IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 12, December 2025

DOI: 10.17148/IJIREEICE.2025.131208

# LoRa BASED HYBRID POWER GENERATION SYSTEM

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**Abstract:** The project develops a solar–wind hybrid power generation system with battery storage to ensure a reliable and sustainable energy supply. It uses an energy management system, MPPT charge controllers, inverter, and real-time monitoring to optimize power generation, storage, and usage while protecting system components. Designed for residential and small commercial applications, the system provides continuous power, improves efficiency, and supports energy independence with reduced environmental impact.

**Keyword:** Wind Turbines, system, power, MPPT

## I. INTRODUCTION

The increasing global demand for clean, reliable, and sustainable energy has driven the adoption of hybrid renewable energy systems. Traditional power grids face challenges such as transmission losses, dependency on fossil fuels, and environmental concerns. Hybrid systems combining solar and wind energy offer a robust solution by leveraging the complementary nature of these sources—solar power is abundant during the day, while wind energy can be harnessed day and night, depending on weather conditions. To enhance efficiency and monitoring, this project integrates a LoRa (Long Range) wireless communication system, enabling real-time tracking of energy generation, storage, and consumption. The system ensures optimal power management through an Energy Management System (EMS) while providing remote monitoring via OLED display and cloud-based analytics

## II. OBJECTIVES

The objectives are:
1. Design and implement a hybrid solar-wind power system to maximize energy efficiency.
2. Monitor system performance in real time using LoRa-based wireless communication.
3. Optimize energy usage through an intelligent Energy Management System (EMS)

## III. METHODOLOGY

### A. BLOCK DIAGRAM

The block diagram illustrates the methodology of Hybrid Power generation system at transmitter end as shown in figure 1(a) and the receiver end shown in figure 1(b).

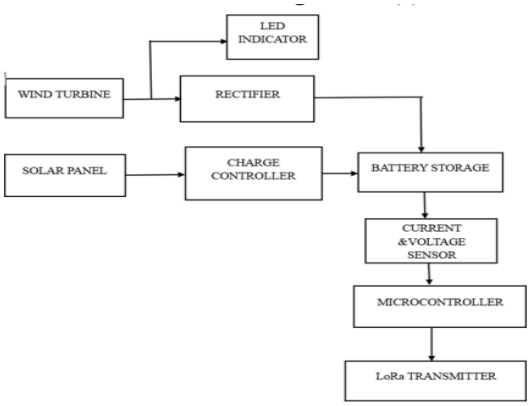
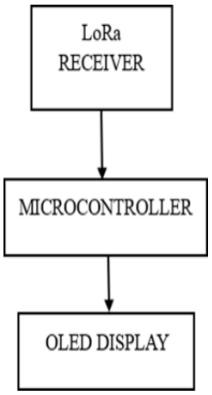



Figure 1(a) Transmitter end




(b) Receiver end

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B. FLOW CHART

As seen in Figure 2, this flow chart depicts the operation of a LoRa-based hybrid power generation system that combines solar and wind energy sources.

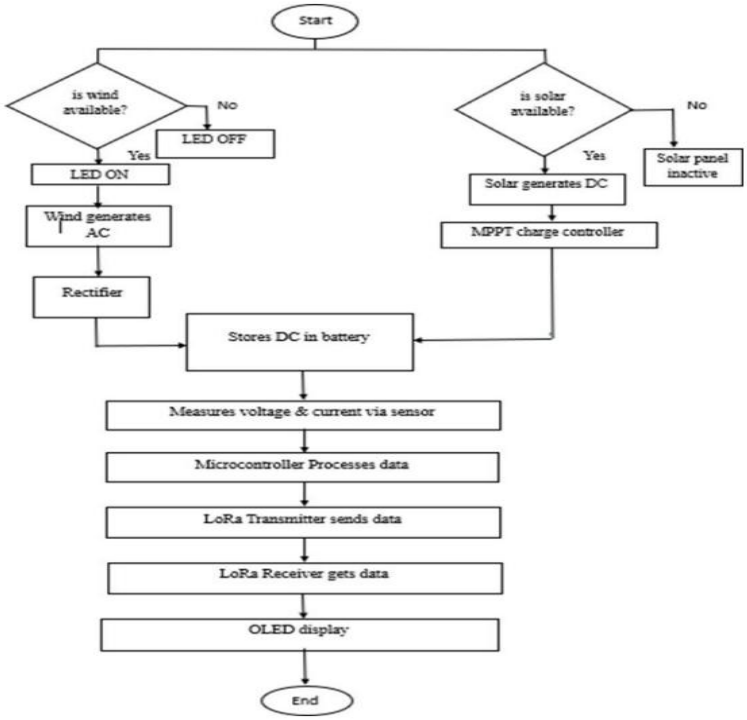
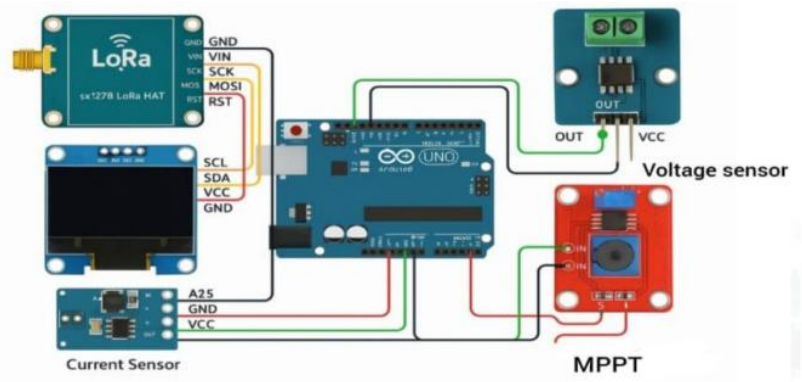



