DESIGN AND DEVELOPMENT OF ALTERNATIVE POWER GENERATION SYSTEM FROM HEAT SOURCES

(REKABENTUK DAN PEMBANGUNAN SISTEM PENJANAAN TENAGA ALTERNATIF DARIPADA SUMBER HABA)

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DEDICATION

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ABSTRACT

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(Keywords: thermoelectric, photovoltaic, heat, power generation)

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 hybrid is equal to the sum of the maximum output power that produced separately from the individuals of PV module and TEG devices. The increasing of the maximum output power happens at 11.00 am until 12.00 at noon. The increasing is from 87.93 watts to 88.63 and from 91.98 watts to 99.27 watts respectively. While for the simulation, it was also shown the increasing in the output power. At the 11.00 am, it was starting to change from 72 watts to 74.3 watts and the other one is showing the same output power. In overall, with the using hybrid PV-TEG, the output that can be generated is higher than compared with an output power of the individual experiment.

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ABSTRAK

REKABENTUK DAN PEMBANGUNAN SISTEM PENJANAAN TENAGA ALTERNATIF DARIPADA SUMBER HABA

Sistem hibrid diantara Photovoltaic dan termoelektrik adalah lebih berkesan untuk me-nukar tenaga solar kepada tenaga elektrik. Projek ini telah menggunakan dua sumber tenaga. Salah satu tenaga tersebut adalah tenaga solar yang menukarkan cahaya radian kepada tenaga elektrik. Manakala,satu lagi adalah tenaga haba, yang bertindak me-nukarkan tenaga haba kepada tenaga elektrik. Oleh itu, projek ini akan menggunakan kedua-dua sinaran solar dan haba dari matahari untuk menjana tenaga elektrik . Tujuan projek ini adalah untuk membina satu sistem hibrid yang akan meningkatkan kecekapan sistem penjanaan kuasa. Dalam kajian ini, kuasa pengeluaran hibrid adalah sama dengan hasil tambah kuasa pengeluaran maksimum yang dihasilkan secara berasingan daripada PV modul dan peranti TEG. Peningkatan kuasa pengeluaran maksimum berlaku pada jam 11.00 pagi hingga 12.00 tengah hari. Peningkatan pengeluaran kuasa ini berlaku da-ripada 87.93 watt kepada 88.63 watt dan daripada 91.98 watt kepada 99.27 watt. Manakala bagi simulasi, menunjukkan juga peningkatan dalam kuasa keluaran.Pada pukul 11.00 pagi , perubahan berlaku daripada 72 watt kepada 74.3 watt manakala satu lagi menunjukkan kuasa keluaran yang sama. Pada keseluruhan, dengan menggunakan hibrid PV-TEG, pengeluaran kuasa yang boleh dihasilkan adalah lebih tinggi berbanding dengan pengeluaran kuasa eksperimen secara individu.

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LIST OF SYMBOLS

°C	Celcius
A	Ampere
V	Volts
W	Watt
K	Kelvin
mm	Milimeter
w/m^2	Watt per meter square
Ω	Ohms
m^2	Meter square
J/s	Joule/second
w/mk	Watt per meter kelvin
%	Percentage
C	Coulombs
J/K	Joule per Kelvin
G	Solar irradiance, w/m^2
Gnm	Nominal solar irradiation
κth	Thermal conductivity
ΔT	Different temperature
Qth	The heat transfer of thermal conduction
Q_J	Joule heat
U_S	Seebeck voltage
T_C	Cold temperature
T_H	Hot temperature
Q_C	Thermal load

Q_H	Heat sink
q	Electron charge, 1.6×10^{-19} C
Eg0	Band gap for silicon
Voc	Open circuit voltage
Isc	Short circuit current
Irs	Reverse saturation current
R	Resistance
R_L	Load resistance
Vm	Voltage at matched load
S	Seebeck Effect
Wm	Power at matched load
m	Resistance ratio
η_{th}^{max}	Maximum thermal efficiency
η_{th}	Thermal efficiency
λ	Solar irradiance in w/m^2
Q_L	Amount of heat transfer
m_{opt}	Resistance ratio m optimum
A_{pv}	The area of the PV module
η_{PV}	Efficiencies of PV module
η_{inv}	Efficiencies of inverter
η_{wire}	Efficiencies of conductors
E_L	Load energy demand
C_B	Battery capacity
C_{PV}	PV array capacity
Ipv	Photovoltaic current

Vpv	Photovoltaic voltage
Ppv	Photovoltaic power
Iph	Photocurrent
Io	Saturation current
Ki	Short circuit temperature coefficient
T	Operating temperature
Tr	Reference temperature
Ns	Number of PV cell in series
Np	Number of PV cell in parallel
A=B	Ideality factor
Ipv	Photovoltaic current
k	Boltzmann constant, $1.3805 \times 10^{-23}\ J/K$

LIST OF ABBREVIATIONS

PV	Photovoltaic
TEG	Thermoelectric generator
TEC	Thermoelectric cooler
TE	Thermoelectric
TEM	Thermoelectric module
DC	Direct current
MPPT	Maximum Power Point Tracking
EMF	Electromotive force
FOM	Figure of Merit
EPV	Energy produced by photovoltaic
STC	Standard Test Condition
SAPV	Standalone Alone Photovoltaic

LIST OF PUBLICATIONS

1. Mohd Shawal Jadin, Nur Asyikin Setapa and Amir Izzani Mohamed, "Development Of Hybrid Thermoelectric And Photovoltaic Power Generation," Measurement, Vol. 10, No. 22, December 2015, ARPN Journal of Engineering and Applied Sciences. (Scopus)

2. Mohd Shawal Jadin, Suriadi, Nur Faiza Mohd Yassin "Thermoelectric for Power Generation" Seminar Nasional dan Expo Teknik Elektro 2014, Medan, 2014.

3. Under review - Mohd Shawal Jadin, Nur Asyikin Setapa, "Potential implementation of TEG based power generation for domestic use in Malaysia", Renewable Energy Review

CHAPTER 1
INTRODUCTION

1.1 Project Background

At present, energy demands used in Malaysia, rising by industrial activity and population increased comfort. Due to increasing demand, the government plans for producing green energy projects and ideas that make use of renewable energy sources, waste heat recovery and put non-conventional sources of energy-based power plants. Electricity in rural areas generated by the generator motor gasoline is too noisy and need too much implementation and high fuel fee [1]. Another aspect under sustained is the environmental issues. Conventional electricity generation produces carbon dioxide, which is released to the atmosphere. This contributes to greenhouse effects and global warming phenomenon. Additional emissions such sulphur dioxide and nitrogen dioxide may also be produced, depending on the type of fossil fuel and the method of burning.

Every day, the world produces carbon dioxide being discharged into the earth's atmosphere and which will still be there in a hundred years' time. This increasing carbon dioxide content increased the warmth of our planet and the lead causes of the so-called "global warming effect". One answer to global warming is to substitute and retrofit technologies with alternatives that have a performance comparable to or better but do not emit carbon dioxide [2]. We call this as alternative energy. Intensification of the use solar energy and waste heat recovery to reduce global energy crisis has received a high demand attributed the fact that both energy resources are easily accessible and abundant, in contrast to other sources such as wind, water, and pressure energy [3].

The 8th Malaysia Plan (2001–2005) had targeted to generate 5% of the country's electricity from renewable energy by 2005, but only 0.3% was achieved. This was further emphasized in the 9th Malaysia Plan where efforts in the utilization of renewable energy resources and efficient use of energy were further promoted [4].In the year 2009, with using fossil fuels like oil, coal and natural gas, Malaysia can produce electricity in almost 94.5% [5] . Despite, this country has provided some of renewable energy sources such as biomass, solar, hydro and wind, but this country continued to be relied on with fossil fuels. The biomass resources have the highest possibility for employed as the renewable energy sources.

In this project, task delegation will apply for the renewable or alternative energy concept. The two sources of energy will be implemented. One of the energy is solar and the other one is heat energy. Use Photovoltaic and Thermoelectric generator as a tool for changing power into electricity. PV and TEG devices have been investigated to increase cell conversion efficiency and thermoelectric figure of merit of each. It is may generate more with PV technology boom. But the PV systems efficiency still highly low, ranging from 4% - 18% depending on the type of PV cell [1]. There is just an interesting alternative way to hybrid PV modules and TEG. It will be the one that promising on how to improve conversion efficiency. Sunlight is employed to PV cells to generate electricity.

A PV cell is the use of silicon as a principal material and coupled with boron or phosphorous applied in the material of creating the environment for the electron liberated when sunlight hits the photovoltaic panel. Effects of solar PV would cause the cell absorbing a photon of light and release electrons. Despite, the TEG module applies the Seebeck effect comprising of pairs of p-type of semiconductor materials and n-type formed temperature for electricity generation [1].

The Seebeck containing a thermocouple cross among two different of the semiconductor will develop a voltage by the difference in temperature. The semiconductor region is covered with hot surfaces would be to generate more freely charge during a day time. In any case, when there a lot left over for throughout of charges electrons in the semiconductor would fend off with each other to move towards the cold side. There is a potential implementation of TEG, which can fully utilize all the available heat sources. TEG to be able utilizes waste heat from systems and directly will be converted into electrical sources. Their characteristic is in free of maintenance and ease in operation. In the early of 1800s, thermo-electric was found. When the intersection of two dissimilar materials is conducted with different temperature, a voltage will generate.

1.2 Problem Statement

The actual harvesting of solar power is still below their full potential. PV of system efficiency is still low to generate power. However, by applying the hybrid system between TEG and PV modules for power generation will promise about how to increase the conversion efficiency. Hybrid PV-the TEG is one appropriate alternative power source on site.Could this solar PV and TEG be at the same time in a panel? Could these energy combinations become one system?

1.3 Objectives

The main objective of this research is to develop a hybrid TE and a PV power generation system. The research, however, will deeply focus on the following aspects:

i. Study the potential implementation of TEG for power generation in Malaysia.
ii. Sizing and design modeling a hybrid TE and PV power generation system.
iii. Analysis hybrid system performance.

1.4 Scope of Research

The scope of this research consists of data acquisition, simulation of circuits, and the development of design model systems. Detailed system design will be described in the research methodology. In summary, the scopes of this project are as follows:

i. Study the potential implementation of TEG for power generation in Malaysia.
ii. Integrate the design of hybrid TE and PV generation systems by using Matlab simulation and hardware development.
iii. Analysis of the TEG and PV working principle and its effect during power generation.
iv. Analysis the hybrid system performance and potential implementation for domestic application.

1.5 Report Organization

CHAPTER 1: The objective of this project is to study the potential implementation of TEG for power generation in Malaysia. The second objective is sizing and design modeling a hybrid TE and PV power generation system. The last is to make an analysis about the performance of the hybrid system of TEG and PV power generation.

CHAPTER 2: This chapter will discuss all the theory of the TEG and PV power generation. Besides, it will also come out with a discussion about the hybrid system in between of TEG and PV module.

CHAPTER 3: The TEG and PV module is used as a tool to generate electricity in this project. This chapter will explain the research methodology for the TEG and PV power generation. This project will come out with the software and hardware development. For the part of the software, the simulation of TEG, PV, and hybrid system will be modeling by using Matlab Simulink. For the part of the hardware, hybrid of TEG and PV will be designed and measured its parameters.

CHAPTER 4: The simulation and performance of this project will be display and discuss in this chapter. All the parameters performances will be analyzed and the graph will be plotted. The experiments are divided into the three parts which are for TEG part, PV part and lastly for the hybrid system between TEG and PV.

CHAPTER 5: In order to increase the efficiency of power generation, the hybrid system of TEG and PV is applied. It was successfully proved that this project is able to increase the output power when the hybrid system was used. The recommendation also will be discussed in this section in order to help this system can simulate and operation with more effectively in next future.

CHAPTER 2
LITERATURE REVIEW

2.1 TEG Power Generator

TEG power generator is a device that will convert the 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 waste energy to useful electrical energy. In 1821, TE was stated as a semiconductor solid that can generate an electric current when it's combining each other and subjected to a temperature difference between hot and cold. It will cause the thermoelectric which can then lead direct current electricity by using the waste heat thermoelectric materials whereas for the other party has been exposed to primary environmental heat [6].

2.1.1 Basic concept of TEG

Thermoelectric power generation is applying the Seebeck effect. If the heat is implemented at the junction of two conductors, the current will be generated. The midpoint of thermoelectric effect lies in the fact that the temperature difference in the results of executing the heat flow. That will lead to spreading of charge carriers. The voltage difference would produce a flow of charge carriers along the hot and cold [7].In the different view, Jean Peltier was found the opposite effect for thermoelectric heating and cooling devices in 1834. He was met roughly Peltier effect which states that there will be the difference in the junction temperature-dependent the direction of current flow [8].

In 1979, Chen J was presented to the thermodynamic analysis of the performance of thermoelectric generators are powered by verbal solar radiation. According to this analysis, he had identified roughly the four classes of important the irreversibility and their effects. This irreversibility including the finite rate of heat transfer between devices and vicinity, the internal heat leaks into the device, the ohmic heat production and heat losses in the solar collector [9]. The main conclusions of the analysis established performance limits for solar powered thermoelectric devices.

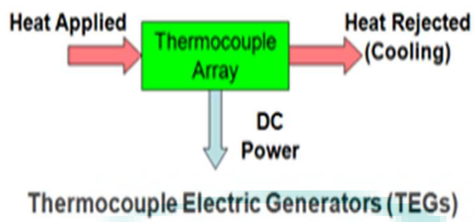


Figure 2.1: Flow diagram of thermocouple electric generator [10]

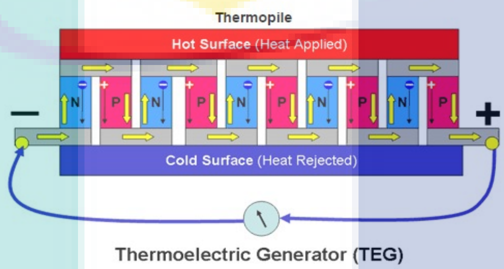


Figure 2.2: The schematic of thermoelectric power generator [10]

2.1.2 Thermoelectric heating and cooling

TE heating and cooling devices are based on the Peltier effect.If a current passed through a circuit of two dissimilar conductors, there will be a rise or fall in temperature at the junction depending on the direction of the current flow. Jean Peltier found that the opposite effect for TE heating and cooling devices in 1834 [6].He was found about the Peltier effect stated that the difference in temperature at the junction will rely on the direction of the current flow [7].

The temperature at the junction will become risen or fallen if a current will go through a circuit of that have two dissimilar conductors. An electron will move from p-type material to n-type material to accommodate thermal energy at the cold junction when applied an electric input into a thermocouple. Through the electrical connector, as they flow from the n-type back to the p-type electrons will dump their extra energy at the hot junction. As the heat was removed from the hot side, the temperature will rapidly drop to the cold side, and then the magnitude of the drop relies on the electric current applied. Figure 2.3 illustrates the schematic of TEG and TEC.

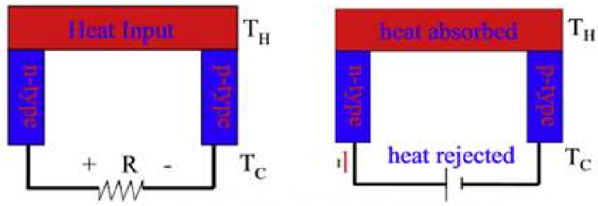


Figure 2.3: The schematic diagram (a) TEG (b) TEC[10]

2.1.3 Thermoelectric material

For the TE materials, it can be defined by three things which are semiconductors, polymers, and ceramics. For certain polymers such as ethylene dioxythiophene, carbon fiber polymer matrix structural composites, have also been demonstrated to exhibit interesting thermoelectric material properties [11]. Semiconductors are materials that can give promising for the thermocouple construction. This is because they have large possibility coefficients for excess 100 μV/°C and also prepare a proper way to reduce thermal conductivity with giving affection towards Seebeck coefficient in bulk of materials. It was also can increase the ZT, the figure of merit [10].

For the polymers, it was successfully proved this material to be able used with TEG devices. Polymers containing insulating polymers and conducting fillers. It has been studied for its advantages such as low-cost synthesis, mechanical flexibility and also environmentally friendly [12]. Then, for the ceramics, it was an important thermoelectric material for the energy conversion to obtain elevated temperatures thermoelectric waste heat from incinerators or combustion engine [13]. The table 1 below shows the examples of the semiconductor, polymer and ceramic materials.

Table 2.1: The value of ZT of the TE material [10]

Material	ZT	Temperature (K)
$Si_{0.8}Ge_{0.2}$	0.66	1073
$BaUO_3$	1.8	900
SiC/B4C + PSS	1.75	873
Mg_2Si	0.86	862
$Fe_{0.9}Mn_{0.1}Si_2$	1.31	773
Zn_4Sb_3	1.4	670
TI_9BiTe_6	0.86	590
$Cu_xSn_1S_4$	0.6	570
Zn_4Sb_3	1.2	460
Graphite	0.54	393
$Sb_{2-x}Bi_xTe$	0.93	300
PbTe	0.87	293
$Pb_{1-x}Mn_xTe$	1.6	700
BiCuSeO	0.9	923
SnSe single crystal	2.6 ± 0	923
3,4-Ethylenedioxythiophene	0.42	Room temperature

2.1.4 Application of thermoelectric for high power generation

TE devices also can apply for the power generation. Thermoelectric generators (TEG), in principle, can offer many advantages over conventional electrical generating power. The waste heat TEG can be used as the product of higher power. TEG is a smart way to control the bad impact of global warming because they were able to energy generation by harvesting waste heat, such as the heat, which is a byproduct of industrial processes, such as the steel industry and automatically portable engines. Realizing the potential of waste heat as energy resources, both industries have become key drivers force behind the development of high power commercial TEG electricity generation.

In the case of waste heat recovery energy generation, some of the top car producers, such as Volkswagen, Volvo, Ford, and BMW, has developed the system TEG-waste heat rehabilitation to increase the fuel economy of their automobiles with the potential power generated from the TEG in the range of ~1 kW [14].Furthermore, most of these automobiles TEGs use BiTe based bulk TE materials, as an optimal ZT in the temperature range of <500 K can be achieved by using this compound. Therefore, the manufacturing processes for this compound have been extensively developed. Table 2.2, shows the available TEG materials features.

Table 2.2: TEG materials features [14]

Temperature (°C)	**Type**	**TEG materials**	**ZT (maximum)**
<150	p n	Bi_2T_3 Bi_2T_3	0.8 0.8
150-500	p p,n p	Zn_4Sb_3 PbTe TeAgGeSb(TAGS)	- 0.7-0.8 1.2
500-700	p n	$CeFe_4Sb_{12}$ $CoSb_3$	1.1 0.8
700-900	p,n p	SiGe LaTe	0.6-1.0 0.4

In another one case study had shown that the ability of the used of waste heat thermoelectric power generation in the manufacturing industrial in Thailand. Besides, the economic viability of the TEG can also be increased when used for the waste heat recovery. However, the generator still dissipates a large amount of unconverted heat from its cold side due to its relatively low conversion efficiency. To overcome this problem, the concept of symbiotic generation was proposed [15].

Based on this idea, the TE is used as dual function devices that can act as a heat generator. When heat flows through a TEG, part of the heat absorbed is converted into electricity, while the rest, instead of being discharged to the ambient, is collected and used for preheating. The figure 2.4 show the illustrates the TE symbiotic system. In this arrangement, a TE device is linked to a fluid heater by attaching the cold side of the TE device to the cold fluid inlet and the hot side the hot fluid outlet. The main purpose of such a cogeneration system is to produce hot fluid. Nonetheless, if the TE device is incorporated, the small part (Q1-Q3) of heat will flow through a bypass, which consists of the TE module, and then it will convert to electrical power. The heat that released on the cold side of the TEG (Q2) will come back in fluid heater inlet and preheats the cold fluid.

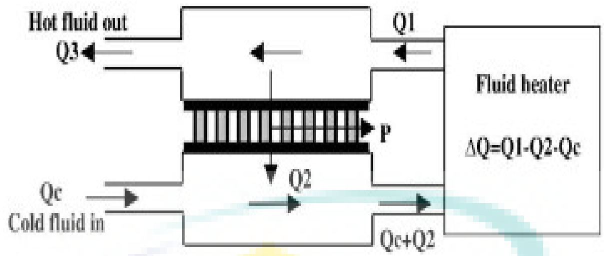


Figure 2.4: TE symbiotic arrangement system [15]

2.1.5 Principle of thermoelectric module

For the Thermoelectric cooler and TEG, basically, has the same of the construction and also equivalent to circuit behavior. There are four main energy processes taking place in the TEM 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 TEM with N thermocouples, the heat transfer of thermal conduction in a TEM is described by

$$Qth = -\Delta T \kappa th \tag{2.1}$$

where;

κth is the thermal conductivity of TEM

ΔT is a different temperature between hot and cold side.

