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The usage of thermoelectric generator as a renewable energy source

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ABSTRACT

Currently thermoelectric generators (TEG) are widely used in biomedical, military and space satellite power applications. TEG of high power plants are mostly used in automobile and industrial engines. This paper discusses TEG as a renewable energy source. Here the TEG in the application is used in the thermoelectric generator power plant. The working principle of this thermoelectric generator is on the heat side of the TEG peltier which is coated in metal in the form of aluminum, which is heated by a heater. And the cold side of the TEG Peltier is placed on the heat sink (as a heat dissipation metal). Heatsinks are submerged in water which are submerged about half or more. If the temperature of the metal being heated and the temperature of heat dissipation metal have a certain difference, then the temperature difference causes TEG to start working. The greater the temperature difference, the greater the electrical energy produced will be. However, if the temperature difference is too large it will damage the bismuth semiconductor material used. After TEG starts working it will produce voltage and current.

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1. INTRODUCTION

The need and electricity consumption are currently not comparable to the effort to provide adequate electricity supply. The current constraint of the lack of electricity supply, is especially due to the lack of electricity supply from the National Electricity Company (PLN). The electricity from PLN is produced from fossil energy sources such as coal, fuel oil, and others that will run out over time if used continuously. To overcome the problem of running out of fossil energy sources, we need to look for other renewable energy sources by utilizing existing energy sources and seeking new innovations in exploiting them. One of the potential renewable energy sources with new innovation is the use of thermoelectric generators (TEG). Currently, the TEG as an energy source has not been utilized optimally.

Application of TEG usage as power generation can be divided into low power generation and high-power generation. Low power generation can generate power from 5 μW to 1 W, and where from 1 W and above the TEG is considered as high-power generation [1-3]. Application of TEG as low power generation are used in biomedical, military, aerospace, and remote. Electric devices that are incorporated in other bodies and use power generation technology are grouped into mobile communications category. They include iPods, MP3 players, and smartphones. Others are used in the medical field like cardiac pacemakers and hearing aids. The electric devices that are incorporated in other bodies have power requirements which rane 5 µW to 1 W. They have a life expectancy of up to 5 years [4, 5]. High power generation of TEG is mostly used in automobile engines and industries. Iron and steel, chemical, petroleum refining, forest product, and food and beverage industries consume enormous amount of energy, in which a large amount escapes to the environment in the from of exhaust heat. Table 1 shows waste heat source temperatures as a sample of mid and high temperature TEG applications.

Table 1. Estimated waste heat source temperatures of a sample mid and high temperature TEG applications [6-8]

Application	Source temperature range (°C)
Automotive exhaust	400-700
Diesel generator exhaust	~500
Primary aluminum Half-Heroult cells	700-900
Glass melting regenerative furnace	~450

The range of the temperature selected is based on the utilization of the TEG. The generation of power requires the systems of waste heat recovery of TEG [9, 10]. Top manufacturers of automobiles, such as BMW, Volvo, Ford and Volkswagen have developed such systems. The systems are intended to improve the fuel economy of the automobiles. The power generated by the thermoelectric generators is within a range of 1 kW [11, 12]. In a vehicle utilizing common gasoline engine, about 40% of the fuel energy is emitted from the exhaust pipe, while about 30% is lost into the coolant. Effective usage of this waste heat increases energy efficiency. Nissan developed the first thermoelectric power generator which was based on Si-Ge elements for automobiles in 1998 [13, 14]. A further advancement of an exceptionally efficient thermoelectric system to recover waste energy from passenger vehicles was made by the Bell Solid State Thermoelectrics (BSST) group that includes BMW, Visteon, and Marlow Industries in 2004 [15, 16]. Yang [17, 18] stated that this system increased fuel economy by about 10%. Hsu et al. [19, 20] created a system for recovering waste heat consisting of 24 TEG modules to generate electricity from the car exhaust pipe. This system was capable of converting power output of 12.41 W at a temperature difference of 30 oC. The focus of the latest researches on the utilization of thermoelectric power generation in the industrial sector has shifted toward utilization of industrial waste heat [2, 21]. This large-scale application of thermoelectric power generation offers a potential alternative of power generation through utilization of industrial waste heat. It is expected that this will aid in solving the universal energy problem and at the same time help in decreasing the global warming phenomenon. An example of such research was done in Thailand by Yodovard et al. [22, 23] in which they measured the potential of waste heat thermoelectric power generation for diesel cycle and gas turbine cogeneration system used by the industrial sector. They estimated that the thermoelectric power generation system was able to recover waste heat from the exhaust of cogeneration system by about 20% for the gas turbine, and 10% for the diesel cycle, corresponding to a net power generation of about 100 MW.

