Thermoelectric Effect as Waste Heat Recovery Technology

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Abstract – **The aim of this research is to utilize waste heat as an alternative source of power, to analyse thermoelectric effect principle as waste heat recovery technology and to apply the thermoelectric effect as waste heat recovery to household appliances. The scope of study for this research is to understand the principle, function and concept of the thermoelectric effect, testing either waste heat can be as alternative energy and simulation on thermoelectric performant using Matlab/Simulink. Waste heat has wide of the range, in this research will focus on utilizing waste heat from household appliances, refrigerator compressor. The use of thermoelectric generators as waste heat recovery rapidly increase in recent years thus, with review initially through the university library using the OPAC system to find book related to the research, journal abstract and internet search on the research that has been done. The waste heat from the low temperature of the heat can be reused or utilize by using thermoelectric effect principle. Therefore, the thermoelectric effect can call as the waste heat recovery technology.**

Keywords-thermoelectric effect (TE), thermoelectric generator (TEG), thermoelectric cooling (TEC), thermoelectric module (TEM) and Matlab/Simulink.

I. INTRODUCTION

Practically, engines convert one-third of their fuel or electricity into usable energy and other two-third are transformed into waste heat. Basically, where energy there is heat is thus, heat gives big advantages if it can be a reuse or become as the alternative energy. Mostly, waste heat recovery system was applied in industries because waste heat gives a big impact to the production. In these recent years, the thermoelectric effect principle was rapidly increased as a waste heat recovery system and improvement in thermoelectric performance. What is the thermoelectric effect? The thermoelectric effect is the process when the temperature different convert to voltage and vice versa [1]. The thermoelectric effect has two concepts when a voltage applied to the thermoelectric device, it will create temperature different between two sides of the thermoelectric module and this process called as the thermoelectric cooling system. Another concept, a thermoelectric device will produce a voltage when there is a difference temperature on each side of the thermoelectric module and it's called as thermoelectric generator system [2].

The problem statement is, in industries around 20% to 50% of your energy is being lost to the environment as waste heat. Waste heat produced by machines that do work and in another process that use energy. The result from electricity change to heat is high different between input and output power thus, the electrical efficiency of power plants will decrease [3]. Waste heat has a wide range in industrial application, household appliances and spacecraft technology. Therefore, this big opportunity to make waste heat as another alternative energy that can be uses and waste heat is free of charge source. Usually, heat produces by a heat engine or source of high-temperature heat and based on the theory the engine will always produce low-temperature heat. The problem is, can thermoelectric technology as waste heat recovery system used for low temperature from household equipment?

Significant of this research is when electricity can be generated from waste heat produced by household equipment it become a big opportunity to reduce cost or electricity bill if that electricity can light up bulbs or rotate the fan thus, it's free of charge. Nowadays, the increase in demand for a house causes increased in electricity bills, thus with waste heat recovery for household appliances can reduce the cost. In addition, reuse waste heat is important to improve the efficiency of energy use with converting waste heat to produce electrical energy and then using it can improve the efficiency of fossil fuel or electricity use [4]. Thermoelectric effect technology gives benefit indirectly in reducing the pollution with no electrical noise pollution and do not use or produce any gases to the environment thus, this response to the problem with global warming [5].

Other significant from investigating thermoelectric effect as waste heat recovery technology is a size of equipment for thermoelectric effect system is smaller compared to other recovery technology. Thus, the thermoelectric concept can reduce the equipment size. Other than that, it works without any moving parts so they are virtually maintenance free hence, it can reduce the cost for maintenance activities [6]. Indirectly, waste heat recovery technologies also react as a cooling system to refrigerator motor due to reuse heat to generate power or energy and this can increase the service life of the motor.

The objective of this research is to utilize waste heat as an alternative source of power, to analyse thermoelectric effect as waste heat recovery technology and to apply the thermoelectric effect as waste heat recovery technology to household appliances. The scope of this research is made a simulation of the thermoelectric module using Matlab/Simulink, experiment on the thermoelectric device and testing thermoelectric device on waste heat from refrigerator compressor. Other than that, focus on investigation the ability of thermoelectric device as new waste heat recovery technology that can be used in household appliances with reuse waste heat (low-temperature) from refrigerator motor to produce the voltage by create temperature different between two side.

