AN ANALYSIS OF THERMOELECTRIC COOLER DRIVEN BY THERMOELECTRIC GENERATOR

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AN ANALYSIS OF THERMOELECTRIC COOLER DRIVEN BY THERMOELECTRIC GENERATOR

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
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2020

DECLARATION

I declare that this report entitled "An Analysis of Thermoelectric Cooler Driven by Thermoelectric Generator " is the result of my own work except for quotes as cited in the references.

Signature :

Author : MUHAMMAD HILMI BIN NORDIN

Date : 26 June 2020

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name : Dr AZDIANA BINTI MD YUSOP

Date : 26 June 2020

DEDICATION

Personally dedicated to my family, supervisor and friends who help me complete my project report for my final year.

ABSTRACT

Nowadays, Energy harvesting technology is popular method to generate electrical energy. Electrical energy not only can be generated using solar panel, but it also can be generated using Thermoelectric Generator (TEG). Thermoelectric generator is a device that convert temperature difference into electrical energy. This project has analysed the potential of this system as a source of heat for TEG to generate the TEC. This system reduced energy consumption of the vehicle. In this project 9 module of the TEG is used to generate the electricity using the temperature difference. Heat from the engine convert temperature difference into electrical energy. The electrical energy is then can be store into supercapacitor. Next, the voltage regulator is use to regulate the output voltage of the supercapacitor to produce constant output voltage. The output voltage from the voltage regulator is constant to generate the thermoelectric cooler to produce constant temperature for cool side 24ºC and hot side 38ºC to control the temperature at the radiator. The advantage of TEG being installed in this system is it can reduce work done by the engine in cooling down the coolant temperature and more power produce by the engine can be used for other operation.

ABSTRAK

Pada masa kini, teknologi penuaian tenaga adalah kaedah yang popular untuk menghasilkan tenaga elektrik. Tenaga elektrik bukan sahaja dapat dihasilkan dengan menggunakan panel suria tetapi juga dapat dihasilkan dengan menggunakan Thermoelectric Generator (TEG). Penjana termoelektrik adalah alat yang mengubah perbezaan suhu menjadi tenaga elektrik. Projek ini telah menganalisis potensi sistem ini sebagai sumber haba bagi TEG untuk menghasilkan TEC. Sistem ini mengurangkan penggunaan tenaga kenderaan. Dalam projek ini 9 modul TEG digunakan untuk menjana elektrik menggunakan perbezaan suhu. Haba dari enjin menukar perbezaan suhu menjadi tenaga elektrik. Tenaga elektrik kemudian dapat disimpan ke dalam superkapasitor. Seterusnya, pengatur voltan digunakan untuk mengatur voltan keluaran supercapacitor untuk menghasilkan voltan keluaran yang tetap. Voltan keluaran dari pengatur voltan adalah tetap untuk menghasilkan pendingin termoelektrik untuk menghasilkan suhu tetap bagi sisi sejuk 24ºC dan sisi panas 38ºC untuk mengawal suhu pada radiator. Kelebihan TEG dipasang dalam sistem ini adalah dapat mengurangkan kerja yang dilakukan oleh mesin dalam menyejukkan suhu penyejuk dan lebih banyak tenaga yang dihasilkan oleh mesin dapat digunakan untuk operasi lain.

ACKNOWLEDGEMENTS

I hereby would like to take this chances to thank all persons who involved directly or indirectly in helping and assisting me in completing Final Year Project (FYP) which is a compulsory subject to all Universiti Technical Malaysia Melaka(UTeM) students in order to complete degree studies.

First, I would like to thanks to my supervisor, Dr Azdiana binti MD Yusop for continuous guide me throughout completing this project. Thank you for your expertise and spiritual advice which bring this project into a success. Besides, his thinking behavior inspire me to always plan before doing something

Next, special appreciation goes to my family who also gave words of encouragement and enthusiasm that accompanied by prayer and hopeful for me to go ahead. Lastly, my friends who helped provide ideas, whether directly or indirectly in addition to jointly face the struggle in completing this projects that are entrusted.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

TEG	:	Thermoelectric Generator.
TEC	:	Thermoelectric Cooler
V	:	Voltage.
A	:	Ampere.
C	:	Celsius.
C_{in}	:	Capacitor Input.
TPEP	:	Thermally Parallel and Electrically Parallel.
TPES	:	Thermally Parallel and Electrically Series.
TSEP	:	Thermally Series and Electrically Parallel.
TSES	:	Thermally Series and Electrically Series.
FET	:	Field-effect transistor.
Zn	:	Zinc.
AC	:	Alternative Current.
Al2O3	:	Aluminum oxide.
COP	:	Coefficient of Performance.
MPPT	:	Maximum Power Point Tracking.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter will explain in detail why this study is being conducted as well as the root factors. Besides that, this chapter also briefly explains all the scope of works and general methodologies taken towards completing this study.

1.1 Project Background

Energy harvesting technology is now a growing method of electric power generation. The electricity is produced not only by the Solar Panel but also by the Thermoelectric Generator (TEG). Despite increasing importance on the environment and on energy issues, and problems of fossil fuels depletion and environmental pollution, the importance of renewable energy sources, such as solar wind and wave, has grown to grow. The technology of thermoelectric generation (TEG) has been used as one of the methods for producing renewables in different industries and situations.

The waste heat was usually ignored and given up. If waste heat could have been used effectively as the thermal energy source by the TEG technology, it would interrupt the energy consumption routine and develop a new sight of energy harvesting. In recent times, TEGs have also drawn attention to applications involving solar energy, vehicles, and human diagnostics, thereby increasing the performance of TEG energy conversion. Firstly, solar energy has been used in recent years as green and cost-effective renewable energy. An energy collector is installed, not only using a solar-tracking system to collect solar and thermal energy but also transform TEG thermal energy into electric energy. This increases the conversion capacity of the system to 38.65% [1]. Second, loss of thermal energy through the gasoline motor vehicle combustion cycle. The waste flow was moved to a hot side of the TEG on the surface of the engine system in order to reduce the fuel consumed and improve the vehicle's performance. The third is that the electricity generated from thermal electricity, but also power is supplied for other wearable devices by the supercapacitor. Regrettably, TEG 's efficiency is less than that of other thermal generators. It can only be used in some applications which use low power consumption. To keep the TEG output voltage relatively close to the desired value, the TEG temperature difference with the environment cannot be controlled. One of the most common electronic components is a voltage regulator, since the TEG power also creates a raw power which otherwise damages the circuit. The temperature difference will take a long time to adjust and the generator's efficiency and success in generating the output power will be affected. The thermoelectric generator is a system that converts the difference in temperature into power. In the supercapacitor the electrical power is then preserved. The thermoenergy from the supercapacitor generates a cooling unit to test the performance of TEGs for the TEC. The advantage of TEG being installed in this system is that the engine can be used for other operations to utilize more power produced. The project proposed is to examine the ability of this device as a heat source for TEG to produce the TEC. That system will reduce the vehicle's energy consumption. At the end of this project an analysis is conducted to test efficiency of TEG to generate the TEC.

1.2 Problem Statement.

Energy harvesting technology is now becoming popular method in the new era. Nowadays every application needs to generate electrical energy using alternative sources. Research on internal combustion engines powered by gasoline from car show that only around 25% of the fuel power is used to drive the motor, while 40% of the energy fuel is lost to exhaust gas, 30% to coolant, 5% for friction and parasite. [2]. Nowadays vehicles need more and more energy to manage the vehicle's communications, navigation, engine control, and safety systems. Using natural source, electrical energy generates for the conversional process, which can be deflated if continuously used. This can also create pollution if they use the process of burning to generate electric energy using coal. So TEG is the best method for recycling waste heat by converting the heat energy into electricity. If waste heat can be used efficiently, the energy generated will be utilize. Vehicle engine is the appropriate part for generating electrical power, because if the engine is started, the engine will produce continuous temperature. Engine vehicle can generate 55ºC warm-up temperature and 55ºC to 104ºC for normal operating range. This project focuses on designing and evaluating the efficiency of the TEG device that can generate TEC to regulate temperature and produce alternative power sources.

1.3 Project Objective.

The objectives of this project are:

1. To produce a conceptual design of TEG for automotive waste heat recovery.
2. To analyze the power produce from TEG using temperature of engine.
3. To analyze the efficiency of TEG to generate the TEC using waste heat form automotive equipment.

1.4 Scope of Work.

This project will concentrate on developing TEG system that is capable of generating TEC. TEG module will generate electrical energy coming from the engine temperature difference and store the energy in the storage element. Engine motorcycle can generate 55ºC warm-up temperature and 55ºC to 120ºC for normal operating range. The TEG peltier thermoelectric power generator (SP1848-27145) will generate a temperature difference of 40ºC in the 3.2V open circuit voltage. TEC1-12703 would achieve a maximum temperature of 50°C if it gets 14.4V and 6.4A. The energy that is stored in the storage element is used to operate the TEC module for cooling system. A comparison is made to analyze the efficiency of TEG to generate the TEC.

1.5 Project Background.

Chapter 1 briefly explains the background of the project and generating electrical system. This part including problem statements, objectives of the project, scope of works in completing the project.

Chapter 2 preceded the end of Chapter 1. Within this chapter, the literature review is covered, where all academic and technical papers related to this project are included. Results, circuit design, type of TEG used were previously covered. In the next chapter, Chapter 2 is then included.

The complete approach used in project implementation is described in Chapter 3. The methodological section discussed how TEG circuits are designed to control the TEC module.

All data and results from the analysis are provided in Chapter 4. In this chapter, all results and findings are discussed and observed. This chapter will present the results for the analysis of the system performance in a suitable diagram.

Chapter 5 would explain ideas and possible works based on the completed project. It will sum up all the conclusion of the process occurs while completing it thesis paper.

CHAPTER 2

BACKGROUND STUDY

This chapter discussed all the relevant information to this study in form of summarization from various trustworthy resources in forms of either published journals or books. The overview of the problems brought by thermoelectric generator and why thermal energy harvesting can be the ideal solution to green technology. The thermoelectric generator, supercapacitor, and thermoelectric cooler theories, including working theory and process are also discussed in this chapter. Previous works of thermoelectric generator projects are reviewed and discussed. Other main components that are used in this project such as voltage regulator, temperature logger to analyzed, in terms on their results, functionality and efficiency.

2.1 Introduction.

The study of literature is one of the approaches used to obtain a whole range of topic analysis experience. The first part includes a critical mission assessment conducted by previous researcher. In addition, this element was made up of various sources to support research and analysis claim. This allows the reader to refer to this section if there is ambiguity about a few terms used for the entire research process in various bankruptcy. Finally, analyzing literature contains a whole past analysis that strengthens a certain aspect of research's comprehension.

2.2 Motivation of previous work.

An Analysis of Thermoelectric Cooler Driven by Thermoelectric generator system found to been done by the previous researcher that related to this project scope from library and website. Hence, it was chosen for a critical review and analysis in this part. The review covers all part of project being done by the researcher.

2.2.1 Thermoelectric power generation using waste-heat energy from internal combusting engine.

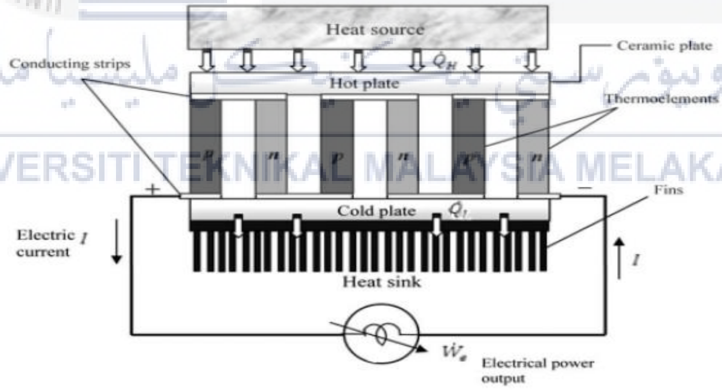

Figure 2.1:Thermoelectric Block Diagram.

The authors build a TEG framework based on figure 2.1 that can be incorporated into the car for electricity generation. This research uses Bismuth Telluride as a substrate for thermoelectric generators. Basis on Seebeck effect The difference of temperature between the warm and cool junction of two different materials, metal or non-metal, to produce tension is known.[3][4]

The thermoelectric generator uses two ceramic plates, based on a figure shown in Figure 2.1, which provide mechanical and electrical insulators for the thermoelement of an n-type and p-type semi-conductor. The electron and holes dependent on thermoelectric materials are controlled by the power and charging carriers. Ceramic plates are generally made of alumina (Al2O3), but substances with higher thermal conductivity (e.g., beryllium and aluminum nitride) are preferable while a large lateral heat transmission is needed. The semiconductor thermoelements (e. G. Silicon-germanium SiGe, lead-telluride PbTe based alloys) that are sandwiched among the ceramic plates are related thermally in parallel and electrically in series to shape a thermoelectric tool (module). More than a pair of semiconductors are typically collectively assembled to form a thermoelectric module and a pair of thermoelements is referred to as a thermocouple within the unit. The junctions connecting the thermoelements among the new and cold plates are interconnected using incredibly accomplishing metallic (e.g. Copper) strips. A fabric's capacity for thermoelectric packages is calculated to a degree of the dimensional parent of merit (ZT) of the cloth in a huge component. In most cases, semi-conductors were the chosen materials for thermoelectric products. The choice of appropriate substances with significantly better ZT for the packages is difficult. Therefore, choosing thermoelectric materials plays a very important role in the transformation of power in thermoelectric programs. Sizing up the heat exchanger is entirely based on the size, orientation and wide range of modules. After designing suitable heat exchanger, the thermoelectric modules are incorporated on the warmth exchanger for overall performance evaluation. In this work, the attempt is on the performance of thermoelectric generator beneath various engine operating conditions like engine velocity, mass drift fee of exhaust gasoline

2.2.2 The thermoelectric analysis of difference heat flux conduction materials for power generation board.

From this research, a design is proposed to convert thermal power by thermoelectric generator (TEG) from indoor and outdoor to electrical energy.[2]. Moreover, the electric power generated is charged as battery or power supply to the supercapacitors in the residence load (e.g. lighting). The conversion efficiency simulation of the TE board was done by means of physically distinct thermal-conductivity materials to assess the performance of the electricity era.[5]. It was determined that, using graphene as the thermally conductive cloth, the conversion efficiency changed into stronger by means of 1.6% and 1.7%, whilst the temperature difference changed into 15C and 40 C, respectively[6]. Unfortunately, as compared to the thermal electricity generation, the efficiency of TEG is a lower. Therefore, it was suggested to be used in a few programs where thermal energy is abandoned or low electricity is needed. In addition, since the temperature difference in the working environment cannot be regulated, the output voltage often varies accordingly. Therefore, a voltage regulator circuit must be designed in the TEG system. Furthermore, if the temperature difference takes a long time, the performance and efficiency of the generation will also be greatly affected.

