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Peltier Power Effect Monitoring as Electrical Energy Generation

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Abstract. *Climate change and the depletion of fossil energy resources have driven the search for alternative energy sources that are more environmentally friendly and sustainable. One promising solution is the development of renewable energy systems that optimally utilize natural resources. Thermogeneration technology, which converts temperature differences into electrical energy, has become a focal point in the advancement of renewable energy. The Peltier module, as the core component of this technology, is capable of generating electrical voltage through the thermoelectric effect caused by a temperature difference between its two sides In this study, the Peltier module is used to generate electricity from industrial waste heat or other ambient heat sources. The objective of this research is to identify the energy conversion efficiency and the practical limitations of the Peltier module in renewable energy systems. By employing a device designed to convert heat energy into electrical energy, while also monitoring temperature and voltage, the study evaluates the performance of the Peltier module and introduces a testing methodology to measure the relationship between temperature and voltage. Test results indicate a linear relationship between temperature and generated voltage, with a slope of 0.0375 V/°C, suggesting that the greater the temperature difference, the higher the voltage produced. This research is expected to contribute to the development of Peltier-based renewable energy technologies and to improve the efficiency of waste heat utilization in supporting more environmentally sustainable energy practices.*

Keywords: *Energy Source, Generator, Peltier, Environmentally Friendly.*

INTRODUCTION

In facing the challenges of climate change and limited fossil energy resources, the search for alternative energy sources that are more environmentally friendly and sustainable is increasingly urgent. One promising solution is the development of renewable energy systems that utilize natural resources optimally and sustainably. Renewable energy technology continues to develop, one of which is the use of thermogeneration, which is the conversion of temperature differences into electrical energy. This approach is attracting attention as an alternative to producing energy efficiently without relying on fossil resources. One of the potential components in thermogeneration technology is the Peltier module, a semiconductor device that can produce a difference in electrical voltage when there is a temperature difference between the two sides of the device. This phenomenon, known as the Peltier effect, is often used in cooling or heating applications. However, along with the progress of research, Peltier modules are increasingly in demand as a tool for generating electricity, especially in the

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context of renewable energy. Its use in heat sources around us, such as industrial waste heat or temperature differences between the environment and the human body, provides an opportunity to create efficient and environmentally friendly energy solutions. In this study, the identification of problems related to energy conversion efficiency and the limitations of practical applications of Peltier modules will be discussed in depth. This research is expected to contribute to the development of renewable energy technology based on Peltier modules, as well as increasing the efficiency and utilization of waste heat in renewable energy systems. Thus, this research will be part of the effort to create more environmentally friendly and efficient energy solutions in the future.

LITERATURE REVIEW

The increasing global demand for clean and sustainable energy has intensified research into renewable energy technologies that can reduce dependence on fossil fuels and minimize environmental impact. Among these technologies, thermoelectric generation stands out as a unique solution due to its ability to directly convert thermal energy into electrical energy using solid-state devices. This process, known as the Seebeck effect, occurs when a temperature gradient across a thermoelectric material induces an electric voltage. The thermoelectric effect has been extensively studied for decades, yet only in recent years has its application for energy harvesting gained momentum. The main appeal lies in its silent operation, compact size, lack of moving parts, and capability to function in harsh environments, making it highly suitable for waste heat recovery and remote energy generation

The Peltier module, more commonly recognized for its cooling capabilities, can be operated in reverse to generate electricity. When a temperature difference is maintained between its two surfaces, the module produces voltage through the thermoelectric effect. Although commercial Peltier modules were initially designed for refrigeration applications, studies have shown that they can effectively function as low-power thermoelectric generators (TEGs) when appropriately integrated into an energy system. Demonstrated the practical application of Peltier modules in wearable energy harvesting, utilizing body heat to generate electricity for powering small electronic devices.

Similarly, other studies have examined the feasibility of using Peltier modules in automotive exhaust systems and industrial machinery to recover waste heat.

Recent studies show a linear relationship between the temperature difference (ΔT) across the Peltier module and the output voltage (V), up to a saturation point where the efficiency begins to decline due to internal resistance and heat leakage (Lin et al., 2014). The slope of this linear region, often expressed in volts per degree Celsius (V/°C), varies depending on the module's material properties and design. Such empirical data is critical for modeling and simulation of thermoelectric systems in practical applications. For instance, when applied in waste heat recovery from industrial environments, accurate monitoring of temperature profiles and power output allows operators to estimate energy recovery potential and justify investments in TEG systems. advancements in nanostructured thermoelectric materials, the efficiency of thermoelectric modules is expected to improve significantly. Integrating machine learning for predictive performance analysis, smart feedback control, and hybrid system integration (with batteries or supercapacitors) are emerging areas of research. The development of modular, scalable, and low-cost monitoring systems will be crucial for supporting widespread adoption of Peltier-based energy harvesting technologies in remote sensors, Internet of Things (IoT) devices, and sustainable building systems.

