Design and Fabrication of a Vertical Axis Wind Turbine with Power Conversion System

A thesis

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Abstract

This project presents the design and fabrication of a Vertical Axis Wind Turbine (VAWT) integrated with a power conversion and monitoring system aimed at harnessing renewable wind energy for practical use in small-scale and off-grid environments. The system is engineered around a vertical axis turbine that rotates a free DC motor, effectively converting mechanical wind energy into electrical energy. The generated power is stored in a rechargeable battery bank, providing a reliable energy reservoir.

To efficiently utilize the stored energy, a buck converter is employed to step down the battery voltage (16V) to 5V and 12V. The 5V output powers the NodeMCU microcontroller and a 16x2 LCD display, which continuously displays the real-time voltage of the battery using data from a voltage sensing circuit. The 12V output is fed into an inverter module that converts DC to 220V AC, allowing the system to power conventional AC loads such as an electric bulb. Manual switches and indicators are included for user control and system status feedback.

This smart energy conversion system combines mechanical design with IoT-based electronics to offer a compact, eco-friendly, and intelligent solution for decentralized power generation. The entire setup is mounted on a fabricated frame using sunboard and other structural elements to ensure lightweight construction and portability. The project demonstrates the potential of integrating renewable energy with smart monitoring for sustainable power generation, particularly in remote, disaster-prone, or under-electrified areas.

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Chapter -1

Introduction

1.1 Introduction

The global energy crisis, environmental degradation, and the rapid depletion of fossil fuels have accelerated the pursuit of sustainable and renewable energy sources. In response to these challenges, wind energy has emerged as a clean, inexhaustible, and economically viable alternative to conventional energy systems. As the world pivots toward green technology, the development and optimization of wind-based energy systems have become a key research and engineering focus. Among the various types of wind turbines, Vertical Axis Wind Turbines (VAWTs) offer a unique set of advantages, particularly for decentralized, small-scale urban and rural applications.

This thesis presents the design and fabrication of a Smart Vertical Axis Wind Turbine (VAWT) system integrated with a power conversion and monitoring unit, aimed at harnessing wind energy for real-time use and storage. The project embodies a multi-disciplinary approach encompassing mechanical design, electrical power generation, energy storage, power electronics, and Internet of Things (IoT) technologies. The system has been designed to be cost-effective, modular, and adaptable for off-grid applications where renewable energy access is critical.

Unlike the more common Horizontal Axis Wind Turbines (HAWTs), which require precise orientation with the wind direction and are often noisy and large in scale, VAWTs are compact, omnidirectional, and can function efficiently in turbulent wind conditions typical of urban environments. These characteristics make them especially suitable for residential and low-wind-speed locations.

In this project, the mechanical rotation generated by the wind acting on the VAWT blades is converted into electrical energy through a free DC motor functioning as a generator. This electrical energy is then directed to a battery bank, enabling energy storage for later use. Storing energy in batteries ensures continuous power supply, even when wind conditions are insufficient. However, raw voltage from the wind turbine system varies and cannot be used

directly to power sensitive electronic devices or standard AC appliances. Therefore, a robust power conversion architecture is necessary to step down, regulate, and convert the stored energy into usable forms.

To address this, the system includes two buck converters: one that steps down the 16V battery voltage to 5V DC to power the NodeMCU microcontroller and LCD display, and another that steps it down to 12V DC to power an inverter module. This inverter is responsible for converting the 12V DC to 220V AC, making the system capable of driving standard household electrical loads, such as lights or small appliances. This dual voltage conversion strategy ensures maximum utility of the stored energy across both low-voltage digital devices and high-voltage AC loads.

An important smart feature of the system is the integration of a voltage sensing circuit connected to the battery, which continuously monitors the battery's voltage level. The voltage data is acquired and processed by the NodeMCU, which then displays the information on a 16x2 I2C LCD display and controls an indicator LED that alerts users to system status, such as low or optimal battery levels. This real-time monitoring enhances the reliability and usability of the system, ensuring that users are informed about the state of energy storage and system performance.

The innovation of this system lies not just in energy generation, but in the seamless integration of power electronics, renewable energy storage, and IoT-based monitoring, all within a compact and affordable platform. The use of NodeMCU also opens pathways for future integration with Wi-Fi-based monitoring platforms like Blynk IoT, allowing remote supervision and data logging capabilities.

