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DESIGN OF A THERMOELECTRIC GENERATOR FOR BATTERY CHARGING USING HEAT FROM A STEAM IRON BASE

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ABSTRACT

This study explores an alternative method of generating electrical energy using a thermoelectric generator that utilizes heat from the soleplate of a steam iron and six thermoelectric units connected in series. Based on the Seebeck effect, the thermoelectric modules convert the temperature difference into voltage. An increase in the heat source temperature leads to higher voltage production by the series-connected thermoelectric modules, although the electrical power output depends on the connected load. The power generator design includes thermoelectric modules, a buck-boost converter, an 18650 lithium-ion battery, and a 5-watt, 12-volt DC lamp. The study addresses key aspects such as the impact of temperature on power output in series-connected and parallel-connected thermoelectric circuits, and the efficient conversion of heat from the steam iron soleplate into electrical energy. The research objectives are threefold: to determine power and temperature values for series-connected thermoelectric circuits, to evaluate power and temperature values for parallel-connected thermoelectric circuits, and to utilize heat from the steam iron soleplate as a thermoelectric heat source for generating electrical energy. Testing involved a buck-boost converter connected to a battery, producing 12.35 volts with a temperature difference of 49°C. Design enhancements, such as integrating heatsinks or coolers on the cold side of the modules to maintain a significant temperature differential, are critical for optimizing performance.

Keywords*: alternative energy, buck-boost converter, heatsink, seebeck effect, thermoelectric.*

I. INTRODUCTION

ENERGY sources are essential components of human life, serving as a primary driver in every sector. The demand for energy, particularly electrical energy, continues to rise, while the electricity supply remains constrained. derived from natural resources, such as natural gas and petroleum, is depleting due to increasing energy demands across all aspects of life [1]. To address this issue, it is imperative to explore viable solutions, particularly through advancements in technology that focus on the development of renewable energy sources. Utilizing renewable energy as an alternative can significantly reduce the consumption of non-renewable energy.

One approach to developing renewable energy is through the use of thermoelectric generators (TEGs). These devices generate electrical power by utilizing temperature differences. Despite their low efficiency, TEGs can directly convert temperature differences into electrical energy. In this study, testing was conducted using a buck-boost converter connected to a battery, demonstrating how temperature differences can be harnessed to generate energy. TEGs also have the capability to charge batteries, making them a promising alternative energy source [2].

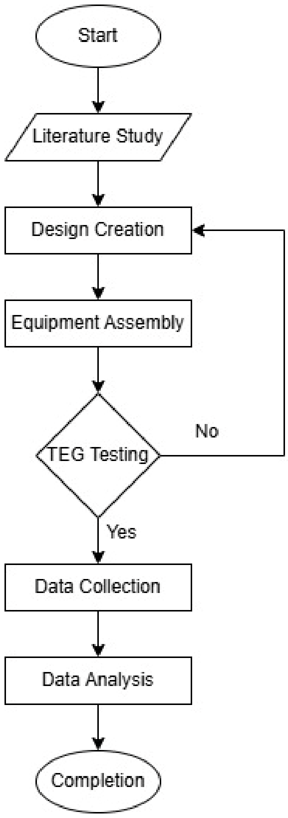


Figure 1. Research flow diagram

Thermoelectric generators (TEGs) utilize the Seebeck effect to generate electricity through temperature differences. These devices can convert unused heat into electrical energy due to their simple design, eco-friendliness, and ease of use. In the laundry industry, one example of such heat energy is the heat from a steam iron base, which is commonly used in steam iron systems.

The objectives of this research are to achieve several key goals. First, it aims to obtain power and temperature values from thermoelectric circuits arranged in series. Second, it seeks to measure and secure power and temperature values from thermoelectric circuits arranged in parallel. Lastly, the study intends to utilize the heat generated from the base of a steam iron as a heat source for thermoelectrics to produce electrical energy. These objectives collectively focus on exploring the efficiency and potential of thermoelectric circuits in different configurations and practical applications.