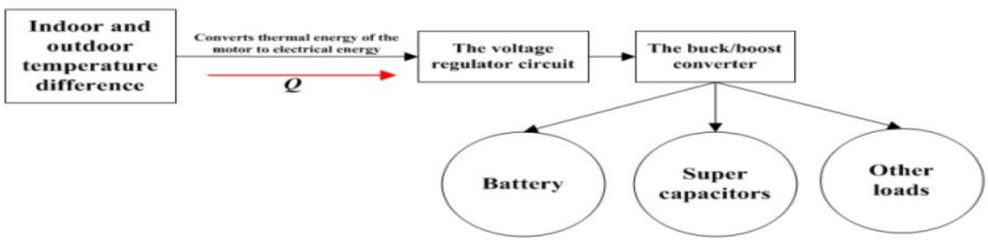

Figure 2.2:the control diagram of TE board power generation system.

The TE Board Power Generation System control method is shown in Figure 2.2. A voltage controller circuit should be used in parallel to the TEG in the output port to stabilise the output voltage under various ambient temperatures. Alternatively, different output voltages for different loads should be given in the network. A buck converter is practically necessarily used for the system. The buck converter is designed to regulate the voltage of the terminal to optimize the power output.

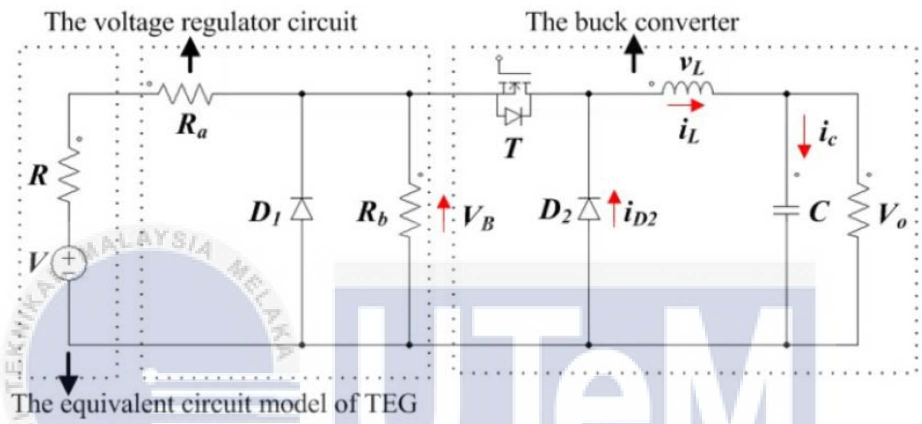

Figure 2.3:show Circuit Diagram.

The buck converter is designed to regulate the voltage of the terminal to optimize the power output. Due to high power density and simple control, other power electronic topology, such as a switch-capacitor based converter, is also useful in TE applications. The electrical characteristics, as shown in Figure 2.3, depend on whether the switch has been disabled. V_B is the TE board terminal voltage, and V_o is the voltage of various loads like battery, super controller, and other equipment.

2.2.3 Optimization of Two-Stage Combined Thermoelectric Devices by a Three Dimensional Multi-Physics Model and Multi-Objective Genetic Algorithm.

Thermoelectric devices have been attracted great attention in the past few decades thanks to their compact size, light weight, strong reliability, low priced operation and environmentally friendly operation. A thermoelectric generator (TEG) and a thermoelectric cooler (TEC) compose the thermoelectric instruments. They include electronic chip cooling, temperature control, heat pump motors, waste heater recovery for electrical power generation.[7][8],etc. The TEG module connected to an external heat load creates a seebeck electric current [9][10], While the TEC is pumped from the cold to the heat end by the Pelter effect by a power supply module [11][12]. This research proposes a three-dimensional multiphysics model coupled with multi-target genetic algorithm to optimize the optimal item number distribution, simultaneously as multi-objective functions, with a coefficient of success and cooling [12]. Compared to previously recorded examples studied under the Thermostat model, this approach improves the exactness of the output forecast. The results demonstrate that the performance of the optimized device is significantly increased by increasing the cooling capacity by 23.3% and the efficiency coefficient by 122.0% as opposed to the initial solution. This improved performance mechanism is analyzed. For engineers and scientists trying to create a thermo-electric combination with optimal performance under the constraints of the total number of elements, the results in this paper should be beneficial. Some of the model used are based on a thermal resistance model which does not respect the Thomson impact and the thermal-electric possible coupling effect, thus preventing them from predicting the device's output accurately. The two-stage structure design can also be reached Therefore, while several works that analyze sensitiveness parameters are provided, the main emphasis is on single parameter analysis, but the deciding factors of system output are related and the optimal value of a particular variable depends upon the value of other variables. The overall analysis of the parameter is therefore important. In this way, several criteria need for simultaneous optimization, the efficiency metrics for the assessment of a CTE include a COP and cooling capacities, all of which are competing targets. In general, these two indicators cannot reach their highest values. At the same time, the cost of a degraded COP stems from a higher refresher power. To solve this contradiction, multi-target optimization is also needed. This thesis was based on the above work to refine the 2-stage CTE by a three-dimensional model of Multiphysics with a multi-target genetic algorithm. The emphasis at every level of CTE is on optimizing the allocation of the element number, where both cooling capacity as well as COP metrics are considered objective functions

2.2.4 Efficiency Calculation of a Thermoelectric Generator.

The thermoelectric generator 's primary objective is to produce electricity from the heat source. Such thermocouples are cost-effective and can be robust if maintained under safe conditions. But, in comparison with other heat generating technology and devices, thermoelectric generators are less efficient. These devices can be used in different places where the heat waste exists, and heat can be used by TEC to generate a low voltage of electricity. Thermostats are compact and low in cost so that their performance in power generation is easier to experiment. Output can be used to compare the efficiency of other power generating systems, and thus, when economic power production is needed, price can also be compared. Both tools operate on the basic basis that Seebeck has suggested and will therefore be easy to understand for undergraduates. The aim of this paper and what makes it different from previous research is that it costs extremely low and, in comparison with previous experiments, that power generation and efficiency is higher. This setup can be integrated into the thermocouple laboratory as well and used as a thermocouple proof [13].

2.2.5 Efficient Boost Converter for Thermoelectric Energy Harvesting.

From this paper, Small TEGs provide an output voltage of a few 10 mV at small temperature differences. A booster converter is required to convert the voltage into a voltage level for sensors and embedded systems. At these low voltages it should be able to operate and start efficiently. Under these conditions, commercially available boost converters operate with low efficiency. Goal of this work is to realize a boost converter which can directly start and operate at high efficiency from several 10 mV[14]. To supply sensors and electronics, the output voltage is adjustable up to 3.6 V. Costs are comparable to commercially available solutions.

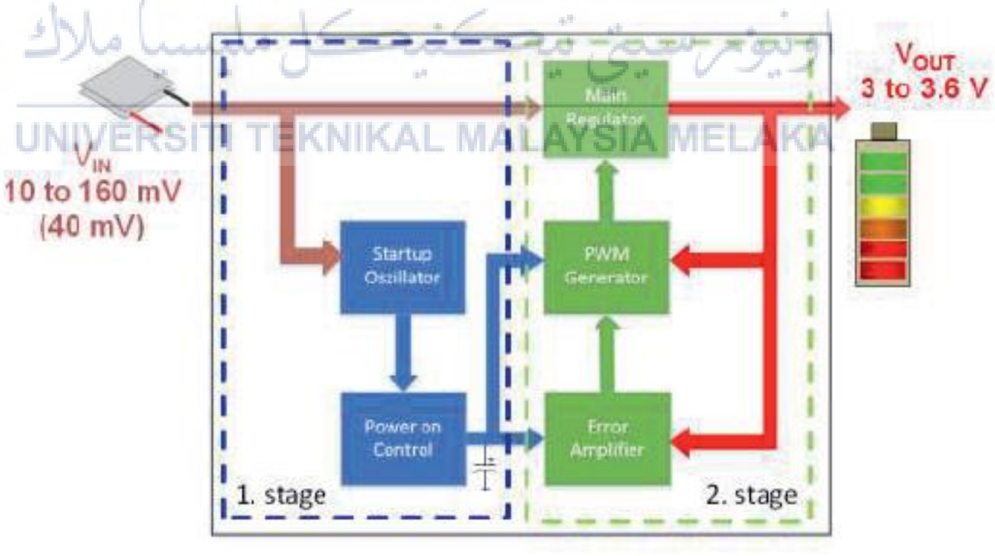

Figure 2.4:Block diagram of the system.

There are 2 separate phases for the converter. The first step is to initiate the converter from low input voltages shown in figure 2.4. The first stage begins with a condenser charging. When the capacitor is charged, the collected energy is used to activate the second stage. The second stage operates with high efficiency and provides a regulated output voltage of 3.6 V. The first stage is a startup circuit for cold start. It operates at an input voltage of about 36 mV. The startup circuit is a self-resonant oscillator connected to a voltage double. It is shown simplified in figure 2.5. The TEG is connected at the V_{IN} node and the energy collected from the TEG is stored in the capacitor C_1 at the output.

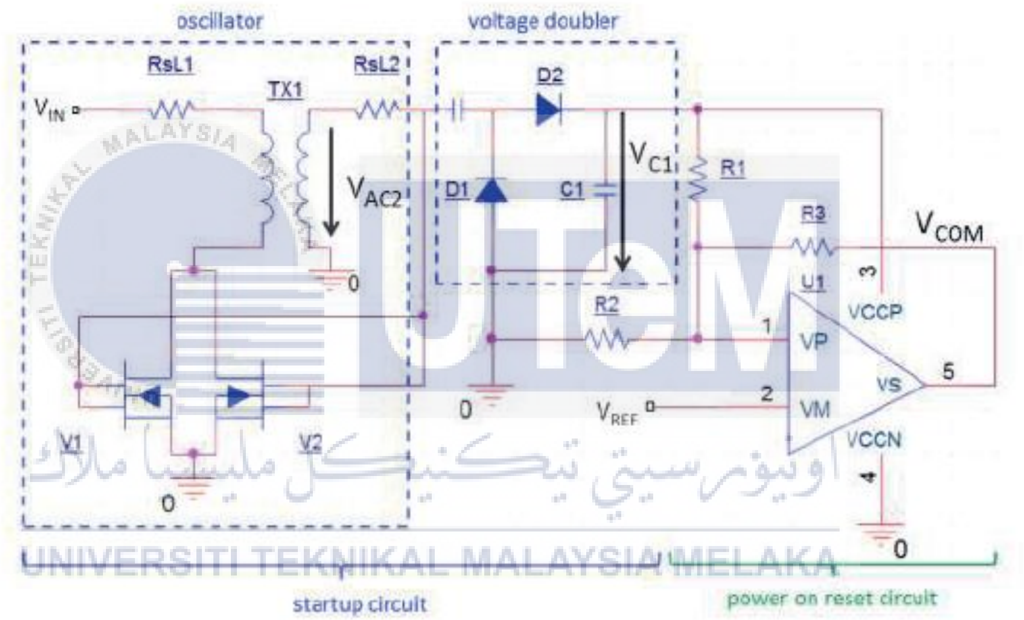

Figure 2.5:The circuit diagram of the system.

$$f_R = \frac{1}{2\pi\sqrt{L_2 * C_{gtot}}} \qquad \text{Equation 2.1}$$

A coupled inductor in conjunction with two transistors builds an oscillator. The use of depletion FETs allows the converter to start from input voltages below the threshold voltage of enhancement FETs because conduction occurs at zero voltage. The parasitic gate capacitors of V_1 and V_2 and the secondary coil winding of TX_1 form a series resonant circuit with a resonance frequency f_R according to Equation 2.1.

Sustain the oscillation and on the other V_{AC2} is rectified by the voltage double to charge the intermediate capacitor C_1. The coupled inductor is realized by a transformer with a secondary inductance of 75 mH. R_sL_1 and R_sL_2 are the winding resistance of the primary and secondary coil in the simulation. While C_1 is charged through the startup circuit, the power on reset circuit on the right side in Fig. 2 senses the voltage V_{C1}. The power on reset circuit consists of a shunt voltage reference V_{REF} and a comparator U_1 with three external resistors. With the voltage reference set to 1.25 V the trip points for V_{C1} become V_{TH+} = 2.8 V and V_{TH-} = 1.9V. The comparator output is low while C_1 is charged but switches into high state as soon as V_{C1} reaches 2.8 V. The startup circuit is optimized for low input voltages. Thus, the overall efficiency of the startup circuit is about 9.5 %. The startup circuit needs 73.1 seconds to charge a 10 μF capacitor to 2.8 V with a measured output power of average 5.6 μW. Although the startup circuit is not suitable for high efficiency conversion, it collects enough energy to start the second stage. When the voltage on the intermediate capacitor C_1 reaches 2.8 V, the power on reset circuit activates the second stage. It consists of the main converter, a triangle wave generator, comparator and an error amplifier. The pulse width modulated (PWM) signal on the N-FET V_1 which turns on the main controller is created by triggering the main controller, which transmits the current through the inductor L and loads the output condenser C_{OUT} to 3.6 V.

2.2.6 Structure of TEG

As shown in figure 2.3, the structure of the thermoelement is shown. Thermoelements are formed by means of the connection of the end of semiconductors p and n. by reference to this figure. When there is a temperature difference between its surfaces, voltage is produced between its open ends.

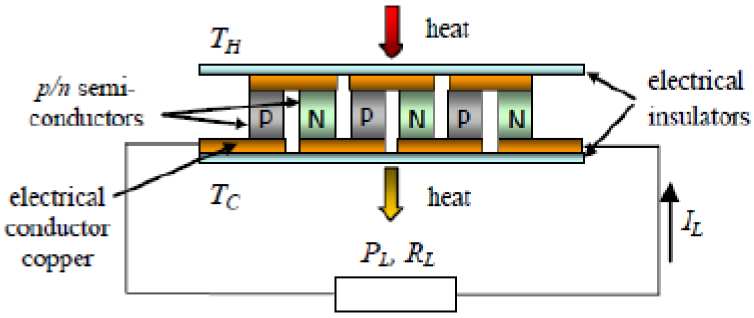

Figure 2.6:A TEM in generator mode.

TEM on the other hand, is made up of a larger number of thermoelements where the construction of the TEM in a generator mode is as shown in Figure 2.6 above. After that, the TEM along with a heater block and a cooler block is what build a TEG.

Materials typically contain a higher value content at higher temperatures, such as plumbing telluride, while a product with high ZT on the cold side, such as bismuth telluride, is used at lower temperatures. [15].

2.2.7 Bismuth Telluride (Bi2Te3).

Bi2Te3 coating is one of the best ways of improving thermoelectric material ZT. This can be done by placing the thermoelectric material under a process known as hydrothermal alkali-metal-salt coating process, that group of pure bismuth particles is then hydrothermally coated by the atomic Bi: Te = 20:1 tellurium ratio. The compressed powders are conducted into bulk compounds with a pressure of around 260C for 30 minutes to reach a bulk bismuth density of 98,9 % to 9,8 % (9,79 g / cm3). The Seebeck coefficient for a Bi2Te3 n-type semiconductor is about -250 µV / K at the end of the cycle [16].

