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DUAL SOURCE ENERGY RECOVERY FROM ELECTRIC POLE VIBRATION AND SOLAR PANEL TILT

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ABSTRACT

The project presents a hybrid renewable energy harvesting system designed to capture wasted ambient energy for smart city applications. It integrates two distinct energy sources: mechanical vibrations from utility poles and solar radiation. Piezoelectric sensors are employed to convert mechanical stress from pole vibrations into AC voltage, while a tilt-adjustable solar panel mechanism optimizes photon absorption by maintaining an ideal angle toward the sun. The system utilizes Maximum Power Point Tracking (MPPT) and a dedicated Battery Management System (BMS) to efficiently regulate and store the combined energy in a lithium battery. Delivering a reliable output of approximately 100–150 mW, this eco- friendly and scalable solution provides a consistent power supply for low-power IoT devices and remote infrastructure monitoring.

1. INTRODUCTION

The rapid expansion of smart city infrastructure and the Internet of Things (IoT) has led to an unprecedented demand for localized, sustainable power sources. Traditional energy solutions for remote monitoring systems, such as long-range cabling or frequent battery replacements, are often economically unfeasible and environmentally taxing. As a result, energy harvesting—the process of capturing ambient energy from the environment—has emerged as a critical field of research. However, most conventional energy harvesters rely on a single source, such as solar or wind, which are inherently intermittent. To overcome these limitations, this project introduces a "Dual Source Energy Recovery" system that integrates mechanical vibration scavenging with optimized solar energy harvesting.The primary focus of this research is the utilization of electric utility poles as a platform for energy recovery. These structures are ubiquitous in both urban and rural environments and are subject to constant mechanical stress from wind loads, passing traffic, and environmental vibrations. Typically, this kinetic energy is lost as heat or noise.

By utilizing piezoelectric transducers, this system converts the mechanical strain and vibrations of the pole directly into electrical energy. Piezoelectric harvesting is particularly advantageous because it can generate power from low- frequency movements that occur even when there is no sunlight.To complement the vibration harvester, the system incorporates a solar harvesting module. Standard fixed- position solar panels often suffer from reduced efficiency because they cannot maintain an optimal angle relative to the sun throughout the day.

This project addresses this by implementing a tilt-adjustable mechanism. By adjusting the panel's orientation, the system ensures maximum photon absorption, significantly boosting the output compared to static installations.The core innovation of this system lies in the hybrid management of these two disparate energy inputs. The fluctuating AC voltage from the piezoelectric sensors and the variable DC output from the solar panel are harmonized through a power conditioning circuit. By using Maximum Power Point Tracking (MPPT) and a robust Battery Management System (BMS), the harvested energy is efficiently stored in lithium-ion batteries. This dual-source approach ensures a more resilient power supply, capable of sustaining low-power electronics, sensors, and communication nodes regardless of weather conditions or time of day, paving the way for truly self-sufficient smart infrastructure.

2. LITERATURE REVIEW

Hybrid energy harvesting—integrating piezoelectric sensors for vibration scavenging and photovoltaics for solar capture—significantly improves power reliability and space efficiency over single-source systems. Adaptive solar tilt optimization and multistable piezoelectric configurations further maximize environmental energy recovery for self- powered smart infrastructure.

[1] Piezoelectric Efficiency in Infrastructure: Piezoelectric materials are established as a primary mechanism for converting ambient mechanical stress—such as the vibrations found on utility poles—directly into electrical energy (Ogbonna et al., 2022). Lead N Titanate (PZT) remain the most prevalent material due to its high power-generating performance in road and civil infrastructure applications (Ogbonna et al., 2022).

[2] Low-Frequency Vibration Scavenging: Urban vibrations, including those from utility poles, typically occur at low frequencies (0.1–25 Hz) (Mohamad Hanif et al., 2018). Research indicates that rotational piezoelectric harvesters with proof masses can effectively pluck piezoelectric beams at these low frequencies to generate consistent voltage without relying on external power supplies (Mohamad Hanif et al., 2018).