This study involves testing with a buck-boost converter connected to a battery, utilizing temperature differences to generate energy. The research addresses three key issues: power output based on temperature in thermoelectric circuits arranged in series, power output based on temperature in thermoelectric circuits arranged in parallel, and efficient power generation using the heat from a steam iron base as the thermoelectric heat source. This research aims to answer these questions while advancing thermoelectric innovation by using the steam iron base as a heat source [3].

II. RESEARCH METHOD

This research employed a single method, the quantitative method, as it involved experimental studies that included direct experimentation and detailed calculations (see Figure 1). Thermoelectrics are capable of converting temperature differences into electrical energy. Under both hot and cold temperature conditions, thermoelectrics generate voltage, current, and power output [4].

A. Alternative and Renewable Energy

According to [5], alternative energy can serve as a substitute for conventional energy and provides an environmentally friendly solution, particularly during energy crises. Non-renewable energy, derived from Earth's resources accumulated over millions of years, contrasts with renewable energy, which comes from unlimited natural resources that remain sustainable even with continuous use.

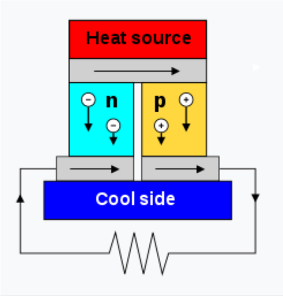


Figure 2. Seebeck effect scheme

Figure 3. Thermoelectric

As highlighted in [1], renewable energy will play a critical role in the future, meeting the daily energy needs of living organisms. Fossil fuels dominate conventional power generation; however, renewable energy sources can address the depletion of non-renewable energy supplies.

B. *Heat Energy*

Renewable energy, such as heat energy, is a sustainable resource that can be used continuously without depletion [6]. This energy source can serve as an alternative energy solution when combined with appropriate technology. Heat energy can be harnessed from waste gases, such as the residual heat produced by steam irons. Unused residual heat, if not utilized efficiently, holds potential for conversion into alternative energy.

The process of converting heat energy into electrical energy requires energy transformation mechanisms [7]. This conversion relies on temperature differences, with a hot source providing heat and a cooler medium, such as water, creating the lower temperature. By combining the heat from a steam iron and the cooling effect of water, thermoelectric devices can generate electrical energy, offering an alternative energy source.

C. *Thermoelectric*

Thermoelectric devices generate voltage by exploiting temperature differences. The voltage produced depends on the magnitude of the temperature differential or input. As an alternative energy source, thermoelectric generators can be utilized for battery charging [8]. Although their efficiency remains low, these devices directly convert temperature variations into electrical energy. Materials with a temperature difference create a potential difference, resulting in current generation through the Seebeck effect.

Figure 2 illustrates the schematic of the Seebeck effect, showing a hot side (heat source) and a cold side (cool source). This temperature difference generates a current in opposite directions, a phenomenon described as thermoelectricity. Both current and voltage can be produced by connecting two different metals, forming a circuit that leverages the temperature differential for power generation.

In this study, the heat source is derived from a steam iron base, while the cold source is maintained at room temperature. The steam iron base is an efficient choice due to its consistent heat output, which remains within the thermal limits of thermoelectric materials, typically ranging from 55 to 100 °C. Although room temperature is adequate as a cold source, higher heat sources may require alternative cold sources, such as ice, to balance the temperature gradient and stabilize energy output.

1) *Thermoelectric Generator 1848 27145 SA (TEG)*

The SP 1848 27145 SA thermoelectric module (see Figure 3) generates an electric potential difference using the temperature gradient across the Peltier surface, a phenomenon known as the Seebeck effect. This module is particularly heat-resistant and can produce a voltage of 4.8 V with a temperature difference of 50 °C, delivering a current of 669 mA, as specified in its datasheet [9].