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II. METHODOLOGY

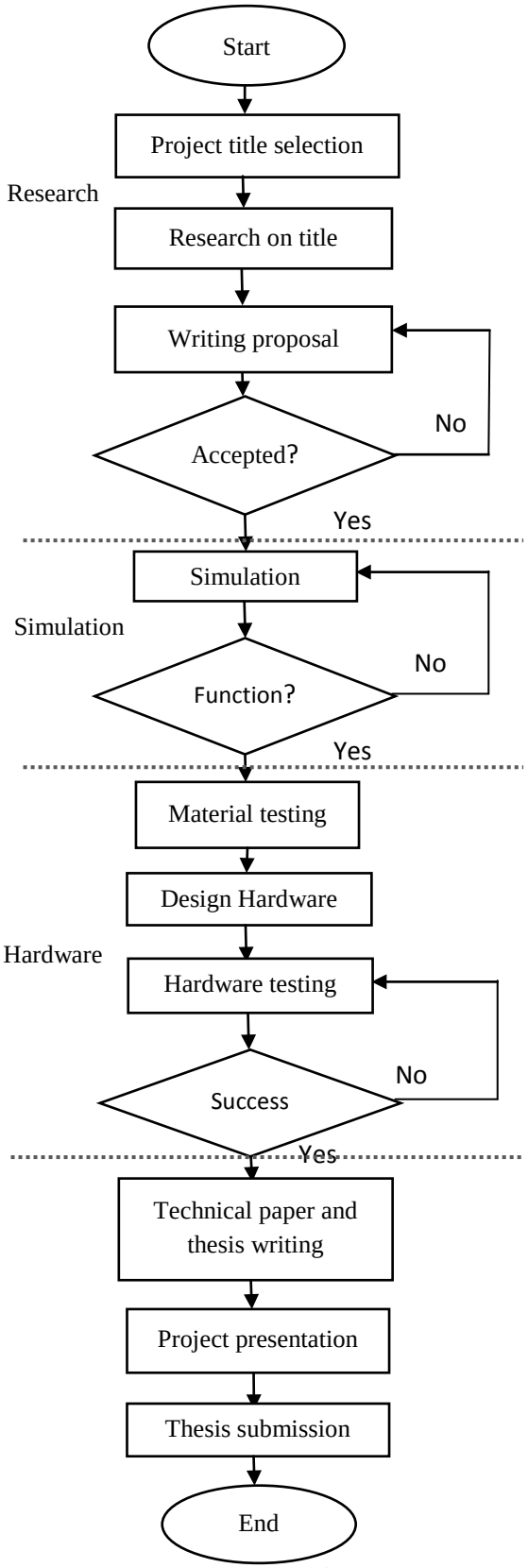

Figure 1: Flow chart of project

A) THERMOELECTRIC MODULE

The TEGs consist of n-type and p-type of semiconductor material that connected electrically in series and thermally in parallel [7]. The TEM was sandwiched between two ceramic plates with one side as hot side and another side is cool side. The hot side was placed on heat sources and the cool side with the heat sink.

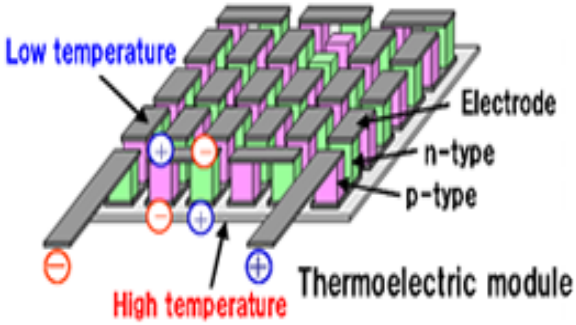

Figure 2: Thermoelectric module connection.

B) SIMULATION THERMOELECTRIC MODULE

The Seebeck effect is the phenomena heat supply and removed by a surface between different materials when different temperature applied at each surface [8].

The rate of supply heat is [9]:

$$Q_H = SIT_H - 0.5I^2R + K(T_H - T_C) \quad \ldots (1)$$

The rate of remove heat:

$$Q_C = SIT_C + 0.5I^2R + K(T_H - T_C) \quad \ldots (2)$$

The output voltage:

$$V = S(T_H - T_L) - IR \quad \ldots (3)$$

The useful output power:

$$P = SI(T_H - T_L) - I^2R \quad \ldots (4)$$

Derivative with respect power (P) to zero, get maximum output power from the module. The optimum current when derivative power equal to zero [10]:

$$I = S(T_H - T_L) / 2R \quad \ldots (5)$$

Thermal efficiency describes percentage of power produced base on heat supply:

$$\eta = P / Q_H \quad \ldots (6)$$

The maximal voltage can be rewritten as:

$$Vmax = ST_H \quad \ldots (7)$$

S is Seebeck coefficient. The parameters of the proposed model can be calculated by:

$$S = Vmax / T_H \quad \ldots (8)$$

When temperature gradient applied to the module under an open circuit condition, the voltage between the hot and the cool side of the module is called Seebeck effect.

