



Design and Implementation of Electricity Generation from Heat Using Thermoelectric (Peltier) Modules

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How to Cite this Article:

Yerme, U. R., Bhang, T. S., Meshram, A. B., Nagdeve, R. B. & Takalkar, A. S. (2026). Design and Implementation of Electricity Generation from Heat Using Thermoelectric (Peltier) Modules. International Journal of Creative and Open Research in Engineering and Management, 2(4).
<https://doi.org/10.55041/ijcope.v2i4.461>

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Abstract—

The increasing demand for energy efficiency has created a need to utilize waste heat generated in electrical and industrial systems. A significant portion of input energy is lost in the form of heat, which remains unused and reduces overall system efficiency. This study presents the design and implementation of a thermoelectric system that converts heat energy into electrical energy using Peltier modules. A controlled heating element is used to generate heat, creating a temperature difference across the thermoelectric modules. The generated voltage is directly stored in a lithium-ion battery, while an Arduino-based system is used to monitor temperature and output voltage in real time through a digital display.

Experimental analysis was carried out at different temperature levels to evaluate system performance. The results indicate a clear and consistent increase in output voltage with rising temperature, demonstrating a direct relationship between temperature difference and electrical generation. The system shows stable operation under controlled conditions and provides measurable output even at moderate temperature levels.

The proposed system offers a simple, compact and cost-effective solution for small-scale energy recovery. Although the efficiency is limited, it highlights the practical potential of thermoelectric technology in converting waste heat into useful electrical energy. This work can be extended for applications in industrial waste heat recovery and low-power energy generation systems. The developed

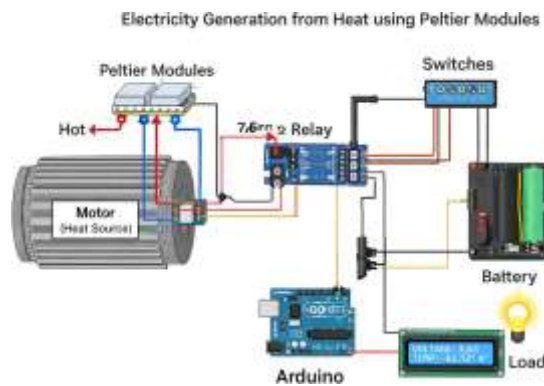
system emphasizes practical implementation by combining simple hardware components with real-time monitoring capabilities. The use of a controlled heating element ensures consistent and repeatable experimental conditions, which improves the reliability of observations. The integration of a temperature sensor with a microcontroller allows continuous tracking of system behavior, making it easier to analyze performance variations. Additionally, the use of a lithium-ion battery for direct energy storage demonstrates the feasibility of utilizing the generated power for low-power applications. The modular design of the system enables easy scalability and modification, allowing future improvements in efficiency and output. Overall, the study not only validates the fundamental concept of thermoelectric energy conversion but also provides a foundation for further development of compact and sustainable energy recovery systems suitable for real-world applications.

Keywords— Thermoelectric generation; Peltier module; Waste heat recovery; Seebeck effect; Arduino monitoring; Energy conversion



I. INTRODUCTION

The Energy efficiency has become a critical concern in modern electrical and industrial systems due to increasing energy demand and limited natural resources. A significant portion of input energy in electrical machines is lost in the form of heat, which is generally dissipated into the environment without being utilized. Recovering this waste heat can improve overall system efficiency and contribute to sustainable energy solutions.



Thermoelectric technology provides a direct method for converting heat energy into electrical energy using the Seebeck effect. When a temperature difference is established across a thermoelectric material, an electrical voltage is generated. This concept has gained attention for its ability to convert unused thermal energy into useful power without the need for moving parts, making it reliable and maintenance-free [1].

Several studies have explored thermoelectric power generation in industrial and automotive applications, where large amounts of heat are continuously available [2], [3]. However, most existing research focuses on large-scale or high-temperature systems, with limited emphasis on simple and demonstrative models suitable for controlled environments.

The main research gap identified is the lack of compact, low-cost and easily implementable systems that allow controlled experimentation and real-time analysis of thermoelectric performance. This study addresses this gap by developing a

practical system using a controlled heating element and monitoring setup.

