Hybrid Footstep Power Generation: A Sustainable Approach to Energy Harvesting

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***Abstract*—This research article shows a complete working system for Hybrid Footstep Power Generation. The growing demand for renewable energy has led to the exploration of innovative energy harvesting techniques. This study focuses on a hybrid footstep power generation system, integrating piezoelectric sensors and a solar panel to generate electricity. The proposed system harnesses mechanical energy from footsteps using piezoelectric transducers and supplements it with solar energy from a 9V photovoltaic panel. The generated power is conditioned using a full-wave bridge rectifier, capacitors, and an inverter circuit before being stored in a 12V lead-acid battery. An I2C-based 16x2 LCD display is used for real-time monitoring. Experimental results demonstrate the efficiency of combining piezoelectric and solar energy sources for low-power applications such as street lighting. The study highlights the feasibility, efficiency, and potential applications of hybrid footstep power generation in high-footfall areas like railway stations, shopping malls, and pedestrian walkways.**

***Index Terms*—Hybrid Energy, Footstep Power, Piezoelectric Sensors, Solar Power, Renewable Energy, Inverter Circuit, Energy Storage, Smart Cities**

I. INTRODUCTION

The increasing depletion of fossil fuels and rising global energy demands necessitate the urgent adoption of renewable and sustainable energy sources. Conventional energy sources, such as coal, oil, and natural gas, contribute significantly to environmental pollution and climate change. As a result, there is a growing need for alternative energy harvesting technologies that can supplement existing power systems while reducing dependency on non-renewable resources.

Among various energy harvesting methods, footstep power generation offers an innovative approach to utilizing wasted mechanical energy from human movement. When people walk, a significant amount of kinetic energy is dissipated into the ground. This energy can be converted into electricity using piezoelectric materials, which generate an electric charge when subjected to mechanical stress. However, the power output from piezoelectric transducers alone is relatively low, making it insufficient for high-power applications.

To address this limitation and enhance system efficiency, this study proposes a hybrid energy harvesting system that integrates solar power with piezoelectric energy generation. The combined approach ensures a more stable and reliable power output, allowing energy to be harvested even in conditions where footstep activity is minimal. The system consists of:

1. Piezoelectric Sensors – Convert footstep pressure into electrical energy.
2. Solar Panels – Harvest solar energy to supplement footstep-generated power.
3. Energy Storage System – A 12V lead-acid battery stores the harvested energy for later use.
4. Power Management & Load – A rectifier circuit, capacitor bank, and inverter circuit regulate the power, which is then used to operate devices such as LED lighting.

Research Objectives:

- To design a hybrid energy system utilizing footsteps and solar energy.
- To analyze the performance of the system in terms of power generation and storage efficiency.
- To evaluate the feasibility of implementing such

a system in public places.

This research explores the feasibility, efficiency, and real-world applications of a hybrid footstep power generation system to support low-power applications such as lighting.

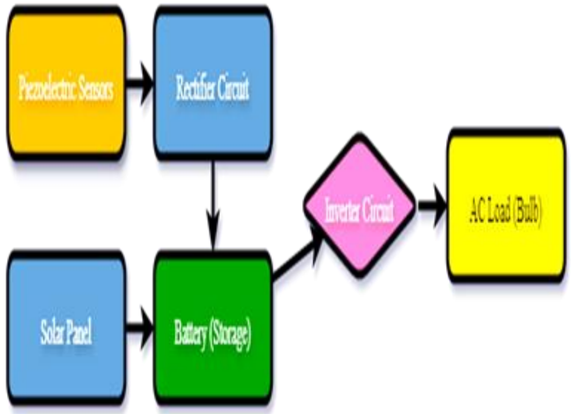

Figure 1- Block Diagram

II. ORGANIZATION OF THE PAPER

This paper would discuss the basic idea of this research in section III "System Overview" with the aid of a block diagram. Further, the associated software and hardware is discussed in section IV. And then the findings of the research have been explained in section V "Results". And finally, the paper concludes in the final section.

III. SYSTEM OVERVIEW

The block diagram of whole methodology has been showing in Fig 1. The hybrid footstep Power Generation System integrates two renewable energy sources: Piezoelectric energy harvesting and solar energy conversion. The syste, is designed to generate electrical energy from foot pressure and sunlight, making it ideal for public spaces such as railway station, shopping malls, and pedestrian walkways. The Hybrid Footstep Power Generation System is designed to harvest energy from two renewable sources:

1. Piezoelectric Energy Harvesting – Converts mechanical stress from footsteps into electrical energy.
2. Solar Energy Harvesting – Utilizes sunlight to generate additional electrical power.

This system aims to improve efficiency and reliability by combining these two energy sources. The generated power is processed through a power management unit and stored in a 12V lead-acid battery, which can then be used to power various electrical loads such as LED lighting or charge small electronic devices.

IV. HARDWARE AND SOFTWARE IMPLEMENTATION

Hardware Implementation

The hardware components are selected based on power requirements and efficiency.