The thesis is structured to provide a comprehensive overview of the conceptualization, design, fabrication, and testing of the Smart VAWT system. The chapters ahead detail the theoretical background of wind energy and VAWT systems, the hardware and electronics involved in energy conversion and storage, and the embedded systems used for control and display. Experimental results, design justifications, and performance evaluations are discussed in-depth to validate the feasibility and effectiveness of the developed prototype.

This project aims not only to contribute to academic knowledge in renewable energy systems but also to offer a practical solution for sustainable power generation, particularly in areas with

intermittent grid access or in eco-conscious communities seeking to reduce carbon emissions. By combining mechanical energy harvesting with intelligent power management and user feedback systems, this Smart Vertical Axis Wind Turbine project exemplifies a step forward in affordable, reliable, and user-friendly renewable energy solutions.

1.2 Aims

The primary aim of this project is to design, fabricate, and implement a smart vertical axis wind turbine (VAWT) system capable of generating, storing, converting, and displaying electrical energy derived from wind power in a compact, efficient, and intelligent manner. The project focuses on providing a sustainable and real-time monitored energy solution suitable for small-scale and off-grid applications.

- The specific aims of the project are:
- To design and construct a Vertical Axis Wind Turbine (VAWT)
- Capture wind energy from all directions efficiently.
- Utilize a low-cost DC motor as a generator to produce DC electricity.
- To develop a power storage system using a battery bank
- Store the generated DC voltage for later use, ensuring continuity of power supply even in the absence of wind.
- To implement a smart voltage sensing and monitoring circuit
- Use a NodeMCU (ESP8266) to read and process the battery voltage in real-time.
- Display the voltage level on a 16x2 I2C LCD screen.
- Indicate the system status using an LED indicator based on battery voltage thresholds.
- To design a reliable power conversion system
- Use a buck converter to step down the 16V battery output to 5V DC for powering the NodeMCU and LCD.
- Use a second buck converter to step down 16V to 12V DC to supply an inverter module.
- To enable AC power output from stored DC energy
- Use an inverter module to convert 12V DC into 220V AC.
- Run small AC electrical loads using this converted energy.

- To integrate all components into a compact and portable system
- Ensure modularity, scalability, and ease of use for real-world deployment in remote or low-wind areas.

1.3 Objectives

Objectives of proposed system is:

- To design a Vertical Axis Wind Turbine for omnidireetional wind energy harvesting.
- To construct and fabricate the vertical axis wind turbine with design.
- To Analysis the performance of vertical axis wind turbine.

1.4 Project Methodology:

The methodology followed for this project consists of systematic stages to design, fabricate, and test a smart vertical axis wind turbine integrated with a power conversion and monitoring system. The development process is divided into the following key steps:

1. Research and Component Selection
   - Study of wind turbine types and selection of a Vertical Axis Wind Turbine (VAWT) due to its ability to work in low wind conditions and receive wind from all directions.
   - Selection of a suitable DC motor that can function effectively as a generator.
   - Identification of electronic components including NodeMCU (ESP8266), voltage sensors, LCD display, buck converters, batteries, inverter module, and LED indicators.

2. Design and Fabrication of the Wind Turbine
   - Design of the turbine blades using lightweight and durable materials.
   - Mechanical assembly of the vertical axis structure to ensure balanced rotation.
   - Coupling the turbine shaft with the free DC motor to generate voltage during rotation.

3. DC Power Generation and Battery Storage

- The mechanical energy from wind rotates the turbine, which spins the DC motor, generating a variable DC voltage.
- The generated voltage is fed into a rechargeable battery bank for storage.

4. Voltage Sensing and Monitoring

- A voltage divider circuit is used to scale down the battery voltage for safe input to the NodeMCU analog pin.
- NodeMCU reads the battery voltage and processes it to display real-time values on an I2C-based 16x2 LCD.
- An LED indicator shows battery voltage status (e.g., Low, Normal, High).

5. Power Conversion System

- A buck converter is used to step down 16V DC from the battery to 5V DC to power the NodeMCU and LCD.
- Another buck converter steps down 16V DC to 12V DC, which is then supplied to the inverter module.

6. AC Power Output

- The inverter converts the 12V DC to 220V AC output.
- This AC voltage is used to operate an AC load (e.g., a fan or bulb) to demonstrate usability of the generated wind energy.

7. System Integration and Testing

All components are integrated on a common platform.

- Testing is carried out to verify:
- Wind turbine rotation and voltage generation.
- Proper charging and discharging of the battery bank.
- Real-time voltage display accuracy.
- Conversion efficiency of buck converters and inverter.

- Load handling capacity of the system.