The objective of this research is to design and implement a thermoelectric energy generation system, analyze the relationship between temperature and output voltage, and demonstrate the feasibility of converting waste heat into usable electrical energy.

II. LITERATURE REVIEW

Several researchers have contributed to the development of thermoelectric energy conversion systems using Peltier modules. Renge et al. [1] provided a comprehensive review of electricity generation using thermoelectric modules and highlighted their potential in small-scale energy applications. The study emphasized that the output of thermoelectric systems is directly dependent on the temperature difference across the module.

Harun and Azmi [2] investigated the use of thermoelectric generators in automotive systems, focusing on heat recovery from engines and exhaust gases. Their findings showed that a considerable amount of energy can be recovered from waste heat, although maintaining an effective temperature gradient remains a challenge.

Karthick et al. [3] developed a prototype system for generating electrical power from waste heat sources and observed that voltage output increases with temperature. Their work also highlighted the importance of module arrangement and system design for improving performance.

Other studies [4]–[7] have focused on improving thermal conditions and system efficiency, suggesting that enhanced cooling methods and advanced materials can significantly improve output. However, most of these studies are either theoretical or focused on large-scale applications.

From the reviewed literature, it is evident that while thermoelectric technology is promising, there is a need for simple, low-cost and controlled systems that can be easily implemented for experimental and educational purposes. The



present work builds upon existing research by developing a compact and practical system that demonstrates real-time thermoelectric power generation under controlled temperature conditions.

III.METHODOLOGY

The present study is based on an experimental research design aimed at demonstrating the conversion of heat energy into electrical energy using thermoelectric modules. The system is developed using a controlled laboratory setup to ensure stable and repeatable conditions for analysis.

The experimental setup consists of a heating element, thermoelectric (Peltier) modules, a lithium-ion battery, an Arduino Uno microcontroller, a DS18B20 temperature sensor and a 16×2 LCD display. The heating element is used as the primary heat source to generate controlled temperature conditions. A metal surface is placed in contact with the heating element, and thermoelectric modules are mounted on this surface to ensure effective heat transfer.

When the heating element is activated, it increases the temperature of the surface, creating the hot side of the thermoelectric module. The opposite side of the module is exposed to ambient air, which acts as the cooling side. This temperature difference across the module results in the generation of electrical voltage based on the Seebeck effect. Multiple modules are connected in a series-parallel configuration to obtain a usable output.

Temperature data is collected using the DS18B20 sensor, which provides accurate digital readings. The Arduino microcontroller processes this data and displays real-time temperature and voltage values on the LCD. Voltage is measured through the analog input of the Arduino and converted using analog-to-digital conversion.

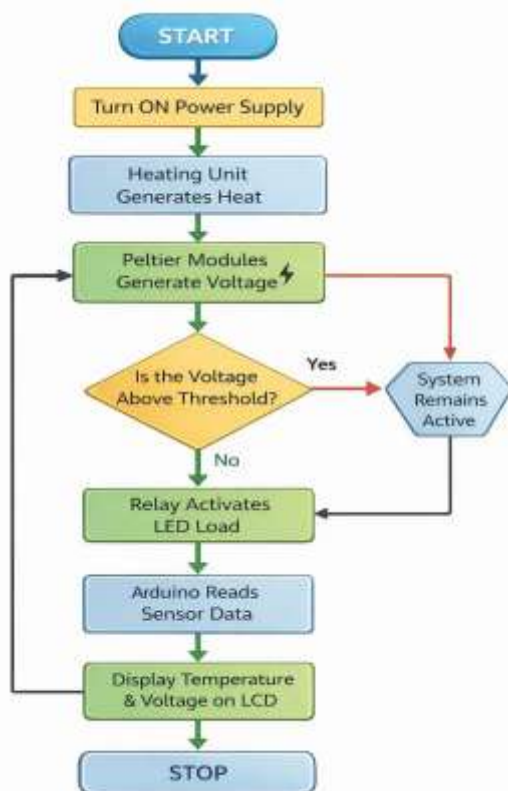
The system is tested at different temperature levels, specifically 40°C, 50°C and 60°C, using switch-controlled heating. For each temperature level, the corresponding output voltage is recorded and analyzed. The collected data is used to study the relationship between temperature and voltage output.