The Bi2Te3 nanostructure is another approach to bulking by means of promising processes of chemical synthesis. In the compaction and sintering of products with the nanopowder Bi2Te3, plasma sintering was applied to produce a very high density of over 97%, and the nanostructure was preserved. Final compacts were calculated from electron micrographs to obtain approximately 90±5 nm of average grain sized. In the assessment of transport properties, the Seebeck coefficient is of about -120 μV / K in particular in the low temperature range [17].

2.3 Thermoelectric Effect.

The temperature difference results in the direct transformation of temperature differences by electrical voltage and vice versa by a thermocouple. If the temperature varies, thermoelectric devices produce a voltage on both sides. Moreover, when a voltage is applied, heat moves from one side to the other, producing a temperature difference. An atomic temperature gradient allows carriers to migrate from the warm to cold side of the material. The word "thermoelectric effect," which is separately classified, comprises the Seebeck effect, the Peltier effect and the Thomson effect.

2.3.1 Seebeck Effect.

The Seebeck effect explains the formation by a temperature gradient of an electric potential [18]. A thermocouple tests the possible difference over a warm and cold edge with two separate materials. This potential difference is proportional to the temperature of heat and cold [19].

The Seebeck voltages at intersection are small, usually just a few micro volts per kilowatt. Certain Seebeck Effect Devices can generate thousands of volts if the temperature difference is sufficient [20]. Some of these units can be serial connected to increase the output voltage or to parallel increase the maximum supply voltage. A wide range of Seebeck effect devices can provide a limited amount of useful electricity if interconnections are maintained at a great difference of temperature.

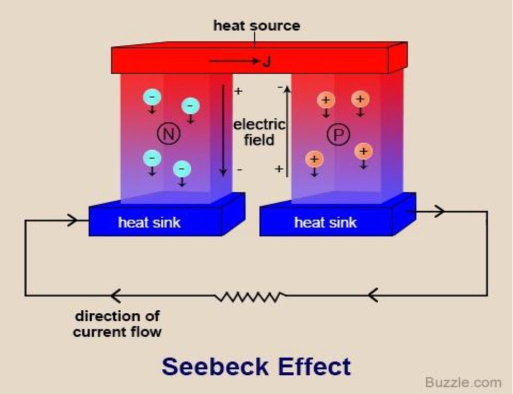

Figure 2.7:The block diagram of seebeck effect.

The action of thermocouples displayed in figure 2.8 is responsible for the Seebeck effect, for roughly measuring temperature differences or for actuating electronic switches capable of switching large systems on and off. This function is used in thermoelectric cooling. Constant / copper, constant / iron, constant / chromelian and constant / alumel form the widely used combination of thermocouples metal.

In the 1800s, Thomas Johann Seebeck discovered the theory. Recently, physicists discovered what they called the Seebeck spin in 2008. The spin Seebeck effect can be seen when heat is applied to magnetized metal. Consequently, electrons are rearranged by their spin. In contrast to ordinary electron motions, this rearrangement produces no heat as a waste product. The Seebeck effect could cause small microchips and spintronics to be faster and more powerful.

2.3.2 Peltier effect.

The Peltier effect is the temperature difference that arises through the application of a voltage between 2 electrodes attached to a semi-conductor sample[21]. It could be beneficial if the heat needs to be transferred on a small scale from one medium to another [18]. The effect of Peltier is one of three thermoelectric effect types, whereas the two other is Seebeck and Thomson[22].

In the Peltier effect unit, the electrodes normally consist of a metal with excellent electric conductivity. The semi-conductor material between the electrodes produces two interconnections of different materials, which in turn induces a pair of thermocouple voltages of the electrodes, induced by a strong electricity to become a semiconductor. [23].

Peltier-effect systems are used for thermoelectric refrigeration in electrical equipment and computers where more conventional methods of cooling are not feasible. The Peltier effect has its name, after its discoverer, French physicist Jean-Charles Athanase Peltier.

The Peltier effect is undesirable in thermoelectric production, since it is parasitic which can reduce the temperature difference between the device and thus enhance effective thermal conductivity of the module[24]. Moreover, according to the current flowing through the device, Peltier effect also pumps heat from one side of the TEG to the other. As a result, the effective thermal resistance of the TEG depends to some extent on the extent of the current in the external circuit [25].

2.3.3 Thomson effect.

William Thomson drew a connection between the effects of Seebeck and Peltier not until 1855, the first major contribution to the comprehension of thermoelectrical phenomena. Thomson 's theory has also shown that a third thermodynamic effect in a uniform driver is required. [26]. It is also called the Thomson effect; the heat or cooling effect is reversible as the electric current flows as well as the temperature gradient[27]. It has been shown that the Peltier heat or power (Qp) at the junction was proportional to the junction current (I) through the relationship $Qp = \Delta I$, where the Peltier coefficient is. Through thermodynamic analysis, Thomson also showed a direct relationship between the effects of Seebeck and Peltier, i.e., that of $\Delta = \Delta T$, where T is the temperature of the junction. Therefore, he expected from thermodynamic principles that thermal power (Qć) would be absorbed or produced along the length of a material rod whose ends would be at different temperatures, which would have become known as the Thomson impact. The current flow and temperature gradient along the rod were shown to be proportional to this force. The Thomson coefficient is the factor of proportionality. William Thomson (later Lord Kelvin) drew up a connection between Seebeck and Peltier in 1855 as the first major contribution to understanding thermoelectrical phenomena.[28]. It has been shown that the Peltier heat or power (Qp) at the junction was proportional to the junction current (I) through the relationship $Qp = \Delta I$, where the Peltier coefficient is. Through thermodynamic analysis, Thomson also showed a direct relationship between the effects of Seebeck and Peltier, i.e., that of $\Delta = \Delta T$, where T is the temperature of the junction. In addition, on the basis of thermodynamic considerations, he predicted what had come to be known as the Thomson effect that thermal power (Q_τ) would be absorbed or evolved along the length of a material rod whose ends would be at different temperatures. This heat was shown to be proportional to the current flow and temperature gradient along the rod. The proportionality factor Δ is known as the Thomson coefficient However, the Thomson effect is usually much smaller than the Joule heater and its coefficient is difficult to achieve in practice. As a result, it is often neglected in most literature.

2.4 DC to DC Voltage Booster.

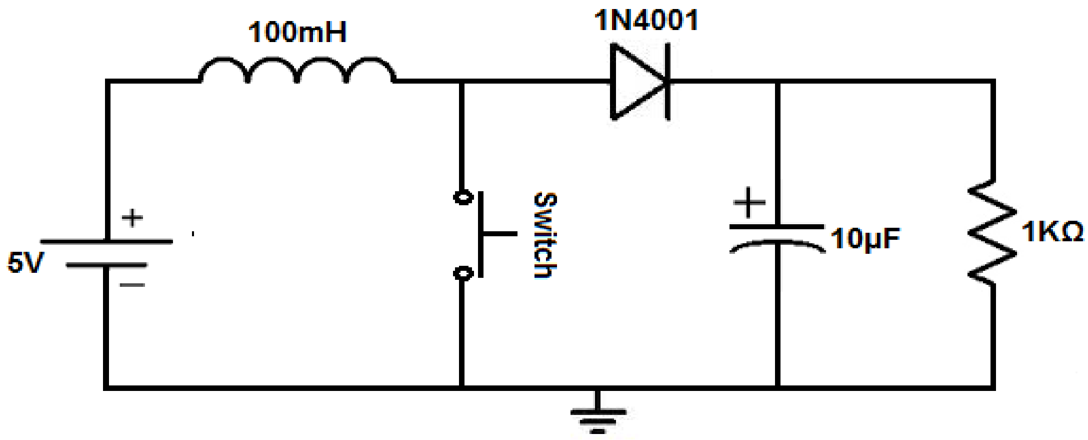

Figure 2.8:Circuit diagram for voltage boosting.

The DC-to - DC converter is primarily based on an inductor and condenser design. The inductor functions as a current energy storage system when fed with DC power. This produces energy from the belt and a magnetic field around it when DC power is supplied. When you turn the DC power off and all the current the inductor loads is transferred to the condenser, the magnetic field disappears. The inductor stores a greater current and dumps it through the condenser each time when the DC power in the circuit is switched on and off and we will use it via a push button. The inductor stores a greater current and dumps it through the condenser each time when the DC power in the circuit is switched on and off and we will use it via a push button button. Therefore, each time we do so, the voltage around the condenser rises to its highest. In Figure 2.9, display the circuit booster voltage graph. The voltage voltage that will increase depends on many variables, including the inductive value, the maximum capacitor voltage capacity, switching speed and the circuit's DC input voltage.

2.5 Supercapacitor.

A supercapacitor (SC), also referred to as an ultracapacitor, has a high capacitance condenser that is much higher than other condensers but has lower voltage limits, linking the gap between electrolysis condensers and rechargeable batteries. In general, it saves 10-100 times the volume or mass per unit of energy than electrical condensers, requires and offers a lot faster charge than the battery and tolerates much more recharge / discharge cycles [8]. There are three kinds of condensers, the most basic being a dry separator condenser. This conventional condenser has a very low capacity and is used mainly for tuning and filtering radio frequencies. The size ranges from a few pico-farads (pf) to low microfarads (μF).

The electrolyte condenser is higher than the condenser and is rated a million times larger than the picofarad in the microfarads (μF). Such condensers are used for filtering, buffering and signal connection through a moist separator. The electrostatic power, like the battery, has to be measured, positive and negative.

The third type is a supercapaciter measured in distances which exceeds the electrolytic condenser thousands of times. Throughout repeated charging and discharge cycles at high current and short duration, the supercapacitor is used for energy saving.

The voltage limits are in all condensers. The electrostatic condenser, while high volt resistance, is limited to 2.5–2.7V in its supercapacitor. 2.8V or higher voltages are possible, but that life span. Various supercapacitors are connected to higher voltages in series. Serial connection decreases total capability and improves internal power. Cords of more than three condensers require tension control to prevent an overvoltage of any cell. Similar safety circuits are shared by lithium-ion batteries.

2.6 Thermoelectric Cooler.

The Peltier effect is used by the thermoelectric cooler to create a heat flow between two different types of materials[29]. The Peltier cooler or thermoelectric heat pump is a thermal pump with an active solid-state pump that transports heat from one side to the next and consumes electricity according to the direction of the current. A Peltier refrigerator, a Peltier heat pump, a solid-state fridge or thermoelectric (TEC) cooler, are also known as this device[30]. These may be used for heating or cooling (cooling), but the key use is cooling in practice. It can also be used for heating or cooling as a temperature controller.

2.7 Thermoelectric Generator.

The thermoelectric effect is the direct heat conversion. According to the Joules law, the current conductor produces heat in proportion to the product of the resistance of the conductor and the square of the current passing through. In the 1820s, by reading it differently, Thomas J. Seebeck reviewed this law. He brought two different metals where the metals meet in different temperature connections. The voltage was found to evolve in relation to the temperature difference between the intersecting components. At the junction of two different metals, the current produced by the temperature difference is called the seebeck effect. Seebeck Effect generates voltage and current quantifiable. The thermoelectric generator can calculate the current density using the following equation.

$$J=\sigma(-\nabla V + E_{emf}) \quad \text{Equation 2.2}$$

The electromotive field strength can be measured using the Seebeck coefficient formula shown in equation 2.2, which is essentially unique to each material used, while the temperature gradient is the delta T. The Peltier Effect is another effect that helps explain the thermoelectric phenomenon. The Peltier effect helps to describe heat dissipation or absorption when the conductive material is connected.

2.8 Chapter Summary.

A literature review related to this study has been conducted in this chapter. A brief explanation on the thermoelectric regarding its structure, power output and efficiency as well as thermoelectric effect also explained. After that, a few conditions are set to study the effect of each onto the performance thermoelectric generator in term of voltage generation and thermal gradient. The methodologies taken for each analysis shall be explained in the next chapter.

CHAPTER 3

METHODOLOGY

In this chapter, all methodology conducted for each part shall explain in detail. The details shall cover the important measures taken in order to prepare both software and hardware before any data can be collected.

3.1 Project Planning.

The preparation of this project is carried out in reasonable date because it is important to ensure that the project has progressed and runs smoothly according to the timetable. Planning of projects typically takes place at the outset of the project, generally with the help of the Gantt chart. The Gantt chart helps the researcher plan and stay on track to complete the project. Essentially, the Gantt chart highlights two types of timeframes, which are time planning and time running of the project. Before this project started, a set of Gantt chart was planned to be the guide throughout this project development. The Gantt chart is shown in **Appendix A**.

3.2 Overview of Project Methodology.

This project requires three major hardware circuitries to develop the final wearable prototype: the thermoelectric generator circuit, the supercapacitor arrangement, the voltage regulator, and the thermoelectric cooler circuit. TEG circuitry involves the use of nine pieces of 40 x 40 mm TEGs connected electrically in series. The goal is to extend the time required to maintain the thermal equilibrium of the surface between the TEGs. An early experiment is made to compare the TEGs thermal configurations versus the output voltage along with time. The voltage generated by the TEGs is stored in a supercapacitor and the voltage regulator controls the voltage to 5V to power the TEC modules that are powered by a 5V. Since most of TEC module powered up high voltage that need continues voltage to operate the TEC.

One must understand the power harvested from one TEG is relatively small, especially when the thermal gradient is small. The output power from thermoelectric generators is about microwatts, hundreds of millivolts and tens of milliamps. It is impossible to power up a TEC module directly from TEGs. Therefore, the 9 pieces of TEG is used. The TEGs can produce about 7V to 8V depend on the temperature difference. As is already known, power will never be increased, no matter how the voltage is boosted. When the voltage is increased, the current decreases and vice versa. This is why the boosting circuit, which is not used in this project, is never capable of being powered directly from the LTC3108. Although the voltage is regulated at 5V, the current at several micro-amps is extremely small. Hence, the supercapacitor is used in the case. All the power from the TEGs is stored in a supercapacitor. Supercapacitor is chosen ahead of battery because it has low equivalent series resistance (ESR). It is capable to produce large current and it can be charged faster than batteries. The drawback is that it also discharged quickly, depending on the loads. When the supercapacitor is fully charged, it provides enough power to switch on the loads.

As for the load, the TEC module is powered using the power that have store in supercapacitor and the efficiency of the TEGs be analyzed to generate the TEC module. The following sub chapter describe in detail for every component used in the prototype for this project.

3.3 Thermoelectric Generator.

There are plenty of models of thermoelectric generators available in the market right now. However, since the designed prototype is small, a small thermoelectric generator is used so that it is more convenience, small, light, and suitable surface of the system.

Figure 3.1:Thermoelectric Generator Module.

SP1848-27145 of the Thermodynamics Company shown in Figure 3.1 is the thermoelectric generator model used for the prototype. The SP1848 has a size of 40 x 40 mm and a width of 3,9 mm. This model is a one-stage module for cooling and heating from 60 ° C to 135 ° C.