8. Performance Evaluation
   - The system is evaluated under different wind speeds and load conditions.
   - Efficiency, stability, and responsiveness of the smart monitoring and conversion circuit are assessed.
   - Suggestions for improvements and scalability are noted.

Chapter-2

Hardware Implementation

2.1 Experimental Equipment's

The proposed Heat Treatment Oven is made of several components and they are:

- Vertical Axis Wind Turbine
- Free DC Motor
- Node MCU
- LCD
- 3.7V Battery
- Battery Chamber
- Manual Switch
- Switch
- Buck Converter
- Voltage Sensing Circuit
- Inverter Circuit
- AC Bulb
- Holder
- Bearing
- Sunboard

2.2 Hardware:

A Water Level Monitoring system designed with Node MCU, LCD, Voltage Sensing Circuit, Switch, Vertical Axis Wind Turbine, Free DC Motor, Inverter Module, Battery, AC Load and several essential hardware components, each playing a critical role in its operation. Below is an outline of these components:

2.2.1 Battery

The 3.7V rechargeable lithium-ion battery serves as the main power storage unit. It stores the energy generated from the wind turbine. Multiple batteries can be connected in series or parallel to create a 16V battery bank for powering the entire system.



Figure 2.1: Battery

2.2.2 Node MCU

we use a NodeMCU or ESP8266 development Board which is transformation of ESP12E wifi module and containing the ESP8266 chip which capacity is 32-bit LX106 RISE. It supports RTOS and it can operate 80MHz to 160MHz with adjustable clock frequency. It contain 1280 KB RAM and also 4 MB of flash memory to store data and programs.



Figure 2.2: Node MCU

2.2.3 Inverter Module

The inverter circuit converts the 12V DC from the battery to 220V AC. This allows the system to power standard AC appliances such as bulbs, fans, or small electronic devices, making the setup more practical and versatile.



Figure 2.3: Inverter Module

2.2.4 Switch

Another switch is used to activate or deactivate specific components of the circuit, such as the inverter module or the AC output. It simplifies operation and enhances user control over energy distribution.



Figure 2.4: Switch

2.2.5 LCD

The I2C LCD component is used in applications that require a visual or textual display. This component is also used where a character display is needed but seven consecutive GPIOs on a single GPIO port are not possible. In cases where the project already includes an I2C master, no additional GPIO pins are required.



Figure 2.5: LCD

2.2.6 Free DC Motor

The free DC motor acts as a generator in this project. When the wind turbine rotates its shaft, it turns the motor and generates DC electricity. It is called a “free” DC motor because it operates without any internal resistance when back-driven, making it efficient for wind-based power generation.



Figure 2.6: Free DC Motor

2.2.7 Wind Turbine

The Vertical Axis Wind Turbine (VAWT) is a type of wind energy converter where the main rotor shaft is set vertically. It allows the turbine to capture wind from any direction, making it ideal for low and inconsistent wind environments. It is easy to install and maintain, and well-suited for small-scale applications.

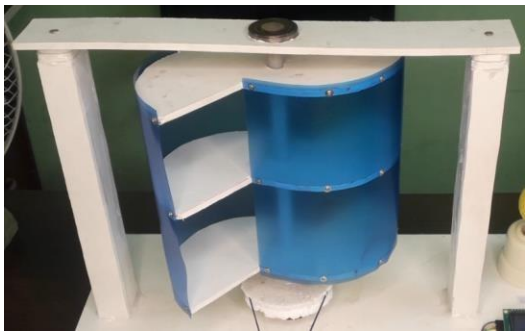


Figure 2.7: Wind Turbine

2.2.8 AC Bulb

The AC bulb is used to demonstrate the final output of the system. It lights up using the 220V AC produced by the inverter, proving that wind-generated and stored energy can be used to run typical household loads.



Figure 2.8: AC Load

2.2.9 Buck Converter

A buck converter is a DC-DC voltage regulator that steps down the 16V battery voltage to 5V and 12V as required. The 5V output is used to power the NodeMCU and LCD, while the 12V output is used for the inverter module.



Figure 2.8: Buck Converter.

Chapter-3

Design and Implementation

3.1 Circuit Diagram

Here we included the Circuit diagram of our proposed system. Here we try to show different components of this system with proper connection in bellow.