The total Joule heat dissipated in an N-couple TEM is

$$Q_J = I^2 R \tag{2.2}$$

where;

R is its electrical resistance.

I is the electric current that flows through TEM.

Irrespective of the temperature gradient, the Joule heat can be considered as equally divided between the two sides of the TEM. The Peltier cooling/heat effect is a phenomenon of heat absorption/dissipation by a junction between two dissimilar materials when electrical current flows through the junction. The absorbed/emitted heat of an N-couple

$$Q_{PH/PC} = SIT_{H/C} \tag{2.3}$$

where;

S is the Seebeck coefficient

$T_{H/C}$ 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 generated Seebeck voltage, called the electromotive force (EMF), in a TEM is expressed as

$$U_S = S\Delta T \tag{2.4}$$

Applying the concept of energy equilibrium for steady-state analysis at both sides of the TEM, 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

$$Q_C = SIT_C - 0.5I^2R - \kappa th\Delta T \tag{2.5}$$

$$Q_H = SIT_H + 0.5I^2R - \kappa th\Delta T \tag{2.6}$$

where;

T_C is the cold side temperature

T_H is the hot side temperature

The TEM's output voltage is then

$$V = U_S + IR \tag{2.7}$$

A good TEM 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

$$Z = \frac{S^2}{R\kappa th} \tag{2.8}$$

where Z is the figure of merit.

2.1.6 The TEG parameters

The regular parameters of TEG involved the hot temperature, T_H ,cold temperature, T, the power at the load matched, Wm, to the internal resistance (R_L = R); the load voltage at the matched load ,Vm (=VR); and the maximum thermal efficiency, η_{th}^{max}. The electrical resistance R and the Seebeck coefficient S of a TEG can be expressed as

$$R = R_L = \frac{V_m^2}{W_m} \tag{2.9}$$

$$S = \frac{2Vm}{\Delta T} \tag{2.10}$$

In fact, the efficiency of a TEG 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

$$I = \frac{S\Delta T}{[(1+m)R]} \tag{2.11}$$

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

$$\eta_{th} = \frac{I^2 R_L}{Q_H} \tag{2.12}$$

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

$$I_{short_{circuit}} = 2I_m = \frac{2W_m}{V_m} \tag{2.13}$$

Based on Ohm's Law and the resulting equations of (12) and (14), the TEG voltage can be obtained as

$$V = -R(I - I_{short_{circuit}}) \tag{2.14}$$

2.2 PV Power Generators

Solar PV is a part of the way, which can produce electrical energy by changing sunlight into direct current electricity by using materials of semiconductors showing photovoltaic effect. PV system uses solar panel comprising of some solar cells to deliver solar power may be used [11]. In macro, power generation of the solar PV is seen as sustainable net power technology. That refers to resources renewable energy is the most abundant and extensive in the earth from the sun. Direct conversion of sunlight to electricity occurred without environmental release or moving during operation. It is also clear, as the PV system which has now been used for fifty years in specialized applications, and system-grid related to PV has been used for over twenty years [12].

2.2.1 Basic concept of PV

In 1839, the solar PV effect reviewed by Edmond Becquerel. The first solar cell is composed of the silicon crystal in 1954. A solar PV cell is composed of the silicon. The photons in light would send power to the atoms when the cells that are exposed to electromagnetic radiation of the sun. This will give you energy electrons will be released from atoms, of the electrons (n-charge) and holes (p-charges) would generate [13]. Ohl in 1941 developed the silicon PV cell. Further refinement of the silicon solar PV cells enables researchers to acquire efficiency by 6% in direct sunlight, which continues to increase to 11% by Bell labs in 1954.

The PV power generating system that rated in kilowatt peak (kWp). A clean system would have expectations when the sun is directly overhead on a bright day. If be compared PV system with conventional power systems, PV systems only just going to be productive only during the daytime. To convey usable voltage, The PV modules should consist of the lot cells in series [13]. Traits of PV modules is depending on the temperature and the solar radiation PV of modules [1].Along with the increase in solar radiation, it will also grow photocurrent and increase the voltage of PV. Hence this is would be increasing the power generated.

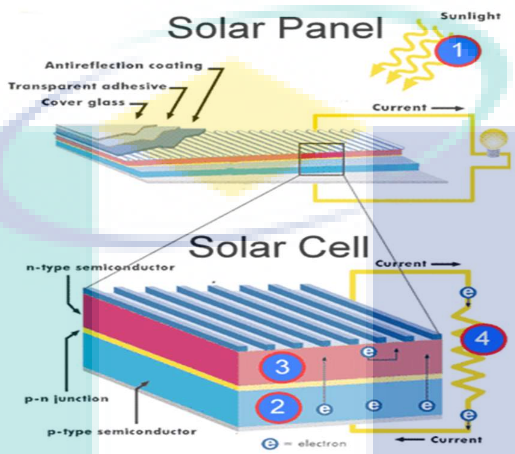


Figure 2.5: The solar panel and solar cell works [14]

2.2.2 Type of PV module

There are many types of PV modules which are monocrystalline modules, polycrystalline modules, thin film module and hybrid modules. For the monocrystalline, cells are cut from a single crystal of silicon. They are effectively slices from a crystal. In appearance, it will have a smooth texture and you will be able to see the thickness of the slice. These are the most efficient and the most expensive to produce. They are also rigid and must be mounted on a rigid frame to protect them.

Polycrystalline cells are effectively a slice cut from a block of silicon, consisting of a large number of crystals. They have a speckled reflective appearance. These cells are slightly less efficient and slightly less expensive than monocrystalline cells and again need to be mounted in a rigid frame. Amorphous cells are manufactured by placing a thin film of amorphous silicon onto a wide choice of surfaces. These are the least efficient and least expensive. Due to the amorphous nature of the thin layer, it is flexible, and if manufactured on a flexible surface, the whole solar panel can be flexible. One characteristic of amorphous solar cells is that their power output reduces over time, particularly during the first few months, after which time they are stable.

2.2.3 PV characteristics parameters

The output of the PV module relies on with the cell temperature, solar irradiance and the output voltage from the PV module [15]. The equivalent circuit of PV cell can describe as shown in Figure 2.6. The I_{ph} represent the photocurrent. I_o is the saturation current. While for Rsh and Rs represent to the shunt and series resistance of the PV cell.

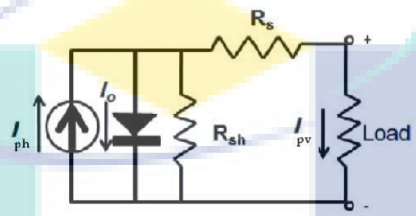


Figure 2.6: The PV cell equivalent circuit [16]

Based on the equivalent circuit in Figure 2.4, the PV module can model mathematically with equations such as below:

$$Iph = [I_{Scr} + Ki(T - 298)] * \frac{\lambda}{1000} \tag{2.15}$$

where;

Iph is the photocurrent module

Iscr is the short circuit current of the PV

Ki is short circuit current temperature coefficient

T is module operating temperature in Kelvin

λ is the solar irradiance value in w/m2

$$I_{rs} = I_{SCr}[\exp\left(\frac{qV_{OC}}{N_S\, kAT}\right) - 1] \tag{2.16}$$

where;

Irs is the reverse saturation current

q is the Electron charge = 1.6 × 10-19 C

Voc= 21.9V

Ns is the number of cells connected in series=36 k is Boltzmann constant = 1.3805 × 10-23 J/K

A = B is an ideality factor = 1.2

T is the module operating temperature in Kelvin

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]\exp\left[\frac{q * E_{g0}}{Bk}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \tag{2.17}$$

where;

I_O is saturation current

T is the module operating temperature in Kelvin = 304.5 K

Tr is the reference temperature = 298 K

Ego is the band gap for silicon = 1.1 eV

A = B is an ideality factor = 1.2

$$I_{PV} = N_P * I_{ph} - N_P * I_0\left[\exp\left\{\frac{q * (V_{PV} + I_{PV}R_S)}{N_S AkT}\right\} - 1\right] \tag{2.18}$$

where;

I_{PV} is the current output of PV module

N_P and N_S are numbers of cell connected in parallel and series cell

2.2.4 I-V and P-V characteristic

The I-V and P-V output curve are the characteristics that can be obtained from the equation in (2.15) until (2.18). These characteristics are depend on the solar irradiance, temperature and output voltage from the PV module.The I-V curve is the plot the current-voltage output characteristic of a PV cell or module. With this output curve, the maximum power can be obtained from the graph plotted. Figure 2.7 show the illustration of the I-V and P-V.

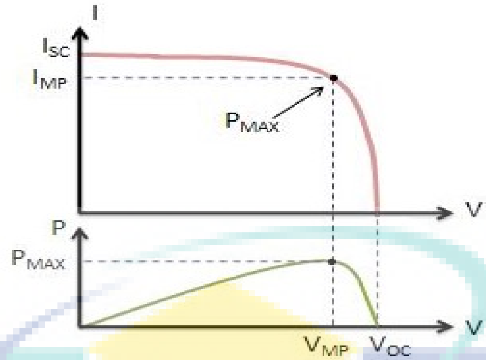


Figure 2.7: I-V and P-V output curve characteristics [17]

In the I-V curve, there is located at the maximum power output. The current and voltage at this maximum power point are designated as the maximum power voltage, Vmp and maximum power current, Imp. By referring to the value of Voc and Isc of the PV module or cell, the value of Vmp and Imp can be estimated. This I-V curve also was used to make a comparison with the PV performances. At the Standard Test condition (STC) with the temperature in 25°C, this curve can be generated [18].

2.3 Hybrid System of TEG and PV module

This system would be called a hybrid system because it has two types of resources that will be used to generate electricity. For example, a combination of TE and solar concentration has been applied to power generation by using a hybrid system. Categories of the combination are necessary the concentration of solar radiation to the generation of TE power generating. The basic concept for both renewable energy is the same, which produce electricity from heat sources, such as waste heat, solar, elevated temperatures and other [19]. In other words, when there is a thermal gradient between the cold and hot surface, TEG and PV module will convert solar energy into electrical energy. In the macro view, between PV module and TEG very much common because of both of these tools from semiconductor p–n devices that do not have moving parts, vacuum and also it's practical without the necessity for maintenance [20].

In other words, when there is a thermal gradient between the cold and hot surface, TEG and PV module will convert solar energy into electrical energy. In the macro view, between PV module and TEG very much common because of both of these tools from semiconductor p–n devices that do not have moving parts, vacuum and also it's practical without the necessity for maintenance [20]. By using the hybrid solar systems, it's more having higher efficiency and stability of performance in comparison with individual solar devices [19]. In 2011, W.G.J.H.M. Van Sark was stated that by using a TEG with a PV module, it can lead 8-23% increase in efficiency [21]. Other research indicates by M.M.M. David, he stated that without the cooling systems, the thermal efficiency of PV might increase until 0.79% and 1.84% with cooling systems integration of traditional The PV panel at 600W / m2 solar radiation.

Then, the prototype panel with liquid cooling can also improve the efficiency up to 3% at 868 W / m2 solar radiation [1]. Furthermore, the output power of a PV system is depending on temperature and solar radiation [21] [22]. Furthermore, the output power of the output power will increase as the solar radiation. However, when the temperature increases, it will reduce the output power of the PV module. In addition, the researchers also state that the MPPT circuit is much recommended to be used in the hybrid system because it will stabilize the output power curve of PV module [23]. Meanwhile, in one case study state that by using a dynamic analysis of hybrid TEG-PV configuration by using MATLAB will get to increase the efficiency as well as to reduce the energy consumption of the system [24].

In contrast, of the research has also indicated that the hybrid system using solar power spectrum via lossless coupling between TEG and The PV would create the output power of the hybrid device is an equal to the sum maximum power output generated separately than individual TEG and The PV devices. In this case, TEG device needs to have primary internal resistance for generating a time without using the full the PV [3]. The numbers of p-n legs are in a position to drive a high Seebeck voltage in TEG. This study has successfully improved the efficiency and power output of the PV devices. Overall, hybrid TEG and the PV modules are regarded economically and helpful. It would enhance thermal stability of power system efficiency and reduce losses by increasing temperature.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The research methodology is a key part to provide an explanation of methods that will be utilized to carry out this project and to ensure that it will be smoothly and orderly. In this project, need to know the outcome of the TEG and PV first before to get the results of the hybrid system in between TEG and PV module. This is explained by the fact that there is a need to analyze and create the value of voltage and current output power for the PV analysis, TEG analysis and for the hybrid analysis. There is need to do a test of the difference temperature for the TEG modules first. The objective of this test is to obtain the voltage and current that generated by the different temperatures between the hot and cold side of TEG module. The Matlab Simulink software will be utilized on this project for the collecting and assessing the data. For the hardware development, it is needed to make the connection to the TEG.

There is also required in order to model for PV system. The suitable PV module must be selected in this project. Analysis of data in the PV module is also examined by using Matlab Simulink. Lastly, there is required to test the hybrid system for TEG and PV module. This system is needed to combine to get its results. The algorithm of hybrid TEG-PV also is built-in the Matlab software. For the hardware development, must be checked that the TEG and PV connected electrically in series. With this connection, a positive and negative of the hybrid circuit will correspond to a negative of PV module and positive of TEG respectively.

3.2 TEG Simulation and Hardware Development

The manual calculation needs to calculate first before doing the simulation in Matlab Simulink. Need to determine the TEG parameters such as hot temperature, Th; cold temperature, Tc; the matched load power to the load resistance, Wm; matched load output voltage, matched load output current and the maximum thermal efficiency. Figure 3.1 show the TEG power generation that will be used in this project. While in the table 1below show the specification of TEG.

Figure 3.1: Waste Heat Recovery Generator

Table 3.1: Specifications of TEG

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

All the calculation refers to the specifications as shown above; the difference temperature can be determined by using the formula below.

$$\Delta T = Th - Tc \qquad (3.1)$$

Based on the Th and Tc, the Tave can be determined

$$\Delta T = \frac{(\mathrm{Th} + \mathrm{Tc})}{2} \qquad (3.2)$$

Based on the value of Vm=24V, Wm=200 watt and ΔT=243K and using the equation (2.9) and (2.10), the electrical resistance R and the Seebeck coefficient S of a TEG can be find out. Through the equation in (2.11), the current value can be obtained with value m=1, R=2.88 and S=0.1975.Thermal efficiency can be determined by using the formula shown below. The thermal power input to hot side and thermal need to find out before to calculate the value of thermal efficiency. The Q_H and k_{th} in W/m2 can be determined by using the formula shown below.

$$kth = \frac{Q_L}{A\Delta T} \tag{3.3}$$

Where Q_L is the amount of heat transfer through the material in J/S or Watt; A is the area of the body in m2. ΔT is the difference temperature between cold and hot side temperature. When the value Q_H and k_{th} is found out, the thermal efficiency can be determined by using equation below

$$nth = \frac{I^2 R_L}{Q_H} \tag{3.4}$$

The figure of merit parameter can be defined by the equation as shown below

$$Z = \frac{S^2}{Rkth} \tag{3.5}$$

Given the FOM, the TEG's thermal efficiency can be reformulated as below

$$nth = \frac{mZ\Delta T}{\{(1+m)^2 + Z[(m+0.5)Th + 0.5\,Tc)]\}} \tag{3.6}$$

The TEG efficiency is the function to the ratio of m. So that, the maximal efficiency can be determined by using the formula given below

$$n_{th}^{max} = \frac{(m_{opt}-1)(\frac{\Delta T}{Th})}{(m_{opt}+\frac{Th}{Tc})} \tag{3.7}$$

where;

$$m_{opt} = (\,1 + ZTave)^2 \tag{3.8}$$

Therefore the maximal efficiency that gets from equation (3.7). Given the parameters of a commercial TEG, the resistance ratio m can be obtained as

$$m_{opt} = \frac{(\Delta T + \; n_{th}^{max}\, Tc)}{(\Delta T - \; n_{th}^{max}\, Th)} \tag{3.9}$$

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

$$Z = \frac{(m_{opt} - 1)}{Tave} \tag{3.10}$$

Then, the thermal conductivity of TEG can be determined

$$kth = \frac{S^2}{RZ} \tag{3.11}$$

The efficiency at the matched load is expressed as

$$nth, m = \frac{Z\Delta T}{[4 + Z(1.5Th + 0.5\,Tc)]} \tag{3.12}$$

The FOM of the TEG is then calculated by

$$Z \; = \frac{4\, n_{TEG}^{max}}{[\Delta T - n_{TEG}^{max}(1.5Th + 0.5\; x\; Tc)]} \tag{3.13}$$

All the calculation above will be used to create a simulation by using Matlab Simulink. The Figure 3.2 and Figure 3.3 show the subsystem and model of TEG that will apply in the Matlab Simulink. The subsystem parameters in this model will implement by using all the calculation that show above. Figure 3.4 show that the TEG hardware development that will generate electricity from the difference in temperature.

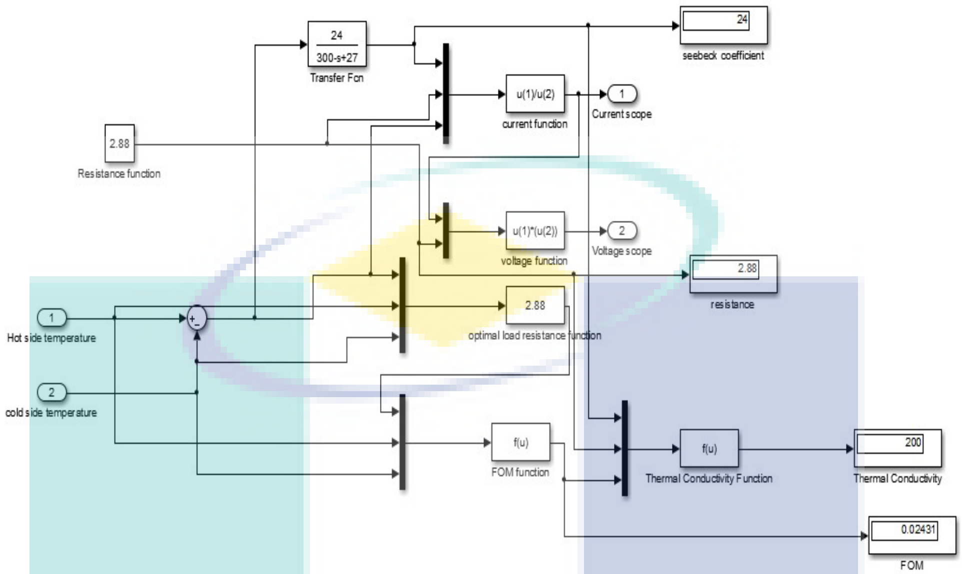


Figure 3.2: Subsystem implementation

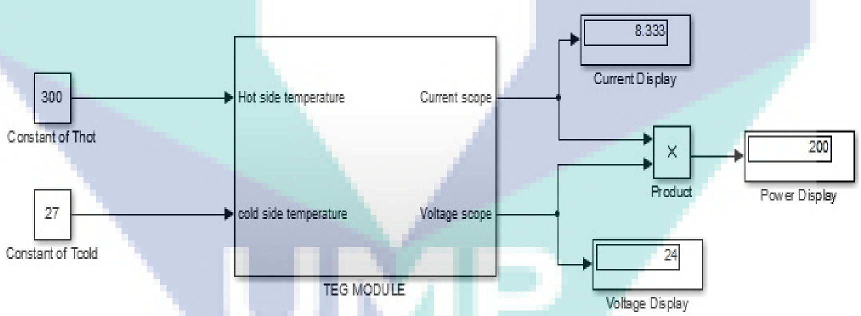


Figure 3.3: TEG model applied in Matlab.

Figure 3.4: TEG development

3.3 PV Simulation and Hardware Development

Figure 3.5 shows the block diagram for the PV model that will be used in this project. It consists of PV module, power conditioner that is consisting of charge controller with maximum power point tracking controller, battery, inverter, and load. In general, PV module will gain energy from the sun and then converts it 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

$$EPV = A_{PV} * Esun * \eta PV * \eta inv * \eta wire \tag{3.14}$$

where;

A_{pv} = the area of the PV module/array and Esun is daily solar irradiation.

