DEVELOPMENT OF PELTIER COOLING SYSTEM FOR AUTOMOTIVE

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ABSTRACT

Nowadays, air-conditioning system of automobile arises to such many problems such as CFC emission that cause air pollution, the usage of fuel is increased and engine performance is decreased. Moreover, the current air-conditioning system is not capable to be used when the engine is not moving. Even when the vehicle is moving the use of air-conditioning system may increase fuel consumption This scenario could be subdued by the introduction of thermoelectric device as an alternating cooling option for car interior. Fuel usage decrease by using this pollution option and reduce engine performance can be prevented since the letter option was in the bracket of ‘Go Green’ region. The project is to make the automotive cabin being cooled by using thermoelectric cooler that can be applied on the car even when the engine is not moving. The system should be automatically turned on when the engine of the car is stop depending on the temperature inside and outside of the car. This temperature can be controlled by temperature sensor. The project is using the source of the automobile battery.

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LIST OF SYMBOLS

%	Percentage
f	Frequency
Ω	Ohm
≤	Less Than Or Equal To
≥	Greater Than Or Equal To
ºC	Degree Celsius
×	Multiplication

LIST OF ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
BJT	Bipolar Junction Transistor
IGBT	Insulated Gate Bipolar Transistor
GTO	Gate Turn-Off Transistor
TEC	Thermoelectric Cooler
LED	Light Emitting Diode
LCD	Liquid Crystal Display
D	Duty Cycle
V	Volt
A	Ampere
AH	Ampere Hour
V_{in}	Input Voltage
V_o	Output Voltage

CHAPTER 1

INTRODUCTION

1.1 Overview

Recently the automobile has been combined with an air-conditioning to make the inside cabin cooling subject. The problem arises when the automobile stop moving on the road and being at rest momentum. This can cause the uncomfortable situation from the temperature inside cabin. This make user sense hot.

The thermoelectric cooler function is the way to make the inside cabin temperature cool at set point of the user. The user will set the temperature required at 25°C and the temperature of the cabin is follow the user set temperature. When the thermoelectric cooler or fan stop running and do not function. This state is the cause of inside the cabin temperature is drop below user setting.

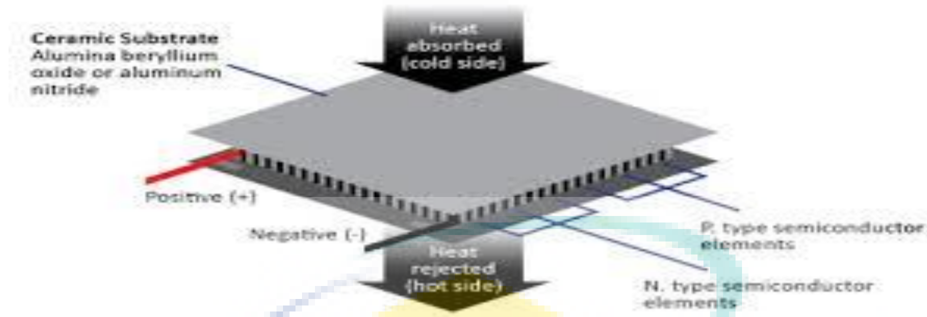

Figure 1. 1 : Thermoelectric Cooler (TEC)

To make the new system, the thermoelectric cooler are used to this system. Thermoelectric cooler in other name is peltier. The peltier with peltier effect is the equipment that support semiconductor. The heat of the peltier is cooling which is absorbing and the other side is heating that release heat after absorbed [1]. The thermoelectric cooler is as **Figure 1. 1**. The thermoelectric cooler is from this principal that the thermoelectric cooler feeding the cabin room to become cooler as the temperature set while the other surface release heat as the exhaust that placed with cooling plate and fan to realease heat. However there are so much concept and style of transistor that can be used in this system. The thermoelectric cooler need enough current driver circuit for electrical direct current load. The transistor that has the less power loss will make the perfect system of the thermoelectric cooler.

There are many type and style of the transistor that can use in this system. The style are Bipolar Junction Transistor (BJT), Metal Oxide Semiconductor Field Effect Transistor

(MOSFET), Insulated Gate Bipolar Electronic Transistor (IBGT) and Gate Turn-Off electronic Transistor (GTO). To make the system running it need a high change frequency that is Buck converter. The fundamental say the change frequency used is square wave wherever it is duty cycle can confirm how long the facility switch can activate.

1.2 Problem Statement

In the day light, there must be an hot temperature. While that happened the air conditioning of automobile these day not function very well. This is the problem that appear from air conditioning system and when temperature is so much hot it can cause the heat stroke. While there also other problem that is the cause of air pollution and cost from the maintenance of air conditioning system.

The thermoelectric cooler (TEC) is the must be the item and system that the people use in the automobile. The system design is the attachment of the thermoelectric cooler and the heat sink on the both side. The system can make the thermal resistance the lowest. This thermoelectric cooler design attached heat sensor can eliminate the worries of air conditioning disadvantages and the improvement of automobile these day.

1.3 Objective

It is important to the important and the system or project result. Thus, it is important to clearly state and recognized the target of the project was assembled. Throughout this project, these are the objectives that may enlighten during this thesis:

1. To create air conditional from thermoelectric cooler that can produce the comfortable temperature in automotive cabin.
2. To control the temperature inside the cabin according user setting with Arduino and Buck converter produce stability output.

1.4 Scope Of The Project

The scope of the project involves the following element:

1. To create the TEC controller using arduino.
2. To create driver circuit in order to control the current of thermoelectric device and cooling fan

1.5 Thesis Outline

This thesis consist 5 chapters. The primary chapter during this thesis consists of the summary, downside statement, objective and scope of work for this project.

The second chapter includes the literature review that associated with this project. Operation and skill employed in creating the system are being even during this chapter.

The third chapter present the analysis methodology, system style and application tool that are employed in this project.

The forth chapter is about the discussion of the result supported the metter statement for this project.

Within the final chapter, the analysis work is summarized the potential future work and suggestion of improvement area unit given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review of this project comprises from the journal on the internet, paper proceedings and research books and lectures. The literature review is done to investigate case of the projects that may arise to overcome it. The literature review gives a great knowledge on fundamental of the project. Among the reviewed project is about the peltier technology in cooling and heating in the industry and how the heat sink and thermoelectric module interacts to cool down the external interfering air.

2.2 Thermoelectric Cooler (TEC)

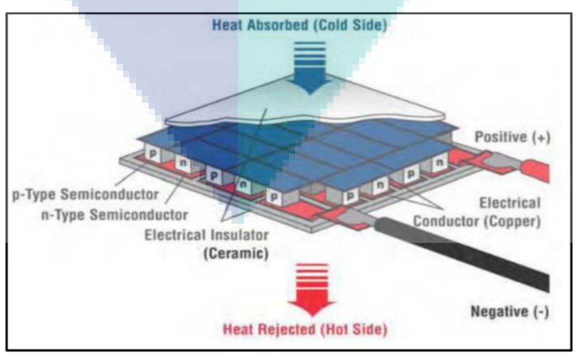

Figure 2. 1: A halfway Of Peltier

A typical thermoelectric module consists of variety of thermocouples sandwiched between two layers of ceramic substrates. The ceramic substrates ought to ideally have a very thermal conduction in order that there's negligible temperature drop across the layer of the substrate however very low electrical conduction to avoid any outpouring current flow through the substrate. A schematic of the development of atypical detective module is shown in **Figure 2.1**.

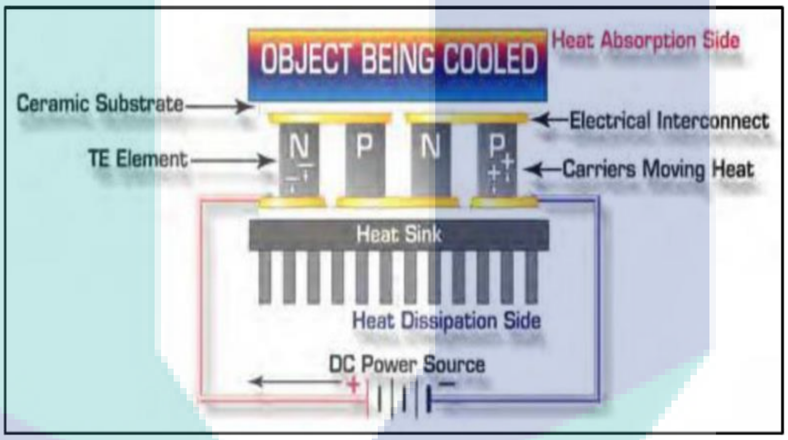

Figure 2.2: Schematic Of Thermoelectric Module Operation

Thermoelectric cooler is achieved with the penalty of DC current provide through one or a series of thermocouples electrically connected serial however thermally in parallel[1]. The schematic of one thermocouple junction that consists of one n-type and one p-type semiconductor material, also called a thermo-element with its operational principle is shown in **Figure 2.2**.

In the n-type semiconductors there exist excess electrons and holes respectively. With the electrical polarity shown in **Figure 2.2**, electrons in p-type and n-type material flow from bottom to high and from high to bottom respectively, so leading to a clockwise electron flow or counter clockwise current flow through this circuit. Heat is absorbed at the highest and free at rock bottom of the schematic shown in the figure. If the polarity is modified, the new and cold junction also because the heat absorption and rejection can interchange [2].

2.3 Peltier Effect

There are three thermoelectrical impacts that are far-famed since the nineteenth century: (i) Seebeck impact (ii) Peltier impact and (iii) Thomson effect. Seebeck in 1821 was discovered that, once a temperature distinction is maintained at the two junctions of a thermocouple composed of two dissimilar conductors, a voltage is generated at the two terminals of the thermocouple junction [3].

Different applications of thermo-electric modules for (i) cooling, starting from consumer product to military or region applications, (ii) power generation, e.g. waste heat recovery (iii) detectors like refrigerant heat flux sensor, ultrasonic detector, intensity detector, fluid flow detector, and infrared ray detector.

2.4 Fuzzy Temperature Using Peltier Module

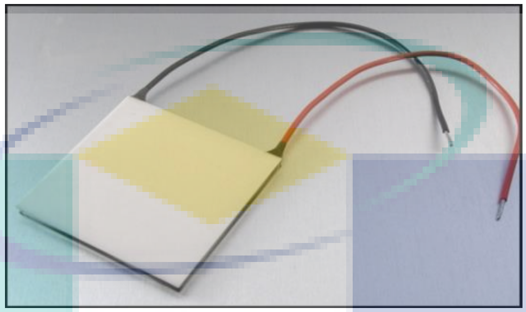

Figure 2.3: Peltier Module

A thermoelectric cooler consists of a thermoelectric module, a conductor was connected to the hot facet and cooling load device connected to the cold facet. The thermoelectric module includes several pairs of p-n kind thermoelectric material connected serial and clamped and soldered with two base plates as shown in **Figure 2.3**. The heat load is absorbed at the cooling load device, conducted to the hot-end plate, and so pumped up to the new facet of the thermoelectric module that is shown within the **Figure 2.4**.

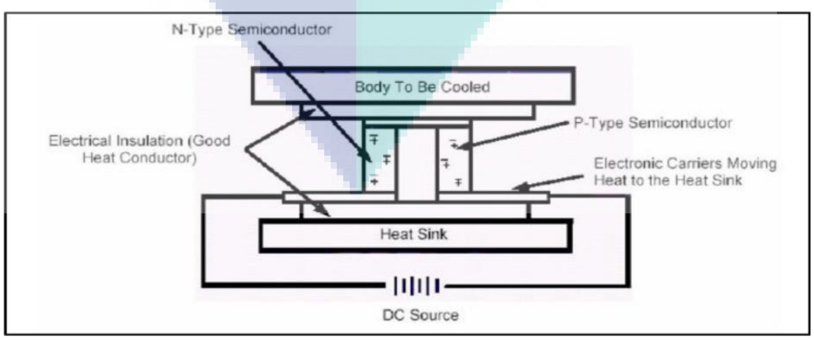

Figure 2.4: Cross Section Of A Typical TEC

The controller design for temperature control of a thermoelectric cooler is not very simple due to the nonlinear dynamic behavior of the thermoelectric module, the effect of dynamic behavior of the thermal masses of the heat sink and the cooling load heat exchanger imposes another problem on the control system design.

2.5 Thermoelectric Generator

Thermoelectric part that's directly converted heat into electrical or electrical into heat is applied energy trade, electrical and electron industry as thermoelectric genera-tion and thermoelectric cooling instrumentation [7]. Thermoelectric part that uses Peltier impact has advantage like eco-friendly, easy structure, high dependability and soundlessness.

Hence, the thermoelectric cooling technique is applied an area cooling of IC manufactures and electronic machines of varied types like infrared rays detector, optical device diode. Additionally it's used the focal plate cooling of charge-coupled device (CCD) part from shrinking of electron elements and high electrification, and high density implementation in a complicated country [5]. Also, it's expanded application for shopper electronics trade like a refrigerator, a cooling system and warmth money dealer similarly as science activity instrumentation and medical instrumentation.