From the data sheet, at a temperature gradient of 60ºC between the hot and cold plates of the SP1848-27145, the maximum voltage converted from the temperature gradient is 2.4V. Meanwhile, the maximum current generated is 469mA. The maximum power of this module is 1.125 W. Finally, the AC resistance of this model is approximately 3.3 Ω. SP1848-27145 is a ceramic and bismuth telluride model.

This model has no moving parts, no noise and no solid status as its main features. It is also small, miniature and lightweight in construction. It is naturally RoHS compatible and environmentally friendly. In terms of quality and high performance, this model offers precise control and outstanding reliability. The CPU cooler and research instrument is most used as a temperature stabilizer, a photonic and medical device, a laser cooler and a CCD sensor. The physical contact of the human body is used for such projects as a heat source on the TEG heat plate and on the cool side of the TEG surface, the ambient temperature is used. A suitable heatsink is used at the cooler plate to dissipate heat from the TEG.

In this part, 4 configuration tests were carried out to find the best configuration that would produce the best output voltage to drive the TEC. The configuration is thermally and electrically series (TSES), thermally series and electrically parallel (TSEP), thermally parallel and electrically series (TPES) and thermally parallel and electrically parallel (TPEP). The best configuration that can produce the best or higher output voltage is used for this project. In this testing 2 module of TEG is use to test the configuration to find the best output voltage.

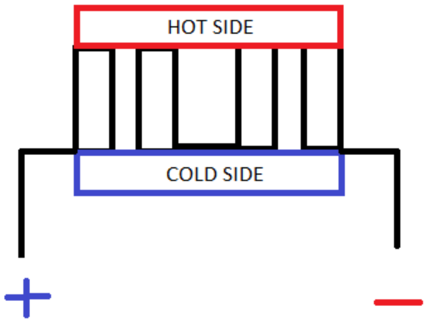

Figure 3.2:The thermally series and electrically series.

In this figure 3.2 show that the thermally series and electrically series. The 2 TEG is arrange in series position. The positive wire from first TEG connected with the negative wire to the second TEG. The negative wire from the first TEG and the positive wire from the second TEG as output measurement part.

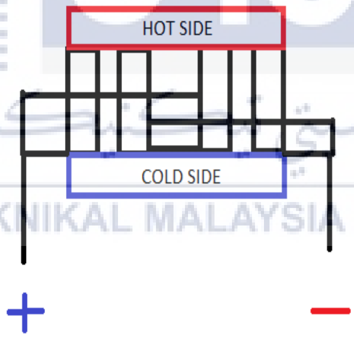

Figure 3.3:The thermally series and electrically parallel.

In this figure 3.3 show that the thermally series and electrically parallel. In this configuration the 2 TEG is arrange in series position and the positive and negative wire is connected each other for TEG 1 and TEG 2. The negative and the positive connection is used to measure the output voltage produce from the TEG.

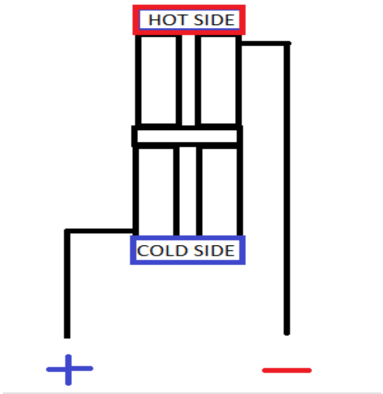

Figure 3.4:The thermally parallel and electrically series.

In figure 3.4 show that the thermally parallel and electrically series configuration. In this configuration TEG 1 and TEG 2 stag. The electric connection connected series. The positive and negative from TEG 1 and TEG 2 is the output measurement.

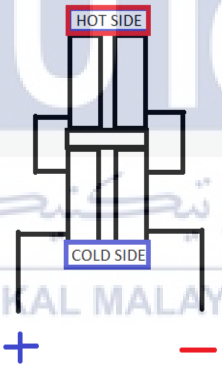

Figure 3.5:The thermally parallel and electrically parallel.

In this figure 3.5 show the thermally parallel and electrically parallel. In this configuration the TEG 1 and TEG 2 stag. The electric connection connected parallel. In this test the best configuration that produce the higher output voltage is used to complete the system to drive the TEC module.

3.4 Charging of Supercapacitor.

Figure 3.6:Supercapacitor.

The prototype had been tested on engine bot to harvest waste heat and store the energy to the 100 F supercapacitor show in figure 3.6. The prototype is worn on engine boat in the ambient temperature of 50 to 120 °C. The experiment is conducted to find the supercapacitor charging time by the TEG. A calculation is made to determine how long the supercapacitor charging. In this project 4 pieces of the super capacitor is used. 2 is connecter series and the branch of the capacitor connected parallel. The total voltage of the connection is 5.4V and the value of the capacitor is 100F.

3.5 Voltage regulator.

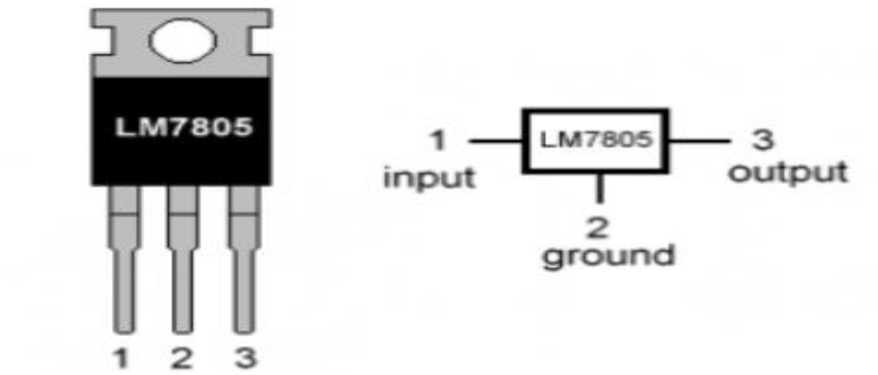

Figure 3.7:Pin out Diagram.

Voltage sources within a circuit will fluctuate since fixed voltage outputs can not be supplied. The IC voltage control system maintains a constant value of the output voltage. The common Integrated Circuit (IC) Voltage Controllers shown in Figure 3.7

is a 7805 IC, a member of the 78xx series of fixed linear voltage regulators used to control these fluctuations. The xx in 78xx indicates the voltage of output. The 7805 IC supplies a power supply powered by +5 volts. 7805 is a 3-component terminal with 3 pins.

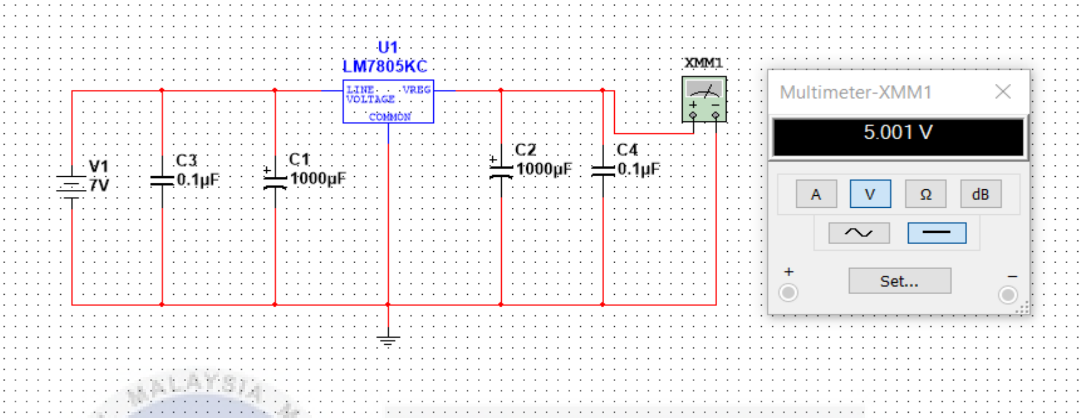

Figure 3.8:simulation voltage regulator circuit.

In this project, the voltage regulator is used to control the output voltage stored in the suparcapacitor to produce a constant output of 5V. The voltage produced by the TEGs is greater than 5V and not constant. Figure 3.8 shows the simulation of the lm7805 voltage regulator.

3.6 TEC Analysis.

Figure 3.9:TEC module.

The Peltier effect is used to produce a heat flow at the junction of two different types of materials in Figure 3.9. Thermoelectric cooling. A Peltier cooler, heater or thermoelectric heat pump is a heat pump active in solid-state heating pump that transfers heat, depending on current direction, from one side of the unit to another. Low thermal conductance ensures that the other side is cold, so that a wide voltage is generated in a temperature gradient, when on one side is hot. The Seebeck coefficient (S) determines the measuring of the magnitude of the electron flow in response to the temperature difference across the material. A Thermoelectric Generator can be used with the Peltier cooler. The voltage is applied across the device when it is operated in a cooler, resulting in a difference in temperature on both sides. When the system is powered by a generator the temperature on one side is higher than on the other, and hence the voltage difference between the two sides increases (the SeEbeck effect). Due to various design and packaging specifications, the well-designed Peltier cooler may nevertheless be a mediocre thermoelectric generator, and vice versa. This project aims to use a thermoelectric generator to conduct a thermoelectrical cooler. The power in the supercapacitor is used to operate the TECs to determine the TEGs' driving capability. This was the time to calculate how long it could take for the TEC to drive through the TEGs and TEG 's efficiency.

3.7 Energy Saving Analysis.

After the prototype is developed, two experiments are conducted to test capability of TEGs to drive the TEC by the prototype. Both experiments are conducted by measuring voltage in the circuits. The components in the complete circuit for the first experiment include 9 pieces of TEGs, fan and hot plate. Meanwhile, the components in the complete circuit for the second experiment include a supercapacitor 2.7V 100F and lm7805 for voltage regulator circuit. The TEC generated using the electricity that produce from the TEG and the components in first experiment and second experiment respectively.

3.8 Chapter Summary.

This chapter discussed the configuration of the TEGs connected to the prototype. Basically, the 9 parts of the TEGs are connected to thermally series and electrically series. Each of the TEG's heat sinks is attached to the cooler plate. Thermoscope I, a thermal joint compound, is used between the TEGs in each stack and the heatsink. The sealant putty is used to hold the heatsink together with the TEGs in each stack. The 5V 100F supercapacitor is used to store the electricity generated by the TEGs. The voltage of the capacitor is then used in the 5V voltage controller circuit. To produce a TEC, the regulator will regulate the voltage up to 5V. The voltage regulator is used to control the voltage from the TEGs when the supercapacitor is charged to provide a consistent voltage output. To monitor the 5V supercapacitator voltage to support the TEC, the supercapacitor is discharged. TEC allows a cooling cycle hot and cold. Finally, an experiment is carried out to decide whether the system will generate the TEC by using TEGs.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will provide all the results obtained from this project, including the output voltage analysis from different configuration of the thermoelectric generators before the prototype is built, thermal gradient of the thermoelectric generators during experiment conduction and the output voltage of the thermoelectric generator from the prototype that was built. Furthermore, all the results obtained from the final prototype is provided in this chapter. The output of each component used in the prototype is shown in this chapter. Finally, the result of testing whether the final prototype is efficient for driving the thermoelectric cooler is provided.

4.1 Introduction.

Basically, this chapter shows all the results achieved by completing all the methodologies in the previous chapter. In addition, an appropriate explanation for each outcome is discussed for a better understanding of each part of this study. Similar to the previous chapter, the result of each part will be described separately in this chapter. For the second part, the result shall be in form of a graph which summarized all the collected data into a group of a day and night reading. The graph shows the test of effect on thermoelectric generator to drive the thermoelectric cooler.

4.2 Thermal Accumulation.

As a mention in previous chapter, the first part mainly to discover the best configuration of thermoelectric generator to get the higher output voltage in engine car part. For the configuration thermoelectric generator peltier is use to test the best configuration. For the first step, set up thermoelectric in 4 configurations, which are thermally series and electrically series, thermally series and electrically parallel, thermally parallel and electrically series and thermally parallel and electrically parallel.

4.2.1 Electrically series.

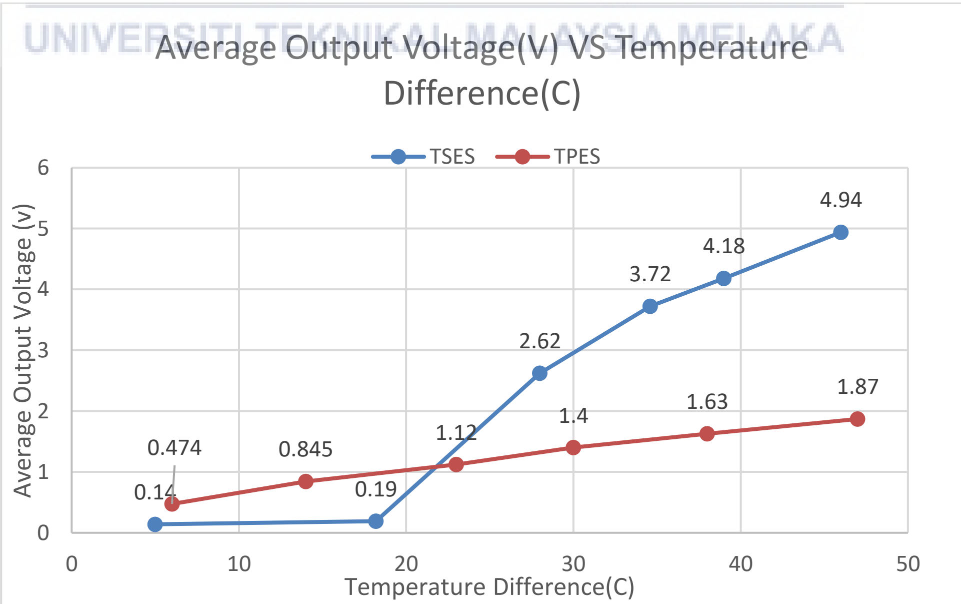

Figure 4.1:Result for electrically series.

In this test to find the best configuration the electrically series test find that the higher average output voltage is thermally series and electrically series (TSES) compare with thermally parallel and electrically series (TPES) at 90C hot side temperature. Base on the result in figure 4.1 show that the TSES produce 4.94V higher than TPES produce 1.87V. Base on the theoretical the series configuration produce higher output voltage compare with the parallel configuration because of the internal resistance in series is higher that parallel.

Next, the total surface area of TEGs expose to the heat also effect the output voltage of the TEGs because in thermally series both of the TEG get heat continues and produce higher seebeck effect compare with thermally parallel only one TEG get continues heat and another TGE steg on the TEG so the seebeck effect is lower. In this test find that the best configuration that can be apply in this system is TSES because it can produce higher average output voltage compare with TPES.

