Design And Implementation Of A Hybrid Solar–Wind Power Generation System Using Arduino Uno

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Abstract

The increasing demand for sustainable and eco-friendly energy sources has accelerated the development of hybrid renewable energy systems. This paper presents the design and implementation of a **dual power generation system** that integrates **solar and wind energy** to provide a reliable and continuous power supply. The proposed system utilizes an **Arduino Uno** as the central controller to manage power generation, battery charging, and load operation. A **12 V rechargeable battery** is employed for energy storage, while a **charging control circuit** ensures safe and efficient power management from both energy sources. A **light-dependent resistor (LDR)** and **servo motor** are incorporated to enable **solar tracking**, allowing the solar panel to automatically align with the direction of maximum sunlight, thereby improving energy harvesting efficiency. A **voltage sensor** continuously monitors the system voltage to protect the battery and connected load. The generated energy is used to power a **40 W load**, demonstrating the practical applicability of the system. The experimental results indicate that the hybrid solar–wind approach enhances power availability and system reliability compared to single-source renewable systems, making it suitable for small-scale and off-grid applications.

***Index Terms* -** Solar Energy, Wind Energy, Dual Power System, Arduino Uno, Renewable Energy, Battery Charging System.

I. INTRODUCTION

The rapid depletion of fossil fuel resources and the growing concerns over environmental pollution have intensified the global focus on **renewable energy sources**. Solar and wind energy are among the most widely available, clean, and sustainable energy resources, making them suitable alternatives to conventional power generation systems. However, the intermittent nature of individual renewable sources—such as reduced solar output during cloudy conditions or low wind availability—limits their reliability when used independently.

To overcome these limitations, **hybrid solar–wind energy systems** have gained significant attention, as they combine the complementary characteristics of both energy sources to ensure improved power availability and system reliability. This paper presents the design and development of a **dual power generation system** that integrates solar and wind energy using an **Arduino Uno**–based control unit. The system incorporates a **battery charging control circuit**, voltage monitoring, and an automatic **solar tracking mechanism using an LDR sensor and servo motor** to maximize energy harvesting. The primary motivation of this work is to develop a **cost-effective, efficient, and sustainable power generation model** suitable for small-scale and off-grid applications, while demonstrating the practical advantages of hybrid renewable energy systems.

