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Self-Powered Griller using Thermoelectric Generator Peltier Module with Backup Power Source

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Abstract:- Grilled whole chicken, also known as "Lechon manok," is the product of small stalls in the Philippines and is one of the businesses that use charcoal as their primary heat source for roasting chicken. Energy deficiency is one of the primary concerns that affect businesses resulting in unproductive service. Lechon manok stalls are one of these dominant businesses in the Philippines. Converting the waste heat produced by the stall into electricity is possible using a thermoelectric generator. It converts heat energy into electrical energy through the Seebeck effect of supporting the stalls' electricity needs. Placing these modules at the top of the machine harvests waste-heat energy by radiation, convection, and conduction. By series and parallel connection of the modules, its output power will increase. Relays were used to switch the flow of current from the battery in the system. Two cells are used for the charging and discharging state. The output node of the modules is connected to a relay, charging batteries with low-level voltage.

Keywords:- *renewable energy, grilled chicken machine, thermoelectric generators.*

I. INTRODUCTION

Energy conservation has been an essential subject in the field of industrial development. Agriculture, mining, forest, business, food, and other major industries have utilized energy for production, consumption, electricity, and distribution of goods and services. With the developing world's population, scientists and engineers explore other sources and ways to harvest viable amounts of energy to sustain the world's energy needs needs. Various methods arose to collect energy from different sources by using machines, devices, and equipment that yields power efficiently and is more economically safe. Designs and innovations are needed to address the developing world's energy consumption.

Electric outages greatly impact works, production, and processes that need a non-stop supply of electricity [1-2]. Due to this power shortage, homes, industries, and businesses' devices and facilities are affected, resulting in decreased productivity, loss of profit, and even damage to appliances and other machinery and devices. Presently various renewable energy systems are deployed in different countries and in different applications and areas (artificial intelligence) to help solve these problems in power shortages, especially for rural electrification purposes [3-14].

Thermoelectric generators (TEGs) are one source of electricity. It converts the temperature difference induced by waste heat into electrical energy by the Seebeck effect and has enticed increasing attention as a green and flexible source of electricity. It comprises numerous legs made up of p- and n-type semiconductors forming thermocouples [15-16]. Heat flows through one of the ceramic plates, which is the hot side, and the cold side is placed with a heat sink to increase the temperature difference. After temperature difference had been induced, power was produced. Using this material to generate electricity can compensate for electricity outages and help electricity-based businesses to run still.

By the heat produced through burning and heating systems, an independent electric energy source can be developed using thermoelectric generators. With this heat energy converted to electrical energy, it is possible to power electrical appliances and provide lighting and other systems that require electricity. Potential placements for TE generators are on furnace walls, on channel way walls, and on passage pipe walls after the furnace. There are no limitations in the usage of TE generators as long as it meets the required output; however, it requires space for its placement [17] as more elements are linked together, as much energy is produced. TE generators are one of the elements in the cogeneration process in residential or industrial heating or burning systems. Aspiring researchers have found that thermoelectric element current, voltage, power, and efficiency are defined in different temperature differences.

The Philippines has a large scale of households that run a small business in the electrified areas, 25% of a sampled four provinces and 15% in non-electrified regions [18]. Lechon manok stall is one of the most famous establishments run in the Philippines that uses electricity. The researchers were enticed to study converting waste-heat energy produced by these stalls using the thermoelectric generators to conserve energy usage and minimize the energy consumed by the power agencies.

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II. MATERIALS AND METHODS

A. Switching Control System

For the heat harvesting of the waste-heat energy, the thermoelectric generator Peltier module SP1848 27145 was used with 90 pieces. To enhance the generated voltage of the Peltier, ten modules were connected in series, creating a total of 9 groups. Then, these nine are connected in parallel to produce a higher current. An experiment was conducted to provide an efficient energy source for the Lechon manok stall to acquire the necessary data to be interpreted and evaluated. For the uninterruptable power source of the system, a switching control system is designed and simulated, see figure 1.

