**FACULTY OF ELECTRICAL ENGINEERING**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**FINAL YEAR REPORT**



# SYSTEM PERFORMANCE EVALUATION OF UTeM SOLAR PV SYSTEM

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**Bachelor of Electrical Engineering (Industrial Power)**

**May 2014**

“ I hereby declare that I have read through this report entitle “System Performance Evaluation of UTeM Solar PV System” and found that it has comply the partially fulfilment for awarding the degree of *Bachelor of Electrical Engineering (Industrial Power).* ”

Signature : ______________________________

Supervisor’s Name : ______________________________

Date : ______________________________

# SYSTEM PERFORMANCE EVALUATION OF UTeM SOLAR PV SYSTEM

**LEW HUEY SIN**



**A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)**

**Faculty of Electrical Engineering**
**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2014**

I declare that this report entitle "System Performance Evaluation of UTeM Solar PV System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature : _________________________

Name : _________________________

Date : _________________________

To my beloved mother and father

## ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people. They have contributed towards my understanding and thought. In particular, I wish to express my deepest gratitude to my supervisor, Dr. Gan Chin Kim for guiding me in this project. The success of this Final Year Project (FYP) is highly influenced by his information, suggestions and ideas. His willingness to assist me through his guidance, encouragement, advices, and continued support has been a great motivation for me to excel in my project. I am also very thankful to Mr Tan Pi Hua for his guidance, advice and motivation. Without their continued support and interest, this project would not have been same as presented here. I would also like to thank all the lecturers and technical staff in FKE for sharing their opinion with me in their area of expertise which leads to the success of this project.

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Last but not least, I would like to say a word thanks to my family members, especially my parents for their constant supports and encouragement throughout the years.

Below is the published work as a result of my Final Year Project.

[1] H. S. Lew, C. K. Gan, and P. H. Tan, “The Performances of UTeM Solar PV Systems: An Evaluation,” in *The 2nd Power and Energy Conversion Symposium (PECS 2014)*, 2014, pp. 129–134.

# ABSTRACT

Renewable clean solar energy can be utilized by using a photovoltaic (PV) system to convert solar energy into electrical energy. This helps to reduce global warming and save the environment as it enables the user to reduce the amount of energy utilization from electricity grid, and it can also supply back the additional energy into the grid. This project presents the performances of the systems concerning mono crystalline silicon (Mono), thin film (TF), and heterojunction with intrinsic thin layer (HIT) grid-connected solar photovoltaic (PV) system, which are installed in the Faculty of Electrical Engineering of Universiti Teknikal Malaysia Melaka. The research was carried out based on the climatic condition in Malaysia. The performances of the solar photovoltaic (PV) inverters were also taken into consideration. The research was conducted at every 5 minutes interval, whereby the data were recorded and analysed to determine the system with the production of the highest energy yield. Several factors, such as inverter losses, cable losses, mismatch, and cloudy weather that influenced the solar photovoltaic (PV) system performance were also considered in this paper. After the data were analysed and the evaluation was done, it was found that the thin film (TF) system performed better than the heterojunction with intrinsic thin layer (HIT) and mono crystalline silicon (Mono) for the highest energy yield and system performance.

## ABSTRAK

Tenaga solar yang boleh dikatakan sebagai sumber tenaga bersih yang boleh diperbaharui boleh ditukar kepada tenaga elektrik dengan menggunakan sistem photovoltaic (PV). Penggunaan teknologi ini boleh membantu mengurangkan masalah pemanasan global dan secara tidak langsung dapat menyelamatkan alam sekitar. Hal ini demikian kerana penggunaan sistem ini dapat mengurangkan penggunaan tenaga daripada grid elektrik dan juga dapat menyalur kembali tenaga tambahan ke dalam grid elektrik. Projek ini membentangkan prestasi sistem yang menggunakan teknologi mono kristal silicon (Mono), filem nipis (TF) dan "heterojunction" dengan lapisan nipis intrinsic (HIT). Semua photovoltaic (PV) sistem ini telah dibina di Fakulti Kejuruteraan Elektrik Universiti Teknikal Malaysia Melaka. Kajian ini dijalankan berdasarkan keadaan cuaca di Malaysia dengan mengambil kira prestasi daripada penyongsang photovoltaic (PV) solar. Kajian ini dijalankan dengan merekodkan data pada setiap 5 minit dan data tersebut akan dikaji untuk menentukan sistem mana yang akan menghasilkan pengeluaran tenaga yang paling tinggi. Beberapa faktor yang akan mempengaruhi prestasi sistem solar photovoltaic (PV) juga akan dipertimbangkan seperti kerugian inverter, kerugian kabel, tidak sepadan, dan cuaca mendung dalam kajian ini. Selepas data diproses dan dikaji, kesimpulannya, penggunaan teknologi filem nipis telah menunjukkan prestasi yang lebih baik daripada teknologi "Heterojunction" dengan lapisan nipis intrinsik (HIT) dan mono kristal silikon (Mono) dalam penghasilan tenaga yang paling tinggi dan prestasi sistem.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | - | Alternating current |
| CSP | - | Concentrated solar thermal |
| DC | - | Direct current |
| FiT | - | Feed-in Tariff |
| FKE | - | Fakulti Kejuruteraan Elektrik |
| FYP | - | Final Year Project |
| HIT | - | Heterojunction with intrinsic thin layer |
| MBIPV | - | Malaysia Building Integrated Photovoltaic |
| Mono | - | Mono crystalline silicon |
| Poly | - | Poly crystalline silicon |
| PV | - | Photovoltaic |
| STC | - | Standard test condition |
| TF | - | Thin Film |
| UTeM | - | Universiti Teknikal Malaysia Melaka |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| A | - | Current |
| Hz | - | Frequency |
| kWh | - | Energy generation |
| kWh/kWp | - | Energy yield |
| m | - | Length |
| V | - | Voltage |
| W | - | Power |
| $Wh/m^2$ | - | Solar irradiance |
| Ω | - | Resistance |
| ℃ | - | Temperature |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

The world global warming is in a critical stage. Scientists have estimated that the world's temperature will rise to another six degree Celsius if the emission of greenhouse gasses are not controlled [1]. This is will have a detrimental effect towards our environment and also causes climate changes to a country. One of the factors that affect global climate change is due to various human activity that changes the atmospheric composition [2].

Beside this, the carbon dioxide content in the atmosphere is steadily increasing which had climbed above 310 parts per million (ppm) and now it has almost reached 400 ppm.



The emission of the carbon dioxide gas that enters into the atmosphere has reached up to 90 million tons a day, and this increases the greenhouse properties that will lead to global warming [3]. Burning of forests and fossil fuels are some of the factors that cause global warming where it will lead to climate change.  Hence, in order to reduce the emissions of these harmful gases into the atmosphere,  the governments around the world need to support the development of clean energy sources, such as solar energy [4], for it is efficient and considered as cleaner fuels with multiple beneficial effects [5].

In Malaysia, the solar photovoltaic (PV) system has been implemented for a few years now, but they are still at the beginning stage due to the high initial cost of the PV system with the low solar electricity tariff rate [6]. This is because of the lack knowledge and information about the solar PV system. The important of the system performance is to determine the highest energy yield of different type of solar PV technology. This can assists the investors to improve the high quality systems. There are natural factors such as solar irradiance and temperature that can affect the system performance[7]. Besides that, the importance of reducing the loss factor from solar equipment also need to be considered. This project is to evaluate on the system performance of solar PV systems connected in grid in Malaysia.

## 1.2 Problem Statement

There are many factors need to be considered in evaluating the performance of solar PV system. Factors that affect the system performance are the temperature losses, dust, cable losses, inverter losses, mismatch, fluctuation losses, transformer and shadow [8]. A good solar PV performance will produce the highest energy yields. For European, they do much research on solar PV performance on their own country but it is not necessarily applicable to tropical countries due to different climate conditions, temperature, ordinances, clouds and etc.

In Malaysia, PV systems or green technology development still lack of awareness among the citizen. Even though PV system is still new, there is lot of research have been conduct but all the relevant research or articles is more focus on solar cell than the solar system [9]. In general, there is no information regarding which solar PV systems is suitable to be installed as there is lack of professional in this field. Furthermore, there is study on the performance of the PV system technology which may affect the energy yields and make it hard to predict the performance level of PV system in Malaysia.

However, the performance of solar PV systems are not fully evaluated yet. Therefore, this study is carried out for determine which solar technology give the best system performance. This study is based on actual system according to tropical country weather conditions. In Universiti Teknikal Malaysia Melaka (UTeM), there are four different types of solar PV systems installed around the area of Fakulti Kejuruteraan Elektrik (FKE) which are the poly crystalline silicon (Poly), mono crystalline silicon (Mono), thin film (TF), and heterojunction with intrinsic thin layer (HIT). This project is to study and find out the details of each PV system to conclude which system produces higher energy yield and this conclusion will help investors to have a better idea on which is a system is to be chosen.

## 1.3 Objective

The objectives of this project are:

- To investigate the system energy performance of PV system according to Malaysia climate conditions
- To evaluate the PV system component losses installed in UTeM FKE

## 1.4 Scope

This project is expected to evaluate the systems performance of the solar PV system and obtain the suitable PV technology of the system at UTeM FKE. There are four different types of solar PV system that are installed in UTeM FKE. The different types of solar panels have different levels of performances under different local climate conditions. The PV technology can be affected by the climate changes and this causes variation in the performance of the whole system. This will indirectly affect the investment of the investors as they are unable to obtain the best performance from the system they have invested due to these factors. Several factors that affect the performance of the system are considered in this project such as dust, cable losses, inverter losses and so on. These data were recorded at a five minute interval. To determine which system produces the best performance in energy yields, it can be done by collecting the data in the laboratory by daily, weekly and monthly. Based on the analysis, the energy yield of each system can be determined. Besides, the importance of reducing the loss factor from the solar equipment also needs to be considered. Therefore, this project was carried out to evaluate the overall performance of Mono, TF and HIT solar PV systems based on UTeM's climate conditions. This will help investors have a better idea on which is the best system that is to be chosen.

