Vertical Axis Wind Turbine Based Street Light System

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Abstract: *This paper presents a smart street lighting system powered by a Vertical Axis Wind Turbine (VAWT) installed along highways. The system utilizes airflow generated by moving vehicles to rotate the turbine and produce electrical energy through generators. The generated power is converted and stored in a battery for continuous operation. An ESP32 microcontroller is used to monitor voltage, current, power, and energy parameters in real time. An LDR sensor automatically detects ambient light conditions and controls the street light, turning it ON at night and OFF during daytime. This approach reduces dependence on conventional electricity and promotes clean energy utilization. The proposed system offers an efficient, low-cost, and eco-friendly solution for smart highway lighting.*

Keywords: Vertical Axis Wind Turbine (VAWT), Smart Street Light, Wind Energy, ESP32, LDR Sensor, Renewable Energy, Energy Harvesting

I. INTRODUCTION

The increasing demand for electrical energy and the depletion of conventional energy resources have created a strong need for sustainable and renewable energy solutions. Street lighting is one of the essential components of urban and highway infrastructure, but it consumes a significant amount of electrical power every day. Reducing the energy consumption of street lighting systems has become an important area of research in recent years [1].

Renewable energy sources such as solar and wind energy offer promising alternatives to conventional power generation. Among these, wind energy has gained considerable attention because of its availability, clean nature, and ability to generate electricity without producing harmful emissions. Wind-based power systems can be implemented in various environments, including highways, where moving vehicles create continuous airflow that can be utilized for energy generation [2][3].

Highway traffic produces aerodynamic disturbances and wind pressure due to the movement of vehicles at high speeds. This otherwise wasted kinetic energy can be captured using wind turbines and converted into useful electrical energy. A Vertical Axis Wind Turbine (VAWT) is particularly suitable for such applications because it can operate efficiently even when wind direction changes frequently. Unlike horizontal turbines, VAWTs do not require complex orientation mechanisms and can be installed in compact spaces near roads or medians [4][5].

The integration of smart technologies has further improved the efficiency of street lighting systems. Modern smart street lights use sensors and microcontrollers to automate lighting control based on environmental conditions. Light-dependent resistor (LDR) sensors can detect surrounding light intensity and automatically switch street lights ON during nighttime and OFF during daytime, minimizing unnecessary power usage [6][7].

In this work, a smart street lighting system powered by a Vertical Axis Wind Turbine is proposed for highway applications. The airflow generated by moving vehicles rotates the turbine, which drives generators to produce electrical power. The generated energy is rectified, stored in a battery, and used to power LED street lights. An ESP32 microcontroller monitors system parameters such as voltage, current, and power, enabling real-time performance observation and efficient control [8][9].

The proposed system aims to provide an energy-efficient, eco-friendly, and cost-effective solution for street lighting. By combining wind energy harvesting with intelligent control, the system reduces dependency on grid electricity and supports sustainable infrastructure development for future smart cities and highways [10].

II. PROBLEM STATEMENT

Conventional street lighting systems on highways rely heavily on grid electricity, leading to high energy consumption, increased operational costs, and greater dependence on non-renewable energy sources. At the same time, the wind generated by fast-moving vehicles on highways is usually wasted without being utilized for any useful purpose. There is a need for an efficient system that can harvest this unused wind energy and convert it into electrical power for street lighting. Additionally, manual or continuously operating street lights often result in unnecessary energy loss during daytime. Therefore, developing a smart street lighting system that combines Vertical Axis Wind Turbine (VAWT) based energy generation with automatic light control can help reduce power consumption, improve energy efficiency, and promote sustainable infrastructure.

III. OBJECTIVES

- To design a Vertical Axis Wind Turbine (VAWT) for harvesting wind energy generated by moving vehicles.
- To generate electrical power from highway airflow for street lighting applications.
- To develop an automatic smart street light control system using an LDR sensor.
- To monitor voltage, current, and power using an ESP32-based monitoring system.
- To reduce electricity consumption and promote sustainable energy usage in highways.

IV. LITERATURE SURVEY

1. Gupta and Sharma (2018) presented a study on "Vertical Axis Wind Turbine for Highway Energy Harvesting," where they explored the possibility of converting airflow generated by moving vehicles into electrical energy using a VAWT system. Their work showed that highway wind can serve as a useful renewable energy source for small-scale power generation. However, the power output was highly dependent on traffic density and vehicle speed.