Major Components:

1. Piezoelectric Sensors (PZT-5A)
   - Generates voltage when stepped on.
   - Connected in series and parallel for optimized output.
2. Solar Panel (9V, 5W)
   - Provides additional power during the daytime.
3. Bridge Rectifier (1N4007 Diodes)
   - Converts AC output from piezoelectric sensors to DC.
4. Capacitors (1000µF, 25V)
   - Stores charge and smoothens fluctuations.
5. Lead-Acid Battery (12V, 7Ah)
   - Stores the harvested energy for later use.
6. Inverter Circuit
   - Converts 12V DC to 220V AC for real-world applications.
7. LCD Display (I2C 16x2)
   - Monitors voltage and power output.
8. Load (LED Bulb)

Used to test the effectiveness of the system

. Software Implementation

Microcontroller

- If an Arduino or ESP8266 is used for data monitoring, software is implemented using:
  - Arduino IDE (for programming the microcontroller).
  - Embedded C or Python (for real-time monitoring of voltage output).

System Algorithm

1. Step 1: Footsteps generate voltage through piezoelectric sensors.
2. Step 2: AC voltage is rectified using a full-wave bridge rectifier.
3. Step 3: Solar panel adds extra voltage to the system.

4. Step 4: Energy is stored in a 12V lead-acid battery.
5. Step 5: The inverter converts DC to AC for powering a load.
6. *Step 6:* The LCD display shows the real-time voltage output

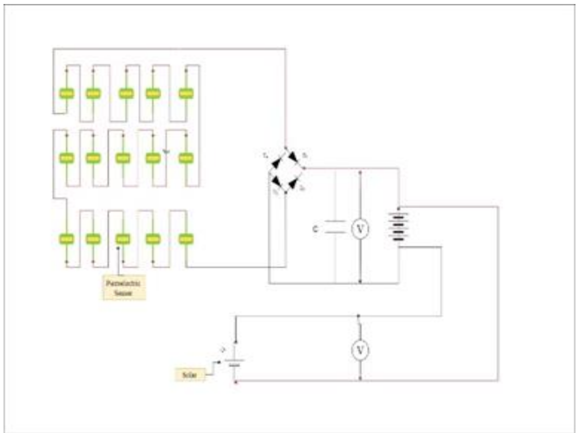

Figure 2 circuit diagram

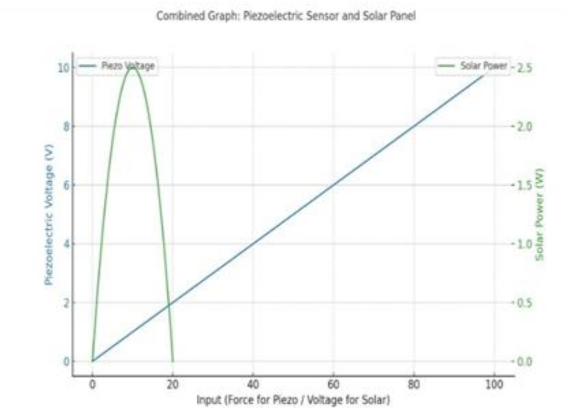

Figure 1. V I Characteristics

V. MATHEMATHICAL EXPRESSION

To analyze the system performance, the following mathematical equation are used :

Piezoelectric output Voltage :

The output voltage of piezeioelectric sensor is given by :

$V=d33xF$

Where V= Output Voltage (V)

D33 = Piezoelectric charge constant ($\frac{C}{N}$)

F= Applied force (N)

Power Generated by Piezoelectric Sensor

The electrical power generated by a single piezoelectric sensor is:

$P=V\times I$

where:

P = Power output (W)

V = Voltage generated (V)

I = Current generated (A)

For N piezoelectric sensors in series, total voltage is:

$V_{total}=N\times V_{single}$

For N piezoelectric sensors in parallel, total current is:

$I_{total}=N\times I_{single}$

Solar Panel Output

The power generated by a solar panel is given by:

$P=V_{OC}\times I_{SC}\times\eta$

Where:

V_{OC}= Open-circuit voltage (V)

I_{SC}= Short-circuit current (A)

η = Efficiency of the panel (%)

Inverter Efficiency

The efficiency of the inverter is calculated as:

$\eta_{inverter}=\left(\frac{P\ input}{P\ output}\right)\times 100\%$

Where:

P_{output}= Power delivered to the load (W)

P_{input} = Power taken from the battery (W)

VI. CONCLUSION

This research presents a Hybrid Footstep Power Generation System that combines piezoelectric and solar energy harvesting to generate electrical power. Key findings include:

The hybrid system improves efficiency compared to standalone piezoelectric systems.

The lead-acid battery efficiently stores harvested energy for continuous usage.

The inverter circuit converts DC to AC, enabling practical applications such as street lighting.

The LCD display provides real-time monitoring, enhancing system usability.

Future Enhancements:

Implementing a charge controller to prevent overcharging.

Using more efficient piezoelectric materials for better energy conversion.

Integrating IoT-based monitoring for remote data collection.

Expanding applications to smart city infrastructure.

This study demonstrates that hybrid footstep power generation is a viable, sustainable solution for energy harvesting in urban environments.

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