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SMART HYBRID RENEWABLE ENERGY MANAGEMENT SYSTEM FOR REMOTE VILLAGES

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Abstract : A Smart Hybrid Renewable Energy Management System (SHRE) for remote villages integrates photovoltaic (PV) solar panels, wind turbines, battery storage, and grid connectivity to provide reliable electricity in rural and remote areas. The system leverages locally available solar and wind resources, storing excess energy in batteries to ensure uninterrupted power during low production periods, such as nighttime or windless days. Grid power acts as a backup to meet energy demands, enhancing system reliability and reducing energy costs. Smart monitoring and control optimize energy usage, minimizing wastage while contributing to sustainability by reducing fossil fuel dependence and greenhouse gas emissions. Scalable and adaptable, SHRE offers an efficient, cost-effective solution for rural electrification and energy sustainability.

IndexTerms - *Renewable Energy, Photovoltaic Panels, Wind Turbines, Battery Storage, Grid Backup, Energy Management*.

INTRODUCTION

Access to reliable electricity remains a significant challenge in rural and remote areas, where grid power is often unavailable or unreliable. The Smart Hybrid Renewable Energy (SHRE) management system for remote villages, integrating multiple renewable sources such as photovoltaic (PV) solar panels, wind turbines, battery storage, and grid connectivity, offers a sustainable and effective solution to this challenge. These systems harness solar energy during the day and wind energy under favorable conditions, creating a complementary power generation profile to ensure continuous energy supply. Excess energy generated during peak production periods is stored in batteries and utilized during low production times, such as nighttime or windless days.

The inclusion of grid power as a backup further enhances reliability, ensuring that energy demands are consistently met. The smart energy management aspect, supported by IoT-based monitoring and control, optimizes power generation, storage, and consumption, reducing energy costs and minimizing wastage. By decreasing reliance on fossil fuels, these systems contribute to sustainability goals and greenhouse gas emission reductions while promoting renewable energy adoption. Scalable and adaptable, the SHRE management system for remote villages provides an efficient and forward-thinking solution for rural electrification and energy independence .

LITERATURE REVIEW

Recent studies have explored various aspects of SHRE management systems for remote villages

A. Literature Survey

1. ***IoT Based Smart Power Grid Monitoring and Control Using Arduino Ch. Uday Sankar et al. - 2022***
   This Paper focuses on real-time monitoring and control of smart power grids. The system uses Arduino, sensors, and IoT technologies to track parameters such as voltage, current, and power usage. The paper highlights IoT's role in improving grid reliability, reducing losses, and enabling remote control for enhanced performance.

2. ***Review on Advancement in Solar Photovoltaic Monitoring Systems Fahad Saleh M. Abdallah et al. - 2021***
   This Paper provides a comprehensive review of recent developments in solar PV monitoring systems. The authors analyze sensor technologies, IoT platforms, and data processing techniques to improve the efficiency of solar energy systems. Key advancements include remote monitoring, fault detection, and performance optimization .

3. ***Solar Photovoltaic Remote Monitoring System Using IoT Kekre & Gawre - 2017***
   This Paper discuss about Solar Photovoltaic Remote Monitoring System Using IoT discusses an IoT-based monitoring

system for solar PV power plants. The paper highlights the use of real-time sensors and cloud platforms to collect and analyze solar power data. The system enhances energy management, enabling better decision-making and resource allocation.

4. ***Enhancement of Hybrid Power Systems Using IoT by Kalaiarasi et al. - 2016***
   This paper Proposes an IoT-based solution to optimize hybrid power systems that combine renewable sources like solar and wind. The system improves power efficiency through real-time monitoring, automated control, and data-driven performance analysis, ensuring continuous energy supply in hybrid setups.