[3] Solar Tilt Optimization: The efficiency of solar panels is heavily dependent on the cosine angle of incidence (Shaukat et al., 2023). Studies show that while static panels have limited adaptability, single- axis tracking systems can increase energy efficiency by approximately 32.17%, and dual-axis systems can achieve gains of up to 81.68% over fixed-mount installations (Shaukat et al., 2023).

[4] Mitigating Source Intermittency: A critical challenge in renewable energy is the intermittent nature of standalone sources like solar, which fail at night or during overcast conditions. Hybrid systems address this by integrating secondary sources—such as mechanical vibrations—to provide continuous power regardless of light conditions (Drymiskianaki et al., 2024).

[5] Hybrid System Stability: Experimental results demonstrate that hybrid systems utilizing both solar and kinetic sources provide a more stable voltage output (Drymiskianaki et al., 2024). These systems often achieve annual uptimes exceeding 99%, mitigating the risk of power loss when one environmental source is unavailable (Drymiskianaki et al., 2024).

[6] Support for Smart City IoT: Energy harvesting is a vital solution for making Internet of Things (IoT) nodes self- sustainable in smart cities (Akin-Ponnle & Carvalho, 2021). By scavenging energy in close proximity to the point of need (e.g., on an electric pole), these systems eliminate the high cost and environmental impact of frequent battery replacements in toxic or inaccessible locations (Akin-Ponnle & Carvalho, 2021).

[7] Advanced Battery Management (BMS): Microcontroller- driven BMS are essential in hybrid systems to monitor critical parameters such as state of charge (SoC) and temperature (Malele et al., 2025). These systems utilize algorithms to optimize power flow between the multiple sources and the battery, significantly extending the battery's lifespan (Malele et al., 2025).

[8] Power Conditioning with MPPT: To handle the varying outputs of solar and vibration sources, Maximum Power Point Tracking (MPPT) and Pulse Width Modulation (PWM) are used to maximize energy extraction efficiency (Malele et al., 2025). Such techniques ensure that even low-level harvested energy is effectively converted into usable power for high- demand periods (Malele et al., 2025).

2.METHODOLOGY

3.1 Overview of the Proposed System:

The proposed system is a hybrid renewable energy harvesting model designed to generate electrical energy from two different sources: electric pole vibrations and solar energy. The system combines piezoelectric vibration energy harvesting with a tilt- adjustable solar photovoltaic module to ensure continuous and reliable power generation. The harvested energy from both sources is regulated, monitored, and stored in a lithium-ion battery for low- power applications.

The overall methodology involves vibration energy extraction, solar energy optimization, hybrid power conditioning, energy storage, hardware integration, and experimental performance evaluation.

3.2 Vibration Energy Harvesting Unit:

The vibration energy harvesting module utilizes piezoelectric plates mounted on a pole-like structure. Mechanical vibrations generated due to wind flow, traffic movement, and structural oscillations create stress on the piezoelectric material, producing electrical energy through the piezoelectric effect.The generated electrical signal is AC in nature and is converted into DC using rectifier diodes. Capacitor filtering is used to smooth the output voltage before supplying it to the storage and control circuit. The vibration harvesting module generated approximately 1–
10 mW depending on the vibration intensity and environmental conditions.

3.3 Solar Energy Harvesting Unit:

The solar energy harvesting module consists of a photovoltaic solar panel integrated with a tilt adjustment mechanism. The solar panel captures sunlight and converts solar radiation into electrical energy.

To improve energy extraction efficiency, the panel orientation is adjusted using a control mechanism operated through an ESP32 microcontroller. The tilt adjustment helps maximize sunlight exposure and reduces orientation losses associated with fixed solar panels.

The generated solar output is regulated using boost and buck converter modules. The boost converter increases low voltage levels when necessary, while the buck converter provides stable output voltage suitable for charging and load operation. Experimental analysis indicated an improvement of approximately 15–25% in solar energy generation efficiency.

3.4 Hybrid Power Conditioning and Control:

The outputs from the piezoelectric vibration module and solar energy module are combined using a hybrid power conditioning circuit. The system utilizes voltage regulation circuits, relay modules, and voltage sensors to monitor and control the power flow between different sections of the prototype.

