solar power, battery, and AC mains supply. This ensures efficient energy utilization and system protection. Overall, the voltage sensor enhances system performance, reliability, and safety by providing accurate voltage monitoring and enabling intelligent power management.

3.7 LCD (16x2) With I2C

The 16x2 LCD display with I2C module is a commonly used output device in embedded systems and Arduino-based projects for displaying real-time data in a simple and readable format. It can show 16 characters per line across 2 lines, making it suitable for displaying sensor readings, system status, and user messages in compact form.

The I2C LCD Display (16x2) is an enhanced version of the standard 16x2 LCD module, integrated with an I2C communication interface. This interface significantly reduces the number of required microcontroller pins from 6–8 pins to just 2 pins (SDA and SCL). As a result, it simplifies wiring complexity and allows easier integration with microcontrollers such as Arduino UNO, ESP32, and Raspberry Pi.

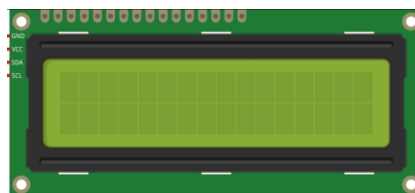


Figure 3.6: LCD (16x2) With I2C

This LCD typically operates at 5V and uses the HD44780 driver chipset, which is widely supported in embedded programming libraries. The I2C module is usually built using a

PCF8574 I/O expander, enabling serial communication between the microcontroller and display. The default I2C address can be modified in some modules, allowing multiple I2C devices to be used on the same bus.

In practical applications, the 16x2 I2C LCD is used to display sensor data such as temperature, humidity, gas levels, and system alerts in IoT-based monitoring systems. It improves user interaction by providing real-time feedback without requiring a computer or mobile interface. Another advantage of this module is its adjustable contrast and backlight control, which enhances visibility under different lighting conditions. Additionally, it supports custom character creation, allowing users to design symbols for specific project requirements. Overall, the 16x2 LCD with I2C interface is a reliable, efficient, and user-friendly display solution that simplifies hardware design while improving readability and system performance in embedded electronics projects.

3.8 Buck Converter

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while drawing less average current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor, or the two in combination.

To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter). It is called a buck converter because the voltage across the inductor “bucks” or opposes the supply voltage.

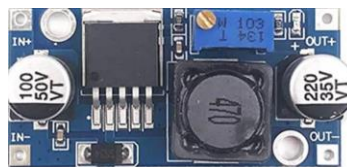


Figure 3.7: DC -DC Buck Converter

DC-DC Buck Converter Step Down Module LM2596 Power Supply is a step- down(buck) switching regulator, capable of driving a 3-A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3 V, 5 V, 12 V, and an adjustable output

version. The LM2596 series operates at a switching frequency of 150kHz, thus allowing smaller sized filter components than what would be required with lower frequency switching regulators.

Specifications of DC-DC Buck Converter Step Down Module LM2596 Power Supply:

- Conversion efficiency: 92%(highest)
- Switching frequency: 150KHz
- Output ripple: 30mA9maximum)
- Load Regulation: $\pm 0.5\%$
- Voltage Regulation: $\pm 0.5\%$
- Dynamic Response speed: 5% 200uS
- Input voltage:4.75-35V
- Output voltage:1.25-26V(Adjustable)
- Output current: Rated current is 2A, maximum 3A (Additional heat sink is required)
- Conversion Efficiency: Up to 92% (output voltage higher, the higher the efficiency)
- Switching Frequency: 150KHz
- Rectifier: Non-Synchronous Rectification
- Module Properties: Non-isolated step-down module (buck)
- Short Circuit Protection: Current limiting, since the recovery
- Operating Temperature: Industrial grade (-40 to +85) (output power 10W or less)

3.9 40-Watt Wind Turbine

A 40-watt wind turbine is a small-scale renewable energy generator used to convert wind energy into electrical power. In this project, the 40W Wind Turbine Generator can be integrated as an additional energy source alongside the solar panel, forming a hybrid renewable system. This turbine typically consists of rotor blades, a shaft, a generator, and a tail vane to align the turbine with wind direction.



Figure 3.8: 40-Watt Wind Turbine

The working principle of the wind turbine is based on the conversion of kinetic energy from moving air into mechanical energy, which then drives the generator to produce electrical energy. When wind flows over the blades, it creates a rotational motion due to aerodynamic lift. This rotation turns the generator shaft, producing DC voltage that can be used to charge a battery or supply power to a load.

