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Design And Construction Of Power Plant Coconut Shells As A Power Supply On Lighting Lamps

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Abstract
The management of coconut shell waste is one of the environmental challenges that requires appropriate solutions. The growing energy demand in line with population growth drives the need for innovative renewable energy–based solutions. One alternative that can be applied is the utilization of Thermoelectric Generator (TEG) technology based on the Seebeck effect in a Biomass Power Plant (PLTBm) system. This study aims to design and develop an electricity generation system that harnesses heat energy from the combustion of coconut shells to produce electrical power for lighting lamps. The research employed a descriptive quantitative method to explain a process or phenomenon without correlating it to other variables. The energy conversion process was carried out using six TEG units connected in series to maximize voltage output. The generated voltage was then regulated and stored in a battery via a Solar Charge Controller (SCC), and monitored using an INA219 sensor connected to an Arduino UNO microcontroller. The experimental results showed that a temperature difference (ΔT) of 227.7°C between the hot and cold sides of the TEG produced a maximum voltage of 15.87 volts. This system was proven to monitor TEG performance in real time and provide a reliable power supply for lighting, offering an alternative renewable energy solution utilizing coconut shell waste.

Keywords: *Power generation, coconut shell, TEG, Seebeck effect, alternative energy, lighting lamp.*

INTRODUCTION

As time goes by, the world faces major challenges in the energy sector due to its heavy dependence on fossil fuels such as oil, coal, and natural gas. Fossil fuels have long been the backbone of global energy generation due to their massive availability in the past and their ability to generate large amounts of energy quickly and efficiently. However, fossil fuels are non-renewable resources, meaning they take millions of years to form, while human consumption continues to increase exponentially . This situation has led to the depletion of fossil fuel reserves, which has then triggered an energy crisis in various parts of the world. In addition to limited availability, the use of fossil fuels also has a negative impact on the environment. The combustion process produces carbon dioxide (CO_2) and other greenhouse gases, which contribute significantly to global warming and climate change. Air pollution from fossil fuel combustion also negatively impacts human health, increasing the risk of respiratory and heart disease. Despite their efficiency in producing energy, fossil fuels have high social and ecological costs and require complex distribution systems and infrastructure (Imran & Rasul, 2020).

In the context of global development, the urgency of energy transition has become a major issue in various sectors, leading to the need to find alternative energy sources that are environmentally friendly, sustainable, and locally available. One potential area being developed is the utilization of biomass waste, particularly coconut shells. In Indonesia, coconuts are a major agricultural commodity that produces large amounts of solid waste in the form of coconut shells (Organization, 2022). Unfortunately, this waste is often not utilized optimally and is simply discarded, potentially polluting the environment.

Coconut shells have several advantages as a biomass fuel. These include their high calorific value, stable heat production, and renewable nature (Prastianto, Informasi, Luhur, & Web, 2024). When managed with the right technology, coconut shells can be processed into charcoal, briquettes, or even used in biomass power plants. Their use is also relatively environmentally friendly, producing lower carbon emissions than fossil fuels and supporting the principles of a circular economy by converting waste into energy (Akbar, Zaenudin, Mutaqin, & Samsumar, 2022).

However, using coconut shells as fuel is not without challenges. One of these is the hard and fibrous physical and chemical characteristics of coconut shells, which require a fairly complex processing process. Furthermore, the logistics of collecting coconut shells from various locations to processing centers requires an efficient system to avoid increasing costs and emissions. Technologies used to convert biomass into energy, such as Thermoelectric Generators (TEGs) or gasification, also require further development and investment for widespread use (Jatmiko, Prahani, Siswanto, Susantini, & Habibbulloh, 2022).

Despite its drawbacks, the potential for utilizing coconut shells as biomass fuel remains promising, especially in coconut-producing regions. This utilization not only contributes to carbon emission reduction and waste management efforts but can also encourage the development of community-based renewable energy. With policy support, technological research, and public participation, coconut shells can be a strategic solution to address global energy challenges and move towards a more sustainable future (Rumayani, Warsito, & Pambudiyatno, 2020).

The Medan Aviation Polytechnic has never previously built a miniature Biomass Power Plant (PLTBm) as a supporting medium for practical work, particularly in the Airport Electrical Engineering Department. The author's interest arose in developing a miniature PLTBm control system that utilizes coconut shells as fuel while examining the effects of volume variations. This device design is equipped with IoT technology and current and voltage sensors to facilitate user monitoring of the generated current and voltage.