Figure 2. Flow chart

The process starts by checking the availability of wind and solar energy: If wind is available, an LED indicator turns ON, and the wind turbine generates AC power, which is then rectified to DC. If solar energy is available, the solar panel generates DC power, which passes through an MPPT charge controller for efficiency optimization. The generated DC (from either or both sources) is stored in a battery. The system measures voltage and current via sensors, and a microcontroller processes this data. The information is then transmitted using a LoRa module, received by another LoRa device, and displayed on an OLED screen. It ensures efficient hybrid energy harvesting and remote monitoring through LoRa communication.

C. SCHEMATIC DIAGRAM

The LoRa-based hybrid power generation system uses an Arduino Uno to monitor and manage renewable sources such as solar and wind energy. It employs voltage and current sensors for power measurement, an MPPT module to maximize energy harvesting, a LoRa module for long-range real-time data transmission, and an OLED display for local monitoring. The system ensures efficient energy utilization, remote accessibility, and scalability for rural and urban applications. Figure 3. shows the Circuit diagram of LoRa-enabled hybrid power generation monitoring system using Arduino Uno.

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## IV. HARDWARE DISCRIPTION

1. Solar Power Subsystem

Solar panels utilize the photovoltaic effect to convert sunlight into direct current (DC) electricity as shown in Figure 4, with monocrystalline silicon panels being particularly efficient and durable. This 10W panel is ideal for low-power applications such as IoT projects and lighting systems, and can integrate into hybrid renewable energy systems. Benefits include being a clean energy source, requiring minimal maintenance, and functioning in off-grid settings.

Figure 4. Solar Pannels

2.WindTurbine

The wind turbine as shown in Figure 5 converts wind's kinetic energy into electrical power and is designed as a compact vertical-axis turbine suitable for low to moderate wind speeds. It operates with low noise, captures wind from all directions, and is simple and reliable for various environments. The turbine is rated at 10 W, starts generating at about 2 m/s, operates at a rated wind speed of 12 m/s, and produces AC power that is converted to DC for battery storage.

Figure 5. Wind Turbine

3. MPPT Charge Controller

The MPPT charge controller is an advanced device that maximizes solar power system efficiency by continuously adjusting to the optimal voltage and current of the solar panel as shown in 5. An MPPT charge controller maximizes solar energy efficiency by continuously adjusting voltage and current to deliver optimal power to batteries under varying sunlight and temperature conditions. It efficiently transfers DC power from solar panels while protecting batteries from overcharging and deep discharge, thereby extending battery life. With efficiency above 95%, it supports 12V, 24V, and 48V systems and includes safeguards against overcharge, overcurrent, and reverse polarity.

Figure 6. MPPT Charge Controller

4. Current Sensor

The ACS712 current sensor as shown in figure7. measures current using the Hall Effect without breaking the circuit and converts it into a proportional analog voltage. In this system, it monitors output current, sends data to a microcontroller,

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and transmits it via LoRa for real-time monitoring and efficient energy management. It operates at 5V, offers complete electrical isolation, and is available in ±5A, ±20A, and ±30A variants.

Figure 7. Current Sensor

5. Voltage sensor

A voltage sensor measures the electrical potential difference in a circuit and converts it into a proportional analog signal for microcontroller processing. In this system, it monitors output voltage in real time to assess performance, prevent overvoltage, ensure safe battery operation, and transmit data via LoRa for remote monitoring. It typically supports 0–25V DC input, operates at 5V, and is widely used in battery monitoring and energy management systems.

Figure 8. Voltage sensor

6. Arduino UNO

The Arduino Uno, as shown in figure 9 which is powered by the ATmega328P, acts as the central controller in the LoRa-based hybrid power generation system. It collects and processes voltage and current data, interfaces with the MPPT charge controller, OLED display, and other components, and transmits data wirelessly via the LoRa module. Operating at 5V with a 16 MHz clock, it features 6 analog inputs, 14 digital I/O pins, and is programmed through the Arduino IDE using a USB Type-B.