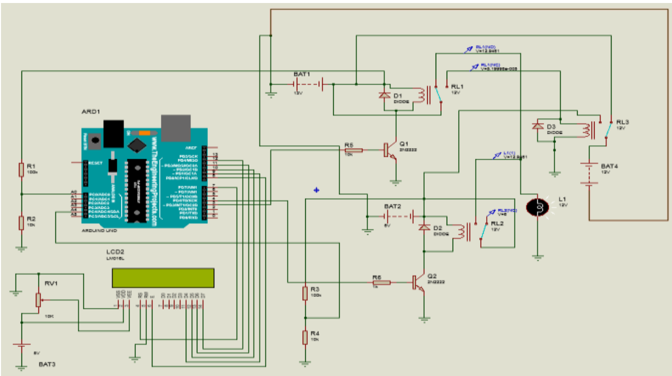

Fig. 1: Electronic configuration of Arduino Uno

The Arduino microcontroller has been proven effective in various applications [19-29].

B. Design and Development of the Machine

Two placements of the TEG Peltier module will be experimented with to test the best placement of the material. The first placement of the TEGs was on the good casing of the griller machine. The design for this is pictured in figure 2. The second placement for the TEGs was above the griller machine. The design is pictured in figure 3. The product produced from this design and development is covered under the intellectual property policy of the university [30].

Fig. 2: TEGs Peltier module placed in the wall casing of the griller machine for harvesting of the waste-heat energy

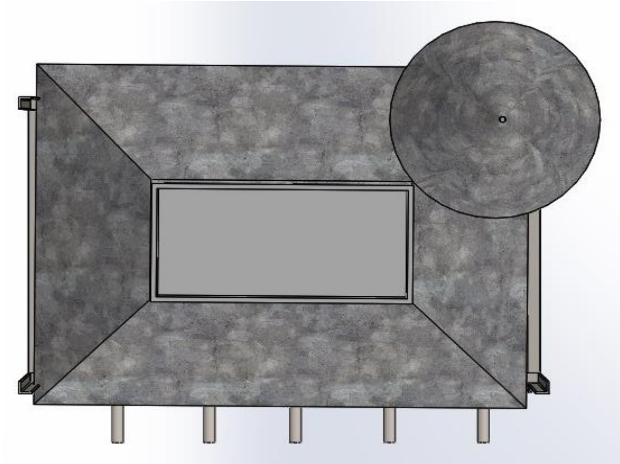

Fig. 3: Top view of TEGs Peltier module placed above the griller machine for harvesting waste-heat energy

A heat sink is also provided for the system to acquire a higher temperature difference. The heat sinks for the Peltieris composed of aluminum sheet for faster heat dissipation and serve as the base of the heat sink, acrylic for the walling, and water as the coolant. The edges of the heat sink were sealed using silicone sealant.

The distance of the TEG Peltier module to each other was also experimented with to get a bigger distance difference for the TEGs. Shown in figure 4 is the first design where Peltier are distanced from each other on the right and left side and in the bottom and upper. Shown in figure 5 is the second design for the modules where it is placed without space in between for the series connection.

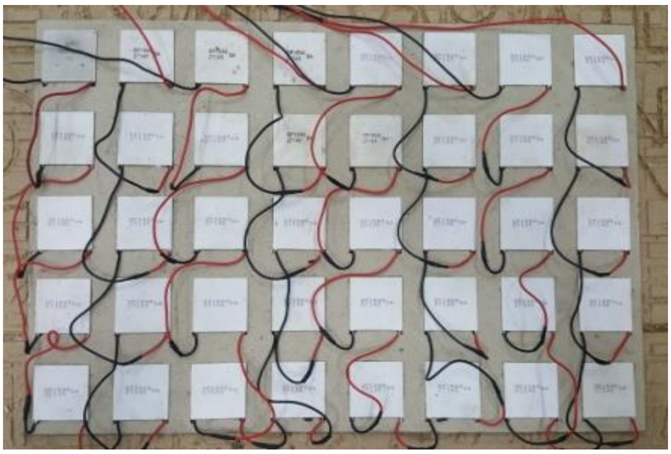

Fig. 4: TEGs Peltier modules distance with each other for heat harvesting design

To test the output power of the modules, they will undergo different testing. To obtain the maximum generated energy of 1 Peltier, it will be tested using iron as the heat source and aluminum as the cooling element. This method will be done to get the maximum output current and voltage of the Peltier modules.