A 40W wind turbine is particularly suitable for low-power applications such as lighting systems, small electronics, and backup charging. It performs best in areas with consistent wind speeds, typically above 3–5 m/s. In this system, the wind turbine can be connected to the battery through a charge controller to regulate voltage and prevent overcharging.

The inclusion of a wind turbine enhances system reliability by generating power even during nighttime or cloudy conditions when solar output is low. This ensures continuous energy availability and improves overall efficiency. Additionally, it reduces dependency on grid electricity and promotes sustainable energy usage.

Overall, the 40-watt wind turbine plays a significant role in hybrid renewable energy systems by providing an alternative and complementary power source, thereby increasing energy generation, system stability, and environmental sustainability.

CHAPTER 4

METHODOLOGY

4.1 Methodology

The methodology of this project involves the design, fabrication, implementation, and performance analysis of a hybrid renewable energy system using solar energy, wind energy, and battery storage for rural electrification. First, the required hardware components such as solar panel, wind turbine, battery, charge controller, ESP32 microcontroller, voltage sensors, current sensors, LCD display, and buck converter were selected based on system requirements. The solar panel and wind turbine were connected to the solar charge controller for controlled battery charging and protection. Voltage and current sensors were connected to the ESP32 to measure electrical parameters from both renewable sources. The ESP32 was programmed using Embedded C in the Arduino IDE for data acquisition, power calculation, LCD display, and IoT communication.

Real-time monitoring was achieved through the ThingSpeak platform using WiFi communication. Finally, system performance was analyzed by observing voltage, current, and power generation under different operating conditions.

4.2 Circuit Diagram

The circuit diagram of the hybrid renewable energy system represents the electrical connections among the solar panel, wind turbine, battery, charge controller, sensors, ESP32 microcontroller, LCD display, and buck converter. The circuit is designed to ensure proper power generation, energy storage, monitoring, and safe system operation.

In this project, the solar panel and wind turbine are connected to the solar charge controller. The charge controller regulates the charging process and safely transfers electrical energy to the 12V battery. It also protects the battery from overcharging, deep discharge, and reverse current flow. The battery acts as the main energy storage unit and supplies backup power to the system.

Voltage sensors and current sensors are connected to both the solar and wind energy sources to measure electrical parameters such as voltage and current. The output signals from these sensors are connected to the analog input pins of the ESP32 microcontroller. The ESP32 processes the sensor data and calculates the generated power from both renewable energy sources.

A buck converter is connected between the battery and the ESP32 to step down the battery voltage to a stable operating voltage suitable for the microcontroller and other electronic components. A 16×2 LCD with I2C module is connected to the ESP32 through SDA and SCL communication pins for displaying real-time system information.

The ESP32 also communicates with the ThingSpeak server using WiFi for remote monitoring and performance analysis. The complete circuit diagram ensures proper integration of all components for efficient operation of the hybrid renewable energy system.