## 1.5 Project Outline

This project consists of five chapters. The first chapter is about the research background, problem statement, objectives, scope and expected outcome. Chapter 2 focus on the theory, basic principles and the review of previous work that have been done. In this chapter includes the basic theory about solar energy, solar cells and solar PV. In Chapter 3, the principles of the methods or techniques used in the previous work, case study, description of the work to be undertaken, project gantt chart and key milestones are discussed. Chapter 4 will be the discussion and analyzes the performances of the Mono, HIT, and TF PV systems. The results present the energy yield, performance ratio, and losses analysis based on spreadsheet data at Standard Test Condition (STC) of irradiance of 1000 $W/m^2$ at 25 ℃ for the systems. Chapter 5 concludes this project and prove the objectives of the project are achieved.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter provides an overview of solar PV system. It includes published materials on the study and research such as journals, case studies, books, technical documents and internet sources that has been selected relevant to this review. This chapter also describe about the theory and basic principles about solar energy, solar cells and solar PV system. Furthermore, summary and discussion of the review were included in this chapter.



## 2.2 Theory and Basic Principles

### 2.2.1 Solar Energy

Energy plays an important role in people's daily lives, their social activities and economical advancement in every nation. There are many different types of renewable energy in this world that can be used to generate electricity such as solar, wind, ocean, hydropower, biomass and so on. Solar energy is one of the best secondary sources of energy due to the fact that it has many benefits compared to other resources. Solar energy is the radiant energy provided by the sun [10]. It is a simply energy which is naturally available and a clean energy source. This energy is harvested in the form of solar radiation that can be used directly to generate electricity [11]. Solar energy have several advantages and disadvantages and they are as shown in Table 2.1. The two main types of solar power conversion of sunlight into electricity are the concentrated solar thermal plant (CSP) and photovoltaic plant. This project focus on photovoltaic plant which is a solar PV system.

Table 2.1: Advantages and disadvantages of solar energy [6,9]

| Advantage | Disadvantage |
| --- | --- |
| No pollutant | Doesn't work at night |
| Low maintenance | Low efficiency in generation of electricity using solar energy |
| High reliability | Solar energy storage has not reached its potential yet. |
| Life span expectation up to 20-30 years | High cost of installing solar panels |
| Ongoing free energy | |
| Save eco-systems and livelihoods | |



### 2.2.2 Solar Cells

Solar cells is a device that converts sunlight into electricity as shown in Figure 2.1 below. Solar PV cell does not produce heat to generate electricity but it can generate electricity directly from the interaction of electrons from the radiant energy with the semiconductor materials in the PV cells. The PV cells are made of different material but the most common material is silicon. This is because the atomic structure of silicon makes it one of the ideal elements in making the cells. The amount of electricity that PV cells are able to generate depends on the size of cells, conversion efficiency and the intensity of light source. There are various types of PV technology such as mono crystalline silicon (Mono), poly crystalline (Poly), thin film (TF) and heterojunction with intrinsic layer (HIT). Each of solar PV technologies has its own performance. The characteristics of the four different types of solar technology are shown in Table 2.2. Figure 2.2 shows the process of solar PV cell to module and lastly become array.

Figure 2.1: Solar cell [13]

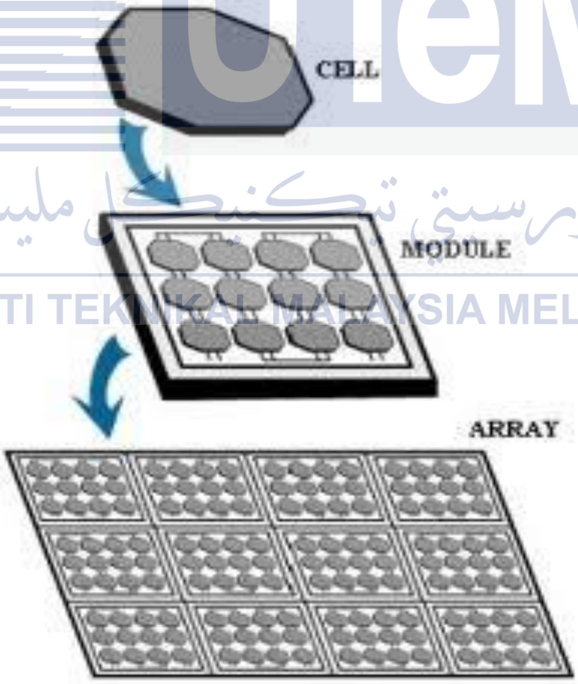




Figure 2.2: Process of solar PV cell [14].

Table 2.2: Various types of solar PV technology [10,11]

| **Characteristic** | **Poly** | **Mono** | **HIT** | **TF** |
|---|---|---|---|---|
| |  |  |  |  |
| Color | Dark blue | Black dark | Dark Blue almost to Black | Gray |
| Efficiency (%) | Less compare to mono-crystalline | High | High | High |
| Energy Yield | Low | Low | High | Higher |
| Cost | Less compare to mono-crystalline | High | Less | Less |
| Temperature coefficient characteristic | Moderate | Moderate | Good | Excellent |

Table 2.2 shows the comparison of four types of solar PV technologies, each of them have their own characteristics and performances. Crystalline solar PV cells are divided into mono-crystalline and poly-crystalline. The manufacturing method between mono-crystalline and poly-crystalline solar cells are different. Due to the manufacturing process of poly-crystalline is simpler than mono-crystalline, the production cost of poly-crystalline is cheaper compared to mono-crystalline cells.

However the poly-crystalline will be less efficient compared to mono-crystalline. The production of thin film requires low usage of silicon in the production but it can produce high yield under heat. The manufacturing process of Thin Film is shorter compare to crystalline

[15]. TF solar cells are cheaper compare to crystalline and HIT cells due to the low temperature processes help to reduce the cell thickness [16].

### 2.2.3 Solar PV System

Solar PV systems are classified into three types: stand-alone system, grid-connected PV system and hybrid PV system. This project focused on the evaluation of the performance of grid connected solar PV system as shown in Figure 2.3. The major components of a solar PV system includes solar array, inverter, battery and protection device.

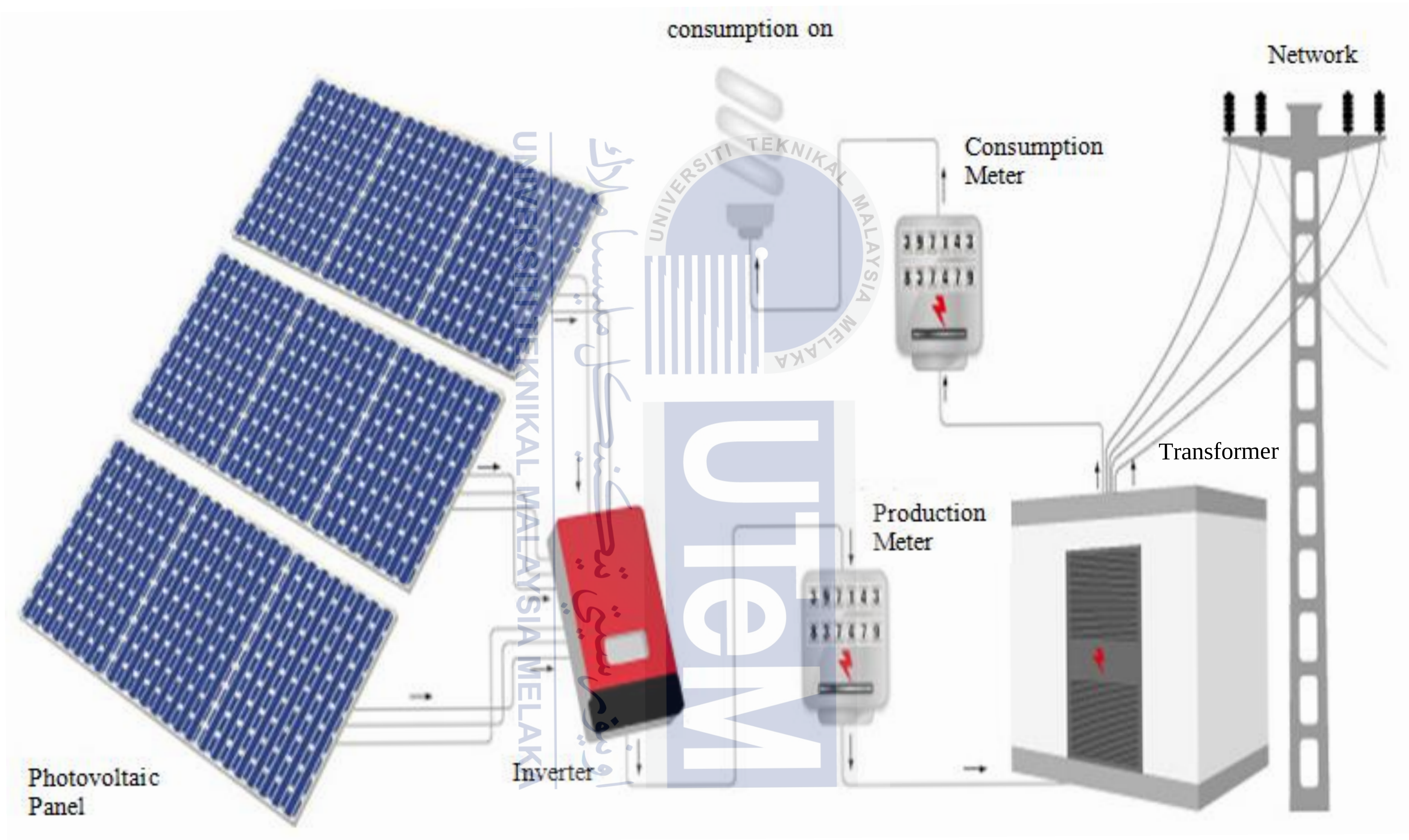


Figure 2.3: Grid-connected solar PV system [17].

