iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IV **Month of publication:** April 2025

DOI: https://doi.org/10.22214/ijraset.2025.69566

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

System to Manage Renewable Sustainable Sources more Efficiently

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Abstract: This paper presents a renewable energy harvesting and monitoring system developed using an Arduino microcontroller. The system combines two energy sources: a solar panel and a linear electromagnetic generator. The harvested energy is stored in a 12V battery through a charge controller, with intermediate stages such as a capacitor bank and energy conversion components. Real-time monitoring of voltage and current is achieved using sensors, and the data is displayed on a 16x2 LCD screen. The system also integrates IoT features for current and voltage tracking. Designed to be simple, cost-effective, and educational, it serves as a practical model for small-scale renewable applications .The project highlights hands-on implementation of energy conversion and monitoring techniques, aiming to build a foundational understanding of sustainable energy systems. It also provides flexibility for future expansion, making it a strong base for research-oriented improvements and real-world applications in the field of renewable energy.
Keywords: Renewable energy, Energy harvesting, Arduino, Linear electromagnetic generator, Solar energy, IoT monitoring, Voltage sensor, Current sensor, Charge controller, Capacitor bank, Sustainable energy system, 16x2 LCD display, Battery storage, Energy monitoring, Low-cost energy solution.

I. INTRODUCTION

In this study, a renewable energy harvesting and monitoring system is developed to track energy generated from sustainable sources with real-time data visualization and control. With the rising global emphasis on clean and sustainable energy, there is a growing need for efficient systems that can harness and monitor renewable sources. This project presents a compact solution that combines solar energy and a linear electromagnetic generator to generate power, which is stored in a 12V battery via a charge controller. Real-time monitoring of voltage and current is implemented using sensors, and the data is displayed through a 16x2 LCD screen. An Arduino microcontroller manages the entire process, offering ease of control and data processing. Additionally, IoT-based monitoring features are integrated for remote tracking of voltage and current. Designed to be simple, cost-effective, and educational, the system serves as a practical example of how small-scale renewable energy applications can be realized while offering a strong foundation for future enhancements and research. The implementation of dual energy sources not only ensures more consistent power availability but also showcases the potential of combining mechanical and solar energy for improved efficiency. By integrating both hardware and software elements, this project bridges the gap between theoretical knowledge and practical application. It also encourages students and researchers to explore innovative solutions that contribute to the broader goal of sustainable development.

II. LITERARTURE SURVEY

Several research efforts have explored Arduino-based renewable energy systems, emphasizing their potential and versatility in energy harvesting and monitoring applications.

S. M. Patil et al. [1]: Proposed applications of IoT in the renewable energy sector, offering insights into how Arduino can be utilized for solar panel monitoring. The study discusses the advantages, challenges, and potential innovations associated with this integration. The paper further discusses challenges such as sensor calibration, data transmission stability, and environmental influence on sensor accuracy. The study concludes by identifying areas of innovation such as AI-based predictive maintenance, energy efficiency tracking, and integration with mobile monitoring applications, contributing significantly to the development of smart renewable energy systems. Chang-Sic Choi et al. [2]: Developed a LoRa-based renewable energy monitoring system with an open IoT platform. The system continuously monitors renewable energy sources and lists various applications of LoRa technology, highlighting its potential in real-world applications. The authors analyze various technical aspects of LoRa such as data rates, interference resistance, and scalability, and emphasize its advantages over conventional wireless protocols. They also highlight real-world applications including rural electrification, agricultural systems, and decentralized microgrids, proving LoRa's viability in low-cost, wide-area monitoring networks.

Kabalci et al. [3]: Introduced an instant monitoring infrastructure for a renewable energy generation system constituted with wind turbines and solar panel arrays. The monitoring platform is based on current and voltage measurements of each renewable source, processed by a microcontroller. The authors emphasize the importance of immediate feedback in energy systems for fault detection, efficiency optimization, and smart control. Their approach includes a user-friendly graphical interface for monitoring, as well as suggestions for integrating GSM modules for remote alerts. The system provides a cost-effective and scalable solution for hybrid energy systems in both rural and urban environments.

Zhiyang Song et al. [4]This study presents the design and implementation of an intelligent monitoring system for solar energy power generation utilizing General Packet Radio Service (GPRS) technology. The system is structured into a three-layer architecture comprising the data acquisition and perception layer, the master array node network transmission layer, and the intelligent monitoring and control center. The hardware components include Ethernet communication modules and GPRS wireless communication circuits, while the sensing layer integrates devices such as light radiometers and temperature sensors. The software is designed to facilitate real-time data acquisition and transmission, enabling continuous monitoring and control of solar power systems. Experimental results demonstrate the system's effectiveness in enhancing maintenance efficiency and ensuring timely detection of operational issues in solar energy installations.