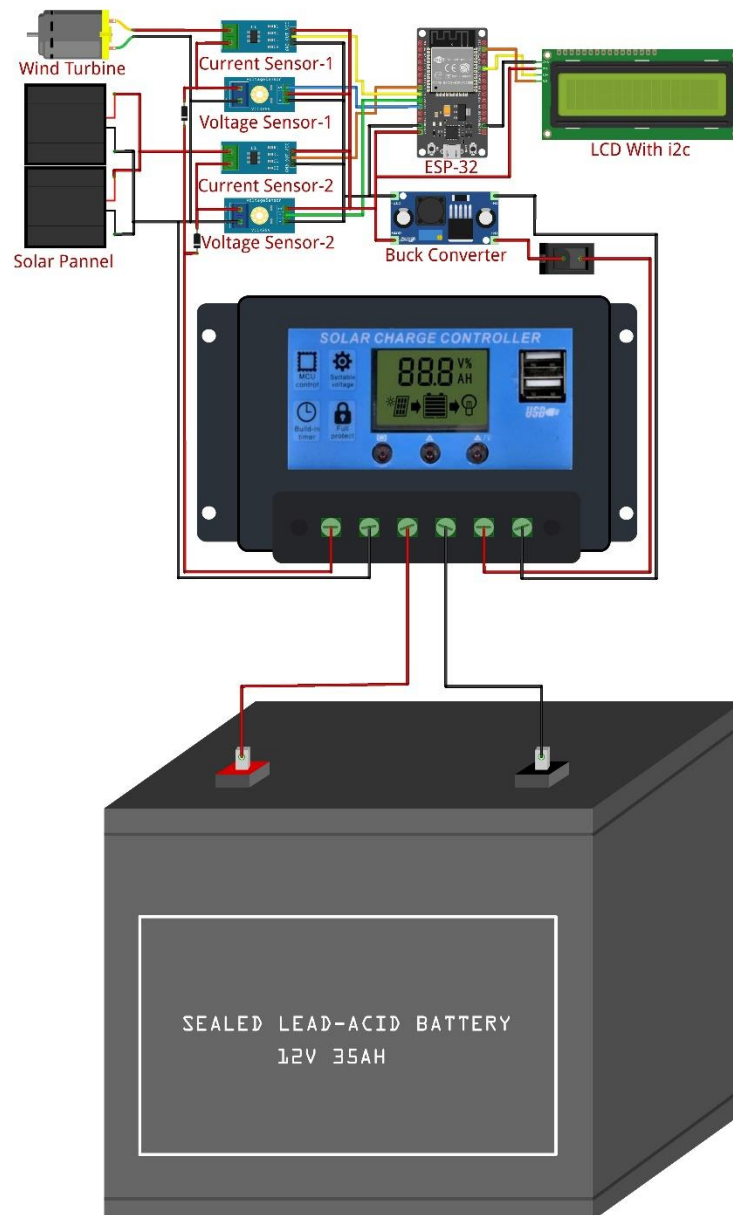


Figure 4.1: Circuit Diagram

4.3 Block Diagram

The block diagram of the hybrid renewable energy system provides a simplified representation of the overall system structure and functional relationships among different components. It helps to understand the flow of energy and information within the system.

In this project, the main energy sources are the solar panel and wind turbine. The solar panel converts sunlight into electrical energy, while the wind turbine converts wind energy into electrical power. Both renewable energy sources are connected to the solar charge controller. The charge controller regulates the charging process and safely stores the generated energy in the 12V battery. It also protects the battery from overcharging and deep discharge.

The battery acts as the energy storage unit of the system. The stored electrical energy can be used when solar or wind energy generation becomes low. A buck converter is connected to the battery to provide a stable and regulated voltage supply for the ESP32 microcontroller and other electronic components.

Voltage sensors and current sensors are connected to the solar and wind energy systems to measure voltage and current values. These sensors send analog signals to the ESP32 microcontroller. The ESP32 processes the collected data and calculates generated power and other electrical parameters.

A 16×2 LCD with I2C module is connected to the ESP32 for displaying real-time voltage, current, and power information. The ESP32 also uploads monitoring data to the ThingSpeak through WiFi communication for remote monitoring and performance analysis.

The block diagram clearly illustrates the energy generation, storage, monitoring, and IoT communication process of the hybrid renewable energy system.

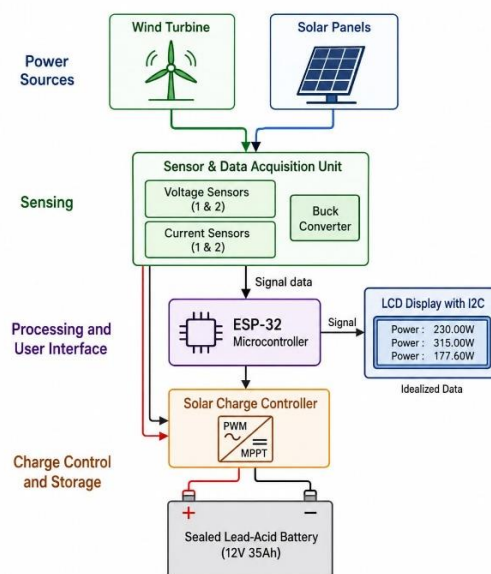


Figure 4.2: Block Diagram

4.4 Complete Project Prototype Image:



Figure 4.3: Complete Project Picture (Front View)



Figure 4.4: Complete Project Picture (Side View)

4.5 Working Principle

The working principle of the hybrid renewable energy system is based on the combined generation, storage, monitoring, and utilization of electrical energy from solar and wind sources. The system is designed to provide continuous and reliable electrical power for rural electrification.

The solar panel converts sunlight into direct current (DC) electrical energy through the photovoltaic effect. At the same time, the wind turbine converts wind energy into electrical energy using a DC generator. Both renewable energy sources are connected to the solar charge controller, which regulates the charging process and safely transfers electrical energy to the 12V battery.

The charge controller protects the battery from overcharging, deep discharge, and reverse current flow. During daytime or high wind conditions, excess generated energy is stored in the battery for future use. The stored energy can supply power during nighttime or low renewable energy generation periods.

Voltage sensors and current sensors continuously measure the electrical parameters of both solar and wind systems. These sensor outputs are connected to the ESP32 microcontroller. The ESP32 reads the analog sensor data, calculates voltage, current, and generated power, and processes the information in real time.

