

DESIGN AND IMPLEMENTATION OF RENEWABLE ENERGY BASED SMART STREET LIGHTING SYSTEM USING HYBRID POWER GENERATION WITH SMART SOLAR TRACKING

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Abstract:

This study focuses on the design and development of a renewable energy-based smart street lighting system that uses hybrid power generation along with an intelligent solar tracking mechanism. The system combines solar and wind energy to create a dependable and independent power source for street lighting, particularly suitable for rural and remote regions where grid supply may be limited. Solar energy is collected through several solar panels connected in series, while wind energy is produced using a brushless DC motor functioning as a small wind turbine. To improve solar energy collection, a tracking system using light dependent resistors and a servo motor is applied to adjust the panel position according to sunlight direction. The generated power from both sources is stored in a battery for night-time use. An Arduino Nano controls the system operations, while an infrared sensor activates LED street lights only when motion is detected, reducing unnecessary energy consumption. The overall system provides a cost-effective, sustainable, and environmentally responsible solution for modern street lighting.

Keywords — Hybrid Power Generation, Wind Energy, Solar Energy, Smart Solar Tracking, Battery Storage, Smart Street Lighting, Energy Efficiency.

I. INTRODUCTION

The growing demand for electrical energy and the continuous reduction of conventional energy resources have increased the need for sustainable and efficient power solutions. Street lighting is an important public facility that supports safety, security, and transportation during night-time. Most traditional street lighting systems depend completely on grid electricity, which leads to high energy expenses and increased environmental impact due to carbon emissions. In many remote, rural, desert, forest, and border regions, reliable grid connectivity is either limited or unavailable, making it difficult to maintain consistent street lighting services. These limitations emphasize the necessity for independent, renewable, and energy-efficient lighting technologies. Renewable sources such as solar and wind energy provide clean and environmentally responsible alternatives that can significantly reduce reliance on fossil fuels and conventional electrical infrastructure.

Solar power is commonly used in outdoor lighting systems because of its wide availability and simple installation process. However, many conventional solar street lighting systems use fixed

solar panels that remain stationary throughout the day. Because the position of the sun changes continuously, fixed panels cannot always receive maximum sunlight, which reduces overall energy generation. In addition, solar-only systems may experience reduced performance during cloudy weather or low sunlight conditions. Wind energy can act as a supportive source of power, particularly in locations where wind flow is available during night-time or unfavourable weather. By integrating solar and wind energy in a hybrid system, the stability and reliability of energy production can be improved. Battery storage also plays an important role by storing generated energy for use during night-time. Furthermore, the use of smart solar tracking technology helps increase efficiency by allowing solar panels to follow the direction of sunlight and capture greater solar radiation.

This project presents the design and development of a hybrid renewable energy based smart street lighting system that combines solar and wind power with intelligent control mechanisms. Multiple solar panels are connected in series to increase voltage output, while a brushless DC motor functions as a small wind generator. The produced electrical energy is rectified, regulated, and stored in a battery for later use. An Arduino Nano microcontroller manages solar tracking and automatic street lighting functions. Light Dependent Resistors (LDRs) detect sunlight intensity and adjust panel orientation through servo motors. In addition, an infrared motion sensor activates LED street lights only during night-time and when movement is detected, which reduces unnecessary energy consumption. This integrated system offers a cost-effective, energy-efficient, and environmentally sustainable lighting solution suitable for remote and underserved areas while demonstrating the practical use of hybrid renewable energy in modern smart infrastructure.

