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Design and Build Thermo Electric Hybrid Power Plant as AGL CBT Laboratory Backup Power Supply

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ABSTRACT: The demand for reliable and environmentally friendly electricity supply has driven the development of more efficient backup power systems. This study aims to design and construct a hybrid power generation installation that combines thermoelectric generators and solar panels as a backup power solution. The system utilizes solar radiation and temperature disparity as primary energy sources, which are then converted into electrical energy and stored in a 200 Ah LiFePO4 battery. The design stages include the selection of key components such as thermoelectric modules, 100 Wp solar panels, maximum power point trackers, battery controllers, and inverters. Simulations and tests were carried out to analyze the system's performance under the climatic conditions of Medan City. The test results indicate that power can be continuously generated from these two energy sources, providing a stable backup electricity supply. With a modular and efficient structure, this system has the potential to serve as a sustainable energy source that reduces dependence on fossil fuels. This design also holds promise as a prototype for educational purposes and a rapid solution during power outages.

Keyword: *Thermoelectric Generator; Solar Panel; LiFePO4*

I. INTRODUCTION

The need for renewable energy sources is increasingly urgent, including the use of energy potential that is often overlooked, such as waste heat. Thermoelectric Generator (TEG) technology can convert this heat into electrical energy, making it potentially an efficient and sustainable backup source [1].

In the context of aviation, the Airfield Ground Lighting (AGL) laboratory has an important role in supporting Computer Based Training (CBT). The stability of the power supply in this laboratory is absolutely necessary because electrical outages, even if brief, can hinder the training and operation process of the device. Therefore, a reliable power backup solution is needed [2].

Several studies on hybrid power plants in Indonesia have highlighted the integration of solar power plants, PLTB, and PLN to increase the electrification ratio in remote areas. However, the application of TEG-based hybrid systems for the specific needs of aviation laboratories is still rarely researched. This creates a research gap that needs to be answered [3]

The Airfield Ground Lighting (AGL) laboratory has a significant electrical need due to its vital function. Therefore, the availability of a backup power supply is an important element to ensure the operational stability of devices such as computers, servers, and network systems. This aims to ensure that the implementation of computer-based exams can take place smoothly without being disturbed by power outages or instability [4].

Based on these conditions, this research is focused on designing a Thermoelectric Generator (TEG)-based hybrid power generation system as a backup power supply, as well as to identify factors that affect its performance and stability.

II. THEORETICAL FRAMEWORK

Design and Build

Design and construction is the process of designing to the physical realization of a tool to solve certain problems functionally and efficiently [5]. In this study, the design is focused on a hybrid system of Thermoelectric Generator (TEG) and wind turbines as laboratory backup power supply.

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Power plant

Power plants are energy conversion systems into electrical energy [6]. As the need for clean energy increases, hybrid systems are being developed to improve reliability. This study uses a combination of turbine mechanical energy and heat energy from TEG [7].

Thermoelectric

TEG works with the principle of the Seebeck effect, which is to generate electricity from temperature differences. Previous studies have shown that TEG SP 1848 is more efficient than TEC 12706 at an average ΔT of 14.87 ºC [8]. This supports the selection of TEG modules for the designed system.

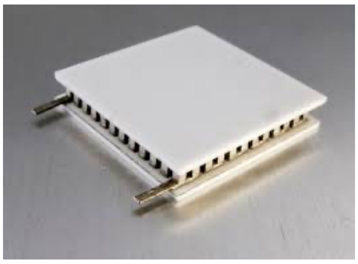

Figure 1. Thermoelectric

Battery and Charger

The battery functions to store the converted energy [9]. Lithium-ion is used because of its high energy density, while a charger is required to maintain current and voltage for stable charging. The system uses a PWM-based charger that matches the characteristics of Li-ion batteries [10].