4.2.2 Electrically parallel.

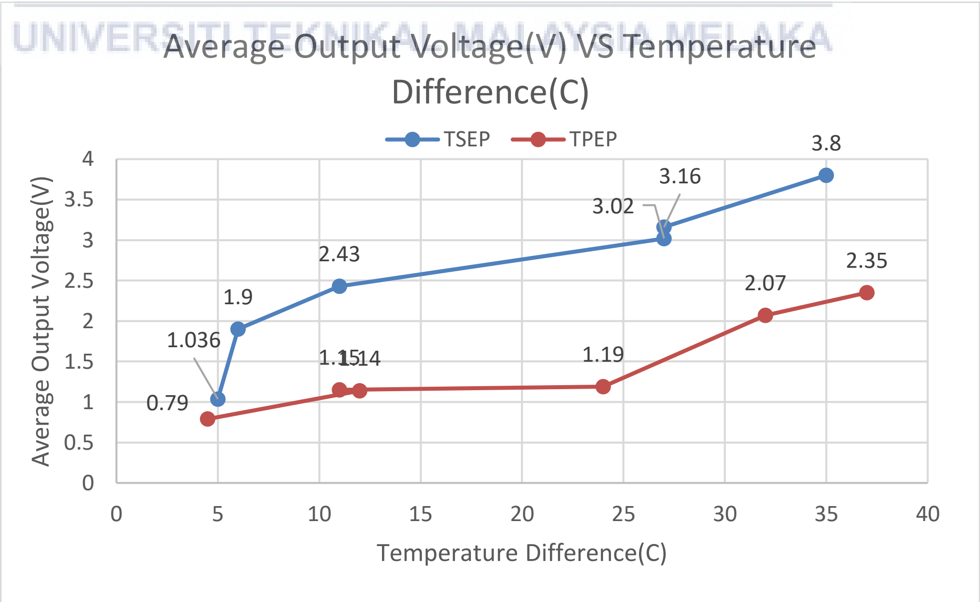

Figure 4.2:Result for electrically parallel.

Base on figure 4.2 show that the average output voltage vs configuration of TEGs. In this testing find that in electrically parallel show that the average output voltage produce from the thermally series and electrically parallel (TSEP) is higher than thermally parallel and electrically parallel (TPEP) at the hot side temperature 90C.Base on the testing TSEP produce 3.80V higher than TPEP produce 2.35V. In theoretical the parallel configuration will produce low voltage compare with series configuration of electrically. The comparison between the electrically series in figure and electrically parallel in figure show that TSES produce higher output voltage compare with the TSEP.

Base on figure and figure show that the best configuration that can be used in this system is TSES because the configuration produces higher average output voltage compare with another configuration. In this system need high value of voltage to drive the thermoelectric cooler that have higher energy consumption to drive the TEC.

4.3 TEG Part.

Base on the experiment that have been done to test the output voltage that come from the TEG. In this test 9 TEG have been used to observe the efficiency of the TEG will generate the TEC base on the output voltage that produce from the TEG. The temperature has been set from 30 degree until 90 degree, but certain configuration does not get until 90 degree because over the limit of the capability of the TEG. The limit for the TEG is below than 120.

4.3.1 The analysis 1 TEG module.

Figure 4.3:Result for 1 TEG.

Base on figure 4.3 show that the temperature difference of 1 TEG. The temperature of the hot side and the cold side of the TEG. The maximum temperature for the hot side is near to 100 degree and temperature maximum for the cold side is near to 35 degree. This temperature difference generated the output voltage of the TEG base on table 4.1.

Table 4.1:Result for 1 TEG.

Temperature (Celsius) ℃	*Temperature (hot side) ℃*	*Temperature (cool side) ℃*	*Temperature difference ℃*	*Output voltage (V)*
40	40	32.3	7.7	0.028
50	50	34.45	15.55	0.055
60	60	35.6	24.4	0.086
70	70	36.38	33.62	0.114
80	80	36.89	43.11	0.139
90	90	-	-	-

Base on table 4.1 show result that the higher out voltage that will produce for 1 TEG is around 0.139 V at 90 degree of hot side temperature and the lower of output voltage is 0.028V at 40-degree hot side temperature.

4.3.2 The analysis 2 TEG module.

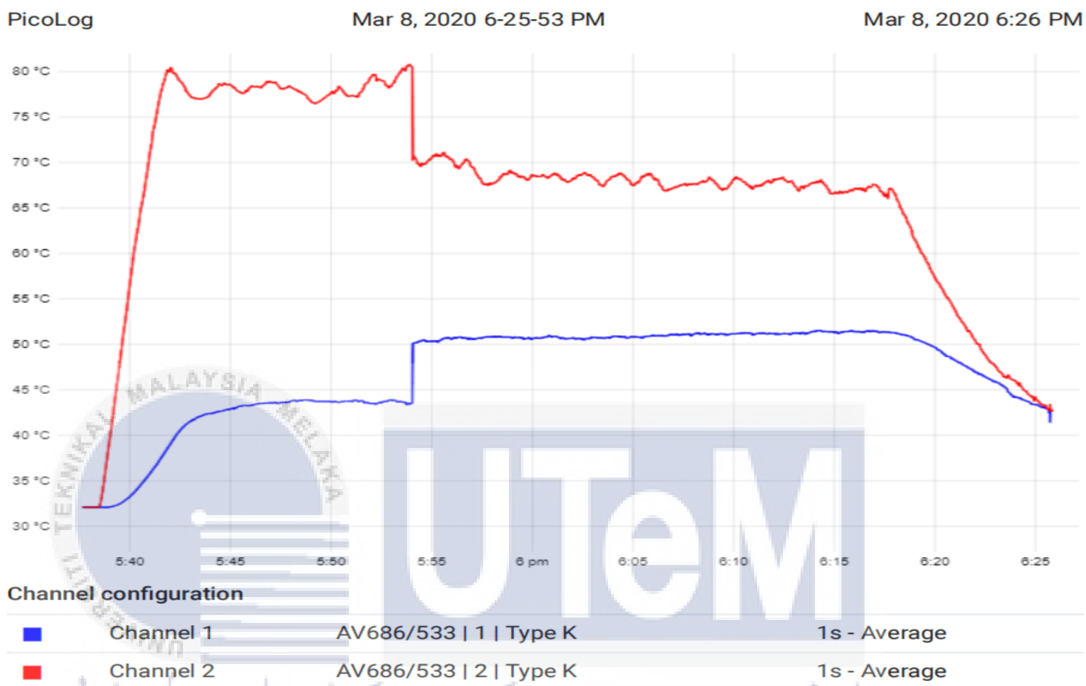

Figure 4.4:Result for 2 TEG.

Base on figure 4.4 above show that the temperature difference of the 2 TEG. In this figure show the gradually decreasing of the temperature because of the prop not touching well at the TEG and the temperature decrease. The temperature show that the output voltage produce base on the temperature difference in figure show. For this figure the maximum temperature for the hot side is 80 degree and for the cold side is 34 degree.

Table 4.2:Result for 2 TEG.

Temperature (Celsius) °C	*Temperature (hot side) °C*	*Temperature (cool side) °C*	*Temperature difference °C*	*Output voltage (V)*
40	40	31.98	8.02	0.13
50	50	32.22	17.78	0.33
60	60	33.33	26.67	0.57
70	70	34.81	35.19	0.73
80	80	39.09	40.91	0.75
90	90	-	-	-

Base on table 4.2 show that the higher out voltage that will produce for 2 TEG is around 0.75 V at 80 degree of hot side temperature and the lower of output voltage is 0.13V at 40-degree hot side temperature.

4.3.3 The analysis 3 TEG module.

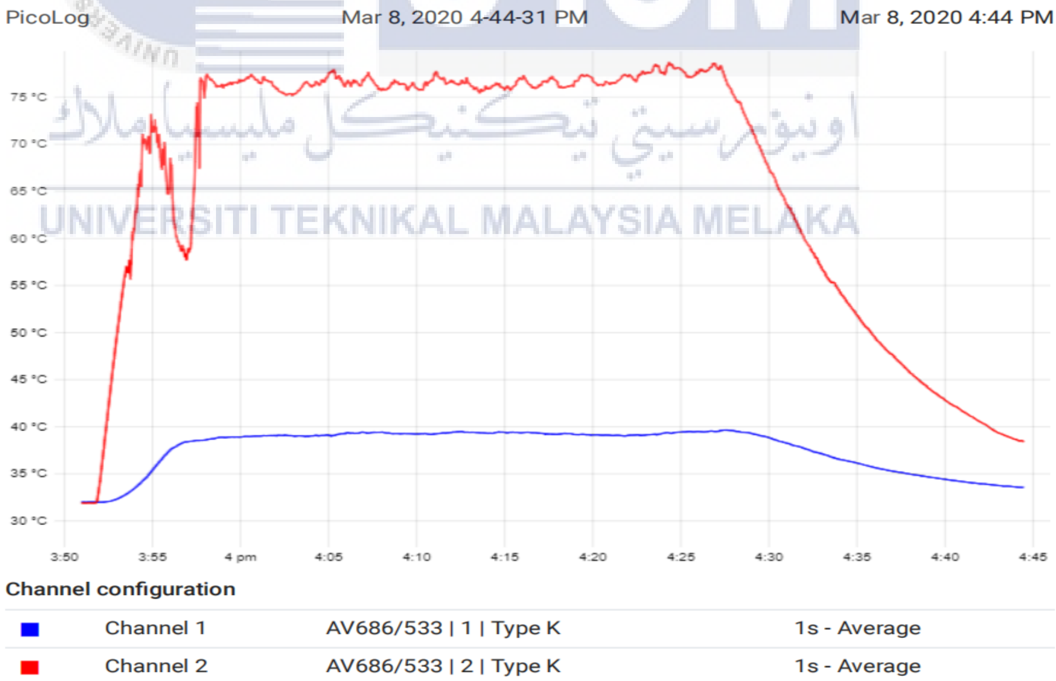

Figure 4.5:Result for 3 TEG.

Base on figure 4.5 show that the temperature of 3 TEG. This figure shows the temperature of the hot and cold side of the TEG constant. For the first phase of the graft show that the hot side temperature is suddenly decrease because the prob that attach at the plate is peel off and then after adjusting the prob the temperature back to normal track. The maximum temperature for the hot side is 80 degree and maximum temperature for the cold side is 38 degree.

Table 4.3:Result for 3 TEG.

Temperature (Celsius) °C	*Temperature (hot side) °C*	*Temperature (cool side) °C*	*Temperature difference °C*	*Output voltage (V)*
40	40	32.05	7.95	0.076
50	50	32.60	17.4	0.175
60	60	33.51	26.49	0.268
70	70	35.67	34.33	0.379
80	80	38.83	41.17	0.492
90	90	-	-	-

Base on table 4.3 result show that the higher out voltage that will produce for 3 TEG is around 0.492 V at 80 degree of hot side temperature and the lower of output voltage is 0.076V at 40-degree hot side temperature. Base on the temperature difference at 40 degree the temperature difference is 7.95 degree and produce 0.076V. For the 80 degree the temperature difference is 41.17 degree and produce 0.492V.

4.3.4 The analysis 4 TEG module.

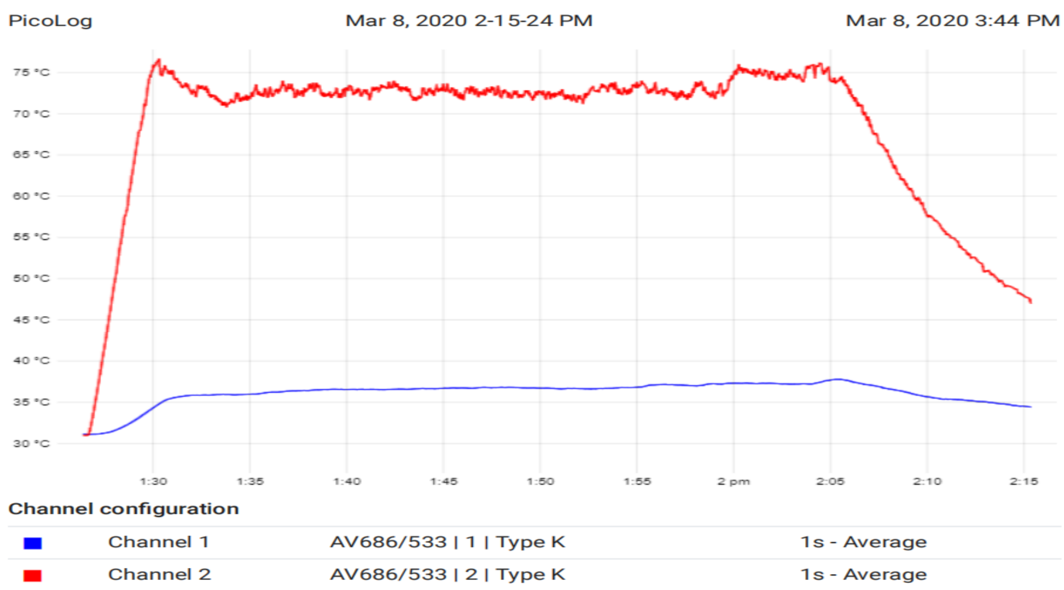

Figure 4.6:Result for 4 TEG.

Base on figure 4.6 show that the temperature of 4 TEG. In this figure show that the temperature for hot side and cold side is nearly constant and the maximum temperature is the hot side is 80 degree and for the cold side is 36 degree.

Table 4.4:Result for 4 TEG.

Temperature (Celsius) °C	*Temperature (hot side) °C*	*Temperature (cool side) °C*	*Temperature difference °C*	*Output voltage (V)*
40	40	31.19	8.81	0.27
50	50	31.53	18.47	0.56
60	60	32.48	27.52	0.85
70	70	33.50	36.5	1.16
80	80	36.4	43.6	1.71
90	90	-	-	-

Base on table 4.4 show that the higher out voltage that will produce for 4 TEG is around 1.71 V at 80 degree of hot side temperature and the lower of output voltage is 0.27V at 40-degree hot side temperature.

4.3.5 The analysis 5 TEG module.

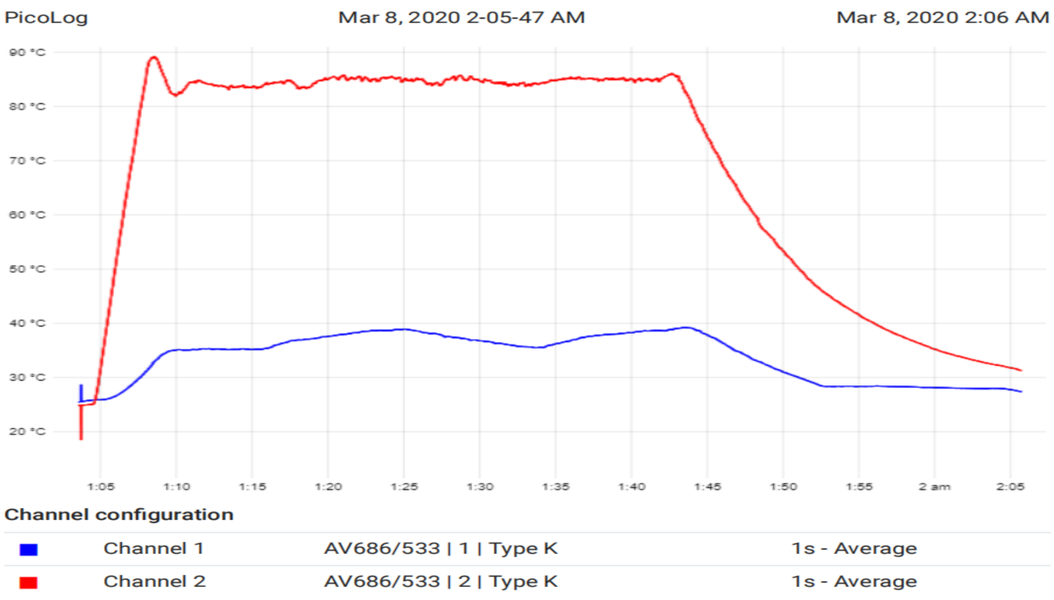

Figure 4.7:Result for 5 TEG.

