© November 2025 | IJIRT | Volume 12 Issue 6 | ISSN: 2349-6002

# Piezo Pathway Electric Generator: A Sustainable Approach for Distributed Energy Harvesting

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***Abstract*—Piezoelectric pathway generators convert ambient mechanical stress from footsteps, vehicular loads and structural vibrations into electrical energy. These systems enable distributed, low-power, autonomous devices to operate without conventional grid dependency, supporting smart city and industrial applications. This paper elaborates on material selection, system architecture, structural modeling, circuit implementation, applications, limitations and projected outcomes. The work aims to develop scalable and durable piezoelectric modules suitable for integration into roadways, pedestrian walkways and industrial flooring.**

## I. INTRODUCTION

The demand for renewable micro-energy systems is increasing due to the expansion of smart cities, IoT networks and distributed sensing systems. Piezoelectricity offers a promising mechanism for energy harvesting, especially in high-traffic environments. Pathway-embedded piezoelectric modules utilize deformation under mechanical stress to generate electrical charge, powering devices such as sensors, streetlights, and communication nodes. The objective of this project is to design, test, and evaluate a piezo-based energy harvesting module optimized for durability, low-frequency mechanical inputs and real-world deployment challenges.

## II. LITERATURE REVIEW

Research highlights the suitability of piezoelectric materials such as PZT for high-output applications and PVDF for flexible pedestrian pathways as core energy harvesting elements. Stacked and cantilever structural designs are commonly used to improve strain levels. Recent studies also explore lead-free materials such as KNN and $BaTiO_3$ to overcome toxicity issues associated with PZT. Frequency mismatch remains a challenge, as typical pathway vibrations (<100 Hz) are lower than the resonance of most piezo materials (~1 kHz).

## III. OBJECTIVES

Primary Objectives

- Harvest mechanical energy from human and vehicle movement.
- Generate electrical power to operate low-energy devices (IoT, sensors, LEDs).

Secondary Objectives

- Improve conversion efficiency using optimized circuits.
- Enhance durability under heavy and repetitive loads.
- Enable scalable, modular integration into existing infrastructure.

## IV. SYSTEM ARCHITECTURE

The proposed system consists of the following blocks

- Mechanical Input Layer (Pathway Tiles/Road Surface)
- Piezoelectric Transducer Array (PZT/PVDF/KNN modules)
- AC-DC Rectifier
- Energy Storage Block (Li-ion Cell)
- DC-DC Boost Converter
- Output Load (LED, Sensor Node and Environmental Monitor)

The placement of multiple piezo modules in an array increases cumulative output.

## V. METHODOLOGY

Material Selection
- PZT (Lead Zirconate Titanate): High piezoelectric coefficient, suitable for heavy loads.
- PVDF: Flexible, robust under dynamic low-pressure footsteps.
- Lead-Free Alternatives: $BaTiO_3$, KNN for eco-friendly applications.

Mechanical Structural Design
- Stacked Diaphragms: Used for high-force road conditions.
- Cantilever Beams: Suitable for pedestrian walkways.
- Encapsulation: Epoxy/MC nylon ensures water, pressure and thermal protection.

Electrical Conversion
- Full-wave bridge rectifier for converting AC to DC.
- Synchronized switch harvesting circuits (SSHI) to improve energy extraction.

Integration
- Modules are embedded into asphalt/concrete tiles without compromising structural safety.

## VI. MATHEMATICAL MODELING

Piezoelectric Voltage Output
- The generated charge:
$$Q=d.F$$
- Where:
  d= piezoelectric charge constant.
  F= applied mechanical force.
- Open-circuit voltage:
$$V=Q/C$$
- For PZT(high $d_{33}$), Higher voltages are achievable under similar forces.

Circuit Design
The conditioning circuit includes:
- A full-wave rectifier based on Schottky diodes to reduce voltage drop.
- A smoothing capacitor(100-1000 µF).
- A boost converter raising voltage to 3.3 V or 5 V.
- A storage module using a 1-5F supercapacitor.

This allows even micro watt harvested energy to accumulate over time.

Applications
Transportation Systems
- Powering traffic lights and road signage.
- Vehicle-monitoring wireless sensors.

Smart City Pathways
- Footstep-powered floor tiles in malls/stations.
- IoT-based environmental sensing.

Industrial Uses
- Machine vibration-powered monitoring nodes.

Specialized Applications
- Marine sensor buoys.
- Wearable power generation systems.

## VII. ADVANTAGES AND LIMITATIONS

Advantages
- Renewable and clean power.
- Long life due to no moving parts.
- Wide applicability across domains.

Limitations
- Low individual power output.
- High installation cost.
- Frequency mismatch with vibration sources.
- Lead toxicity concerns in PZT materials.

## VIII. EXPECTED RESULTS

Based on literature and simulation:
- Each PVDF tile generates 1-3mW under footsteps.
- A PZT stack can produce 10-50mW under vehicle load.
- A 1-meter tile array can power LED street markers.
- Multiple tiles can run IoT sensors continuously.

Expected outcomes from your report:
- Reduced maintenance.
- Support for sustainable city initiatives.
- Improved infrastructure resilience.

## IX. FUTURE SCOPE

- Hybrid systems combining piezo + solar + triboelectric.
- AI-based traffic sensing using self-powered nodes.
- Large-scale pavement integration for smart highways.
- Development of low-cost, biodegradable piezo materials.

## X. CONCLUSION

Piezoelectric pathway generators demonstrate a viable solution for autonomous micro-energy generation, contributing significantly to sustainable smart cities. Although challenges related to efficiency, cost and environmental factors persist, advancements in materials and system design continue to enhance feasibility. Future integration with IoT infrastructure and hybrid energy harvesting technologies will further expand potential use cases.

## REFERENCES

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