III. METHODS

Research Methods

This type of research is Research and Development (R&D) with the aim of producing products through validity, practicality, and effectiveness tests [11]. The development model used is Four-D (4D) which consists of Define, Design, Develop, and Disseminate stages [12]. The test was carried out on the rooftop of the Medan Aviation Polytechnic dining room in the period April to July 2025 as shown in Figure 2.

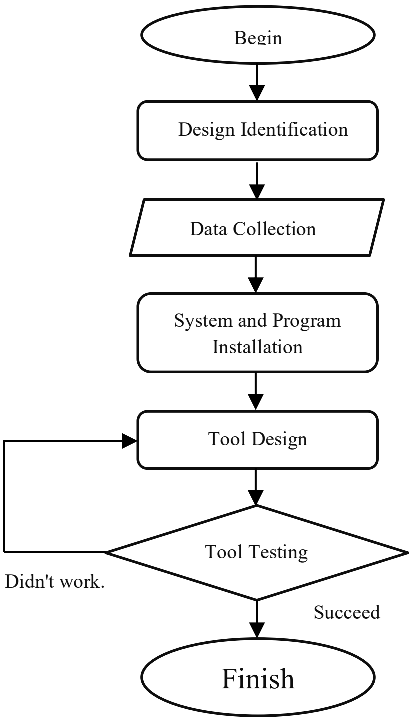

Figure 2. Research Flow Chart

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The research stage starts from design identification, which is defining the concept of the tools and methods used, then continues with data collection, system installation, hardware design and input-output design, to tool testing to ensure the suitability of its function.

System Design

The designed system utilizes a combination of wind turbines and Thermoelectric Generators (TEGs) as energy sources. The energy produced is channeled through the charger for battery charging, then the tension is increased with a booster according to the load needs. The main components consist of a turbine as a mechanical drive, a generator as an energy converter, a TEG based on Bismuth Telluride (Bi_2Te_3) material, a 200 Ah $LiFePO_4$ battery, and a PWM-based charger to maintain charging stability. The system workflow is shown in Figure 3, which illustrates the relationships between components in generating power supply for the Airfield Ground Lighting Laboratory.