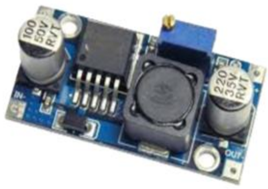


Figure 4. Step-Up Buck-Boost Converter

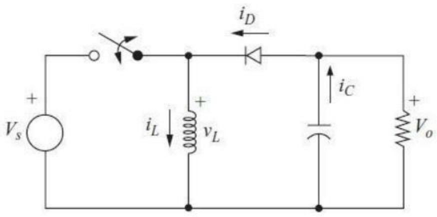


Figure 5. Design of Buck-Boost Converter

2) Thermoelectric Cooler TEC1-12706 (TEC)

This thermoelectric device operates on the Peltier effect, converting electrical energy into heat or cold at its surfaces. The TEC1-12706 module has dimensions of 40 mm x 40 mm with a thickness of 3.8 mm. It can achieve a maximum temperature difference of 66 °C on the cold side and 138 °C on the hot side. The module supports a maximum current of 6 amperes and a maximum voltage of 14.4 volts [10].

D. Buck-boost Converter

The Buck-Boost Converter (see Figure 4) is incorporated into the design (see Figure 5) to regulate the voltage output from the thermoelectric module. This converter ensures the output voltage meets the requirements for battery charging [11]. The converter can either increase or decrease the input voltage depending on the system's needs.

The average output voltage depends on the duty cycle of the converter, which is determined by the on-time and off-time ratio of the switching mechanism. When the switch is closed (ON), the current in the inductor increases, storing energy. When the switch is open (OFF), the stored energy is released, and the current flows toward the load. This DC-to-DC converter is crucial for maintaining a stable voltage supply.

In this study, the nominal voltage fluctuates over time, requiring regulation to produce stable D.C. voltage. A buck-boost converter is employed for this purpose. This converter can either increase (boost) or decrease (buck) the voltage by adjusting the duty cycle. The buck-boost converter works in conjunction with other components to regulate and enhance voltage.

The system begins with thermoelectric modules placed on a steam iron base, connected in series. These modules feed into the buck-boost converter. While the buck-boost converter can step up the voltage to meet battery specifications, it does not increase the current. As a result, the energy transfer rate is slower due to the low current, but the voltage is sufficient to allow energy flow into the battery, albeit at a slower rate.

E. Battery

The generated power can be utilized for battery charging through a series circuit. Batteries are integral in energy system design, serving as both an output voltage source and a storage medium for generated power [12].

A notable example is the lithium-ion 18650 battery, a rechargeable and maintenance-free secondary battery. Lithium-ion batteries are widely used in modern electronic devices such as smartphones, laptops, and electric vehicles. Unlike earlier battery types such as Ni-Cd and Ni-MH, lithium-ion batteries are environmentally friendly as they do not contain hazardous materials [13].

These batteries offer several advantages over other secondary batteries, including lighter weight, excellent energy storage stability (lasting up to 10 years or more), high energy density, and no memory effect. These features make lithium-ion batteries more effective and efficient than alternative battery types.

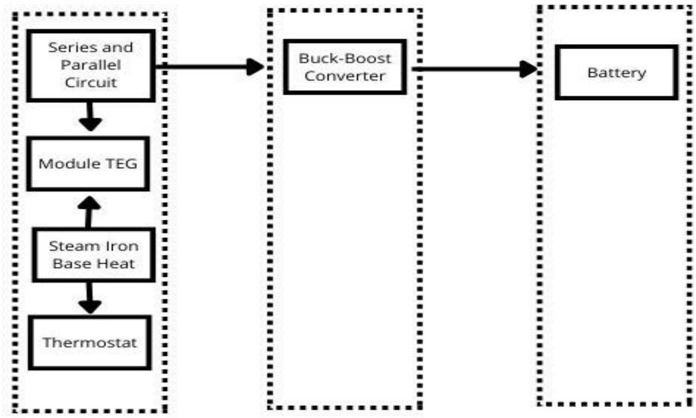
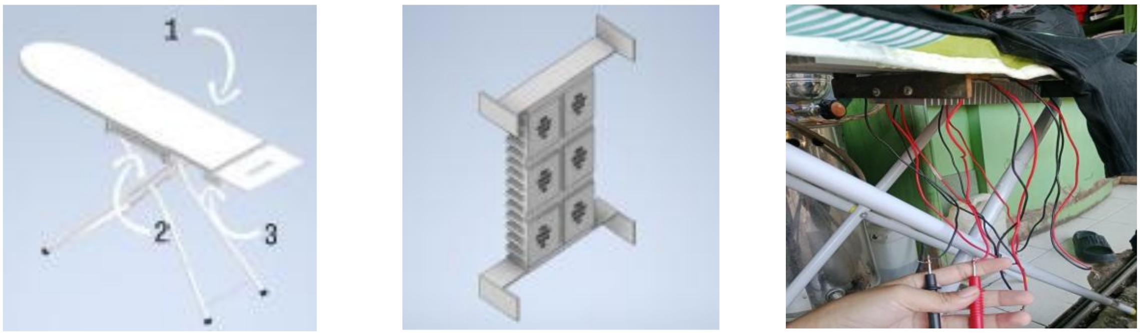