METHODS

This study aims to design and develop an electronic device that prioritizes both security and user convenience. In the development process, the essential components were identified to ensure optimal device performance and functionality. At the initial stage of the research, the device requirements were identified with a primary focus on two aspects: system security and user-friendliness. The system being developed is designed to convert heat energy into electrical energy, control temperature and voltage, and efficiently monitor the device's performance. Based on the results of the needs assessment, components were selected according to the required specifications, and a flowchart of the device was created.

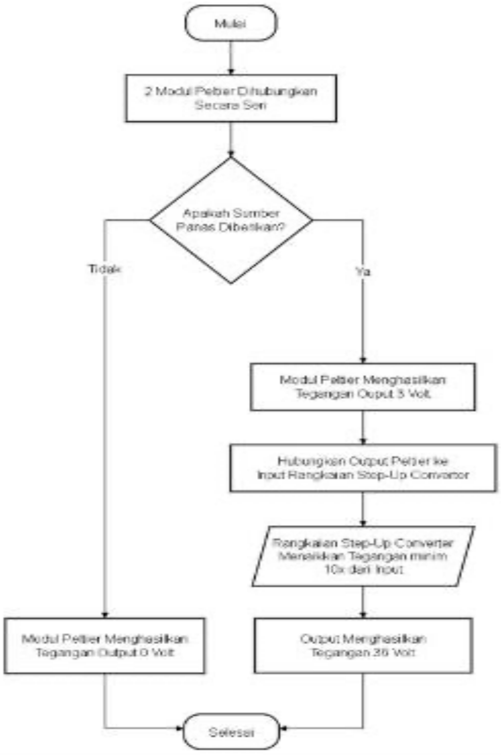

Figure 1. Device Flowchart

The following components were selected for the system design:

1. Peltier TEC1-12706-12VDC

   The Peltier TEC1-12706-12VDC module is used to convert heat energy generated by the system into electrical energy based on the thermoelectric principle.

2. Heatsink

   The heatsink is used to cool the Peltier module and other components by dissipating heat into the surrounding air, thereby preventing overheating and maintaining system stability.

3. ESP32 Devkit V.4

   A development board based on the ESP32 chip, which is utilized for data processing and device communication over a network, especially for Internet of Things (IoT) applications.

4. Booster Step-Up Module (2.5V to 5–12VDC)

   This boost converter module functions to increase low input voltage to a higher output voltage required to power other components in the system.

5. Voltage Sensor

The voltage sensor is used to measure the voltage within the circuit, enabling real-time monitoring to ensure system stability.

6. NTC Temperature Sensor

The NTC (Negative Temperature Coefficient) temperature sensor is used to monitor the system's temperature and control device performance based on detected temperature changes, utilizing its characteristic of decreasing resistance with increasing temperature.

After selecting the appropriate components, the next step was to design the circuit schematic.

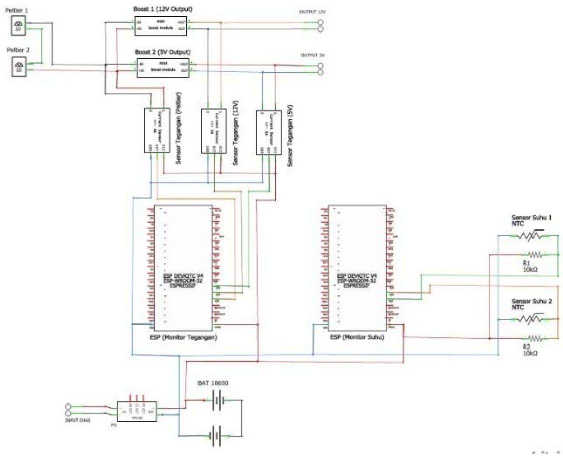

Figure 2. Circuit Scheme

RESULTS

The testing was carried out to verify whether the implemented system met the predetermined specifications and design requirements.

Figure 3. Peltier-Based Power Generation Prototype

The testing method focused on the system's functionality and several key parameters, particularly the output voltage of the Peltier module, which is highly dependent on temperature variations. The data obtained from these tests were used to analyze system performance and evaluate the accuracy of the system in meeting the design objectives. The testing was conducted by measuring the output voltage generated by the Peltier module TEC1-12706-12VDC at various temperature points ranging from 0°C to 80°C.