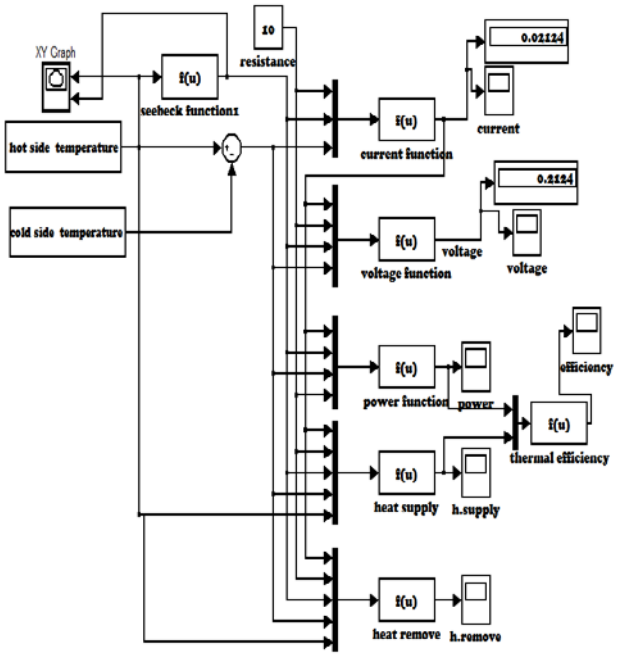

Figure 3: Block diagram simulation using Matlab/Simulink

III. RESULT AND DISCUSSION

A Matlab/Simulink simulation was created to predict and analyse the performance or output from the thermoelectric module based on the formula from the previous research. In this simulation, the input data were used to calculate output voltage, output current and output power and those inputs are:

- The range of temperature at the hot side of the thermoelectric module.
- The ranges of temperature at the cool side of the thermoelectric module.
- The constant resistance value (10ohm).

In this simulation, taking Bismuth Telluride thermoelectric device (TEC1-12706) cooling module as an example and module were used in hardware development. Other than that, aluminium and copper heat sink was used and placed at the cold side of the thermoelectric module to improve the thermoelectric module performance.

A) SIMULATION RESULT

Practically, the temperature on the cool side not constant because went the voltage generated from the thermoelectric module, current transferring the heat to the cool side of the module. Thus, the temperature on the cool side of the module will increase. The graph in Figure 4 showed rapidly increases in output voltage, after a few second it shown slowly decreasing due to the decrease in temperature different. The reason of decreased because the current start to flow and transfer the heat to the cool side. Therefore, the temperature starts decreasing when current start transfers heat, the output voltage constant when the current start to constant transferring heat and the output current produce only small amount. The output current affect the output power generated by module due to small amount output current, the power only can produce around 0.33W (Refer Figure 5).

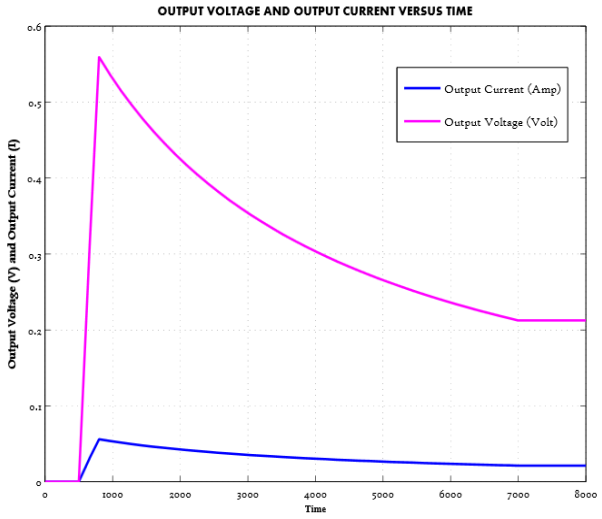

Figure 4: Graph of the output voltage and output current based on testing.