This research can provide new insights into the performance benefits of biomass power plants, while also exploring the potential use of alternative fuels such as coconut shells. Therefore, the development of this biomass power plant design can be an innovative step in supporting practical understanding and research in the engineering field.

Theoretical basis

Power plants

A power plant is a collection of equipment and machines used to generate electrical energy by transforming energy from various energy sources. Most power plants generate

alternating current (AC). In addition, some power plants use synchronous generators powered by fuel or natural resources. The main components of a power plant include the primary energy installation, the prime mover installation, the cooling installation, and the electrical installation (Dermawan & Purnomo, 2021).
Power plants are starting to adopt the use of coconut shells as their primary fuel, replacing coal. Coconut shells are chosen because they are a more environmentally friendly and sustainable renewable energy source. Although their energy content is slightly lower than coal, coconut shells can still generate enough heat to convert heat into electrical energy.
The main advantage of coconut shells lies in their sustainability and reduced environmental impact. Unlike coal, which produces high carbon emissions and other harmful pollutants, burning coconut shells produces cleaner emissions and can support efforts to mitigate the impacts of climate change. Furthermore, coconut shells are abundant agricultural waste in Indonesia, so their use in power generation encourages productive waste utilization and supports a circular economy (Grzesik, Kuźma, & Żurawski, 2016).
Coconut shells show significant potential as an efficient and environmentally friendly alternative fuel for large-scale biofuel power plants. With proper management, coconut shell utilization can be a strategic step toward a clean and sustainable energy transition.

Coconut shell

The coconut tree is a monocotyledonous plant belonging to the palm family, mostly growing in areas between 100°N and 100°S at altitudes up to 500 m above sea level, with a temperature range of 240°C and plenty of sunlight (Aris, 2024).. The coconut tree is a plant that can be utilized from the trunk, leaves, fiber, flowers to the fruit and shell.
Coconut is a plant that can be utilized from the stem, leaves, fiber, flowers to the fruit and shell. Coconut shell is the part that covers the coconut fruit. Coconut shell has a chemical composition similar to wood, containing lignin, pentoses, and cellulose. Coconut shell is usually used as a basic ingredient in making charcoal and activated charcoal, this is because coconut shell is a material that can produce a calorific value of around 6500 - 7600 kcal/kg. In addition to having a fairly high calorific value, coconut shell is also quite good for activated charcoal material. Viewed in terms of its use, activated charcoal is widely used as liquid absorbent in the sugar industry, cooking oil, soft drinks, and alcohol. In the chemical industry, it is used to produce acetone, methanol, phenol, and cresol. Meanwhile, in the rubber industry, it is used as a coagulation agent. In addition, it can also function to protect something from toxic gases from organic materials, recover volatile solvents, and remove odorous gases in air conditioners.

Thermoelectric

A thermoelectric device is a device used to generate electrical energy by exploiting the thermal conductivity of metallic materials. A thermoelectric elec- troelectric (TEG) operates on the principle of directly converting temperature differences into electrical energy, a phenomenon known as the Seebeck effect. This principle states that when two different types of materials or metals are connected and placed at two points with different temperatures, an electric current will flow between them.
Each type of material has a different Seebeck coefficient value, a parameter that indicates how much electrical voltage can be generated due to a temperature difference. The higher the Seebeck coefficient value of a material, the greater the voltage or potential difference produced. The relationship between the Seebeck coefficient value and the resulting

electrical voltage is described in a specific mathematical equation, which reflects the magnitude of the conversion of thermal energy into electrical energy (Hercog, Lerher, Truntič, & Težak, 2023).

Battery

A battery or accumulator is an electric cell in which a reversible electrochemical reaction occurs with a high degree of efficiency. A reversible electrochemical reaction means that the battery can undergo two processes: converting chemical energy into electrical energy during use (discharging), and conversely, converting electrical energy back into chemical energy during charging. This is achieved by regenerating the electrodes through the flow of an electric current in the opposite direction (Priambodo, 2021).
The way a battery works relies on chemical reactions within an electrochemical cell. Each cell has two electrodes, an anode (negatively charged) and a cathode (positively charged), which are immersed in an electrolyte solution. When the battery is used, a reduction and oxidation (redox) reaction occurs between the two electrodes, causing electrons to flow from the anode to the cathode through the external circuit, thus generating an electric current. Furthermore, ions in the electrolyte move to maintain the charge balance within the system.