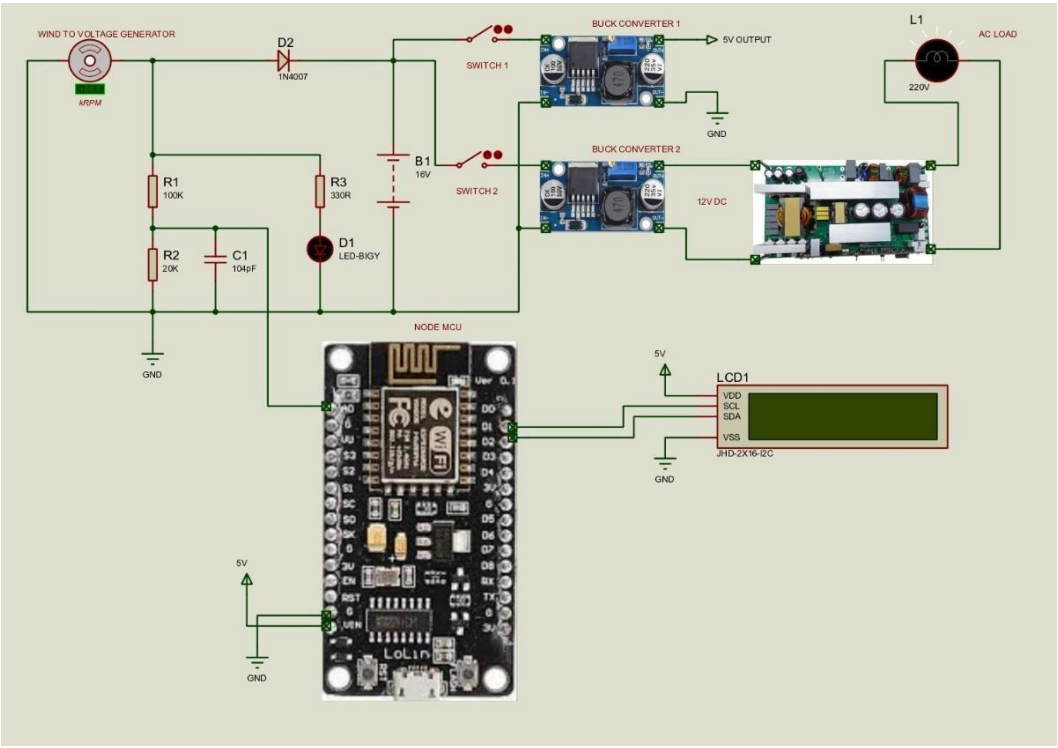


Figure 3.1: Circuit diagram of Proposed System.

Here a Vertical axis wind turbine is designed to generate power from a Free DC Motor by the rotation of wind turbine, after power generation this power will be store to Battery bank and one Voltage sensing circuit will read generated voltage value by using a node MCU and that will be show in a LCD Display and an indicator light, then we will use this battery voltage to power on our node MCU, LCD Display, that's why we use a Buck converter to convert 16V Battery voltage to 5V DC. Another Buck converter is used here to get 12V DC from 16V Battery Voltage, this 12V DC will be connect with a Inverter Module that will provide 220V AC. and

This AC voltage will be use here to run a AC Load. Here Node MCU will read generated voltage value from wind turbine and that will show in our LCD for manual monitoring.

3.2 Block Diagram

Here we included the block diagram of our proposed system. In this system we try to show different part of working as different blocks in bellow.

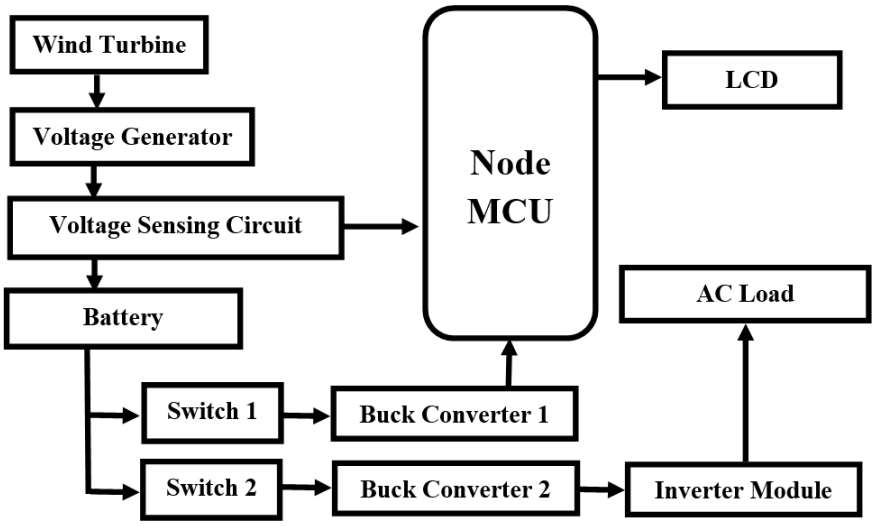


Figure 3.2: Block Diagram of Proposed System.