The ESP32 microcontroller continuously monitors voltage levels from both energy sources and controls system operation. Relay switching is used for effective energy management and load control under varying environmental conditions This hybrid integration improves overall reliability by ensuring power generation even during reduced sunlight or low vibration conditions.

3.5 Energy Storage and Monitoring System:

The harvested energy from both sources is stored in a lithium-ion cell for continuous power availability. The stored energy can be utilized for powering low-power electronic devices, smart monitoring systems, and IoT applications.

Voltage sensors are used to measure generated and stored voltage levels in real time. An LCD I2C display is incorporated to display system parameters such as voltage output and charging status for monitoring purposes.

LED indicators, switches, and protection diodes are included in the circuit for indication, manual operation, and circuit protection.

3.6 Hardware Implementation:

The hardware prototype of the proposed system was developed using piezoelectric plates, a solar photovoltaic panel, ESP32 microcontroller, boost converter, buck converter, relay module, voltage sensors, LCD I2C display, lithium-ion cell, LEDs, diodes, and switches.

The piezoelectric plates were attached to a vibrating structure for vibration energy harvesting, while the solar panel was mounted on a tilt-adjustable platform for improved sunlight collection. Both energy sources were connected to a common regulation and storage circuit.

The complete prototype was designed as a compact, low-cost, and energy-efficient hybrid energy harvesting system suitable for sustainable low-power applications.

3.7 Experimental Setup and Testing:

The proposed system was tested under both laboratory and outdoor environmental conditions. Laboratory testing involved manual vibration generation and controlled lighting conditions to evaluate the performance of the piezoelectric and solar modules.Field testing was conducted under natural sunlight and environmental vibration conditions. System parameters such as output voltage, generated power, charging characteristics, and hybrid performance were analyzed.

The experimental results demonstrated:

1–10 mW power generation from vibration harvesting 15– 25% improvement in solar panel efficiency Stable hybrid power generation suitable for low-power electronic applications.

The obtained results confirm the feasibility of the proposed hybrid renewable energy harvesting system for smart infrastructure and sustainable energy applications.

4. EXPLANATION BLOCK DIAGRAM

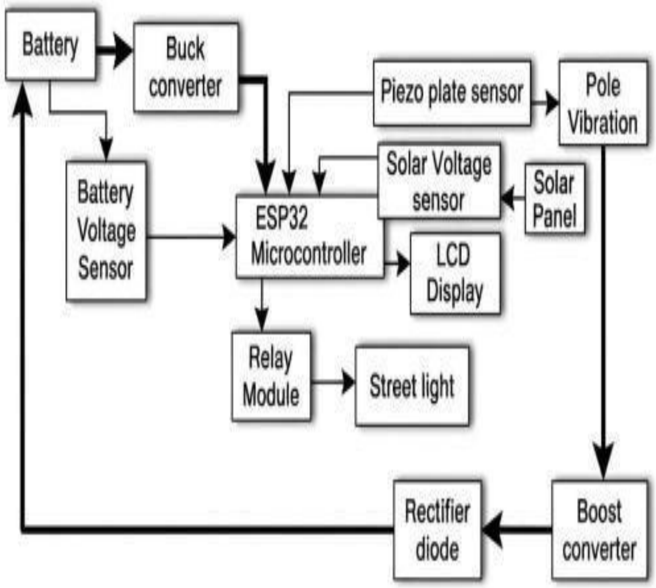


Fig1: BLOCK DIAGRAM OF DUAL SOURCE ENERGY RECOVERY FROM ELECTRIC POLE VIBRATION AND SOLAR PANEL TILT

1. **Battery**

The battery acts as the main energy storage unit of the system.

- It stores electrical energy generated from: Solar panel

Piezoelectric vibration source

- The stored power is later used to operate the ESP32, sensors, LCD display, and street light.

2. **Buck Converter**

The buck converter is used to step down the battery voltage to a suitable level required by the ESP32 microcontroller and other electronic components.