Relay Module

A relay module is an electronic component that functions to control the flow of electricity through control signals originating from other devices, such as microcontrollers or switches. Relays work as automatic switches that allow control of other devices or electrical circuits, either by turning the electric current on or off. The way relays work is based on the principle of electromagnetism. When an electric current flows through an electromagnetic coil inside the relay, this coil generates a magnetic field that attracts a metal lever (armature) connected to a spring. This armature movement changes the position of the switch contacts, for example from the open position (Normally Open/NO) to the closed position, or from the closed position (Normally Closed/NC) to the open position. Once the electric current to the coil is stopped, the magnetic field disappears and the armature returns to its original position, so that the switch contacts return to their initial state (Andreansyah, 2024).
The relay module has three main input pins, each with a specific function for activating the relay. These pins are GND (ground or 0 volts), VCC (positive voltage, usually 5 volts), and IN (as an input signal that activates the relay via a sensor). This module is widely used in various home automation systems, such as to control lights, fans, and water pumps.

Solar Charge Controller (SCC)

A solar charge controller is an electronic device that regulates the flow of direct current (DC) from the solar panel to the battery and from the battery to the load. This device is designed to prevent overcharging when the battery is fully charged and to prevent high voltages that can originate from the solar panel. Conditions such as overcharging and excessive voltage can shorten the battery's lifespan.
The main functions of the solar charge controller include:
Regulates the charging current to the battery to prevent overcharging or voltage exceeding the limit. Regulates the output current from the battery to prevent the battery from being completely drained (full discharge) or overloaded. Monitors the battery temperature to maintain its optimal condition. Solar charge controllers are equipped with various ports, including input terminals for solar panels, output terminals to the battery, and load

terminals that allow direct power flow to electrical devices. In addition, these devices are generally equipped with an interface display that displays information such as voltage, current, battery capacity, and charging status. Solar charge controllers also have internal protection features, such as protection against short circuits, too high or low voltage, and excessive temperature. One important feature of a good solar charge controller is its ability to detect battery capacity. This detection is done by monitoring the battery voltage level. This tool will charge the battery until it reaches a certain voltage, and if the voltage decreases, recharging will be carried out again (Setiyo, Saputra, Sudjoko, & Faizah, 2023).

DC LED Light

Direct current (DC) LED (Light Emitting Diode) lamps are a type of lamp that uses light-emitting diodes to produce lighting with high energy efficiency and low power consumption. These lamps operate using direct current and are widely used in various fields, from home lighting to industrial and outdoor applications. One of the main advantages of LED lamps is their ability to produce a greater amount of light (lumen) per unit of power (watt) compared to incandescent lamps or fluorescent lamps. In addition, LEDs have a long service life, which is between 25,000 and 50,000 hours, thus reducing the frequency of replacement and lowering maintenance costs (Wicaksani & Nurpulaela, 2023) Another advantage is their environmental friendliness, as DC LED lights do not contain hazardous substances like mercury, which is commonly found in fluorescent lamps. They can also operate at low voltages, making them safer for various applications, including solar power systems. In their applications, DC LED lights generally require an additional component in the form of an LED driver, which controls the input current and voltage, ensuring stable lamp performance and protection from power fluctuations.

The INA219 sensor is a module designed to measure current and voltage in electronic systems, particularly in power monitoring applications. This sensor uses a differential measurement method to obtain high-precision current, voltage, and power data. Its measurement capabilities include currents up to 3.2 amperes and voltages up to 26 volts. The INA219 uses an I2C communication interface, allowing this sensor to efficiently interact with microcontrollers such as Arduino or Raspberry Pi through the same data path, thus simplifying system integration. This sensor is ideal for use in battery monitoring systems, power distribution management, and energy efficiency measurements in solar power systems (Maulia, Ismeddiyanto, & Suryanita, 2019)

The INA219 module is equipped with several main pins that support its functions. The I2C pins consist of SDA (serial data line) and SCL (serial clock line) which are used for data communication with the microcontroller. In addition, there is a VCC pin as a power source for the sensor and GND as a ground line. For voltage measurement, this sensor has VIN+ and VIN- pins that are connected to the voltage source to be measured. There is also an OUT pin that can be used to connect a load to the system (Wicaksani & Nurpulaela, 2023).