## 2.3 Review of Previous Related Works

To introduce solar PV system in Malaysia is considered a major challenge due to several reasons such as different climate conditions, temperature, irradiances, clouds and losses which will affect the system's performance. Based on the research by Engel-Cox [18], Malaysia is a country with high level of solar energy as it is a tropical country. However, the radiation level is quite low. There are metrological centers in our country but their analytical data are seldom published and thus the information is limited. The knowledge about solar radiation and metrology needs to be considered before selecting the solar technology or evaluate the solar PV system performance. Therefore, more effort should be given to develop a better understanding for implementing the highest energy yields. Thus, Malaysia government launched a program known as feed-in-tariff (FiT) to provide more place for the installation of solar PV system.

Based on the journal research by Rafiza Abdul Rahman [19], the paper focused on the performance analysis of a 6.08 kWp grid-connected PV system. The purpose of this paper is to present the operational system performance of grid-connected PV systems to Malaysian. The climatic parameters such as solar irradiant, ambient temperature and solar PV module being monitored. On the other hand, the electrical parameters being monitored are the DC current, DC voltage, AC current, AC voltage and energy output from the inverter. The system performance was also quantified using several quantities which describe both PV array performance and the overall system performance. There will be less power generated by the PV array during cloudy, shading and rainy period.



According to Elhodeiby [9], this paper focused on the performance analysis of 3.6 kW rooftop grid connected thin film PV system. The evaluations are based on monthly, daily and annual performance of the solar PV system by observing the metrological changes under their operational conditions. The PV system of PV array, grid tied inverter, system efficiency, capacity factor and electrical energy were assessed. Thus, the analysis shows that the average daily energy yield is 4.35 kWh/kWp/day higher than the energy produce in Germany, Denmark, Sweden, Poland and Northern Ireland.

According to the journal with the title 'Status of a Grid-connected Malaysia Building Integrated Photovoltaic (MBIPV) Project in Malaysia' by M. Z. Hussin [20], it is regarding the evaluation made on the problem face by solar PV system connected in grid. There are two types of problem which includes technical problems which are the inverter fault, sensor fault and environmental problem like shading effect and lower energy. All the problems mentioned above will affect the PV system performances in terms of final yield and performance ratio. In addition, it might also reduce the energy produced by PV array and energy payback period when the issues of shading effect, lightning strikes due to inappropriate grounding and the technical problem which influences the PV system performance are taken into consideration. When shading effect problem occurs even in one module, it will have a strong influence to the overall PV performances which will lead to the power output wastages. The energy produce by the system will also be affected when clouds block the sunlight that shines across the array. This will influence the modules of crystalline technology rather than thin film modules. Furthermore, the shade on the PV array is usually caused by trees, houses or building. So, it is vital to know that in tropical climate to make sure that the objects will not shade the PV arrays that will affect the performance of the solar PV system. Next, another issue that will affect the system is on the critical design issue referring to air circulation between air gap on the back of the modules. It needs to provide a proper ventilation to prevent the temperature on the back module to increase and reduce its output power. Thus, in order to evaluate the performances of the PV system under the real condition like environmental effect and technical effect there must be a proper design for grid-connected PV system. Meanwhile, the installer should also consider other issues such as how fit the PV modules and inverters in enduring various environmental effects by conducting site assessment before any real implementation of the PV system.



According to I. Daut [21] indicate that the performance of solar PV system will dependent on its orientation and tilt angle of the solar panel. As the tilt angle vary, it may affected the amount of solar radiation fall on the surface of the PV module. Besides the factor of solar irradiation, M. Z. Hussin [22] state that inappropriate sizing of solar PV grid connected will influence the system performance, energy yield and performance ratio based on local climate condition.

Based on journal by C. K. Gan [23] evaluated on the system performance of rooftop and ground mounted for crystalline and thin film technology. It shows that system performance are affected by the module characteristic and environment factors. Solar PV system component losses such as dust, array and lightning rod shading, DC cable loss, transformer efficiency and etc. The result presented that the thin film roof top and ground mounted system generate the higher energy yield compare to crystalline system.

Next, another journal by Marion [8] states that the evaluation on solar PV system performance is very important for the PV industry. Performance parameters of solar PV systems must be evaluated properly for the growth of one industry. This can give the investors on more detail regarding the solar PV system and can improve the system's quality. The performance of solar PV is defined as the whole system performance with respect to the energy yield, solar resources and effect of the system losses [8]. By considering the solar irradiance, it might be affected by the inverter inefficiency, wiring, mismatch, system down time and other losses that will affect the rated output. The energy yield of solar PV system is the number of hours that the solar PV array would produce at its own power rating. Performance ratio of PV system will be affected by the PV module temperature. Thus, variation of the solar radiation and the ambient temperature will affect the performance of the solar PV system. Therefore, it is important to clearly evaluate on the weather as it will affect the system performance.



## 2.4 Summary and Discussion of the Review

Solar energy is a renewable energy that comes from the sun. It is a natural source of energy to generate electricity. Every area has its own geographic location. According to Engel-Cox [18], Malaysia is a country with high level of solar energy as it is a tropical country. Besides, Malaysia has the potential to produce large amount of solar power due to its location at the equatorial region [6]. The journal by Rafiza Abdul Rahman [19] reviews on the climatic and electrical parameters that influence the PV array performance and the overall system performance in Malaysia whereas Elhodeiby [9] focuses more on observing the metrological changes under their operational conditions in EGYPT. Next, Elhodeiby [9] only focus on one type of solar technology which is the thin film that is connected in grid PV system and M. Z. Hussin [20] focus mainly on the performance of thin film and crystalline module. Therefore, evaluation on system performance need to be carried out rather than focus on the solar cells. This can help the investment have the better idea on the level of the system performance.

Beside climatic factors, M. Z. Hussin [20] also evaluates on the technical and environmental problem which are the factors that will give a strong influence to the overall PV performances which will lead to the power output wastages. Consequently, this will affect the energy generated by the system and affect the energy yield. Based on journal by C. K. Gan [23] stated the system performance affected by the module characteristics and environmental factors. The system perform better in term of energy yield and system performance is mainly driven by the lower temperature coefficient. is lower According to Marion [8], by considering the solar irradiance, it might affect the inverter efficiency, wiring, mismatch, system down time and other losses that will affect the rated output. As a result, variation of the solar radiation and the ambient temperature will affect the performance of the solar PV system. Therefore, it is important to determine the weather’s effect as it will affect the system performance. For Europeans, they research on solar PV performance in their own country but it is not necessarily applicable to tropical countries due to different climatic conditions.

Meanwhile, as mention in journal [18], in Malaysia we have limited knowledge and information about what PV system is as many people assume that solar PV system is the solar thermal system. There is lack of information about the solar PV system, many resources such as journals or articles focus more on solar cell rather than solar system. Hence, a lot of people do not know the details of solar PV system. There is not much studies made on the performance of the PV system technology such as HIT, thin film and crystalline which may affect the energy yields. Thus, no one can estimate or predict the performance level of PV system in Malaysia.

From the literature review, the solar PV system carries out system performance which affect the energy output, and meanwhile, energy output is affected by the module temperature and solar irradiance as well. Beside the factors mentioned in all the journals and articles, dust, cable losses, and inverter losses are amongst the important factors that have an impact on the overall performance of the solar PV system. With all of the losses, the amount of energy yield will be affected. Therefore, this project is to evaluate on the performance of solar PV systems connected in grid with different types of solar technology such as Mono, TF and HIT systems based on the UTeM's climate condition in term of system performance, energy yield, and energy generation.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

Generally, this chapter is a brief introduction on the method used and the process flow on the evaluation of the performance of the solar PV system as shown in Figure 3.1. Firstly, journals, books, conference papers and information on the projects done on this topic by other people are used as references in this project. This is to survey and find out the theories and fundamentals of the project. Next, evaluation and analysis on the system performance is based on the three types of solar PV system with different types of solar technology.



Figure 3.1 shows the process flow on the evaluation of the performance of the solar PV system. The parameters of the data, such as the direct current (DC), DC voltage, DC input power, energy generation, frequency, alternating current (AC), AC voltage, and AC output voltage were recorded from the inverter. At every 5 minute interval, the data were recorded and analyzed to determine the system with the highest energy yield. Module specification sheet and inverter spreadsheet were needed to perform the evaluation on the performances of the systems. In addition, system component losses and PV module degradation rate were considered before the evaluation on systems' performances could be carried out. In terms of the PV system performance metrics, the system energy yield (kWh/kWp) was the key indicator, which took into consideration the temperature coefficient.

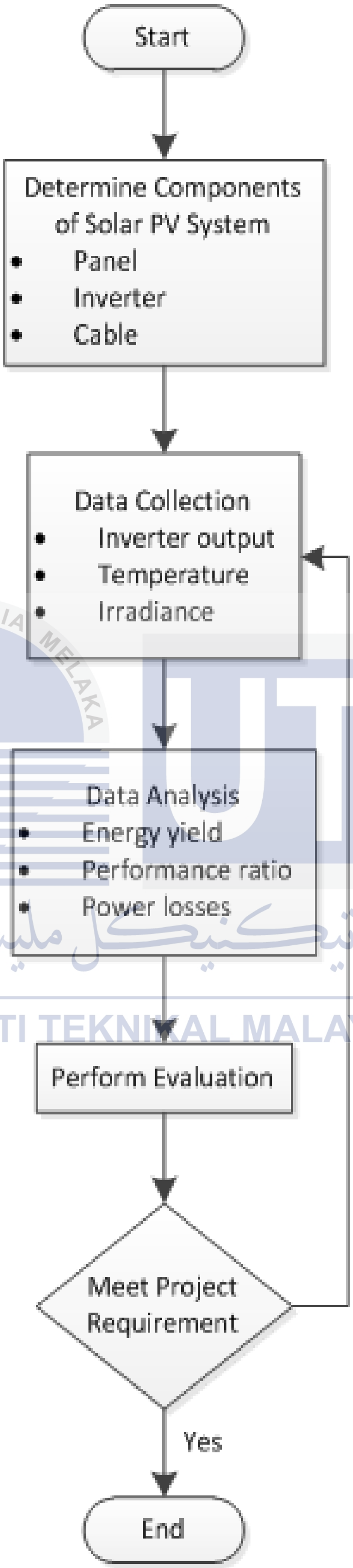


Figure 3.1: Process flow on the evaluation of the performance of the solar PV systems.