Figure 6. Block Diagram Design



(a) (b) (c)

Fig 7. Thermoelectric Design: (a) Planning the iron base, (b). TEG circuit, (c). Implementation

F. 12-Volt DC Lamp

A 12-volt DC (Direct Current) system operates at a voltage of 12 volts, with current flowing in a single direction, unlike alternating current (AC), where the flow alternates. Power sources for 12-volt DC include batteries, DC adapters, solar panels, and other devices providing direct current. This voltage is widely used in electronic devices, automotive systems (e.g., car lights), and LED lighting systems due to its stability and efficiency.

Additionally, 12-volt DC is considered safer for everyday use because of its relatively low voltage, which reduces the risk of electric shock. It is often preferred for applications requiring voltage stability and energy efficiency. In this research, a 5-watt lamp is utilized as part of the system [14].

G. Block Diagram

The block diagram in this study illustrates the thermoelectric system, which utilizes waste heat from a steam iron as the heat source. It provides a detailed overview of the process flow, from the initial stage to the final stage of the research.

The input for the system is waste heat from a steam iron, with temperatures ranging between 33–75°C, measured using a thermostat. This heat is then processed by a thermoelectric generator (TEG) module. Multiple TEG units are used in the system, supported by a buck-boost converter.

The buck-boost converter plays a critical role in regulating the voltage, either stepping it up or down as needed. This component is particularly important for battery charging, ensuring voltage stability and compatibility.

In the final stage, the circuit and its components are set up to deliver power to the load. In this study, a battery serves as both the load and the power output storage. Once the power is collected and stored in the battery, it can be applied effectively in various industrial settings, offering practical benefits [15].

In Figure 6, this study begins by arranging thermoelectric modules in series and parallel configurations. Prior to this step, the thermoelectric modules are exposed to a heat source—specifically, the steam iron base used in this study. On the cold side, the modules are subjected to a cooling source, which, in this case, is room temperature.

TABLE 1
MEASUREMENT OF THERMOELECTRIC PERFORMANCE IN A SERIES CIRCUIT BASED ON MODULE QUANTITY

Amount of Thermoelectric	Voltage (v)	Current (A)	Power (W)	ΔT (°C)
1	1.01	0.43	0.99	46
2	2.14	0.45	2.14	48
3	3.23	0.41	2.71	41
4	5.24	0.43	4.45	42
5	7.05	0.45	7.05	49
6	8.00	0.46	8.00	52

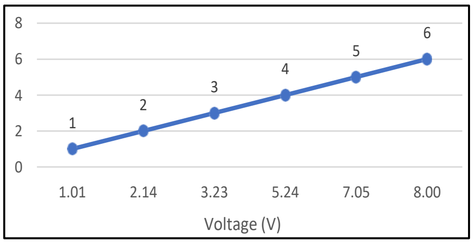


Figure 8. Voltage Testing Based on the Number of Thermoelectric Modules Arranged in Series

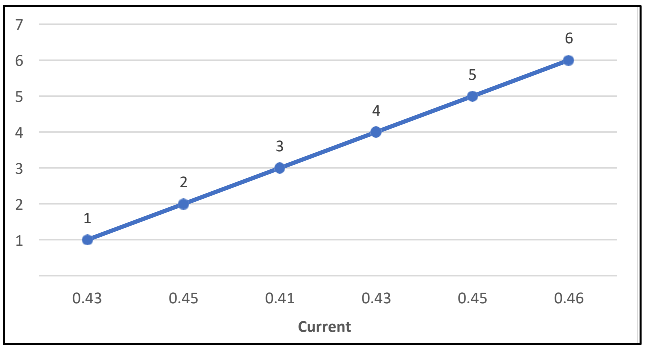


Figure 9. Current Testing Based on the Number of Thermoelectric Modules Arranged in Series