The LM2596 stepdown is a type of step-down switching voltage regulator (buck converter) designed to provide high efficiency in converting DC to DC voltage. This component is very commonly used in various electronic applications, especially for low to medium power systems such as microcontroller systems, IoT devices, and portable power supplies (Raka et al., 2024). The LM2596 works on the principle of switching regulator, which is different from linear regulators because it does not dissipate excess voltage as heat, but instead uses energy storage elements in the form of inductors and capacitors to transfer energy from input to output with high efficiency, which can reach more than 75% to 90% (Endriatno, Safarun, & Kaimuddin, 2024). This regulator is widely used to reduce the voltage from the main power source such as a 12V or 24V battery to a lower working voltage according to load requirements, for example 5V or 3.3V for microcontrollers or sensors. Due to its high efficiency and equipped with protection features such as over-temperature and short-circuit, the LM2596 is a popular choice compared to linear regulators such as the 7805 which tend to dissipate power as heat (Cahyadi et al., 2020).

The Arduino IDE (Integrated Development Environment) is software used to write, edit, and upload programs to the Arduino microcontroller board. This IDE supports modified C/C++ programming languages, making hardware programming easier. One of the main features of the Arduino IDE is its ability to provide various libraries that allow users to access and control sensors, actuators, and other modules more practically (Andrianto, 2019). The Arduino IDE has several key features, such as a verify button to check for errors in the code, an upload button to upload the program to the microcontroller, and settings for the board and port used. Using the Arduino IDE is crucial in developing Arduino-based applications because it simplifies the entire programming process, from writing code and checking for errors to uploading the program to the hardware. Before uploading the program, users need to configure the board and port appropriately for the device being used (Kamal et al., 2023).

METHOD

This research uses a quantitative descriptive approach, which in its development process utilizes Research and Development (R&D). The quantitative descriptive approach is utilized to analyze measurement data, including voltage, current, and power generated by the Thermoelectric Generator (TEG) system, which are then presented in the form of calculation tables. Meanwhile, the R&D approach is applied in the design, manufacturing, and testing stages of the TEG-based power generation system prototype to ensure its feasibility and performance (Meilani & Wuryandani, 2021).

This research includes several stages as follows:

a. Problem Identification

Field observations were conducted to identify issues, including the suboptimal use of coconut shell waste as an energy source and the need for alternative energy sources for street lighting. The potential of biomass as an alternative fuel has been demonstrated in various previous studies.

b. Literature Study

Literature collection was conducted to strengthen the theoretical basis for developing a TEG-based power plant monitoring system. Studies show that Thermoelectric Generators (TEGs) can convert heat energy directly and efficiently into electrical energy, especially for small-scale applications such as street lighting (Nugroho & Wicaksono, 2022). The use of the Arduino Uno as a microcontroller is very common in monitoring system projects due to its ease of programming and compatibility with various sensors (Fitriani et al., 2022). The INA219 sensor is used to measure current and voltage in real time with a high degree of accuracy, making it ideal for renewable energy-based systems (Siregar & Ramadhan, 2023). These studies form the basis for designing efficient, automated systems that comply with the principles of alternative energy utilization.

c. System Design

This stage includes designing the system circuit by selecting key components such as the TEG, Arduino Uno, INA219 sensor, relay, battery, LCD, SCC, and lights. These components are designed in the form of a system block diagram.

d. Tool Assembly

The designed components are then assembled according to the block diagram to form a prototype TEG-based power plant monitoring system. This stage includes the physical installation and assembly of the entire system.
e. Microcontroller Programming
Arduino Uno is programmed using Arduino IDE software to manage the system's working logic, such as voltage and current readings from the INA219 sensor, relay operation settings, and data display on the LCD. Tool testing after the assembly and programming process is complete, the system is tested to evaluate the TEG's performance in generating electricity from coconut shell heat, the sensor's accuracy in reading data, and the overall operational stability of the system (Muliyati, Syafriwel, & Siregar, 2024).
f. Testing and Data Collection
The system was tested to evaluate the TEG's performance in converting coconut shell heat into electrical energy. Voltage, current, and power measurement data were collected quantitatively, then processed and presented in a calculation table. The test results were consulted with and validated by the supervising lecturer.
g. Data Analysis
The measurement results are analyzed to determine the energy conversion efficiency, stability of electrical output, and sensor accuracy in reading data.