Figure 9. Arduino UNO

7. OLED Display

The 0.96″ OLED display which is a compact, low-power screen with high contrast and excellent visibility in low light as shown in Figure 10. In the LoRa-based hybrid power generation system, it displays real-time voltage, current, power output, and communication status with clear detail using its 128×64 resolution. Based on the SSD1306 driver, it operates at 3.3V or 5V, consumes about 20 mA, requires no backlight, and offers long lifespan and wide temperature tolerance.

Figure 10. 0.96” OLED display module

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## V. SOFTWARE DESCRIPTION

1. Arduino Software

The Arduino Uno can be programmed using the Arduino IDE on Windows, macOS, and Linux. The IDE, written mainly in C/C++, allows easy code editing, compiling, and uploading of sketches to Arduino boards, with flexibility to modify layouts and schematics if needed. It includes built-in tools such as Auto Format, Archive Sketch, Fix Encoding & Reload, Serial Monitor, Programmer selection, and Burn Bootloader, which simplify debugging, code management, and microcontroller setup.

- Auto Format: Indents the code so that opening and closing curly braces line up, and the statements inside curly braces are properly indented.
- Archive Sketch: Archives a copy of the current sketch in .zip format, placing it in the same directory as the sketch.
- Fix Encoding & Reload: Resolves discrepancies between the editor's character map encoding and other operating systems' character maps.
- Serial Monitor: Opens the Serial Monitor window and starts exchanging data with any connected board on the currently selected port. Usually resets the board if it supports reset over serial port opening.
- Programmer: Used to select a hardware programmer when programming a board or chip without using the onboard USB serial connection. Normally used to upload a bootloader to a new microcontroller.
- Burn Bootloader: It installs a bootloader on the Arduino microcontroller, which is required for new ATmega chips but not for normal use. It also sets the correct fuse settings, provided the proper board is selected from the Boards menu.


Figure11 Arduino IDE

2. Embedded C

Embedded C is one of the most widely used programming languages for developing electronic devices. Every processor in an electronic system relies on embedded software to carry out specific tasks, and Embedded C plays a crucial role in controlling these operations. Many everyday devices such as mobile phones, washing machines, and digital cameras function using microcontrollers programmed in Embedded C. It is preferred in embedded system development because it is easy to understand, highly reliable, portable across platforms, and scalable for different applications.


Figure12 Embedded C Icon

## VI. LoRa MODULE

This is a LoRa (Long Range) module, specifically, the Ai-Thinker Ra-02 LoRa module enables long-range, low-power wireless communication. It uses spread-spectrum modulation, providing robust and interference-resistant data

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transmission while consuming minimal power. This specific module operates in the 433MHz frequency band and is based on the SemtechSX1278 transceiver chip. It's designed for easy integration into various IoT projects.
Specifications: Some Specifications are Frequency: 433MHz band, Modulation: LoRa spread spectrum, Power Output: Up to +20dBm, Sensitivity: -148dBm, Half-duplex SPI communication, Bit rate: 300kbps.
Key features: The system offers long-range communication up to 10–15 km under ideal conditions while consuming very low power, making it suitable for battery-operated devices. Its high sensitivity enables reliable reception of weak signals, and spread-spectrum modulation enhances communication robustness, making it versatile for various applications.
LoRa modules are commonly integrated with development boards and sensors and are widely used in LoRaWAN networks for low-power IoT applications. They use chirp modulation to simplify receiver design and improve reliability. A LoRa packet consists of a preamble, optional header, payload, and optional CRC; in explicit mode, the 3-byte header includes payload length, error correction rate, and CRC settings. The maximum payload size is up to 255 bytes, depending on parameters such as spreading factor, bandwidth, coding rate, and header/CRC usage.


Figure 13 Ai- Thinker Ra-02

## VII. RESULTS

The images illustrate the hardware configuration of the LoRa-based hybrid power generation system. Figure 14 (a) shows the arrangement of key components such as the Arduino board, LoRa modules, sensors, and MPPT charge controller, while Figure (b) highlights the wiring connections. All components are mounted on a wooden base for testing and measurement, enabling real-time data acquisition, processing, and wireless communication.

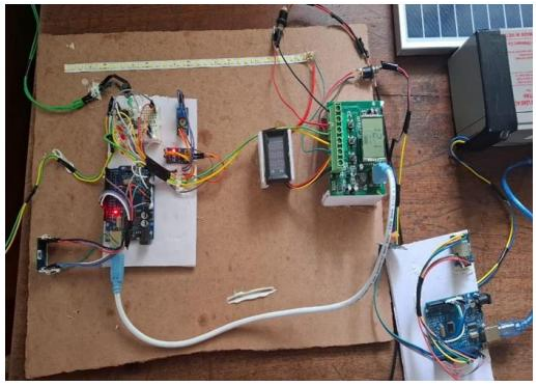

Figure 14 (a) Hardware setup of the LoRa-Based Hybrid Power Generation System.