A buck converter is used to provide a stable operating voltage to the ESP32 and other electronic components. The calculated system parameters are displayed on the 16×2 LCD with I2C module for local monitoring. Simultaneously, the ESP32 uploads the data to the ThingSpeak through WiFi communication for remote monitoring and performance analysis.

Thus, the hybrid system ensures efficient energy generation, storage, monitoring, and uninterrupted power supply for rural electrification.

4.6 Cost Analysis:

Table 2: Cost Analysis.

No	Product Name	Specification	Qty	Unit Price	Total Price	Market Price	
01.	Microcontroller	ESP-32	1	550	550		
02.	Battery	12V	1	2000	2000		
03.	Voltage Sensor	ZMPT101B	2	220	440		
04	Current Sensor	ACS712	2	230	460		
04.	LCD (16x2) With I2C		1	500	500		
05.	Buck Converter	LM2596	1	120	240		
06.	Wind Turbine	40 Watt	1	3000	3000		
10.	Others				1500		
Total =					8500/=		12,000/=

CHAPTER 5

RESULT AND DISCUSSION

5.1 Data Analysis

Table 3: Data analysis

Interval	Solar Voltage (V)	Solar Current (A)	Wind Voltage (V)	Wind Current (A)	Solar Power (W)	Wind Power (W)	Total Hybrid Power (W)
10.00 am	17.0	1.21	1.50	1.36	20.57	2.04	22.61
10.30 am	16.73	1.46	2.70	2.62	24.43	7.07	31.50
11.00 am	16.97	2.74	0	0	46.50	0.0	46.50
11.30 am	17.0	2.66	1.50	1.36	45.22	2.04	47.26
12.00 am	16.71	2.34	2.51	2.39	39.10	6.00	45.10
12.30 am	16.91	2.32	2.39	2.37	39.23	5.66	44.89
01.00 pm	17.0	2.18	4.3	2.22	37.06	9.55	46.61
01.30 pm	16.79	1.46	3.38	1.5	24.51	5.07	29.58
02.00 pm	14.0	0.73	2.87	0.73	10.22	2.10	12.32
03.00 pm	13.66	0.82	2.47	0.84	11.20	2.07	13.27
04.00 pm	11.52	0.47	3.27	0.51	5.41	1.67	7.08
05.00 pm	12.06	0.96	0.55	0.93	11.58	0.51	12.09

Here is the Calculation,

1.Solar:

Average Solar Voltage (V_S)

$$= \frac{17.0 + 16.73 + 16.97 + 17.0 + 16.71 + 16.91 + 17 + 16.79 + 14.0 + 13.66 + 11.52 + 12.06}{12}$$

$$\therefore V_S = 15.52W$$

Average Solar Current (I_S)

$$= \frac{1.21 + 1.46 + 2.74 + 2.66 + 2.34 + 2.32 + 2.18 + 1.46 + 0.73 + 0.82 + 0.47 + 0.96}{12}$$

$$\therefore I_S = 1.61A$$

$$\text{Solar Power } P_S = V_S \times I_S = 15.52 \times 1.61$$

$$\therefore P_S = 24.98W$$

Therefore, the average solar panel output generated from the collected experimental data was approximately 24.98 W.

2.Wind Turbine:

Average Wind Voltage (V_W)

$$= \frac{1.50 + 2.70 + 0 + 1.50 + 2.51 + 2.39 + 4.3 + 3.38 + 2.87 + 2.47 + 3.27 + 0.55}{12}$$

$$\therefore V_W = 2.28W$$

Average Wind Current (I_W)

$$= \frac{1.36 + 2.62 + 0 + 1.36 + 2.39 + 2.37 + 2.22 + 1.5 + 0.73 + 0.84 + 0.51 + 0.93}{12}$$

$$\therefore I_W = 1.40A$$

$$\text{Wind Power } P_W = V_W \times I_W = 2.28 \times 1.40$$

$$\therefore P_W = 3.19W$$

Therefore, the average wind turbine output generated from the collected experimental data was approximately 3.19 W.

3.Total Hybrid Power Generation:

$$P(\text{total}) = P(\text{solar}) + P(\text{wind})$$

$$= 24.98 + 3.19$$

$$\therefore P(\text{total}) = 28.17 W$$

The combined hybrid renewable energy system successfully produced an average total power of approximately 28.17 W.