Here a Vertical axis wind turbine is designed to generate power from a Free DC Motor by the rotation of wind turbine, after power generation this power will be store to Battery bank and one Voltage sensing circuit will read generated voltage value by using a node MCU and that will be show in a LCD Display and an indicator light, then we will use this battery voltage to power on our node MCU, LCD Display, that's why we use a Buck converter to convert 16V Battery voltage to 5V DC. Another Buck converter is used here to get 12V DC from 16V Battery Voltage, this 12V DC will be connect with a Inverter Module that will provide 220V AC. and This AC voltage will be use here to run a AC Load. Here Node MCU will read generated voltage value from wind turbine and that will show in our LCD for manual monitoring

3.3 Full overview

This is the Full overview of our proposed system.

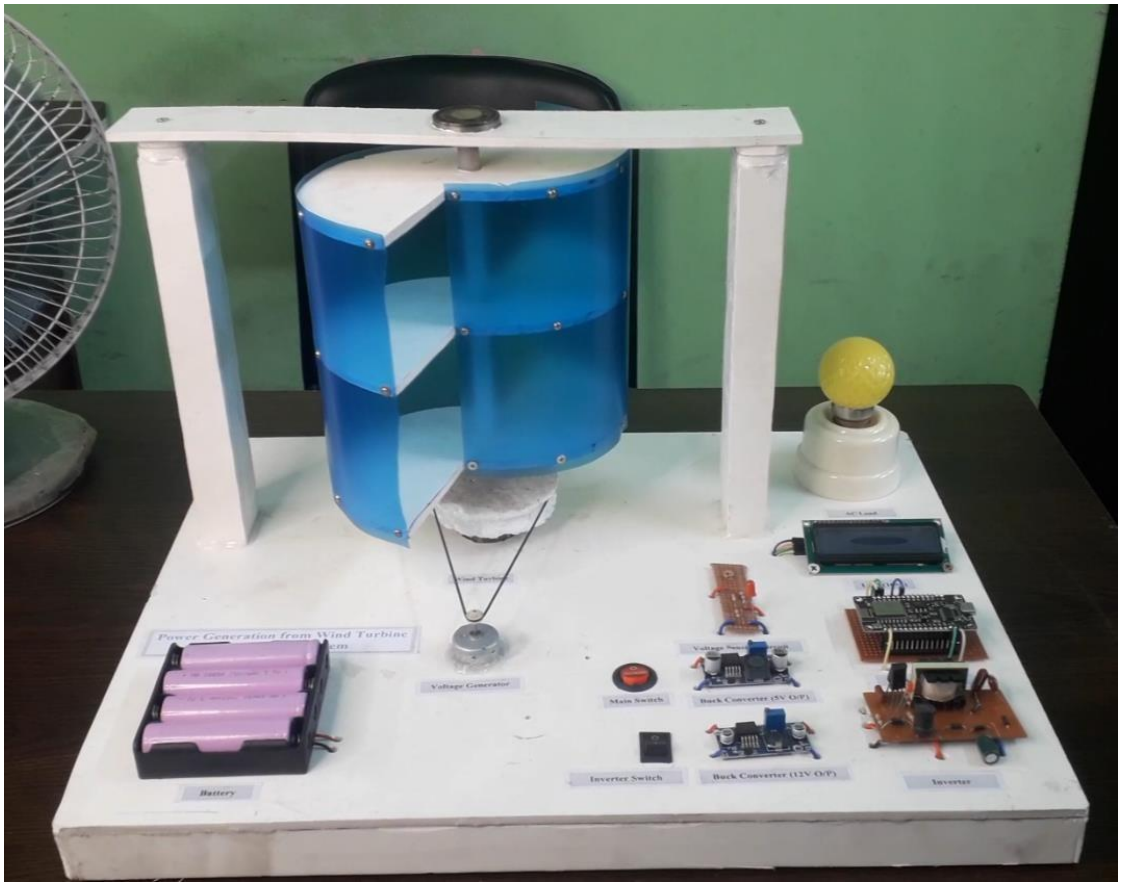


Figure 3.3: Full overview of Proposed System.

