SUSTAINABLE HYBRID ENERGY HARVESTING FOR SELF-POWERED DEVICES.

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Keywords:

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Introduction:

The rapid advancement of modern electronic devices such as IoT sensors, wearable systems, and remote monitoring units has created a growing demand for reliable and continuous power sources. Conventional batteries suffer from limitations such as finite lifespan, frequent replacement, maintenance costs, and environmental concerns. These challenges have led to the exploration of sustainable alternatives like energy harvesting systems.

Energy harvesting refers to capturing ambient energy from the environment and converting it into usable electrical power. Among various techniques, solar, piezoelectric, and electromagnetic induction are widely used due to their complementary nature. However, individual energy sources are often unreliable due to environmental dependency—for instance, solar energy is unavailable at night, while piezoelectric and electromagnetic sources depend on motion.

To overcome these limitations, a hybrid energy harvesting system is proposed. This system integrates multiple energy sources to ensure continuous and reliable power generation. By combining solar energy with vibration and motion-based harvesting techniques, the system enhances efficiency, reduces dependency on batteries, and supports sustainable development.

This project aims to develop a self-powered system capable of operating low-power electronic devices efficiently, especially in remote and maintenance-free environments.

Objectives:

1. To design a hybrid energy harvesting system combining solar, piezoelectric, and electromagnetic sources.
2. To improve reliability by ensuring continuous power availability from multiple sources.
3. To develop efficient signal conditioning and power management circuits.
4. To store harvested energy using a rechargeable battery system.

5. To demonstrate the working of the system by powering low-power devices.

Methodology:

1. The proposed system integrates three energy harvesting techniques: solar, piezoelectric, and electromagnetic induction. Each source generates energy independently and contributes to the overall system output.
2. The solar panel acts as the primary energy source, converting sunlight into DC electrical energy. A buck converter is used to regulate and stabilize the voltage before supplying it to the storage system.
3. The piezoelectric module generates electrical energy from mechanical vibrations and pressure. Since the output is low and irregular, it is amplified using an operational amplifier and then boosted to a usable voltage level using a boost converter.
4. The electromagnetic induction module generates power through relative motion between a magnet and coil. The induced AC signal is rectified and boosted to match the required voltage level for storage.
5. All three conditioned outputs are combined using an OR-ing diode network, which ensures safe and efficient power merging without backflow. The combined energy is stored in a rechargeable battery, which acts as an energy buffer.
6. A voltmeter is used to monitor the output of each source, and the stored energy is used to power a load such as IoT devices or sensors. This multi-source approach ensures continuous power generation even if one source is unavailable.

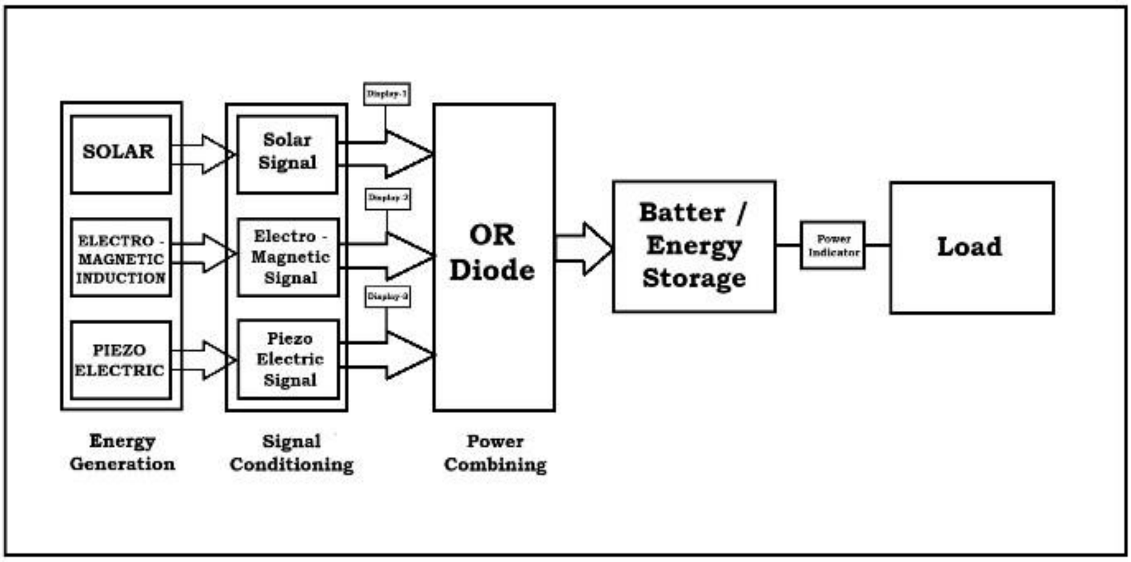

Figure 1: Block diagram of Hybrid Energy Harvesting System.

Result and Conclusion:

1. The developed hybrid energy harvesting system successfully demonstrates the capability to generate and combine energy from multiple sources. Experimental results show that solar energy provides the highest output during daytime, while piezoelectric and electromagnetic sources contribute under motion and vibration conditions.

2. The system efficiently stores the combined energy in a battery and delivers a stable power supply to the load. Voltage measurements from individual sources confirm that hybridization enhances overall energy availability and improves system reliability.
3. Performance comparisons indicate that relying on a single energy source is not sufficient for continuous operation. In contrast, combining multiple sources ensures better efficiency and a more consistent and uninterrupted power supply.
4. The hybrid system offers a sustainable and reliable solution for powering low-energy devices. It reduces dependence on conventional batteries, lowers maintenance requirements, and supports eco-friendly energy generation.
5. This project presents a practical approach to self-powered systems using renewable energy. It is highly relevant for applications in IoT, smart cities, healthcare, and environmental monitoring, with strong potential for real-world implementation in modern energy-efficient systems.