2.6 The Effect Of Pulse Width Modulation (PWM) Frequency On The Reliability Of Thermoelectric Modules

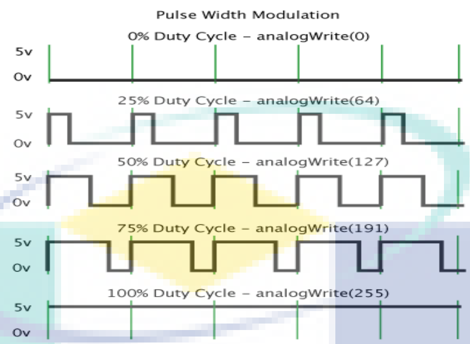

Figure 2.5 : PWM Signal And Duty Cycle

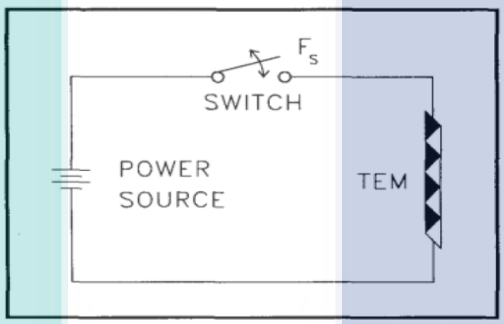

Figure 2.6 : PWM Circuit

Pulse-width-modulation (PWM) control has several advantages once used to control power to thermoelectric modules (TEM's). This scheme permits the utilization of smaller, lighter electronic equipment that dissipates less heat than a comparable linear controller. However, suddenly turning power on and off to a TEM has been better-known to cause thermal cycling that reduces the dependableness of the module. This thermal cycling fatigues the solder junctions causing a rise within the module's resistance.

Therefore, some system design were use PWM controllers within the cooling apparatus. PWM temperature controllers deliver power to a TEM by switch power to the module either fully on or fully off. This can be sometimes done via a transistor. The PWM signal consists of a periodic square wave with a variable TON. This TON, once expressed as a percentage of the period (P) of the sq. wave, referred to as the duty cycle. Power to a TEM is adjusted by varied the duty cycle of the square wave [6]. An example of a PWM signal is shown on **Figure 2.5** and example of a PWM circuit is shown in **Figure 2.6**.

1.7 Buck Converter

A buck convertor could be a change of magnitude DC to DC converter. For a DC–DC converter, input and output voltages are each DC. It uses an influence conductor as a switch to show on and off the DC supply to the load. The switch action is en-forced by a BJT, a MOSFET, or an IGBT. **Figure 2.5** shows a simplified diagram of a buck converter that accepts a DC input and uses pulse-width modulation (PWM) of switch frequency to regulate the switch. An external diode, at the side of external electrical device and output capacitance, produces the regulated dc output. Buck, or step down converters produce a mean output voltage under the input supply voltage**.**

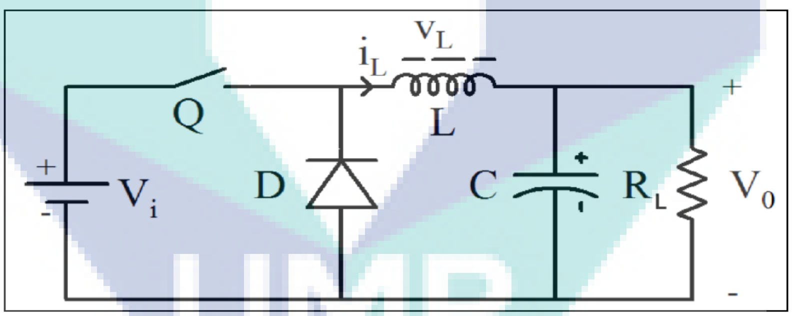

Figure 2.7: Buck Converter

1.8 Buck Converter operation

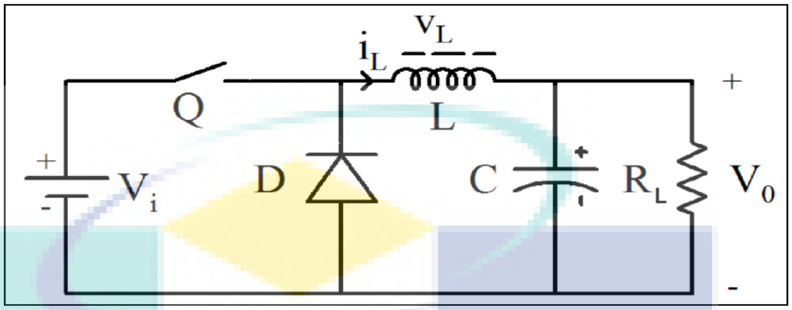

Figure 2.8: switch Q shut on and off

The operation of a buck device happens in two modes. The primary mode is once switch Q shut, and also the other is once switch Q open. When switch Q closes, current flows from the provision voltage (Vi) through the inductance and into the load, charging the inductance by increasing its field and increasing Vo. Diode D are on re-verse bias, therefore obstruction the path for current. an inductance reduces ripple in current passing through it and also the output voltage would contain less ripple content since the current through the load resistance is that the same as that of the inductance [4]. At identical time, the current through the inductance will increase and also the energy keep within the inductance will increase. Once output voltage (Vo) reaches the specified price, switch Q is open and diode D is turned on. **Figure 2.8** shows this mode

CHAPTER 3

METHODOLOGY

3.1 Introduction

Method of used are very important to complete this project without any problem. This chapter is related to the previous chapter in the way to solve the project. In order to have a good controller design, some step will be applied. The project has the core part which is hardware part.

3.2 Work flow

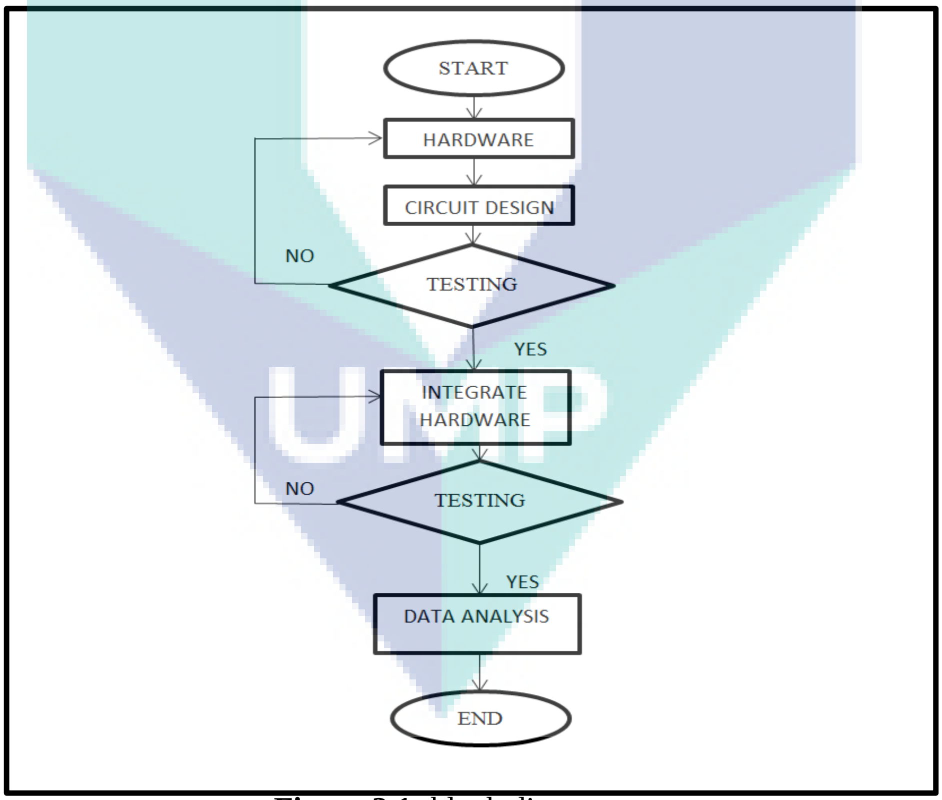

Figure 3.1: block diagram

Block diagram in **Figure 3.1** illustrate the works to complete the project whenever it's begin by doing the proposal consist of the target, scope of project, diagram and additionally some literature review. The progress the core way of element which is hardware system part. In this part in spite of everything the components is purchased, the circuit is then designed and being tested. If no downside occurred, each half are integrated and being analyzed. For the testing part, there will be plenty of attempts if unsuccessful, correction is being created on coding or the circuit should be applied if the result is not satisfied. If satisfied, the problem is proceed to the last part that is analyzed and obtaining result.

3.3 Hardware

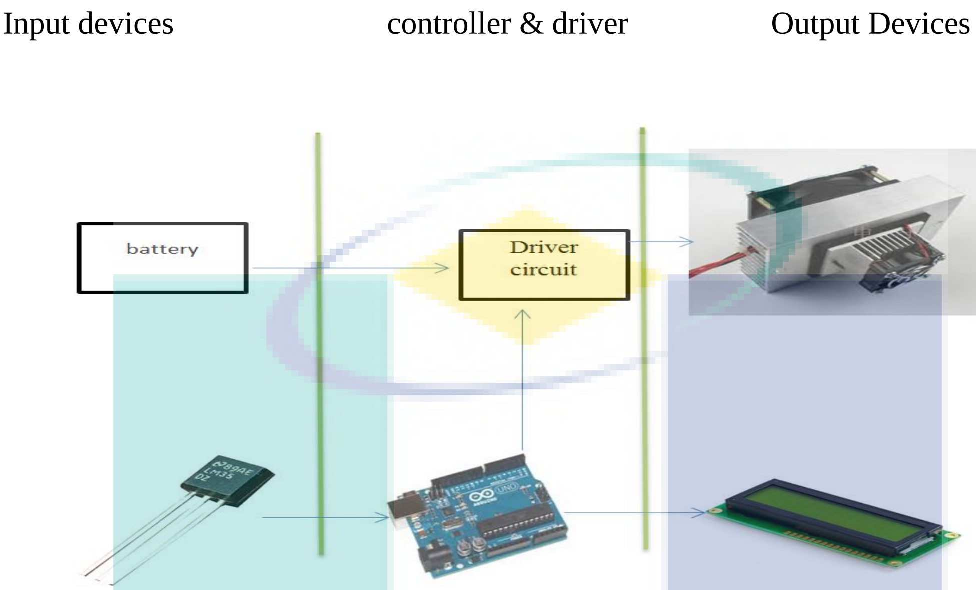

Figure 3.2: Overall System

Figure 3.2 shows every stage for the hardware design. There are two stages like controller circuit and isolation circuit. The need of the system are going to be developed consequently in every of the circuit.

3.3.1 Controller Circuit

The function of the controller circuit system is to monitor the input signal and determine the set point. The input in the controller circuit consists of temperature sensor and user desire temperature. The temperature sensor use to give feedback value to the controller. The controller will use both of the temperature inputs in order to control the car temperature. The controller circuit also display the information of the car condition through Liquid Crystal Display (LCD).

3.3.2 Controller

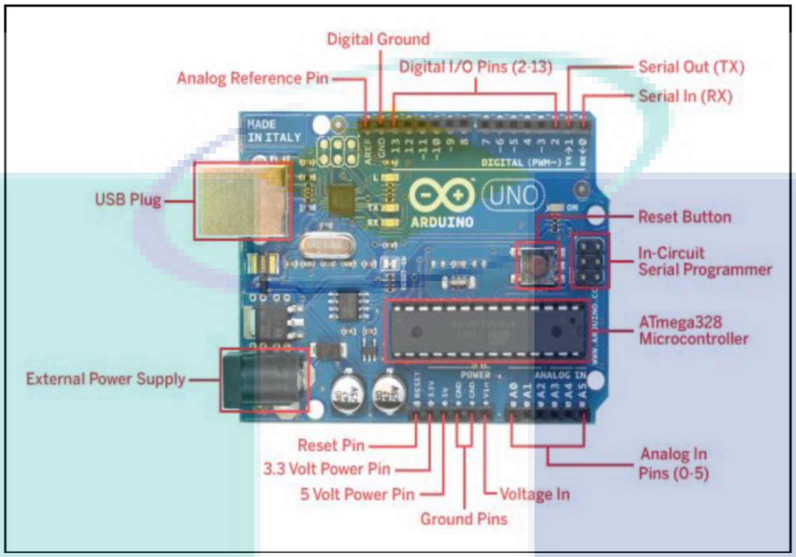

Figure 3.3 : Arduino UNO Diagram

As to regulate the system, Arduino UNO system is chosen to be as primary system of this project. The Uno may be a microcontroller board supported the ATmega328P. the pin diagram for Arduino UNO is shown in **Figure 3.3** . This arduino has 14 digital input/output pins of that 6 will be used as PWM outputs, 6 analog inputs, a 16 megahertz quartz crystal, a USB affiliation, a power jack, an ICSP header and a reset button. The microcontroller contains everything required to support the microcontroller. It simply merely connect it to a laptop with a USB cable or power it with AC-to-DC adapter or battery to get started

3.3.3 Temperature Sensor

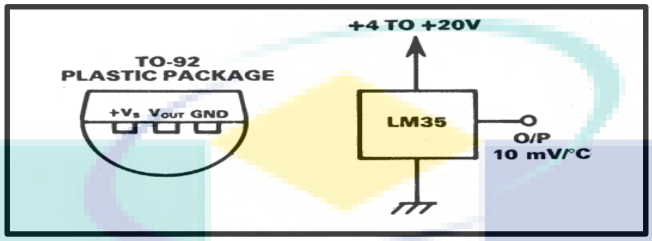

Figure 3.4 : LM35DZ Schematic Diagram

In this project, the kind of sensor used is temperature sensor. LM35DZ of tem-perature sensor is chosen during this project. The temperature sensor functions as a measuring device for the system. The temperature from the inside and exterior of the automobile are going to be measured and send to the controller as feedback. The options output of LM35DZ gain of 10mV/°C. From **Figure 3.4**, the output voltage from the temperature sensor is measured at terminal Vout. For instance, if the sensor measures temperature of 40°C the output voltage from the sensor is 0.674V. The temperature sensor operational vary is from 0°C to 100°C. This range are appropriate for measure the temperature interior and exterior of the automobile. As a result of the automobile temperature doesn't exceed 100°C and cooler below than 0°C. From **Figure 3.4,** two sensors are employed in order to measure the outside and interior temperature. Pin A0 can scan the output voltage from the outside temperature sensor wherever Pin A1 can scan the output voltage from the inside temperature sensor.