2. Kumar et al. (2019) proposed a system in their paper "Smart Street Lighting Using Renewable Energy Sources," where solar and wind energy were integrated to power street lights automatically. The system used sensors for light detection and reduced electricity consumption significantly. However, the hybrid setup increased system complexity and installation cost.

3. Patel and Mehta (2020) introduced an energy-efficient model in "Automatic Street Light Control Using LDR and Microcontroller," where LDR sensors were used to control street lights based on ambient light conditions. Their approach reduced unnecessary daytime power usage and improved automation. However, the system depended entirely on external power sources for operation.

4. Reddy et al. (2021) presented "ESP32 Based Real-Time Energy Monitoring System," where an ESP32 microcontroller monitored voltage, current, and power parameters of electrical systems. The system enabled real-time data acquisition and performance analysis with good accuracy. However, sensor calibration was necessary to maintain measurement precision over long-term use.

5. Singh and Verma (2022) proposed "Wind Energy Based Smart Highway Lighting System," where roadside wind turbines were installed to capture airflow generated by fast-moving vehicles. Their research demonstrated reduced dependency on conventional electricity for highway lighting..

6. Joshi et al. (2023) developed a sustainable model in "IoT Enabled Smart Street Light Using Wind Energy," where IoT-based monitoring was combined with wind energy harvesting for intelligent street light control. The system improved energy management and reduced operational costs. However, network dependency and maintenance challenges remained key limitations.

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Comparison Table

Author & Year	Method Used	Advantages	Limitations
Gupta and Sharma (2018)	VAWT for highway wind energy harvesting	Utilizes vehicle-generated wind, renewable source	Output depends on traffic density
Kumar et al. (2019)	Hybrid solar-wind smart street lighting	Reduces grid power usage	High installation cost
Patel and Mehta (2020)	LDR with microcontroller for automatic lighting	Saves energy through automation	Requires external power source
Reddy et al. (2021)	ESP32 based energy monitoring	Real-time voltage and current monitoring	Sensor calibration needed
Singh and Verma (2022)	Roadside wind turbine street lighting	Reduces conventional electricity use	Low efficiency in less traffic
Joshi et al. (2023)	IoT enabled smart street light	Smart monitoring and control	Network dependency

V. WORKING OF SYSTEM

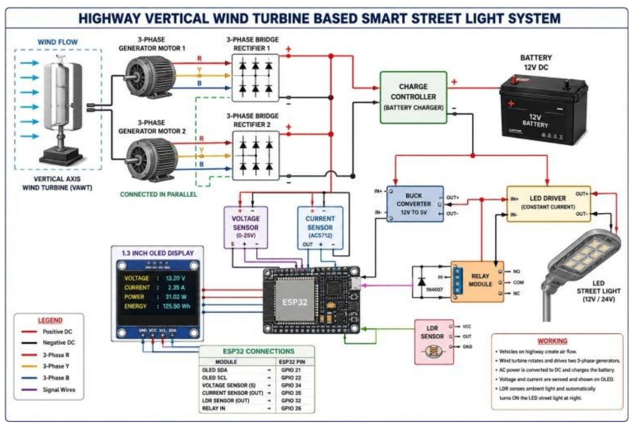

Fig 1: Design of the system

1. Wind Flow Generation

Vehicles moving at high speed on the highway create continuous airflow around the road. This moving air acts as the primary energy source for the system and is utilized instead of being wasted.

2. Rotation of Vertical Axis Wind Turbine (VAWT)

The generated airflow strikes the blades of the Vertical Axis Wind Turbine (VAWT). Due to the aerodynamic force, the turbine rotates around its vertical shaft and converts wind energy into mechanical energy.

3. Electrical Power Generation

The rotating turbine shaft is mechanically connected to two 3-phasegenerator motors connected in parallel. As the shaft rotates, both generators produce 3-phase AC electrical power.

4. AC to DC Conversion

The AC output from each generator is supplied to separate 3-phase bridge rectifiers. These rectifiers convert the generated alternating current (AC) into direct current (DC), making it suitable for battery charging and electronic components.