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Fig. 5: TEG Peltier distance design two where there's no space in between for the series-connected modules

III. RESULTS AND DISCUSSIONS

A. TEG Peltier Module Testing

The accumulated output power of one Peltier module was recorded and served as the basis for the number of TEG Peltier modules to be used. The working capacity is shown in table 1, where Tin is the temperature in the cold region of the module, Tf is the temperature in the hot region of the module, delta T is the temperature difference (Tf-Tin), and the voltage is the generated voltage from the Peltier.

Tin	Tf	delta T	Voltage
27	34.6	7.6	0.11
28.3	38.2	9.9	0.335
28.7	87	58.3	0.73
30.1	91.2	61.1	0.918
30.8	92.1	61.3	1.15
32.4	96	63.6	1.481
32.7	99.3	66.6	1.725
33	103	70	1.83
34.6	116	81.4	1.92
35.3	119	83.7	2.24

Table 1: The working capacity of 1 TEG Peltier module was experimented with using iron as a heat source and aluminum as the cooling element

B. Testing for TEG Peltier Modules Placement

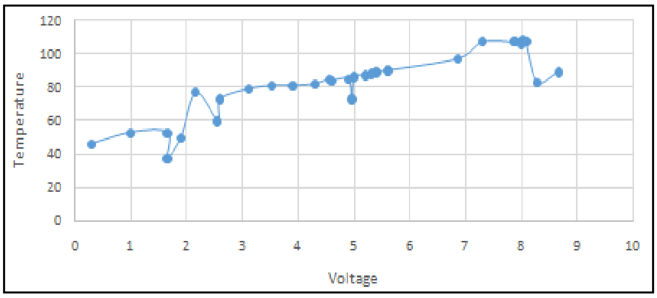

Fig. 6: The output voltage of the TEG Peltier module placed in the wall casing

The generated power for the TEG Peltier module, which is placed at the wall casing of the griller machine, is shown in figure 4. The experiment uses 10 Peltier modules without an external dummy load.

The generated power for the TEG Peltier module, where it is placed above the machine, is shown in figure 5.

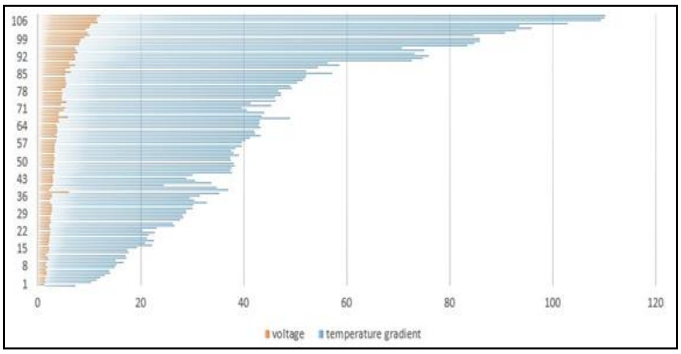

Fig. 7: The output power of the TEG Peltier module placed above the machine

C. Machine Testing with TEG Peltier Modules

The griller machine was tested with the TEG Peltier module consisting of 90 pieces attached to the heat sink above the machine to determine whether the system supplied the necessary power needed for the Lechon manok griller. Shown in figure 6 is the graph of the generated power from the experiment.