3.3.4 Display

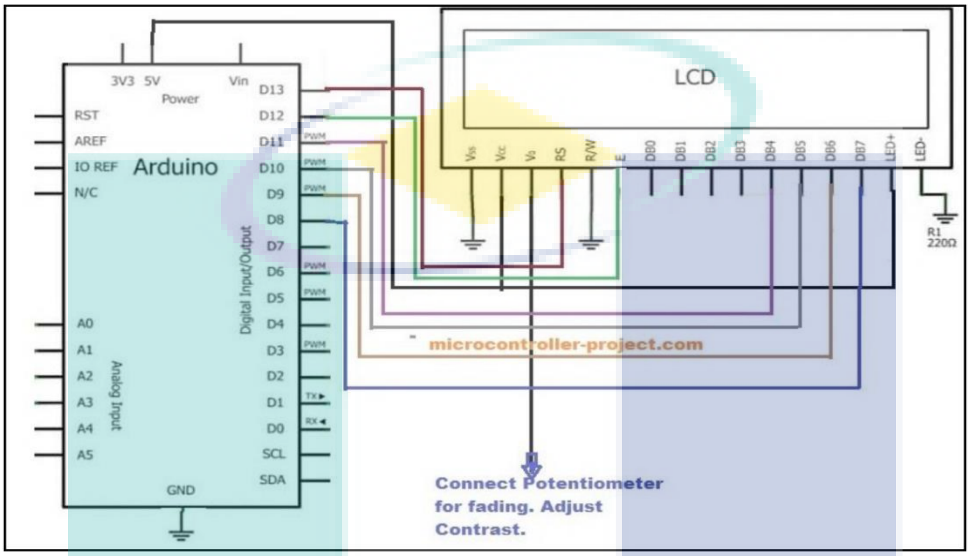

Figure 3.5 : 16x2 LCD With Arduino

LCD (Liquid Crystal Display) screen is an electronic display module and find notice a good vary of applications. This project used a 16x2 LCD as a display to indicate that speed of cooling fan and the temperature need. A 16x2 LCD means that it can display 16 characters per line and there are 2 such lines. Figure 3.5 below show the 16x2 digital display with affiliation to Arduino UNO. In digital display, every character is displayed in 5 this digital display has 2 registers, specifically command and information. The command register stores the command instructions given to the digital display.

A command is an instruction given to initialize, clearing its screen, setting the indicator position, controlling display. The info register stores the data to be displayed on the digital display. The data is that the ASCII value of the character to be displayed on the digital display.

3.3.5 Driver Circuit

3.3.5.1 Power Transistor Driver

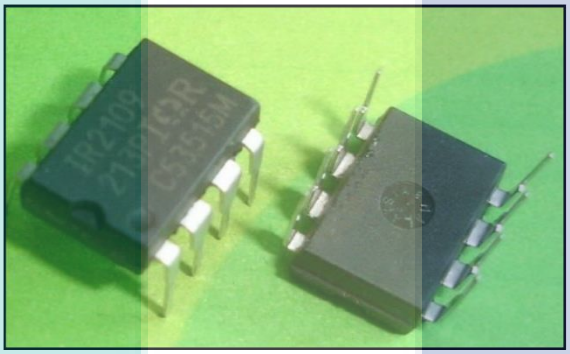

Figure 3.6 : IR2109 Power Transistor Driver

To switch on the power MOSFET the PWM signal from the microcontroller isn't ample enough. The minimum VGS for the IRFZ46N power MOSFET is 10V whereas the utmost amplitude of the PWM signal is 5V. Thus to encounter this problem, a power electronic transistor driver is required so as to drive the power MOSFET. During this project, IR2109 are going to be used to drive the power electronic transistor. The IR2109 is a 0.5 bridge driver design to drive N-channel power MOSFET. Then it's high and low facet floating output voltage. the concept to drive the power MOSFET, the high facet of the floating output voltage are going to be used wherever the low facet output voltage are going to be left unconnected. Same as above, 2 of this driver will be required to drive the power MOSFET. **Figure 3.6** show the power electronic transistor.

Figure 3.7 : Fan Circuit With Buck Circuit

In this project, the thermoelectric cooler module and cooling fan is operates in DC voltage. Buck converter is used to manage the electricity module and cooling fan. The function of this device is to manage the output voltage and to ensure the

3.4 Software involved

3.4.1 Arduino

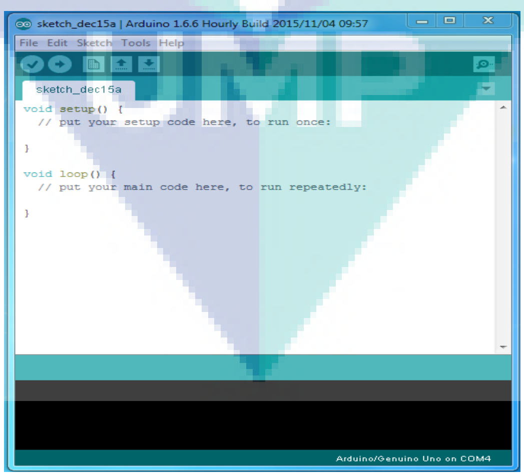

Figure 3.8 : Arduino Software INTERFACE

The software development of this project is constructed using Arduino software. The Arduino software can be found on Arduino main website. Arduino UNO board can be programmed after finish installed the Arduino software. So many basic examples provided in the software that the user can learn. **Figure 3.14** show the Arduino software

3.5 Test cabin

Figure 3.9: Cabin Model

The test Perspex cabin is made from acrylic. A hole on the top is made to flow the thermoelectric cooler straight inside the cabin. The model is exposed to the sunlight during experiment.

3.6 Microcontroller

Microcontroller	ATmega328P
Operating voltage	5V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (6 pin with PWM output)
PWM Digital I/O pins	6
Analog Input Pins	6
DC Current per I/O pin	20mA
DC Current for 3.3V pin	50mA
Flash Memory	32KB (ATmega328P) 0.5KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
length	68.6 mm
width	53.4 mm
Weight	25 g

Table 3.1 : Arduino UNO Specification

Table 3.1 show the specification of the arduino UNO. The control unit need this to control the system or running the project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

To make the air conditioning and make the thermoelectric cooler as the cooling option is a big task to be done. It need more knowledge and analysis. In this chapter, all the result about the project will be discussed and analyzed in details.

In previous chapter the project has only the hardware part. To make analysis the system should be running. The method and equipment chosen are very important for record data

4.2 Controller system board

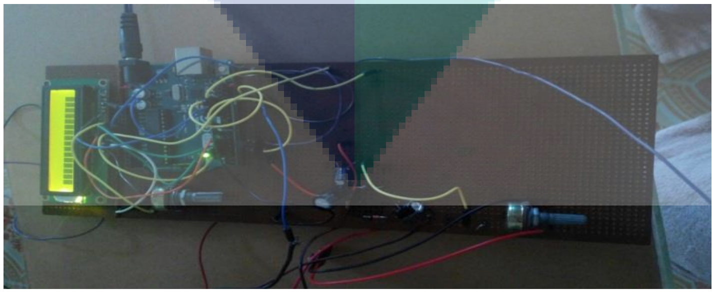

Figure 4.1: Control System Board

The system controller board is created to control the driver circuit and shows display on the LCD display screen with consist of fan speed and temperature. **Figure 4.1** show the view of the controller system board.

4.3 Liquid Crystal Display

The Liquid Crystal Display (LCD) screen is an electronic display module. A 16x2 LCD is very basic module and it is commonly used in many projects. The LCD is used to display the temperature and speed of fan in order to collect the data.

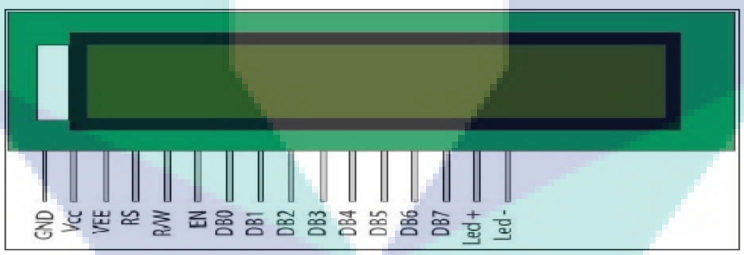

Figure 4.2 : Schematic Diagram LCD

Figure 4. 3: information Displayed

In **Figure 4. 2** above show the LCD pin out. This LCD has backlight that supplied with 5V to turn on. The LCD Digital pin will connected with wire or connection to the Arduino. **Figure 4. 3** show the LCD display of fans speed and temperature sensor reading when the system running.

4.4 Full System

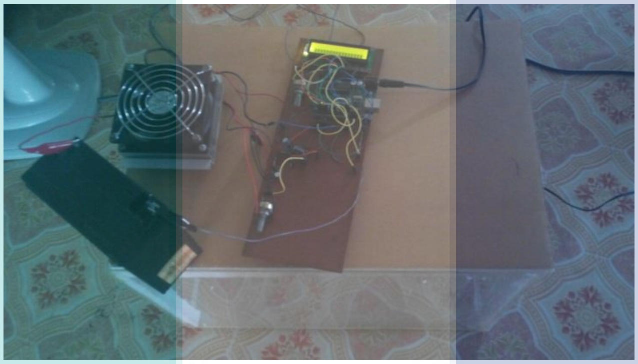

Figure 4. 4: system of project

Figure 4. 4 show the full system view . The system is connected to the battery, sensor and the load fan and thermoelectric cooler (TEC). It was place under the hot daylight for a few moment. There are many testing situation that has been done.

Time(min)	Temperature inside (°C)	Temperature outside (°C)
0	34	36
10	40	49
20	41	40
30	45	44
40	38	33
50	44	42
60	45	42
70	46	43
80	41	40
90	43	42
100	38	35
110	42	41
120	44	41

Table 4. 1 Temperature Data in Day light on 12pm to 2pm

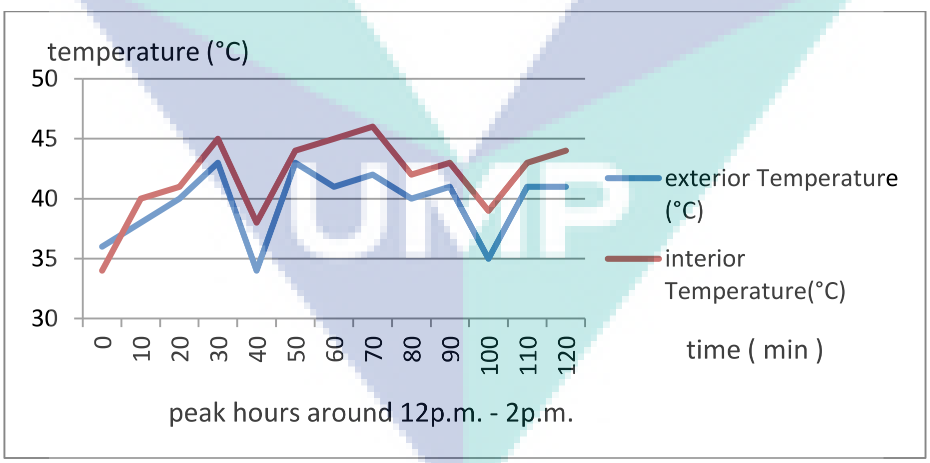

Figure 4. 5 : Graph car temperature

The first test is to collect data about the temperature inside of the car alone. The temperature measures is collected on 19th October 2016 at peak hours around 12p.m. - 2p.m. in the **Table 4.1**. **Figure 4.5** shows the graph temperature versus time. The temperature inside the car is rapidly increase when it is exposed to the hot day of sun light. The highest temperature outside the car is 46°C and the minimum is 34°C while inside temperature of the car the maximum is 42°C and the minimum is 34°C. The result is collected in every 10 minutes as shown in **Table 4.1** .

Time(min)	Temperature inside car
5	29.5
10	29.0
15	28.6
20	28.4
25	28.1
30	27.6
35	27.2
40	26.0
45	25.1
50	24.0
55	23.5
60	23.1

Table 4.2: Temperature at night

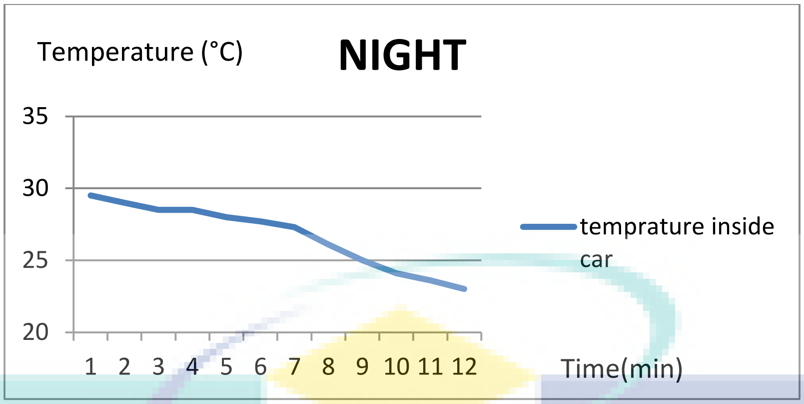

Figure 4.6: Temperature Graph Inside Car At Night

The result measure at 8p.m. to 9p.m on 18th October 2016. The temperature inside the car are collected in every 5 minutes as in Table 4.2. Table 4.2 show the temperature graph inside of the car on the display. The temperature state the maximum is 29°C and the minimum is 23°C.