II. PROPOSED STATEMENT

A. Connection diagram

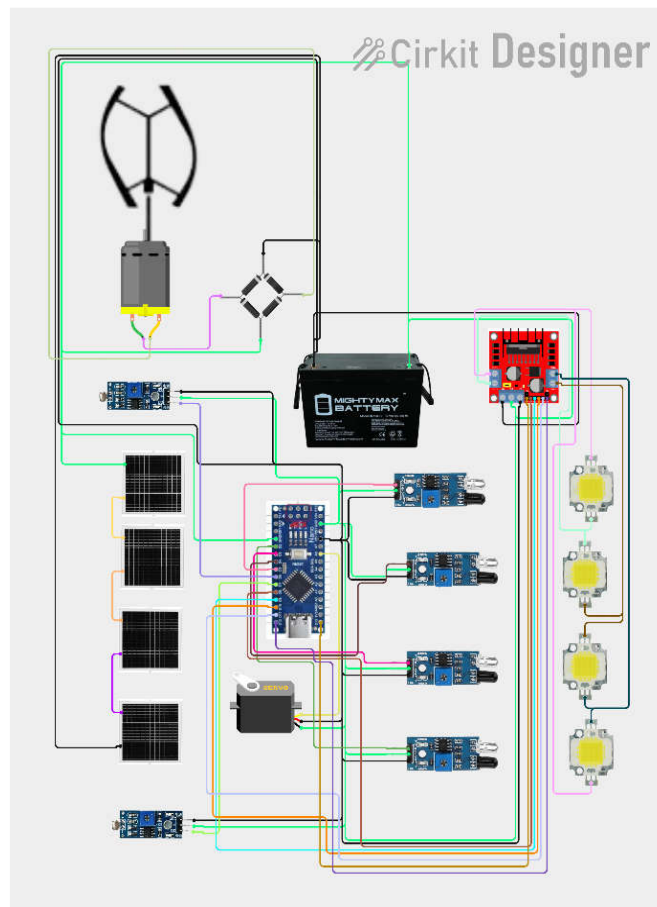


Fig. 1 Connection Diagram of Proposed System

III. WORKING

A. Hybrid Power Generation (Solar and Wind)

The proposed system produces electrical energy by combining solar and wind resources in a hybrid configuration. Solar power generation is achieved through four photovoltaic panels connected in series to obtain a higher output voltage and improve battery charging capability. During daytime, the panels absorb sunlight and convert solar radiation into direct current (DC) electricity. This generated energy becomes the primary power source for the system.

Along with solar energy, wind energy is also utilized to support power generation. A Brushless DC (BLDC) motor is employed as a small wind generator. When wind rotates the shaft of the motor, electrical energy is produced in the form of alternating current (AC). Since the storage unit requires DC input, the generated AC is passed through a bridge rectifier to convert it into DC.

The hybrid arrangement of solar and wind sources increases system reliability. When solar radiation decreases due to cloudy weather or evening hours, wind energy can still contribute to power generation. This complementary operation helps maintain continuous energy production and improves the efficiency and stability of the overall system.

B. Solar Tracking Mechanism

To improve the efficiency of solar energy collection, an automatic solar tracking mechanism is incorporated in the system. This mechanism helps the solar panels maintain proper alignment with the direction of sunlight throughout the day. Light Dependent Resistors (LDRs) are used as sensors to detect the intensity and direction of incoming sunlight.

The signals received from these sensors are processed by the Arduino Nano microcontroller. Based on programmed instructions, the controller determines the direction in which the solar panel should move. A servo motor is then activated to rotate the panel toward the region receiving the highest sunlight intensity.

This continuous adjustment enables the solar panel to capture maximum solar radiation compared to fixed-position panels. As a result, the system can generate more electrical energy and improve the overall efficiency of solar power utilization.

C. Energy Storage System

The electrical energy produced from both solar panels and the wind generator is stored in a rechargeable battery for later use. Since batteries require direct current for charging, the generated power from the wind turbine is first rectified and regulated before being supplied to the battery. The battery functions as the main energy storage unit of the system.

During night-time or periods of low energy generation, the stored energy is used to operate the street lighting system. This storage capability ensures continuous and reliable operation even when renewable energy sources are temporarily unavailable, thereby improving the stability and practicality of the entire lighting system.

D. Intelligent Automatic Street Lighting

The smart street lighting system is designed to reduce unnecessary energy consumption through automated control techniques. An LDR sensor is used to monitor surrounding light conditions and determine whether it is daytime or night-time. When sufficient sunlight is present, the lighting system remains turned off to conserve energy.

During night-time, the system becomes active and uses an infrared (IR) motion sensor to detect the presence of vehicles or pedestrians. When movement is identified, the sensor sends a signal to the Arduino Nano microcontroller. The microcontroller then processes this input and activates the LED street light according to the programmed control logic.

An H-bridge driver circuit is used as a switching interface between the controller and the lighting unit. This allows the LED street light to turn on only when required. If no motion is detected for a certain period, the system can switch off or dim the light to reduce power consumption.

Through this intelligent control approach, the system improves energy efficiency, extends battery life, and maintains adequate visibility and safety on roads while minimizing electricity wastage.

IV. HARDWARE SETUP

A. Solar Power Generation Unit

The solar power generation unit includes four photovoltaic solar panels connected in a series arrangement to increase the overall output voltage of the system. These panels absorb sunlight and convert solar radiation into direct current (DC) electrical energy through the photovoltaic effect. The produced DC power is then directed to the charging and regulation circuit. This electrical energy is further utilized for charging the battery and supplying power to different components of the system, supporting efficient operation of the smart street lighting setup.

B. Wind Power Generation Unit

Wind energy generation is achieved using a Brushless Direct Current (BLDC) motor that operates as a small wind turbine generator. When wind rotates the shaft of the motor, electrical energy is produced in the form of alternating current (AC). Since the storage system requires direct current, the generated AC output is passed through a bridge rectifier circuit. This conversion process transforms the AC power into DC power, which is then supplied to the charging system for battery storage.

C. Battery Storage Unit

A rechargeable battery is incorporated in the system to store electrical energy generated from both solar panels and the wind turbine. The DC power obtained after rectification and voltage regulation is supplied to the battery for charging. The battery functions as the primary energy storage unit of the system. During night-time or when power generation is low, the stored energy is used to operate the street lighting system, ensuring reliable and uninterrupted performance.