Based on those applications, hot source used by TEG comes from another equipment. This paper describes how TEG heating is performed without using hot source from another equipment. In order for TEG to be used as an alternative energy source that works reliably, continuously and optimally with self heating, a further study on TEG as a substitute electrical energy source for providing electrical energy needs to be conducted [24]. The use of TEG as a thermoelectric generator is at least to meet the household needs. The first working principle of this thermoelectric generator is the hot side of the TEG peltier which is coated with metal in the form of aluminum. The aluminum is heated by heater. And the cold side of the TEG peltier is placed on the heatsink (as a heat dissipation metal). About half or more of the heatsink is submerged in water. If the temperature of the metal being heated and the temperature of the heat dissipation metal reaches a certain temperature difference, then the temperature difference causes TEG to start working [25]. The greater the temperature difference, the greater the electrical energy produced will be. However, if the temperature difference is too large, it will cause damage to the bismuth semiconductor material used [26]. After TEG starts working it will produce voltage and current. The voltage and the current produced are not enough to generate large power. In order for TEG to generate large power, it is necessary to have equipment or supporting circuits to gradually increase the voltage and the current.

2. RESEARCH METHOD
2.1. Literature study

Thermoelectric generator (TEG) is a solid-state device that produces electrical energy from the temperature difference applied to TEG. This generator technology was first introduced by Thomas Johann Seebeck in 1821 [27]. Seebeck reports that the thermoelectric potential energy can be developed with the presence of temperature differences in two different materials. As a result, this phenomenon is referred to as the "Seebeck effect". Usually, a large number of TE elements are connected electrically in series and thermally in parallel to increase the TEG output power. The standard size of the TEG module varies from 40×40×3 mm to 50×50×5 mm [28]. For flexible TEG, the thickness varies from 10 to 500 μm [29]. The standardized TEG modules usually use tellurium (Te), bismuth (Bi), antimony (Sb) or selenium (Se) to form the basis of the TE system [30, 31]. The combination of Bismuth telluride (Bi_2Te_3) and antimony telluride (Sb_2Te_3) are TE materials that are most commonly used because of their high efficiency at room temperature. In addition, these materials are also easily stored in thin films to make flexible modules [29, 32]. The physical form of TEG used in this study is shown in Figure 1. The benefits of TEG include a longer life span than that of other power generation systems, absence of moving parts, absence of harmful pollutant emissions during operation, absence of operating and maintenance costs, absence of chemical reactions with the environment (i.e. environmentally friendly), reliable operation, solid-state operations, and the use of low potential of thermal energy [33, 34].

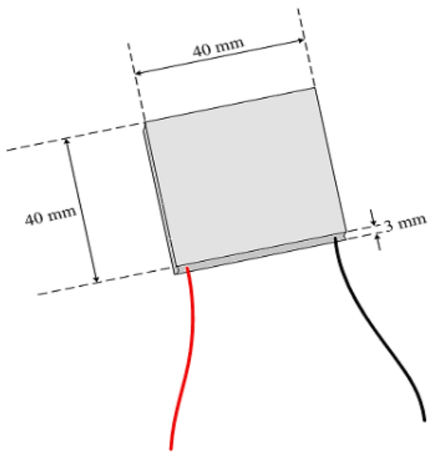


Figure 1. Physical form of TEG [35]