Table 1. Results of Peltier Output Voltage Measurements

No	Temperature (Degree)	Voltage (Volt)
1	0	0
2	10	0.375
3	20	0.75
4	30	1.125
5	40	1.5
6	50	1.875
7	60	2.25
8	70	2.625
9	80	3

The test results showed a clear relationship between temperature and the measured voltage. At 0°C, the measured voltage of the Peltier module was 0 Volts. At this temperature, there is no significant temperature difference between the hot and cold sides of the Peltier module, resulting in a low output voltage. This indicates that the thermoelectric effect at low temperatures is not sufficient to generate a significant voltage.

At 80°C, the measured voltage increased to 3 Volts. At this higher temperature, the temperature difference between the hot and cold sides of the Peltier module becomes greater, resulting in a higher voltage output. This indicates that the system successfully converted heat energy into electricity in accordance with the basic working principle of the Peltier module.

Based on these test results, it can be concluded that there is a relationship between temperature and the measured voltage. This relationship is linear based on the available measurement points. To clarify this relationship, a linear equation can be formulated to describe the correlation between temperature and voltage.

$$V = m \cdot T + bV$$

Where:

V = voltage generated (in Volts),

T = temperature (in degrees Celsius),

m = slope of the line, which indicates the rate of change in voltage per unit change in temperature,

b = constant representing the intercept of the line on the voltage axis.

Based on the measurement points (0°C, 0V) and (80°C, 3V), the slope of the line (m) can be calculated as follows:

$$m = \frac{(V_2 - V_1)}{(T_2 - T_1} = \frac{(3V - 0V)}{80\ °C - 0°C} = \frac{3V}{80°C} = 0.0375\ {}^{V}/_{°C}$$

Thus, the linear equation describing the relationship between temperature and voltage can be written as V=0.0375·T

Figure 4. Monitoring Peltier Voltage and Temperature

Based on the test results conducted on the Peltier module, a clear relationship can be observed between temperature and the voltage generated. The testing shows that at 0°C, the measured voltage is 0 Volts, while at 80°C, the voltage increases to 3 Volts. This data indicates that the greater the temperature difference between the hot and cold sides of the Peltier module, the higher the voltage produced.

The test results demonstrate that the relationship between temperature and the voltage generated by the Peltier module is linear or nearly linear. Calculations show that for every 1°C increase in temperature, the voltage increases by 0.0375 Volts, following the mathematical equation V=0.0375T.

where V is the voltage in Volts and T is the temperature in degrees Celsius. This supports the fundamental theory of the Peltier effect, which states that a temperature difference between the two sides of the module will generate a voltage. However, to gain a more comprehensive understanding, further testing across a wider temperature range and with more measurement points is recommended. Although the relationship between temperature and voltage is linear, several external factors can influence the voltage generated:

1. Electrical Current

   Higher electrical current can enhance the temperature difference between the sides of the module, thereby increasing the output voltage.
2. Peltier Module Quality

   The quality of the Peltier module can affect its efficiency and voltage output. Defective or low-quality modules may produce lower voltages.
3. Environmental Factors

   Humidity, atmospheric pressure, and other environmental conditions can affect the material's conductivity and the module's performance. Further testing that takes these factors into account will provide a more accurate assessment of the Peltier module's performance under real-world conditions.

The testing confirms that the system's control mechanism functions according to the specified requirements. The voltage generated by the Peltier module increases proportionally with the rise in temperature, in line with the basic principle that a Peltier module generates voltage as a result of a temperature difference.

CONCLUSION

The testing demonstrated a clear and linear relationship between temperature and the voltage generated by the Peltier module. The measured voltage at 0°C was 0V, while at 80°C it increased to 3V. This indicates that the system operates according to the basic principle of the Peltier module, where a temperature difference between the two sides of the module generates electrical voltage. From the two measurement points (0°C, 0V) and (80°C, 3V), a slope of 0.0375 V/°C was obtained. This means that for every 1°C increase in temperature, the voltage rises by 0.0375 Volts. This linear relationship suggests that the system can reliably generate consistent voltage in response to temperature increases. The tested control system performed well and in accordance with the designed specifications. Although testing was conducted within a temperature range of only 0°C to 80°C, the system was able to produce measurable and accurate voltage output. This indicates that the system design was effectively implemented in this initial testing phase.

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