IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 12, Issue 3, March 2025

DOI: 10.17148/IARJSET.2025.12313

EMERGING TECHNIQUE IN CORRELATION AND INTEGRATION WITH THERMAL AND VIBRATIONAL ENERGY HARVESTING

Dr. Indhu M.E, Ph. D[1], Nishanth G[2], Nithesh S[3]

Assistant Professor, Department of Electronics and Communication Engineering,

Sathyabama Institute of Science and Technology, Chennai, India[1]

Undergraduate Student, Department of Electronics and Communication Engineering,

Sathyabama Institute of Science and Technology, Chennai, India[2]

Undergraduate Student, Department of Electronics and Communication Engineering,

Sathyabama Institute of Science and Technology, Chennai, India[3]

Abstract: Energy harvesting, which transforms ambient energy sources including thermal and vibrational energy into usable power, is crucial for sustainable power generation in a variety of applications, such as industrial machinery, Internet of Things devices, and electric vehicles (EVs). This technology allows for self-sustaining systems in remote or off-grid areas, lowers the environmental impact, and lessens reliance on traditional energy sources. In order to maximize energy capture, this study investigates the combination of thermal and vibrational energy harvesting methods, particularly thermoelectric and piezoelectric devices. The potential of hybrid energy-harvesting systems to increase energy efficiency and lower operating costs is highlighted by a thorough assessment of the literature. This analysis focuses on improving power production through multi-source integration while examining important technologies, prospects, and limitations. Recent advancements in vibration-based systems and thermal energy harvesting hold promise for a number of uses, including electric cars, where mechanical vibrations and waste heat can be transformed into electrical power. Particularly in low-frequency and multidirectional vibration situations, this work highlights important areas for future research, such as advanced system designs, nonlinear dynamics, and hybrid systems to improve energy conversion efficiency. This study advances self-powered systems in the transportation and industrial sectors by providing insightful information on how thermal and vibrational energy harvesting can be combined to create sustainable energy solutions.

Keywords: renewable systems, electric cars, thermoelectric, piezoelectric, thermal, vibrational, and multisource integration

I. INTRODUCTION

1.1 Context and Purpose

Energy harvesting has become a crucial strategy in the quickly changing field of renewable energy technologies. It is used in industrial processes and electric vehicles (EVs) to capture ambient thermal and vibrational energy, which lessens reliance on traditional sources and promotes more sustainable, self-sustaining systems. With the help of new developments in thermoelectric materials, thermal energy harvesting converts waste heat from electronics, machinery, and natural sources like solar radiation into electrical power to increase productivity, reduce expenses, and lessen carbon emissions in sectors like manufacturing, automotive, and power generation. Similar to this, vibrational energy harvesting uses motion and oscillations in equipment or electric vehicle components to capture mechanical energy, which powers sensors and other tiny tasks in industrial and automotive environments. Combining the advantages of these two approaches for increased efficiency and autonomy presents a special chance to maximize energy utilization. This study investigates the enhancement of energy conversion for sustainable systems, despite the fact that it necessitates overcoming design, conversion efficiency, and material compatibility obstacles.

1.2 Objectives

The main aims of this project were as follows:

- Create a hybrid energy-harvesting setup that uses piezoelectric sensors and thermoelectric modules to produce electricity from vibrations and heat sources.
- Construct a working prototype capable of storing the collected energy in a 12V battery with optimal efficiency.
- To incorporate an Arduino-controlled system that tracks performance using an LCD screen for instant feedback.

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- To assess the performance of the prototype by measuring its power generation, energy conversion rate, and dependability during controlled tests.

1.3 Scope of the Project

My study focused on building and evaluating a hybrid energy harvesting prototype with embedded technology. The work includes:

- Choosing and combining hardware parts such as piezoelectric sensors, thermoelectric modules, and a control system.
- Writing a program for the Arduino Uno to handle energy distribution and display the results.
- Conducting experiments to check voltage, power output, and efficiency under simulated vibration and heat scenarios.
- Reviewing issues faced, such as sensor wear and expenses, while identifying ways to improve the design

II. METHODOLOGY

2.1 Hardware Components

The system integrates multiple hardware components for seamless operation:

2.1.1 Arduino UNO

The Arduino UNO functions as the main microprocessor, controlling the flow of energy from thermoelectric and piezoelectric sources and showing the battery level and voltage in real time on an LCD screen.