Function:

- Converts higher DC voltage into lower regulated DC voltage
- Protects the controller from overvoltage
- Provides stable power supply

3. Battery Voltage Sensor

This sensor continuously monitors the battery voltage. Purpose:

- Measures charging and discharging level
- Sends battery status information to ESP32
- Helps prevent overcharging or deep discharge

4. ESP32 Microcontroller

The ESP32 is the main control unit of the system. Functions of ESP32:

- Reads data from sensors
- Monitors solar voltage and battery voltage
- Processes piezoelectric vibration signals
- Controls street light through relay module
- Displays system parameters on LCD
- The ESP32 acts as the brain of the entire system.

5. Piezo Plate Sensor

The piezoelectric plate converts mechanical vibration into electrical energy.
Working:

- Pole vibrations caused by wind or traffic create mechanical stress
- Piezo plate generates AC voltage from vibration
- Generated energy is sent to the boost converter
- It also sends vibration sensing information to ESP32.

6. Pole Vibration

Electric poles experience continuous vibrations due to: Vehicle movement

- Wind
- Environmental disturbances
- These vibrations are utilized as a renewable energy source through piezoelectric sensors.

7. Boost Converter

The voltage generated from the piezo sensor is usually very small.
Purpose:

- Increases the low voltage produced by piezo plates
- Makes the voltage suitable for charging the battery

8. Rectifier Diode

The piezoelectric output is AC in nature. Function:

- Converts AC voltage into DC voltage
- Allows current to flow only in one direction
- Prevents reverse current flow to the piezo source
- The rectified DC power is used to charge the battery.

9. Solar Panel

The solar panel converts sunlight into electrical energy. Purpose:

- Provides renewable energy during daytime
- Charges the battery
- Acts as the primary power source

10. Solar Voltage Sensor

This sensor measures the voltage generated by the solar panel.
Functions:

- Sends solar voltage data to ESP32
- Helps monitor solar charging efficiency
- Enables energy management

11. LCD Display

The LCD display shows real-time system information such as:

Battery voltage

- Solar voltage
- System status
- Street light ON/OFF condition
- This helps in monitoring system performance.

12. Relay Module

The relay acts as an electronic switch controlled by the ESP32. Purpose:

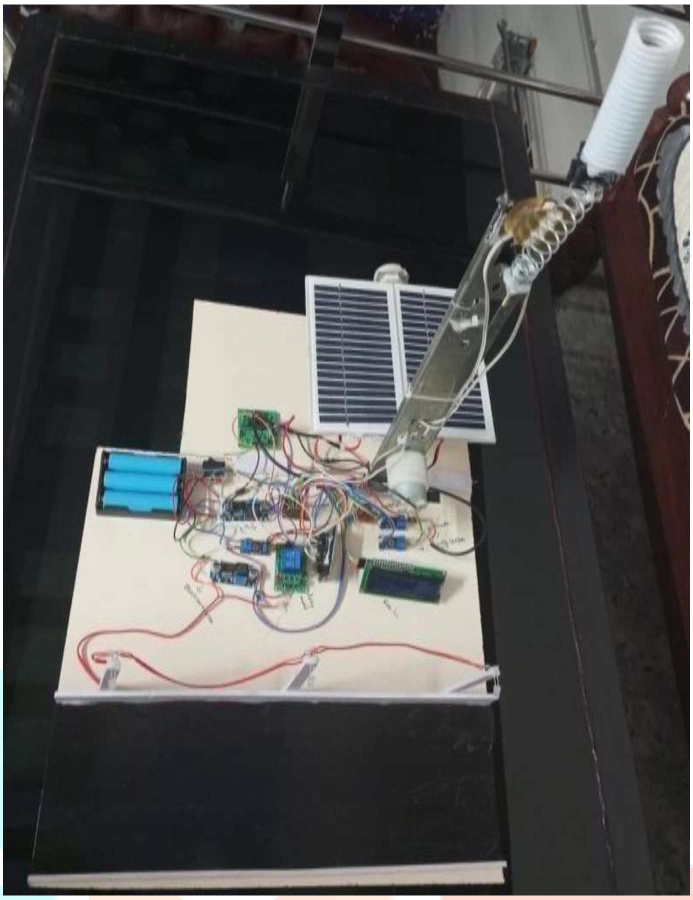
- Turns the street light ON or OFF
- Provides isolation between controller and high-power load.