RESULTS AND DISCUSSION

Research result

This research resulted in a waste-to-energy power generation system based on *a Thermoelectric Generator* (TEG) that is used as a power source for an automatic lighting system with DC lamps. This system is built from a number of integrated main components, including the TEG, INA219 sensor, *solar charge controller* (SCC), battery as energy storage media, LM2596 *step-down module* , Arduino Uno, relay, and DC lamps as the final load.

Hardware Manufacturing

Six TEGs are connected in series, with the positive side of the first TEG connected to the negative side of the second TEG, and so on. The overall *output* is taken from the positive terminal of the first TEG and the negative terminal of the last TEG. With this configuration, the electrical energy generated from the heat of combustion of coconut shells can be optimally utilized to charge batteries and power loads such as lamps.

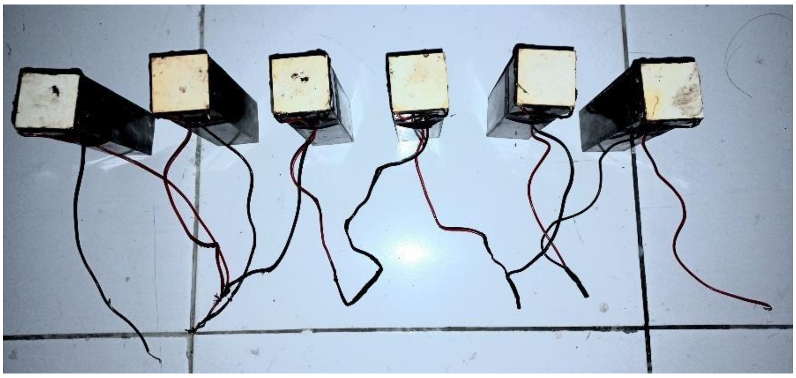

Figure 1. Physical form of TEG

Connecting the TEG to the INA219 sensor and LCD with the help of Arduino UNO. The TEG *output* is directly connected to the INA219 sensor *input* (VIN + and VIN-). The INA219 reads the voltage and current values from the TEG. The measurement results are displayed in *real time* on the LCD in Volts, Milliamperes, and Milliwatts.

Software

The software installation process for this project involves several steps to ensure the program is installed correctly and functions as needed. The software used is the Arduino IDE, which plays a role in creating and uploading programs to the Arduino UNO microcontroller. Through the Arduino IDE, users can write, edit, and upload code that regulates the system's operation, from reading sensor data to controlling devices such as lights and relays. In this software installation process, the Arduino IDE acts as *a platform* for compiling and creating commands that are later uploaded to the connected Arduino *board* . The image below shows the process of creating *a sketch* or series of commands that have been customized to the needs, which are displayed through the Arduino IDE interface. This software allows users to program Arduino microcontrollers using C and C++-based programming languages (Aamir & Mekhilef, 2016). The Arduino IDE also provides various functions and libraries that facilitate communication with sensors and other devices connected to the Arduino or similar microcontrollers, so that the hardware can be accessed and controlled according to the program created.

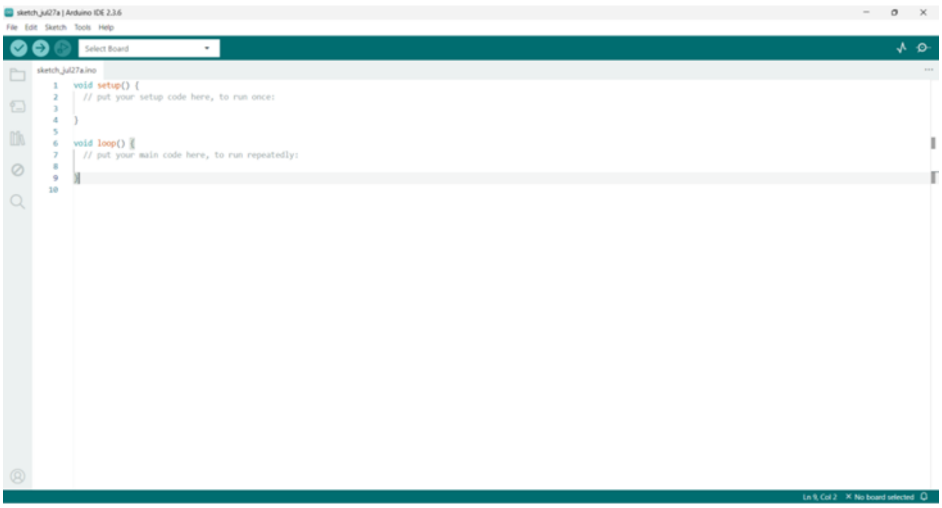

Figure 2. Initial display on the Arduino IDE

A library is a collection of Arduino program code used to provide instructions to a component. Its function is to make it easier for users to access and execute complex functions, making them easier to use and more organized.