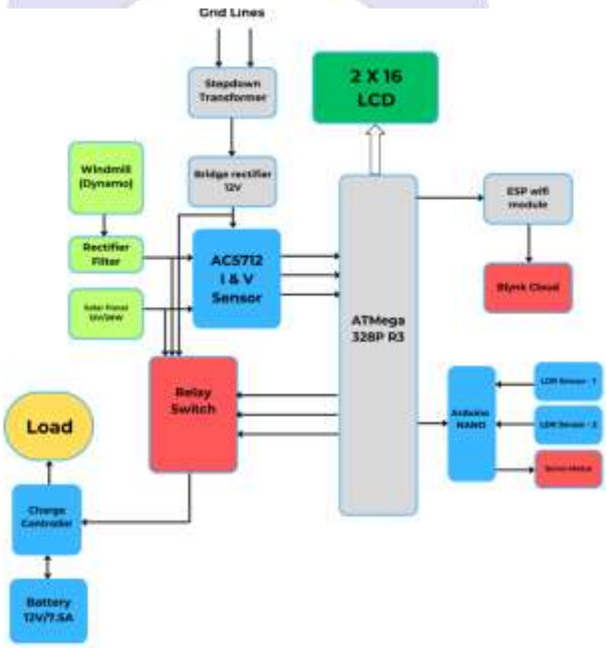
B. Proposed System

The Smart Hybrid Renewable Energy (SHRE) Management System for Remote Villages integrates solar panels, wind turbines, battery storage, and grid connectivity to provide a reliable and sustainable electricity supply in rural areas. The system generates power using solar and wind resources, stores excess energy in batteries, and uses grid power as a backup during low renewable generation periods. The charge controller ensures optimal battery charging, while a relay switch automatically selects the active energy source based on availability. IoT-based monitoring enables real-time tracking of system performance, optimizing energy usage, reducing dependence on fossil fuels, and ensuring uninterrupted power supply for economic and social development.

METHODOLOGY

A. Block Diagram

The block diagram illustrates a hybrid energy system that integrates renewable energy sources and grid power for efficient energy management. It features a stepdown transformer and regulator to covert grid voltage to 12V and 5V for system use.Renewable energy is harnessed through a solar panel and a windmill dynamo, with the generated AC power converted to DC by a rectifier filter. A relay switch manages the selection between power sources, while a charge controller regulates the charging of a 12V battery. The system is controlled by an ATMega328P R3 microcontroller, which coordinates operations, interfaces with sensors, a servo motor, and cloud connectivity for real-time monitoring. The load represents the devices powered by the system, ensuring uninterrupted operation and optimized use of renewable energy.



B. Working of Proposed System

The **SHRE management system for remote villages** combines renewable energy sources (solar and wind), battery storage, and grid power for reliable electricity supply. The block diagram consists of:

1. **Energy Generation**: Solar panels and wind turbines generate DC and AC power, respectively. The AC from the windmill is converted to DC via a rectifier.
2. **Power Regulation**: A **charge controller** manages energy flow to the battery, ensuring optimal charging.
3. **Storage**: A 12V battery stores excess energy for later use.
4. **Source Switching**: A **relay switch** prioritizes renewable energy and switches to grid backup during insufficient generation.
5. **Monitoring and Control**: The **microcontroller** processes data from sensors and controls energy flow.
6. **IoT Integration**: Real-time monitoring is enabled via an IoT module, transmitting system parameters to a cloud platform for remote access.
7. **Load Management**: The energy stored or directly generated is supplied to the load efficiently.

C. Components Description

1. Solar Panel (12V/20W):

Converts sunlight into DC electricity for immediate use or battery storage.

Fig. 2. Solar Panel

2. Windmill with Dynamo:

Captures wind energy, generating AC power that is rectified into DC for the system.

Fig. 3. Windmill with dynamo

3. Battery (12V/7.5Ah):

Stores excess energy from renewable sources to ensure continuous power supply during low generation periods.

Fig. 4. Battery

4. Charge Controller:

Prevents overcharging and deep discharging of the battery, ensuring safe energy regulation.

Fig. 5. Charge Controller

5. Relay Switch:

Automatically switches between solar, wind, and grid power based on availability, prioritizing renewable sources.

Fig. 6. Relay Switch

6. Microcontroller (ATMega328P R3):

Acts as the central controller, processing sensor data, managing power flow, and enabling IoT integration.

Fig. 7. Arduino

7. Current & Voltage Sensor (AC5712):

Monitors system voltage and current, providing data for energy management and analysis.

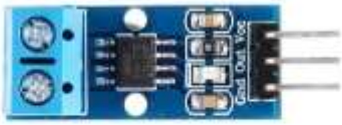


Fig. 8. V & I sensor

8. Wi-fi Module:

Enables real-time monitoring and control via cloud-based platforms or mobile applications.

Fig. 9. Wi-fi Module

9. LCD Display (2x16):

Displays system parameters such as power source status, battery level, and energy metrics.

Fig. 10. LCD display

10. Arduino Nano:

The **Arduino Nano** is a compact microcontroller board based on the **ATmega328P**, featuring 32KB Flash memory, 14 digital I/O pins (6 PWM), 8 analog inputs, and communication support for UART, SPI, and I2C. Operating at 5V with an input range of 7–12V, it is ideal for space-constrained applications such as IoT systems, robotics, energy management, and sensor-based automation projects.