η_{PV} = Efficiencies of PV module.

ηinv = Efficiencies of inverter.

$\eta wire$= Efficiencies of conductors.

The difference between the energy at the front end of a PV system, EPV, and at the load side is given by

$$\text{Energy difference} = \sum_{k=1}^{366} (E_{PV} - E_L), \tag{3.15}$$

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.

$$c_v = \left(\frac{c_{pv}}{c_L}\right) \tag{3.16}$$

$$c_S = \left(\frac{c_B}{c_L}\right) \tag{3.17}$$

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

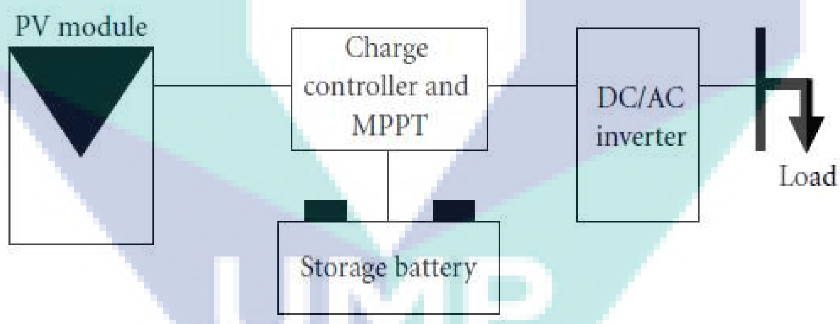


Figure 3.5: The PV block diagram

The Simulink for PV can be created with the following steps:

Step 1:

The model of the subsystem in Figure 3.6 will convert the module operating temperature given in degrees Celsius to Kelvin. By the following equation, the T_{rk} and T_{ak} can be calculated.

Figure 3.6: C to Kelvin subsystem

$$T_{rk} = 273 + (reference\ temperature) \tag{3.18}$$

$$T_{ak} = 273 + (Operating\ temperature, Tcell) \tag{3.19}$$

where T_{rk} is the reference temperature and T_{ak} is the operating temperature

Step 2:

In the step 2, the I_{ph} can be found by using the equation (2.15). Figure 3.7 show the I_{ph} subsystem. Insolation/ Irradiation = 200W/m2, module operating temperature T_{aK} = 31.5 ^{o}C, module reference temperature T_{rK} = 25 ^{o}C and Short circuit current (I_{sc}) at reference temperature = 5.00 A

Figure 3.7: Photocurrent subsystem

Step 3:

For the next step, the reversed current is calculated. By using the equation in (2.16), the Irs can be determined. The model in Figure 3.8 will takes short-circuit current I_{SC} at reference temperature = 5.00A and module reference temperature T_{rK} = 25^{o}C as input.

Figure 3.8: I_{rs} subsystem

Step 4

In this step, the Io of a saturation current (A) need to be calculated. Figure 3.9 shows the subsystem that will describe of the Io. By using the equation in (2.17), the Io can be obtained.

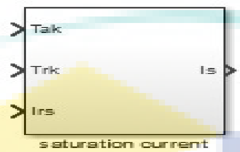


Figure 3.9: Saturation current subsystem

Step 5:

Figure 3.10 shows for the subsystem in step 5. This model takes operating temperature in Kelvin T_{aK} and calculates the product N_sAkT, the denominator of the exponential function.

Figure 3.10: NsAkT subsystem

Step 6:

The model in figure 3.11 will execute the function given by the equation in (2.18)

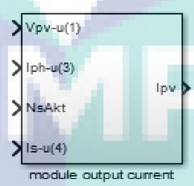


Figure 3.11: Module output current subsystem

where Vpv = Voc, Ns=36, Np=1

Step 7:

All six models of step 1 until step 6 will be interconnected in the subsystem. The final model is shown in Figure 3.12. To measure the Ipv, Vpv, and Ppv in this model the workspace will be added. While Figure 3.13 show the PV system development. Both of these figures will be used to generate the output current and output voltage and the result will be compared in simulation and the measured value.

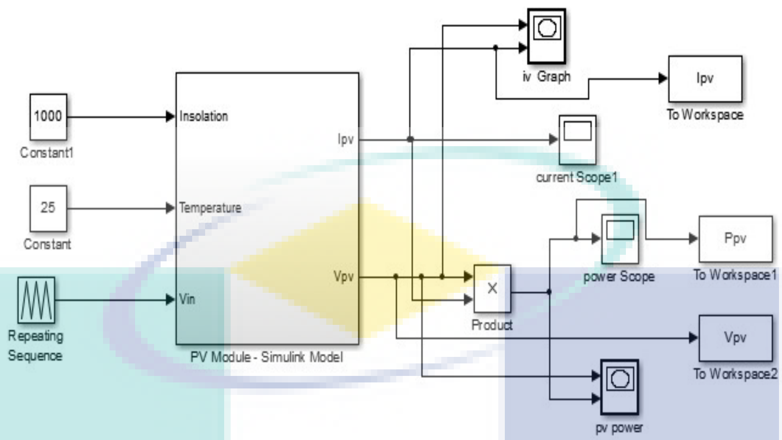


Figure 3.12: PV model applied in Matlab

Figure 3.13: PV system development

The solar radiation and temperature that was 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 the current and power output. The generated current under standard condition (25°C) is given as

$$I(T1) = G \times \frac{I_{SC}(T1)}{G_{nm}} \tag{3.21}$$

where:

T1 = standard temperature under condition (25°C)

G = solar irradiation in W/m2

Isc = nominal current of the module in A

Gnm = nominal solar irradiation (=1000 W/m2 or one sun)

Then, with the using formula below the generated current at a given temperature, I_L can be computed.

$$I_L = I(T1) \times (1 + K(T - T1)) \tag{3.22}$$

where ;

T = temperature of the area under study

K = temperature coefficient of the module at I_{sc}

The generated power can be calculated by using the formula below

$$P = I_L \times V \tag{3.23}$$

where V= module open circuit voltage in volts

3.3.1 MPPT for solar tracking

(MPPT) is a technique that in use by the solar charge controller to get the maximum possible power from PV device [25]. MPPT is used for prediction the maximum power point occurrence by using perturb and observation algorithm in looking for maximum output parameters in terms of voltage and current, from that it will increase the fill factor [26]. Maximum efficiency is meant 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. To get the real V-I characteristic so the fill factor is measured on it.The maximum efficiency and fill factor are defined by formula as showed below.

$$\eta = \frac{\mathrm{Pmax}}{\mathrm{Pin}} = \frac{\mathrm{Vmax.\,Imax}}{\mathrm{A} \times \mathrm{Ga}} \tag{3.24}$$

where;

Ga is the ambient irradiation

A is cell area.

$$FF = \frac{\text{Pmax}}{\text{Voc} \times \text{Isc}} = \frac{Vmax \times Imax}{\text{Voc} \times \text{Isc}} \tag{3.25}$$

where;

V_{oc} is the open-circuit voltage

I_{SC} is the short circuit current

3.4 Modelling and Hardware Development.

The hybrid system combines with the solar PV system with the reliability and heating capability of a TEG. Solar power system providing power during the summer with abundant sunshine. While of TEG system providing power and heat as necessary during the season with inadequate solar insolation or during bad weather. Figure 3.14 show the block diagram of a hybrid system between TEG and PV power generation. This system is called the hybrid system because it was combined with two types of sources of energy that are the TEG and PV module. The hybrid system, TEG will operate in case the PV module cannot cover the load demand. The excess energy will be stored in the battery storage to be used in case of an energy deficit. The energy deficit is identified as the disability for the TEG and PV module to provide power to the load at a specific time. The Figure 3.15 and Figure 3.16 will show the hybrid system that sizing in Matlab Simulink and build in the hardware development. The output result will be compared with the simulation and measured value.

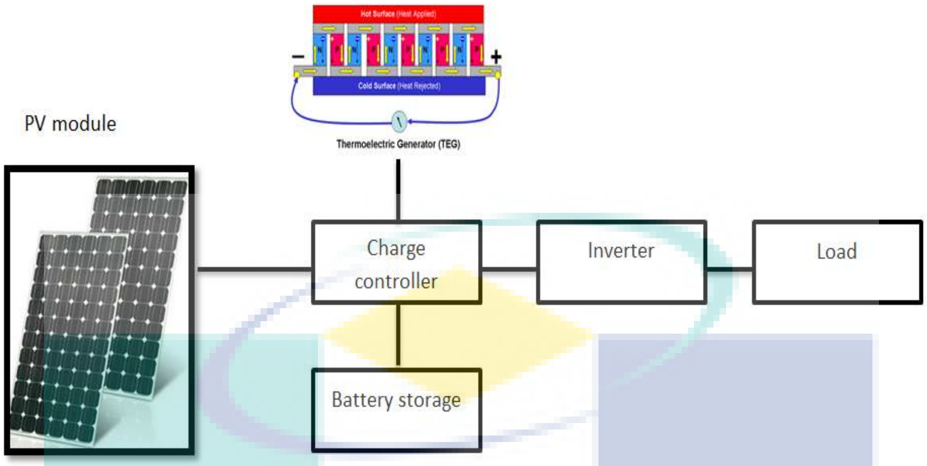


Figure 3.14: Block diagram of hybrid TEG and PV power generation

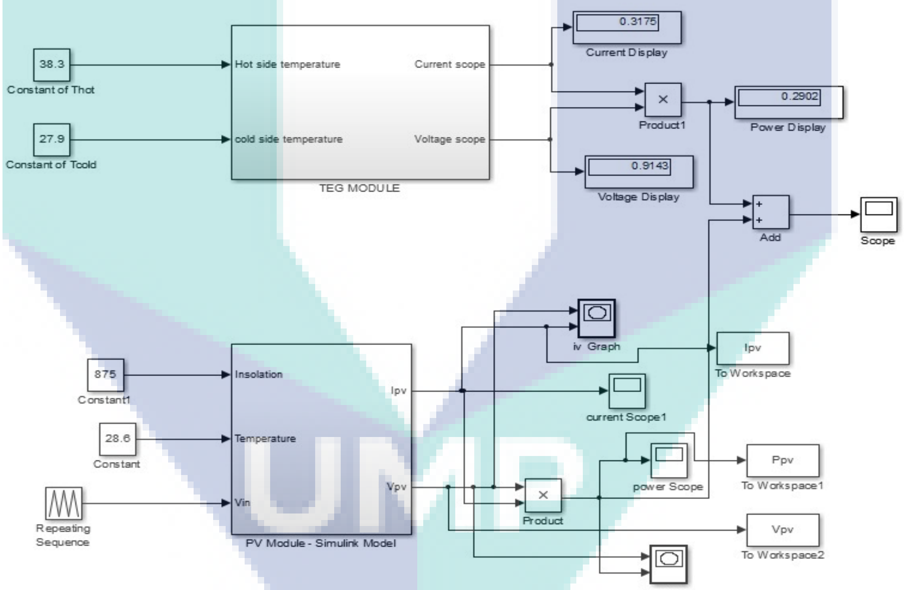


Figure 3.15: Hybrid system in Matlab

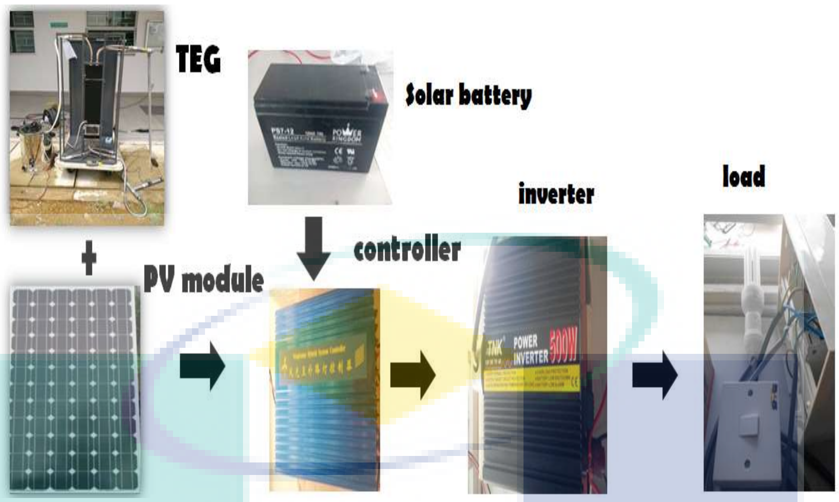


Figure 3.16: Hybrid PV-TEG hardware development

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the results and analysis for TEG, PV and the hybrid of development between TEG and PV power generation. Every these tool will be created in the simulation by using the Matlab Simulink. Then the results of current, voltage and power from the simulation will be compared with the measurement. The components employed in the analysis were calculated first. This focus of this project is for minimizing the cost system while the maintaining the system reliability. A prototype of the advanced hybrid TEG and PV module power generation system has been developed and tested. The temperature was measured by using a thermometer with a probe, which is it can determine the hot side and cold side temperatures of the thermoelectric power modules. The data of solar irradiance of PV system are also taking out from the weather station at the Universiti Malaysia Pahang, Malaysia. This project conducted with the three differences of experiments. The first experiment is about the TEG. Then, it was continuing with the experiment of the PV system. Lastly, the hybrid system between TEG and PV will be conducted. All these experiments were carrying out at the area of Universiti Malaysia Pahang with a different day and date.

4.2 TEG Power Generation

Experiment in the TEG power was conducted. Two types of experiment were conducted for the TEG. The first experiment is carried out with the using the normal water. For the rest experiment, the ice was used to replace the normal water. The boiler was used to measure the hot temperature; while for the cold, the temperature is taken from the normal water and ice cubed. The K-type thermometer was used to take the temperature reading. For the current and voltage reading, the multimeter was used. These experiments were carrying in two different locations. For the first experiment, the TEG test was conducted at the Alternative energy laboratory and the other location is in the workshop. Both of these locations are in the area of Universiti Malaysia Pahang.

4.2.1 Experiment 1(Using the normal water)

Since the maximum temperature of the boiler is 100 ^{0}C and the heat pump is 80^{0}C, so the hot temperature can be set in this range only. The initial temperature for the cold and hot was taken at 27.3 ^{0}C and 30.0 ^{0}C respectively. Table 4.1(appendix) shows that when the temperature increasing so that the output current and voltage also increase. The output power range that recorded is between 0.05 watts to 5.44 watts at 2.7 ^{0}C to 32.0 ^{0}C. Figure 4.1 illustrate the power that generated from the measured and simulated from Matlab. The simulation is proposed from the model by using the Matlab Simulink. The equation (2.9)-(2.14) was used to build its subsystem. Both on the graph show that as the temperature increase, the power that generated also increase. The power measured shows the higher result compare with the simulation result. In overall, the power that generated from TEG is directly proportional to the temperature

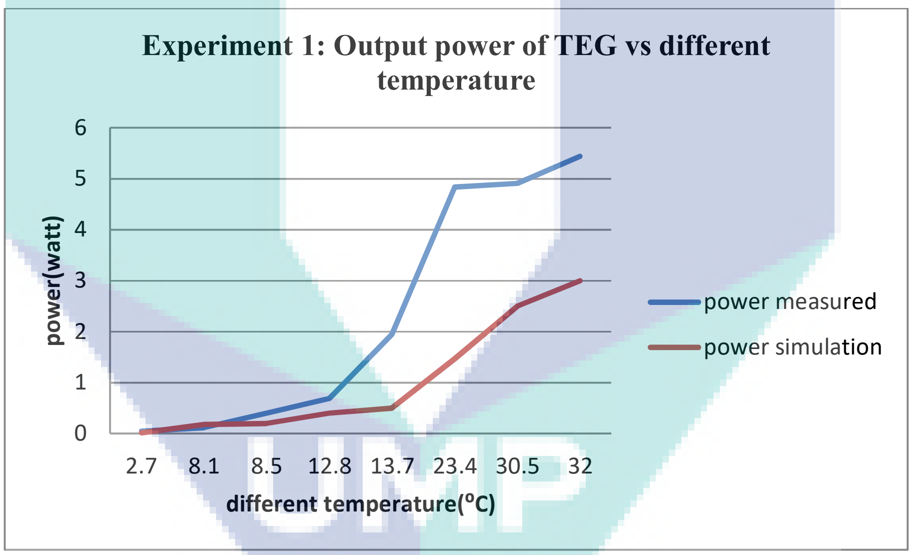


Figure 4.1: The TEG power generated vs different temperature.

Figure 4.2 illustrates the power output of TEG versus time. It shows that the output power will increase with time. In the 5 minutes to 10 minutes early, the output power of TEG for the measured and simulation generated uniformly. But in the 15 minutes above, the output power that generated from the measured is higher than comparing with output power that produced from the simulation. In overall, show that the output power of TEG is directly proportional to time.

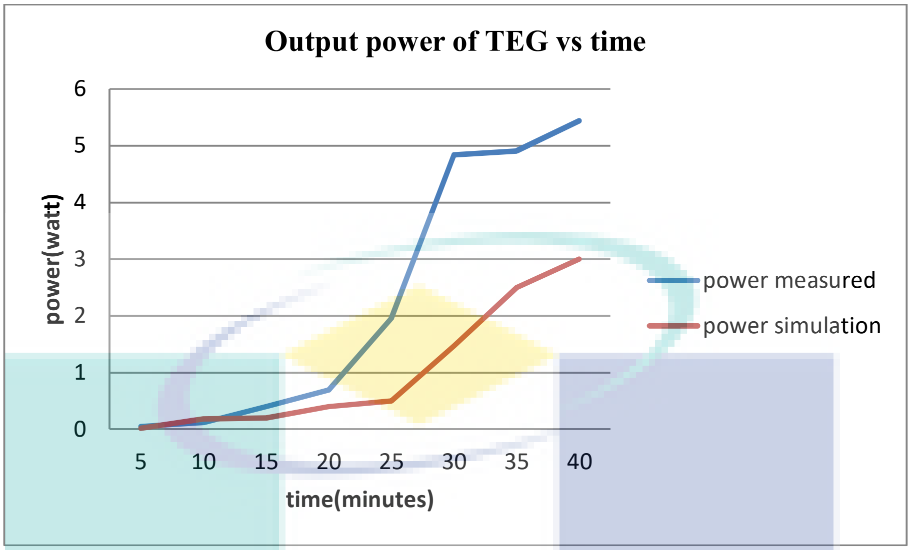


Figure 4.2: Output power TEG vs time

In figure 4.3, it was illustrated a graph of the output voltage of TEG versus time. In the 5 minutes to 20 minutes early, the simulation graph show that the voltage is higher than compared with an output voltage that generated from the measured value. However, after 20 minutes, the output voltage of measured is rapidly increasing. The output voltage of simulation is uniformly increased. In overall, the output voltage simulation of TEG is directly proportional to time.

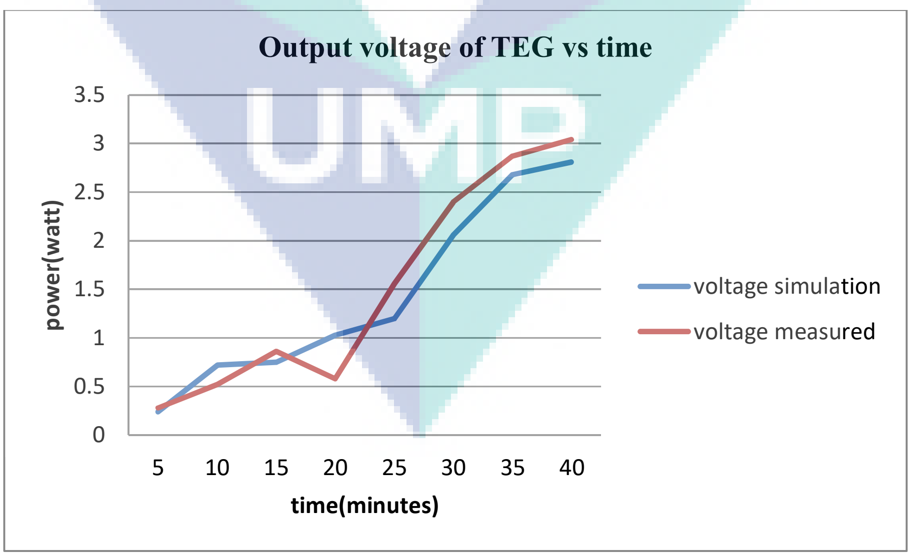


Figure 4.3: Output voltage TEG vs time

The figure 4.4, it was showing the graph of the output current of TEG versus time. The output current that generated from TEG is higher than compared with the output current that produced from simulation. But at the minute time range, both of the TEG show the same value. After that, the current from TEG rapidly increases with the 1.8 amperes. While from the simulation, the current that produced is 1 ampere. In overall, the output current of TEG is directly proportional to time.