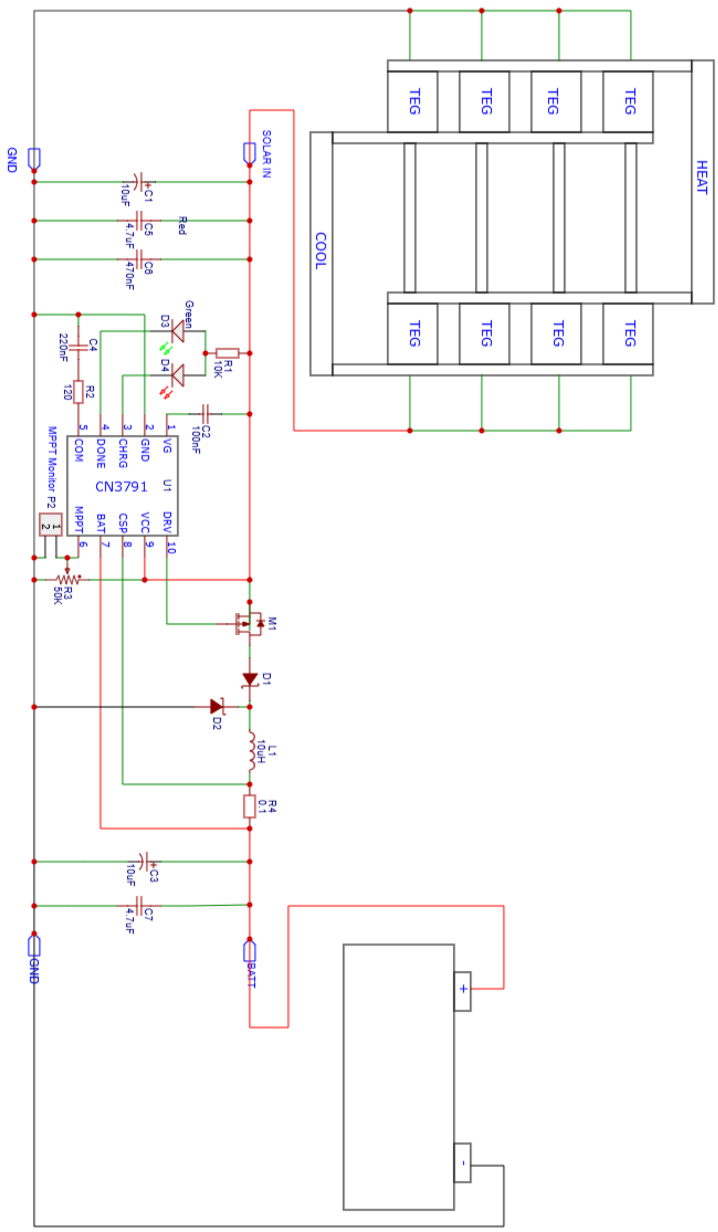

Figure 3. Wiring Working Tool

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Testing Procedure

Testing is performed to assess the function, performance, and characteristics of the device. The parameters measured include output voltage, current, charging efficiency, and power supply stability. The test results are then analyzed to ensure the reliability of the system while evaluating its potential use as a learning medium and a backup energy source in a laboratory environment.

IV. DISCUSSION

Testing is performed to assess the function, performance, and characteristics of the device. The parameters measured include output voltage, current, charging efficiency, and power supply stability. The test results are then analyzed to ensure the reliability of the system while evaluating its potential use as a learning medium and a backup energy source in a laboratory environment.

Preliminary tests were carried out on the Thermoelectric Generator (TEG) module to evaluate its ability to convert temperature difference (ΔT) into electrical energy. The tools used include the TEG TEC1-12706 module, fanned heatsink, heat source, multimeter, and resistive load. The module is installed between two media with different temperatures; The hot side faces the heat source and the cold side is equipped with a heatsink with thermal paste to improve thermal conductivity.

The measurement results show that the output power of the TEG is highly dependent on ΔT. The greater the temperature difference, the resulting voltage increases, according to the principle of the Seebeck effect. The TEG specifications are presented in Table 1.

Table 1. Thermoelectric Specifications

Specifications	Information
Model	TEC1-12706
Dimension	40 mm x 40 mm x 3.6 mm
Material	Bismuth Telluride (Bi_2Te_3)
Maximum Voltage (Vmax)	15.4 Volt
Maximum Current (Imax)	6 Ampere
Maximum Power (Pmax)	±90 Watts (when conditions are optimal)
Optimal Temperature Difference (ΔT)	±65–70 °C
Conversion Efficiency	5–8% (depending on temperature and usage conditions)
Working Temperature	-40°C to 150°C
Type	Thermoelectric Generator (Peltier Module – used in reverse)

Table 1 shows the specifications of the TEG used. This data is important to determine the performance of the module and its operational limits. The test results show that the greater the ΔT between the hot and cold sides, the higher the voltage produced, making this module suitable for power backup applications.

In addition, tests were carried out on *the Solar Charge Controller* (SCC) to evaluate its ability to manage the flow of electricity from the photovoltaic module to the $LiFePO_4$ battery. SCC functions to optimize charging while protecting cells from overcharging and over-discharging. The test was carried out by assembling solar modules, SCCs, and batteries, then periodically measuring the voltage and current with a multimeter. The solar panels are positioned perpendicular to the sun to obtain maximum energy.

Figure 4. Solar Charge Controller

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Figure 4 shows the SCC plan used. From the test results, it can be seen that the device is able to regulate the incoming current to the battery stably without voltage spikes, which indicates that the protection function is running well.