After arranging the thermoelectric modules and positioning them on the steam iron base, cables from the modules are connected to the buck-boost converter (also referred to as a voltage booster). This connection is necessary because the output voltage and current from the thermoelectric modules alone are relatively low. The buck-boost converter is then adjusted to output the voltage required by the system specifications, enabling it to transfer energy efficiently to the battery. The battery used in this study is a lithium-ion type, which can be charged to power various devices, such as lights or other electronic systems.

III. RESULT AND DISCUSSION

This study aims to develop a circuit capable of generating output energy from thermoelectric modules. Two types of circuits are evaluated: series and parallel circuits. Figure 7 illustrates a circuit comprising six thermoelectric modules connected in series.

The research focuses on converting heat and cold energy from both sides of the thermoelectric modules. Due to the susceptibility of thermoelectric modules to damage from excessive heat, precautionary measures are necessary. In this study, the thermoelectric modules are enclosed with heatsinks on both the hot and cold sides. On the hot side, a heatsink prevents the module from overheating, while on the cold side, it serves as a cooler alongside room temperature. The thermoelectric module is positioned between layers of heatsinks to maintain an optimal temperature gradient.

Once the thermoelectric modules are properly positioned, additional components, such as the buck-boost converter, are connected to regulate and increase the voltage. The generated energy is then directed to a lithium-ion battery for storage. This setup allows the stored energy to be used for various practical applications.

Based on Table 1, the results indicate that a single thermoelectric module generates a current of 0.43 A, while connecting six thermoelectric modules in series only slightly increases the current to 0.46 A. As additional modules are connected in series, from 2 to 6 modules, the voltage rises to 8.00 V (see Figure 8); however, the current remains constant at 0.46 A (see Figure 9), with no significant variation

TABLE 2
MEASUREMENT OF SIX THERMOELECTRIC MODULES BASED ON STEAM IRON SOLEPLATE TEMPERATURE IN A PARALLEL CONFIGURATION

No.	ΔT (°C)	Voltage (V)	Current (A)	Power (W)
1	14	1.00	0.30	0.30
2	24	2.50	0.40	1.13
3	32	3.00	0.41	1.50
4	36	4.10	0.41	3.20
5	41	5.00	0.43	4.25
6	46	7.00	0.42	6.44
7	49	8.00	0.45	8.00
8	49	8.06	0.46	8.46
9	57	8.20	0.47	9.02
10	61	8.25	0.49	9.24

TABLE 3
THERMOELECTRIC MEASUREMENTS IN PARALLEL CIRCUITS BASED ON THERMOELECTRIC QUANTITY

Amount of Thermoelectric	Voltage (v)	Current (A)	Power (W)	ΔT (°C)
1	1.01	0.43	1.01	46
2	1.23	0.98	1.23	47
3	1.44	1.00	1.44	49
4	1.05	1.11	1.05	49
5	1.45	1.20	1.45	53
6	1.50	1.30	1.50	54

TABLE 4
MEASUREMENT OF SIX THERMOELECTRIC MODULES BASED ON STEAM IRON BASE TEMPERATURE IN PARALLEL CONFIGURATION

No.	ΔT (°C)	Voltage (V)	Current (A)	Power (W)
1	19	1.00	1.20	1.2
2	24	1.00	1.21	1.21
3	40	1.50	1.25	1.87
4	41	1.10	1.26	1.38
5	46	1.16	1.28	1.48
6	47	1.20	1.29	1.54
7	50	1.20	1.30	1.56
8	53	1.29	1.30	1.67
9	59	1.55	1.31	2.03
10	61	1.98	1.33	2.63

in temperature differences. These measurements suggest that in a series circuit, the voltage increases proportionally with the number of modules, while the current remains unchanged.