In figure 4.7 show that the temperature difference of the 5 TEG. This figure show the maximum temperature of 5 TEG is 90 degree for hot side and for the cold side is 40 degree.

Table 4.5:Result for 5 TEG.

Temperature (Celsius) ºC	*Temperature (hot side) ºC*	*Temperature (cool side) ºC*	*Temperature difference ºC*	*Output voltage (V)*
40	40	26.00	14	1.23
50	50	26.53	23.47	1.88
60	60	27.38	32.62	2.98
70	70	28.88	41.12	3.08
80	80	30.11	49.89	3.36
90	90	-	-	

Base on table 4.5 show that the higher out voltage that will produce for 5 TEG is around 3.36 V at 80 degree of hot side temperature and the lower of output voltage is 1.23V at 40-degree hot side temperature.

4.3.6 The analysis 6 TEG module.

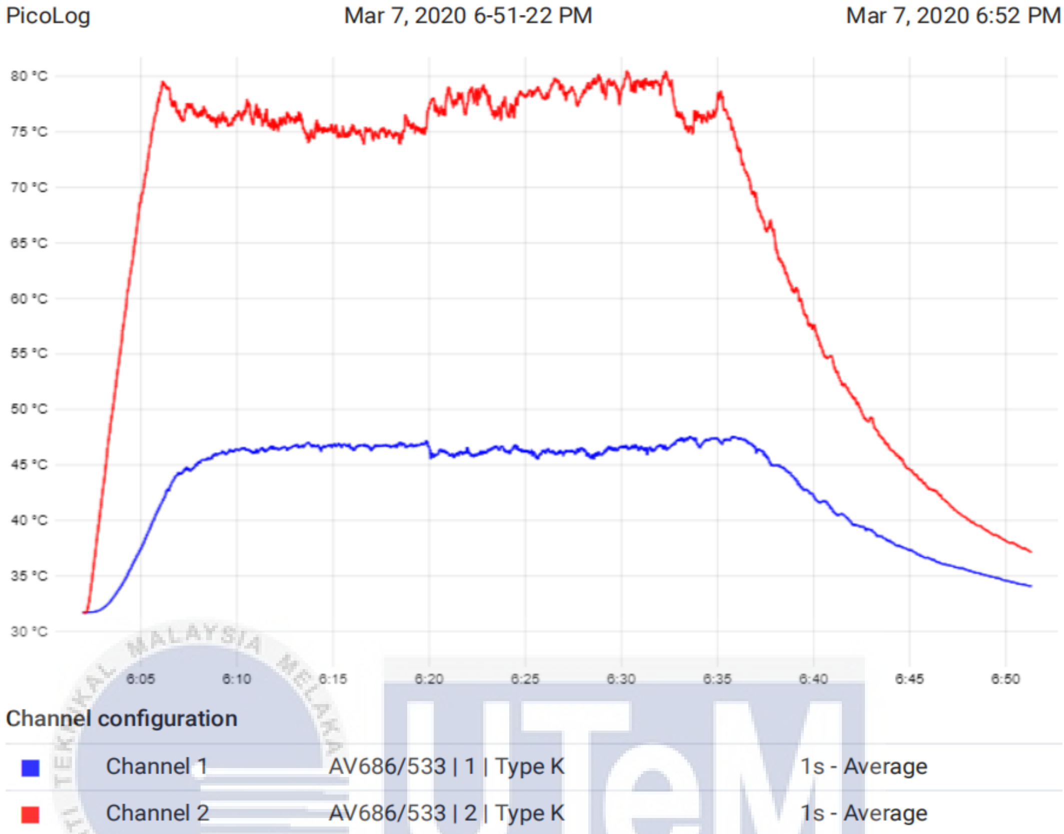

Figure 4.8:Result for 6 TEG.

. Figure 4.8 show that the temperature difference of the 6 TEG. In this figure the maximum temperature of the hot side is 80 degree and the maximum temperature of the cold side is 45 degree.

Table 4.6:Result for 6 TEG.

Temperature (Celsius) °C	*Temperature (hot side) °C*	*Temperature (cool side) °C*	*Temperature difference °C*	*Output voltage (V)*
40	40	31.9	8.1	1.21
50	50	33.05	16.95	2.26
60	60	34.85	25.15	3.25
70	70	37.76	32.24	4.20
80	80	42.15	37.85	4.48
90	90	-	-	

Base on table 4.6 show that the higher out voltage that will produce for 6 TEG is around 4.48 V at 80 degree of hot side temperature and the lower of output voltage is 1.21V at 40-degree hot side temperature.

4.3.7 The analysis 7 TEG module.

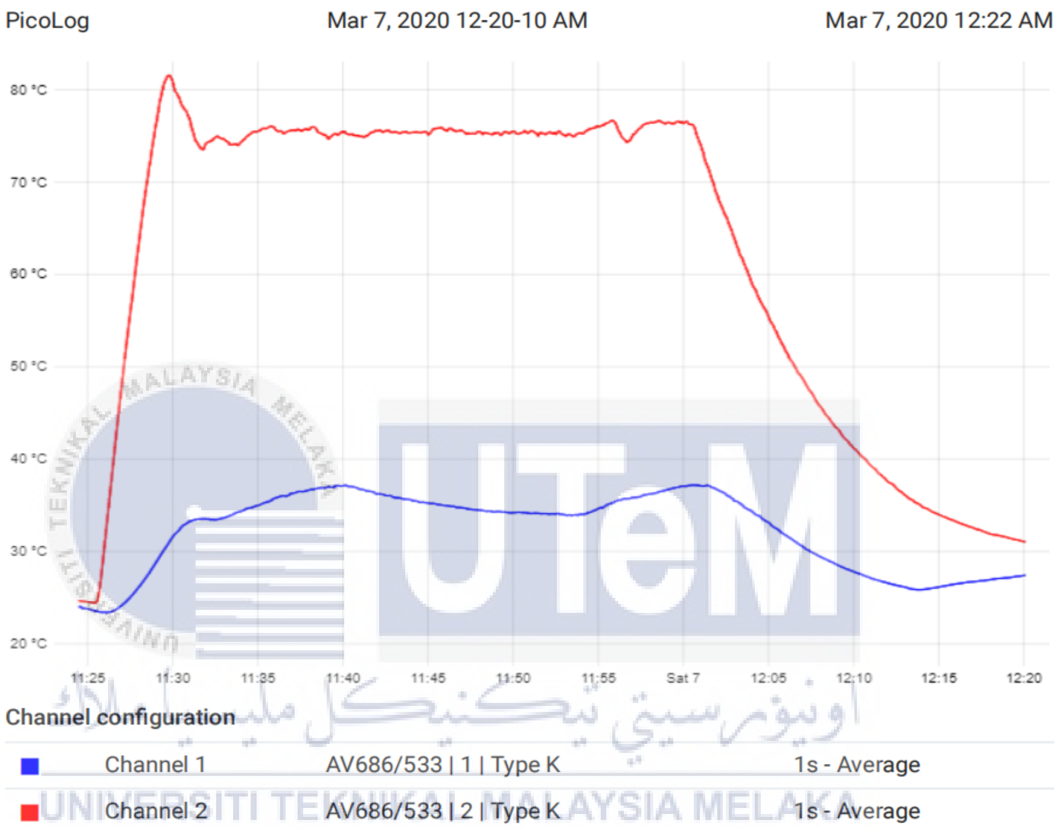

Figure 4.9:Result for 7 TEG.

Base on figure 4.9 show that the temperature for 7 TEG. In this figure the value of the temperature at cold side is fluctuate because of the temperature of the environment. The maximum temperature for the hot side is 80 degree and for the cold side is 38 degree.

Table 4.7:Result for 7 TEG.

Temperature (Celsius) °C	*Temperature (hot side) °C*	*Temperature (cool side) °C*	*Temperature difference °C*	*Output voltage (V)*
40	40	23.59	16.41	1.79
50	50	24.26	25.74	2.73
60	60	25.55	34.45	3.69
70	70	27.16	42.84	4.49
80	80	30.00	50.00	4.99
90	90	-	-	-

Base on this result show that the higher out voltage that will produce for 7 TEG is around 4.99 V at 80 degree of hot side temperature and the lower of output voltage is 1.79V at 40-degree hot side temperature.

4.3.8 The analysis 8 TEG module.

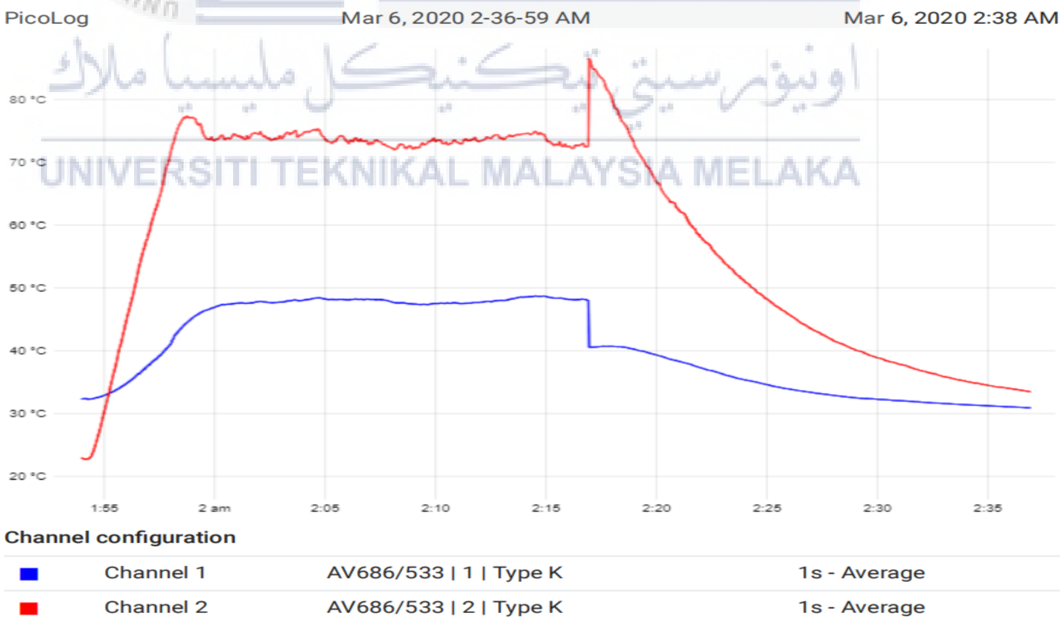

Figure 4.10:Result for 8 TEG.

Base on figure 4.10 show that the temperature at 8 TEG degrease gradually because of the prop does not attach properly at the surface of the TEG so the temperature result is decrease. In this figure the maximum temperature at hot side is 80 degree and the maximum temperature at the cold side is 48 degree.

Table 4.8:Result for 8 TEG.

Temperature (Celsius) ºC	*Temperature (hot side) ºC*	*Temperature (cool side) ºC*	*Temperature difference ºC*	*Output voltage (V)*
40	40	33.78	6.22	3.05
50	50	35.97	14.03	4.20
60	60	37.93	22.07	5.21
70	70	40.67	29.33	6.11
80	80	40.62	39.38	6.93
90	90	-	-	-

Base on this result show that the higher out voltage that will produce for 8 TEG is around 6.93 V at 80 degree of hot side temperature and the lower of output voltage is 3.05V at 40-degree hot side temperature.

4.3.9 The analysis 9 TEG module.

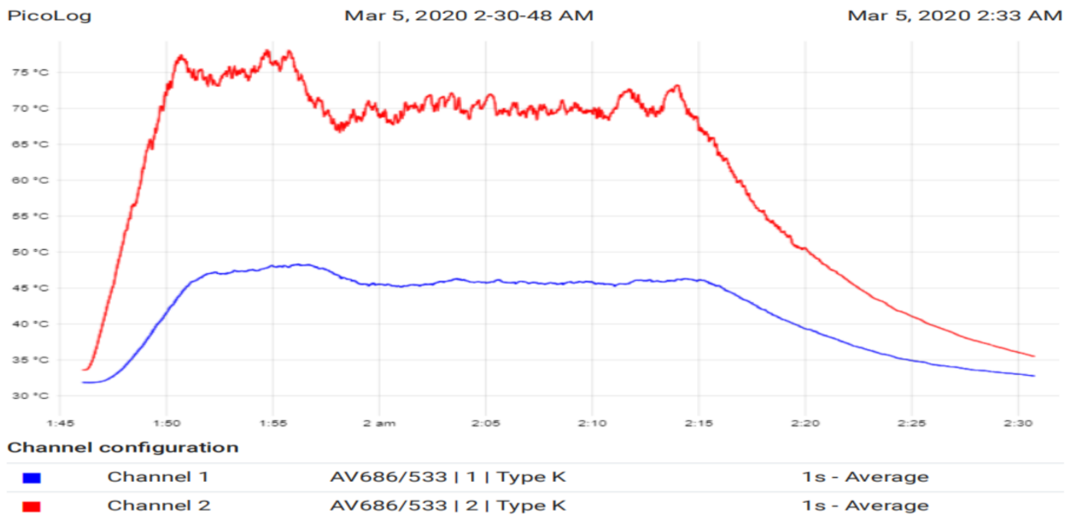

Figure 4.11:Result for 9 TEG.

Base on figure 4.11 show that the temperature of the 9 TEG for hot and cold side. Base on this figure the maximum temperature for the hot side is 80 degree and maximum temperature for the cold side is 48 degree.

Table 4.9:Result for 9 TEG.

Temperature (Celsius) ºC	*Temperature (hot side) ºC*	*Temperature (cool side) ºC*	*Temperature difference ºC*	*Output voltage(V)*
40	40	32.00	8.00	2.22
50	50	33.53	16.47	4.16
60	60	36.86	23.14	5.83
70	70	40.34	29.66	7.19
80	80	45.46	34.54	7.81
90	90	-	-	-

Base on this result show that the higher out voltage that will produce for 1 TEG is around 0.160 V at 90 degree of hot side temperature and the lower of output voltage is 0.028V at 40 degree hot side temperature. Base on this result the higher number of TEG will produce the higher output voltage. For this result 9 TEG is enough to produce 5V output voltage.