3.4 Applications

This project offers a wide range of practical applications in both rural and urban settings, especially where grid power is unavailable or unreliable. The smart wind turbine system is designed to promote the use of renewable energy and intelligent power management. Below are the key application areas:

Remote and Off-Grid Areas

Used as a standalone renewable energy source in remote villages, hill regions, or islands where conventional electricity supply is not feasible.

Rural Electrification Projects

Ideal for small-scale power generation to light homes, charge devices, and operate low-power appliances in rural regions.

Disaster-Prone Areas

Acts as a reliable backup power system during natural disasters like floods, cyclones, or earthquakes where grid power fails.

Educational Demonstration Units

Serves as a hands-on learning tool for students and researchers studying renewable energy, power electronics, and smart monitoring systems.

Smart Homes and IoT Projects

Can be integrated into smart home systems to power sensors, microcontrollers, and communication devices using wind energy.

Battery Charging Stations

Used to charge 12V or 16V battery banks in an eco-friendly way for portable devices, LED lighting, or solar-assisted systems.

Agricultural Applications

Powers DC water pumps, sensors, or communication devices in off-grid farms and fields.

Street Lighting Systems

Integrated with solar or battery storage to power street lights in rural or urban areas using hybrid renewable energy.

Military or Emergency Camps

Provides a renewable, transportable, and independent power source in temporary field setups.

Small-Scale Commercial Use

Suitable for powering small AC appliances, tools, or equipment in mobile shops or kiosks.

Chapter - 4

Results and Discussion

4.1 THEORY

Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied, via the national grid. The energy available for conversion mainly depends on

1. The wind speed

2. Swept area of the turbine.

3. Air density

4.2 MATHEMATICAL MODEL

The following table shows the definition of various variables used in this model:

E = Kinetic Energy (J)	p = Density (kg/m3)
m = Mass (kg)	A = Swept Area (m2)
v = Wind Speed	Cp= Power (m/s) Coefficient
P = Power (W)	r = Radius (m)
Dm/d t- Mass flow rate (kg/s)	x = distance (m)
DE/dr-Energy Flow	t = time (s)

4.2.1 Rate (J/s)

Under constant acceleration, the kinetic energy of an object having mass m and velocity v is equal to the work done Win displacing that object from rest to a distance s under a force F, i.e.: E=W = Fs

According to Newton's Law, we have;

Hence,

E= mas.....(1)

Using the third equation of motion:

F = ma

$v^2 = u^2 + 2as$

We get:

$$a = \frac{(v^2 - u^5)}{2a}$$

Since the initial velocity of the object is zero, i.e u=0 we get:

$$a = \frac{v^2}{2a}$$

Substitution it in equation (1), we get that the kinetic energy off a mass in motions is:

$$E = \frac{1}{2} mv^2 \cdots\cdots\cdots\cdots (2)$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dm}{dt} \ldots\ldots\ldots (3)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = pA\frac{dx}{dt}$$

We get:

$$\frac{dm}{dt} = pAv$$

Hence, from equation (3) the power can be defined as:

$$P_2^{\uparrow} = pAv^2 \text{.....(4)}$$

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the **Betz Limit** or **Betz' Law**. The theoretical maximum **power efficiency** of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient" and is defined as:

$$C_{Pmax} = 0.59$$

Also, wind turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine-strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on only 10-30% of the power of the wind is

ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation (4) and the extractable power from the wind is given by:

$P_{avail} = \frac{1}{2} \rho A v^3 C_p$ ..... (5)

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$A = \pi r l$ ..... (6)

4.3 CALCULATIONS WITH GIVEN DATA

We are given the following data:

Given

Blade length, L= 0.1778m

Wind speed, v= 22 m/sec

Air density, ρ= 1.23 kg/m^3

Current, I = 0.0017A

Voltage, V = 29 volt

Power Coefficient C_p=0.35 (As well lowest design)

r = 0.0762m

A = πrl

= π×0.17018×0.1778

= 0.0425m^2

Actual Power Output

P = I×V

= 0.0017×29

= 0.0493W

We can then calculate the power converted from the wind into rotational energy in the turbine using equation (7):

$P=\frac{1}{2}\rho A v^3 C_p$

$=\frac{1}{2} \times 1.15 \times 0.0425 \times 22^3 \times 0.35$

= 91.07 W

=0.091 KW

EFFICIENCY

Efficiency is the state or quality for being efficient.