Figure 8 and 9 depict the power output based on the number of thermoelectric modules. The tests were conducted using 1 to 6 thermoelectric modules arranged in series. From the data, it is evident that power output increases as more thermoelectric modules are added in series. However, the temperature differences observed across the modules remain consistent. This confirms that in a series circuit, power output increases with the number of modules used, provided the temperature differential is maintained [16].

Table 2 shows that a single thermoelectric module produces a voltage of 1.00 V at a temperature of 14°C; however, the buck-boost converter does not generate an output voltage at this level. This issue persists until the thermoelectric module voltage reaches 3.00 V. The buck-boost converter specifications require a minimum input of 4.00 V to function. Consequently, output voltage from the buck-boost converter is only observed once the input from the thermoelectric modules reaches 4.00 V.

The buck-boost converter serves to both increase and stabilize the voltage. For instance, when the thermoelectric output voltage reaches 8.00 V, the buck-boost converter boosts it to 12.00 V, a level sufficient for utilization or storage in a battery.

Thermoelectric measurements arranged in parallel demonstrate that the voltage remains constant while the current increases. As shown in Table 3, the voltage values range from 0.43 V to 1.30 V, with minimal variation in temperature differences. Despite the low output current, it increases from 0.43 A with one module to 1.30 A when six modules are connected in parallel. This indicates that in a parallel circuit, the voltage remains the same, but the current increases proportionally to the number of modules, even if the overall output remains low.

The tests reveal that thermoelectric power increases as more modules are connected in parallel. For instance, the power output of a single thermoelectric module was 1.01 volts, while connecting six mod-

TABLE 5
BATTERY CHARGING

No.	Time	Thermoelectric			Buck-Boost Converter			Battery	
	(Minutes)	(V)	(A)	(W)	(V)	(A)	(W)	(V)	(%)
1	0	7.80	0.42	3.27	11.79	0.16	1.88	11.31	10
2	30	8.05	0.43	3.46	12.00	0.17	2.04	11.42	10.09
3	60	8.09	0.44	3.55	12.05	0.17	2.04	11.53	10.19
4	90	8.10	0.45	3.64	12.10	0.18	2.17	11.64	20.10
5	120	8.09	0.44	3.55	12.09	0.17	2.05	11.75	30
6	130	8.05	0.43	3.46	12.00	0.16	1.92	11.86	30.28
7	150	8.10	0.46	3.72	12.15	0h.19	2.30	11.97	40.23
8	180	8.00	0.42	3.36	12.00	0.16	1.92	12.08	50.08
9	210	8.05	0.43	3.46	12.10	0.17	2.05	12.19	50.53
10	240	8.12	0.47	3.81	12.20	0.19	2.31	12.30	60.49
11	270	8.05	0.44	3.54	12.00	0.16	1.92	12.41	70.51
12	300	8.10	0.45	3.64	12.05	0.17	2.04	12.51	90.07
13	330	8.15	0.49	3.99	12.25	0.20	2.45	12.60	100

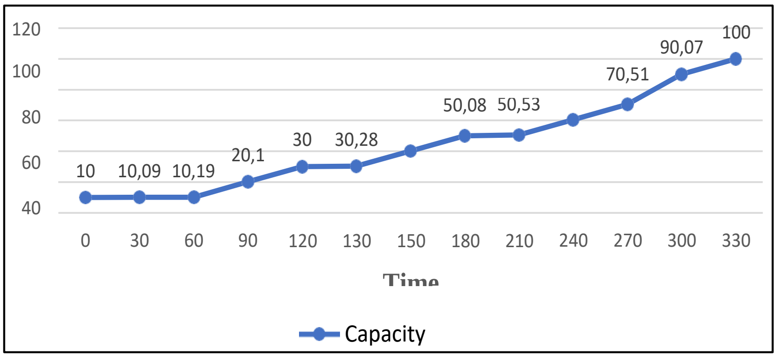


Figure 10. Capacity Measurement Graph Based on Time

ules resulted in an output of 1.5 volts. However, while power increases with additional modules in parallel, it remains lower than in a series circuit. The results consistently show that parallel configurations produce relatively low power compared to series configurations (see Table 4). As such, this study prioritizes the use of series configurations for further research.