Fig. 11. Arduino nano

C. Circuit Diagram

The circuit diagram represents a hybrid renewable energy system integrating solar and wind energy with a tracking mechanism and load management. The **solar panel** and **wind turbine** generate renewable energy, which is regulated and directed through a power supply system. An **Arduino board** acts as the central control unit, processing inputs from components like **LDR sensors** for solar tracking and interfacing with a **servo motor** to optimize solar panel positioning. The system also incorporates a **Wi-Fi module** for remote monitoring, a **2x16 LCD display** for status updates, and an **ACS712 sensor** to measure current flow. Power supply regulation is achieved using a **regulated power supply**, and relay drivers ensure seamless control of connected loads and devices. This integrated setup enables efficient renewable energy generation and usage. drivers ensure seamless control of connected loads and devices. This integrated setup enables efficient renewable energy generation and usage.

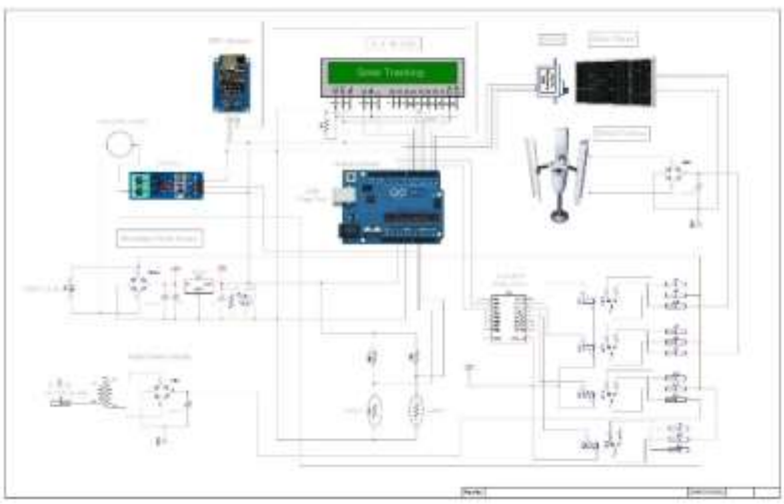


Fig. 12. Circuit diagram

IMPLEMENTATION AND DESIGN

A. Flow Chart

The flowchart represents the operational sequence of a hybrid renewable energy system that combines solar and wind energy sources. The process begins with energy generation from the **solar panel** and **wind turbine**, which is regulated and directed through a **power management system**. Inputs from **LDR sensors** are processed by the **Arduino board**, which controls a **servo motor** to adjust the solar panel's position for maximum sunlight capture. The system continuously monitors energy flow using an **ACS712 current sensor** and updates the user through a **2x16 LCD display**. Additionally, a **Wi-Fi module** facilitates remote monitoring and control of the system. The energy generated is stored in a battery or supplied to the load as required, ensuring efficient and uninterrupted power delivery.

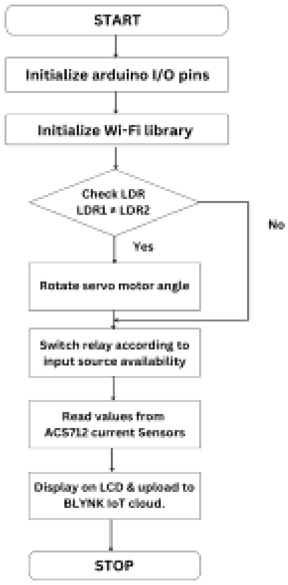


Fig. 13. Flow Chart

B. Setting Up the Arduino

1. **Arduino IDE**
   The **Arduino Integrated Development Environment (IDE)** is an open-source platform used to write, compile, and upload code to microcontroller-based boards like **Arduino Nano**. It supports programming languages such as **C** and **C++** and simplifies programming using built-in libraries and tools. The IDE allows direct interfacing with Arduino boards via **USB communication** and features an easy-to-use interface for development and debugging [1].
2. **Blynk Platform**
   Blynk is an IoT platform designed to monitor and control hardware remotely. It provides real-time visualization, data storage, and communication between hardware and mobile applications via **Blynk Cloud**.

RESULT AND ANALYSIS

A. Results

The project successfully integrates a **hybrid renewable energy system** combining solar and wind power. **Solar tracking** using LDR sensors and servo motors optimizes solar panel orientation, improving energy generation. The wind turbine supplements power during low sunlight conditions. The **Arduino Nano** serves as the central control unit, managing sensors and energy flow, while real-time system data is displayed on a **2x16 LCD** and monitored remotely via the **Wi-Fi module** and **Blynk app**. This setup ensures reliable, optimized energy production for off-grid applications.