To get the efficiency, both the equal power generated and theoretical power expected were analyzed

(ACTUAL POWER OUTPUT)/(THEORITICAL POWER OUTPUT) × 100

Actual power was 0.0493 watts

Theoretical power expected to be produced was 91.07 Watts

Therefore (0.0493)/(91.07) ×100

=0.054%

Here we get lower efficiency cause this prototype is designed here with plastic board and simple design and our system is not test where wind system is basically need to set for get proper output.

4.4 Result

Here we will show the operational output of our proposed system.

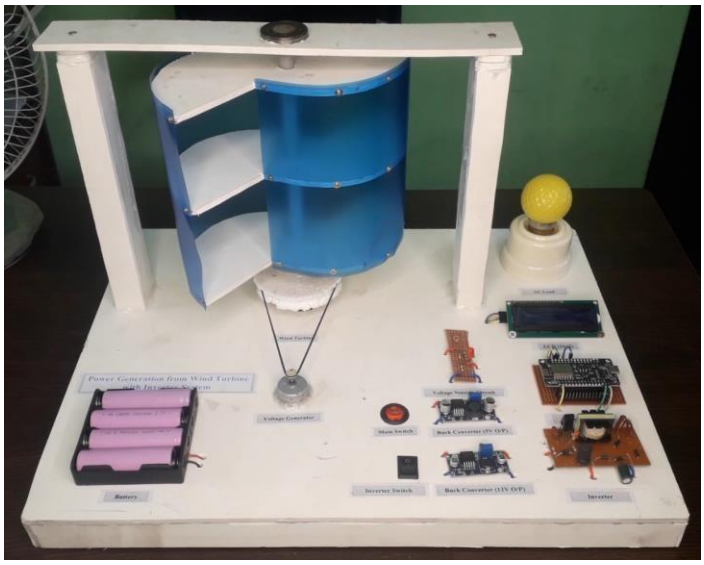


Figure 4.4.1: Front view of Proposed System.



Figure 4.4.2: Wind Turbine is Rotating and Power Generation ON.



Figure 4.3: Generated Voltage showing on LCD.

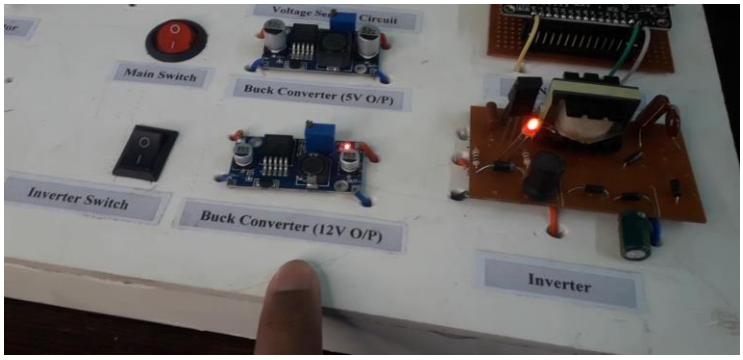


Figure 4.4: Inverter Module is Inverting DC to AC Voltage.



Figure 4.5: AC Load is Running.

Chapter - 5

Conclusion and Recommendation

5.1 Advantages

Advantages of proposed System is showing here in bellow:

- Utilizes clean and renewable wind energy
- Operates efficiently in low and variable wind conditions
- Vertical axis design captures wind from all directions
- Simple and low-cost construction with readily available components
- Provides both DC and AC power outputs
- Reduces dependency on grid electricity
- Includes real-time voltage monitoring and smart display
- Portable and suitable for remote or off-grid locations
- Low maintenance due to fewer moving parts
- Environmentally friendly and promotes sustainable energy use

5.2 Disadvantages

Disadvantages of Proposed System is:

- Power generation depends on wind availability and speed
- Lower efficiency compared to horizontal axis wind turbines in high wind areas
- Limited power output suitable only for small loads
- Requires stable mounting to avoid vibration and imbalance
- Battery storage has limited life and may need periodic replacement
- Inverter and buck converters may introduce energy losses
- System performance may drop during calm weather conditions
- Initial setup may require precise alignment and tuning
- Maintenance is needed for mechanical parts and electrical connections

5.3 Limitation

- Limited power output – suitable only for low-power devices.
- Depends entirely on wind availability.
- Free DC motor has low energy conversion efficiency.
- Battery capacity is limited.
- Voltage output fluctuates with wind speed.
- Requires manual switching – not fully automated.
- Inverter supports only small AC loads.
- No IoT-based real-time remote monitoring.
- Frame material (sunboard) is not weatherproof.
- Not easily scalable for large applications.