III. SYSTEM OVERVIEW

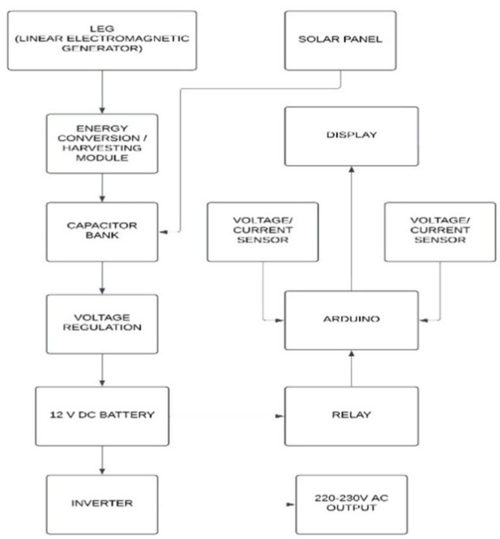


Fig. 1. Block Diagram

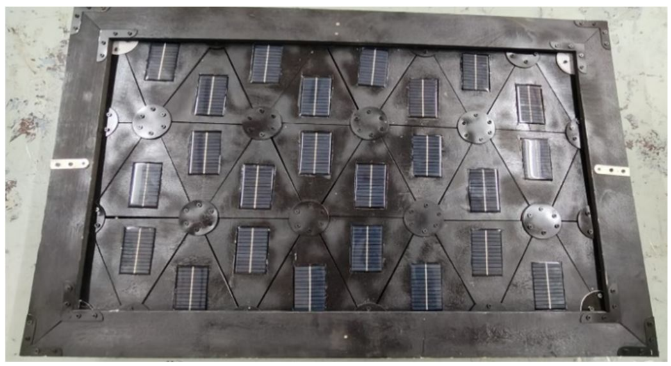
The proposed system efficiently manages and monitors renewable energy generated from multiple sources such as a Linear Electromagnetic Generator (LEG) and a solar panel. The key components and their functionalities are as follows:

1) Linear Electromagnetic Generator (LEG): Converts mechanical energy (e.g., vibration or motion) into electrical energy. The output is typically unregulated AC or pulsating DC.
2) Solar Panel: Captures solar energy and converts it into DC electricity.
3) Energy Conversion / Harvesting Module: Processes the raw energy from the LEG into usable DC voltage. This includes rectification, filtering, and impedance matching to improve efficiency.
4) Capacitor Bank: Temporarily stores the harvested energy to stabilize voltage and current flow before regulation. It also acts as a buffer to smooth out fluctuations.
5) Voltage Regulation: Ensures that the output from the capacitor bank is regulated to a suitable voltage level (e.g., 12V DC) for safe charging and operation.
6) 12V DC Battery: Stores regulated energy for long-term use. It supplies consistent power to the system and loads when generation is low.
7) Voltage/Current Sensors: Measure the voltage and current at different stages (e.g., after energy generation, before/after battery, and near output). These sensors send real-time data to the Arduino.

8) Arduino Board: Acts as the processing unit. It receives data from the sensors and controls the system accordingly. It also communicates with the display and relay.
9) 16x2 LCD Display: Displays voltage, current, and system status (e.g., source input, battery level, load status) in real-time, allowing user monitoring.
10) Relay Module: Controlled by the Arduino, it manages load connection and disconnection, ensuring protection and automation.
11) Inverter: Converts stored 12V DC battery power into 220–230V AC for household or industrial use.
12) 220–230V AC Output: Final usable power output for AC appliances.

This modular system architecture ensures efficient energy harvesting, real-time monitoring, secure energy storage, and reliable AC power delivery.

IV. METHODOLOGY



A. Linear Electromagnetic Generator (LEG)
The LEG is used as one of the primary energy sources in the system. Mechanical energy, often derived from motion or vibration, is converted into electrical energy through electromagnetic induction. The generated AC voltage is typically irregular and is therefore routed to the Energy Conversion / Harvesting Module for conditioning.

B. Solar Panel
The solar panel serves as the secondary energy source, converting sunlight into DC electricity. It supplies power directly to the capacitor bank and system modules during daylight conditions. Its output is monitored and displayed in real-time via the Arduino-based display unit.