## 3.2 Principles of the Methods and Techniques Used

The research method used in this research is via case study or field research. Field research is one of the techniques used for quantitative data collection [24]. All collected data are analyzed to obtain relevant findings in this project. According to Rafiza Abdul Rahman [19], an irradiance sensor and two temperature sensors can be used to obtain the necessary climatic parameters for evaluation on the performance monitoring. The function of irradiance sensor is to obtain the solar irradiance whereas the temperature sensor is to get the ambient temperature and PV module temperature correspondingly. Besides, the climatic data are being recorded at every 15 minutes interval. The criteria for the data collected such as: AC power, AC energy, AC current, AC voltage, DC current, DC voltage, module, temperature, ambient temperature and irradiance.

Apart from that, some quantities were used to describe the input and output of the grid-connected PV system. The DC input power and AC output power of the inverter can be computed as per Equation 3.1 and Equation 3.2:

$$P_{DC} = V_{DC} \times I_{DC} \tag{3.1}$$

$$P_{AC} = V_{AC} \times I_{AC} \tag{3.2}$$



Where:

$V_{DC}$ is input voltage to the inverter

$I_{DC}$ is input current to the inverter

$V_{AC}$ is output voltage from the inverter

$I_{AC}$ is input current from the inverter

Hence, the inverter efficiency is shown in Equation 3.3:

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} \times 100\% \tag{3.3}$$

Where:

$\eta_{inv}$ is inverter efficiency

$P_{AC}$ is output power of the inverter

$P_{DC}$ is input power of the inverter

Next, the relationship between the total energy output from the inverter and the size of PV array was determined. The final yield of the system can be determined using the equation as shown in Equation 3.4:

$$Y_f = \frac{E_{AC}}{P_{array\_STC}} \tag{3.4}$$

Where:

$E_{AC}$ is the AC energy output from inverter in kWh

$Parray_{STC}$ is the peak PV array capacity at standard test condition in KWp

Another term introduced by Rafiza Abdul Rahman [19] is the performance ratio which is defined as the system that describes the relation of the final energy yield to the solar irradiation received for a particular period as shown in Equation 3.5.



$$PR = \frac{Y_f}{I \times t} = \frac{Y_f}{H} \tag{3.5}$$

Where:

$Y_f$ is the final energy yield

H is the solar irradiation in $kWhm^{-2}$

I is the irradiance in $kWm^{-2}$

t is the time in hour

Similarly for the journal from Hasimah [25], monthly average meteorological data is used to estimate the energy yield. They also suggest that the differences in solar radiation that lead to different output on the sizing of the PV system. In addition, they introduce a prediction tool name PVSYST for the study purposes, sizing, simulation and data analysis of the complete PV systems. With this software, it can improve the life cycle, cost and the performance of the system.

But according to Olawale Saheed Ismail [26], a pre-survey was carried out by distributing sets of questionnaire to the residents and an interview with a village elder is conducted. This is done to identify and map out the area of our research.

## 3.3 Case Study

Different types of solar PV system in grid-connected installed in FKE at UTeM with the solar technology which are mono crystalline silicon (Mono), thin film (TF), and heterojunction with intrinsic thin layer (HIT). All these systems are connected to the solar laboratory in UTeM. Each of the solar PV system consists of three inverters in grid connected system. The brand of the inverter used is SMA Sunny Boy 2000HF and each with a power specification of 2 kW. For more detail about the specification of the inverter may refer to appendices. Therefore, all the data taken are based on real time data which can be obtained in this solar laboratory by using Sunny Web Box software. Even though there are three inverters inside the laboratory but the data obtained is based on one inverter only due to the total amount of energy generation is the sum up of all the data of each inverter. The systems detail was tabulated in Table 3.1.



Table 3.1: Various type of solar PV system

| **Parameters** | **System 1** | **System 2** | **System 3** |
|---|---|---|---|
| Panel Type | Mono | HIT | TF |
| Brand | SolarWorld Germany | Panasonic | Sharp Japan |
| Maximum Power | 6.12kW | 5.64kW | 6.24kW |
| Quantity | 24 units | 24 units | 48 units |
| Location | Admin Rooftop | Admin Rooftop | Laboratory Rooftop |

A healthy solar PV system will produce the highest energy yields. To evaluate on solar PV system, factors that influences the performance must be considered. One of the most common factors is the cloudy weather. Besides that, other factors such as inverter losses, mismatch, cable losses and etc also have an effect on the performance.

Figure 3.2 shows the single line diagram of the PV configuration. The system capacities for the three different types of solar PV system were 6.12 kW, 5.64 kW, and 6.24kW. As for the PV module arrangement, 24 pieces of Mono and HIT PV modules were connected in series with 3 strings. The Mono system produced a system voltage of 251.2 V with the total current of 8.12 A, whereas the HIT system produced 344 V and 5.47 A.  The 48 pieces of thin film PV module was connected in series with 2 strings which produced system voltage of 368.8 V and 5.64 A.

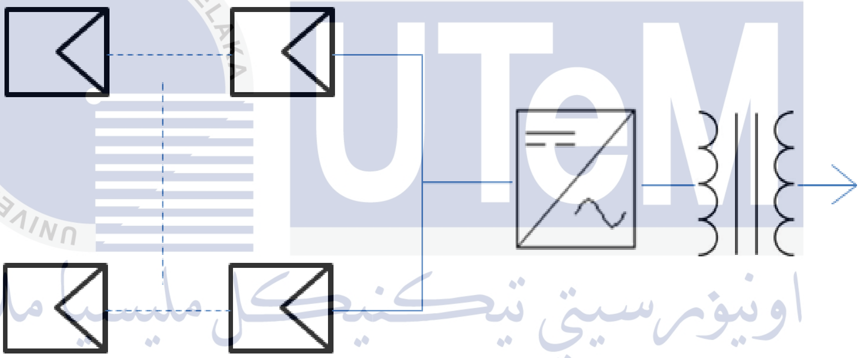



Figure 3.2: Single line diagram of PV configuration [23].

The technical characteristics of the module installed at UTeM FKE are shown in Table 3.2. These characteristics indicate that TF had lower temperature coefficient compared to the Mono and HIT types of modules. This particular characteristic can have an effect on the overall performance of the systems, especially in a hot climatic tropical country, such as Malaysia.

Table 3.2: Module characteristic

| **Characteristics** | **Mono** [27] | **HIT** [28] | **TF** [29] |
|---|---|---|---|
| Maximum power ($P_{max}$) | 255 W | 235 W | 130 W |
| Open-circuit voltage ($V_{oc}$) | 37.8 V | 51.8 V | 60.4 V |
| Short-circuit current ($I_{sc}$) | 8.66 A | 5.84 | 3.41 A |
| Maximum power voltage ($V_{mp}$) | 31.4 V | 43.0V | 46.1 V |
| Maximum power current ($I_{mp}$) | 8.15 A | 5.48 A | 2.88 A |
| Temperature coefficient of ($P_{max}$) | -0.45 %/°C | -0.30 %/°C | -0.24 %/°C |
| Temperature coefficient of ($V_{oc}$) | -0.30 %/°C | -0.25 %/°C | -0.30 %/°C |
| Temperature coefficient of ($I_{sc}$) | 0.004 %/°C | -0.03 %/°C | 0.07 %/°C |

## 3.4 System Performance Evaluation Procedure

For this project, the method used in this research focus mostly on collecting the data and then proceeds to analytical work to determine the best performance of the solar PV system that is to be chosen. Before collecting the data, some studies and researches need to be done. The data will be recorded and evaluated on the solar PV system performances according to the highest energy yields. The data will be recorded every 5 minute interval. The data can be obtained at solar laboratory through SMA of the Sunny Web Box. Based on the daily, weekly and monthly data that are collected, they are analyzed and based on the analysis, the energy yield of each system can be determined.

Microsoft Office Excel is one of the tools used to arrange the data in an orderly manner for analysis and examination of the data. The parameters of data collected are DC current (A), DC voltage (V), input power (W), frequency (Hz), AC voltage (V) and output power (W). First, the data needs to be categorized according to each type of solar PV technology according to its inverter serial number. The data collected was based on one inverter although each system have three inverter with own rating of 2 kW.