Table 2. Test Results 20 %

DURATION	COLD TEMPERATURE	HOT TEMPERATURE	VOLTAGE
0 Minutes	29°C	0°C	0 V
5 Minutes	48°C	135°C	2.26 V
8 Minutes	50°C	155°C	5.21 V
10 Minutes	65°C	170.2°C	6.1 V

Table 2 shows that the voltage increases with ΔT. The initial voltage of 0 V (0th minute) rises to 6.1 V at the 10th minute. This pattern shows that TEG responds quickly to changes in ΔT, but the pace of increase slows down near the 10th minute. This condition corresponds to the Seebeck effect theory, where the stress is directly proportional to the temperature gradient, but approaches the saturation point when the material reaches the limit of thermal conversion.

Figure 5. Testing of the appliance with capacity 20 %

Figure 5 shows the voltage increase over time. This visualization confirms that the TEG reacts according to the principle of the Seebeck effect and achieves an initial voltage rise rapidly, but is close to saturated at the last minute.

Table 3. Test Results 50 %

DURATION	COLD TEMPERATURE	HOT TEMPERATURE	VOLTAGE
15 Minutes	60°C	182°C	8 V
18 Minutes	66°C	189°C	10.6 V
21 Minutes	70°C	201°C	12.3 V
25 Minutes	80°C	206°C	12.5 V

In table 3, the initial voltage was recorded at 8 V at the 15th minute with a ΔT of about 122 °C, then rose steadily to 12.5 V at the 25th minute. This pattern indicates that the cooling system is still working effectively to keep the cold side low, so the ΔT is relatively large. These results are consistent with findings [13] which show that the TEG voltage increases sharply at ΔT above 120 °C, although the maximum value in the study is lower (7.19 V).

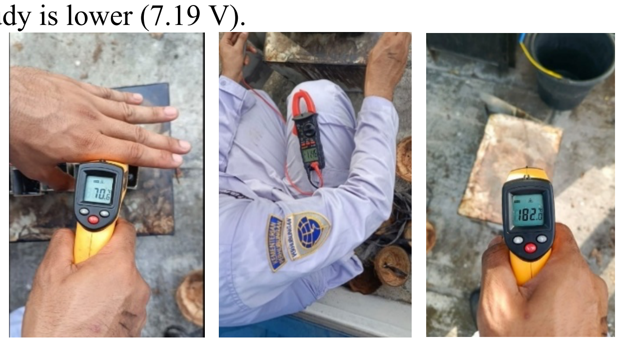

Figure 6. Test Results 50 %

Figure 6 shows the voltage increasing steadily until the last minute. This visualization confirms that the cooling system and TEG work effectively to maintain the performance of the appliance.

Table 4. Test Results 75 %

DURATION	COLD TEMPERATURE	HOT TEMPERATURE	VOLTAGE
30 Minutes	50°C	200°C	12.39 V
34 Minutes	66°C	198°C	13.1 V
37 minutes	78°C	207°C	13.4 V
40 Minutes	80°C	239°C	13.8 V

Table 4 shows that at 75% capacity, the TEG voltage is close to the optimal condition, which is 13.8 V at the 40th minute. The voltage increase is relatively slower than the 50% capacity, indicating that the TEG module is starting to approach the maximum performance threshold. This shows that the increase in ΔT is still having an effect, but the module is starting to reach a saturation point at the output voltage.

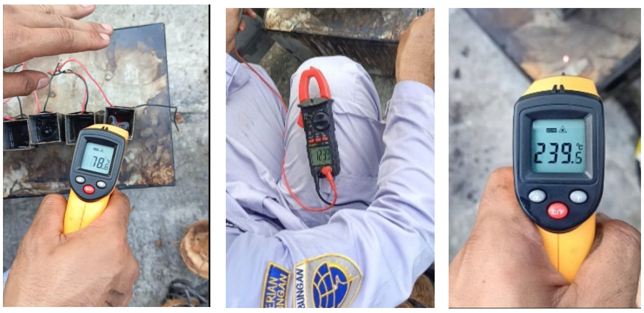

Figure 7. Test Results 75%

Figure 7 shows the voltage increase progressively until it is close to the maximum. This visualization confirms that the TEG module is starting to reach the optimal performance limit, and the cooling system is still working effectively to keep the cold side going, so that the ΔT remains large enough.