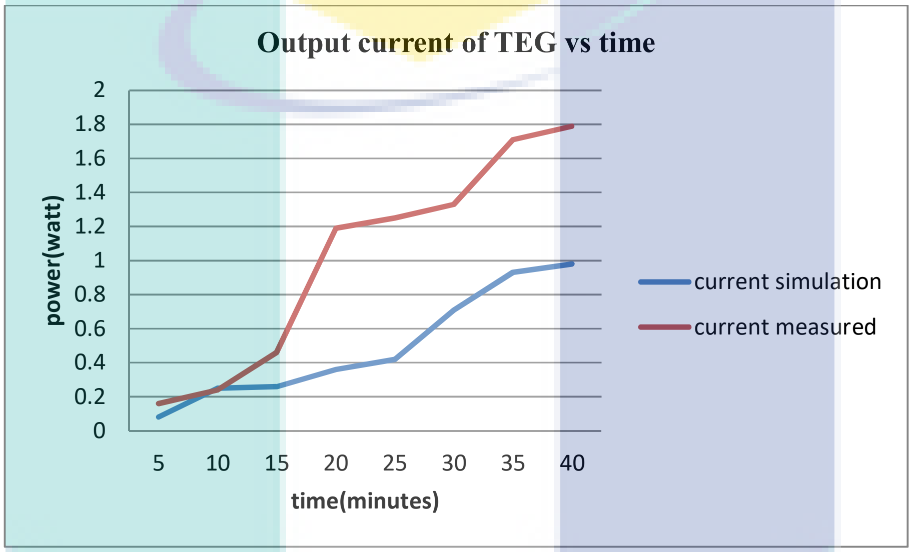


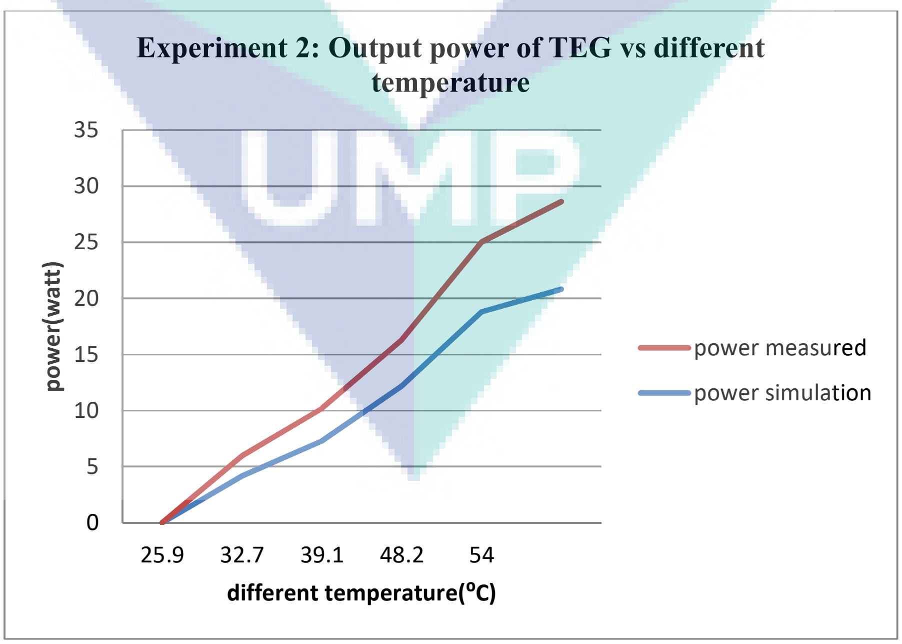
Figure 4.4: Output current TEG vs. time

4.2.2 Experiment 2 and Experiment 3(Using the ice cubed)

The experiment of the TEG was repeated again. In this experiment, all the configurations of TEG were set-up same with the previous experiment. It was conducted in a workshop at the University Malaysia Pahang. The difference is the ice was used to maintain the cold temperature. Two experiments were conducted with using this ice cubed but the date and time were different. In this case, the cold temperature was still increasing as the hot temperature increase. This two experiment were illustrated and comparing in Figure 4.5. The table 4.2 for experiment 2 (appendix) shows that the output power was generated by the range temperature between 40^{0}C to 80^{0}C and cold temperature in 15^{0}C to 26^{0}C. While for the table 4.3 for experiment 3(appendix) shows that the output power was generated by the range temperature between 27.5^{0}C to 78.8^{0}C and cold temperature in 28.8^{0}C to 36.4^{0}C.

The effect of the ice is the power that generated from these two experiments is higher than compared with the previous experiment. The output current and voltage increasing with temperature. Therefore, for the experiment 2 the power produced rapidly increases from the 4.17 watt to 20.80 watts. For the simulation, the power that's generated is also increasing as the temperature was increased. The power that simulated is from 1.8 watts to 7.83 watts. This experiment shows that the power of TEG that generated from the calculation is higher compared with the simulation.

In experiment 3, the result was taken in three minutes at the time of range. It means that the temperature will increase in every three minutes. The initial reading for the hot and cold temperature is at 27.7 ^{0}C and 28.8 ^{0}C respectively. Within the range of different temperature between -1.3 ^{0}C to 42.4 ^{0}C, the TEG can generate power in between 0.0036 watts to 19.22 watts. The result shows that the power that generated from the TEG increase as the temperature increase. For the simulation that shows from the Matlab, it was illustrated that the power that can be generated is between 0.0042 to 4.82 watts. The results of measurement are higher than compared with the results show in a simulation. Based on Figure 4.5, show that the power that generated from TEG for both of experiments was directly proportional to temperature. In overall, experiment 2 show the much better in order to generate power compared with the experiment 3.



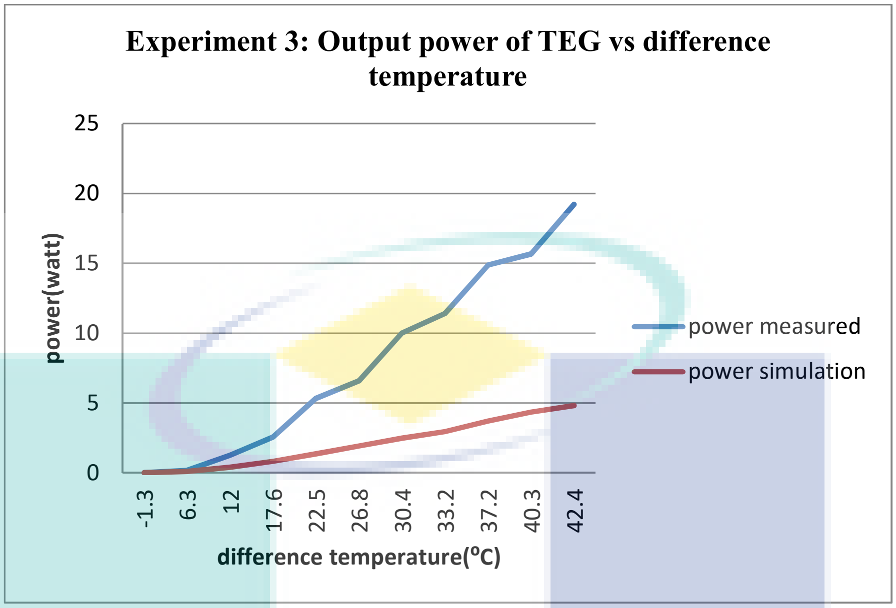
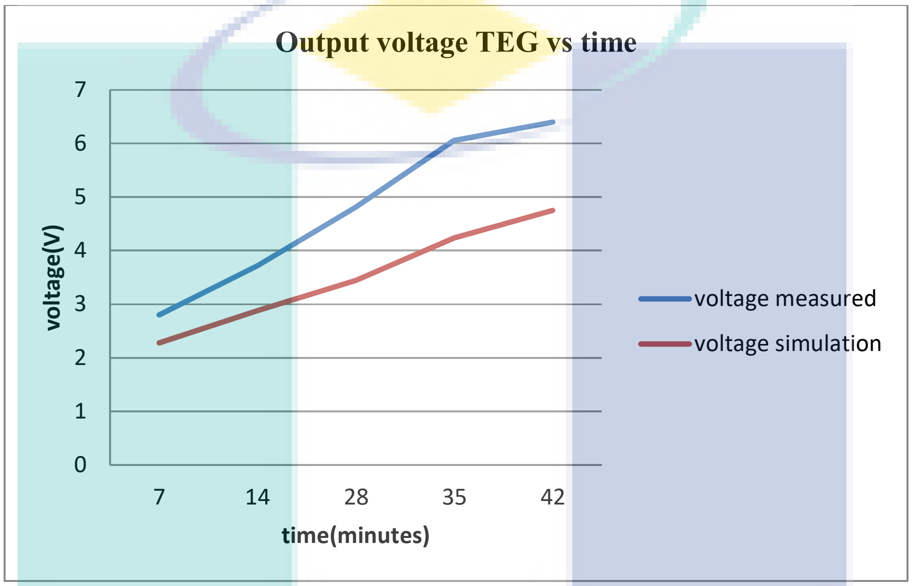


Figure 4.5: Comparison of the two experiment of the output power of TEG vs different temperature

For the output voltage generated, Figure 4.6 show the comparison between the output voltage versus time for the experiment 2 and experiment 3. Figure 4.6 shows the output voltage from measured and simulation from Matlab.For experiment 2, the output voltage from measured show the higher value, compare with the value that produced from the simulation. In the 42 minutes, the output voltage that can be generated is from 2.80 volts to 6.40 volt. While for the simulation, it can be generated from 2.28 volt to 4.75 volts. Based on experiment 2, the output current of TEG is shown directly proportional to time.

For experiment 3, the output voltage measured is higher than compared with the output voltage that produced from the Matlab simulation. In the 30 minutes, the output voltage is increased from 0.06 volt to 6.24 volt. While for the simulation, the output voltage is between 0.01 volt to 3.73 volts. Based on experiment 3 the output voltage TEG is directly proportional to time. Both of the experiment show the output voltage increase as the time increase. The different between experiment 2 and experiment 3 is in the time range. Experiment 2 take a longer time to generate a voltage in 42 minutes compare with the experiment 3 it takes only 30 minutes to reach the voltage in 6.24 volts.

In overall, the output voltage that generated in the experiment 2 is higher than compared with the experiment 3. The output voltage that can be reached by the experiment 3 is 6.40 volts. The longer the time taken, the higher the output voltage that can be generated. Experiment 2 is much better in order to generate an output voltage with the using ice cubed compared with the experiment 3.



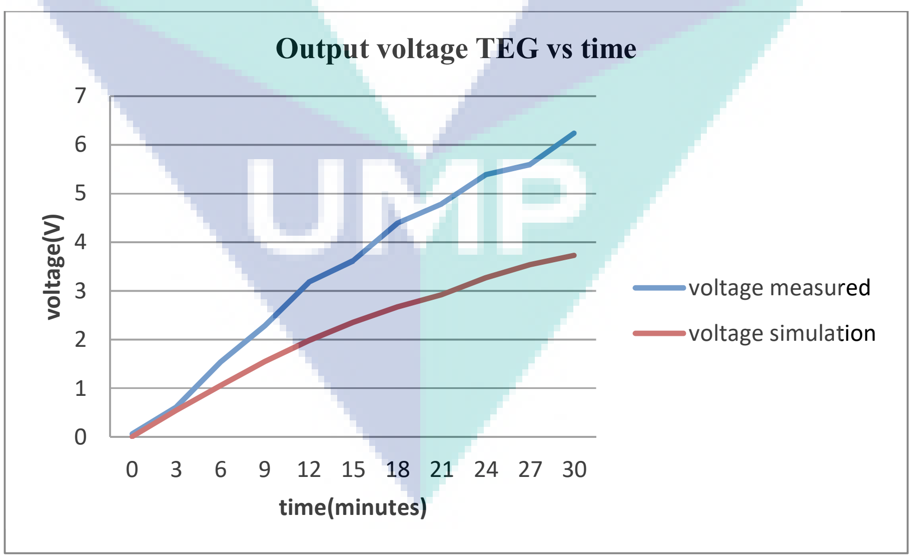
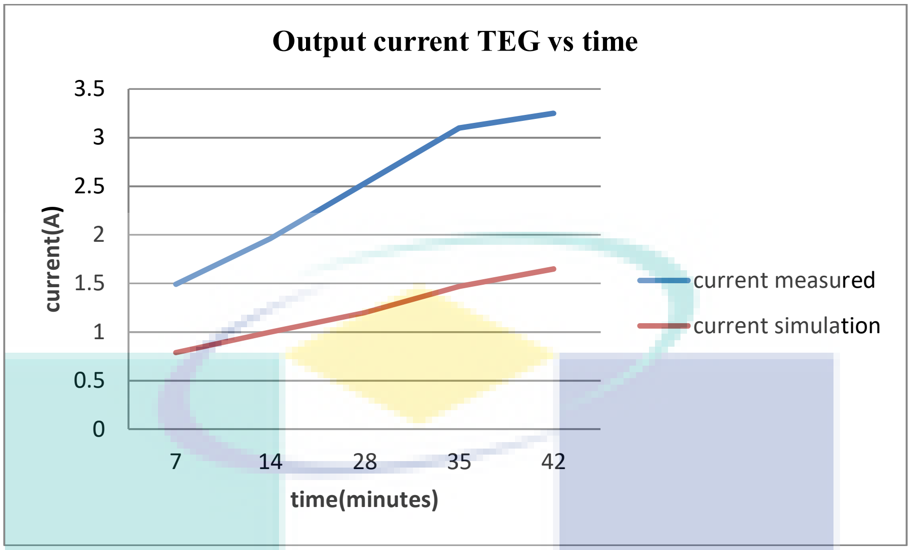


Figure 4.6: Comparison of the two experiment of the output voltage of TEG vs different temperature

For the output current generated, Figure 4.7 show the comparison between the output current versus time for the experiment 2 and experiment 3.In Figure 4.7 below, show that the output current of TEG versus time. For the experiment 2, the output current that generated from measuring is higher than compared with the output current that generated from Matlab simulation. In the 42 minutes, the output current that can be generated is from 1.49 A to 3.25 A. While for the simulation, it can be generated from 0.79 A to 1.65 A. Based on experiment 2, the output current of TEG is directly proportional to time.

In experiment 3, the output current that taken from the measurement is higher than compared with the output current that produced from the Matlab simulation. The output current increases from 0.006 A to 3.08 A. While for the simulation, the output current is between 0.04 A to 1.3 A. Based on experiment 3, the output current of TEG is directly proportional to time. Both of the experiment shows the output current increase as the time increase. The different between experiment 2 and experiment 3 is in the time range. Experiment 2 take a longer time to generate current in 42 minutes compare with the experiment 3 it takes only 30 minutes to reach the highest current.

In overall, the output current that generated in experiment 2 is higher than compared with the experiment 3. The highest output current that can be reached by the experiment 3 is 3.25 A. The longer the time taken, the higher the output current that can be generated. Experiment 2 is much better in order to generate an output current with the using ice cubed compared with the experiment 3.



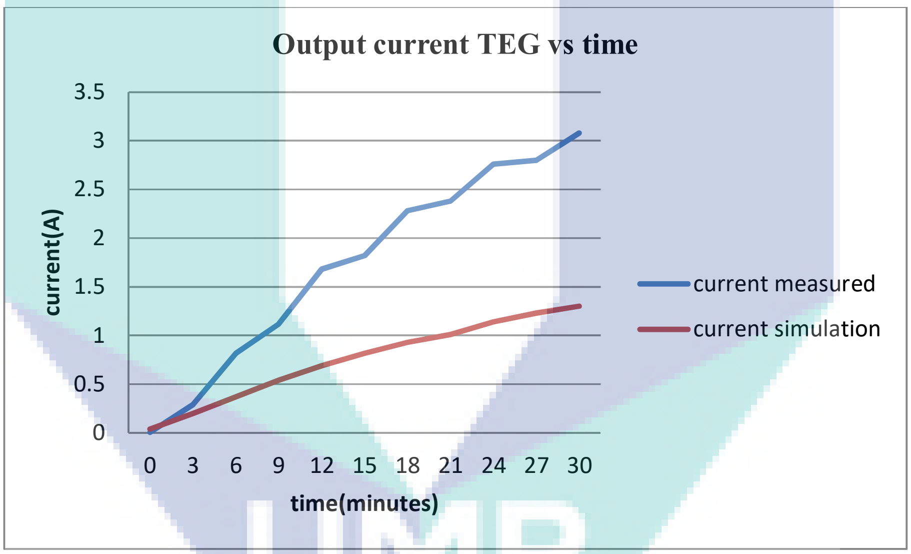


Figure 4.7: Comparison of the two experiment of the output current of TEG vs different temperature

4.3 PV power generation

The manual calculation for PV module must be done first. Using the specifications in the Table 4.4 will describe the operating PV cell temperature, short circuit current, voltage on open circuit and maximum power output of the module. Figure 4.8 shows the specification for SW80 mono/R5E. While at Table 4.5, show the value calculation for the PV characteristics. In this PV system, five experiments will be conducted in different day and time. The location of the experiment was carry out in the Alternative energy laboratory at Universiti Malaysia Pahang.

Figure 4.8: SW80 mono/R5E

Table 4.4: Specifications of PV SW80 mono/R5E

Pmax	80 Wp
Vmpp	17.5 V
Impp	4.6A
Voc	21.9V
Isc	5.00 A
NOCT	46 °C
Thermal coefficient Isc	0.036 %/K
Thermal coefficient Voc	-0.33 %/K
Rated power	80 Wp +/- 5 %

Table 4.5: Value calculation for the PV characteristics

Operating PV cell temperature, Tcell	31.5 °C
Short circuit current, Isc-corrected	5.01 A
Voltage at open circuit, Vvoltage-corrected	21.44 V
Maximum power output, Ppower-corrected	54.5 Wp

4.3.1 Experiment 1

The standalone system equipment consists of the PV module, battery, controller, inverter and also the load. It was conducted in the Alternative energy laboratory at Universiti Malaysia Pahang. For the experiment 1, a multimeter was used to take a reading of the current and voltage. From these values, the power generated from the PV module can be calculated.The temperature and solar irradiance were taken from the weather station at UMP. This value will be used as the input to produce the current and also power generated from the PV simulation. The temperature range that was used is between 25.6 °C to 27.4 °C. While for the solar irradiance is between 294 w/m^2 to 1020 w/m^2.

When the solar irradiance increases so that the current and voltage also increases. Based on Figure 4.9, at the 9.30 am to 10.30 am shows that the power increase but when at 11.30 am to 2.30 pm the power is rapidly dropping. This is caused by the bad weather. At this time range, the rain was dropped so that it will influence about the solar irradiance and temperature as well as the current and voltage reading also affected. But the power fast increased at 3.30 pm and slowly drop until 6.30pm. Figure 4.9 was illustrated the power calculation from the PV module and power simulation from the Matlab. The graph shows the power calculation is higher than compared with power simulation. For the simulation, the Matlab will produce the output IV and PV characteristics. From IV output, the maximum voltage and current can be generated from that. This value is used to compare with the power that generated from the calculation.