Discussion of Research Results

This research discussion describes the performance of a TEG-based coconut shell power generation system in meeting its design objectives and specifications. Each component is tested and analyzed in detail to assess energy conversion effectiveness, sensor accuracy, power supply stability, and automatic control system response (bin Daud & Kuan, 2020).

Test Results

a. TEG Testing

TEG testing was conducted to assess the module's ability to convert heat energy from burning coconut shells into electrical energy. The main parameters observed included the temperature difference between the hot and cold sides (ΔT) and the voltage generated from the combustion process. In this study, the TEG testing stages were as follows:

1. Prepare 6 TEG modules.
2. Install the TEG above the waste incineration chamber.
3. Make sure the cold side of the TEG is cooled (water) to create the maximum temperature difference between the hot side and the cold side.
4. Connect the TEG to the SCC and INA 219 to measure the voltage displayed on the LCD.
5. Do coconut shell burning.
6. Record the temperature of the hot side and cold side using an infrared thermometer.
7. Note any voltage changes that occur.

Table 1. TEG Test Data

Time	**Hot Temperature (°C)**	**Cold Temperature (°C)**	**ΔT (°C)**	**Voltage (V)**
10 minutes	159.3 (°C)	56 (°C)	103.3 (°C)	9.03 V
20 minutes	178.5 (°C)	45.1 (°C)	133.4 (°C)	10.98 V
30 minutes	205.9 (°C)	39.3 (°C)	166.6 (°C)	12.79 V
40 minutes	240.7 (°C)	33.8 (°C)	206.9 (°C)	14.45 V
50 minutes	252.9 (°C)	25.2 (°C)	227.7 (°C)	15.87 V

The TEG test results show that a temperature difference between 166.6 to 227.7°C produces a voltage of 12 to 15 Volts. From these observations, it can be seen that the TEG voltage output is greatly influenced by the magnitude of the temperature difference on both sides of its surface. The greater the ΔT formed due to the increase in temperature on the hot side and the temperature difference with the cold side, the higher the voltage produced. This finding is in line with the principle of the *Seebeck effect* , which states that an electric potential difference arises when there is a temperature gradient between two points on a conductor material (Lu et al., 2018).

b. *Monitoring* System Testing

monitoring system in a coconut shell power plant functions to monitor the TEG output voltage in *real-time* . This system uses an INA219 sensor connected to an Arduino Uno microcontroller, with the measurement results displayed on the LCD. Testing the *monitoring system* aims to ensure the accuracy of the sensor readings. The testing method is carried out by comparing the voltage value read on the LCD with the measurement results using a measuring instrument. The difference in value is then processed using the percentage *error formula* , which is the comparison result multiplied by 100%. The following is the calculation formula.

1) $Error\ value = \frac{|\ Nilai\ Komponen - Nilai\ Referensi\ |}{Nilai\ Referensi} \times 100\%$

Testing is performed on several different values. All *error values* are then averaged to obtain the average percentage *error , using the formula:*

2) Average $error = \frac{\Sigma\ Error}{n}$

Based on this test, *error values* that are below the tolerance threshold of 5% are considered still accurate and suitable for use.

Table 2. Voltage Test Data on the INA219 Sensor

Voltage Measurement with a Multimeter (V)	LCD Display (V)	Difference (V)	Error (%)
11.02	10.86	0.16	1.45
11.45	11.21	0.24	2.09
11.59	11.47	0.12	1.03
12.01	11.78	0.23	1.91
12.37	12.11	0.26	2.10
12.86	12.69	0.17	1.32
13.12	12.98	0.14	1.06
Rate-Rate		0.18	1.56

The test results show that the average voltage *error* on the INA219 sensor compared to a multimeter is 1.56%, so that the accuracy level obtained reaches 98.44%. This finding proves that the *monitoring system* based on the INA219 sensor and the Arduino Uno microcontroller is able to provide fairly accurate readings of the TEG output voltage. The low *error value* indicates that the INA219 sensor works well in measuring voltage in *real-time* , and the LCD can display data accurately. Thus, this *monitoring system* can be relied upon to continuously monitor the performance of waste-to-energy power plants (Irsyam, Algusri, & Marpaung, 2023).