Bismuth Telluride-based thermoelectric modules are primarily designed for cooling or combined cooling and heating applications where electrical power creates a temperature difference across the module. By using the "reverse" modules, however, where a temperature differential is applied across the sides of the module, electrical power can be generated. Although power output and generation efficiency are very low, it is often possible to obtain useful power where a source of heat is available.

The output voltage from the couple (generator) in volts:

$$V = S \times DT \qquad \text{Equation 4.31}$$

Where: V = the output voltage from the couple (generator) in volts.

S = the average Seebeck coefficient in volts/°K.

DT = the temperature difference across the couple in K where DT = T_h - T_c.

The generator output current in amperes:

$$I = \frac{S \ x \ DT}{R_c + R_L} \qquad \text{Equation 4.32}$$

Where: I = the generator output current in amperes.

R_C = the average internal resistance of the thermoelectric couple in ohms.

R_L = the load resistance in ohms.

The heat input in watts:

$$Q_h = (S \times T_h \times I) - (0.5 \times I^2 \times R_C) + (K_C \times DT) \qquad \text{Equation 4.33}$$

Where: Qh = the heat input in watts

Kc = the thermal conductance of the couple in watts/°K

Th = the hot side of the couple in °K

The efficiency of the generator (Eg):

$$E_g = \frac{V \times I}{Q_h} \qquad \text{Equation 4.34}$$

Table 4.10: Efficiency table

The Number of TEGs	Average Seebeck Coefficient in volt/k	The Generator Output Current(A)	The Heat Input (W)	The Efficiency of Generator (%)
1	3.224m	32.00m	0.481	0.92%
2	0.0183	98.66m	0.767	9.60%
3	0.0119	45.11m	0.691	3.20%
4	0.0392	120.36m	0.979	21.00%
5	0.0673	191.86m	1.5275	42.00%
6	0.1184	215.38m	2.185	44.14%
7	0.0998	207.10m	1.958	52.77%
8	0.1759	252.90m	3.344	52.40%
9	0.2261	254.40m	4.193	47.38%

In this project, based table 4.10 the result the efficiency of the TEGs will increase if the number of the TEG increase. As you can see when the number of the TEG is one the efficiency of the TEG is 0.92%. When the number of the TEG is nine the efficiency of the TEG increase to 47.38%

4.4 Charging of Supercapacitor.

After the TEGs voltage is regulated at 5.4 V, the energy is stored in an energy storage device. As mentioned in Chapter III, the energy storage device used in the prototype is a 100F supercapacitor, the output current is about 254mW. To fully charge the supercapacitor, it will take some time. The time taken can be calculated theoretically. The calculation is shown below.

Figure 4.12:Supercapacitor.

$$I_C = C\frac{dv}{dt} \qquad \text{Equation 4.35}$$

$$\frac{dv}{dt} = \frac{I_C}{C}$$

$$\frac{dv}{dt} = \frac{254mA}{100F}$$

$$\frac{dv}{dt} = 2.54\text{mV}s^{-1}$$

$$t = \frac{V}{2.54mVs^{-1}}$$

$$t = \frac{5.4V}{2.54mVs^{-1}}$$

$$t = 2125.985 seconds = 35.43 \text{ minutes}$$

Based on the equation 4.35 show that, to charge the supercapacitor from 0 V to 5.4 V using the output of the TEG, the time take is about 35.43minits. Therefor time for supercapacitor fully charging will help to operate the TEC because it has a short time to fully charge.

4.5 Voltage Regulation by Using LM7805.

After the prototype is built and the output voltage is experimented, it is connected to the voltage regulation circuit. The Lm7805 will regulate the output voltage to 5V from the TEG output.

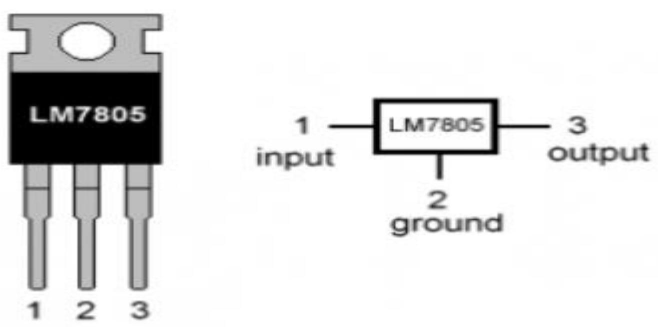

Figure 4.13:Lm7805 module.

The LTC3105 is fully successfully regulated the input voltage from the TEGs to the configured output voltage, which is 5 V. base on the simulation using the lm7805 the output voltage will be regulated in to 5V base on figure 4.13.

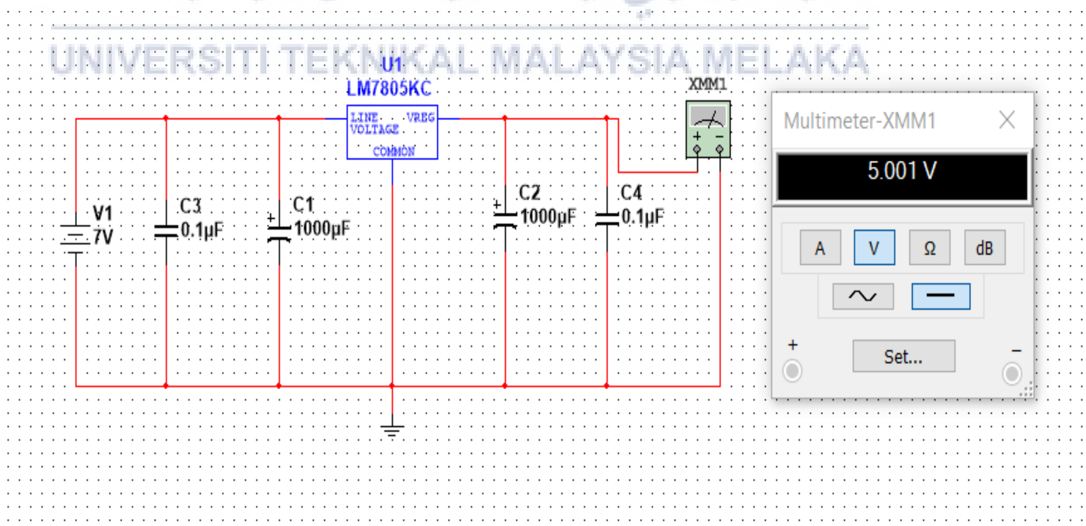

Figure 4.14:simulation voltage regulator.

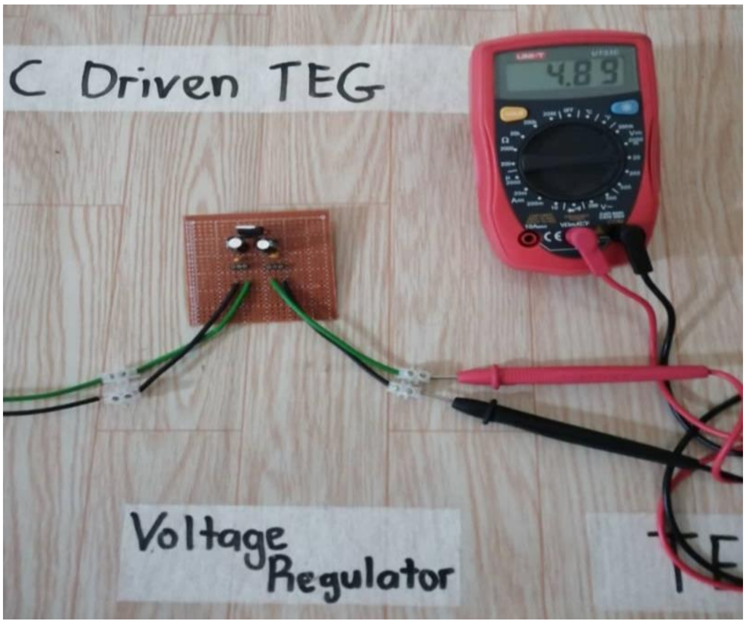

Figure 4.15:voltage regulator.

From the four figures 4.15 shown above, the input power and output power of voltage regulator can be calculated. Also, the efficiency of voltage regulator can be discovered. Below are the calculation of powers and efficiency of Lm7805.

The efficiency of Lm7805 boost converter can be calculated.

$$\text{Efficiency\%}=\frac{Output\ Power}{Input\ Power}\times 100\% \qquad \text{Equation 4.36}$$

$$\text{Efficiency \%} = \frac{1.244W}{1.272W}\ X\ 100\%$$

$$\text{Efficiency \%} = 97.8\ \%$$

The efficiency of Lm7805 is only about 97.8 %. It is relatively high but since there are many power-hungry components in the harvesting board and in the internal structure of Lm7805 chip, the efficiency is expected to be high.

4.6 TEC output temperature

Base on the output temperature produce by the TEGs, the TEC will produce 24.11C for the cold side and 38.40C for the hot side using 5V constant output.

Figure 4.16:Method to measure TEC.

In figure 4.16 show that the location of the thermocouple of the picolog located to measure the output temperature that generated using the TEG.

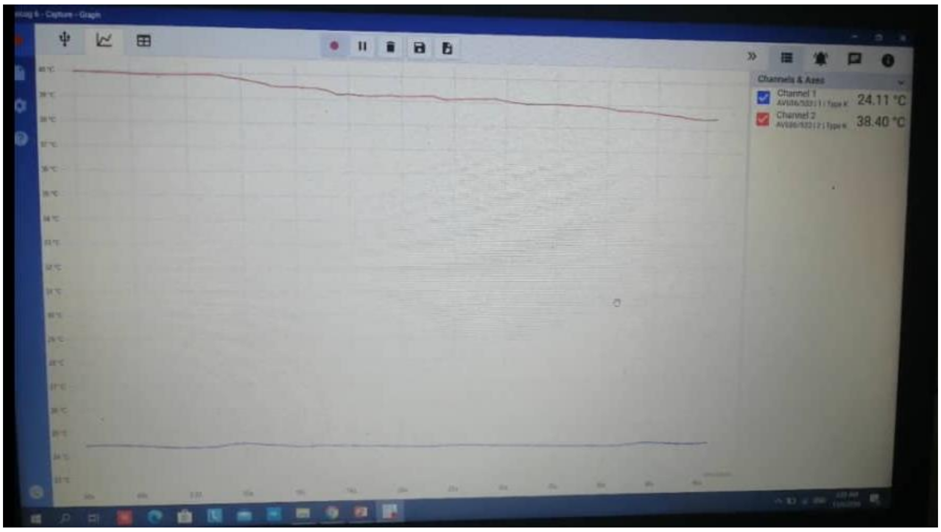

Figure 4.17:Output temperature for the TEC.

Base on figure 4.17 show the output temperature that produce from TEG is 24 degree for the cold side and for the hot side is 38.40 degree. Base on the theoretical when an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction.

In this project the input supple for the TEC is constant because the regulator circuit regulate the voltage to 5V. Then the temperature at the TEC is constant base on the input power to generate the TEC is constant. So, the temperature produce for the TEC at 5V supply is 24 degree for cold side and 38 degree for the hot side.

4.7 Product Features for Application.

These green technologies solution to solar designer to increase the power efficiency with additional features (thermoelectric generator). Besides that, the thermoelectric converting heat energy into useful electrical energy even solar less efficient during a cloudy day. Thus, it helps to solve energy harvesting problem.

This proposed project is relevant to sustainability and environmentally friendly as it operates in silence, small, high reliability, scalability, and durability. Plus, it does not involve any working fluid, has no moving parts, and zeroes chemical reactions and requires minimal maintenance.

The different location in the car is determined to use TEG thermal waste energy (heat) as a source of electrical energy to power electronic devices. It is possible to generate electrical energy from heat using thermoelectric generator (TEG) which operates based on the Seebeck effect.

Thermoelectric generator in series consists of an optical concentration system, an absorber, a heat sink and a thermoelectric generator sandwiched between the absorber and the heat sink. Aluminum heat sink is designed to release heat from the high temperature side to the low temperature side inside the Peltier module into the surroundings. Then, it connected to the designed circuit. Supercapacitors are used as a storage device to store electrical energy generated to prevent the electrical energy wasting and act as second or a backup electrical energy source when there is no electricity. The designed circuit has USB port for the application purpose.

4.8 Chapter summary.

This chapter discussed each result obtained when all described methodologies are conducted properly. From the first part, the configuration of the TEGs with the highest cumulative voltage is determined. In the second part, the thermal gradient for each condition is varied due to various factors. Thus, the voltage generated by each condition is also differ from each other. Finally, when the basic configuration relates to the TECs to fine the capability of the TEGs to drive the TECs module and the voltage generated is also greatly affected. An overall and more detailed conclusion regarding these results shall be discussed in the next chapter

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter provides conclusion of the overall project including discussion on the achievement of the objectives and the overall working of the prototype. At the end of this chapter, a future recommendation is given to further improve on this project.

5.1 Conclusion.

To conclude the overall project, it is safe to say that the project objectives have been successfully achieved. Thermoelectric generator is successfully designed and developed using thermoelectric generator module. The thermoelectric generator circuit configuration had successfully generated sufficient voltage to operate the TEC, yet it also able to maintain its thermal gradient. The supercapacitor which stores the harvested energy to drive the thermoelectric cooler. The prototype can reduce the time needed to charge the supercapacitor. This is achieved by using a 100 F supercapacitor (relatively low) as the energy storage device and ensures the supercapacitor charging more than 5V. Furthermore, the objective analyzes the efficiency of TEG to generate the TEC using waste heat form automotive equipment is successfully accomplished. Also, to analyze the efficiency of TEG to generate the TEC using waste heat form automotive equipment. Furthermore, all the TEGs will generated the electricity by using wasted heat. Finally, the prototype developed is proved to drive the TEC up to 47% depend on the quantity of the TEGs used.

5.2 Recommendation.

There are several recommendations are listed to improve the designed thermoelectric generator to drive the thermoelectric cooler. Firstly, the storage of the energy needs to have a low discharging rate because the TEC is high voltage component and need to store more voltage to reduce lack of voltage store. Next, as you know that the TEGs is low voltage generator so the TEGs need to boost the output voltage of the TEG so it will be used in high voltage equipment. The boosting circuit need to design with no effected the current value because when the boosting is operated they will boost the voltage but the value of current will drop it will take time to charging the supercapacitor or storage. The TEG module need to have a good air circulation because it will control the temperature difference of the module to get the constant output voltage.