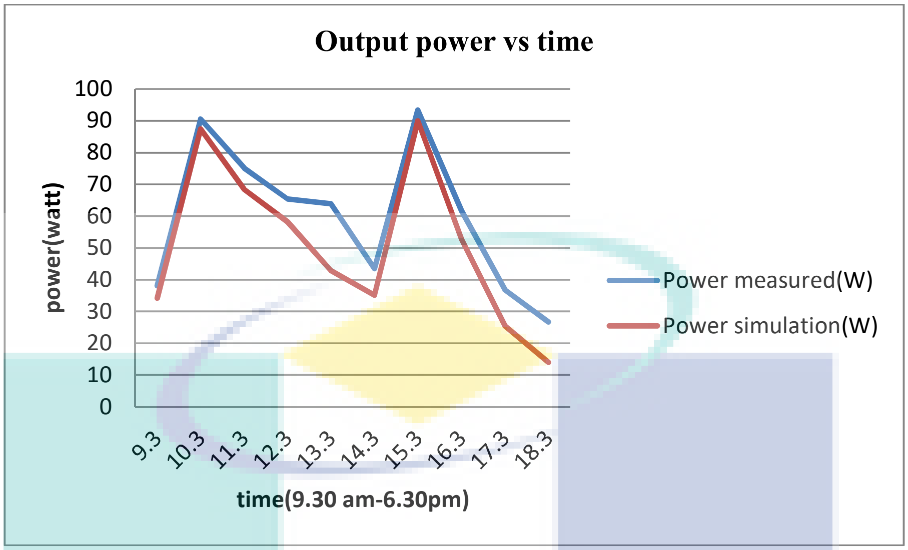


Figure 4.9: The power vs time from the PV module measured and simulation of Matlab Simulink

The Table 4.8(appendix) shows the generated current and generated power calculation that calculated based on from the equation in (3.21) to (3.23). Based on Table 4.6 (Appendix), the graph of the solar irradiance and temperature can be computed in the Figure 4.10 and Figure 4.11. From these values, the Figure 4.12 and Figure 4.13 also computed graph for the PV module current and PV power during the day. It has shown that similar with the power that computed from the simulation.

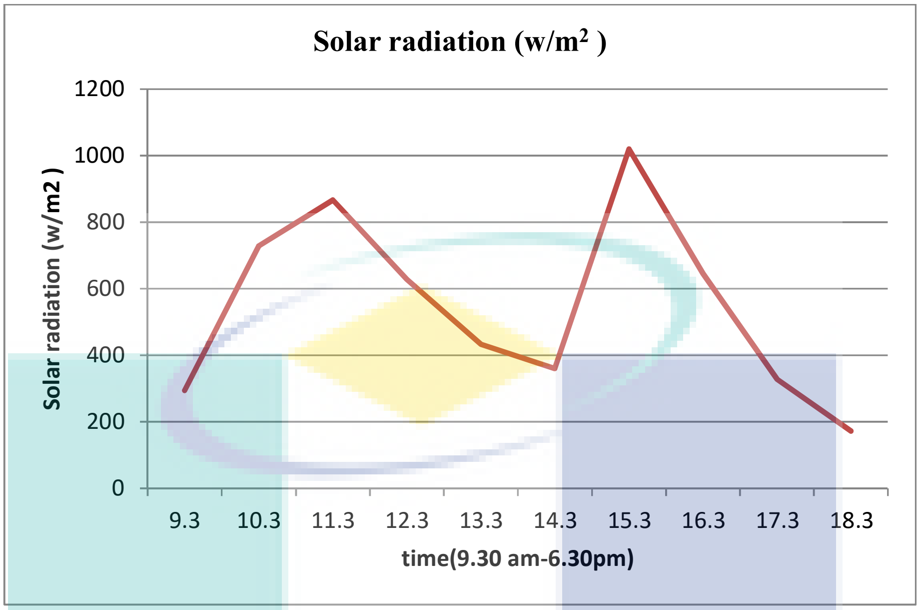


Figure 4.10: Solar irradiance vs time

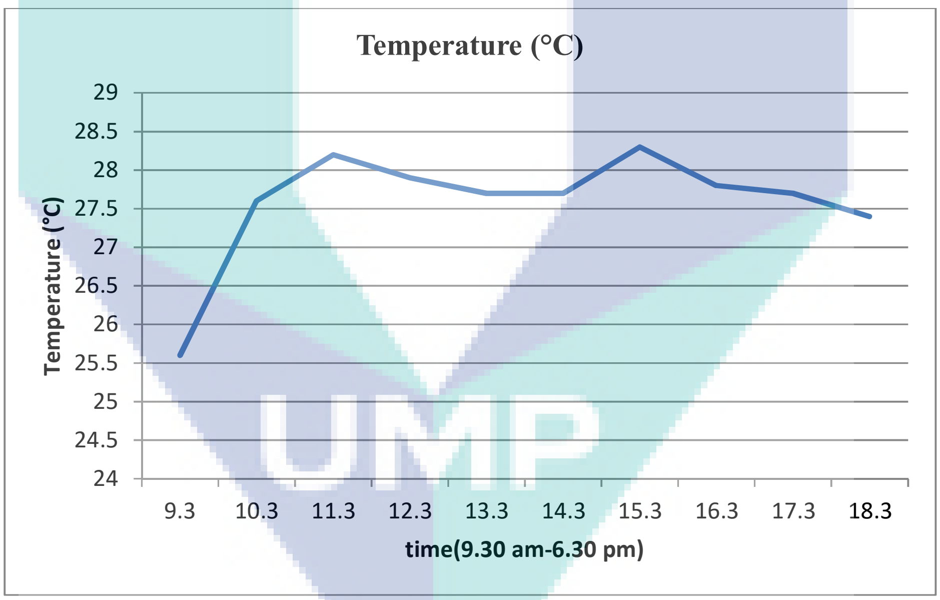


Figure 4.11: Temperature vs time

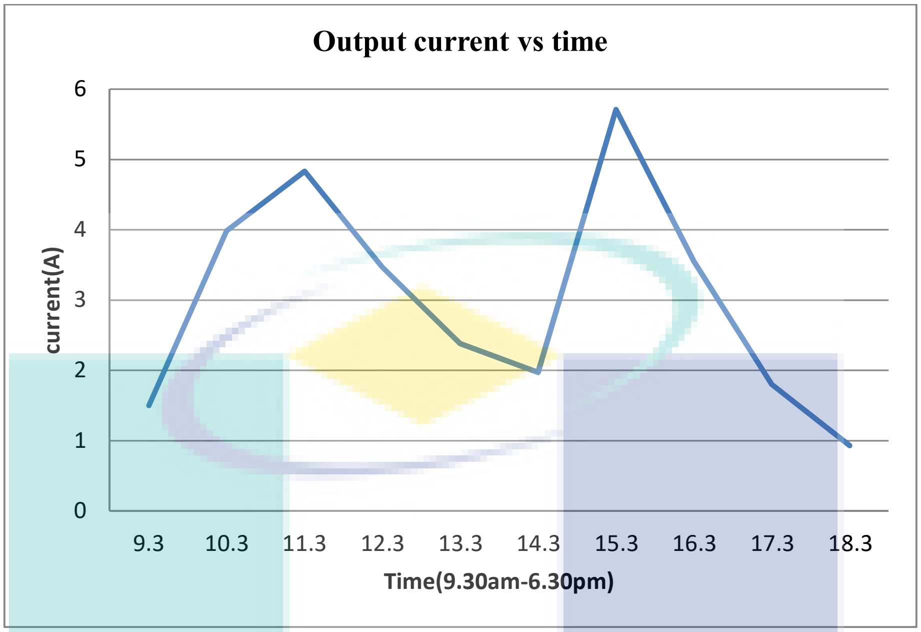


Figure 4.12: PV module current during daytime

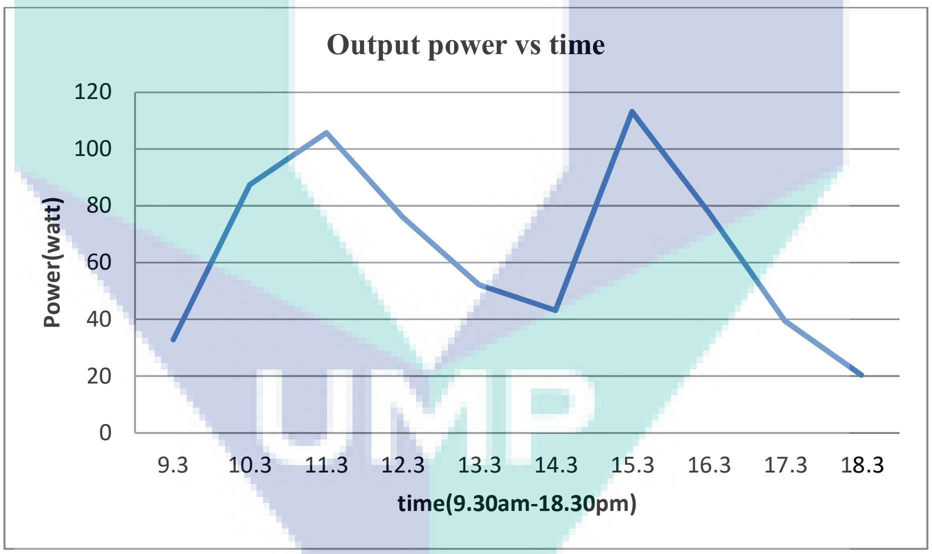


Figure 4.13: PV module power during daytime

4.3.2 Experiment 2

The experiment continues with the other solar irradiance and temperature range. The temperature range that was used is between 25.6 °C to 28.3 °C. While for the solar irradiance is between 162 w/m^2 to 972 w/m^2.When the solar radiation increases so that the current and voltage also increases. The Figure 4.14 shows the power generated that was taken from the 8.00am to 5.00pm. It was illustrated the power measured from the

PV module and power simulation from the Matlab. From 8.00 am to 12.00 at noon, the power is rapidly increasing since the solar irradiance was increased. Then, it will slowly drop in the evening. At noon, the power generated is 90.92 watts. In the simulation, the power generated is almost similar which is 90.10 watts. The graph shows the power measured is higher than compared with power simulation. For the simulation, the Matlab will produce the output IV and PV characteristics. From IV output, the maximum voltage and current can be generated from that. This value is used to compare with the power that generated from the calculation.

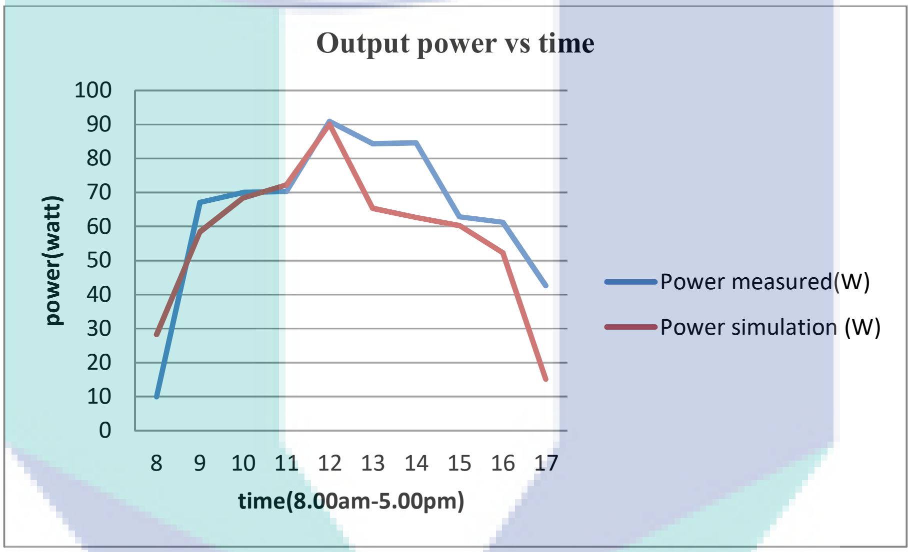


Figure 4.14: The power vs. time from the PV module measured and simulation of Matlab Simulink.

The Table 4.11(appendix) shows the generated current and generated power calculation that calculated based on from the equation in (3.21) to (3.23). Based on table 4.9(appendix), the graph of the solar irradiance and temperature can be computed in the Figure 4.15 and Figure 4.16. From these values, the Figure 4.17 and Figure 4.18 also computed graph for the PV module current and PV power during the day. It has shown that similar with the power that computed from the simulation.

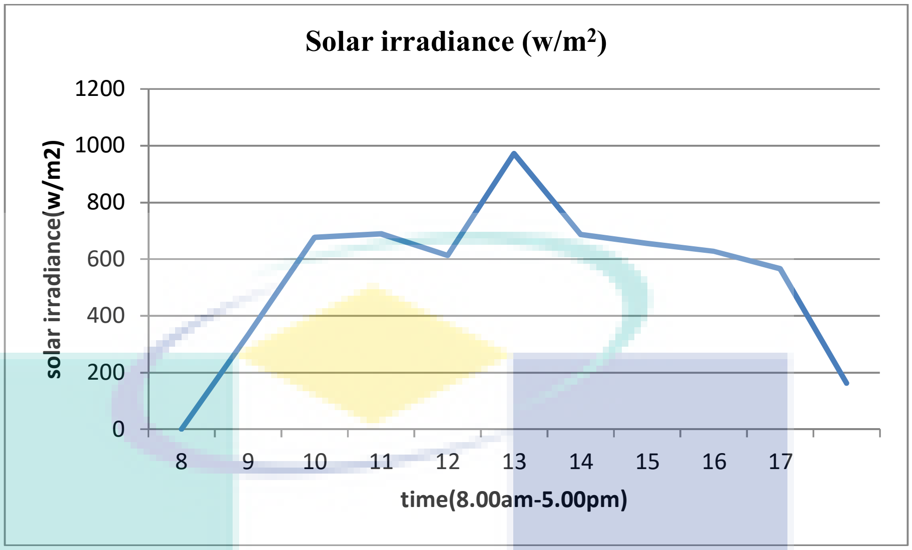


Figure 4.15: Solar irradiance vs time

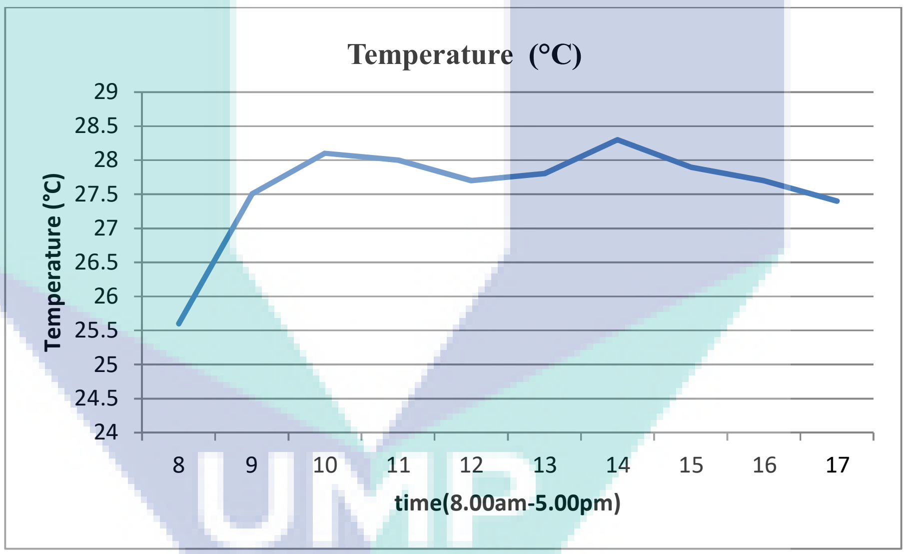


Figure 4.16: Temperature vs time

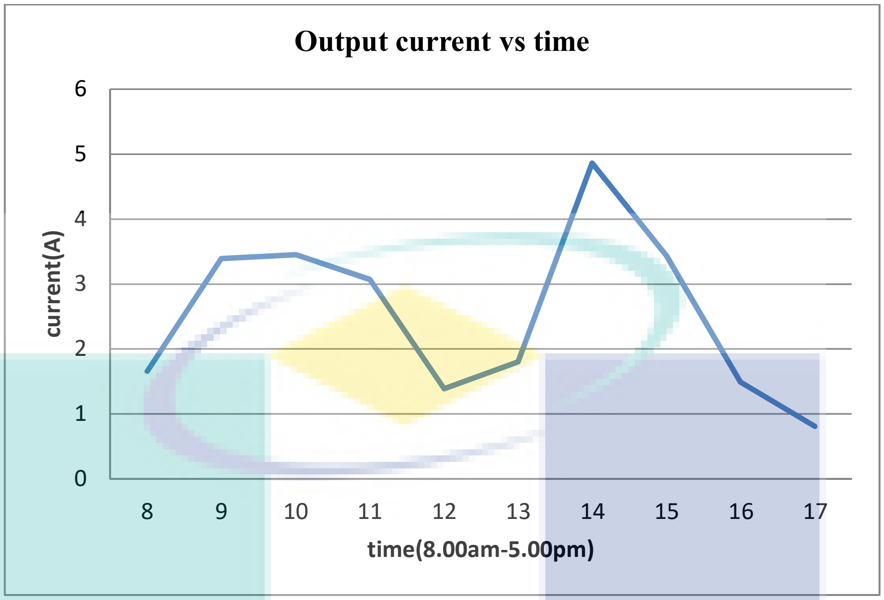


Figure 4.17: PV module current during daytime

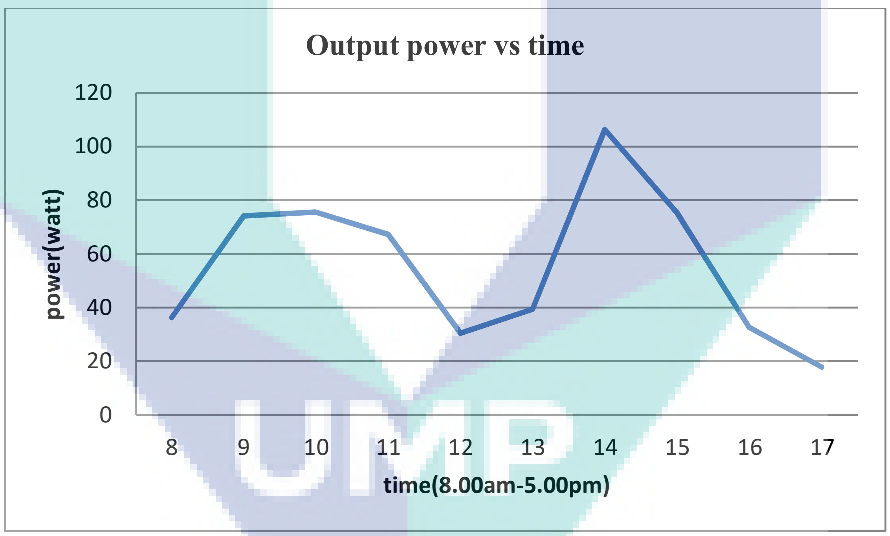


Figure 4.18: PV module power during daytime

4.3.3 Experiment 3

The experiment is repeated again with the difference in temperature and solar irradiance. The temperature range that was used is between 25.4 °C to 28.2 °C. While for the solar irradiance is between 242 w/m^2 to 896 w/m^2. When the solar radiation increases so that the current and voltage also increases. The Figure 4.19 shows the power generated that was taken from the 8.00am to 5.00pm. It was illustrated the power measured from the PV module and power simulation from the Matlab. From 8.00 am to

9.00am, the power is constantly increasing but at 10.00am to 12.00 at noon the power slowly drops. This happens because the condition of the weather is overcast. But after that, the power becomes increasing and slowly drop since the evening. The graph shows the power measured is higher than compared with power simulation. For the simulation, the Matlab will produce the output IV and PV characteristics. From IV output, the maximum voltage and current can be generated from that. This value is used to compare with the power that generated from the calculation.

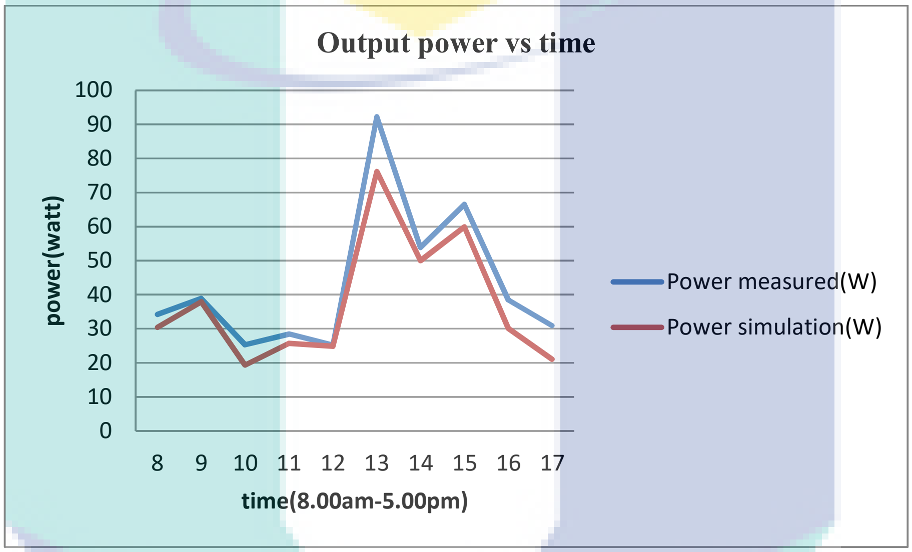


Figure 4.19: The power vs time of the PV module measured and simulation of Matlab Simulink

The Table 4.14(appendix) shows the generated current and generated power calculation that calculated based on from the equation in (3.21) to (3.23). Based on the Table 4.12(appendix), the graph of the solar irradiance and temperature can be computed in the Figure 4.20 and Figure 4.21. From these values, the Figure 4.22 and Figure 4.23 also computed graph for the PV module current and PV power during the day. It has shown that similar with the power that computed from the simulation.