Apart from solar irradiance and temperature data, the temperature coefficient data for the respective PV system technologies are obtained from the manufacturer's specification sheet. The power estimated and power losses are shown in Equation 3.6 and Equation 3.7,

$$P_{estimated} = P_{mp}\left(1 + \gamma_{coef}(T_{cell} - T_{stc})\right) \tag{3.6}$$

$$P_{losses} = P_{mp}\left(\gamma_{coef}(T_{cell} - T_{stc})\right) \tag{3.7}$$

Where:

$P_{mp}$ is maximum power of system capacity

$\gamma_{coef}$ is temperature coefficient

$T_{cell}$ is PV module cell temperature, ℃

$T_{stc}$ is temperature at standard test condition, 25 ℃

Next, to evaluate the system performance several formulas will be used for calculation as per Equation 3.8, Equation 3.9, Equation 3.10 and Equation 3.11. Energy yield is the amount energy that can be produced in one hour with respect to the system power capacity.



$$Energy\ Yield = \frac{Energy\ Output}{System\ Power\ Capacity} \tag{3.8}$$

Inverter efficiency is to determine the power losses in the inverters in order to convert direct current (DC) to alternating current (AC).

$$Inverter\ Efficiency = \frac{Output\ Power}{Input\ Power} \times 100\% \tag{3.9}$$

Total energy production can be defined as the sum of power produced from PV array based on system performance and irradiance in a week.

$$Total\ Energy\ Production = Power\ from\ Array\ Capacity \times Weekly\ Irradiance \times System\ Performance \tag{3.10}$$

Performance ratio is to determine the level of solar PV system performance.

$$Performance\ Ratio = \frac{Total\ Energy\ Production}{Weekly\ Irradiation \times System\ Power\ Capacity} \quad (3.11)$$

In order to calculate the losses affect the systems performance, cable losses and temperature losses can be calculated refer to Equation (3.12) and Equation (3.13).

$$E = a \times R \times {I_b}^2 \quad (3.12)$$

Where:

E : energy losses in a wire, Watt (W)

a : number of line coefficient, a=1 for single line, a = 3 for 3-phase circuit.

R : resistance of one active line (Ω)

$I_b$ : current in Ampere (A)

Percentage temperature losses is to determine the power losses from module.

$$Percentage\ temperature\ losses\ = -\gamma_{coef.}(T_{cell} - T_{stc}) \times 100\% \quad (3.13)$$



Where:

$\gamma_{coef}$ is temperature coefficient

$T_{cell}$ is PV module cell temperature, °C

$T_{stc}$ is temperature at standard test condition, 25 °C

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Introduction

This chapter briefly explain and discuss the performance of the system for TF, Mono and HIT solar PV system based on UTeM's climate conditions in term of energy yield, energy generation and system performance. Several factors such as inverter losses, cable losses, mismatch and cloudy weather that influence the solar PV system performance are also considered in this section. The results present the performance of the system based on energy yield, performance ratio and losses analysis at Standard Test Condition (STC) of solar irradiance with 1000 W/m$^2$ at 25 °C.



## 4.2 Project Achievement

### 4.2.1 Energy Yield

Energy yield is the amount of energy that can be produced in one hour with respect to the system power capacity of each solar PV system. For a good and healthy system, the system will be able to produce the highest energy yield. Table 4.1 and Figure 4.1 shows the total energy generation and total energy yield from September 2013 to April 2014.

According to the module characteristic, the Mono module has a higher temperature coefficient compared to the HIT and TF module. This causes the Mono module to have a lower output power. Table 4.1 shows that the total energy generation and energy yield for the thin film are 6446.13 kWh and 1033.03 kWh/kWp which are higher than the HIT system by 920.90 kWh and 56.38 kWh/kWp. Mono system produces the lowest energy generation and energy yield among the three types of solar PV system. It is lower than the thin film system by approximately 12.93% and 11.8% respectively. With this result, it shows that the thin film system produces the best performance in terms of energy yield.

Table 4.1: Total energy generation and total energy yield from September 2013 to April 2014

| | | Energy Generation (kWh) | | | Energy Yield (kWh/kWp) | | |
|---|---|---|---|---|---|---|---|
| Year | Month | TF | HIT | Mono | TF | HIT | Mono |
| 2013 | September | 350.36 | 298.74 | 298.12 | 56.15 | 52.97 | 48.71 |
| | October | 882.14 | 751.52 | 756.04 | 141.37 | 133.25 | 123.54 |
| | November | 766.62 | 642.70 | 653.44 | 122.86 | 113.95 | 106.77 |
| | December | 824.34 | 687.03 | 702.20 | 132.11 | 121.81 | 114.74 |
| 2014 | January | 886.88 | 751.99 | 773.00 | 142.13 | 133.33 | 126.31 |
| | February | 954.77 | 825.95 | 833.40 | 153.01 | 146.45 | 136.18 |
| | March | 1009.12 | 885.15 | 896.50 | 161.72 | 156.94 | 146.49 |
| | April | 771.90 | 682.15 | 699.89 | 123.70 | 120.95 | 114.36 |
| | **Total** | **6446.13** | **5525.23** | **5612.59** | **1033.03** | **976.65** | **917.09** |

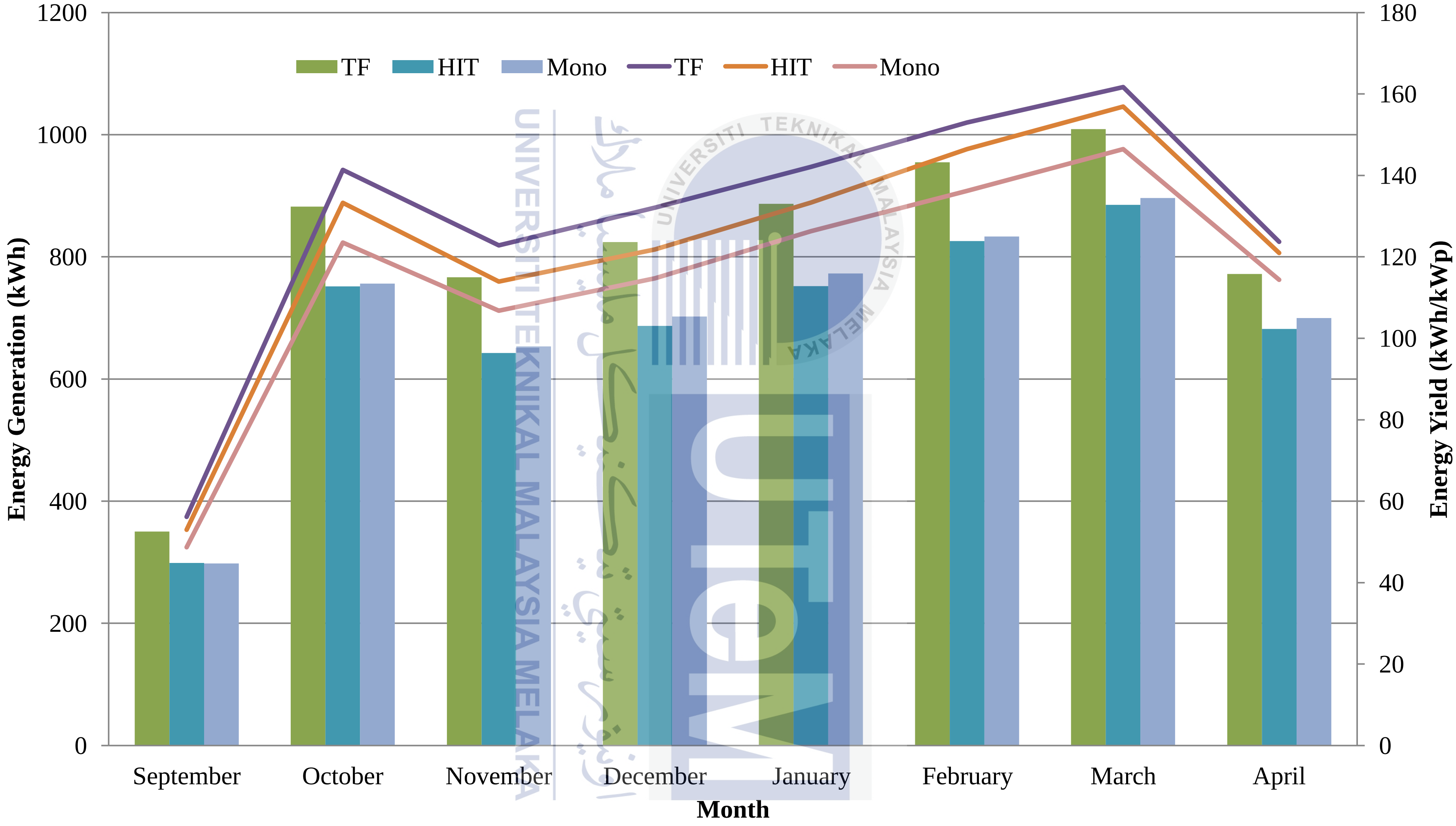


Figure 4.1: Graph of total energy generation and total energy yield from September 2013 to April 2014.

In Figure 4.1 shows the total energy generation and energy yield from September 2013 until April 2014. The bar chart shows that TF systems generate the most energy follow by Mono and HIT systems. The line graph shows that TF systems has highest energy yield for every month. This is due to TF module has a lower temperature coefficient compare to HIT and Mono systems. Energy generation by Mono system is higher than HIT system but in terms of energy yield HIT system performs better than Mono system due to the system capacity for Mono system higher than HIT system.

Next, evaluation on the systems performance based on daily data collection as shown in Table 4.2 is done and Figure 4.2 shows the graph of energy generation and energy yield in March. PV technology energy generation based on daily energy yield in March is shown in Figure 4.3.