Time (min)	Temperature(°C)
0	30.7
1	16.9
2	15.1
3	14.9
4	14.9
5	15
6	14.8
7	15
8	14.9
9	15
10	14.8

Table 4. 3: Temperature Of Thermoelectric cooler

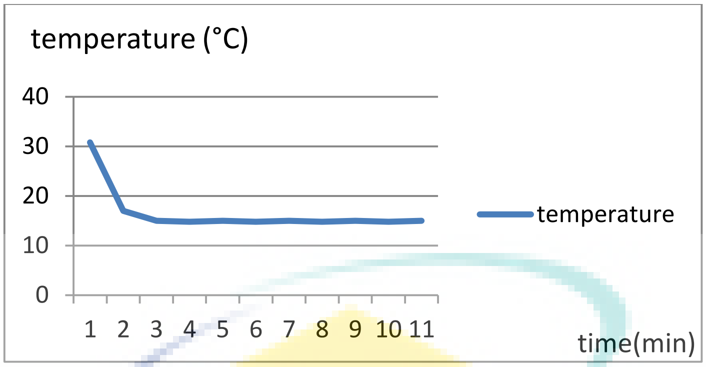

Figure 4.7 : Temperature Graph of Thermoelectric cooler

The testing temperature is recorded using arduino software. It also record the temperature at Taman Melor resident at night and in University Malaysia Pahang parking lot at the day time. The temperature is recorded with the serial monitor application in arduino software. The thermoelectric cooler module is directed supply with 12V battery. Then read the serial monitor reading and collect the data.

Time (min)	Temperature inside car (°C)	Temperature outside car (°C)
0	38	40
10	37	37
20	36	36
30	34	34
40	32	34
50	32	35
60	32	34
70	33	35
80	32	34
90	33	33
100	32	33
110	33	33
120	32	32

Table 4.4 : temperature using thermoelectric cooler

The other testing is conducted with thermoelectric cooler module attached in the car module. The user setting is set to 28 °C. The full system is connected as shown in **Figure 4.4 .Table 4.4** is the result taken during the period of time in every 10 minutes as the system running.

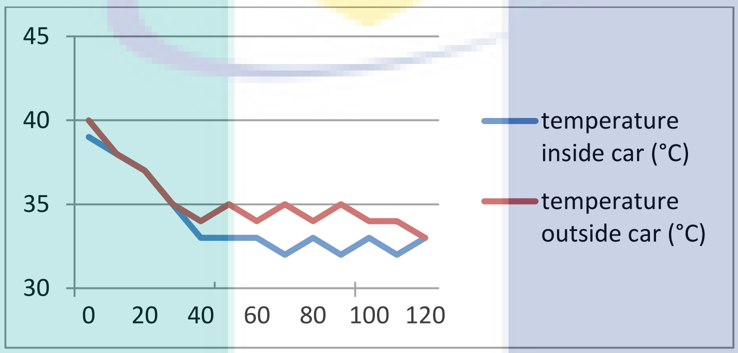

Figure 4.8: temperature graph using thermoelectric cooler module

From **Figure 4.8**, the temperature inside the car is collected are lower than the outside the car. The thermoelectric cooler module is switch on and off in order to cool the temperature inside cabin according user setting point.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In chapter 5, the whole system of project will conclude the project meet the objective or not. Every design or created. It has their own objectives and ways to achieve the goals. The objective of this project are:

1. To create air conditional from thermoelectric cooler
2. To control the temperature inside the cabin according user setting with Arduino.
   1. Thermoelectric cooler that can produce the comfortable temperature in automotive cabin
   2. Buck converter produce stability output.

As the objectives of project meet the the result, objectively and theoretically this project has finished. The project has accomplished the all objective where the system is able to create the air conditional in the cabin. The readings of temperature sensors and speed of fan will be displayed on Liquid Crystal Display (LCD).the temperature inside the cabin is set as the user need. Then the user can charged the battery while the car is start as the use of other air conditioning.

5.2 RECOMMENDATION

Any mistake or suggestion while conducting the project will be stated here. There are several improvement that can be done to improve the system capabilities of the systems in the future:

(i) Place a LED to the output to inform that the system is running.

(ii) Use the exhaust to make heat sink reduced the temperature faster.

(iii) install the thermoelectric cooler system into the real automobile and get the real result of the thermoelectric cooler.

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APPENDIX A

Arduino Programming

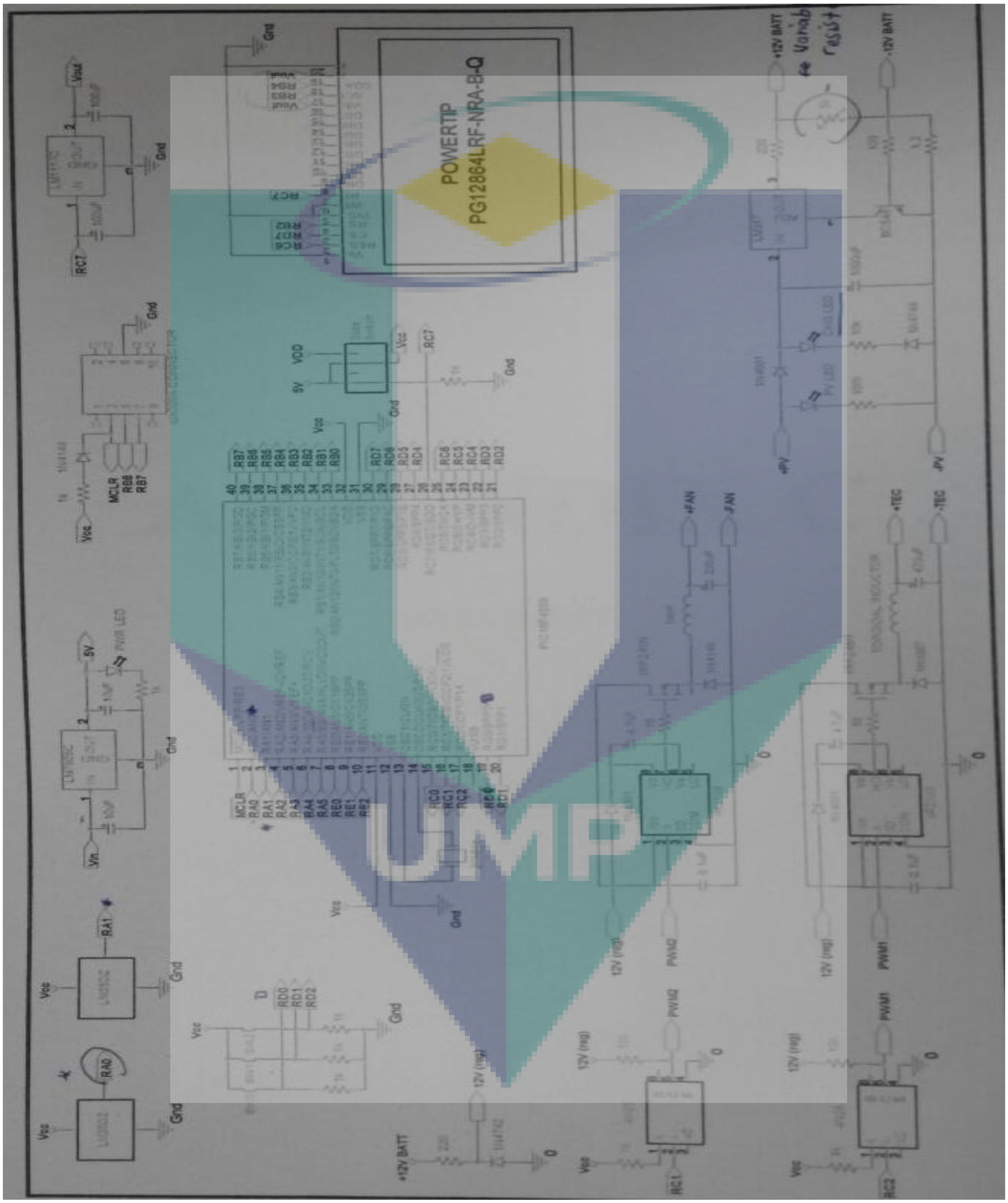
```
//Declare variables

#include<LiquidCrystal.h>

LiquidCrystal lcd(12, 11, 5, 4, 3, 2);

int tempC;

int tempPin = 0; //temp plugged analog pin 0

int ledPin = 13; //led is connected to pin 13

int fan1 = 7; //fan is connected to pin 7

int tec1 = 8;

int fanLCD;

int fanSpeed;


//write setup function


void setup()

{

Serial.begin(9600); //Open serial port to connect with temp sensor

pinMode(ledPin, OUTPUT);

pinMode(fan1, OUTPUT);

pinMode(tec1, OUTPUT);
```

```
pinMode(tempPin, INPUT);
lcd.begin(16,2);
}

//write loop that control what we want arduino do

void loop()
{

  tempC = analogRead(tempPin); // taking yhe temp pin reading and setting it equal to
        the tempC variable
  tempC = (5.0*tempC*100.0)/1024.0; //will convert the analog input into a
        themperiture in celcius
  Serial.println((byte)tempC); //will output the converted themperature to pc
   if (tempC < 29)
   {
     fanSpeed = 0;
     digitalWrite(ledPin, LOW);
     digitalWrite(fan1, LOW);
     digitalWrite(tec1, LOW);

  }
  if ((tempC >= 29) && (tempC <= 70))
  {
```

```
  fanSpeed = map(tempC, 25, 50, 32, 255);
  fanLCD = map(tempC, 25, 50, 0, 100);
  analogWrite(fan1, fanSpeed);
  digitalWrite(ledPin, HIGH);
  digitalWrite(fan1, HIGH);
  digitalWrite(tec1, HIGH);

}
if(tempC > 70)
{

  digitalWrite(ledPin, HIGH);
  digitalWrite(fan1, HIGH);
  digitalWrite(tec1, HIGH);

}
else
{
  digitalWrite(fan1, HIGH);

  }
  lcd.print("TEMP: ");
  lcd.print(tempC);
  lcd.print("C ");
  lcd.setCursor(0,1);
```

```
    lcd.print("FANS: ");
    lcd.print(fanLCD);
    lcd.print("%");
    lcd.clear();
}
int readTemp()
{
  tempC = analogRead(tempPin);
  return tempC*0.48828125;
  }
```

APPENDIX B



APPENDIX C

DATA SHEET

·M·C·C·

Micro Commercial Components

Micro Commercial Components
20736 Marilla Street Chatsworth
CA 91311
Phone: (818) 701-4933
Fax: (818) 701-4939

BC546B
BC547A/B/C
BC548A/B/C

NPN Silicon

Amplifier Transistor

625mW

Features

- Through Hole Package
- 150°C Junction Temperature
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0 and MSL rating 1
- Marking: Type Number
- Lead Free Finish/Rohs Compliant) ("P"Suffix designates Compliant. See ordering information)

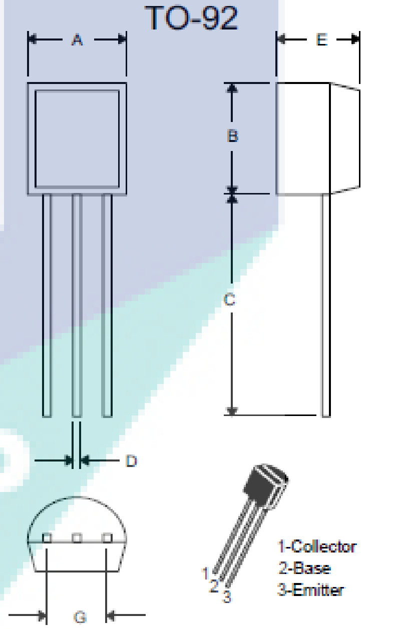
Mechanical Data

- Case: TO-92, Molded Plastic
- Polarity: indicated as below.

Maximum Ratings @ 25°C Unless Otherwise Specified

Charateristic		Symbol	Value	Unit
Collector-Emitter Voltage	BC546	V_{CEO}	65	V
	BC547		45	
	BC548		30	
Collector-Base Voltage	BC546	V_{CBO}	80	V
	BC547		50	
	BC548		30	
Emitter-Base Voltage		V_{EBO}	6.0	V
Collector Current(DC)		I_C	100	mA
Power Dissipation@T_A=25°C		P_d	625	mW
			5.0	mW/°C
Power Dissipation@T_C=25°C		P_d	1.5	W
			12	mW/°C
Thermal Resistance, Junction to Ambient Air		$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction to Case		$R_{\theta JC}$	83.3	°C/W
Operating & Storage Temperature		T_j, T_{STG}	-55~150	°C

TO-92



DIMENSIONS					
	INCHES		MM		
DIM	MIN	MAX	MIN	MAX	NOTE
A	.170	.190	4.33	4.83	
B	.170	.190	4.30	4.83	
C	.550	.590	13.97	14.97	
D	.010	.020	0.36	0.56	
E	.130	.160	3.30	3.96	
G	.010	.104	2.44	2.64	

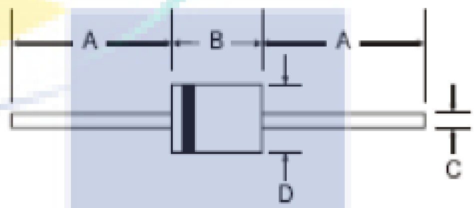
1N4001 - 1N4007

1.0A RECTIFIER

Please click here to visit our online spice models database.