c. Battery Testing with a Light Load

The test was conducted using a 12 Volt 5 Ah battery and a 12 Volt 5 Watt lamp. This test was conducted to determine how long the battery can power the lamp load and how long the battery can (Aliyu et al., 2018). From the test, with a voltage of 12.9 Volts to 10.6 Volts the lamp will still be on, while at a voltage of 10.5 Volts and below the lamp will turn off, indicated by the *solar charge controller indicator* which gives a signal to charge the battery.

This test was conducted from 7:00 PM to 7:00 AM, which means that a 12 Volt 5 Ah battery with a 5 Watt lamp load can last for 12 hours. The table presents the test results of the battery charging process using TEG. In this test, charging takes place from an initial voltage of 12.5 Volts to a full voltage of 12.9 Volts. The charging process is carried out by utilizing six TEG units capable of producing a minimum voltage of 12.1 Volts to be able to charge the battery. The charging duration from 12.5 V to 12.9 V was recorded as 30 minutes, starting at 19.00 to 19.25.

Figure 3. Battery Testing with Light Load

d. Overall System Testing

After all hardware and software components were tested separately, a complete system test was conducted to assess the performance of the *Thermoelectric Generator* (TEG)-based waste-to-energy plant. This test included displaying sensor measurement data on the LCD, the battery charging process, and the distribution of energy to the load (Kartikasari, Gazali, Irawati, & Fatah, 2023). The stage began with the combustion of coconut shells as a heat source. The bottom side of the TEG was placed on a combustion furnace, while the cold side was cooled with water to create a significant temperature difference (Lukman Prihasworo, Dhanis Woro Fittrin, Unan Yusmaniar Oktiawati, Hidayat Nur Isnianto, 2020). This temperature difference produced an electrical voltage that was measured by the INA219 sensor. Data from the sensor was then sent to the Arduino UNO for processing and displayed on the LCD, then compared with the measurement results using a digital multimeter to ensure the level of measurement accuracy. Next, the resulting voltage was flowed to *the Solar Charge Controller* (SCC) to be adjusted to the battery charging capacity. This test aimed to ensure the battery could be charged and able to store energy that was then used to light the lights for a certain period (Sunardi et al., 2020). Further testing was conducted to determine the duration of the lights based on the charged battery capacity. The test results proved that the TEG-based waste-to-energy plant system functioned well, capable of producing enough electricity to turn on the lights automatically, and operating the lighting system according to changing light conditions. Thus, it can be concluded that this system works according to the design and objectives of the research, namely utilizing renewable energy from waste as a source of lighting.

CONCLUSION

Based on the results of the generation system trial with six *Thermoelectric Generator* (TEG) units, the following conclusions were obtained:

a. The TEG-based waste-to-energy power generation system successfully generates enough voltage to charge a 5 Ah battery with a working voltage of 12 V, and is capable of powering a 5 Watt 12 Volt DC lamp. This device utilizes six TEG modules arranged in series, capable of producing a voltage of between 12 and 15 Volts at a temperature difference (ΔT) of 150 °C to 200 °C.
b. TEGs utilize the *Seebeck effect* to convert heat energy from waste combustion into electrical energy. The resulting voltage increases as the temperature difference (ΔT) between the hot and cold sides increases. Tests show that with six TEG modules, the system can generate a voltage of between 12 and 18 volts, which can be used to charge batteries and light lamps.
c. *monitoring* system and Arduino UNO are capable of measuring and displaying voltage, current, and power parameters with an accuracy of up to 98.44% during operation, displayed on the LCD. The direct display of information on the LCD simplifies the process of monitoring the power plant's performance and enables early detection of potential component damage.

Suggestion

a. The use of *a water block* on the cold side of the TEG serves to maintain a greater temperature difference between the hot side and the cold side, thereby increasing the efficiency of converting heat energy into electricity.
b. Integration with other renewable energy sources could be a further development, for example, combining a waste-to-energy system with solar or wind power. This combination of various renewable energy sources will increase the system's efficiency and reliability in the long term. Furthermore, to support sustainability and minimize the environmental impact of the waste incineration process, the use of smoke filters or exhaust gas filtration systems is recommended.

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