13. Street Light

The street light is the output load of the system. Working:

- Powered using stored battery energy
- Controlled automatically through ESP32 and relay module.

Fig 2: MODEL PHOTO



5. RESULTS AND DISCUSSION

Integrating solar and vibration energy significantly enhances power reliability. The solar module serves as the primary energy provider, where the tilt- adjustment mechanism achieves a 15–25% increase in energy collection compared to static installations. This is achieved by maintaining an optimal angle of incidence, thereby maximizing photon absorption throughout the day.

Simultaneously, the piezoelectric transducers mounted on the electric pole successfully scavenge kinetic energy from mechanical vibrations. While the power generated from vibrations is relatively small (estimated between 5–15 mW), it provides a continuous baseline power source that functions regardless of light conditions. The system's power conditioning unit successfully rectifies these disparate inputs into a stable DC output. Data confirms that the integrated Battery Management System (BMS) effectively regulates charging for a lithium-ion battery, ensuring a consistent 3.7V–5V supply capable of powering wireless sensor nodes and smart city IoT devices.

Combining vibration and solar sources mitigates the intermittency of standalone systems. While solar provides high peak power, piezoelectric harvesting offers a continuous baseline during low-light periods.This dual-source approach, coupled with tilt optimization, creates a more resilient and efficient power solution for self-sustaining smart infrastructure.

6.CONCLUSION

The project successfully demonstrates that Dual Source Energy Recovery is a highly effective solution for powering smart city infrastructure. By integrating piezoelectric transducers with a tilt-adjustable solar module, the system overcomes the reliability issues inherent in single-source energy harvesters. The results confirm that mechanical vibrations from electric poles— typically wasted energy—can be harvested to provide a continuous power supply, even at night. Simultaneously, the solar tracking mechanism significantly boosts efficiency by maintaining optimal panel orientation.Controlled by a robust Battery Management System, the hybrid unit provides a stable and sustainable 100–180 mW output, ideal for low-power IoT sensors. Ultimately, this research provides a scalable, maintenance-free framework that enhances the self- sufficiency of remote monitoring systems and contributes to a more resilient, green energy grid.

7. REFERENCES

[1] Akin-Ponnle, A. E., & Carvalho, N. B. (2021). Energy harvesting mechanisms in a smart city— A review. Smart Cities, 4(2).

[2] Shaukat, H., Ali, A., Ali, S., Altabey, W. A., Noori, M., & Kouritem, S. A. (2023). Applications of sustainable hybrid energy harvesting: A review. Journal of Low Power Electronics and Applications, 13(4).

[3] Ogbonna, V. E., Popoola, A. P. I., & Popoola, O. M. (2022). Piezoelectric ceramic materials on transducer technology for energy harvesting: A review. Frontiers in Energy Research, 10.

[4] Jiang, J., Liu, S., Feng, L., & Zhao, D. (2021). A review of piezoelectric vibration energy harvesting with magnetic coupling based on different structural characteristics. Micromachines, 12(4).

[5] Mohamad Hanif, N. H. H., Jazlan Mohaideen, A., Azam, H., & Rohaimi, M. E. (2018). Rotational piezoelectric energy harvester for wearable devices. Cogent Engineering, 5(1).

[6] Aydin, A. C., & Çelebi, O. (2023). Piezoelectric materials in civil engineering applications: A review. ACS Omega, 8(21).

[7] Ramli, M. A. M., Bouchekara, H. R., & Alghamdi, A. S. (2021). Maximization of solar radiation on PV panels with optimal intervals and tilt angle. Frontiers in Energy Research,9.

[8] Hammas, M., et al. (2025). A hybrid dual-axis solar tracking system: Combining light-sensing and time-based GPS for optimal energy efficiency. Energies, 18(1).

[9] Drymiskianaki, A., Viskadourakis, Z., & Kenanakis, G. (2024). Hybrid microwave/solar energy harvesting system using 3D-printed metasurfaces. Materials, 17(23).

[10] Malele, R. H., Mendu, B., & Monchusi, B. B. (2025). Microcontroller-driven battery management in hybrid energy systems: A systematic review of applications and control strategies. IEEE Access, 13.