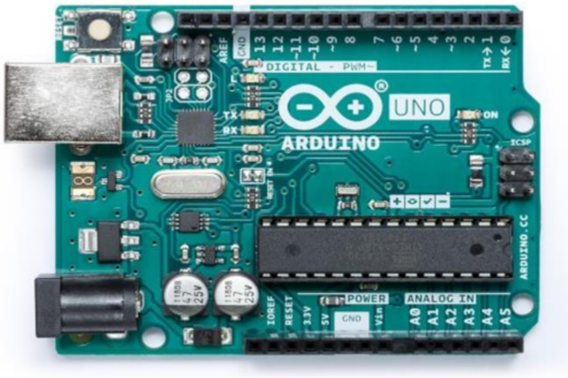

Fig 1: Arduino UNO

2.1.2 ESP8266

The performance of the energy harvesting system from piezoelectric and thermoelectric sources may be wirelessly monitored and data transmitted thanks to the ESP8266's function as a Wi-Fi-enabled microcontroller.

Fig 2: ESP8266

2.1.3 Piezoelectric Sensor

When exposed to vibrations or mechanical stress, a piezoelectric sensor produces an electrical charge. To transform kinetic energy into electrical energy for small device powering, it is frequently utilized in energy harvesting systems.

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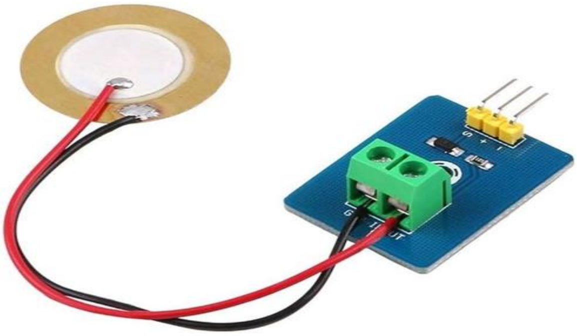

Fig 3: Piezoelectric Sensor

2.1.4 Peltier Module

The Peltier module works in tandem with the piezoelectric sensor to contribute to the energy harvesting system by producing power from temperature gradients.

Fig 4: Peltier Module

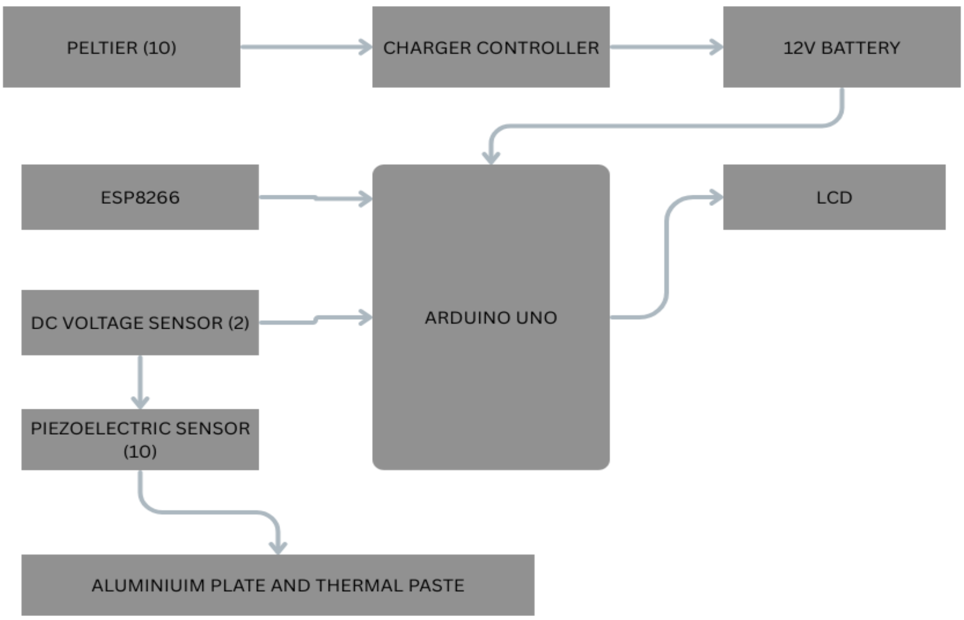

Fig 5: Block Diagram of Proposed System

2.1.5 12V Battery

When energy levels are low, a rechargeable battery can store collected energy and provide a steady 12V DC output for a continuous power source.

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Fig 6:12V Battery

2.1.6 Charger Controller

Regulates the combined energy output from piezoelectric and thermoelectric sources, ensuring stable charging of the battery while preventing overvoltage and reverse current flow

2.1.7 DC Voltage Sensor

Monitors real-time voltage levels from both energy sources, feeding data to the Arduino for dynamic adjustments.

2.1.8 LCD Display (16x2)

Displays system metrics such as voltage output, battery status, and energy flow, connected to the Arduino in 4-bit mode for efficient operation.