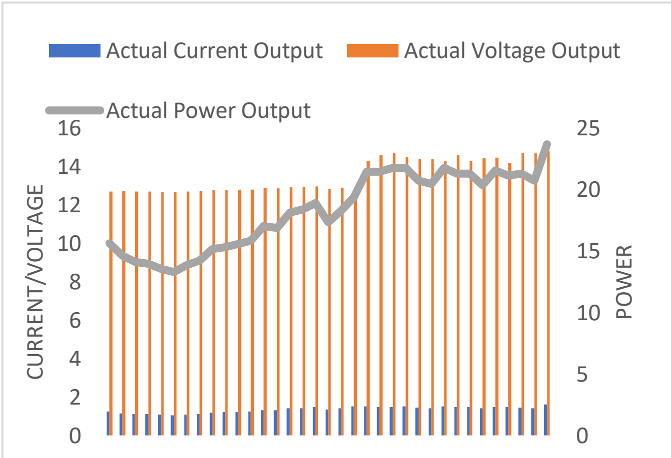

Fig. 8: Recorded actual generated power of the TEG Peltier module with its corresponding current and voltage level

The data gathered in Table 1 shows that the voltage output of one Peltier module increases as the temperature differences increase. This relationship between the voltage and temperature gradient resulted as desired since the Peltier's output voltage characteristic also increases as the temperature gradient increases. This result was relevant in the actual design testing and important data used to compare the ideal voltage output of the component.

Conduction, convection, and radiation can transfer heat can be transferred by three processes. Conduction was the transfer of heat along with a solid object; this process made the handle of a poker hot, even if only the tip was in the fireplace. Convection transfers heat through the exchange of hot and cold molecules; this is the process through which water in a kettle becomes uniformly hot even though only the bottom of the kettle contacts the flame. Radiation was the transfer of heat via electromagnetic (usually infrared) radiation; this is the principal mechanism of a fireplace warms a room [31].

For figure 2, the machine harvests waste-heat energy through the conduction method of heat transfer only. The Peltier modules were attached outside the casing where it will harvest heat that was conducted by the steel plate casing. The temperature gradient using figure 2 was small, resulting in the Peltier's low voltage output. There are a lot of factors that affect the generated power; some are unequal distribution of heat to the Peltier that leads to unbalance generated voltage of each Peltier module.

For figure 3, the cooling system and the Peltier modules were placed directly above the area where the smoldering charcoal's heat was released. This design catered to the three heat transfer processes, namely conduction, radiation, and convection. The radiation heat process occurred since the Peltier module was not insulated or connected to media other than air. It was designed to be directly in contact with the heat. Conduction of heat occurred due to the module's design, where the medium of conduction used was ceramic, the built-in heat region of the module. Convection occurs due to cold air that flows freely inside the machine. Colder air drops down, and warmer air rises due to warm/hot air being less dense than cold air. Since the cooling, along with the modules, were attached to the above burning area of the griller, the water, which was the cooling element of the cooling system, at a higher temperature, will conduct heat and become hotter. In this case, the water in the heat sink was changed and filled with colder water. Water was used as the cooling element and not air since it has better heat dissipation [32].

In the arrangement of the Peltier modules, since the distance between the hot and cold plate was little in figure 4, the heat from the hot region dominated the cod region giving a small temperature gradient and output voltage. If the Peltier modules were to be arranged with space between them, even having heat dissipation to the air, the hot temperature would eventually spread to the cold region since the plates in the Peltier had more heat conductivity than air.

To minimize the conduction of heat from the hot region to the cold region, the modules were arranged in a way that the ten series-connected modules were firmly in contact with each other, see figure 5, so that the heat will distribute to the connected hot region plates and not in the cold region of the module.

As we can see from the graph in figure 4, the generated voltage was quite high due to the very high temperature in the hot region. This output only lasted for seconds due to the unstable heat distribution to the modules.

The disadvantage of figure 2 was that some Peltier has space between the conducting medium, and some don't. Also, the wirings that connect the module to the motor were burnt, which damaged the Peltier, and the heat insulator for the circuit was damaged. Indicated in figure 5 was the generated power from figure 3. This design generates a more stable power than the design in figure 2. This resulted in that figure 3 being better than figure 2. To calculate the theoretical voltage value for comparison purposes to the experimental (actual) generated power, the formula (1) was used.

$$V_o = \frac{\alpha N(T_h - T_c)}{1 + \frac{2rL_C}{L}} \quad (1)$$

where r = λ/λC, α = 190uV/C, N=2304, L=0.16cm, LC=0.18cm, Th=refer to the hot region temperature, Tc=refer to the cold region temperature, λ = 16*10^-3 W/cm-°C, and λC = 0.32 W/cm-°C.