Table 4.2: Daily performance of energy generation and energy yield in March

| | Energy Generation (kWh) | | | Energy Yield (kWh/kWp) | | |
|---|---|---|---|---|---|---|
| Day | TF | HIT | Mono | TF | HIT | Mono |
| 1 | 36.30 | 32.21 | 32.46 | 5.82 | 5.71 | 5.30 |
| 2 | 29.38 | 25.96 | 26.56 | 4.71 | 4.60 | 4.34 |
| 3 | 31.15 | 28.27 | 28.77 | 4.99 | 5.01 | 4.70 |
| 4 | 28.49 | 25.41 | 26.01 | 4.57 | 4.51 | 4.25 |
| 5 | 38.71 | 33.61 | 33.70 | 6.20 | 5.96 | 5.51 |
| 6 | 39.08 | 34.08 | 33.95 | 6.26 | 6.04 | 5.55 |
| 7 | 36.96 | 32.52 | 32.80 | 5.92 | 5.77 | 5.36 |
| 8 | 35.16 | 30.85 | 31.08 | 5.63 | 5.47 | 5.08 |
| 9 | 35.69 | 31.27 | 31.69 | 5.72 | 5.54 | 5.18 |
| 10 | 36.54 | 31.49 | 32.00 | 5.86 | 5.58 | 5.23 |
| 11 | 39.46 | 34.64 | 34.67 | 6.32 | 6.14 | 5.67 |
| 12 | 37.09 | 32.61 | 32.72 | 5.94 | 5.78 | 5.35 |
| 13 | 31.58 | 28.18 | 28.76 | 5.06 | 5.00 | 4.70 |
| 14 | 29.09 | 25.80 | 26.40 | 4.66 | 4.57 | 4.31 |
| 15 | 31.53 | 27.70 | 28.14 | 5.05 | 4.91 | 4.60 |
| 16 | 22.19 | 19.04 | 20.12 | 3.56 | 3.38 | 3.29 |
| 17 | 18.41 | 16.52 | 17.14 | 2.95 | 2.93 | 2.80 |
| 18 | 20.66 | 18.55 | 19.17 | 3.31 | 3.29 | 3.13 |
| 19 | 37.14 | 32.63 | 32.76 | 5.95 | 5.79 | 5.35 |
| 20 | 23.84 | 20.67 | 21.24 | 3.82 | 3.66 | 3.47 |
| 21 | 28.26 | 24.47 | 25.38 | 4.53 | 4.34 | 4.15 |
| 22 | 34.65 | 29.92 | 30.60 | 5.55 | 5.30 | 5.00 |
| 23 | 41.25 | 35.62 | 35.48 | 6.61 | 6.32 | 5.80 |
| 24 | 37.52 | 32.97 | 32.97 | 6.01 | 5.85 | 5.39 |
| 25 | 36.46 | 31.99 | 32.57 | 5.84 | 5.67 | 5.32 |
| 26 | 39.35 | 34.26 | 34.25 | 6.31 | 6.07 | 5.60 |
| 27 | 40.23 | 34.30 | 33.98 | 6.45 | 6.08 | 5.55 |
| 28 | 35.73 | 31.18 | 31.15 | 5.73 | 5.53 | 5.09 |
| 29 | 16.82 | 14.87 | 15.47 | 2.70 | 2.64 | 2.53 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 | 30.87 | 27.54 | 27.97 | 4.95 | 4.88 | 4.57 |
| 31 | 29.53 | 26.02 | 26.54 | 4.73 | 4.61 | 4.34 |
| **Total** | **1009.12** | **885.15** | **896.50** | **161.72** | **156.94** | **146.49** |
| **Average** | **32.55** | **28.55** | **28.92** | **5.22** | **5.06** | **4.73** |

Table 4.2 shows the daily performance of energy generation and energy yield in March. TF system achieves the highest energy generation and energy yield which are 1009.12 kWh and 161.72 kWh/kWp. In March, the least energy generation is HIT system while for energy yield is Mono system. The highest peak output of TF system is 41.25 kWh with the highest energy yield is 6.61 kWh/kWp and lowest energy yield is 2.70 kWh/kWp. The average energy yield for TF system is 5.22 kWh/kWp in March.

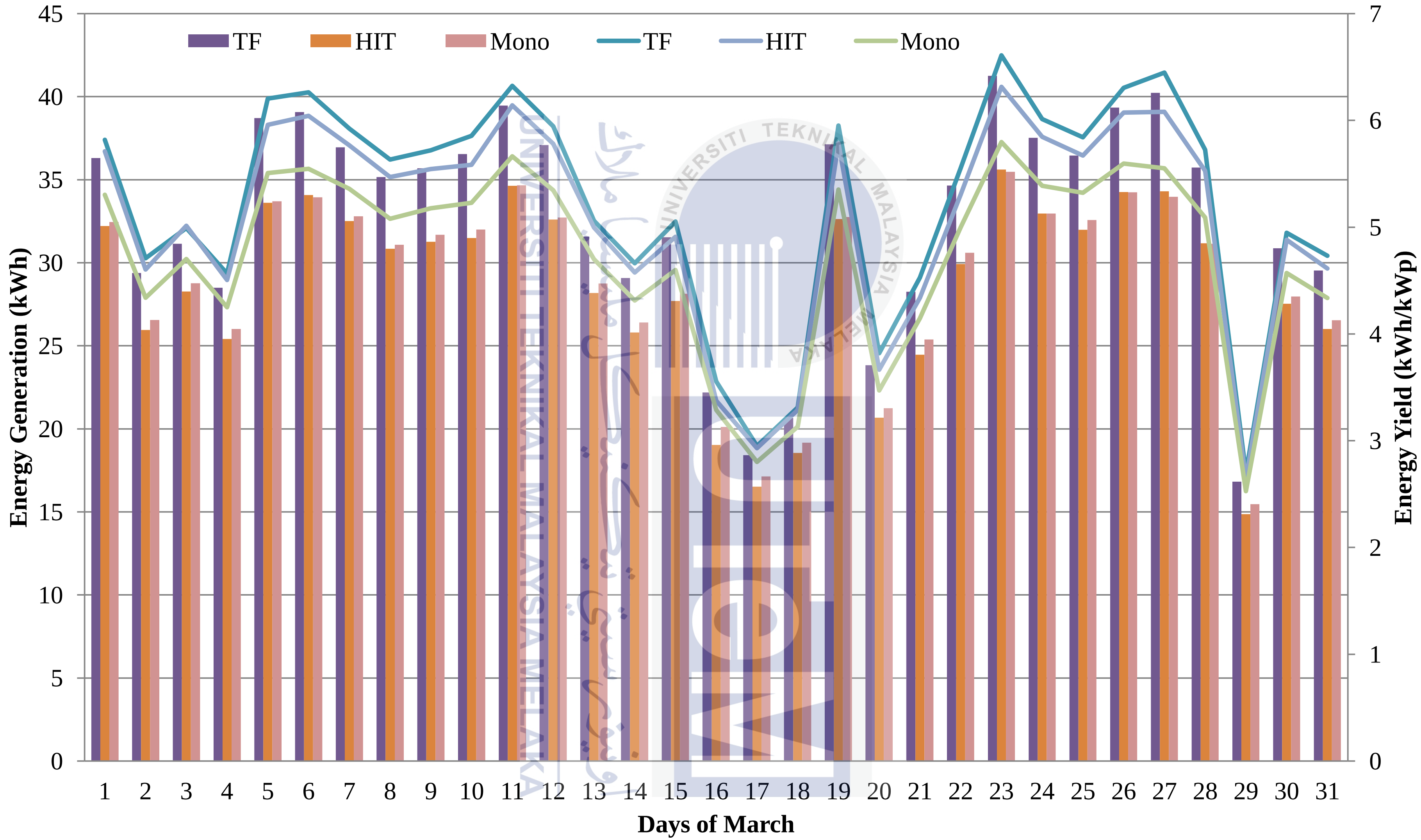


Figure 4.2: Graph of daily energy generation and energy yields in March.

Based on Figure 4.2, the daily energy generation and energy yield in March indicate that the amount of energy generated and produced by TF are highest among the other two types of system. The highest energy yield represents the best performance. According to the data obtained, there are several rainy days. However, the solar PV system from thin film still produces the most energy compared to Mono and HIT systems.