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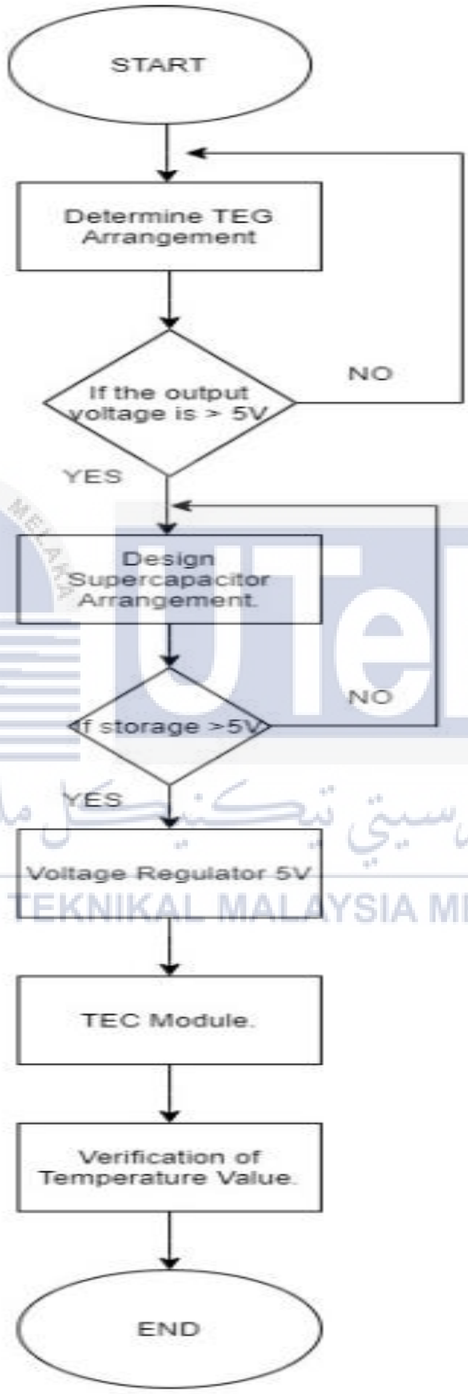
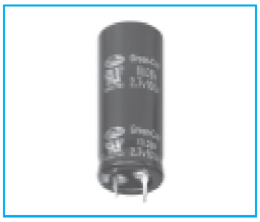
APPENDICES


START
Determine TEG Arrangement
If the output voltage is > 5V
NO
YES
Design Supercapacitor Arrangement.
If storage >5V
NO
YES
Voltage Regulator 5V
TEC Module.
Verification of Temperature Value.
END

Green-Cap (ELECTRIC DOUBLE LAYER CAPACITORS)

Upgrade

DB Snap-in Terminal Type, Standard Series

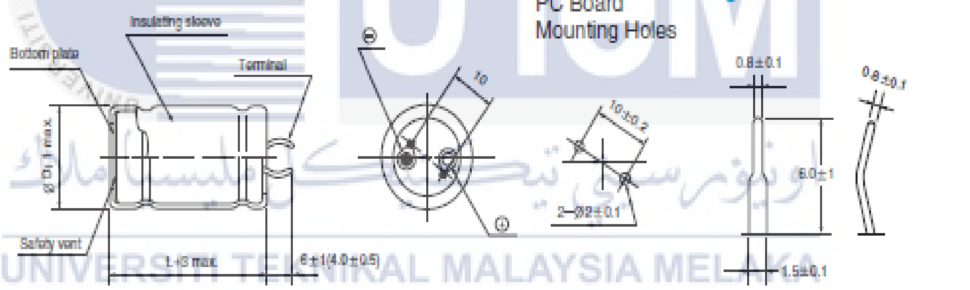


- Endurance : 2.5V 70°C 2000 hours, 2.7V 65°C 2000 hours
- The middle size and high capacitance, low resistance
- Charge and discharge efficiency are higher than in batteries

Item	Characteristics		
Operating temperature range	-25 ~ +70°C	-40 ~ +65°C	
Rated Voltage	2.5 VDC	2.7 VDC	
Capacitance tolerance	-20 ~ +20% or 0% ~ +20% at 20°C		
Temperature characteristics	Capacitance change	Within ±5% of initial value at +20°C	
	Internal resistance change	Within 50% of initial value at +20°C	
Endurance (2.5V:70°C, 2.7V:65°C)	Test time	2000 hours	
	Capacitance change	Within ±30% of specified value	
	Internal resistance change	Less than 100% of specified value	
Shelf life (2.5V:70°C, 2.7V:65°C)	After 2000 hours no load test same as endurance		
Life Time at RT[(1)]	10 years	(1) I△CI < 30% and △ESR < 100% of specified value, respectively and LC < specified value	
Cycle Life (25°C)[(2)]	500,000 cycles	(2) Cycle : between rated voltage and half rated voltage under constant current at 25°C	

DRAWING

Unit : mm



CHARACTERISTIC LIST & DIMENSIONS

Rated Voltage	Capacitance (F)	ESR, 1KHz (mΩ)	ESR, DC (mΩ)	LC (72hr) (mA)	Max Continuous Current(A)		Max Peak Current(A)	Specific Energy		Weight (g)	Volume (ml)	Dimension ØD×L(mm)
					△T=15°C	△T=40°C		(Wh/kg)	(Wh/L)			
2.5	100	15.0	35.0	0.25	6.0	10.0	27.7	3.62	5.07	24	17	22×45
	200	10.0	20.0	0.50	8.0	130	50.0	4.13	5.46	42	32	30×45
	300	6.0	15.0	0.75	9.5	15.5	68.2	4.20	5.41	62	48	35×50
	360	6.0	12.0	0.90	12.0	19.5	84.6	4.17	5.41	75	58	35×60
	400	6.0	10.0	1.00	13.0	21.0	100.0	4.63	6.01	75	58	35×60
2.7	100	7.0	9.0	0.26	12.5	20.0	71.1	4.82	5.92	21	17	22×45
	120	7.0	9.0	0.32	12.5	20.0	77.9	5.28	6.80	23	18	22×47
	200	6.0	8.0	0.54	13.0	21.0	103.8	5.33	6.37	38	32	30×45
	300	3.5	5.0	0.81	16.0	26.5	162.0	5.33	6.31	57	48	35×50
	360	3.0	3.2	0.75	23.0	38.0	225.8	5.13	6.31	71	58	35×60
	400	3.0	3.2	0.83	23.0	38.0	236.8	5.70	7.02	71	58	35×60
	400	2.8	3.0	1.00	25.0	40.0	245.5	5.06	6.48	80	63	35×65
	450	2.8	3.0	1.00	25.0	40.0	258.5	5.18	6.77	88	67	35×70
	500	2.9	3.1	1.10	25.0	40.0	264.7	5.69	7.52	89	67	35×70
	600	3.0	3.2	1.30	25.0	40.0	277.4	6.75	9.02	90	67	35×70
	600	2.8	3.0	1.30	25.0	40.0	289.3	6.08	7.43	100	82	35×85

※ Ø35 4 pin type terminal drawing is same see pages.

TIGER ELECTRONIC CO.,LTD

Product specification

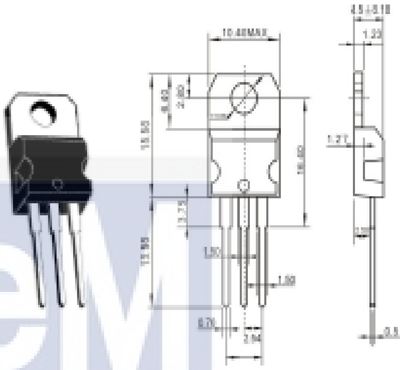
3-Terminal 1A Positive Voltage Regulator **LM7805**

GENERAL DESCRIPTION

The LM7805 series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

ABSOLUTE MAXIMUM RATINGS (Ta = 25 °C)

Parameter	Symbol	Typ	Unit
Input Voltage	V_I	35	V
Output Voltage	V_O	5.0	V
Peak Current	I_{PK}	2.2	A
Operating Temperature Range	T_{OPR}	0~125	°C
Storage Temperature Range	T_{STG}	-65~150	°C



TO-220

ELECTRICAL CHARACTERISTICS (Ta = 25 °C)

(Refer to test circuit, Io = 500mA, Vi = 10V, Ci= 0.33uF, Co=0.1uF unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Voltage	V_O	V_I = 8V to 20V	4.85	5.0	5.15	V
Line Regulation (Note1)	Regline	V_O = 8V to 25V		4.0	100	mV
		V_I = 8V to 12V		1.6	50	
Load Regulation (Note1)	Regload	I_O = 5.0mA to1.5A		9	100	mV
		I_O =250mA to 750mA		4	50	
Quiescent Current	I_Q	T_J =+25 °C		5	8	mA
Ripple Rejection	RR	f = 120Hz, V_O = 8V to 18V	62	73		dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		2		V
Output Resistance	r_O	f = 1KHz		0.015		Ω
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		230		mA
Peak Current	I_{PK}	T_J =+25 °C		2.2		A

HB

Thermoelectric Cooler

TEC1-12706

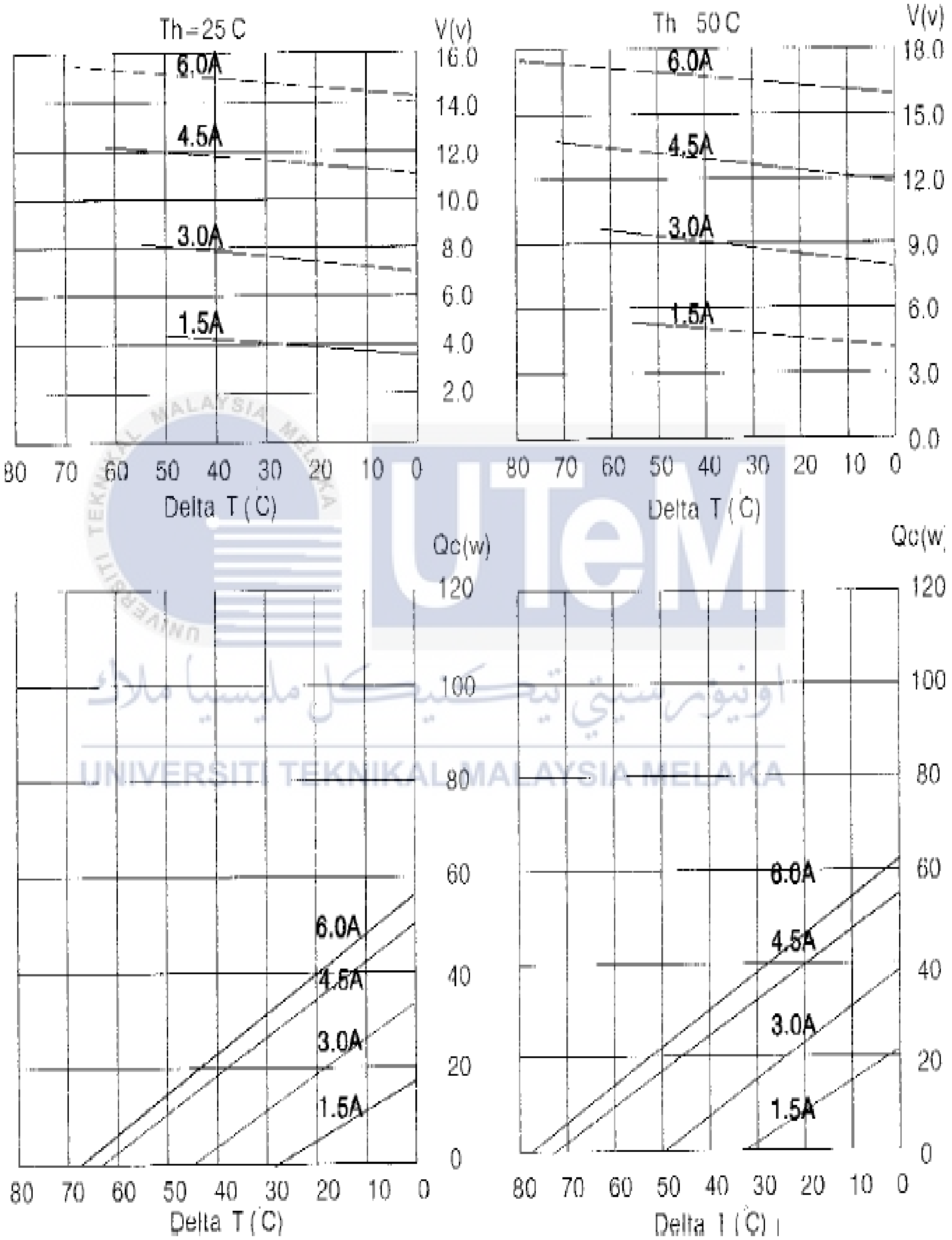
Performance Specifications

Hot Side Temperature (° C)	25° C	50° C
Qmax (Watts)	50	57
Delta Tmax (° C)	66	75
Imax (Amps)	6.4	6.4
Vmax (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30

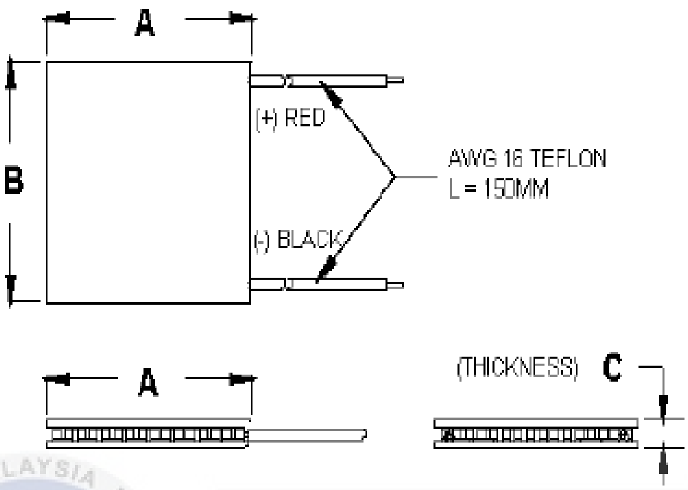
Performance curves on page 2

 Rev 2.03

TEC1-12706


Th=25 C
V(v)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
6.0A
4.5A
3.0A
1.5A
80 70 60 50 40 30 20 10 0
Delta T (C)
Th 50 C
V(v)
18.0
15.0
12.0
9.0
6.0
3.0
0.0
6.0A
4.5A
3.0A
1.5A
80 70 60 50 40 30 20 10 0
Delta T (C)
Qc(w)
120
100
80
60
40
20
0
6.0A
4.5A
3.0A
1.5A
80 70 60 50 40 30 20 10 0
Delta T (C)
Qc(w)
120
100
80
60
40
20
0
6.0A
4.5A
3.0A
1.5A
80 70 60 50 40 30 20 10 0
Delta T (C)

TEC1-12706



Ceramic Material: Alumina (Al_2O_3)
Solder Construction: 138°C, Bismuth Tin (BiSn)

Size table:

A	B	C			
40	40	3.8			

Operating Tips

- Max. Operating Temperature: 138ºC
- Do not exceed Imax or Vmax when operating module.
- Life expectancy: 200,000 hours
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- Please consult HB for moisture protection options (seeling).
- Failure rate based on long time testings: 0.2%.

 Rev 2.03