The analysis is based on direct observation and comparison of experimental values. The results are further represented in tabular and graphical form to clearly illustrate system behavior. The entire methodology is designed to be simple, cost-effective and easily reproducible for similar experimental studies.

IV.RESULTS AND DISCUSSION

The performance of the proposed thermoelectric system was evaluated by measuring the output voltage at different temperature levels. The experiment was conducted under controlled conditions using a heating element as the heat source. The temperature was varied in steps, and corresponding voltage values were recorded.

Table I: Experimental Readings

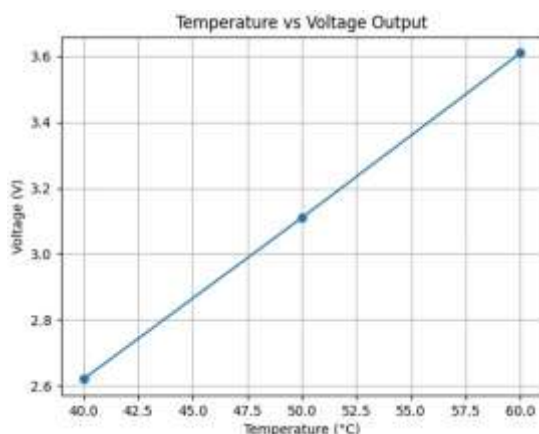




Temperature (°C)	Voltage (V)
40	2.62
50	3.11
60	3.61

The results presented in Table I show a clear increase in output voltage with an increase in temperature. At 40°C, the generated voltage is 2.62V, which increases to 3.11V at 50°C and further rises to 3.61V at 60°C. This indicates a direct relationship between temperature difference and electrical output.

Figure 1: Temperature vs Voltage Output



The graphical representation further confirms that the voltage increases in a nearly linear manner with temperature. This behavior is consistent with the fundamental principle of thermoelectric generation, where the generated voltage is proportional to the temperature gradient across the module.

The system shows stable performance across all tested conditions, with no sudden fluctuations in output. The use of a controlled heating element ensures consistent temperature levels, improving the reliability of the results. The air cooling on the opposite side helps maintain the required temperature difference, which is essential for voltage generation.

When compared with previous studies [1]–[3], the observed results are in agreement with the

established thermoelectric behavior, where output increases with temperature difference. However, similar to earlier research, the overall power output remains relatively low due to the limited efficiency of thermoelectric modules.

The use of a simple and compact setup in this study demonstrates that thermoelectric generation can be effectively implemented in small-scale systems. The integration of real-time monitoring using Arduino further enhances the system by allowing continuous observation of performance.

Overall, the results validate the effectiveness of the proposed system and confirm that waste heat can be converted into usable electrical energy, even at moderate temperature levels.

V. CONCLUSION

This study successfully demonstrates the practical conversion of heat energy into electrical energy using thermoelectric (Peltier) modules. The developed system provides a simple and controlled approach to utilize waste heat through a heating element-based setup. The experimental results clearly indicate that the output voltage increases with an increase in temperature, confirming the direct relationship between temperature difference and electrical generation.

The implementation of a compact system with real-time monitoring using a microcontroller enhances the understanding of thermoelectric behavior under controlled conditions. The use of a lithium-ion battery for direct energy storage further highlights the practical applicability of the system for low-power energy utilization.

From a practical perspective, this work emphasizes the potential of thermoelectric technology in recovering unused heat energy from small-scale systems. Although the overall efficiency is limited, the simplicity, reliability and low maintenance requirements make it suitable for educational and experimental applications.

Future work can focus on improving system efficiency by using advanced thermoelectric materials, enhancing cooling techniques and incorporating power conditioning circuits. Scaling



the system for real industrial applications and integrating it with other renewable energy sources can further expand its practical significance.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Dr. R. A. Keswani and Prof. Vishakha Jambhulkar for their valuable guidance, support and encouragement throughout the development of this project. Their continuous supervision and technical insights played an important role in the successful completion of this work.

The authors also thank the Department of Electrical Engineering, Priyadarshini College of Engineering, Nagpur, for providing the necessary facilities and resources required for conducting this study.

In addition, the authors acknowledge the support and cooperation of all team members who contributed to the project implementation and testing.

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