4. Battery Capacity and Backup Analysis:

Battery Specification = 12V, 9Ah

Formula:

$$\text{Battery Energy} = \text{Voltage} \times \text{Ampere} \times \text{hour}$$

$$\text{Battery Energy} = 12 \times 9$$

$$\text{Battery Energy} = 108 \text{ Wh}$$

$$\text{Assuming Load} = 20\text{W}$$

$$\begin{aligned}\text{Backup Time} &= \frac{\text{Battery Energy}}{\text{Load}} \\ &= \frac{108}{20}\end{aligned}$$

$$\therefore \text{Backup Time} = 5.4 \text{ hours}$$

Therefore, the battery can provide backup power for approximately 5.4 hours.

5. Efficiency Analysis:

$$\text{Solar Efficiency} = \left(\frac{\text{Actual Output}}{\text{Rated Output}} \right) \times 100$$

$$\text{Solar Efficiency} = \left(\frac{24.98}{40} \right) \times 100$$

$$\text{Solar Efficiency} = 62.45\%$$

$$\text{Wind Efficiency} = \left(\frac{3.19}{40} \right) \times 100$$

$$\text{Wind Efficiency} = 7.97\%$$

6. Daily Energy Production:

Assumptions:

$$\text{Solar operation time} = 8 \text{ hours/day}$$

$$\text{Wind operation time} = 5 \text{ hours/day}$$

$$\text{Daily Solar Energy} = 24.98 \times 8 = 199.84 \text{ Wh/day}$$

$$\text{Daily Wind Energy} = 3.19 \times 5 = 15.95 \text{ Wh/day [Let]}$$

$$\text{Total Daily Energy} = 199.84 + 12.65 = 215.93 \text{ Wh/day}$$

Therefore, the hybrid system can produce approximately 215.93 Wh of electrical energy per day.