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**



Dim	DO-41 Plastic	
	Min	Max
A	25.40	—
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All Dimensions in mm		

Mechanical Data

- Case: DO-41
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020D
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Mounting Position: Any
- Ordering Information: See Page 2
- Marking: Type Number
- Weight: 0.30 grams (approximate)

Maximum Ratings and Electrical Characteristics @T_A = 25°C unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

Characteristic	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ T_A = 75°C	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load	I_{FSM}	30							A
Forward Voltage @ I_F = 1.0A	V_{FM}	1.0							V
Peak Reverse Current @T_A = 25°C at Rated DC Blocking Voltage @ T_A = 100°C	I_{RM}	5.0 50							µA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +150							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

Universiti Malaysia PAHANG

PUSAT PENGURUSAN PENYELIDIKAN (RMC)

BORANG PENGESAHAN
LAPORAN AKHIR PENYELIDIKAN

TAJUK PROJEK : DEVELOPMENT OF PELTIER COOLING SYSTEM FOR AUTOMOTIVE

Saya : AMIR IZZANI MOHAMED

(HURUF BESAR)

Mengaku membenarkan **Laporan Akhir Penyelidikan** ini disimpan di Perpustakaan Universiti Malaysia Pahang dengan syarat-syarat kegunaan seperti berikut :

1. Laporan Akhir Penyelidikan ini adalah hakmilik Universiti Malaysia Pahang
2. Perpustakaan Universiti Malaysia Pahang dibenarkan membuat salinan untuk tujuan rujukan sahaja.
3. Perpustakaan dibenarkan membuat penjualan salinan Laporan Akhir Penyelidikan ini bagi kategori TIDAK TERHAD.
4. * Sila tandakan (/)

[ ]	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau Kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972).
[ ]	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh Organisasi/badan di mana penyelidikan dijalankan).
[/]	TIDAK TERHAD	

Tandatangan & Cop Ketua Penyelidik

DR. AMIR IZZANI BIN MOHAMED
SENIOR LECTURER
FACULTY OF ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI MALAYSIA PAHANG
26600 PEKAN
PAHANG DARUL MAKMUR
TEL : 09-424 6144 FAX : 09-424 6111

....

Tarikh : ~~12/~~ 7/12/2017

CATATAN : **Jika Laporan Akhir Penyelidikan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan ini perlu dikelaskan sebagai SULIT dan TERHAD.*

UMP/RMC/LA-2/07

RESEARCH MANAGEMENT CENTRE

PRELIMINARY IP SCREENING & TECHNOLOGY ASSESSMENT FORM

(To be completed by Project Leader submission of Final Report to RMC or whenever IP protection arrangement is required)

1. PROJECT TITLE IDENTIFICATION :

DEVELOPMENT OF PELTIER COOLING SYSTEM FOR AUTOMOTIVE

Vote No: 1403123

2. PROJEK LEADER :

Name : AMIR IZZANI MOHAMED

Address : FKEE UMP PEKAN

Tel : 094246144 Fax : 094246111 E-mail: amirizzani@ump.edu.my

3. DIRECT OUTPUT OF PROJECT *(Please tick where applicable)*

Scientific Research	Applied Research	Product/

		Process Development
[ ] Algorithm [ ] Structure [/] Data [ ] Other, please specify ________ ________ ________ ________	[ ] Method/Technique [/] Demonstration/Prototype [ ] Other, please Specify ________ ________ ________ ________	[ ] Product/Component [ ] Process [ ] Software [ ] Other, please specify ________ ________ ________ ________

4. INTELLECTUAL PROPERRTY *(Please tick where applicable)*

- [/] Not patentable
- [ ] Patent search required
- [ ] Paten search completed and clean
- [ ] Invention remains confidential
- [ ] No publications pending
- [ ] No prior claims to the technology
- [ ] Inventor technology champion
- [ ] Inventor team player
- [ ] Monograph available
- [ ] Industrial partner identified
- [ ] Patent Pending
- [ ] Technology protected by patents pending

5. LIST OF EQUIPMENT BOUGHT USING THIS VOT

No	Item	Serial No	Location
1	WATEC 902 ULTIMATE CAMERA	W134BC10680	FKEE UMP E11-C30

6. STATEMENT OF ACCOUNT

a) APPROVED FUNDING RM : 28 400.00

b) TOTAL SPENDING RM : 28 366.77

c) BALANCE RM : 33.23

7. TECHNICAL DESCRIPTION AND PERSPECTIVE

Please tick an executive summary of the new technology product, process, etc., describing how it works. Include brief analysis that competitive technology and signals the one that it may replace. Identify potential technology user group and the strategic means for exploitation.

a) Technology Description

This research studies the possibility of TEC to replace conventional air-cond. This promote the use of battery in a vehicle thus supporting the electric-vehicle (EV) development worldwide.

b) Market Potential

None

c) Commercialization Strategies

None

8. RESEARCH PERFORMANCE EVALUATION

a) CHAIRMAN OF FACULTY RESEARCH COMMITTEE

	Excellent	Very Good	Good	Satisfactory	Fair	Weak
Research Status	☐	☐	☐	☐	☐	☐
Spending	☐	☐	☐	☐	☐	☐
Overall Status	☐	☐	☐	☐	☐	☐

Comment/Recommendations :

____

____

____

____

____

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____

…………………………………… **Name** : ………………………………...

Signature and stamp **Date** : ……………………………………

b) RMC EVALUATION

	Excellent	Very Good	Good	Satisfactory	Fair	Weak
Research Status	☐	☐	☐	☐	☐	☐
Spending	☐	☐	☐	☐	☐	☐
Overall Status	☐	☐	☐	☐	☐	☐

Comments :

____

____

____

____

____

Recommendations :

☐ Needs further research

☐ Patent application recommended

☐ Market without patent

☐ No tangible product. Report to be filed as reference

…………………………………
Signature and Stamp of Director
Research Management Centre

Nama : ……………………………..
Date : ………………………………

FINAL OUTCOME

DETAILS OF RESEARCH PROGRAM *(Maklumat Penyelidikan)*

A Name (Project Leader) : AMIR IZZANI MOHAMED

Staff No : 01557

Grant No : RDU1403123

Type of Grant : UMP

Grant's Tittle : DEVELOPMENT OF PELTIER COOLING SYSTEM FOR AUTOMOTIVE

Faculty/CoE/Centre : AEC

Expected Output *(Jangkaan Hasil)*

B

TOTAL RESEARCH OUTPUT

i. Publications Published Under Grant

	Indexed	Non-Indexed
Number of articles in journal/ Journal	1	
Number of manuscripts		
Number of books		
	International	**National**
Indexed Conference Proceeding	1	
Non-Index Conference Proceeding		

ii. Intellectual Property

	Filed		Granted	
	International	**National**	**International**	**National**
Number of Patents				
Number of Copyright				
Number of Trade marks				

Others (please specify)				

III. Collaboration

	In the process of discussion	Signing
Memorandum of Understanding (MOU)		
Memorandum of Agreement (MOA)		
Letter of Intent (LOI)		
Others (training, sharing technology, etc.)		

HUMAN CAPITAL DEVELOPMENT

Human Capital	Number				Others (please specify)
	On-going		Graduated		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
PhD Student					
Master Student	3				1 related to this grant and 2 other study other topic
Undergraduate Student					
Total					

EXPENDITURE ***(Perbelanjaan)***

Total Budget Approved *(Jumlah peruntukan diluluskan)*	**RM 28 400**
Amount Spent *(Jumlah perbelanjaan)*	**RM 28,366.77**
Total Balance Until 15 / 11 / 2017 *(Jumlah baki sehingga)*	**RM 33.23**
Percentage of Amount Spent *(Peratusan Belanja)*	99.88 %

C

Date: **12 December 2017**
Tarikh:

Signature & Stamp:
Tandatangan & Cop:

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Development of Parabolic Concentrator- Based Thermoelectric Generator

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Keywords: power generation; waste heat; thermoelectric.

Abstract

Thermoelectric generator (TEG) is one of the solutions to produce energy from waste heat and produce pure DC voltage. TEG is based on solid state technology with no moving parts and works on the principle of Seebeck effect. In this work, TEG was combined with a solar concentrator to produce a device that able to convert solar energy to electrical energy. The concentrator was used to concentrate thermal energy from the sun onto one side of the thermoelectric module which acts as the hot side. The assembled system is able to produce maximum power output up to 0.157W with 0.479% of an efficiency achieved.

1. Introduction

Increasing pressure on the demand and increased costs related to energy and sustainability has further increased the need for the implementation of more efficient power generation systems which not only benefited to humans but also to the development of a country. Because fossil fuels such as coal, oil, and natural gas are the largest used energy sources, an intense demand exists for economically and commercially viable renewable energy source [1]. The used of fossil fuels to generate electricity is very important to the world including Malaysia. Power Generation in Malaysia is largely dependent on pipeline gas, Liquefied Natural Gas (LNG) and coal. Tenaga Nasional Berhad (TNB), the largest Malaysian energy provider releases that Gas and LNG, coal and oil/distillates required about RM 18 billion for total fuel cost only in 2014 [2]. These high expenditures are only for the running costs to light up Malaysian houses. Besides increasing in energy demand as a factor, the escalated of gas prices and government's gradual rationalization of subsidies for regulated domestic gas also contribute in high expenditures for the reliable power system [3]. The fuel cost expenditures for TNB shows a big increase from RM11.2 billion in 2013 to RM13.3 billion in 2014 [4]. All of this facts and numbers proved that large cost is needed to support the energy demand and were expected to not decrease.

One of the alternative energy solution to reduce the use of fossil fuels in generate electricity is by using TEG. TEG may be utilized to recover waste heat from systems which then will be convert into electrical power [5] without the need of moving components. Presently, it is used as a low power application as remote and off-grid power generators for unmanned sites, solar PV back-up and waste heat recovery for automobiles. Even though the efficiency for TEG is relatively small, yet this device still can be considered to enter high power application. As a comparison to Photovoltaic (PV) Generator, TEG is much smaller, lighter and it doesn't require big space. With the increasing cost of fossil fuels and waste heat recovery technology causes TEG become better known, especially in the applications in the rail system as well as in the communication system [6].

In addition, more researchers have been engaging in these semiconductor materials since it was discovered in 1950s because of their better thermoelectric performance than pure metals [7]. After the energy crisis in 1970s, the researches on TE power have been a spotlight all over the world [8]. Nowadays, with the increasing gap between limited supply and increasing demand of power, researches on waste heat recovery by TEG becomes critical. The available waste heat sources includes industrial heat-generating process, the exhausted waste heat of transportation vehicles, solar energy, combustion of solid waste and geothermal energy and so on [9]. A typical TEG driven by solar power usually consists of a thermal collector which used to absorb heat from the solar radiation and the heat will be carry through a groups of flow pipes to the TEG.

Building Scientific Research Center (BSRC) [10] presented a new concept of roof design named "The Thermoelectric Roof Solar Collector (TERSC)", be made up of thermoelectric modules (TEM), a rectangular fin heat sink, a copper plate, a transparent acrylic sheet and air gap. Research results showing that 1.2W power can be obtained using 10 TEM in 0.0525 m^2 surface area, under solar radiation intensity of about 800 W/m^2 at ambient temperature between 30 and 35^oC. Even with the electrical conversion efficiency is low as 1-4%, it is still popular in remote areas and some special fields. In this paper, a TEG system based on solar concentration is proposed as an effective way in harvesting the waste heat. The heat source from concentrated solar radiation is used to generate the electricity. TEG is known to have very small energy conversion efficiency. So, to obtain the best output, thermal energy that needs to supply to the TEG must be sufficient.

2. Theory

2.1 TEG operation

For estimating the TEG efficiency and electric output power, a widely used formula based on the TE material characteristics figure of merit ZT with the unit for Z is 1/^{o}C can be found in [11]:

$$Z = \frac{{\alpha_{seeb}}^2}{\rho^k} \quad (1)$$

Where a- Seebeck coefficient, ρ- electrical resistivity and k-thermal conductivity are the most crucial parameters for TEG units. In general, the efficiency of the TE module output can be estimated [14].

$$n = \frac{\Delta T}{T_{hot}}\left(\frac{\sqrt{1+ZT_m}-1}{\sqrt{1+ZT_m}+T_{cold}/T_{hot}}\right) \quad (2)$$

Where T_m is TEG module mean temperature, $\Delta T = T_{hot} - T_{cold}$ if the temperature difference between TEG hot and cold sides. The values of thermal conductivity, electrical resistance and Seebeck coefficient are all temperature dependent. Furthermore, to get an accurate estimation of TE module parameters, temperature gradients within the TE-module legs have to be taken into account and the TE material properties is constant over the full operating temperature range. This will provide some additional error margin, but given the approximation of the input data, it can be expected not to give significant variation in the results.

TEG operating is dependent on both hot and cold temperatures (T_{hot} and T_{cold} respectively) and the temperature difference between the cold and hot sides. Using the common TEG unit model with source resistance (see Fig. 1), TEG output voltage can be estimated using the Seebeck coefficient and temperature difference ΔT as

$$U_{TEG} = \alpha_{Seeb}\Delta T - R_{TEG}.I_{load} \quad (3)$$

Where α is a Seebeck coefficient, R_{TEG} is resistance of the TEG and I_{load} is the current of the load in the TEM. The electric output power of the TE module is [15]

$$P_{load} = {I_{load}}^2.R_{load} = \frac{{\alpha_{Seeb}}^2.\Delta T^2}{(R_{TEG}+R_{load})^2}R_{load} \quad (4)$$

Maximum power output is reached with the load resistance $R_{TEG} = R_{load}$. This case is referred as maximum power point (MPP) operation

$$P_{load,max} = \frac{{\alpha_{Seeb}}^2.\Delta T^2}{4R_{load}} \quad (5)$$

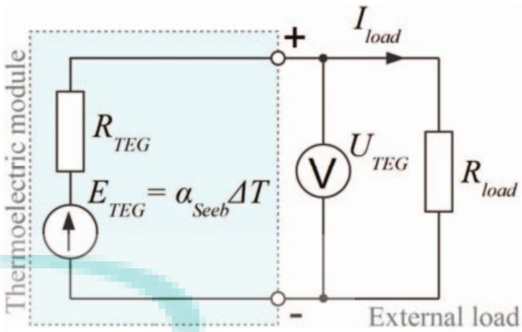

Fig. 1: TEG unit equivalent circuit with external load [12].