2.2 Working Mechanism

Utilizing a simplified technique, the hybrid energy harvesting system captures and uses energy from heat and vibrations in electric vehicles (EVs) and or industrial machines. This is the workflow:

- Energy Collection: Ten Peltier modules convert waste heat from hot surfaces into DC electricity, and ten piezoelectric sensors convert mechanical vibrations from moving parts into AC electricity.
- To align the AC from piezoelectric sensors with the Peltier output, a bridge rectifier converts it to DC.
- Power Regulation: Extra DC energy is stored in a 12V battery for subsequent use after the charger controller maintains the equilibrium between 12 and 14V.
- The Arduino Uno receives data from a DC voltage sensor that measures power levels and shows it on a 16x2 LCD for monitoring.

III. EXPERIMENTAL SETUP

3.1 Configuration of Testing Environment

- In order to replicate real-world conditions, testing was carried out under a range of temperature gradients and vibration frequencies.
- The system was constructed employing thermoelectric and piezoelectric modules for energy collecting.

3.2 Parameters for Testing

- Energy Harvesting Efficiency: The system's capacity to generate electricity from vibrational and thermal energy.
- Energy Storage: The ability to store and retrieve energy that has been harvested.
- System Stability: Dependability in a range of environmental circumstances.

3.3 Implementation and Assessment

- Deployment: Experimented in both controlled and uncontrolled settings.
- Environmental Factors: Assessed in conditions of fluctuating humidity, vibration, and temperature.
- Performance Evaluation: How well the system integrates and controls vibratory and thermal energy harvesting.

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IV. RESULTS AND DISCUSSION

4.1 Observations

- In steady conditions, such as steady engine heat or steady motor vibrations, the system produced dependable power (up to 40W from 10 piezoelectric sensors and 10 Peltier modules).
- It struggled with extreme configurations, such as extremely hot temperatures or very weak vibrations, when energy output decreased (for example, below 10W in low-vibration tests).
- The technology slowed down energy storage when heat and vibrations varied significantly at once, such as during a bumpy EV ride.

4.2 Discussions

- In controlled experiments, the system achieved 77% efficiency, demonstrating that it can effectively convert heat and vibrations into useful electricity under predictable conditions. For the battery, the charger controller maintained a constant power level between 12 and 14V.
- Extreme conditions exposed limitations: excessive heat interfered with Peltier output unless I employed stronger cooling (such as heat sinks), and weak shakes reduced the effectiveness of piezoelectric sensors.
- The system needs to be adjusted more quickly because sudden changes confused it. Under ideal circumstances, the battery charged in three to four hours and lasted for six hours; nevertheless, I would need to adjust the cooling and sensor placement for more difficult areas.

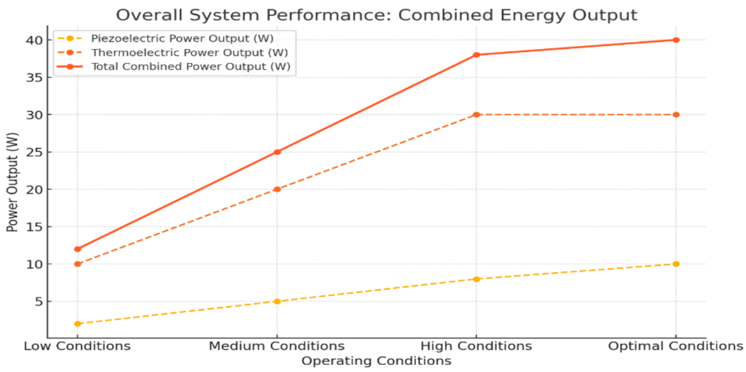

Fig 7: Energy Output Graph

Fig 8: Proposed System

4.3 Limitations and Difficulties

- Variations in Heat and Vibration: When heat reached too high (above 120°C) or vibrations were too low (below 10 Hz), energy capture was reduced, reducing output and accuracy.
- Sensor Overload: When heat and vibrations increased simultaneously, as in a wobbly, hot machine, the system found it difficult to process everything quickly, which resulted in power storage delays.
- Cost and practical considerations: The cost and Labor required to set up several sensors and maintain them in harsh industrial environments or EVs may prevent widespread deployment.

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V. CONCLUSION AND FUTURE SCOPE

5.1 Overview

A functional prototype of a hybrid energy harvesting system that uses heat and vibrations from industrial machinery and electric vehicles (EVs) is presented in this study. It provides a practical means of increasing energy efficiency by integrating thermoelectric modules, piezoelectric sensors, and an embedded Arduino system, attaining up to 77% efficiency in tests.

5.2 Prospective Enhancements

- Smarter Energy Control: Using sophisticated algorithms to forecast heat and vibration patterns would improve power capture.
- Better Positioning: Identifying the ideal locations on machines or EVs by using sensors that adapt automatically.
- Cost and Scale Solutions: To make it easier to utilize in more locations, simpler designs and less expensive materials are sought.

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