5. Battery Charging and Energy Storage

The rectified DC power is fed into a charge controller, which regulates the charging process and protects the battery from overcharging or deep discharge. The regulated power is stored in a 12V battery for continuous energy supply.

6. Voltage and Current Monitoring

A voltage sensor continuously measures system voltage, while the ACS712 current sensor measures charging and load current. These sensors provide real-time electrical data to the controller.

7. ESP32 Processing and Control

The ESP32 microcontroller acts as the main control unit of the system. It collects sensor readings, calculates parameters such as voltage, current, power, and energy consumption, and manages the overall system operation.

8. Display of Electrical Parameters

The processed data is displayed on a 1.3-inch OLED display. This allows real-time monitoring of important system values such as battery voltage, current flow, generated power, and energy usage.

9. Power Supply to Control Circuit

A buck converter steps down the battery voltage from 12V to 5V, providing a stable power supply for the ESP32, sensors, relay, and other low-voltage electronic modules.

10. Automatic Light Detection Using LDR

An LDR (Light Dependent Resistor) sensor continuously detects ambient light intensity. During daytime, when sunlight is available, the sensor output indicates high brightness.

11. Relay-Based Street Light Switching

Based on LDR readings, the ESP32 controls the relay module.

During daytime, the relay remains OFF, keeping the street light OFF.

During nighttime, the relay turns ON automatically, supplying power to the LED street light.

12. LED Street Light Illumination

Power from the battery passes through the LED driver, which provides constant current to the LED street light. The street light illuminates the highway efficiently during low-light conditions, ensuring safety while minimizing power consumption.

VI. SYSTEM DESIGN

System Overview

The proposed system is designed to generate electrical energy from the airflow produced by moving vehicles on highways and use that energy to power an automatic smart street lighting system. The system consists of a Vertical Axis Wind Turbine (VAWT), power generation unit, energy storage unit, sensing unit, control unit, and lighting unit. The airflow created by vehicles rotates the turbine, which drives generators to produce electrical power.

Components Description

1. Vertical Axis Wind Turbine (VAWT)

Fig.2.VAWT

The VAWT is the primary energy harvesting component of the system. It captures airflow generated by moving vehicles and converts wind energy into rotational mechanical energy. It is suitable for highway applications because it can operate efficiently even when wind direction changes frequently.

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2. 3-Phase Generator Motors

Fig.3.3-Phase Generator Motor

Two 3-phase generator motors are connected to the turbine shaft. As the turbine rotates, these generators convert mechanical energy into 3-phase AC electricalenergy. Using two generators increases the total power output.

3. Bridge Rectifiers

The generated AC power cannot directly charge the battery or operate electronic devices. Therefore, 3-phase bridge rectifiers are used to convert AC power into DC power suitable for storage and usage.

4. Charge Controller

The charge controller regulates the charging process of the battery. It protects the battery from:

Overcharging

Deep discharge

Reverse current flow

This ensures safe and efficient battery operation.

5. Battery (12V DC)

The 12V battery stores electrical energy generated by the wind turbine. It provides continuous power to the street light and control circuit, especially when wind flow is low or unavailable.

6. Voltage Sensor

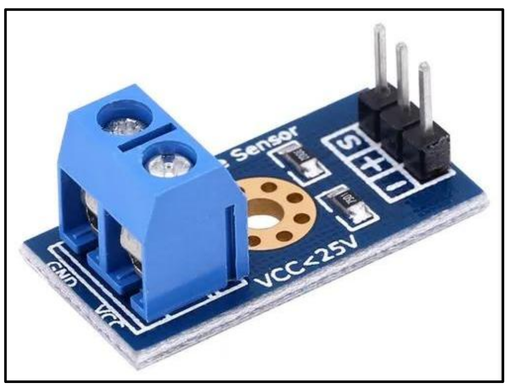

Fig.4.Voltage Sensor

The voltage sensor measures the system voltage or battery voltage in real time. It sends voltage data to the ESP32 for monitoring and analysis.