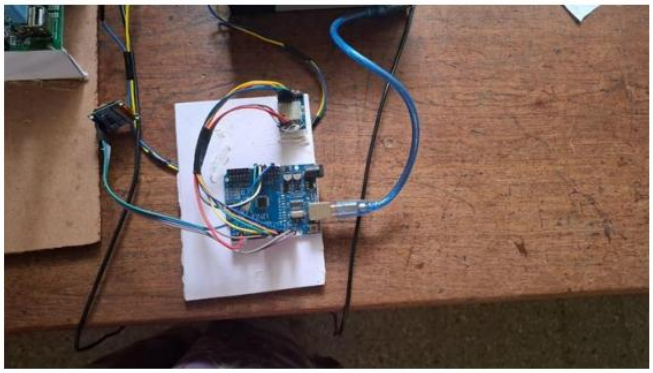

Figure 14 (b) Component interconnection.

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## VIII. APPLICATIONS

1. Smart Agriculture: LoRa-powered hybrid systems provide energy for irrigation and farm operations, while LoRa sensors monitor soil and weather conditions for optimized resource use.
2. Off-Grid Electrification: LoRa supports monitoring and control of hybrid power systems in remote villages, islands, and mountain regions where grid access is unavailable.
3. Educational Institutions in Remote Areas: Schools in off-grid regions can use hybrid systems for electricity, while LoRa helps monitor power consumption and remotely troubleshoot technical issues.
4. Smart Street Lighting in Villages: Hybrid systems can power street lights in offgrid regions, with LoRa enabling centralized monitoring and fault detection.
5. Environmental Monitoring Stations: Remote weather, air quality, or wildlife monitoring stations can run on hybrid power and transmit sensor data over LoRa networks.

## IX. ADVANTAGES

1. Renewable Energy Utilization: The hybrid system combines two renewable energy sources, solar and wind, which complement each other Enhanced Reliability.
2. Increased Energy Reliability: The system's ability to harness both solar and wind energy ensures that power is available even when one source is not generating efficiently.
3. Cost-Effectiveness in the Long Term: Once installed, the maintenance costs for solar panels and wind turbines are generally low. Technical Superiority
4. Scalability and Flexibility: The system can be scaled to meet various energy needs, from small residential setups to larger commercial or industrial applications.
5. Remote Monitoring & Control: LoRa enables real-time monitoring of power generation, storage, and consumption from distant locations, reducing the need for frequent site visits.

## X. LIMITATIONS

1. Complex System Design: Balancing solar and wind components with energy storage and inverters requires complex engineering and optimization.
2. High Initial Costs: The combined cost of solar panels, wind turbines, inverters, charge controllers, batteries, and monitoring systems is often higher than single source systems.
3. Distance and Propagation: Factors like distance between source and destination, line-of- sight, and propagation issues can affect data reception.
4. Restricted Duty Cycle: LoRa systems have a restricted duty cycle (1%), which can limit the frequency of data transmission.
5. Data Transmission Delay: LoRa's low data rate and long-range design can introduce delays, making it less suitable for time-critical control operations.

## XI. FUTURE SCOPE

1. AI-Driven Energy Management: Integrating artificial intelligence and machine learning algorithms to predict energy demand, optimize power distribution, and forecast solar/wind energy production more accurately.
2. Smart Grid Integration: Seamless connection with national or local smart grids to allow dynamic energy trading, enabling households or industries to sell excess power and improve grid stability.
3. Enhanced LoRa Networks: Upgrading to LoRaWAN with adaptive data rates and mesh networking to improve reliability, expand coverage, and support larger networks of sensors and devices.
4. Hybrid Storage Solutions: Combining battery storage with other advanced storage technologies like supercapacitors or hydrogen fuel cells for improved energy retention and quicker response times.
5. Self-Healing Networks: Implementing fault-tolerant communication and automated rerouting to ensure uninterrupted monitoring and control even during component failures.

## XII. CONCLUSION

The LoRa-based hybrid power generation system combines solar and wind energy with smart communication to provide a reliable and sustainable power solution. LoRa enables low-power, long-range monitoring of energy generation, storage, and system performance, even in remote areas. The system improves efficiency through remote monitoring, fault detection, and predictive maintenance, while reducing carbon emissions and operational costs. Its scalable design makes

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it suitable for homes, industries, and community projects, positioning it as a future-ready solution for clean energy and IoT-enabled smart grid management.

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