The basic principle of TEG is based on the concept of Seebeck effect of thermoelectric materials in which the voltage generated is directly proportional to the temperature gradient [27] as mathematically shown below:

$$V = \alpha \Delta T \quad (1)$$

In which α is the Seebeck coefficient ($V K^{-1}$) of the thermoelectric materials (TE) and ΔT is the temperature difference between the two generator surfaces at K. The TEG system consists of p-type and n-type semiconductors in which p-type has surplus of holes and n-type has surplus of electrons to carry electric current Figure 2. When heat flows from the hot surface to the cold surface through thermoelectric material, the free charge (electrons and holes) from the semiconductor also moves. This charge movement converts thermal energy into electrical energy. The typical value of the commercially available N-type Seebeck coefficient for Bismuth Telluride (Bi_2Te_3) is -150×10^{-6} VK^{-1}, while for p-type Antimony Telluride (Sb_2Te_3) is $101\text{-}161\times10^{-6}$ VK^{-1} at room temperature [36]. TEG works by converting heat energy into electrical energy when certain temperature difference occurs between the two sides of the peltier. If the metal is heated at a temperature of 80°C while the temperature of heat dissipation metal is 50°C so that the peltier experiences a difference in temperature of 30°C. The temperature difference causes TEG to work optimally, in which the greater the temperature difference, the greater the electrical energy produced. However, if the temperature difference is too large, it will cause damage to the bismuth semiconductor material used [27]. This scheme can be seen in Figure 3.

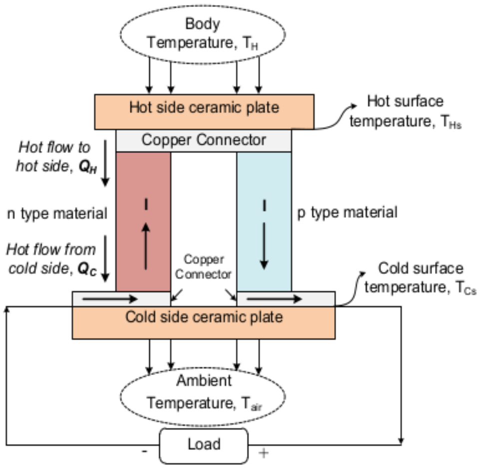


Figure 2. Single thermoelectric pair comprising of n-type and p-type materials. Heat flows from hot side to top side ($Q_H - Q_C$) and electrical current (I) is flowing from n-type to p-type material due to temperature gradient ($\Delta T = T_{Hs} - T_{Cs}$) [37]

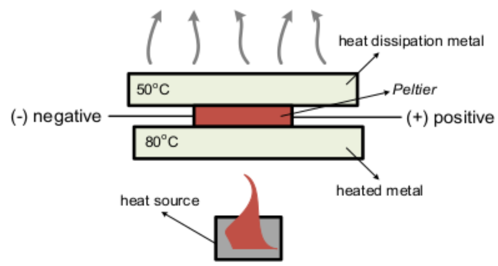


Figure 3. Seebeck effect on TEG [38]

2.2. TEG Application for power plants with self heating

TEG applications for power plants with self heating can be made in the form of block diagrams such as Figure 4. In box 1, there is a 50 watt/220 volt heater to heat metal plates in the form of aluminum. The heat from aluminum is then transferred to the hot side of the TEG peltier. And the cold side the TEG Peltier is placed on the heat sink (as a heat dissipation metal). About half or more of the heatsink is submerged in water. If the temperature of the metal being heated and the temperature of the heat dissipation metal reaches a certain temperature difference, then the temperature difference will cause the TEG to start working. With a certain temperature difference between the two peltier sides, the two sides of the copper connecting to the thermoelectric will give rise to voltage and current. The voltage generated is in the range of 2-5 volt dc with a current of 2-3 ampere.