II. SYSTEM OVERVIEW & ARCHITECTURE

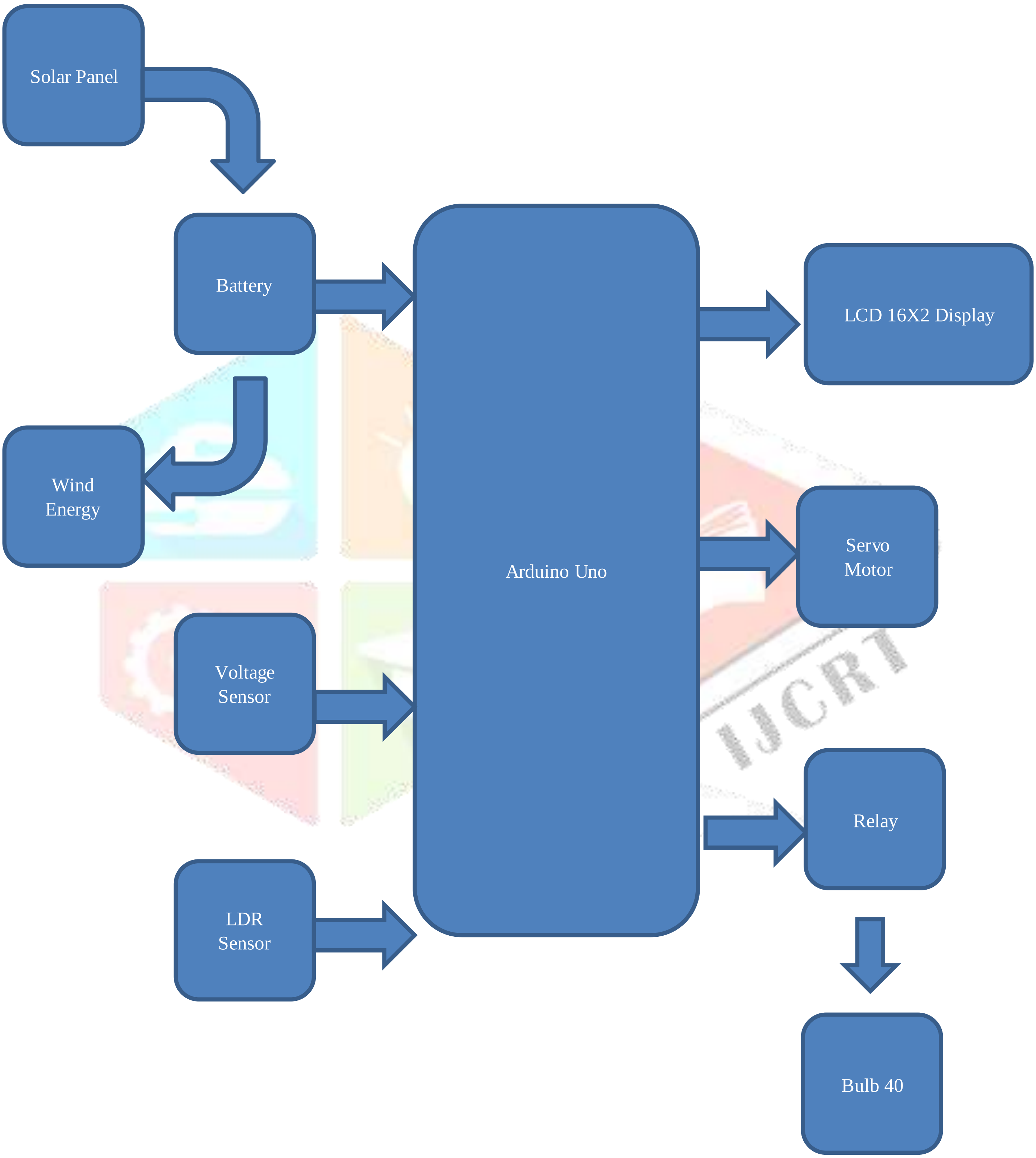


Fig 1 shows Block Diagram of the system

The proposed **dual power generation system** is designed to harness energy from both **solar and wind sources** to provide a continuous and reliable power supply. The overall system architecture consists of a **solar panel**, a **wind energy source**, an **Arduino Uno microcontroller**, a **12 V rechargeable battery**, a **charging control circuit**, multiple sensors, and an electrical load. The integration of these components enables efficient energy generation, storage, monitoring, and utilization.

The **solar panel** converts sunlight into electrical energy, while the **wind energy source** generates power from wind motion. The outputs from both energy sources are fed into a **charging control circuit**, which regulates the charging process and prevents battery overcharging or deep discharge. A **12 V battery** is used to store the generated energy and supply power to the load during periods of low solar or wind availability.

The **Arduino Uno** acts as the central control unit of the system. It continuously monitors system parameters using connected sensors and controls the overall operation. A **voltage sensor** measures the battery and supply voltage to ensure safe operating conditions, while an **LDR sensor** detects light intensity for solar tracking. Based on the LDR readings, the Arduino controls a **servo motor** that adjusts the orientation of the solar panel to align with maximum sunlight, thereby improving energy harvesting efficiency.

The stored energy is utilized to power a **40 W electrical load**, demonstrating the practical applicability of the system. This modular and scalable architecture makes the proposed dual power system suitable for small-scale renewable energy applications and off-grid power solutions.

III. HARDWARE COMPONENTS

The proposed dual power generation system is developed using commonly available and cost-effective hardware components. Each component plays a crucial role in ensuring efficient energy generation, control, and utilization.

1. ARDUINO UNO

The **Arduino Uno** serves as the main control unit of the system. It is responsible for monitoring sensor data, controlling the charging process, and managing the solar tracking mechanism. The microcontroller processes inputs from the voltage sensor and LDR sensor and generates control signals for the servo motor. Its simplicity, low power consumption, and ease of programming make it suitable for renewable energy–based applications.

2. SOLAR PANEL AND WIND ENERGY SOURCE

The **solar panel** converts solar radiation into electrical energy, while the **wind energy source** generates power from wind movement. These two renewable sources operate together to improve power availability. When sunlight is insufficient, wind energy contributes to power generation, ensuring better system reliability.

3. 12V BATTERY AND CHARGING CONTROLLER

A **12 V rechargeable battery** is used to store energy generated from both solar and wind sources. The **charging controller** regulates the charging process by maintaining safe voltage levels and preventing overcharging or deep discharge of the battery. This enhances battery life and ensures stable power delivery to the load.

4. VOLTAGE SENSOR

The **voltage sensor** continuously monitors the battery voltage and system output voltage. The sensed data is sent to the Arduino Uno, enabling real-time monitoring and protection of the battery and connected load from abnormal voltage conditions.

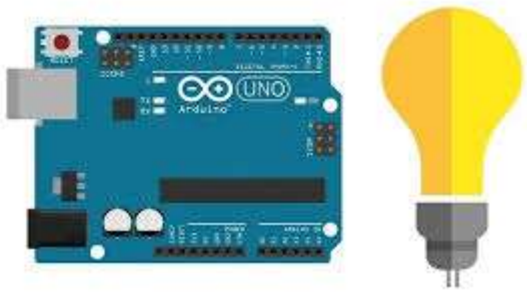
5. LDR SENSOR

The **Light Dependent Resistor (LDR)** sensor is used to detect light intensity. It provides input to the Arduino Uno for solar tracking operations. By comparing light levels, the system determines the direction of maximum sunlight for optimal panel orientation.