3. Methodology

There are four experiments conducted in this project. All the experiment was done using the same Bismuth Telluride (Bi_2Te_3) thermoelectric module. The parameters of TEM output are taken with and without load. The load used in this experiment is a dummy load with the value of 10Ω, 0.25W. A dummy load was used in purpose to characterize the performance of TEM with the load.

The first experiment was conducted just by using one TEM in the TEG. The objective for this experiment is to determine the voltage, current and power output that can be generated by using just one TEM. In the second experiment, two identical TEM were used and connected in series connection. The objective of this experiment is to characterize the performance of series connected TEM. In the third experiment, two identical TEM were used and connected in parallel connection. The objective of this experiment is to characterize the performance of parallel connected TEMs. The results of series and parallel experiment will be compared with each other.

Before each TEM installed into TEG, all of them are tested with fire and heat sink first. The objective for this action is to make sure every TEM can work perfectly before it was taken to experiments. The first testing was done by using a multimeter to check the continuity of TEM. Both probes were attached to the positive and negative wire of the TEM. If there is no open circuit, the TEM should be in good condition. The TEM was also tested with small fire from several candles. A heatsink was attached at the cold side of the TEM. If the TEM is in good condition, the multimeter will show some voltage generated as shown in Fig. 2.

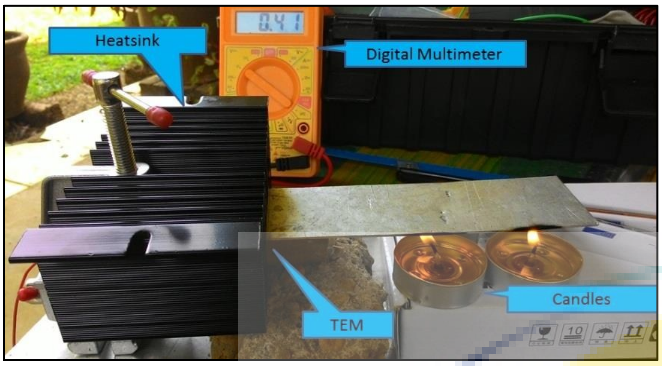

Fig. 2: TEM testing setup using candle and heatsink

3.1 Parabolic concentrated Thermoelectric Generator System

The system block diagram in this paper is shown in Fig. 3. It features four main parts which are solar concentrator, receiver, cooling system and load. The source of thermal energy comes from solar radiation. The concentrator then will reflects and concentrates solar radiation from sun to the receiver. The receiver which contains TEM will then absorbs the thermal energy and converts it into electrical energy. As mentioned before, TEM needs differential temperature between hot side and cold side (ΔT) to generate electricity. So the cold side needs to be maintained at low temperature. To maintain the low temperature, water is used. After the TEM able to generate electrical energy, the output of TEM will be connected to DC-DC converter. The converter used is Boost type converter, functioned to boost the voltage lower than 5V to fixed output of 5V. Any loads that use 5V input can be connected to the output of the DC-DC converter.

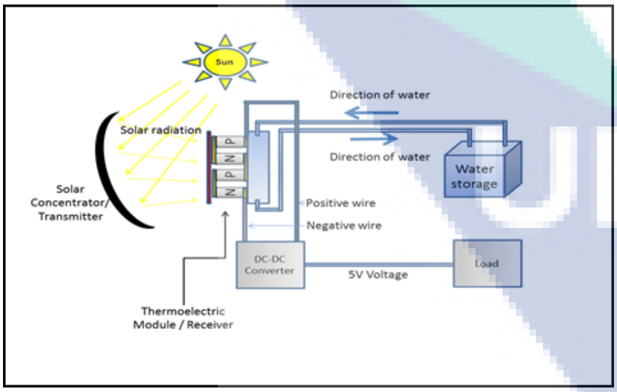

Fig. 3: Thermoelectric generator with solar concentrated system layout

Thermoelectric material was placed inside the TEG to act as a receiver. Two pieces of SP1848-27145 SA TEM device was chosen. The size of TEM was 40mm x 40mm dimension each. A plate of aluminum 120mm x 150mm was attached to the TEM surface. Aluminum plate is chosen because of its high thermal conductivity which it will function as heat conductor to allow thermal energy from concentrated solar radiation to enter the TEM. Thermal paste which also an excellent heat conductor was applied at the surface of TEM before the TEM was attached to make sure there is no microscopic air gap between the aluminum plate and TEM

3.2 Heat transfer

At the hot side of TEM, a high thermal energy was needed to get the highest temperature difference (ΔT) possible. As mentioned before, the hot side of TEM was attached to an aluminum plate with help of thermal paste. A parabolic dish concentrator was used to collect sun radiation and focused it to a point on the aluminum plate. The concentrator was made out by using a television satellite dish transmitter and a lot of pieces of mirror. Television satellite dish is a perfect dish for a concentrator because it was designed as a transmitter.

For the cold side, a cooling system was used to maintain the low temperature. It was a tricky part of this project to maintain the low temperature because a TEM is made from very high thermal conductivity materials. So it is important to make sure that the cold side does not receive too much heat from the hot side because it may get the TEM to be broken. The cold side of TEM will be attached to a pipe made from an aluminum trunk. Inside the pipe, pumped water will flow through it. The water will absorb the heat from TEM and cool of the cold side of the TEM. The water was stored inside a polystyrene box and circulated by using a water pump. It will travel from the polystyrene box through the plastic pipe and the aluminum pipe to carry heat from cold side of TEM. It then flows back through the plastic pipe into the polystyrene box. With the data taken from the experiment, the proposed model of the TEG hardware is design. After several design have been considered, the final shape for TEG hardware is as shown in Fig.4 below.

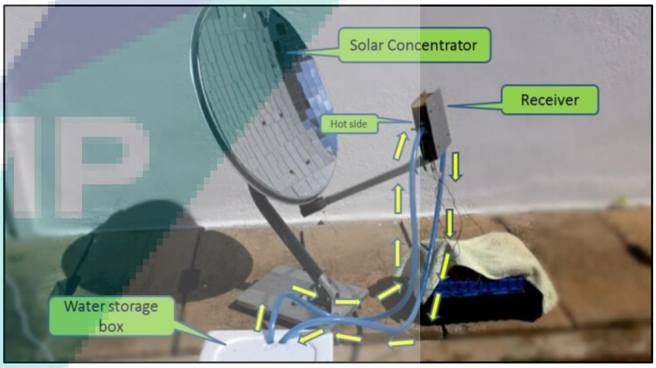

Fig. 4: Thermoelectric Generator System Hardware

There are four main parts of this TEG system which are parabolic solar concentrator, solar receiver, cooling system and loads. The parabolic solar concentrator will serves to reflect and concentrates solar radiation to the receiver. The solar receiver, contained with TEM will absorb the thermal energy from solar radiation. To generate electrical energy, TEM needs temperature difference between hot side and the cold side of TEM to create the temperature difference, a cooling system which made from aluminum trunk, water and polystyrene box will serve to remove the heat from the cold side. The output from TEM will then be connected to several loads. For the loads that need 5V input, the output of TEG will be connected to DC-DC converter first it goes to the load. The parameters taken from the experiment are open circuit voltage (V_{OC}), short circuit current (I_{OC}), voltage with load (V_{load}), current with load (I_{load}), temperature for hot side and cold side, and ambient temperature.

4. Result & Discussion

The electrical power output from the parabolic dish thermoelectric power generator over temperature difference is illustrated in Fig. 5, Fig. 6 and Fig. 7. The highest value data from the experiment is taken and tabulated as in table 1 below. The measured current and voltage for constant resistance of 10Ω in terms of electrical power generation. To obtained the value of power, the formula use is:

$$P = IV \qquad (6)$$

Where P-power, I-current and V-voltage. The differential temperature, ΔT can be simply calculated using hot side temperature and the cold side temperature using formula:

$$\Delta T = T_h - T_c \qquad (7)$$

Where T_h is hot side temperature and T_c is cold side temperature.

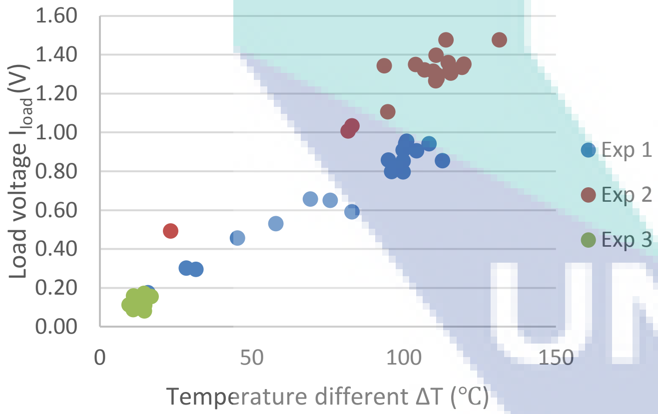

Fig. 5: Graph of voltage with load against delta T for all experiments.

The output voltage produced by a series connection in experiment 1 and 2 is way higher than output voltage of parallel connection in experiment 3 as shown in Fig. 5. While voltage output for both experiment 1 and 2 is increase rapidly, voltage output for experiment 3 is constantly dropping.

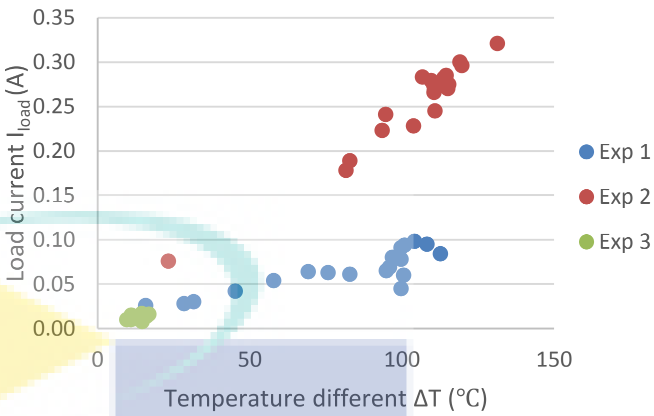

Fig. 6: Graph of current with load against delta T for all experiments.

Fig. 6 shows temperature rise with the respect of increasing current load. The resulting current load as a function of temperature different in experiment 1 and 2 shows a good linear fit. We found that the slope of the temperature different change with respect to the load current coincided with the value calculated using equation 7 which is not shown in this paper for simplicity because the trend of the calculations curve is the same as the experiment.

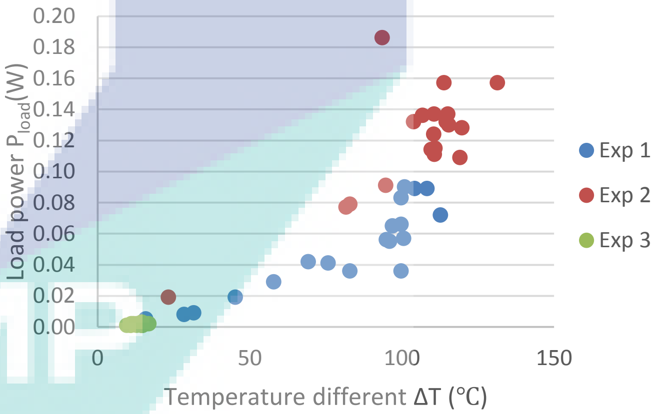

Fig. 7: Graph of power with load against delta T for all experiments.

Based on the graph in Fig.7, the maximum power output of 0.157W was obtained when the temperature difference between the hot side and cold side of TEM was at the highest degree which is 135°C. By using the calculation method in equation 2, the maximum efficiency achieved is 0.479%. It can be considered as very low efficiency compared to Bi_2Te_3 TEM studied by R. Amatya [13] which have 3% efficiency. However, further details of TEG efficiency value has not been studied in this paper and will be researched in the future for a better understanding of its advantages and disadvantages.

As shown in table 1, parameters obtained for experiment 2 and experiment 3 suggest that series connection of two TEM is better than parallel connection as the output power of TEM with series connection is much higher compared to TEM with parallel connection. For some reason, the output from parallel connection is very low and not consistent. Even though the temperature difference is low, the output of this connection is still lower than single TEM output. Referring to the research done by Andrea [14], the parallel connection will leads to higher I^2R losses. So the parallel connection can leads to low performance of TEG system. The illustrated results show that connecting TEG in series produces better electrical system efficiency, provided that the load remained constant. The temperature-mismatch situation leads to a power production drop from 0.157W to 0.003W, for the series and parallel case respectively.

Exp.	V_{load}/V	I_{load}/A	P_{load}/W	ΔT/°C
1	1.230	0.128	0.157	131.5
2	0.946	0.086	0.081	81.4
3	0.184	0.014	0.003	83.2

Table 1: Highest values of data obtained from all experiment.