C. Energy Conversion / Harvesting Module
This module rectifies and conditions the variable AC output from the LEG into a usable DC voltage. It consists of a bridge rectifier, capacitor bank, impedance matching circuit, and voltage regulation. The output of this module charges the capacitor bank and feeds into the voltage regulation stage.

D. Capacitor Bank
The capacitor bank stores energy temporarily from both the solar panel and LEG after rectification and harvesting. It also smooths out voltage fluctuations and provides a stable input to the voltage regulation unit. This ensures consistent charging of the 12V battery and prevents voltage dips during load changes.

E. Voltage Regulation
This stage ensures that the output voltage from the capacitor bank is stepped down or regulated to a safe, usable 12V DC. It protects downstream electronics and is essential for safe charging of the 12V battery.

F. 12V DC Battery
The regulated power is stored in a rechargeable 12V battery, which serves as the main energy reservoir. It supplies consistent DC power to the system and is connected to the inverter for AC conversion. Battery health and charge levels are monitored using sensors.

G. Inverter
The inverter converts the 12V DC from the battery into standard 220–230V AC, which can be used to power household appliances or be fed into a mini-grid. It plays a crucial role in making the system compatible with regular AC loads.

H. Voltage/Current Sensors
Two sets of sensors are used:
- One set monitors the input parameters (from the solar and LEG side).
- The other set monitors the battery output and load consumption. These sensors provide real-time analog data to the Arduino, enabling intelligent decision-making, system diagnostics, and safety operations.

I. Arduino
The Arduino Uno acts as the brain of the system. It reads sensor data, compares it with predefined safety thresholds, and sends control signals accordingly. It can:
- Activate or deactivate relays based on voltage/current limits.
- Display real-time data on the LCD.
- Trigger alerts via a buzzer (if connected).
- Enable safe energy flow management.

J. Relay
The relay acts as a switch between the battery and inverter. It is triggered by the Arduino to connect or disconnect the battery output based on voltage or current faults. This prevents over-discharge, overcurrent, or other hazardous conditions.

K. Display Unit (LCD)
The display module shows real-time data such as input voltage, current, battery status, and fault messages. It helps users monitor the system easily without needing a computer interface.

V. RESULT AND DISCUSSION
The system has been successfully tested in both simulated and real-time conditions where energy inputs from renewable sources were varied. The system responded accurately to changes in load and generation, demonstrating its capability to manage energy flow and ensure system stability.

Voltage and Current Monitoring: The voltage and current sensors precisely detected variations in input from the solar panel and Linear Electromagnetic Generator (LEG). Voltage surges and abnormal current values were successfully recorded and displayed, ensuring safe operation and efficient charging of the 12V DC battery.

Energy Harvesting and Storage Efficiency: Energy from both the solar panel and LEG was effectively harvested using the energy conversion module. The system regulated voltage using a capacitor bank and voltage regulation stage, charging the battery without overloading or undercharging.

These results confirm that the proposed system efficiently utilizes renewable energy sources and enables real-time monitoring of energy parameters. The system lays the foundation for sustainable energy use in small-scale applications and can be further enhanced with advanced control features and cloud-based data logging for deeper insights.

To further improve the efficiency and effectiveness of Pavegen's energy harvesting system, several technological upgrades can be considered. One significant enhancement would be refining the flywheel-based energy storage mechanism, which currently helps stabilize and extend the energy output from each footstep. By optimizing the rotational mass and bearings in the flywheel, greater kinetic energy retention and smoother energy transfer through electromagnetic induction can be achieved. Additionally, upgrading the generator coils and magnets could improve energy conversion efficiency. The integration of advanced power electronics, such as active rectification circuits and dynamic impedance matching, can also minimize energy losses during AC-to-DC conversion. On the energy storage front, transitioning from traditional batteries to supercapacitors or hybrid storage systems can ensure faster charging and longer lifecycle performance. Finally, incorporating IoT-based analytics and edge computing within each tile can allow for real-time monitoring, adaptive power routing, and predictive maintenance, making the system more intelligent and scalable for future smart city infrastructures.

VI. CONCLUSION

This paper presents an efficient and cost-effective solution for managing renewable sustainable energy using an Arduino-based hybrid system. The integration of solar and linear electromagnetic sources allows continuous and dual-mode energy harvesting, enhancing reliability and energy availability. Real-time monitoring using voltage and current sensors provides accurate data visualization through a display, helping users to track performance easily. The use of affordable and widely available components such as Arduino, sensors, and relays ensures the system's practicality, scalability, and accessibility for small-scale applications. Overall, the proposed system not only promotes clean energy utilization but also increases efficiency, supports sustainability, and lays a solid foundation for future upgrades like smart energy management and remote monitoring.