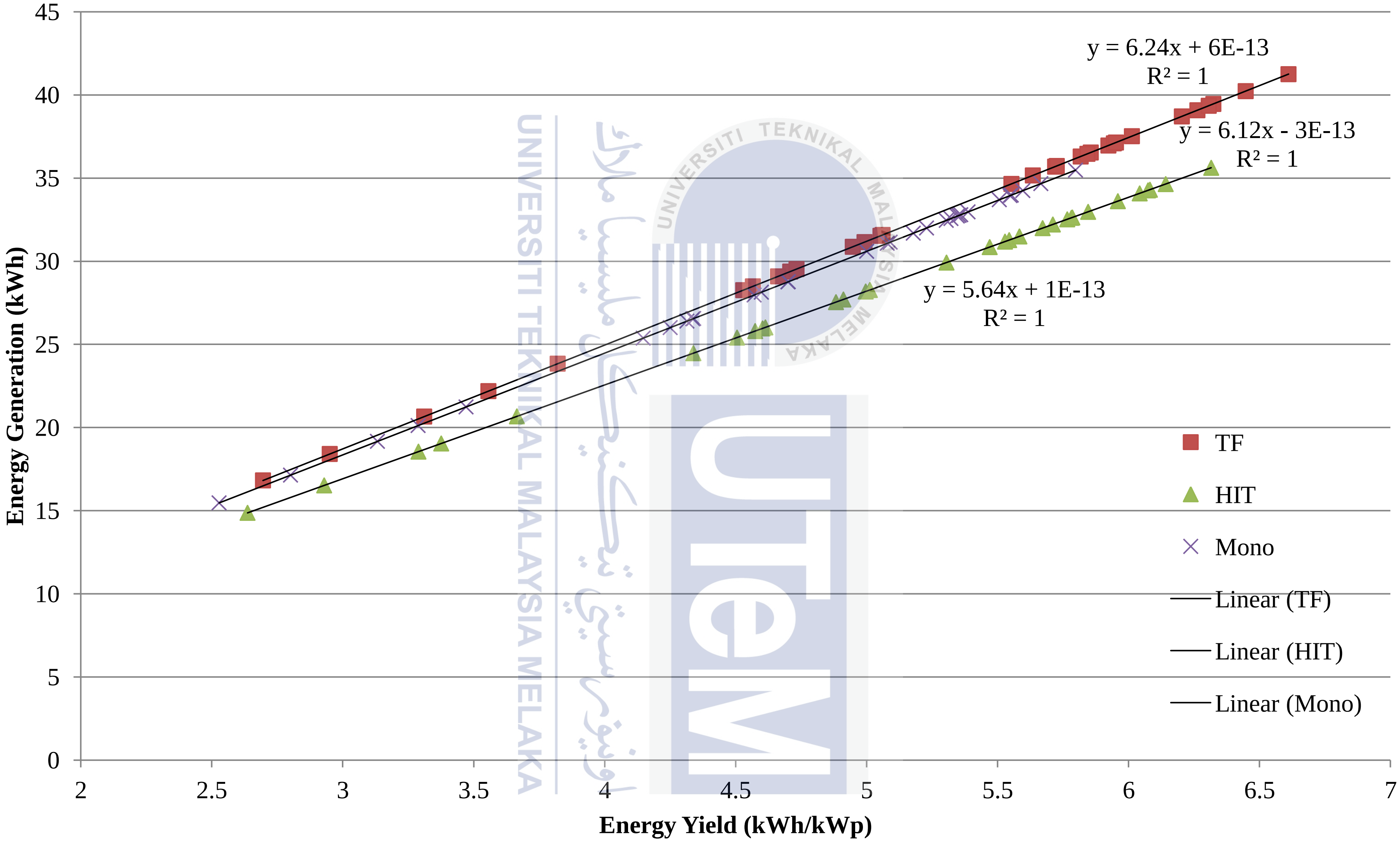


Figure 4.3: PV technology energy generation based on daily energy yield in March.

Figure 4.3 shows the graph of PV technology energy generation based on energy yield in March. It shows that the energy generation is directly proportional to the energy yield. As the energy generation increases, the energy yield also increases.

### 4.2.2 The Performance Ratio of the PV Systems

System performance is the overall performance level of the system. As discussed earlier, the TF system produced the highest energy yield as compared to Mono and HIT systems. This is because the performances of the systems were affected by the solar irradiance and other factors. A week of data collection from 3 March 2014 until 9 March 2014 for each type of the solar PV system was shown in Table 4.3, Table 4.4 and Table 4.5. The daily performance ratio for each systems based on each inverter was analysed and proceed for the overall system performance level for each systems. Table 4.6 shows the overall performance ratio for Mono, HIT and TF systems. When the solar irradiance fluctuates, it affects the performances of the systems for power generation, as shown in Figure 4.4. Meanwhile, Figure 4.5 shows the overall systems performance ratio against energy yield. Next, Table 4.7 shows the solar PV system performance level for Mono, HIT and TF systems.

Table 4.3: Performance ratio for TF system

| Date | Solar Irradiance ($Wh/m^2$) | Energy Generation (kWh) | | | Total Generation (kWh) | Energy Yield (kWh/kWp) | Performance Ratio (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Inverter 1 | Inverter 2 | Inverter 3 | Total | | Inverter 1 | Inverter 2 | Inverter 3 | Total |
| 3/3/2014 | 5863 | 10.31 | 10.4 | 10.44 | 31.15 | 4.99 | 84.54 | 85.28 | 85.61 | 85.14 |
| 4/3/2014 | 5405 | 9.44 | 9.5 | 9.55 | 28.49 | 4.57 | 83.97 | 84.50 | 84.95 | 84.47 |
| 5/3/2014 | 7051 | 12.82 | 12.91 | 12.98 | 38.71 | 6.20 | 87.41 | 88.03 | 88.50 | 87.98 |
| 6/3/2014 | 7132 | 12.91 | 13.07 | 13.1 | 39.08 | 6.26 | 87.03 | 88.11 | 88.31 | 87.81 |
| 7/3/2014 | 6783 | 12.22 | 12.35 | 12.39 | 36.96 | 5.92 | 86.61 | 87.54 | 87.82 | 87.32 |
| 8/3/2014 | 6528 | 11.64 | 11.74 | 11.78 | 35.16 | 5.63 | 85.73 | 86.46 | 86.76 | 86.31 |
| 9/3/2014 | 6607 | 11.79 | 11.93 | 11.97 | 35.69 | 5.72 | 85.79 | 86.81 | 87.10 | 86.57 |
| **Total** | **45369** | | | | **245.24** | **39.30** | **85.87** | **86.67** | **87.01** | **86.52** |

Table 4.4 : Performance ratio for HIT system

| Date | Solar Irradiance ($Wh/m^2$) | Energy Generation (kWh) | | | Total Generation (kWh) | Energy Yield (kWh/kWp) | Performance Ratio (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Inverter 1 | Inverter 2 | Inverter 3 | Total | | Inverter 1 | Inverter 2 | Inverter 3 | Total |
| 3/3/2014 | 6058 | 9.40 | 9.43 | 9.44 | 28.27 | 5.01 | 82.54 | 82.80 | 82.89 | 82.74 |
| 4/3/2014 | 5575 | 8.45 | 8.47 | 8.49 | 25.41 | 4.51 | 80.62 | 80.81 | 81.00 | 80.81 |
| 5/3/2014 | 7135 | 11.19 | 11.2 | 11.22 | 33.61 | 5.96 | 83.42 | 83.50 | 83.65 | 83.52 |
| 6/3/2014 | 7208 | 11.35 | 11.36 | 11.37 | 34.08 | 6.04 | 83.76 | 83.83 | 83.90 | 83.83 |
| 7/3/2014 | 6942 | 10.81 | 10.85 | 10.86 | 32.52 | 5.77 | 82.83 | 83.14 | 83.21 | 83.06 |
| 8/3/2014 | 6640 | 10.26 | 10.29 | 10.30 | 30.85 | 5.47 | 82.19 | 82.43 | 82.51 | 82.38 |
| 9/3/2014 | 6748 | 10.40 | 10.42 | 10.45 | 31.27 | 5.54 | 81.98 | 82.14 | 82.37 | 82.16 |
| **Total** | **46306** | | | | **216.01** | **38.30** | **82.48** | **82.66** | **82.79** | **82.64** |

Table 4.5: Performance ratio for Mono system

| Date | Solar Irradiance ($Wh/m^2$) | Energy Generation (kWh) | | | Total Generation (kWh) | Energy Yield (kWh/kWp) | Performance Ratio (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Inverter 1 | Inverter 2 | Inverter 3 | Total | | Inverter 1 | Inverter 2 | Inverter 3 | Total |
| 3/3/2014 | 6057 | 9.42 | 9.65 | 9.70 | 28.77 | 4.70 | 76.24 | 78.10 | 78.50 | 77.61 |
| 4/3/2014 | 5575 | 8.54 | 8.71 | 8.76 | 26.01 | 4.25 | 75.09 | 76.58 | 77.02 | 76.23 |
| 5/3/2014 | 7135 | 10.99 | 11.32 | 11.39 | 33.70 | 5.51 | 75.50 | 77.77 | 78.25 | 77.18 |
| 6/3/2014 | 7508 | 10.98 | 11.42 | 11.55 | 33.95 | 5.55 | 71.69 | 74.56 | 75.41 | 73.89 |
| 7/3/2014 | 6945 | 10.67 | 11.03 | 11.10 | 32.80 | 5.36 | 75.31 | 77.85 | 78.35 | 77.17 |
| 8/3/2014 | 6640 | 10.17 | 10.41 | 10.50 | 31.08 | 5.08 | 75.08 | 76.85 | 77.52 | 76.48 |
| 9/3/2014 | 6747 | 10.33 | 10.64 | 10.72 | 31.69 | 5.18 | 75.05 | 77.30 | 77.89 | 76.75 |
| | **46607** | | | | **218** | **35.62** | **74.85** | **77.00** | **77.56** | **76.47** |

Table 4.6: Performance ratio for Mono, HIT and TF systems based on solar irradiation and energy yield

| Date | Solar Irradiance (Wh/m^2) | | | Energy Generation (kWh) | | | Energy Yield (kWh/kWp) | | | Performance Ratio (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mono | HIT | TF | Mono | HIT | TF | Mono | HIT | TF | Mono | HIT | TF |
| 3/3/2014 | 6057 | 6058 | 5863 | 28.77 | 28.27 | 31.15 | 4.70 | 5.01 | 4.99 | 77.61 | 82.74 | 85.14 |
| 4/3/2014 | 5575 | 5575 | 5405 | 26.01 | 25.41 | 28.49 | 4.25 | 4.51 | 4.57 | 76.23 | 80.81 | 84.47 |
| 5/3/2014 | 7135 | 7135 | 7051 | 33.7 | 33.61 | 38.71 | 5.51 | 5.96 | 6.20 | 77.18 | 83.52 | 87.98 |
| 6/3/2014 | 7508 | 7208 | 7132 | 33.95 | 34.08 | 39.08 | 5.55 | 6.04 | 6.26 | 73.89 | 83.83 | 87.81 |
| 7/3/2014 | 6945 | 6942 | 6783 | 32.8 | 32.52 | 36.96 | 5.36 | 5.77 | 5.92 | 77.17 | 83.06 | 87.32 |
| 8/3/2014 | 6640 | 6640 | 6528 | 31.08 | 30.85 | 35.16 | 5.08 | 5.47 | 5.63 | 76.48 | 82.38 | 86.31 |
| 9/3/2014 | 6747 | 6748 | 6607 | 31.69 | 31.27 | 35.69 | 5.18 | 5.54 | 5.72 | 76.75 | 82.16 | 86.57 |
| **Total** | **46607** | **46306** | **45369** | **218** | **216.01** | **245.24** | **35.62** | **38.30** | **39.30** | **76.47** | **82.64** | **86.52** |

Table 4.3 presents the one week data collection from 3 March 2014 until 9 March 2014 on the performance ratio of the TF analysis. The total solar irradiance received at 45369 Wh/m$^2$ and total energy generation is 245.24 kWh with the average performance ratio of 86.52 %. Each inverter performance ratio is 85.57 %, 86.67 % and 87.01 % respectively.