5. Conclusion

The power generation from the combined system of parabolic concentrator and thermoelectric modules was developed. The results of the temperature, power output and overall conversion efficiency are derived from the experimental carried out with different amount and connection of TEM. The performances of the systems are greatly affected by the heat sink temperature. The presented results suggest that the pattern of load voltage, current and power for the series connection with two TEM produced is not too much different from the previous parameter of one TEM series connection. Thus, the series electrical connection enables more of the available power to be captured. However, the connection of two TEM with parallel connection leads to a low performance of the TEG system. The experimental shows that the generation of electrical power with the use of low cost parabolic concentrator and thermoelectric modules is a feasible option and also suitable for isolated energy demand where the conventional grid is not available.

Acknowledgement

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DEVELOPMENT OF HYBRID THERMOELECTRIC AND PHOTOVOLTAIC POWER GENERATION

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ABSTRACT

Hybrid photovoltaic and thermoelectric systems more effectively convert solar energy into electrical energy. Two sources of energy are used in this project. One of the energy is solar energy that converts radiant light to electrical energy. The other one is heat energy, which converts heat energy into electrical energy. Therefore, this project will utilize both of the solar radiation and heat from the sun as to generate more electricity. The aim of this project is to build a hybrid system that will increase the efficiency of the power generation system. In this research, the output power of the hybrid is equal to the sum of the maximum output power that produced separately from the individuals of the PV module and TE generator devices. The maximum output power that can be generated was up to 99.27 watts respectively. Overall, by using hybrid PV-TE generator system, the output that can be generated is better than the individual system.

Keywords: photovoltaic, thermoelectric, hybrid system, solar radiation.

INTRODUCTION

8th Malaysia Plan (2001–2005) has targeted to generate 5% of the country's electricity from renewable energy sources by 2005. However, only 0.3% was achieved. This was further emphasized in the 9th Malaysia Plan where the efforts in the utilization of renewable energy resources and efficient use of energy were extensively promoted [1]. The actual harvesting of solar energy is still below their full potential. Therefore, by applying a hybrid system could help to increase the conversion efficiency.

This paper will explore the possibility of integrating the PV system with thermoelectric (TE) generator in order to increase the power generation. The two sources of energy which are solar and heats will be utilized to convert into electricity. PV directly converts into electricity from sunlight (solar radiation) while TE generates electricity when there is a different temperature occurs at the junction of two conductors according to the Seebeck effect. There is a huge potential of employing TE generator in which various wasted heat sources can be harvested to convert into electricity. One of advantage of TE generator is that it is free of maintenance and ease in operation just like a PV system.

This paper will deeply focus on the designing and modelling a hybrid TE and PV power generation system. The remainder of this paper is organized as follows: Section 2 discusses the basic theoretical studies of TE. The research methodology is given in Section 3. Then, result and discussion are given in Section 4 and finally concluding remark appears in Section 5.

PV AND TE POWER GENERATOR

TE power generator is a device that will convert heat into electrical energy by applying the Seebeck effect. TE is one of the technologies that are to be deemed to recover and convert the industrial process of waste energy into more useful electrical energy. It will generate electric current when there is a difference in temperature between its both sides. In one study, it shows the possibility to take benefit from the waste heats produced by manufacturing industries in Thailand by generating electrical energy harvested using TE generator system. Besides, the economic viability of the TE generator can also be increased when used for the waste heat recovery [2].

PRINCIPLE OF TE

There are four main energy processes taking place in the TE pellets, which are thermal conduction, Joule heating, the Peltier cooling/heating effect, and the Seebeck effect. The phenomenon of thermal conduction is a Fourier process that is described by the thermal conductivity κi of the material. For a TE with N thermocouples, the heat transfer of thermal conduction in a TE is described by

$$Qth = -\Delta T \kappa th \qquad (1)$$

where κth is the thermal conductivity of TE and ΔT is a different temperature between hot and cold side. The total Joule heat dissipated in an N-couple TE is

$$Q_J = I^2 R \qquad (2)$$

where R is its electrical resistance. I is the electric current that flow through TE. Irrespective of the temperature gradient, the Joule heat can be considered as equally divided between the two sides of the TE. The absorbed/emitted heat of an N-couple

$$Q_{PH/PC} = SIT_{H/C} \qquad (3)$$

where S is the Seebeck coefficient and $T_{H/C}$ is the temperature of the hot or cold side.

When a temperature gradient is imposed on a conductor under an open-circuit condition, the creation of an electrical potential difference between the hot and cool sides of the conductor is called the Seebeck effect. The

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generated Seebeck voltage, called the electromotive force (EMF), in a TE is expressed as

$$U_S = S\Delta T \quad (4)$$

Applying the concept of energy equilibrium for steady-state analysis at both sides of the TE, the absorbed heat generated by the thermal load, Q_C, and the liberated heat removed by the heat sink Q_H, are respectively given by

$$Q_C = SIT_C - 0.5I^2R - \kappa_{th}\Delta T \quad (5)$$

$$Q_H = SIT_H + 0.5I^2R - \kappa_{th}\Delta T \quad (6)$$

where T_C is the cold side temperature and T_H is the hot side temperature. The TE's output voltage is then

$$V = U_S + IR \quad (7)$$

A good TE must combine a large Seebeck coefficient S with low electrical resistance R and low thermal conductivity κth. The figure-of-merit (FOM) parameter is then defined as

$$Z = \frac{S^2}{R\kappa_{th}} \quad (8)$$

where Z is the figure of merit. The regular parameters of TE involves the hot temperature,T_H ,cold temperature, T_C, the power at the load matched, W_m, to the internal resistance (R_L = R); the load voltage at the matched load, V_m (=V_R); and the maximum thermal efficiency, η_{th}^{max}. The electrical resistance R and the Seebeck coefficient S of a TE can be expressed as

$$R = R_L = \frac{V_m^2}{W_m} \quad (9)$$

$$S = \frac{2V_m}{\Delta T} \quad (10)$$

In fact, the efficiency of a TE is a function of the load. Assume that the load resistance is defined as R_L = mR, where m is the resistance ratio between the load and internal resistance. The current can be expressed as

$$I = \frac{S\Delta T}{[(1+m)R]} \quad (11)$$

The thermal efficiency of a TE generator is defined as the ratio of the electric power output to the thermal power input to the hot side, which can be expressed as

$$\eta_{th} = \frac{I^2R_L}{Q_H} \quad (12)$$

The maximum current of TEG is the short-circuit current at zero load voltage, V_L=0 which referred as

$$I_{shortcircuit} = 2I_m = \frac{2W_m}{V_m} \quad (13)$$

Based on Ohm's Law and the resulting Equation. (12) and (13), the voltage of TE generator can be obtained as

$$V = -R(I - I_{shortcircuit}) \quad (14)$$

PV THEORY

PV is a part of the way, which can produce electrical energy by converting sunlight into direct current electricity by using semiconductor materials showing photovoltaic effect. The output of the PV module influences by the cell temperature, solar irradiance and the output voltage of the PV module [2]. The equivalent circuit of PV cell can be described as shown in Figure-1. The I_{ph} represent the photocurrent. I_o is the saturation current. While for R_{sh} and R_s represent the shunt and series resistance of the PV cell. Detail equation for PV cell is stated in [3].

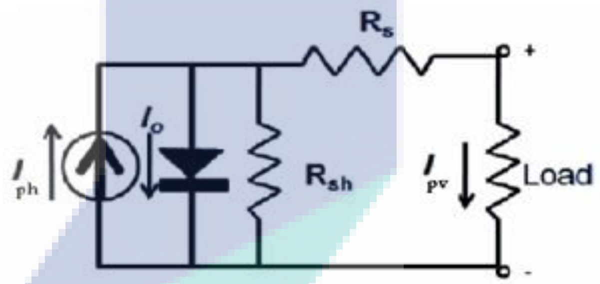

Figure-1. Condition the PV cell equivalent circuit [3].

The I-V and P-V output curve are the two important characteristics that should be considered in designing a PV system. These characteristics depends on the solar irradiance, temperature and output voltage from the PV module. The I-V curve is the output current-voltage characteristic of a PV cell or module. With this output curve, the maximum power can be obtained. The Figure-2 illustrates the I-V and P-V curves.

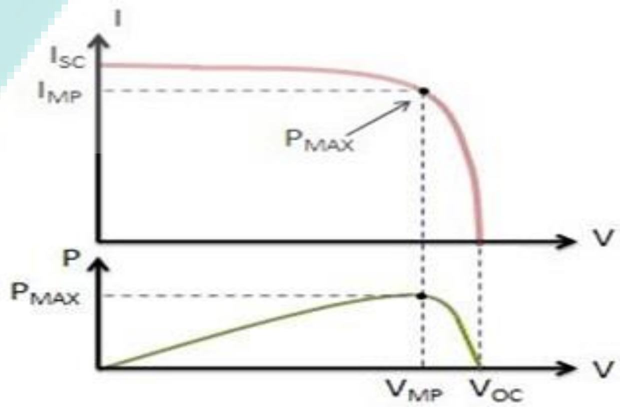

Figure-2. I-V and P-V output curve characteristics.

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The current and voltage at this maximum power point are designated as maximum power voltage, V_{mp} and maximum power current, I_{mp}. By referring to the value of V_{oc} and I_{sc} of the PV module or cell, the value of V_{mp} and I_{mp} can be estimated. In the Standard Test condition (STC) this curve can be generated [4].

HYBRID TE AND PV SYSTEM

The output power of a PV system depends on temperature and solar radiation [5][6]. It will increase as the solar radiation increased. However, when the temperature increases, it will reduce the output power of the PV module. In addition, the researchers also stated that the used of MPPT circuit is much recommended to be used in the hybrid system because it will stabilize the output power of the PV system [7]. Meanwhile, in one case study states that by using a dynamic analysis of hybrid TE and PV configuration using MATLAB the efficiency of the system will increase [8].

RESEARCH METHODOLOGY

Prior to developing the hybrid system, simulation is required in order to get optimal system design. There is a need to test for different temperature for the TE generator modules. The objective of this test is to obtain the performance of TE generator at different temperatures between the hot and cold sides of TE module. The Matlab Simulink software is utilized in this project for the collecting and assessing the data. In the first step, the characteristic of the individual system of TE generator and PV system will be evaluated. Then, a complete system of the hybrid system will be simulated to study its performances. Finally, the hybrid system is developed. The performance of the system was tested with the real data. A comparison is made between simulation and real results.

TE GENERATOR

Table-1 provides the specification of TE generator that was used in designing the hybrid system.

Table-1. Specifications of TE generator.

Brand Name	Thermonamic
Model Number	TEG200-24V
Heat source	543 K
Water temperature	300 K
Matched output power	200 W
Matched load output Voltage	24 VDC
Matched load output current	8.4 A
Open circuit voltage	48 VDC
Dimension Size	106 mm × 120 mm × 600 mm

The different temperature can be determined by using Equation. (15) and Equation. (16).

$$\Delta T = T_h - T_c \tag{15}$$

$$\Delta T = \frac{(T_h + T_c)}{2} \tag{16}$$

Based on T_h and T_c, the T_{ave} can be determined based on the value of V_m=24 V, W_m=200 watt and ΔT= 243K and using the Equation. (9) and (10). Thus, the electrical resistance, R and the Seebeck coefficient, S of a TE generator can be obtained. Through Equation. (11), the current value can be obtained with value m=1, R=2.88 and S=0.1975. The Q_H and k_{th} in W/m^2 can be determined by

$$k_{th} = \frac{Q_L}{A\Delta T} \tag{17}$$

where Q_L is the amount of heat transfer through the material in J/S or Watt and A is the area of the body in m^2. ΔT is the difference temperature between cold and hot side. When the value Q_H and k_{th} are obtained, the thermal efficiency can be determined by using

$$\eta_{th} = \frac{I^2 R_L}{Q_H} \tag{18}$$

The FOM can be defined by

$$Z = \frac{S^2}{R k_{th}} \tag{19}$$

Given the FOM, the TE generator's thermal efficiency can be determined by

$$\eta_{th} = \frac{mZ\Delta T}{\{(1+m)^2 + Z[(m+0.5)Th + 0.5\,Tc)]\}} \tag{20}$$

TE generator efficiency is the function to the ratio of m. So that, the maximal efficiency can be determined by using

$$\eta_{th}^{max} = \frac{(m_{opt} - 1)\left(\frac{\Delta T}{T_h}\right)}{\left(m_{opt} + \frac{T_h}{T_c}\right)} \tag{21}$$

Where,

$$m_{opt} = (1 + ZT_{ave})^2 \tag{22}$$

Therefore the maximal efficiency that gets from equation (21). Given the parameters of a commercial TE generator, the resistance ratio m can be obtained as

$$m_{opt} = \frac{(\Delta T + \eta_{th}^{max} T_c)}{(\Delta T - \eta_{th}^{max} T_h)} \tag{23}$$

After that, the FOM of the TEG can be found as

$$Z = \frac{(m_{opt} - 1)}{T_{ave}} \quad (24)$$

Then, the thermal conductivity of TEG can be determined

$$k_{th} = \frac{S^2}{RZ} \quad (25)$$

The efficiency at the matched load is expressed as

$$\eta_{th,m} = \frac{Z\Delta T}{[4 + Z(1.5T_h + 0.5\ T_c)]} \quad (26)$$

The FOM of the TEG is then calculated by

$$Z = \frac{4\ \eta_{TEG}^{max}}{[\Delta T - \eta_{TEG}^{max}(1.5T_h + 0.5\ \times\ T_c)]} \quad (27)$$

PV SYSTEM

In general, PV module will convert energy from the sun into DC current. The DC current will flow through a power conditioner to supply load through an inverter. The daily output or energy produced by a PV module is given by

$$EPV = A_{PV} \times E_{sun} \times \eta_{PV} \times \eta_{inv} \times \eta_{wire} \quad (28)$$

where A_{pv} is the area of the PV module, Esun is daily solar irradiation. η_{PV} is the efficiencies of PV module, η_{inv} is the efficiencies of inverter and η_{wire} is the conductor efficiency. The difference between the energy at the front end of a PV system, E_{PV}, and at the load side is given by

$$Energy\ difference = \sum_{k=1}^{366}(E_{PV} - E_L), \quad (29)$$

where E_L is the load energy demand.