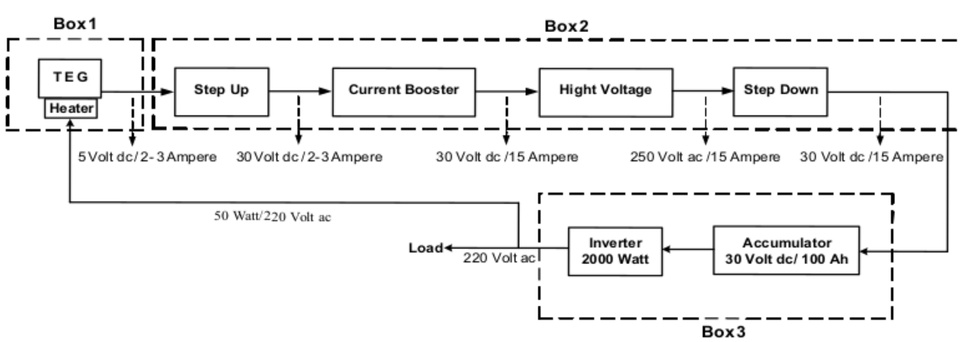
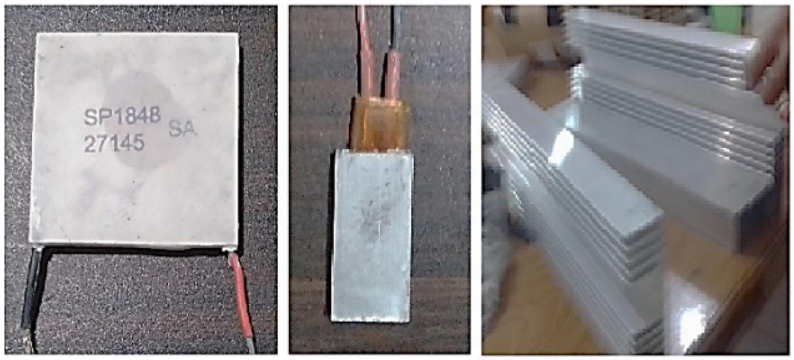


Figure 4. Block diagram of the TEG application for power plants

3. RESULTS AND ANALYSIS

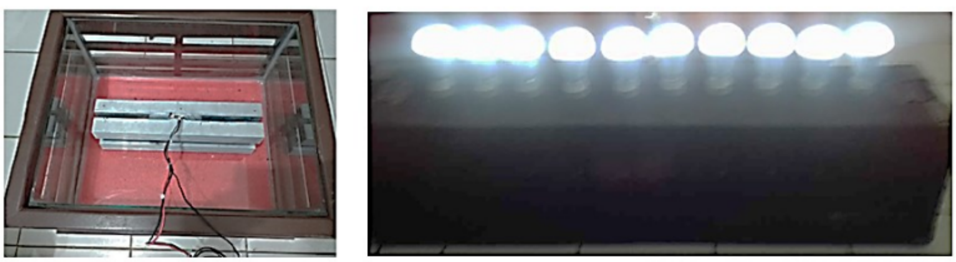
3.1. Tool designing

In designing, TEG used is type TEG SP 1848-27 145 SA Figure 5 (a) as many as 2 pieces arranged in parallel, 50 Watt/220 Volt ac heater as shown in Figure 5 (b) as many as 1 piece, and heatsink Figure 5 (c) as many as 5 pieces. The results of tool designing are such as Figure 6 (a), with the varying LED loads as Figure 6 (b).



(a) (b) (c)

Figure 5. (a) Thermoelectric generator type SP 1848 – 27 145 SA, (b) heater 50 watt/220-volt ac, (c) heatsink



(a) (b)

Figure 6. (a) Design results, (b) varying LED loads

3.2. Results of measurement

The results of measurement showed that the temperature of the hot side of the peltier of TEG was 74°C and the temperature of the cold side of the peltier was 42°C. The output voltage and current from TEG for the varying loads as Table 2.