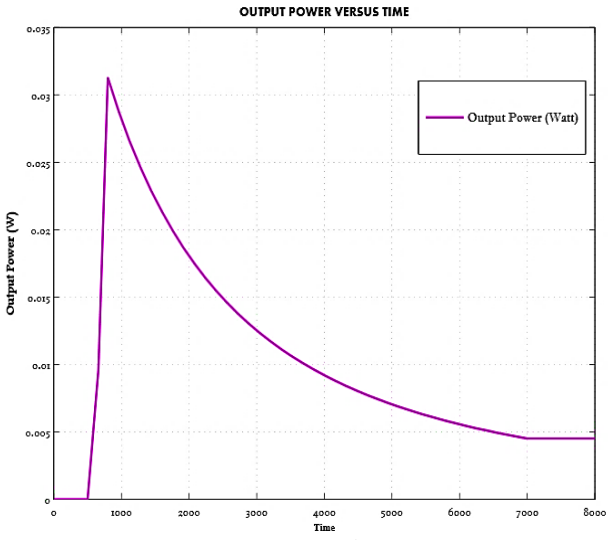

Figure 5: Graph of output power.

The purpose of the simulation is to analyse other factors that can affect performances of the thermoelectric module and to analyse the thermoelectric output before develop thermoelectric as waste heat recovery technology. First, the internal resistance will increase with increasing temperature at the hot side of the thermoelectric module. Increasing the resistance of thermoelectric module will affect the output current and indirectly affected output power. However, increasing in internal resistance not affected the output voltages, the output voltage will

increase when difference temperature increased. Other than that, the efficiency of the thermoelectric module depends on output power and the rate of heat supply when the output power decreasing this will affect the efficiency of the thermoelectric device.

B) EXPERIMENT RESULT

Table 1 shows the output from thermoelectric modules after placed on refrigerator motor. The experiment was use three TEC1-12706 modules connected in parallel arrangement to get the large value of output voltage to driving a small dc motor. The TEC modules directly supply the output the load (DC motor). At first when TEC module was placed the output voltage is around 0.6V after a few second, the voltage start to drop due to decrease in temperature different between two sides because when current start to flow in TEC circuit, the heat from hot side will be transferred to the cool side by current.

However, the output current only produce small amount when TEC modules connected in a parallel array. Figure 7 shows the testing on refrigerator motor and Figure 8 shows the voltage at the load. The voltage shows for three TEC modules connected in parallel thus, for a module, its produce around 0.2V. The ambient temperature during the experiment also can give affect the TEC module performance because temperature surrounding is a cooling agent to the heat sinks. In this experiment, three thermoelectric modules and three heat sinks were used. The type of heat sink is two aluminium heat sink and one copper heat sink. The materials of heat sink also affect the output of thermoelectric module because the capability to conduct or absorb heat to create difference temperature and between aluminium and copper, copper is the good conductor for heat compare with aluminium heat sink.

Table 1: Output range from TEG module

Output Voltage (Volt)	0.2V – 0.6V
Output Current (Amp)	30mA - 100mA
Ambient Temperature (℃)	30℃ - 34℃
Temperature at hot side (℃)	80℃ - 104℃
Temperature at cool side (℃)	45℃ - 98℃

Figure 7: Experiment TEG module at refrigerator motor

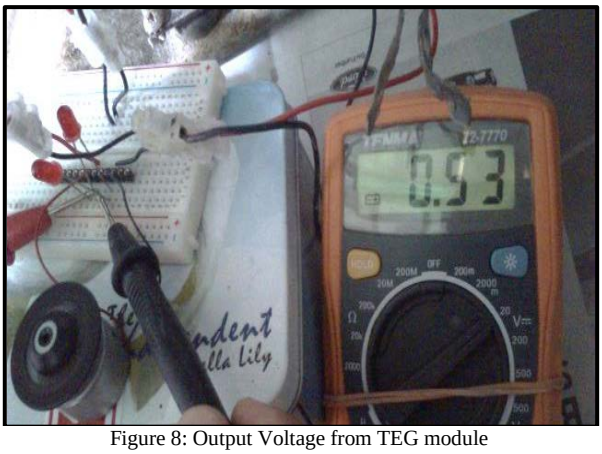

Figure 8: Output Voltage from TEG module

IV. CONCLUSION

Mathematical models of the thermoelectric module in Matlab/Simulink have been well developed to simulate thermoelectric module behaviours and analyse their performances. In addition, simulation allows for design and analysis the thermoelectric output. According to the simulation, for a thermoelectric device producing a larger value of output voltage, it needs to create high difference temperature value. The experiment data presented show the waste heat with low temperature from household appliances can utilize as an alternative source of power by using thermoelectric effect concept. Thus, thermoelectric effect principle can be used as waste heat recovery technology and waste heat from household appliances as low-temperature from refrigerator motor can reuse using the thermoelectric module.