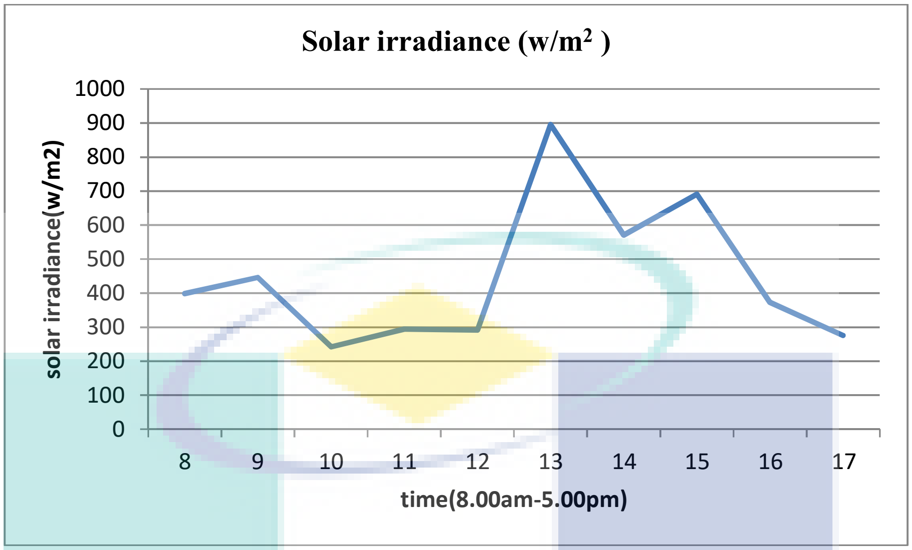


Figure 4.20: Solar irradiance vs time

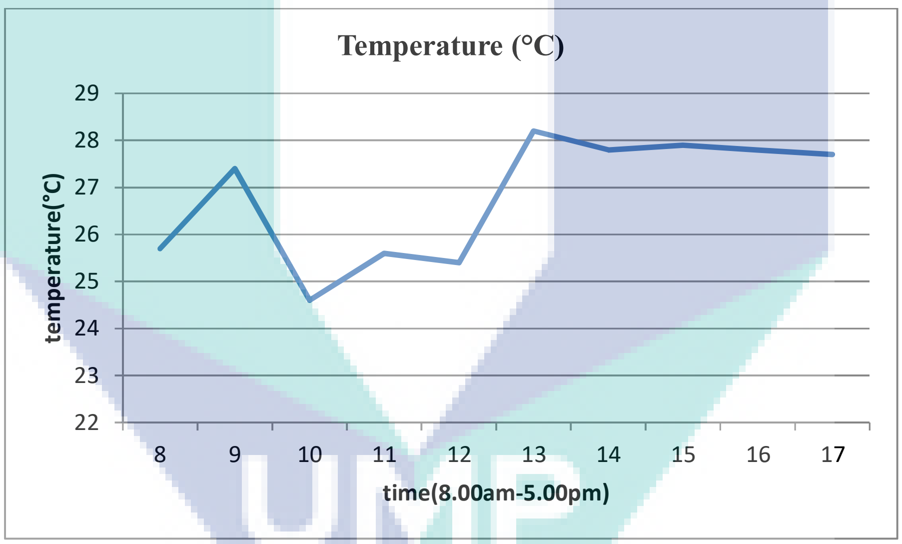


Figure 4.21: Temperature vs time

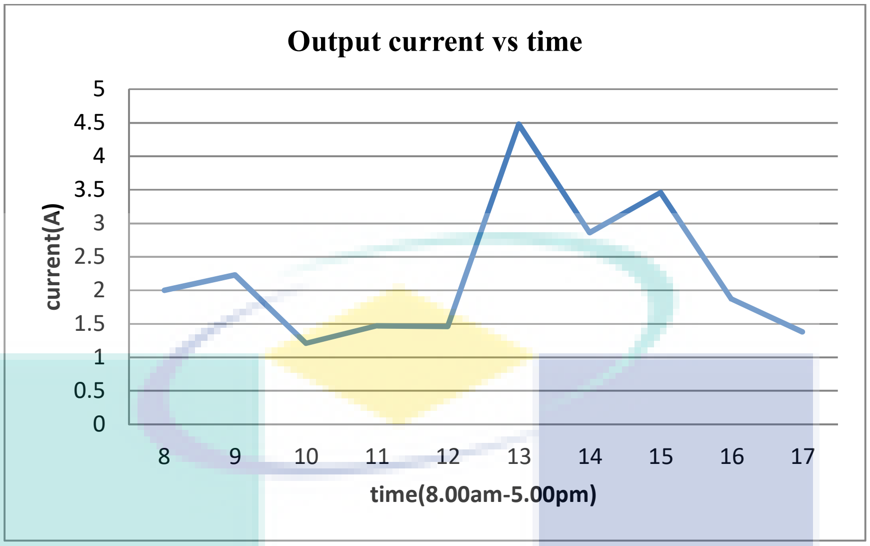


Figure 4.22: PV module current during daytime

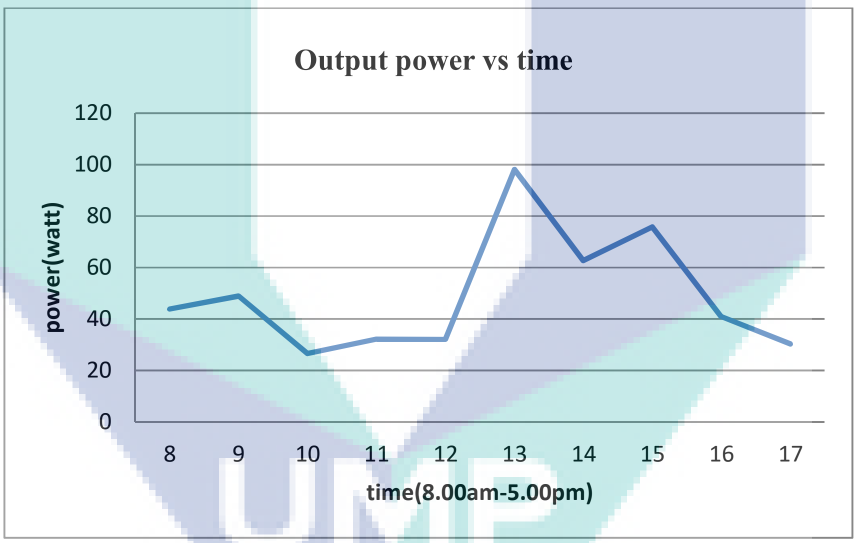


Figure 4.23: PV module power during daytime

4.3.4 Experiment 4

The experiment is repeated again with the difference in temperature and solar radiation. The temperature range that was used is between 25.6 °C to 28.6 °C. While for the solar irradiance is between 285 w/m^2 to 1018 w/m^2. When the solar radiation increases so that the current and voltage also increases. The Figure 4.24 shows the power generated that was taken from the 8.00am to 5.00pm. It was illustrated the power measured from the PV module and power simulation from the Matlab. During this experiment, the weather condition is very good. The power that generated show in figure 49 below is slowly increased at 8.00 am until 1.00 at noon with the power generated is from 25.72 watts to 97.94 watts. Then, from 2.00pm to 5.00 pm, it slowly drops since the decrease of the solar radiation and temperature. For the simulation, the graph that is generated is almost same with the actual measured. The power starts to increase with the 25 watts to 88 watts and drops from 86 watts to 22 watts. The graph shows the power measured is higher than compared with power simulation. For the simulation, the Matlab will produce the output IV and PV characteristics. From IV output, the maximum voltage and current can be generated from that. This value is used to compare with the power that generated from the measured.

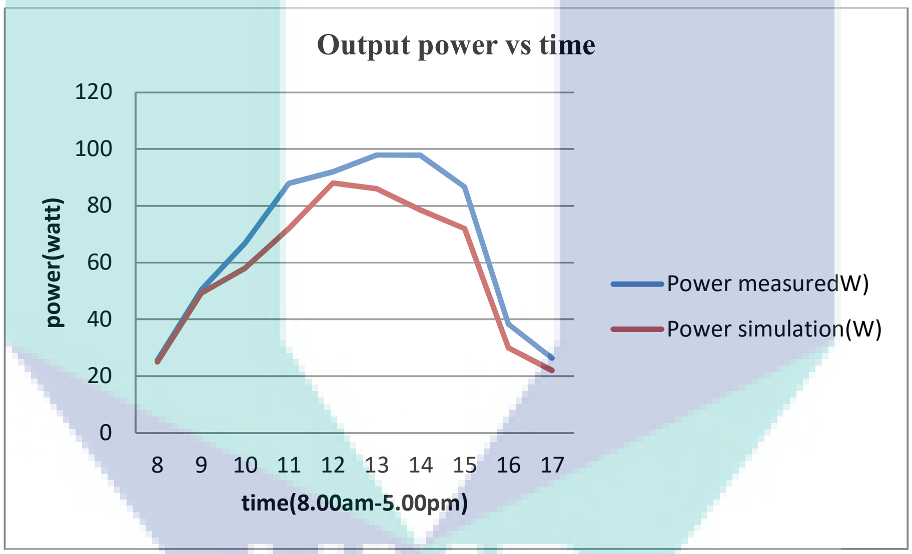


Figure 4.24: The power vs time of the PV module measured and simulation of Matlab Simulink

The Table 4.17(appendix) shows the generated current and generated power calculation that calculated based on from the equation in (3.21) to (3.23). Based on the Table 4.15(appendix), the graph of the solar irradiance and temperature can be computed in the Figure 4.25 and Figure 4.26. From these values, the Figure 4.27 and Figure 4.28 also computed graph for the PV module current and PV power during the day. It has shown that similar with the power that computed from the simulation.

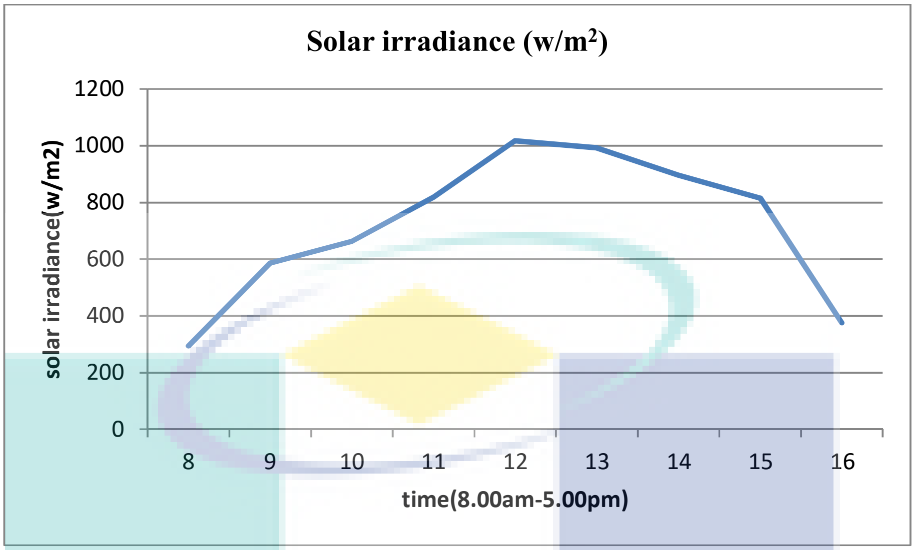


Figure 4.25: Solar irradiance vs time

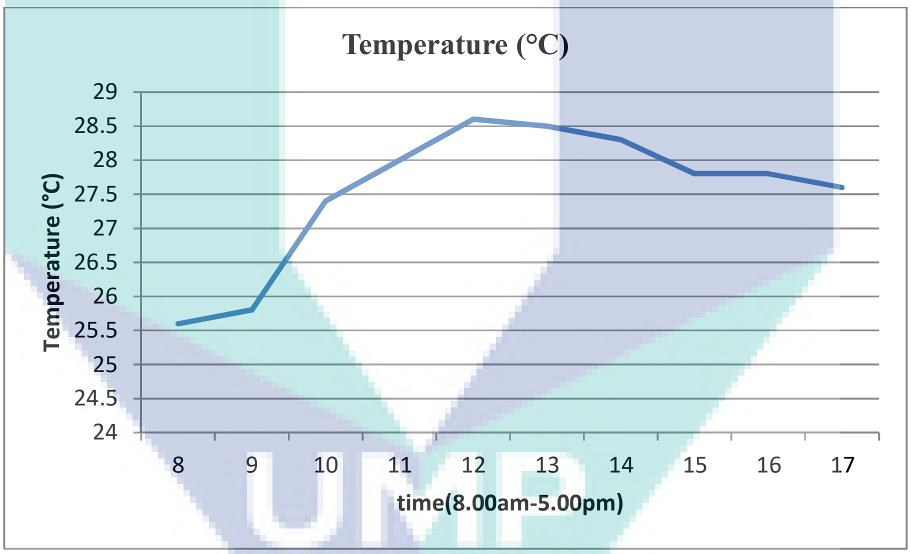


Figure 4.26: Temperature vs time

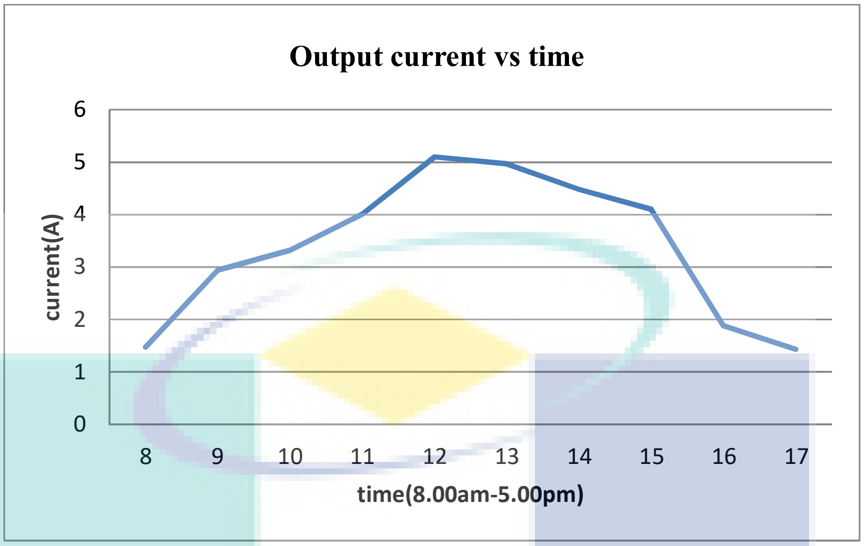


Figure 4.27: PV module current during daytime.

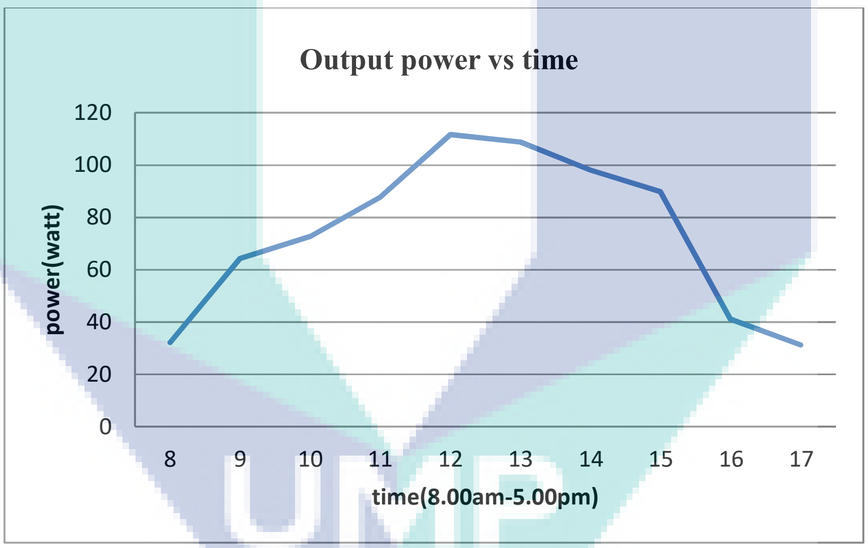


Figure 4.28: PV module power during daytime.

4.3.5 Experiment 5

The experiment is repeated again with the difference in temperature and solar irradiance. The temperature range that was used is between 25.7 °C to 28.0 °C. While for the solar irradiance is between 229 w/m^2 to 661 w/m^2. When the solar radiation increases so that the current and voltage also increases. The Figure 4.29 shows the power generated that was taken from the 8.00am to 5.00pm. It was illustrated the power measured from the PV module and power simulation from the Matlab. At 8.00 am to

10.00 am, power slowly increased, but after that rapidly drop until 1.00 at noon. This happens because the rainfall at this time range cause the solar irradiance and temperature also decrease. However, at 2.00 pm, the power increase again and slowly decreases until 5.00pm. For the simulation, the graph that is generated is almost same with the actual calculation. The graph shows the power measured is higher than compared with power simulation. For the simulation, the Matlab will produce the output IV and PV characteristics. From IV output, the maximum voltage and current can be generated from that. This value is used to compare with the power that generated from the measurement.

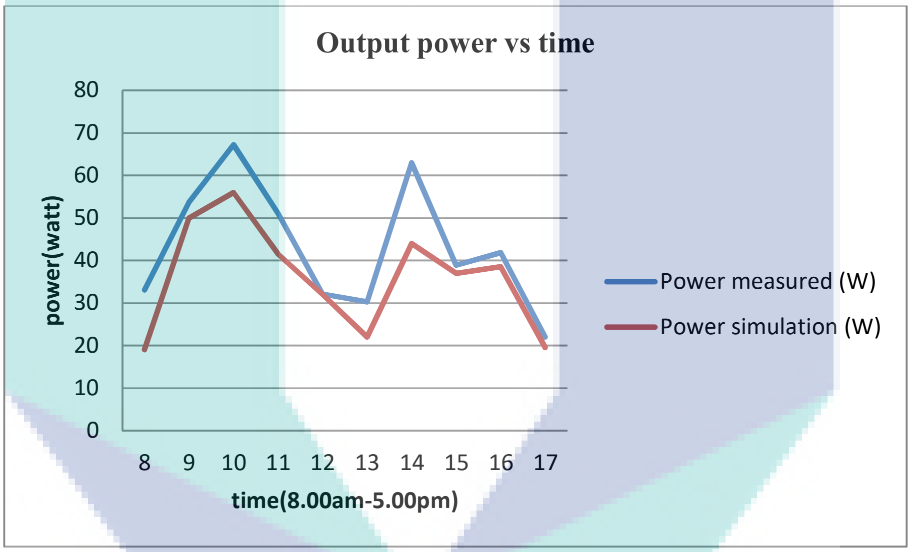


Figure 4.29: The power vs time of the PV module measured and simulation of Matlab Simulink

The Table 4.20(appendix) shows the generated current and generated power calculation that calculated based on from the equation in (3.21) to (3.23). Based on the Table 4.18(appendix), the graph of the solar irradiance and temperature can be computed in the Figure 4.30 and Figure 4.31. From these values, the Figure 4.32 and Figure 4.33 also computed graph for the PV module current and PV power during the day. It has shown that similar with the power that computed from the simulation.