The energy difference may be either positive ($E_{PV} > E_L$) or negative ($E_{PV} < E_L$). If the energy difference is positive, it means that there is an excess of energy, and if it is negative then there will be an energy deficit. The excess energy is stored in batteries in order to be used in case of an energy deficit. Meanwhile, the energy deficit can be defined as the disability of the PV array to provide power to the load at a specific time. For optimizing SAPV, the following parameters are defined for sizing a PV array and battery storage, respectively.

$$c_v = \left(\frac{c_{pv}}{c_L}\right) \text{ and } c_S = \left(\frac{c_B}{c_L}\right) \quad (30)$$

where C_B and C_{PV} are the battery capacity and PV array capacity at the specific load, respectively. C_L is the load demand.

Solar radiation and temperature that were taken from the weather station will be used to calculate the generated current and the generated power. With the using formula below, the generated current and generated power can be obtained. These outputs will be compared with the output that generated from the MATLAB Simulation. Solar radiation and temperature will become the input to generate current and power output. The generated current under standard condition (25°C) is given as

$$I(T_1) = G\ \times \frac{I_{SC}(T_1)}{G_{nm}} \quad (31)$$

where T_1 is the standard temperature under test condition (25°C), G is solar irradiation in w/m^2, I_{sc} is the nominal current of the module in A and G_{nm} is nominal solar irradiation (1000 W/m^2). Then, using equation (32), the generated current at a given temperature, I_L can be computed.

$$I_L = I(T_1)\ \times\ (1 + K(T - T_1)) \quad (32)$$

where T is the temperature of the area under study and K is the temperature coefficient of the module at I_{sc}. The generated power can be calculated by using the formula below

$$P = I_L\ \times\ V \quad (33)$$

V is the PV module open circuit voltage.

MPPT is a technique that is used by solar charge controller to get the maximum possible power from a PV system [9]. MPPT is used for prediction of the maximum power point occurrence by using perturb and observation. An algorithm will find maximum by reading voltage and current. From that, it will increase the fill factor [10]. Maximum efficiency is defined by the ratio between the maximum power and the incident light power. While, the fill factor is the ratio of the maximum power that can be given to the load and the product of Voc and Isc. The maximum efficiency and fill factor are defined by formula as shown below.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{max}\ \times I_{max}}{A\ \times G_a} \quad (34)$$

where G_a is the ambient irradiation and A is cell area.

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{V_{max}\ \times I_{max}}{V_{oc} \times I_{sc}} \quad (35)$$

where V_{oc} is the open circuit voltage and I_{SC} is the short circuit current, respectively.

SYSTEM MODELING AND HARDWARE DEVELOPMENT

The hybrid system combines with the solar PV system with the reliability and heating capability of a TE generator. Figure-3 shows the block diagram of a hybrid system between TE and PV power generation. The energy deficit is identified as the disability of the TE and PV module to provide power to the load at a specific time.

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The Figure-4 and Figure-5 show the complete model of the hybrid.

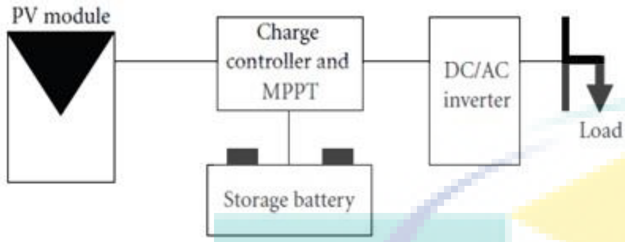

Figure-3. The PV block diagram.

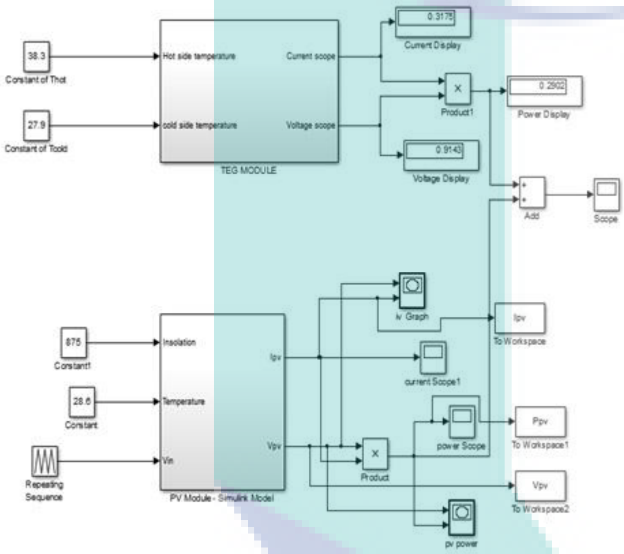

Figure-4. Hybrid system in MATLAB.

Figure-5. TEG development.

RESULTS AND ANALYSIS

To test the system, hot water was boiled by using a water heater. In the experiment, the result was recorded every three minutes. The initial reading for the hot and cold temperature is at 27.7 °C and 28.8 °C, respectively. The TE system can generate power between 0.0036 to 19.22 watts for the temperature range between -1.3 °C to 42.4 °C. The result shows that the power generated from TE generator increases as the temperature increase. In simulation, the power that can be generated is between 0.0042 to 4.82 watts. As illustrated in Figure-6, the output voltage that can be reached was 6.40 volts. The output current that can be generated ranges from 1.49 A to 3.25 A. While from simulation, it can generate from 0.79 A to 1.65 A. The output current that was taken from measurement is higher than from simulation.

For analysing the performance of the PV system, a model was created based on the real PV module specifications. SW80 mono/R5E Solar World PV module was used to design the system. Detailed PV module specifications are given in Table-2. The location of the experiment was carried out in the Universiti Malaysia Pahang. The experiment was run under different temperature and solar radiation as given in Table-3. When the solar radiation increases, the current and voltage also increase. The Figure-7 shows the power generated that was taken from the 8.00 am to 5.00 pm. It shows the measured power from the PV module and the power from MATLAB simulation.

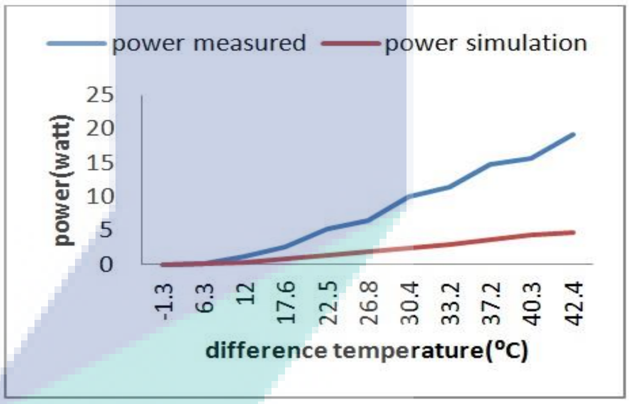

Figure-6. The output power of TE generator vs different temperature.

Table-2. Specifications of SolarWorld PV module SW80 mono/R5E.

P_{max}	80 Wp
V_{mpp}	17.5 V
I_{mpp}	4.6A
V_{oc}	21.9V
I_{sc}	5.00 A
NOCT	46 °C
Thermal coefficient I_{sc}	0.036 %/K
Thermal coefficient V_{oc}	-0.33 %/K
Rated power	80 Wp +/- 5 %

The power that generated show in Figure-7 below is slowly increased from 8.00 am to 1.00 pm with the total

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generated power between 25.72 to 97.94 watts. Then, from 2.00 pm to 5.00 pm, it slowly droped due to the decrease of the solar irradiance and temperature. Based on the simulation result, the output power is almost the same with the actual measured values. The power starts to increase from 25 to 88 watt and drop from 86 to 22 watts. The graph shows that the power measured is higher than simulation.

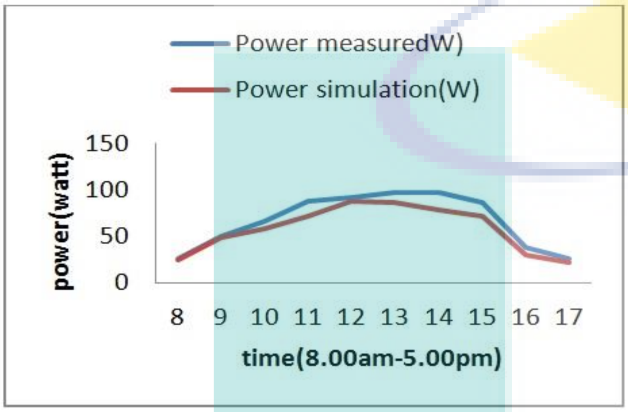

Figure-7. The power vs time of the PV module measured and simulation.

Table-3. Temperature and solar irradiance.

Time (hour)	Temperature (°C)	Solar irradiance (w/m^2)
8.00	25.6	294
9.00	25.8	587
10.00	27.4	663
11.00	28.0	819
12.00	28.6	1018
13.00	28.5	993
14.00	28.3	896
15.00	27.8	816
16.00	27.8	376
17.00	27.6	285

The experiment between the PV module and TEG was conducted. During the experiment, the solar irradiance range between 819 w/m^2 to 1023 w/m^2. While for the ambient temperature was between 28 °C to 28.6 °C. The reading of parameters were recorded every 15 minutes. As the hot-side temperature increase, the cold-side temperature also increases. Figure-8 shows the relationship between the output power of PV-TEG versus solar irradiance. It compares between measured value and simulated value. The measured output power is higher result compared to simulation.

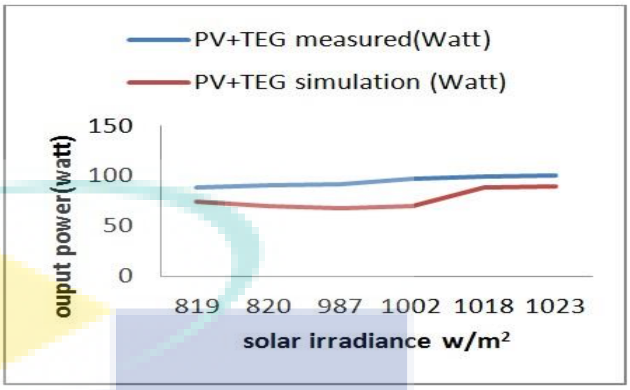

Figure-8. Hybrid power output vs. solar irradiance.

Theoretically, if the solar irradiance increase, the output will also increase. While in the Figure-9 below shows the hybrid output power versus time. This is due to the increase of temperature difference between the hot side and cold side. In this case, it is also shown that the measured output power is higher than the simulation value. Figure-10 shows the power generated by the measured and simulated value of the hybrid system. The hybrid output power measured is higher simulation value. Overall, by using a hybrid PV-TE generator system, the output that can be generated is higher compared with output power of the individual experiment.

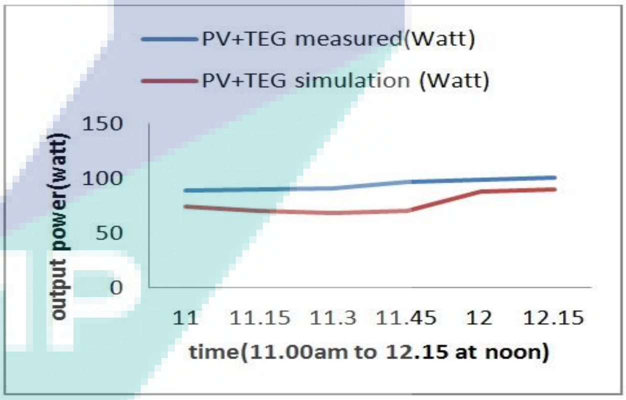

Figure-9. Hybrid output power vs time.

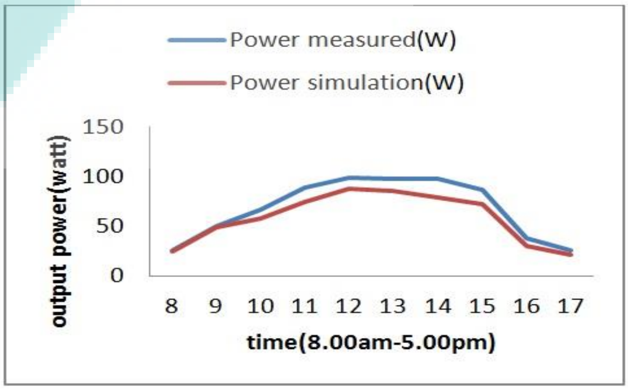

Figure-10. The output power of hybrid TE-PV system vs time.

CONCLUSION AND RECOMMENDATION

Based on the result and analysis of the development of the hybrid system between the PV and TE power generation, it showed that the system can produced a better power generated. It was stated that with the increasing in the difference temperature between the hot side and the cold side of the TE generator system, the output would increase. However, during the experiment, the voltage that can be generated is below than 10 volts. The highest value that can be generated from the individuals TEG experiment is about 6.40 volts only. The boiler that has been used can heat up the water up to 100 °C. However, TE may withstand up to 250 °C. Theoretically, the voltage should increase as the hot temperature increased and the temperature differences between the hot and cold sides must be as far as possible. To overcome this problem, the best liquid to replace water is oil that can keep a higher temperature. Another thing to consider is the flow rate of both cold and hot liquids. A study is required in order to optimize the flow rates. Overall, the proposed hybrid system could produce more power than the independent system.

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