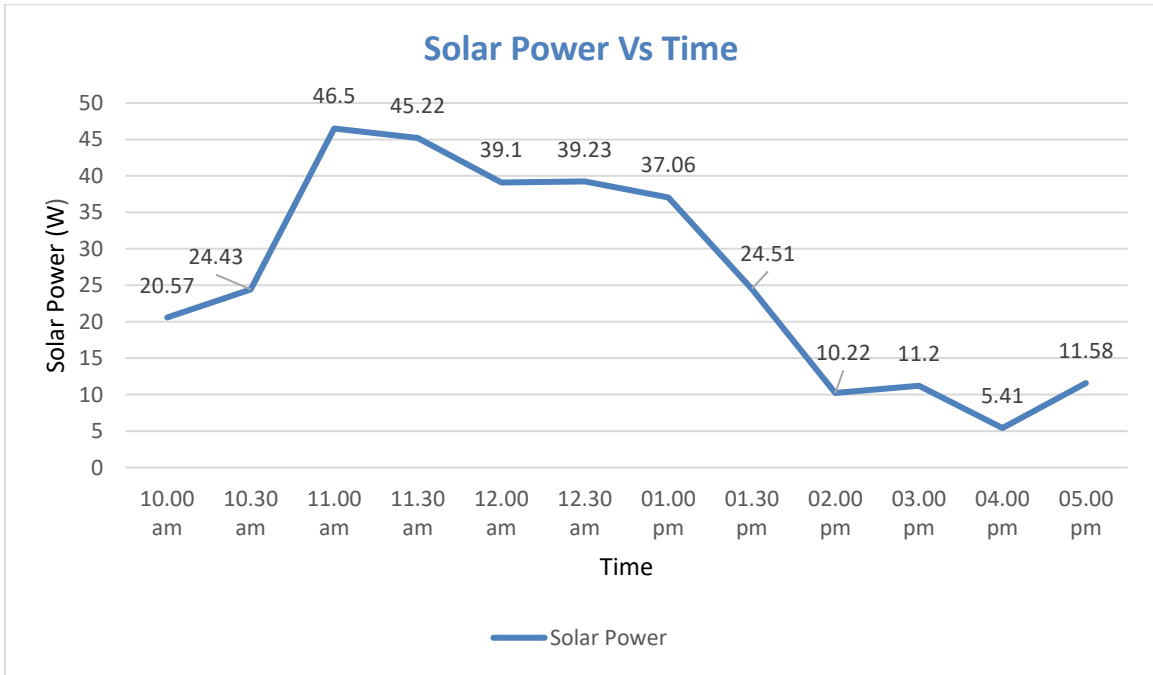


Figure 5.1: Solar Power Vs Time Graph

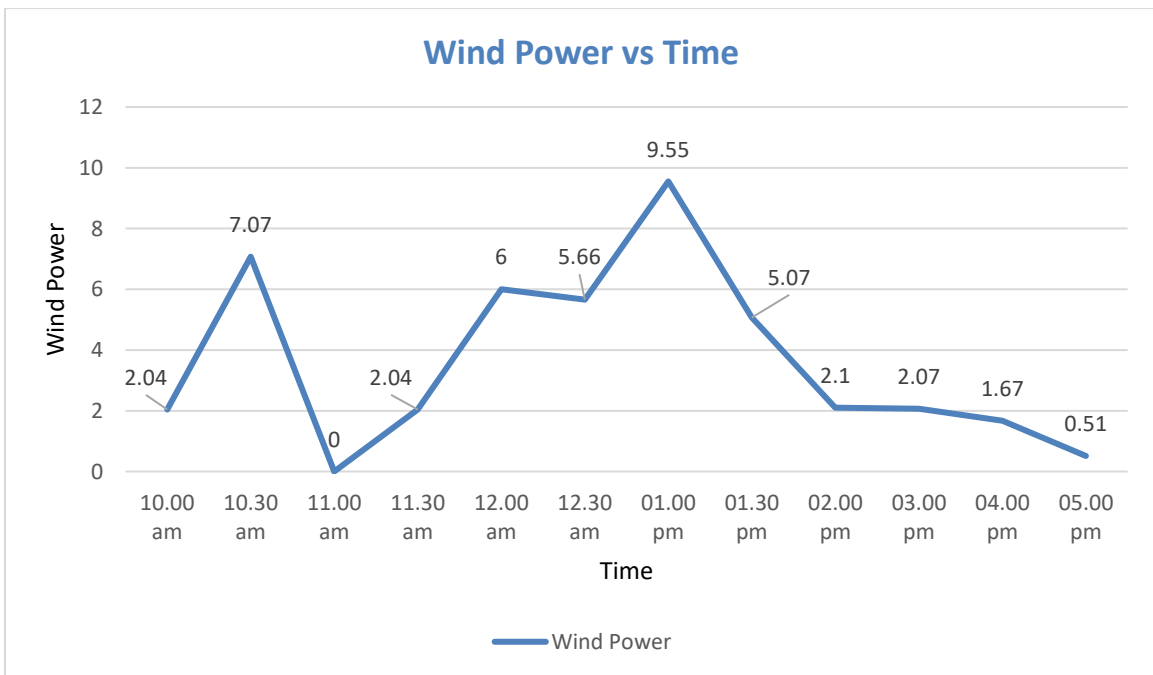


Figure5.2: Wind Power Vs Time Graph

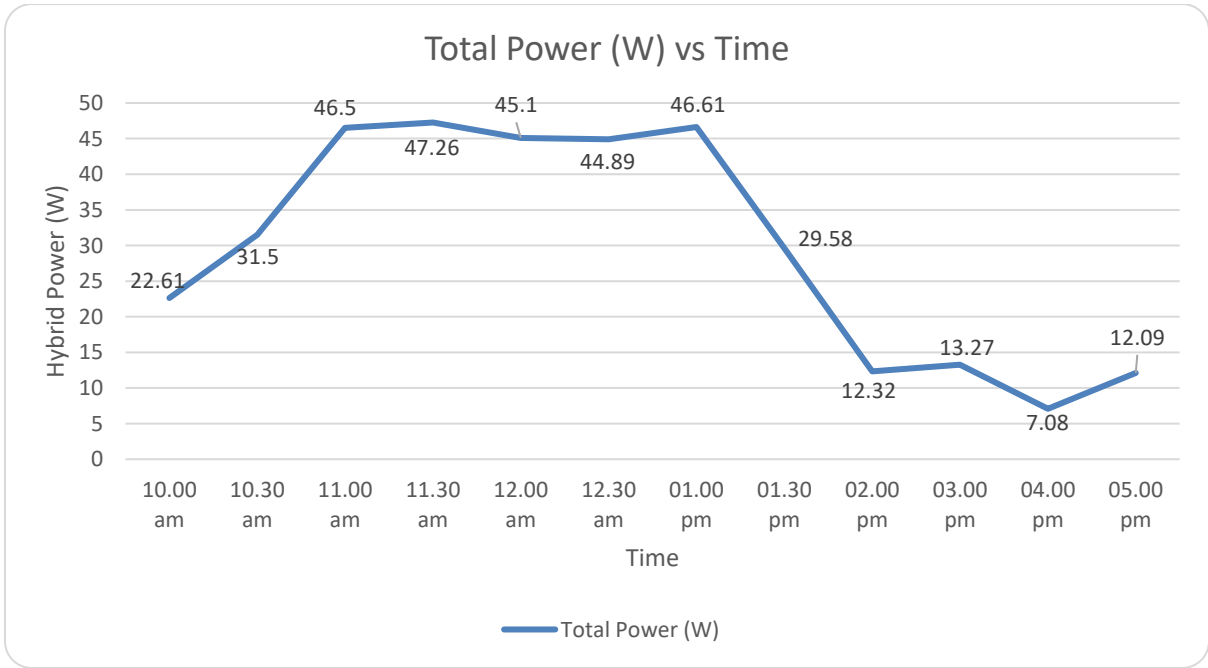


Figure5.3: Hybrid Output vs Time Graph

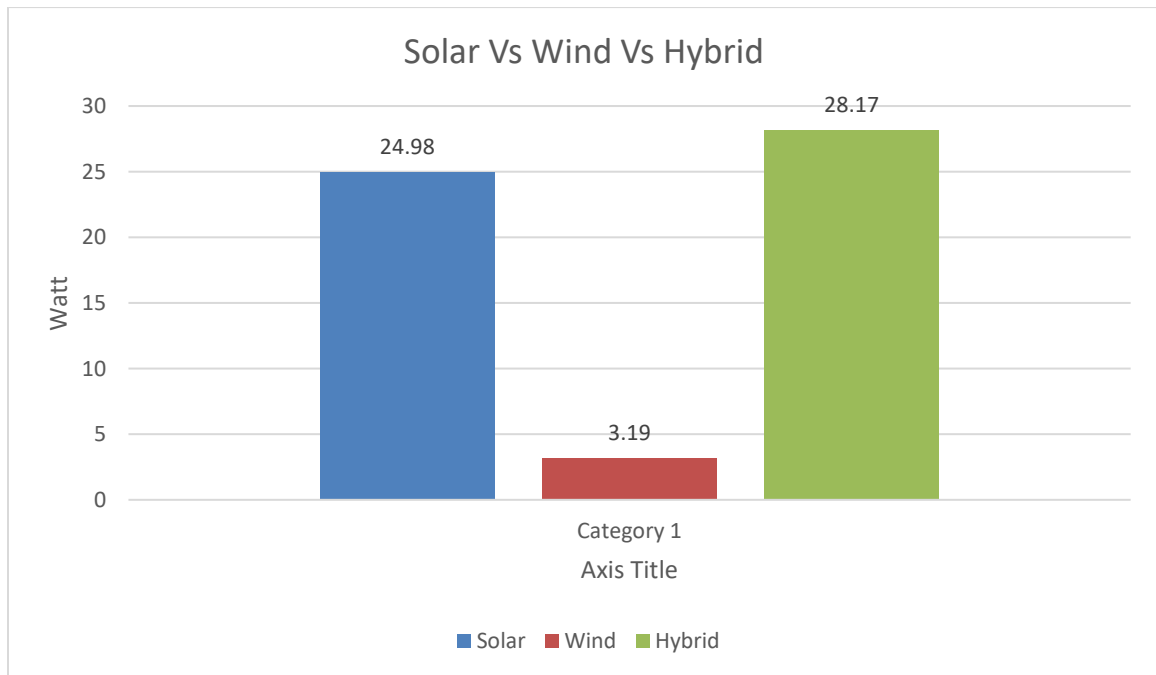


Figure 5.4: Comparison Bar Chart

5.2 Result and Analysis

Table 4: Summary of Experimental Results of Hybrid Renewable Energy System

Parameter	Solar (40W)	Wind Turbine (40 W VAWT)	Total Hybrid System
Voltage (V)	15.52	2.28	-
Current (A)	1.61	1.40	-
Power (W)	24.98	3.19	28.17

The implemented Hybrid Renewable Energy System was experimentally analyzed under different operating conditions using a 40W solar panel, a vertical axis wind turbine (VAWT), and a 12V, 9Ah battery storage system. During testing, the solar panel generated an average voltage of 15.52V, current of 1.61A, and output power of approximately 24.98W, while the wind turbine produced an average output power of about 3.19W under low to moderate wind conditions. The combined hybrid system therefore generated an average total output power of approximately 28.17 W. The battery charging performance was also analyzed, where the battery voltage increased from 11.9V to 12.7V during charging operation, indicating stable energy storage capability. Experimental observations showed that solar energy contributed the major portion of total power generation due to higher solar irradiance, whereas the wind turbine provided supplementary backup generation during fluctuating environmental conditions. Compared to single-source solar systems, the proposed hybrid configuration improved system reliability and ensured continuous energy availability during low sunlight conditions. The ESP32-based monitoring system successfully displayed voltage, current, and power data on the LCD and uploaded real-time information to the ThingSpeak IoT platform for remote monitoring and analysis. The charge controller effectively protected the battery from overcharging and deep discharge, improving operational safety and battery life. From the overall experimental results, the system demonstrated stable output performance, efficient energy management, and reliable operation for small-scale rural electrification and educational renewable energy applications.