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7. Current Sensor (ACS712)

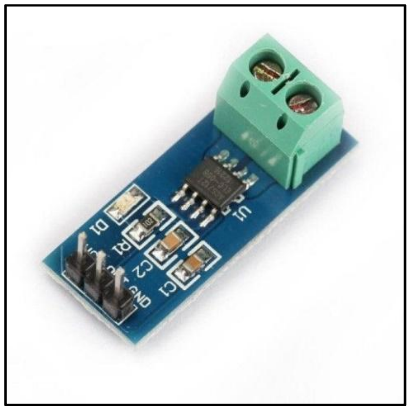

Fig.3.Current sensor

The ACS712 current sensor measures charging current and load current. It helps in calculating:

8. ESP32 Microcontroller

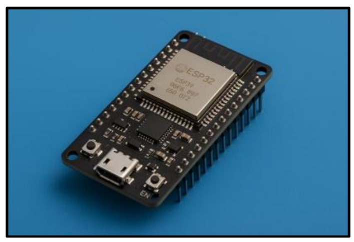

Fig.8.ESP32

The ESP32 acts as the brain of the system. It performs the following tasks:
Reads sensor data
Calculates voltage, current, power, and energy
Controls relay switching
Monitors system performance
Sends data to OLED display

9. OLED Display

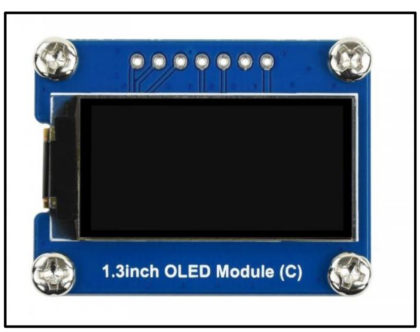

Fig..9.OLED

A 1.3-inch OLED display is used to display real-time system parameters such as:
Voltage

Current
Power
Energy
This helps users monitor system performance easily.

10. Buck Converter

The buck converter steps down battery voltage from 12V to 5V to provide a stable power supply for ESP32 and sensors.

11. LDR Sensor

The Light Dependent Resistor (LDR) detects ambient light intensity. It enables automatic control of street lights based on day and night conditions.

12. Relay Module

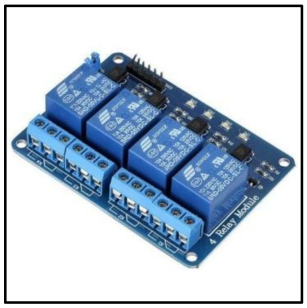

Fig. Relay Module

The relay module works as an electronic switch controlled by the ESP32. It turns the LED street light ON or OFF according to the signal received from the controller.

13. LED Driver

The LED driver supplies constant current to the LED street light. This improves LED performance and prevents damage caused by current fluctuations.

14. LED Street Light

The LED street light is the output device of the system. It illuminates the highway during nighttime while consuming less power compared to conventional lighting.

VII. RESULTS

The developed Highway Vertical Wind Turbine Based Smart Street Light System successfully demonstrated the generation and utilization of electrical energy from vehicle-induced airflow. The Vertical Axis Wind Turbine (VAWT) rotated effectively when exposed to airflow, proving its ability to capture wind energy from highway conditions. The connected generator motors produced electrical output, which was successfully converted from AC to DC using bridge rectifiers and stored in the battery through the charge controller.

The sensing and monitoring section performed accurately during testing. The voltage sensor and ACS712 current sensor continuously measured system parameters and transmitted real-time data to the ESP32 microcontroller. The OLED display successfully showed important electrical values such as voltage, current, power, and energy, allowing easy monitoring of system performance. The recorded values confirmed stable operation of the energy harvesting and storage system.

The smart lighting functionality also worked as expected. The LDR sensor effectively detected ambient light intensity and enabled automatic switching of the street light. During daytime, the LED remained OFF to avoid unnecessary power usage, while during low-light or nighttime conditions, the relay activated and turned the LED street light ON automatically. Overall, the proposed system achieved efficient renewable energy utilization, reduced dependency on conventional electricity, and demonstrated a practical solution for sustainable highway street lighting.

VIII. CONCLUSION

The Highway Vertical Wind Turbine Based Smart Street Light System demonstrates an effective approach for utilizing vehicle-generated airflow as a renewable energy source for street lighting. The proposed system successfully integrates a Vertical Axis Wind Turbine (VAWT), energy storage, sensing modules, and an ESP32-based smart control unit to generate, monitor, and efficiently utilize electrical power. Automatic light control using the LDR sensor helps reduce unnecessary energy consumption during daytime, while real-time monitoring improves system reliability. The overall system provides an eco-friendly, cost-effective, and sustainable solution for highway lighting, reducing dependence on conventional electricity and supporting green infrastructure development.