For the percent error, formula (2) was used.

$$\%error = \frac{(theoriticalvalue - experimentalvalue)}{theoreticalvalue} x100 \quad (2)$$

The temperatures used for the hot and cold region were recorded from the experiment. Some of the data calculated are shown in figure 7.

voltage	theoretical voltage output	Voltage percent error (%)
1.23	2.872493	57.18005
1.48	4.131667	64.17911
1.34	4.48581	70.12803
1.53	4.761255	67.86561
1.66	5.154747	67.79667
1.79	5.548239	67.73751
1.64	5.469541	70.01576
1.88	5.902382	68.14845
1.54	6.02043	74.42043
1.8	6.531969	72.44323
2.13	5.941731	64.15186
1.98	6.768065	70.74496
1.6	6.689366	76.08144
2.04	7.00416	70.87445
2.2	6.807414	67.68229
2.19	7.594398	71.16296
2.08	8.735525	76.18918
2.23	8.184636	72.75383
2.3	8.892922	74.13674

Fig. 7: Some calculated theoretical voltage value and its corresponding percent error

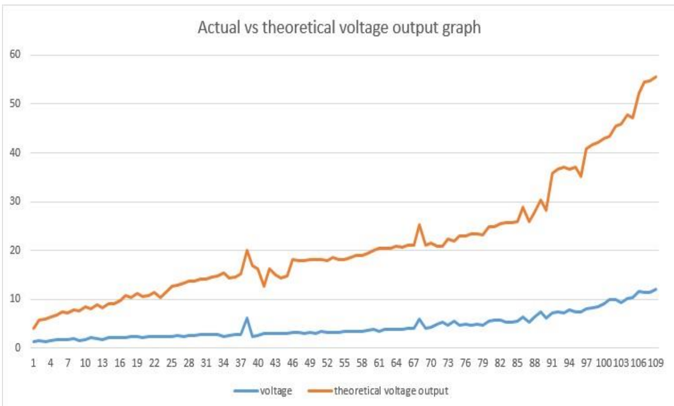

Fig. 8: Data comparison between the theoretical voltage value and the experimental voltage value

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From the overall computation of the data gathered, the highest percent error was 84.245% which means that a significant drop exists during actual testing of the modules. This significant drop indicates that the material useddoesn't have an accurate and precise structure due to a very high difference between the actual and estimated output. It was portrayed in figure 8 that the graphical differences between the actual and theoretical voltage output graph where it can be traced that the actual voltage had values lower than the theoretical voltage. Power also has a lower value in this data alone since it is directly proportional to voltage and current.

IV. CONCLUSION

This study has achieved its objectives. There were three objectives that this study focused on solving. First was the provision of electrical energy to power the motor that drives the griller using harvested energy from the burning of charcoal. This objective was achieved through the use of the thermoelectric generator Peltier module. Using different designs and system manipulation, the researchers accomplished the first objective, which had a maximum of 1.6A and 14.8V or approximately 23.68Watts which was 94.72% of the motor's power rating.Errors such as random errors were factors that affect the efficiency of the system. The random error in the test was the unpredictable heat flow (turbulent flow) released from the burning of charcoal. This was achieved through the use of batteries which provided power for up to 9.633 hours per battery. One battery was being charged if the battery reached threshold voltage while the other battery was supplied. Since the batteries provided power to run the motor, downtime of the stalls production was reduced.Lastly, the third objective, which was the provision of power to decrease the operational cost at 80% of the entire system compared to the existing Lechon “manok” stalls, was also accomplished with a percent save of 86.7%, which had a value greater than the proposed operational decrease. This calculated percent saving implied that the designed system worked as desired.

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