5.4 Future Scope

The future scope of proposed system is showing here in bellow:

- Integration with solar panels to create a hybrid wind-solar energy system
- Implementation of wireless data transmission (IoT) for remote monitoring
- Use of Maximum Power Point Tracking (MPPT) for improved energy efficiency
- Development of a mobile app or web interface for real-time energy tracking
- Scaling up the turbine size and power output for household or community-level use
- Addition of automatic blade angle adjustment for optimized wind capture
- Integration of AI-based algorithms to predict wind patterns and adjust system operation
- Enhancement of energy storage system with smart battery management
- Use of 3D printing technology to fabricate lightweight turbine components
- Commercial deployment for powering street lights, surveillance systems, or public facilities

5.5 Conclusion

The project titled "Design and Fabrication of a Smart Vertical Axis Wind Turbine with Power Conversion System" successfully demonstrates a compact, efficient, and intelligent renewable energy solution tailored for small-scale and off-grid power applications. The integration of mechanical, electrical, and IoT-based technologies offers a modern approach to sustainable energy harvesting, storage, and utilization.

Through the careful design and fabrication of a Vertical Axis Wind Turbine (VAWT), the system proves capable of harnessing wind energy from all directions—making it highly suitable for low-wind urban and rural environments. The use of a free DC motor as a generator provides a simple yet effective way to convert mechanical rotation into electrical energy. Unlike traditional horizontal axis turbines that require wind alignment, the vertical axis model functions efficiently in turbulent and variable wind conditions.

One of the critical achievements of this project is the smart power management system. The generated DC power is stored in a rechargeable battery bank, ensuring energy availability even during non-windy periods. The incorporation of a NodeMCU microcontroller, along with a voltage sensing circuit, allows for real-time monitoring of battery voltage. Displaying this data on a 16x2 LCD screen and indicating it through an LED status system enhances user awareness and system intelligence.

To ensure stable operation of the electronics and power delivery to end-use devices, buck converters are used to convert 16V DC from the battery bank into usable 5V and 12V DC outputs. The 5V output powers the control and display systems, while the 12V output feeds into an inverter module that efficiently converts DC to 220V AC. This enables the system to power AC appliances, bridging the gap between renewable generation and practical usage.

From the beginning stages of design, component selection, and fabrication to final testing and performance evaluation, the project followed a systematic engineering methodology. Each stage was carefully executed to ensure functionality, reliability, and integration of all subsystems. The system was able to power small AC and DC loads, proving its potential as a viable energy

solution in remote, disaster-prone, or electricity-deficient areas.

Despite some limitations such as dependence on wind speed and modest power output, the project offers a solid foundation for future development. It demonstrates how renewable energy can be made accessible, affordable, and intelligent through localized design and smart electronics.

In conclusion, this smart wind energy system serves as a promising prototype for sustainable development. With further enhancements such as integration with solar energy, MPPT algorithms, and wireless monitoring systems, the solution can be scaled up and adapted for broader community, educational, or emergency power needs. This project not only contributes to green energy innovation but also supports the global push toward clean, decentralized, and intelligent power systems.

REFERENCES

[1] Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). Wind Energy Explained: Theory, Design and Application. Wiley.

[2] Hau, E. (2013). Wind Turbines: Fundamentals, Technologies, Application, Economics. Springer Science & Business Media.

[3] Heier, S. (2014). Grid Integration of Wind Energy: Onshore and Offshore Conversion Systems. John Wiley & Sons.

[4] Patel, M. R. (2006). Wind and Solar Power Systems: Design, Analysis, and Operation. CRC Press.

[5] Ackermann, T. (Ed.). (2005). Wind Power in Power Systems. John Wiley & Sons.

[6] Bharadwaj, A., & Singh, R. (2018). Smart Wind Turbine System with IoT-Based Monitoring. International Journal of Renewable Energy Research, 8(3), 1017–1025.

[7] Kumar, S., & Sharma, R. (2020). Design and Implementation of a Vertical Axis Wind Turbine for Small-Scale Power Generation. International Journal of Scientific & Engineering Research, 11(6), 126–131.

[8] Arduino. (n.d.). NodeMCU and Power Supply Guide. Retrieved from https://www.arduino.cc

[9] Texas Instruments. (n.d.). DC-DC Buck Converter Design Guide. Retrieved from https://www.ti.com

[10] S. Singh and V. K. Gupta, "Water Pumping and Level Control Automation," Automation and Control Systems Review, vol. 8, pp. 87-94, 2020.