When measuring six thermoelectric modules arranged in parallel, the highest voltage observed was 1.98 V, with a current of 1.33 A at the highest temperature. Although the current output increased, the voltage remained relatively low. This low voltage prevents the parallel circuit from being compatible with the buck-boost converter, which requires a minimum input of 4.00 V. Consequently, the parallel circuit cannot connect to the buck-boost converter due to insufficient voltage output.

Based on Table 5, the results indicate that the series circuit is more efficient than the parallel circuit, primarily because the voltage produced by the parallel circuit is too low to meet the specifications of the buck-boost converter. The buck-boost converter requires a minimum input of 4 volts, whereas the parallel circuit does not reach this threshold. Although the current in a series circuit is lower than in a parallel circuit, this only affects the battery's charging time.

If the parallel configuration is used, the buck-boost converter cannot step up the voltage, preventing energy transfer to the battery. As a result, the series configuration was chosen for this study. Efficiency can be further improved by increasing the temperature differential, using alternative heat or cooling sources such as ice, applying the device in areas with larger hot surfaces, or increasing the number of thermoelectric modules.

The table above shows that the buck-boost converter produces a voltage ranging from 11.79 volts to 12.25 volts, sufficient for battery charging. As charging progresses, the battery voltage increases, with measurements taken at 30-minute intervals. With a stable input voltage of 8 volts from the thermoelectric module, the buck-boost converter maintains a consistent output voltage.

However, the current output of the buck-boost converter is lower than that of the thermoelectric module. This discrepancy occurs because the input power exceeds the output power of the buck-boost converter. Despite this, the voltage from the thermoelectric module can be successfully increased using the buck-boost converter, ensuring the system remains functional for battery charging.

This test measured data every 30 minutes to monitor the charging process using the thermoelectric circuit. The initial measurement recorded a starting voltage of 7.80 V with a power output of 3.27 W. Over time, as the charging duration increased, both the voltage and power output improved. The buck-boost converter provided a relatively stable output, ranging from 11.79 V to 12.25 V. As a result, a battery with an initial 10% capacity was gradually charged, accompanied by a corresponding increase in power output.

Figure 10 indicates that the voltage generated by the thermoelectric modules exceeded the battery's voltage. This higher output voltage is attributed to the arrangement of thermoelectric modules in series and the heat provided by the steam iron soleplate. A significant temperature difference led to a steady increase in battery voltage at 30-minute intervals.

IV. CONCLUSION

This study investigated the use of thermoelectric modules to design alternative energy for lighting. The findings highlight that as the temperature of the steam iron soleplate increases, a series circuit of thermoelectric modules generates higher voltage. However, the electrical power produced depends on the connected load.

In a series configuration, the total voltage output increases with the number of thermoelectric modules, while the current remains constant compared to a single module. An increased temperature on the module's hot side enhances the temperature difference between the hot and cold sides, thereby increasing the generated voltage. For instance, in experiments with six thermoelectric Peltier modules arranged in series, the power output was 3.92 W, with a voltage of 8.00 V and a current of 0.49 A, which was higher than in the parallel configuration.

In contrast, a parallel circuit benefits from increased current as the temperature rises, thereby generating more electrical power, depending on the load. However, the power output in a parallel circuit remains lower than in a series circuit. Experiments with six thermoelectric modules in parallel produced a power output of 2.63 W, which was notably less efficient than the series configuration.

Efficiently generating electrical power from the heat of a steam iron using thermoelectric modules requires optimizing the series circuit configuration. Maximizing the temperature difference between the hot and cold sides of the modules is also critical. This can be achieved by incorporating design modifications, such as using heatsinks or coolers on the cold side, to maintain a significant temperature gradient. In the temperature test conducted on the steam iron soleplate, a temperature difference (ΔT) of 56°C was achieved, with T1 measured at 92°C and T2 at 36°C.

The study concludes that the energy output of thermoelectric modules arranged in series and parallel configurations can be compared to evaluate their efficiency. The results align with the research objectives, demonstrating that wasted heat from the steam iron base can be effectively utilized as an energy source. Furthermore, the study highlights the potential of thermoelectric modules as energy harvesters. This capability was exemplified in this research, where the modules successfully powered a lamp and demonstrated the feasibility of powering other electronic devices.

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