6. SERVO MOTOR FOR SOLAR TRACKING

The **servo motor** is used to adjust the position of the solar panel based on signals from the Arduino Uno. Controlled by LDR sensor data, the servo motor rotates the solar panel towards the direction of maximum sunlight, thereby increasing energy harvesting efficiency.

7. LOAD



A **40 W bulb** is connected as the system load to demonstrate the practical utilization of the generated power. The load operates using the energy stored in the battery, validating the effectiveness of the dual renewable energy system.

IV. WORKING PRINCIPLE OF THE DUAL POWER SYSTEM

The proposed dual power system operates by simultaneously utilizing **solar and wind energy sources** to ensure continuous power generation and efficient energy utilization. The working principle of the system is based on energy generation, regulated battery charging, intelligent solar tracking, and controlled load operation.

When sunlight is available, the **solar panel** converts solar radiation into electrical energy. At the same time, the **wind energy source** generates electrical power from wind motion. The outputs from both sources are fed into a **charging control circuit**, which regulates the voltage and current before supplying power to the **12 V battery**. This controlled charging mechanism prevents overcharging and deep discharge, thereby enhancing battery life and system safety.

The **Arduino Uno** continuously monitors the battery voltage using a **voltage sensor**. Based on the sensed voltage levels, the controller ensures safe power delivery to the connected load. An **LDR sensor** is used to detect the intensity and direction of sunlight. The Arduino processes the LDR readings and generates control signals for the **servo motor**, which adjusts the orientation of the solar panel to face the direction of maximum sunlight. This automatic solar tracking mechanism significantly improves the efficiency of solar energy harvesting compared to fixed-panel systems.

The energy stored in the battery is supplied to the **40 W load** whenever required. During periods of low solar availability, wind energy continues to contribute to battery charging, ensuring uninterrupted operation. Thus, the coordinated operation of solar and wind sources, along with intelligent control and monitoring, enables the system to provide a reliable and efficient dual renewable energy solution suitable for small-scale and off-grid applications.

V. RESULTS & DISCUSSION

The proposed dual power system was tested under different environmental conditions to evaluate its performance and reliability. The experimental results demonstrate that the integration of **solar and wind energy sources** significantly improves overall energy availability compared to single-source renewable systems. During daytime conditions with sufficient sunlight, the solar panel contributed the majority of the generated power, while the wind energy source provided additional support, especially during low-light or cloudy conditions.

The **solar tracking mechanism** using the LDR sensor and servo motor showed improved energy harvesting efficiency when compared to a fixed solar panel setup. The automatic alignment of the solar panel toward maximum sunlight resulted in a noticeable increase in output voltage and faster battery charging. The **voltage sensor** enabled effective monitoring of battery levels, ensuring stable system operation and protection against overcharging.

The **12 V battery** successfully stored energy generated from both sources and supplied power to the **40 W load** without interruption during testing. Practical observations indicated that the system maintained consistent load operation even when one of the energy sources was temporarily unavailable. This confirms the effectiveness of the hybrid approach in enhancing system reliability and energy utilization efficiency.

Overall, the results validate the feasibility of the proposed Arduino-based dual renewable energy system for small-scale applications. The system demonstrates stable performance, improved energy efficiency, and reliable load operation, making it suitable for off-grid and low-power renewable energy applications.

IV. CONCLUSION & FUTURE SCOPE

This paper presented the design and implementation of a **dual power generation system** integrating **solar and wind energy** using an **Arduino Uno**–based control unit. The proposed system effectively combines two renewable energy sources to overcome the limitations of individual power generation methods. The inclusion of a **battery charging control circuit**, **voltage monitoring**, and **automatic solar tracking using an LDR sensor and servo motor** significantly enhances energy harvesting efficiency and system reliability. Experimental results demonstrated stable operation and successful powering of a **40 W load**, validating the practical feasibility of the system for small-scale and off-grid applications.

The dual power approach offers several benefits, including improved power availability, better energy utilization, reduced dependency on conventional energy sources, and environmentally friendly operation. The modular design and low-cost components make the system suitable for rural electrification, standalone renewable setups, and educational purposes.

Future enhancements can focus on integrating **IoT-based monitoring** to enable real-time data visualization of power generation, battery status, and load consumption through cloud platforms. Additionally, the system can be upgraded to support **higher-capacity loads** by using advanced charge controllers, higher-rated batteries, and power inverters. Further improvements may include the implementation of **maximum power point tracking (MPPT)** techniques and intelligent energy management algorithms to further increase system efficiency and scalability.

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