VII. ACKNOWLEDGMENT

We would like to express our sincere gratitude to Principal Mr. Vikrant Joshi and Head of Department Ms. Ashwini Khade for giving us the opportunity to present our project. Our heartfelt appreciation goes to our guide, Mr. Mahadeo Narlawar, for his invaluable guidance, continuous support, and constant motivation throughout this journey. We would also like to acknowledge the contributions of all the departmental faculty members and non teaching staff for their unwavering support in our learning.

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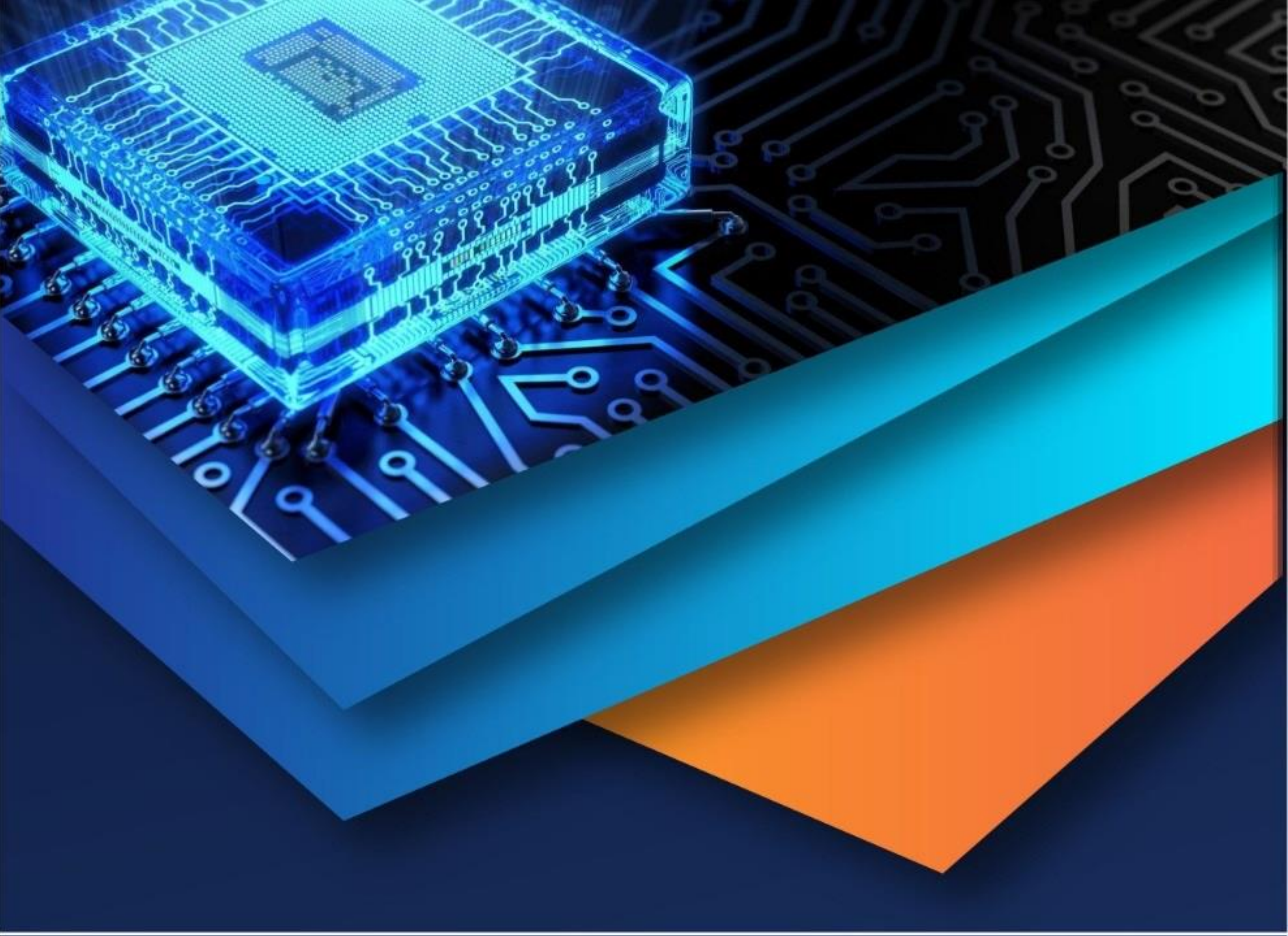

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