IX. FUTURE SCOPE

The proposed system can be further improved by increasing turbine efficiency through advanced blade design and lightweight materials to maximize power generation under varying wind conditions. Future enhancements may include the integration of **solar panels** to create a hybrid renewable energy system for more reliable power availability. IoT-based remote monitoring and cloud data storage can also be added for real-time analysis and maintenance prediction. Additionally, implementing AI-based traffic analysis could enable adaptive street light brightness control based on vehicle movement, further improving energy savings and smart city applications.

REFERENCES

[1] P. Gupta and R. Sharma, "Vertical Axis Wind Turbine for Highway Energy Harvesting," *International Journal of Engineering Research & Technology (IJERT)*, vol. 7, no. 5, pp. 245–250, 2018.
[2] A. Kumar, S. Patil, and M. Joshi, "Smart Street Lighting Using Renewable Energy Sources," *International Journal of Scientific Research in Engineering and Management*, vol. 3, no. 6, pp. 112–118, 2019.
[3] J. F. Manwell, J. G. McGowan, and A. L. Rogers, *Wind Energy Explained: Theory, Design and Application*, 2nd ed. West Sussex, UK: Wiley, 2010.
[4] T. Burton, N. Jenkins, D. Sharpe, and E. Bossanyi, *Wind Energy Handbook*, 2nd ed. Chichester, UK: Wiley, 2011.
[5] N. Patel and H. Mehta, "Automatic Street Light Control Using LDR and Microcontroller," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 9, no. 4, pp. 324–329, 2020.
[6] Espressif Systems, *ESP32 Series Datasheet*, Shanghai, China, 2023.
[7] Allegro Microsystems, *ACS712 Fully Integrated Hall Effect Current Sensor IC Datasheet*, 2022.
[8] M. H. Rashid, *Power Electronics: Circuits, Devices and Applications*, 4th ed. Pearson Education, 2013.
[9] S. Reddy, K. Rao, and P. Naidu, "ESP32 Based Real-Time Energy Monitoring System," *International Journal of Innovative Technology and Exploring Engineering*, vol. 10, no. 8, pp. 88–94, 2021.
[10] S. Singh and A. Verma, "Wind Energy Based Smart Highway Lighting System," *International Journal of Engineering Science and Computing*, vol. 12, no. 3, pp. 27654–27660, 2022.
[11] V. Joshi, P. Kulkarni, and R. Deshmukh, "IoT Enabled Smart Street Light Using Wind Energy," *International Journal of Computer Applications*, vol. 184, no. 22, pp. 15–20, 2023.
[12] B. K. Bose, *Modern Power Electronics and AC Drives*. Upper Saddle River, NJ, USA: Prentice Hall, 2002.
[13] C. C. Chan, "The State of the Art of Electric and Hybrid Vehicles," *Proceedings of the IEEE*, vol. 90, no. 2, pp. 247–275, 2002.
[14] H. Abu-Rub, M. Malinowski, and K. Al-Haddad, *Power Electronics for Renewable Energy Systems*. Wiley, 2014.
[15] D. Linden and T. B. Reddy, *Handbook of Batteries*, 4th ed. New York, USA: McGraw-Hill, 2011.
[16] M. Kezunovic, "Smart Grid and Intelligent Monitoring Systems," *IEEE Smart Grid Newsletter*, vol. 5, no. 2, pp. 10–18, 2019.
[17] F. Blaabjerg and D. M. Ionel, "Renewable Energy Devices and Systems," *IEEE Industry Applications Magazine*, vol. 21, no. 5, pp. 20–28, 2015.

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[18] A. S. Bahaj, "Generating Electricity from Highway Wind Energy," *Renewable Energy Journal*, vol. 35, no. 9, pp. 2033–2038, 2010.
[19] M. R. Patel, *Wind and Solar Power Systems: Design, Analysis and Operation*, 3rd ed. CRC Press, 2012.
[20] International Energy Agency (IEA), *World Energy Outlook 2023*, Paris, France: IEA Publications, 2023.