RECOMMENDATION

A. Thermoelectric Device as Waste Heat Recovery on Photovoltaic Module.

During the operating PV panel, solar radiation not completely converted to electricity, the rest of it will be converted to heat and it depend to the type of PV panel used. Thus, heat produced from PV panel become waste heat release to the atmosphere. Therefore, heat from PV panel can reuse to generate electricity using the thermoelectric module and this can improve production of photovoltaic (PV) with reuse heat and at the same time can reduce temperature PV panel. Therefore, we want to analyse the impact or improvement in the electrical output of PV cell after we apply the thermoelectric effect technology.

B. Using waste heat from air-conditioner

Most central air conditioning system consist two parts, they consist the cold side that is located at in our house and the hot side consist of a compressor and the fan which is placed at the outside of our house. The compressor is the heart of air conditioning system because acts as pump and causing the refrigerant to flow through the system,

compressor function to draw low temperature, low pressure and make refrigerant in a gaseous state. This because by compressing refrigerant gas can raise the pressure and temperature of the refrigerant then this high-pressure and high-temperature gas flow to the condenser coil. Thus, waste heat from the compressor and condenser coil can be reused to generate electricity and this electricity can be uses to driving a fan in the air conditioner system or use to lighting a lamp in a room.

C. Using both thermoelectric concepts on car

Car engines are built like cylinders, the hot gas with mini explosion cause the fuel burn in the cylinder and cause the cylinder becomes hot. Thus, a car engine produces a lot of heat and because of that car engine need be cool continuously to avoid damage. Therefore, TE concept can be applied in car system by placing TEG at the cylinder with high temperature to produce electricity. Then TEC concept was placed at radiator where heat exchanger of liquid occurs, this can increase an efficiency of the heat exchanger. The electricity produced by TEG module can be supplied to TEC system at the radiator. Besides that, it can be supplied to driving the fan at the radiator and it can reduce the fuel cost because a certain car runs the fan using the fuels. Thus, the energy used in driving the fans it wasted.

D. Self-generate thermoelectric modules.

This research showed that low-temperature waste heat from household appliances can generate electricity and driving a small dc motor. The opportunity to generate electricity to start up or driving electrical equipment can be achieved with increasing the output power from TE module. Therefore, to generate a larger value of voltage, higher difference temperature between each side of TE module is needed. Thus, we need to create a cooling system at the cool side or side with the heat sink. The simple cooling system is using a fan to help the heat sink cool faster with release excess heat from the heat sink to the environment. When the TE module can produce larger amount of voltage and current that can drive a fan, the system is called as self-generated thermoelectric generator when the power produce is supply to the fan that use to cool the heat sink. Other than that, the system can be improved by improving the power output until it can light a bulb or a fan for air circulation at home.

E. Conductor between the heat source and thermoelectric module.

In this research and testing, the thermoelectric module was placed at semi-circle material. This cause the thermoelectric module was not fully connected to the heat source surface and its one of the reason can affect the output power of the thermoelectric module. Therefore, to make module was fully connected, either create semi-circle conductor between TE module or develop TE module with semi-circle shape.

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REFERENCES

[1] D.M Rowe . Thermoelectric handbook, Macro to nano. Publisher by CRC Press, Dec 9, 2005.

[2] D.M Rowe (ed). CRC Handbooks of Thermoelectrics. MA: CRC Press. Dec 12, 2010.

[3] U.S Department of Energy. Waste Heat Recovery in Technology and Opportunities in U.S Industry. Prepared by BSC, Incorporated, March 2008.

[4] Yadav A, Pipe KP, Shtein M. Fiber. Based Flexible Thermoelectric Power Generator. Publisher by J Power Sources 2008.

[5] Cecelia Arzbaecher et al. “Industrial Waste Heat Recovery: Benefits and Recent Advancements in Technology and Applications”. University of California, Santa Barbara, Rep 2007.

[6] David Yan. “Modeling and Application of a Thermoelectric Generator”. Dept Electrical and Computer Engineering, University of Toronto, Rep 2011

[7] Basel.I.Ismail, et al. “Thermoelectric Power Generation using Waste-Heat Energy as an Alternative Green Technology”, Dept of Mechanical Engineering, Lakehead University, Canada. Rep August 1, 2008.

[8] J. Yan, “Analytical Model of Parallel Thermoelectric Generator” in Applied Energy, Elsevier Ltd, Volume 123, Pages 47-54, 15 June 2014.

[9] N.M. Khattab et al. “Optimal Operation of Thermoelectric Cooler Driven by Solar Thermoelectric Generator” in Energy Conversion & Management. Elsevier Ltd, 2006.

[10] Huang-Liang Tsai. “Model Building and Simulation of Thermoelectric Module Using Matlab/Simulink”. Department of Electrical Engineering, Da-Yeh University, Chang-Hua, Taiwan, ROC. Rep, 2009.