5.3 Advantages

- The system provides continuous power supply using both solar and battery backup.
- It reduces dependency on the national electricity grid.
- Solar energy is renewable and environmentally friendly.

- The system helps in reducing electricity bills significantly.
- It automatically manages charging through the solar charge controller.
- Battery life is improved due to proper charging control.
- It works efficiently in remote and rural areas without grid access.
- Low maintenance cost makes it economically beneficial.
- Real-time monitoring through sensors improves system reliability.
- It is simple in design and easy to implement for small projects.

5.4 Applications

- It can be used in home lighting systems.
- Suitable for rural electrification projects.
- Useful in street lighting systems.
- Can be implemented in smart agriculture systems.
- Applicable in remote monitoring stations.
- Used in small-scale industrial backup systems.
- Helpful in educational and research projects.
- Can power small electronic devices in off-grid areas.
- Suitable for disaster-prone regions where power is unstable.
- Can be integrated into smart home energy systems.

5.5 Limitations

- Initial installation cost is relatively high.
- Energy generation depends on weather conditions.
- Solar panel efficiency reduces during cloudy days.
- Battery storage capacity is limited.
- Requires proper placement for maximum sunlight exposure.

5.6 Discussion

The implemented Hybrid Renewable Energy System demonstrated stable and reliable performance under different operating conditions by integrating solar energy, wind energy, and battery storage.

During the experimental analysis, the solar panel generated an average output power of approximately 24.98W, while the vertical axis wind turbine (VAWT) produced an average output power of

approximately 3.19 W under available wind conditions. The combined hybrid system therefore achieved an average total output power of about 28.17 W, ensuring continuous energy generation for low-power DC applications.

The experimental results showed that solar energy contributed the major portion of the total generated power due to higher solar irradiance during daytime operation. In contrast, the wind turbine provided supplementary backup power during fluctuating sunlight conditions, improving overall system reliability. Compared to a single-source solar system, the hybrid configuration provided more stable output performance and reduced dependency on environmental variations.

The 12V, 9Ah battery demonstrated stable charging and discharging characteristics throughout the testing period. The battery voltage gradually increased from approximately 11.9V to 12.7V during charging operation, indicating efficient energy storage capability. The solar charge controller successfully prevented overcharging and deep discharge, which improved battery protection and operational safety.

The ESP32-based IoT monitoring system effectively displayed real-time voltage, current, and power data on the LCD and uploaded system parameters to the ThingSpeak cloud platform for remote monitoring and analysis. This real-time monitoring capability simplified system supervision and improved performance observation.

Although the wind turbine generated comparatively lower power due to low and inconsistent wind speed conditions, the overall hybrid system demonstrated satisfactory performance for small-scale renewable energy applications. The integration of multiple renewable energy sources improved energy continuity, system flexibility, and operational efficiency. Therefore, the proposed system can be considered a low-cost, environmentally friendly, and sustainable solution for rural electrification, educational research, and small-scale backup power applications.

CHAPTER 6

CONCLUSION

6.1 Conclusion

The Hybrid Energy System designed and implemented in this project successfully demonstrates an efficient and reliable method of combining solar energy with battery storage. The main objective of reducing dependency on conventional grid electricity has been effectively achieved through proper integration of renewable energy technology. The system ensures continuous power supply by utilizing solar energy during the daytime and switching to battery backup during low or no sunlight conditions.

The use of a solar charge controller enhances system performance by protecting the battery from overcharging and deep discharge, thereby increasing its lifespan. The real-time monitoring system using sensors and LCD display provides accurate information about voltage, current, and battery status, which improves system control and safety. The overall design is simple, cost-effective, and suitable for small-scale applications.

From the experimental results, it is clear that the system performs efficiently under different environmental conditions. Although there are limitations such as dependency on weather and limited storage capacity, these can be improved in future developments by using advanced batteries and higher efficiency solar panels.

In conclusion, this hybrid energy system is a sustainable and practical solution for rural electrification, home applications, and educational purposes. It contributes to energy conservation and supports the use of clean renewable energy for a better future.

6.2 Future Scope

- Smart IoT-based monitoring can be added for remote control.
- Advanced lithium-ion batteries can replace lead-acid batteries.
- AI-based energy management can optimize power usage.
- Wireless energy monitoring using mobile apps can be implemented.

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