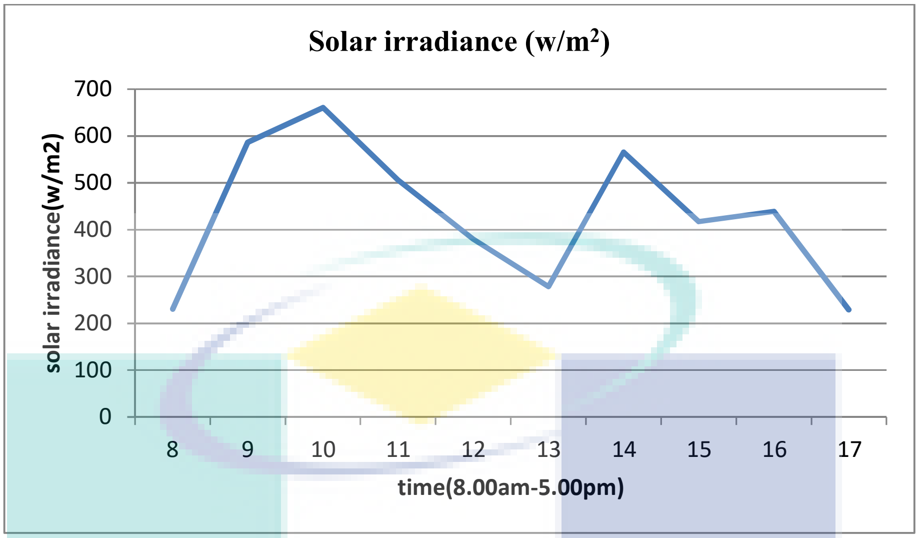


Figure 4.30: Solar irradiance vs time

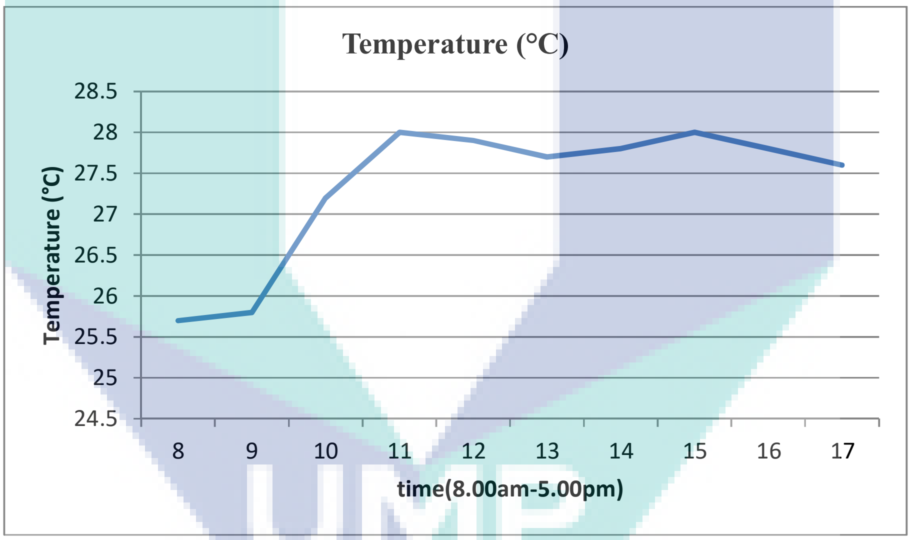


Figure 4.31: Temperature vs time

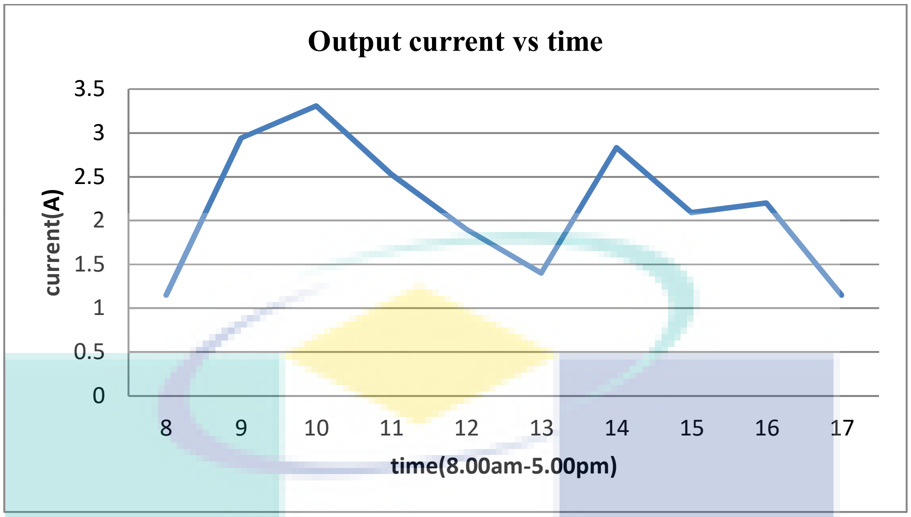


Figure 4.32: PV module current during daytime

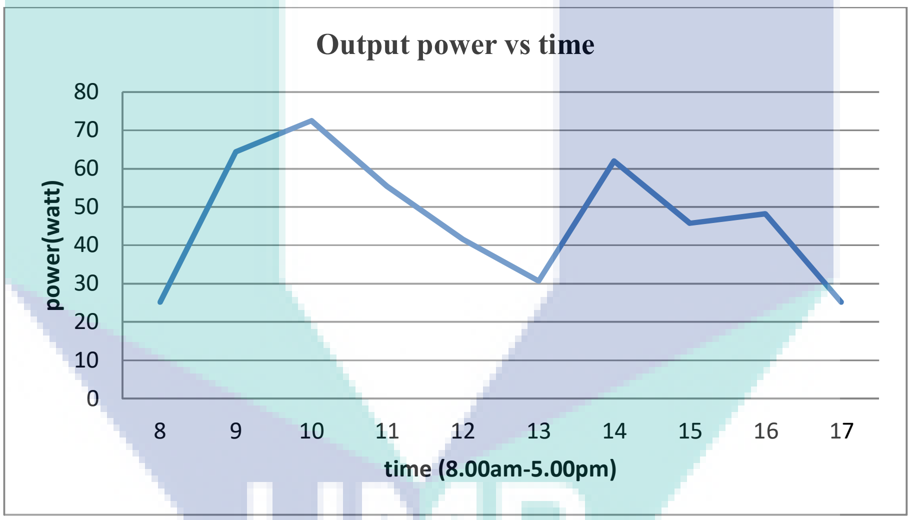


Figure 4.33: PV module power during daytime

4.4 Hybrid System Between TEG and PV Power Generation

Figure 4.34 shows the hybrid system between TEG and PV module. The system of TEG and PV module must be combined to get the maximum output power. Then, the value will be compared with the separate system of TEG and PV module. For the hybrid simulation, the TEG and PV Simulink must be combining to become one system. Then the system will be used to find the value of current, voltage and output power. For the hardware development, equipment that needed to complete this hybrid system is the hybrid charge controller, battery, inverter, socket switch, circuit breaker, and thermometer with probe and water heater. For sizing system, one complete arrangement will design to put all this equipment in one place.

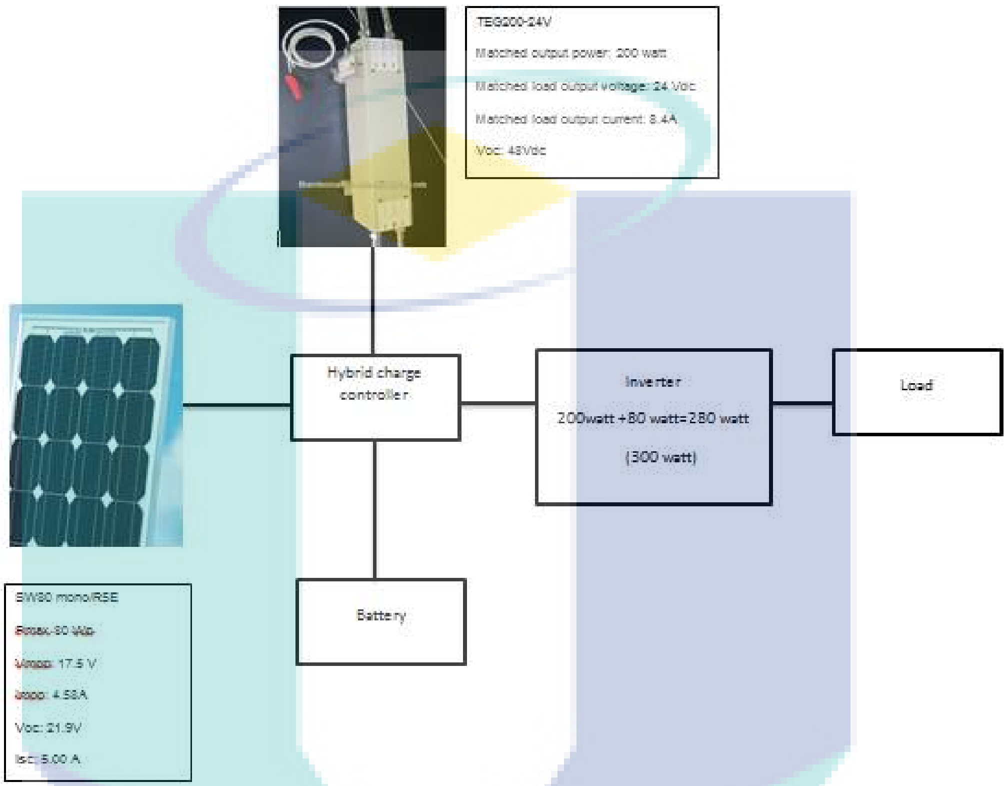


Figure 4.34: Hybrid system of TEG and PV module

The experiment between the PV module and TEG was conducted. This experiment uses the solar irradiance in the range between of 819 w/m^2 to 1023 w/m^2. While for the temperature is between 28 °C to 28.6 °C. The reading of parameters is taken out in 15 minutes time of range since the temperature of TEG is rising quickly. As the hot temperature increase, the cold temperature also increases. The Table 4.21 and Table 4.22 (appendix) shows the parameters of the PV module and TEG from the calculation and Matlab simulation. Besides, the TEG current and voltage also will increase as the temperature increase. In the Table 4.23 and Table 4.24 (appendix) shows the parameters that generated from the hybrid PV-TEG, power generation system.

Based on the parameters that tabulated in the Table 4.24, the graph in the Figure 4.35 can be plotted. It was shown that the relationship between the hybrid output power between the PV-TEG versus solar irradiance. It was compared with the simulation and measured value. The measured output power shows the higher result compared with simulation in Matlab. As the solar irradiance increase, the output also will increase. While in the Figure 4.36 below show the hybrid output power versus time. As the time increases, the output power also will increase. This is because of the different temperature between the hot side and cold side increase. In this case, it was also shown that the measured output power is higher than compared with the simulation value.

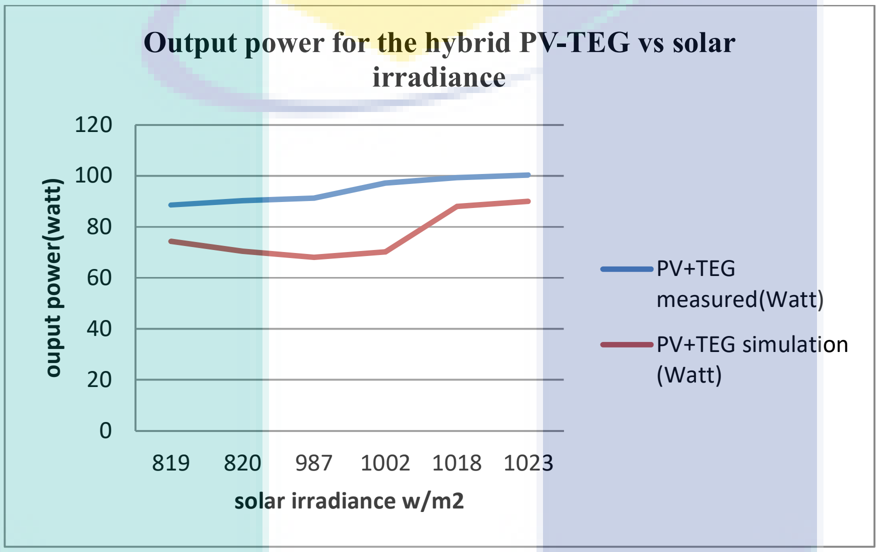


Figure 4.35: Hybrid output power vs. solar irradiance

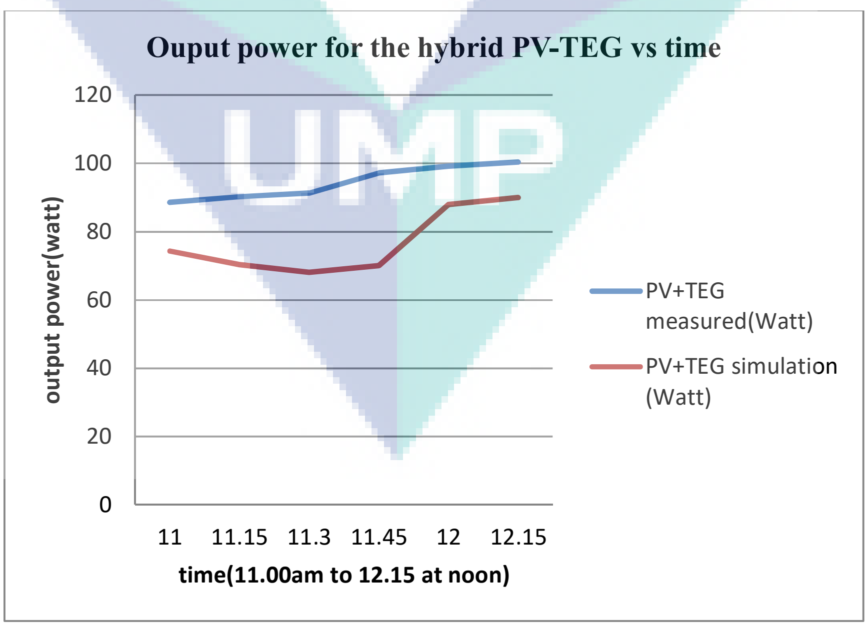


Figure 4.36: Hybrid output power vs time

The Figure 4.37 shows the hybrid power that generated from the PV module and TEG. Show also the hybrid power that plotted from the Matlab simulation. The hybrid output power measured is higher than comparing with simulation value. This experiment was started at 8.00 am to 5.00pm. When this system was hybridized with PV-TEG, show that the output power that can be generated is higher than compared with the individual test for the PV system power generation. Based on the graph below, the increasing of the output power happens at 11.00 am until 12.00 at noon. The increasing is from 87.93 watts to 88.63 and from 91.98 watts to 99.27 watts respectively. While for the simulation, it was also shown the increasing in the output power. At the 11.00 am, it was starting to change from 72 watts to 74.3 watts and the other one is showing the same output power. In overall, with the using hybrid PV-TEG, the output that can be generated is higher than compared with an output power of the individual experiment.

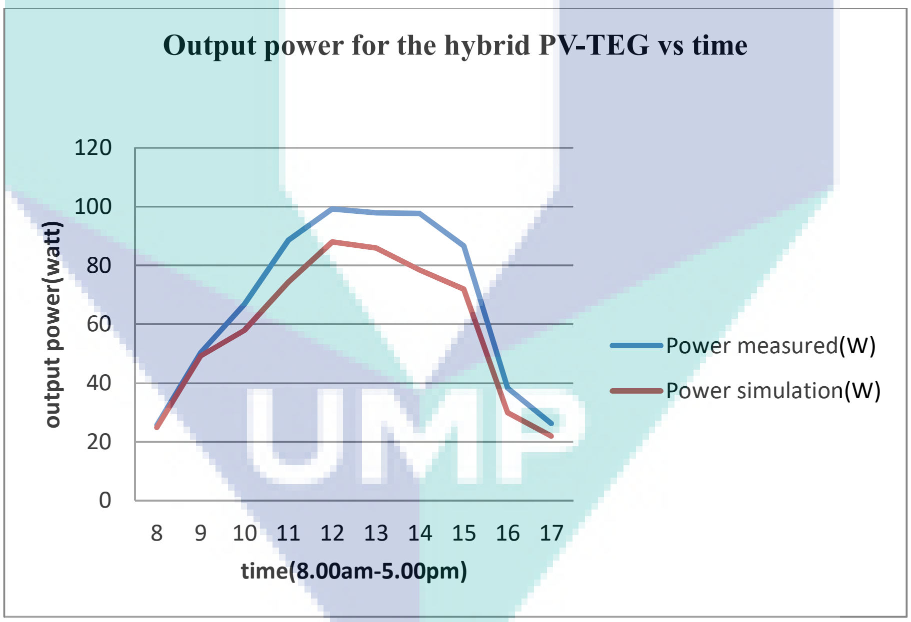


Figure 4.37: Output power hybrid TEG-PV vs time

4.5 The potential implementation of TEG for power generation in Malaysia

4.5.1 Biomass

In Malaysia, biomass is regarded as the sustainability of the energy for fossil fuels [32]. Biomass residues have a great opportunity to be used as the power source in Malaysia by using empty fruit bunch, fiber and shell of palm oil. Recently, oil palm production in this country shows the improvement. The fresh fruit bunch production has been recorded 98.45Mt in 2011, which are 100% increase in 10 years. At the same time, production of the oil palm residue also had led the same pattern.

Because of lack specialists in the optimization of biomass waste into the country not encouraging of using biomass energy so most unwilling taking risk using this energy as power generating. In the scope of electric power generation, biomass can be viewed as a role to replace the old units and use for a small plant in the range of 20 to 50 MW [33]. Some of the high-efficiency technologies are already available for the biomass utilization. For example the energy performance system combustor (34 to 36%) and fluidized-bed combustor (36 to 38%). It was stated that biomass as energy sources can be utilized to TEG as a tool for the capture and convert heat into electrical energy. With the using of TEG function, it generates electricity that will run the fan on the biomass cook stove. The biomass of the cook stove was used as a TE generator. Through this investigation, the efficiency of combustion could be upgraded. At the same time, it also decreases the fuel composition and the emission level.

The electricity is very important for the biomass cook stove because it is to give power to the fan, as the air will blow through the stove. This situation will improve the fuel ratio as well as complete a combustion process. When the temperature in the stoves changes, it will fluctuate the output voltage of the TE module. This article is proving that TEG can be invoked as a very convenient way for the generate electricity [34]. The figure 4.38 show the sided view of the biomass-fired stove. It was also proved that the generator could be generated in the variety of weather condition such as in the rainy day or hot day. Based on this statement, Malaysia also has potential to apply this as a new technology for the power generation.

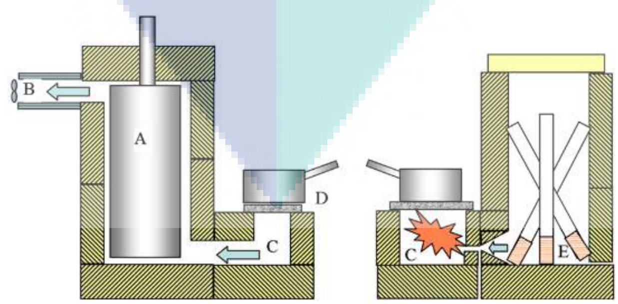


Figure 4.38: The two-sided view of biomass cook stove,(A) water tank, (B)combustion gas exit and fan, (C) hot incoming combustion gasses, (D) cooking plate, (E) pyrolyzing chamber [34].

4.5.2 Waste heat

Organic waste has been dominating the waste of Malaysia which comprises more than 40% than the number of waste flows. Between the 1980s and 1990s, the organic waste recorded the overall average of 50% and most of this waste is processed from the food waste and kitchen waste [35]. This country has a municipal solid waste comprises of waste, plastic bottles, glass, paper, metal, and fabric. Due to the increasing of population and the economic development have made the volume of solid waste increased in Malaysia. In 2003, listed a total of rate waste production in Malaysia is 1.7kg per day per person [36], while in 1987 this number was much lower at 0.7kg per day per person [37]. Just 3% of wastes generated in Malaysia is recycling [38].

Thermoelectric generators have been proposed for waste heat recovery applications, and advancements in thermoelectric materials development have highlighted the technology's energy efficiency and commercial potential. Thermoelectric generators have been used to power space vehicles for several decades [39] [40]so the research and development contributions and expertise from the space industry are invaluable in the development of terrestrial waste-heat recovery TEG. The heat source temperature is typically higher (~1000 °C) resulting in the use of thermo-electric materials such as silicon germanium which are suitable for high-temperature power generation. From electronics to industrial furnaces, numerous waste-heat sources at low- (>250 °C), mid- (~250-650 °C), and high- (>650 °C) temperatures exist. TEGs have mostly been proposed for waste-heat recovery in mid- and high-temperature applications such as automotive, engine, and industrial applications with untapped exhaust and process heat because of the potential for appreciable power generation [41]. The mid- to high-temperature exhaust and process heat types of applications are the focus of the discussion here, and sample heat source temperatures and applications are shown in Table 14.25.