Fig. 14. Prototype

B. System Performance

The system's performance was evaluated in terms of **energy generation**, **efficiency**, and **reliability**:

1. **Solar Tracking**: LDR sensors and servo motors enhanced solar panel output by maintaining optimal sunlight exposure.
2. **Wind Contribution**: The wind turbine provided supplementary power during low-light conditions.
3. **Energy Distribution**: The Arduino microcontroller ensured smooth operation, managing energy from solar, wind, and battery sources.
4. **Remote Monitoring**: Real-time data tracking and remote control through the **Blynk app** optimized energy management and system performance. The system demonstrated high efficiency and reliability in energy generation, storage, and load management, making it suitable for remote areas.

C. Performance Analysis

1. **Energy Generation**: Solar tracking significantly improved energy output, while wind turbines ensured continuous supply during variable conditions.
2. **Efficiency**: The hybrid system reduced grid reliance, with efficient energy storage and load balancing.
3. **Reliability**: Real-time monitoring via sensors (LDR, ACS712) and the Arduino ensured reliable operation with minimal downtime.
4. **Load Management**: Automatic power switching prioritized renewable sources, preventing energy wastage.
5. **Remote Monitoring**: The Blynk app provided real-time data visualization and system control for off-grid applications.

D. Challenges and Solutions

1. **Solar Tracking Issues**:
   a) *Challenge*: Environmental factors affect panel orientation.
   b) *Solution*: Improved LDR calibration and tracking algorithms.
2. **Wind Turbine Fluctuations**:
   a) *Challenge*: Inconsistent energy generation.
   b) *Solution*: Store excess energy in batteries during peak wind conditions.
3. **Battery Storage Limitations**:
   a) *Challenge*: Overcharging and limited capacity.
   b) *Solution*: Use smart charge controllers and expand battery capacity.
4. **Power Distribution**:
   a) *Challenge*: Managing energy flow from multiple sources.
   b) *Solution*: Integrate a smart relay-based power switching system.
5. **Wi-Fi Connectivity**:
   a) *Challenge*: Weak connectivity in remote areas.
   b) *Solution*: Use long-range Wi-Fi modules or LoRa communication.
6. **Blynk App Interface**:
   a) *Challenge*: Complex user interface.
   b) *Solution*: Simplify UI with intuitive controls and visual data representation.
7. **Power Consumption**:
   a) *Challenge*: High consumption by system components.
   b) *Solution*: Use low-power components and enable sleep mode.
8. **Data Accuracy**:
   a) *Challenge*: Real-time reporting inconsistencies.
   b) *Solution*: Calibrate sensors periodically and buffer data for smoother reporting.

By addressing these challenges, the system achieves **optimal performance**, providing an efficient, reliable, and remotely controlled renewable energy solution for off-grid applications.

CONCLUSION AND FUTURE SCOPE

A. Conclusion

The **Smart Hybrid Renewable Energy (SHRE) Management System for Remote Villages** successfully integrates solar and wind power to provide a sustainable and reliable energy solution for remote and off-grid areas. The system combines solar panels, wind turbines, and battery storage to ensure continuous power supply while minimizing dependency on external grid power. The use of the **ATMega328P microcontroller**, **LDR sensors**, and **ACS712 current sensors** enables real-time monitoring, solar tracking, and optimized energy management, enhancing the system's efficiency and reliability. Additionally, the integration of the **Blynk app** provides remote monitoring and control, allowing users to analyze energy performance and make adjustments conveniently. The project achieves its objective of delivering a cost-effective, scalable, and environmentally sustainable energy solution, offering a viable model for rural electrification and energy independence, particularly in areas with unreliable grid access.

B. Future scope

The future of hybrid energy systems lies in their ability to combine renewable energy sources like solar and wind with advanced energy storage technologies to create reliable, efficient, and sustainable power solutions. Increasing adoption of hybrid systems will be driven by growing environmental concerns, government incentives, and the need for energy reliability in regions with fluctuating renewable energy availability. Technological advancements, including improved energy storage, smart grid integration, and optimized energy management systems, will enhance efficiency and cost-effectiveness. Hybrid systems are particularly suited for **microgrid applications**, enabling localized power generation and resilience in remote areas or during grid disruptions. Potential applications include residential and commercial buildings for energy self-sufficiency, industrial facilities for reducing carbon emissions, and remote communities for providing reliable electricity access. Key challenges include seamless **grid integration** to manage energy fluctuations, reducing upfront system costs, and establishing supportive regulatory frameworks to promote hybrid system deployment. With ongoing advancements, hybrid energy systems are set to play a critical role in sustainable energy generation, addressing environmental challenges while improving energy accessibility and independence.

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