Table 5. Test Results 100%

DURATION	COLD TEMPERATURE	HOT TEMPERATURE	VOLTAGE
45 Minutes	93°C	225°C	12.8 V
48 Minutes	97°C	230°C	13.1 V
53 minutes	103°C	227°C	13.4 V
60 Minutes	112°C	251.3°C	13.91 V

Table 5 shows that at full capacity, the highest voltage was recorded at 13.91 V at the 60th minute. Although ΔT is very large, the voltage rise begins to slow down, signaling that the TEG is approaching its maximum thermal limit. The integration of SCC and $LiFePO_4$ batteries makes the power flow more stable than previous research.

Figure 8. Test Results 100 %

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Figure 8 shows a steady trend of voltage increase until it reaches its maximum. This visualization confirms that the system can generate electricity without relying on sunlight, with good thermal efficiency and low operating costs. However, there are limitations, such as the emergence of smoke from heat sources and the need to develop TEG materials to withstand long-term high temperature exposure.

In the design of a hybrid power generation system, the integration of TEGs with secondary energy sources such as solar panels or biomass is used to ensure sustainable power availability. The main working principle is to utilize the Seebeck effect, which is the direct conversion of temperature differences into electricity. The use of the SP1848 module which has high efficiency in the range of 150–250°C combined with a heat source from biomass combustion and an aluminum heatsink-based cooling system. Solar Charge Controller (SCC) is used to regulate the distribution of power from the TEG and solar panels to the battery. The results of laboratory simulations showed that the system was able to generate a total voltage of ±18 V from six assembled TEG modules, enough to charge a 12 V DC battery with a capacity of 12 Ah [15].

The results of this test are in line with similar research. For example, research [13] show the two TEG series are capable of generating a maximum voltage of 7.19 V from a household-scale biomass furnace. This value is lower than the achievement of this study which reached 13.91 V, thanks to the integration of TEG with solar panels and the use of large-capacity $LiFePO_4$ batteries. Research [1] on a portable stove with eight TEG modules also managed to produce a power of around 9.24 W, but its application is still limited to a household scale, in contrast to this study which is focused on a laboratory backup power supply. In addition, the research [14] with the heat source from the coconut shell producing an average of 10.05 V and a power of 13.84 W, but the stability of the output is affected by fluctuations in biomass combustion. In contrast, the integration of SCCs and solar panels in this study made the power supply more consistent.

The performance and stability of a hybrid-based TEG system is influenced by several important factors, including temperature differences that determine the size of the output voltage, the quality of thermoelectric materials such as bismuth telluride (Bi_2Te_3) which determines the conversion efficiency, and the effectiveness of the cooling system to maintain temperature stability. The suitability of the load with the TEG power capacity also has a significant effect, so a regulator is needed to maintain voltage stability. Integration with solar panels improves the reliability of the system, while the efficiency of energy storage in the battery plays a role in ensuring continuity of power supply. High-quality batteries allow power to be stored for longer and used stably, supporting the achievement of a reliable hybrid power generation system.

V. CONCLUSION

Based on tests, the hybrid power generation system with six TEG modules is capable of generating a maximum voltage of 13.91 V at 251.3°C on the hot side and 112°C on the cold side, demonstrating that biomass combustion can efficiently activate the TEG, while the integration of the Solar Charge Controller (SCC) and a 200 Ah $LiFePO_4$ battery maintains the stability of the power output. This system has the potential to be used as an educational prototype and emergency energy solution in remote areas. However, further development requires improved cooling efficiency to make the cold side temperature more stable, better combustion and smoke ventilation settings to reduce pollution, and the use of TEG modules that are resistant to high temperatures and smoke exposure for longer tool life.

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