Table 4.25: Sample heat source temperatures and applications [39]

Application	Heat source temperature
Automotive exhaust	400-700 °C
Diesel generator exhaust	~500 °C
Primary aluminum Hall-Heroult cells	700-900°C
Glass melting regenerative furnace	~450 °C

4.5.3 Hot spring

Malaysia is one of the countries that have good potential to become the hot spring tourism industry. Many of the hot springs in use as picnic spot or as the place to release tension after hard work [42]. The main reason for exploring of the hot spring resources are to determine the subsurface reservoir temperature geochemical and isotopic composition of the hot springs [43]. One related article stated that the power that distributed with hot spring is thought to be highly possible as renewable energy [44]. As the mention in the section above, Malaysia provides many hot springs and it will become a great opportunity for this country to use hot spring as electricity supply. Hot spring can be commercialized to be used as the power generation. For example, Japan as a developing country has been used the hot spring thermal energy with the TEG for the power generation. This country act wisely with find out a solution to increase the energy efficiency and to avoid global warming from happening. It was proven also as a clean technology [44].

The figure 4.39 show the illustration of TEG schematic with a hot spring. It has of thermo-electric generators and distribution switchboards with a battery charger. It is in places such as a hot springs resort and waste incineration plant in which the heat fluids corresponding to be used in thermo-electric power generation are readily available. The hot spring in the hot chamber will flow in the opposite direction towards with cold mountain water in the cold chamber. So that, the counter flow will form. This will allow the homogeneous of different temperature in TE module from side to side of the long chamber as well as built up a performance of the TE power generation. It was proven that the hot spring can be used with TEG system. To be compared with Malaysia, this country still does not provide this technology. However, the Malaysia government can take this opportunity to make the Japan as an example to create this technology in Malaysia. As the TEG is already available and provided with much hot springs, TE power generation by using hot spring sources can be generated.

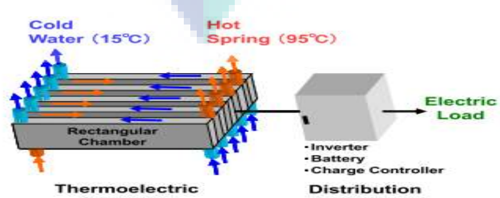


Figure 4.39: Illustration of the thermoelectric system [44].

4.6 Suggestion TEG as the power development of energy in Malaysia

In Malaysia, air pollution has created a serious environmental concern. Expansion level of contamination encouraging the economic development not a wonder as widely the energy input has been used within the production for the promotion of heavy industries [45]. Based on the development of renewable resources that have been used for power generation, Malaysia also can be used the TEG as the new technology as a tool to catch and swap energy into electric energy. For example, the hybrid TEG with solar is the one way that can be used for power generation. This stems from the fact that this system more effectively converts solar energy into electrical energy. Solar (PV) Power Systems is effective in most places with unobstructed access to sunlight. A TEG is appropriate for use in all climates (hot, cold, wet, dry) and its rugged design is not susceptible to airborne contaminants [46].

Furthermore, solar-thermoelectric hybrid system is environmentally friendly and has no harmful emissions [8]. Moreover, the fittings of PV do not have any moving parts and its requiring minimum maintenance and long lasting. The electricity produced does not release emissions of greenhouse or other gasses, and the operation is almost quietly [47]. Normally, many investigations between solar and the wind had been investigated by the researchers, the concept is still same with TEG for the how the power can be generated from this source. Thermoelectric generators are tools that can be used directly to switch out the heat into electricity by applying the Seebeck effect phenomenon [48].

The main advantage of this system is once as the power grid does not reach, it would fulfill the principal power needs to electrify remote areas. Power generated from both TEG and solar components is stored in a battery bank for use whenever required. The hybrid system will use more than one of the energy production methods, for example, the common device that used is sunlight and TEG device. Thermoelectric is a transition of thermal energy from a hotter object to a cooler object ("object" in this sense designating a complex collection of particles which are capable of storing energy in many different ways) [49].

In a macro view, as the production solar and wind power were used in common, the reliability of the system can be improved [48]. Normally, if there was no sunshine, there is a much wind. Their strength is almost unchanged if the hybrid solar and TEG is used. The difference here is just the tool and source that used. Malaysia should be more focus and prepared with another technology with applied renewable sources in the future. This is just not only for the country development but also for maintaining the green of the environment as well as for the sake of human life.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the result and analysis of the development of the hybrid system between the PV-TEG power generation shows that the efficiency of the power that is generated is increased. The output power that generated from the hybrid is higher than compared with the individual experiment from the PV and TEG system. During conducting this experiment, the result shows that as the solar irradiance increase, so that the output power that can be generated also increase. It was also stated that with the increasing time, the difference temperature for the hot side and cold side in the TEG system also would increase. This phenomenon causes the increasing in the output power.

However, during conducting an experiment for the TEG, 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. This is generated from the experiment 2. This voltage value shows that it cannot be able to generate power to supply the electricity to the load. For the output current, also show the lowest value. These values are impossible to produce the output power since its range in the low state. To avoid this problem, the ice cube can be used to increase the output current and output voltage in this system. By using the ice, it can be constantly the cold side temperature as well as to get the increase of the difference in temperature. From that, the output power can be slowly increased.

By comparison with the three experiments that has been conducting for TEG system, show that the experiment 1 is getting the worse output power. This is because its output current and voltage is very low compared with two others experiment. It voltage that generated in the range between 0.28 volt to 3.04 volt. The normal water was used for the cold side in TEG. When the temperature on the hot side becomes increase, the cold side also increases. This phenomenon has really given the bad effect towards to generate the output voltage and current. To overcome this problem, the cold side in the TEG system must be assumed with the constant temperature. The tap water can be used to constant the cold side temperature. This is because the tap water will not circulate with the same water. Therefore, it may reduce the hot heat that generated from the hot side temperature. With the constantly the cold side temperature, the output power can be increased with the increase of the different temperature.

The boiler that has been used for the hot side temperature also faced with the problem. This is because the boiler range is only 100 °C. However, the boiler is only able boiling water at 80°C with the highest value is at 6.40 volts. This is because the pump water that has been used is not strong enough to accommodate high temperatures. When this happens, the difference in temperature that will be produced is also limited. This is giving trouble to generate higher power. To avoid this happening, the best water pump with the right specifications must be selected.

During conducted an experiment in the PV system, the problem that has to be faced is the bad weather condition. As the bad weather such as the heavy rain happens, the experiment cannot be smoothly conducted. This is because there is no sun to supply the electricity directly to the load. When this happens, it cannot charge the battery during a day. In another case, in the overcast day it was also will affect the process of the output power to be generated. As this bad weather condition, automatically it will cause the effect to the output current and output voltage as the solar irradiance decrease. In overall, this hybrid system design could be able to produce a new power generation between the PV module and TEG. It was successfully approved that this hybrid system more efficiently used than by separate.

5.2 Recommendation

The most common storage battery used in the hybrid system is the lead acid battery with the tubular plates either vented lead acid or valve-regulated lead acid. The chosen battery should be specifically designed for solar applications. The battery should have been specially designed for solar applications. Battery capacity must be designed so that the battery can store the whole energy required load capacity at a time when the TEG is not supposed to run and solar production is not available. This cases will happen normally during at night or in the early morning when the load in the low condition. For the charge controller component, there is needed to make sure that the selection of this component with the right specification so that both of PV module and TEG can are able charging the battery. The rated charging current must be matching with the maximum charge current of the batteries. Charge controller needs to be managed for the various charges. These charges must be included in the fixed and the floating charge equalizer in order to maximize battery lifetime.

For the selection of the components of the inverter, it is very important to make sure that this inverter is can supply the load when the solar output is not available and TEG would not run. Improperly used this component will cause the damaged to the capacity battery of lifespan and give effect to the efficiency of the solar use. There is a need to assure that the operating mode of the inverter must have the highest quality, robustness, and durability. Due to the high power demand occurs during the sunlight, a significant share of the PV-generated electricity can be used directly when generated. A storage system should preferably be large enough to supply the evening and the night loads in order to limit the use of energy based power generation and hence the running costs. By using a hybrid solution, it will cover the demand peaks. Instead of using only PV, it will also limit the required size of the PV production unit needed, which can lower the investment cost of the system.

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APPENDIX

Experiment 1 (using the normal water)

Table 4.1: The parameters that generated from the TEG measured and simulation.

Hot temperature (^0C)	Cold temperature (^0C)	Different temperature (^0C)	Voltage (V)	Current (A)	Power (W)	Power Simulation (W)
30.0	27.3	2.7	0.28	0.16	0.05	0.02
35.7	27.6	8.1	0.52	0.24	0.12	0.18
40.8	32.3	8.5	0.86	0.46	0.40	0.20
44.5	32.8	12.8	0.58	1.19	0.69	0.40
45.4	31.7	13.7	1.56	1.25	1.95	0.50
56.3	32.9	23.4	2.40	1.33	4.84	1.47
66.4	35.9	30.5	2.87	1.71	4.91	2.50
71.3	39.3	32.0	3.04	1.79	5.44	3.00

Experiment 2 (using the ice cubed)

Table 4.2: The parameters that generated from the TEG calculation and simulation

Hot temperature (^0C)	Cold temperature (^0C)	Different temperature (^0C)	Voltage (V)	Current (A)	Power (W)	Power Simulation (W)
40.9	15.0	25.9	2.80	1.49	4.17	1.8
50.0	17.3	32.7	3.72	1.96	7.29	2.90
60.0	20.9	39.1	4.81	2.53	12.17	4.10
70.0	21.8	48.2	6.06	3.10	18.79	6.23
80.0	26.0	54.0	6.40	3.25	20.80	7.83

Experiment 3 (using the ice cubed)

Table 4.3: The parameters that generated from the TEG calculation and simulation.

Hot temperature (^0C)	Cold temperature (^0C)	Different temperature (^0C)	Voltage (V)	Current (A)	Power (W)	Power Simulation (W)
27.5	28.8	-1.3	0.06	0.006	0.004	0.004
35.0	28.7	6.3	0.62	0.29	0.18	0.11
41.0	29.0	12.0	1.54	0.82	1.26	0.40
47.0	29.4	17.6	2.29	1.12	2.56	0.83
52.5	30.0	22.5	3.18	1.68	5.34	1.36
57.6	30.8	26.8	3.62	1.82	6.59	1.93
62.2	31.8	30.4	4.39	2.28	10.01	2.48
66.0	32.8	33.2	4.79	2.38	11.40	2.96
71.1	33.9	37.2	5.39	2.76	14.88	3.71
75.6	35.3	40.3	5.60	2.80	15.68	4.36
78.8	36.4	42.4	6.24	3.08	19.22	4.82

Experiment 1

Table 4.6: Temperature and solar irradiance

Time (hour)	Temperature (°C)	Solar irradiance (w/m^2)
9.30	25.6	294
10.30	27.6	729
11.30	28.2	867
12.30	27.9	628
13.30	27.7	434
14.30	27.7	360
15.30	28.3	1020
16.30	27.8	645
17.30	27.7	329
18.30	27.4	172

Table 4.7: The current, voltage and power from the PV module and simulation.

Time (hour)	Current (A)	Voltage (V)	Power measured (W)	Current simulation (A)	Voltage simulation (V)	Power simulation (W)
9.30	1.95	19.53	38.08	1.8	19.0	34.2
10.30	4.8	18.87	90.58	4.6	19.0	87.4
11.30	3.92	19.16	75.11	3.8	18.0	68.4
12.30	3.39	19.29	65.40	3.2	18.2	58.24
13.30	3.27	19.55	63.93	2.2	19.5	42.9
14.30	2.23	19.49	43.46	1.85	19.0	35.15
15.30	4.84	19.3	93.41	5.0	18.0	90.0
16.30	3.20	19.29	61.73	3.1	17.0	52.7
17.30	1.87	19.71	36.86	1.5	17.0	25.5
18.30	1.38	19.4	26.77	0.8	17.5	14.0

Table 4.8: The generated current and generated power of the PV module during the day.

Time (hour)	Current /A	Power/watt
9.30	1.50	32.85
10.30	3.99	87.381
11.30	4.83	105.777
12.30	3.47	75.993
13.30	2.38	52.122
14.30	1.97	43.143
15.30	5.71	113.223
16.30	3.55	77.745
17.30	1.80	39.42
18.30	0.93	20.367

Experiment 2

Table 4.9: Temperature and solar irradiance

Time (Hour)	Temperature (°C)	Solar irradiance (w/m^2)
8.00	25.6	332
9.00	27.5	677
10.00	28.1	689
11.00	28.0	613
12.00	27.7	972
13.00	27.8	687
14.00	28.3	655
15.00	27.9	628
16.00	27.7	566
17.00	27.4	162

Table 4.10: The current, voltage and power from the PV module and simulation.

Time	Current (A)	Voltage (V)	Power measured (W)	Current simulation (A)	Voltage simulation (V)	Power simulation (W)
8	0.53	18.7	9.911	1.66	17.0	28.22
9	3.44	19.5	67.08	3.34	17.5	58.45
10	3.63	19.3	70.06	3.60	19.0	68.40
11	3.72	18.9	70.31	3.80	19.0	72.20
12	4.76	19.1	90.92	4.87	18.5	90.10
13	4.62	18.25	84.32	3.44	19.0	65.36
14	4.38	19.32	84.62	3.28	19.1	62.65
15	3.21	19.59	62.88	3.14	19.2	60.29
16	3.13	19.58	61.29	2.83	18.5	52.36
17	2.2	19.37	42.61	0.89	17.0	15.13

Table 4.11: The generated current and generated power of the PV module during the day.

Time (hour)	Current /A	Power/watt
8.00	1.66	36.35
9.00	3.39	74.24
10.00	3.45	75.56
11.00	3.07	67.23
12.00	1.39	30.44
13.00	1.80	39.42
14.00	4.86	106.43
15.00	3.44	75.34
16.00	1.49	32.63
17.00	0.81	17.74

Experiment 3

Table 4.12: Temperature and solar irradiance

Time (hour)	Temperature (°C)	Solar irradiance (w/m^2)
8.00	25.7	399
9.00	27.4	446
10.00	24.6	242
11.00	25.6	294
12.00	25.4	292
13.00	28.2	896
14.00	27.8	571
15.00	27.9	691
16.00	27.8	373
17.00	27.7	276

Table 4.13: The current, voltage and power from the PV module and simulation.

Time (hour)	Current (A)	Voltage (V)	Power measured (W)	Current simulation (A)	Voltage simulation (V)	Power simulation (W)
8	1.8	19.01	34.22	1.9	16.0	30.4
9	2.01	19.32	38.83	2.23	17.0	37.91
10	1.43	17.69	25.30	1.21	16.0	19.36
11	1.53	18.6	28.46	1.47	17.5	25.73
12	1.51	16.81	25.22	1.46	17.2	24.82
13	4.64	19.88	92.24	4.48	17.0	76.16
14	2.79	19.3	53.85	2.86	17.48	49.99
15	3.40	19.57	66.54	3.46	17.31	59.9
16	2.02	19.00	38.40	1.87	16.04	30.0
17	1.63	18.96	30.90	1.40	15.0	21.0

Table 4.14: The generated current and generated power of the PV module during the day.

Time (hour)	Current /A	Power/watt
8.00	2.00	43.8
9.00	2.23	48.84
10.00	1.21	26.50
11.00	1.47	32.20
12.00	1.46	31.97
13.00	4.48	98.11
14.00	2.86	62.63
15.00	3.46	75.77
16.00	1.87	40.95
17.00	1.38	30.22

Experiment 4

Table 4.15: 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

Table 4.16: The current, voltage and power reading

Time (hour)	Current (A)	Voltage (V)	Power measured (W)	Current simulation (A)	Voltage simulation (V)	Power simulation (W)
8	1.35	19.05	25.72	1.47	17.00	25.00
9	2.61	19.33	50.45	2.90	17.00	49.30
10	3.42	19.55	66.86	3.00	19.30	58.00
11	4.64	18.95	87.93	4.00	18.00	72.00
12	4.98	18.47	91.98	5.00	17.60	88.00
13	5.16	18.98	97.94	4.90	17.55	86.00
14	5.10	19.17	97.77	4.40	17.84	78.50
15	4.42	19.62	86.72	3.88	18.56	72.01
16	2.04	18.77	38.30	1.6	18.75	30.00
17	1.42	18.54	26.33	1.40	15.71	22.00

Table 4.17: The generated current and generated power of the PV module during the day.

Time (hour)	Current /A	Power/watt
8.00	1.47	32.20
9.00	2.94	64.39
10.00	3.32	72.71
11.00	4.01	87.82
12.00	5.10	111.69
13.00	4.97	108.84
14.00	4.48	98.11
15.00	4.10	89.80
16.00	1.88	41.17
17.00	1.43	31.32

Experiment 5

Table 4.18: Temperature and solar irradiance

Time (hour)	Temperature (°C)	Solar irradiance (w/m^2)
8.00	25.7	230
9.00	25.8	587
10.00	27.2	661
11.00	28.0	506
12.00	27.9	380
13.00	27.7	278
14.00	27.8	566
15.00	28.0	417
16.00	27.8	439
17.00	27.6	229

Table 4.19: The current, voltage and power reading

Time (Hour)	Current (A)	Voltage (V)	Power measured (W)	Current simulation (A)	Voltage simulation (V)	Power simulation (W)
8	1.7	19.47	33.10	1.0	19.00	19.00
9	2.71	19.83	53.74	2.90	17.24	50.00
10	3.46	19.42	67.1932	3.00	18.67	56.00
11	2.67	19.11	51.0237	2.50	16.60	41.50
12	1.70	18.86	32.08	1.80	17.78	32.00
13	1.59	19.03	30.26	1.30	16.92	22.00
14	3.2	19.68	62.976	2.80	15.71	44.00
15	1.99	19.55	38.90	2.00	18.50	37.00
16	2.34	17.88	41.84	2.10	18.33	38.50
17	1.22	18.02	21.98	1.10	17.73	19.50

Table 4.20: The generated current and generated power of the PV module during the day.

Time (hour)	Current /A	Power/watt
8.00	1.15	25.19
9.00	2.94	64.40
10.00	3.31	72.50
11.00	2.53	55.41
12.00	1.90	41.61
13.00	1.40	30.70
14.00	2.83	62.00
15.00	2.09	45.77
16.00	2.20	48.18
17.00	1.15	25.19

Hybridization PV-TEG experiment

Table 4.21: The parameters of the PV module and simulation.

Temperature(ºC)	Solar irradiance (W/m^2)	PV Voltage (V)	PV Current (A)	PV power (watt)	PV Power simulation (watt)
28	819	17.66	4.98	87.93	74.3
28.1	820	19.01	4.7	89.35	81.0
28.3	987	19.12	4.68	89.5	82.0
28.4	1002	19.82	4.53	89.78	85.5
28.6	1018	19	4.84	91.98	88.0
28.5	1023	19.09	4.87	92.96	89.2

Table 4.22: The parameters of the TEG and simulation.

Thot(°C)	Tcold(°C)	voltage (V)	Current(A)	Power (Watt)	Power simulation (Watt)
38.3	27.9	1.07	0.65	0.7	0.3
40	28.1	1.25	0.71	0.89	0.4
50	29.8	1.4	1.28	1.79	1.1
60	34.5	3.91	1.9	7.43	1.75
70	38.6	3.87	2.4	7.29	2.65
80	44.2	3.92	1.9	7.44	3.44

Table 4.23: The parameters of the hybrid PV-TEG and simulation.

Time (hour)	Current (A)	Voltage(V)	Power calculation(W)	Power simulation(W)
8	1.35	19.05	25.72	25
9	2.61	19.33	50.45	49.3
10	3.42	19.55	66.86	58
11	4.64	19.10	88.63	74.3
12	4.98	19.93	99.27	88
13	5.16	18.98	97.94	86
14	5.1	19.17	97.77	78.5
15	4.42	19.62	86.72	72.01
16	2.04	18.77	38.3	30
17	1.42	18.54	26.33	22

Table 4.24: The hybrid PV and TEG power generation with time

Time (Minutes)	PV Power(Watt)	TEG Power(Watt)	PV+TEG calculation (Watt)	PV+TEG simulation (Watt)
11	87.93	0.7	88.63	74.3
11.15	89.35	0.89	90.24	70.4
11.3	89.5	1.79	91.29	68.1
11.45	89.78	7.43	97.21	70.12
12	91.98	7.29	99.27	88
12.15	92.96	7.44	100.4	90