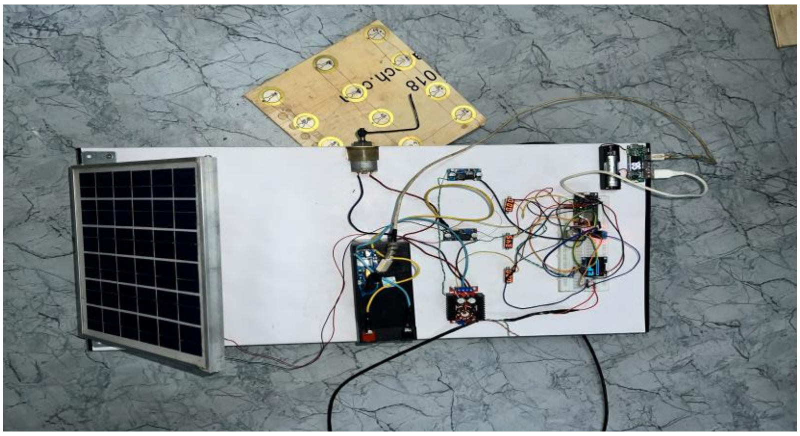

Figure 2: Model of Hybrid Energy Harvesting System.

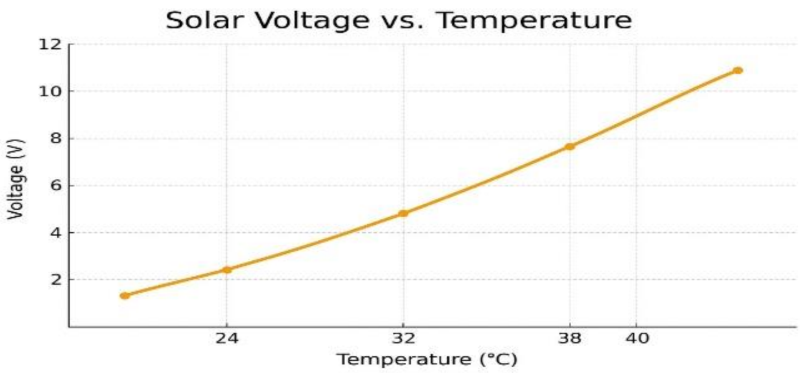

Figure 3: Solar Voltage Graph.

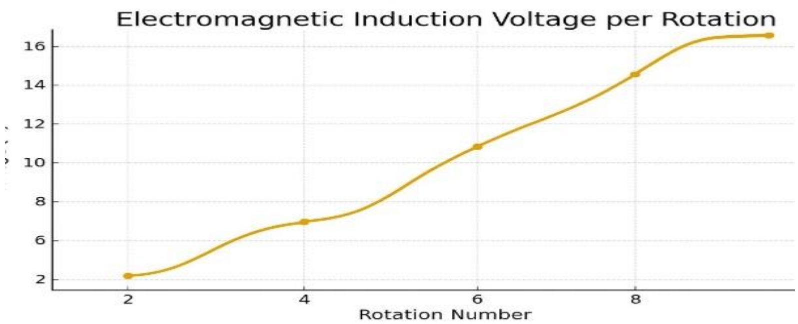

Figure 4: Electromagnetic Induction Voltage Graph.

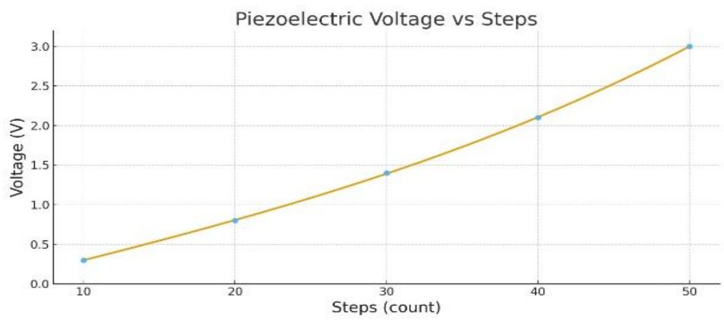

Figure 5: Piezoelectric Voltage Graph.

Table 1: Performance Comparison of Energy Sources

Source	Minimum Voltage	Maximum Voltage	Nature of Output	Key Observation
Solar	1.3 V	10.9 V	DC	Most stable and primary energy source
Electromagnetic	2 V	17 V	AC (converted to DC)	Highest peak voltage with motion
Piezoelectric	0.3 V	3 V	AC (converted to DC)	Low output, depends on vibration

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Future Scope:

1. The proposed system can be further enhanced by integrating advanced power management techniques such as Maximum Power Point Tracking (MPPT) to improve efficiency.
2. Future improvements may include the use of supercapacitors for faster energy storage and intelligent microcontrollers for automatic source switching and load management. The system can also be miniaturized for wearable and biomedical applications.
3. Integration with IoT platforms can enable real-time monitoring and remote control of energy usage. Additionally, incorporating more energy sources such as RF or thermal energy can further increase system reliability.
4. This technology has strong potential in smart cities, environmental monitoring, and industrial automation, making it a promising solution for future sustainable energy systems.