D. Solar Tracking Arrangement

The solar tracking system is designed using Light Dependent Resistors (LDRs), a servo motor, and an Arduino Nano microcontroller. The LDR sensors continuously monitor the intensity of sunlight from different directions. The detected signals are sent to the microcontroller, which analyzes the data according to programmed instructions. Based on this information, the controller activates the servo motor to rotate the solar panel toward the direction receiving the strongest sunlight, improving solar energy capture.

E. Smart Street Lighting Unit

The smart street lighting unit is built around an Arduino Nano microcontroller and includes several components such as an infrared (IR) motion sensor, an LDR sensor for detecting day and night conditions, an H-bridge driver circuit used as a switching interface, and LED street lights. During daytime, the lighting system remains turned off to avoid unnecessary energy use. At night, the IR sensor monitors movement from vehicles or pedestrians and sends a signal to the microcontroller. Based on the programmed control logic, the controller activates the LED street light through the driver circuit. If no motion is detected for a certain time, the system

switches off or dims the light, helping to reduce energy consumption and extend battery operating time.

V. HARDWER MODULE

The hardware section of the proposed system includes solar panels, a BLDC motor functioning as a wind generator, a bridge rectifier, a rechargeable battery, and an Arduino Nano microcontroller. Additional components such as LDR sensors, an IR motion sensor, a servo motor for solar tracking, an H-bridge driver circuit, and LED street lights are also incorporated. All these elements are combined to develop a hybrid renewable energy-based smart street lighting system designed for efficient and reliable operation.

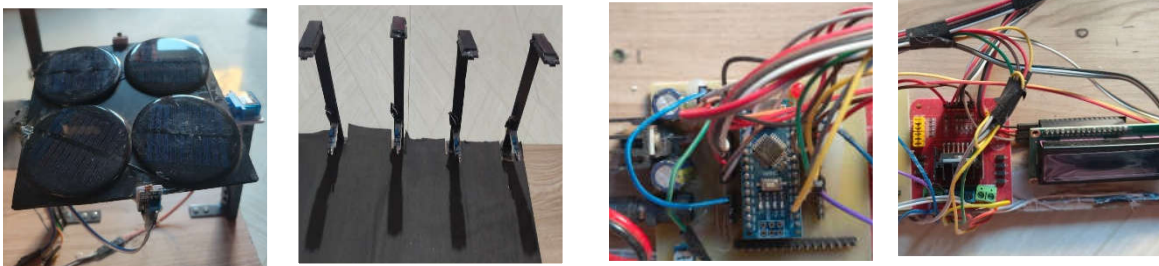


Fig. 2. Hardware setup of the design and implementation of renewable energy based smart street lighting system using hybrid power generation with smart solar tracking

VI. RESULT

TABLE I
HYBRID POWER GENERATION

Sr. No.	Time	Solar	Wind	Hybrid
1	Morning (9AM)	0.458 W	0.036 W	0.494 W
2	Afternoon (12PM)	0.933 W	0.036 W	0.969 W
3	Mid day(3PM)	1.041 W	0.036 W	1.077 W
4	Evening (6Pm)	0.642 W	0.036 W	0.678 W

VII. CONCLUSION

The proposed work successfully presents the design and development of a renewable energy based smart street lighting system that operates using a hybrid combination of solar and wind power along with an intelligent solar tracking mechanism. By integrating two renewable energy sources, the system provides stable and dependable power generation even under changing environmental conditions. The solar tracking arrangement improves the efficiency of energy collection by allowing the panels to follow the direction of maximum sunlight. A battery storage unit stores the generated electrical energy and supplies power during nighttime operation. The Arduino Nano microcontroller manages the solar tracking process and controls the automatic street lighting functions, including motion-based activation to reduce unnecessary energy consumption. The lighting system operates only when required, which helps improve energy efficiency and extend battery life. Overall, the prototype demonstrates a low-cost, eco-friendly, and grid-independent solution suitable for public lighting, particularly in rural and remote locations.

FUTURE SCOPE

A. Development of EV Charging Stations on Highways

In future applications, the hybrid renewable energy system can be extended to support the establishment of electric vehicle charging stations along highways. The electricity produced from combined solar and wind sources can be used for charging EV batteries, thereby decreasing reliance on conventional grid power. Such systems would encourage environmentally friendly transportation and assist in the wider adoption of electric vehicles. In addition, these charging facilities could be installed in remote highway areas where access to grid electricity is limited, enabling independent and sustainable operation.

B. On-Road Dynamic Charging Technology

Another possible advancement involves the introduction of dynamic wireless charging systems integrated within road infrastructure. Through this technology, electric vehicles could receive power while traveling on highways. Renewable energy generated from hybrid sources could supply the required electricity for the embedded charging system, reducing the need for large vehicle batteries and improving efficiency for long-distance travel.

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