Table 2. The results of measurement of outgoing volt and current from TEG with varying loads

Loads (Watt)	Outgoing Voltage (Volt)	Outgoing Current (Ampere)	Description
60	5.43	2.87	
75	5.25	2.73	
90	5.08	2.57	
130	4.95	2.45	Loaded with LED lights of Hannochs brand
180	4.78	2.36	
300	4.13	2.11	
500	4.07	2.09	

3.3. Analysis

Table 2 indicates that the greater system loads, the lower outgoing voltage and current from TEG drastically, while temperature of hot side and cold side peltier is fixed. The result of measurement of outgoing voltage and current from TEG is showed graphically as Figure 7. Outgoing voltage from TEG will be raised by a step-up circuit to 30 Volt dc and a fixed current. This step up circuit is in box 2 in Figure 4. The output current of this step-up circuit it will be raised again by a series of Current Booster Circuits. The Current Booster circuit is a circuit that serves to raise a small input current into a large output current, where the output current (Iout) can be adjusted according to needs. The current output from Step Up is still very small, ranging from 2 Amper to a maximum of 3 Amperes. This Current Booster circuit increases the current to 9 Amper with a working voltage of 30 Volt dc. The output voltage of the Current Booster circuit is raised again by the High Voltage Circuit or called the High Voltage Boost Converter Circuit. The High Voltage circuit is a voltage booster circuit that can increase a small input voltage from 6 Volt dc to 12 Volt dc into an output voltage ranging from 100 Volt dc to 1000 Volt dc depending on the need, while the output current is constant. In designing this high voltage with a maximum power of 2250 Watts. The High Voltage circuit is useful for storing power. The power in the high voltage circuit will be channeled to the load (± 1200 Watt) and to heat the heater again.

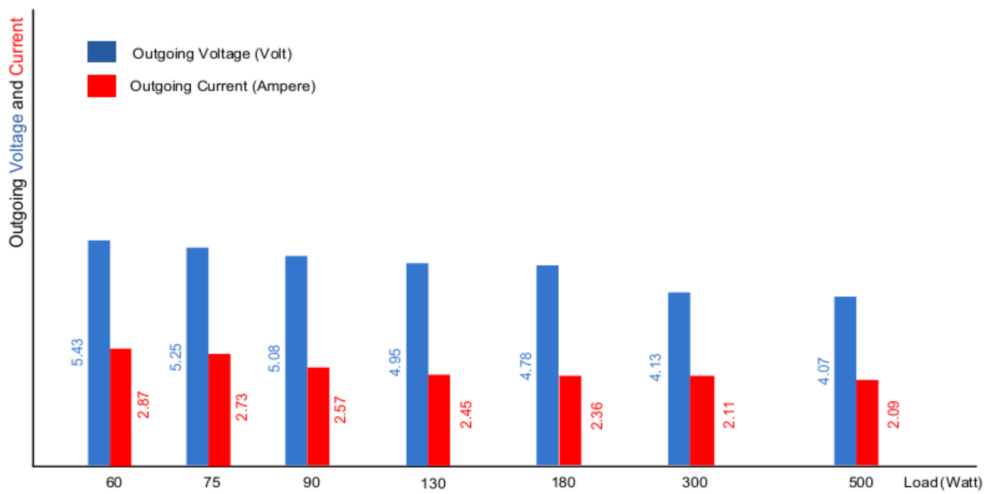


Figure 7. The measurement result of outgoing voltage and current from TEG with varying loads

4. CONCLUSION

Based on the results of material selection and design, the optimal thermoelectric generator type is the type of TEG SP 1848-27 145 SA as many as 2 pieces arranged in parallel. When heated with a heater of 50 Watt/220 Volt ac the temperature of hot side of the TEG peltier is 74°C and the temperature of the cold side of the TEG peltier is 42°C. The result indicates that the greater system loads, the lower outgoing voltage and current from TEG drastically, while temperature of hot side and cold side peltier is fixed. These voltages and currents are increased gradually through several circuits in order to be able to meet the needs of electric power in one household of ±1200 watt.

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