Table 4.4 shows the performance ratio for HIT system within one week duration from 3 March 2014 until 9 March 2014. The result shows that when there is a fluctuation of solar irradiance, this will also affect the performance of the system in term of energy yield, energy generation and the performance ratio of the system. The highest solar irradiance for HIT system is 7208 Wh/m$^2$ which produces the energy yield of 6.04 kWh/kWp with a performance ratio of 83.83% on 6 March 2014. The total average performance ratio for HIT system is 82.64%.

Table 4.5 shows the performance ratio for Mono system. The result shows that the performance ratio for the Mono system is below 80 % as compared to HIT and TF systems. The total solar irradiance for mono system is 46607Wh/m$^2$ and has a value of 35.62 kWh/kWp for energy yield with a performance ratio of 76.47%.

Table 4.6 shows the performance ratio for Mono, HIT and TF systems based on solar irradiation and energy yield. Total solar irradiation for Mono, HIT and TF systems are 46607 Wh/m$^2$, 46306 Wh/m$^2$ and 45369 Wh/m$^2$. As the solar irradiation varies, it can be seen that the energy generated by the systems and the performance ratio are also affected. The average performance ratio for one week of data collection shows that TF achieves the highest performance ratio as compared to HIT and Mono systems.



Based on the one week data collection, the result shows that the daily performance ratio of TF systems has the highest perfomance ratio followed by HIT and Mono systems. The daily system performance of TF system was perform better compare to HIT and Mono systems due to TF module has the low temperature coefficient.

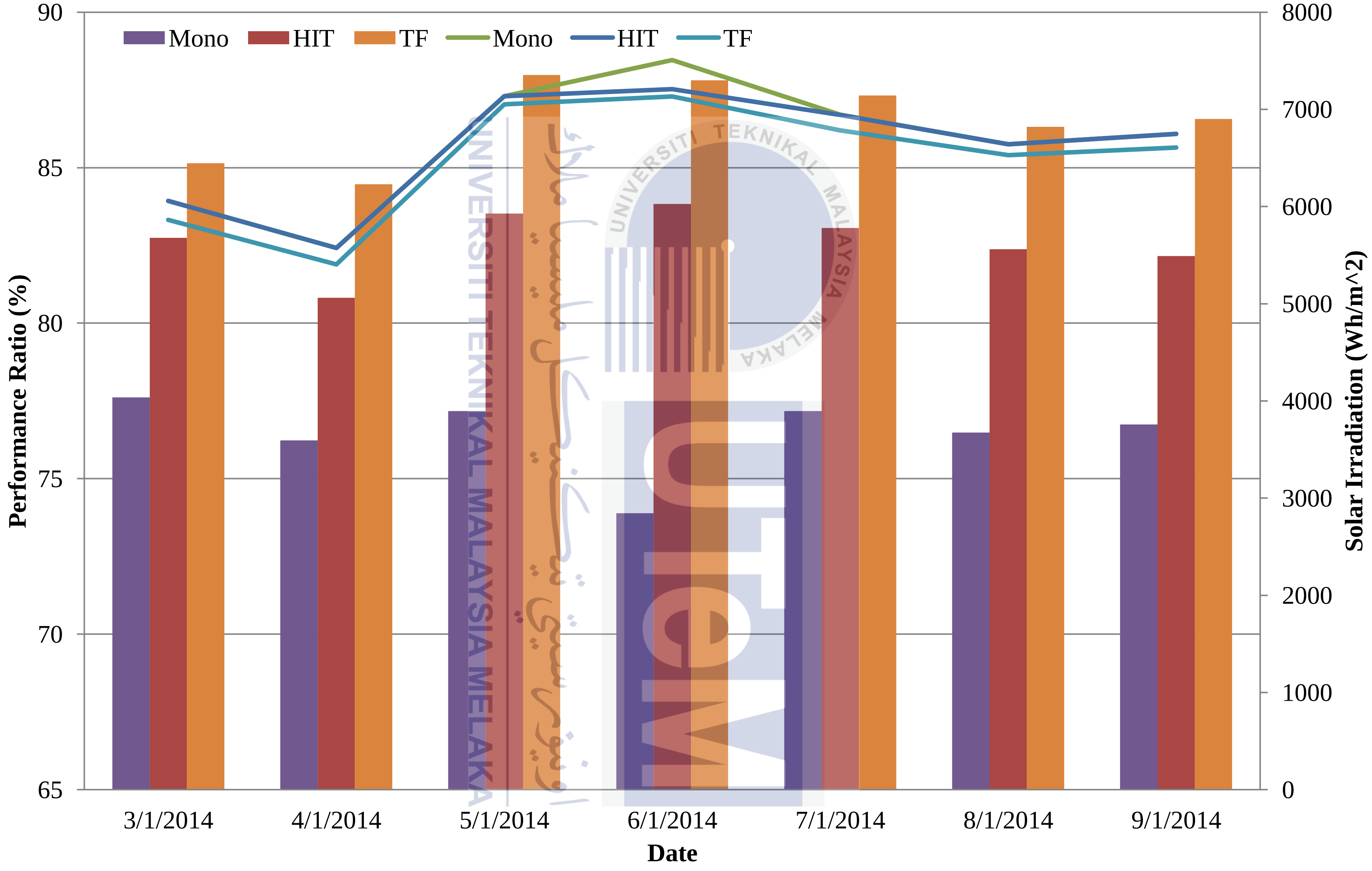


Figure 4.4: Performance ratio for solar irradiation.

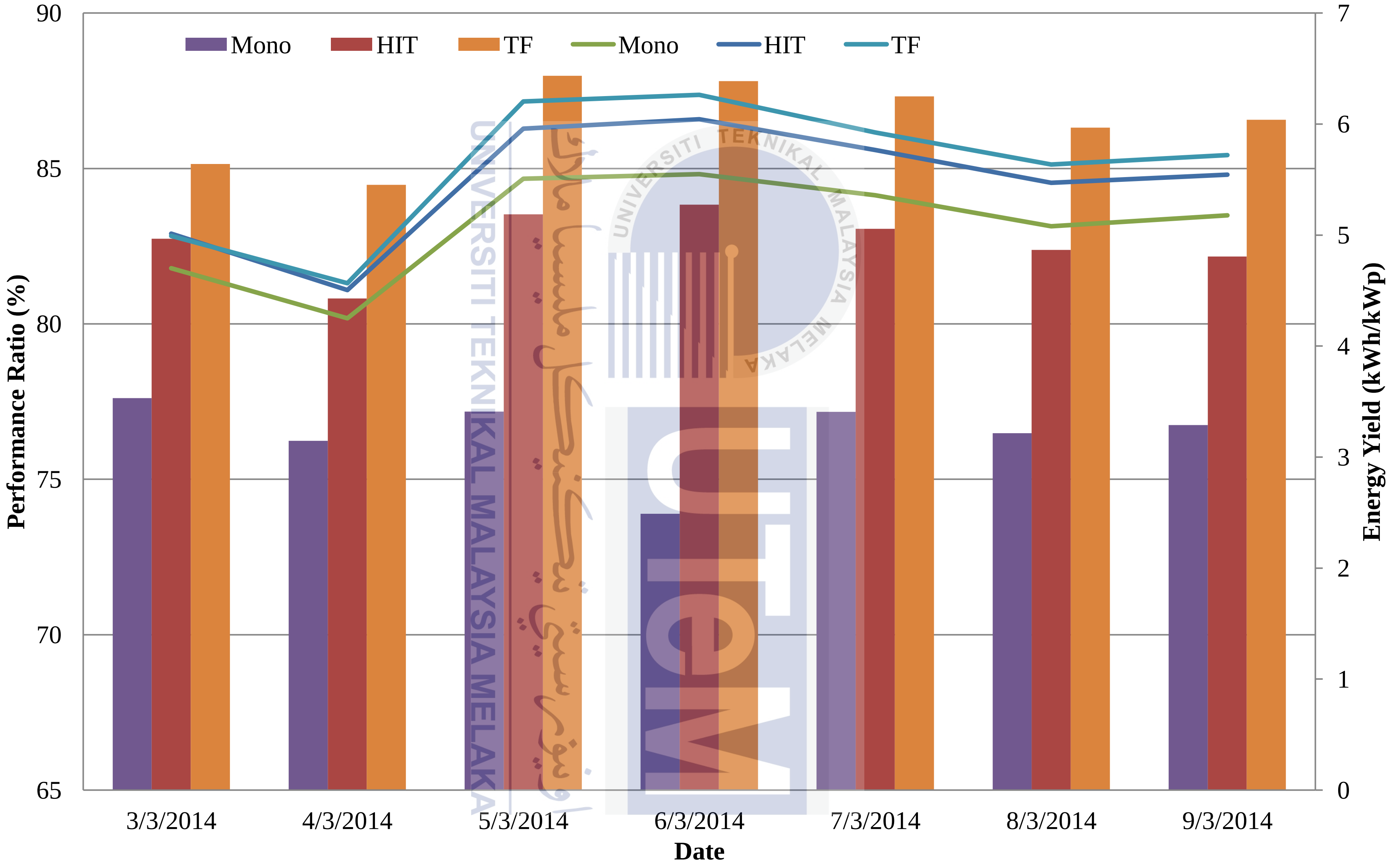


Figure 4.5: Performance ratio for energy yield.

Figure 4.4 and Figure 4.5 show the relationship of performance ratio for solar irradiance and energy yield. The solar irradiance will affect the energy generation and lead to the variation in the performance ratio for the systems. From the bar chart, it can be seen that the TF and HIT systems performance level achieved over 80% whereas Mono systems only above 70%.  Besides, a healthy solar PV system will generate the highest energy yield. Based on the result obtained, TF system has the highest energy yield and performance ratio compare to Mono and HIT systems.

Table 4.7: System performance level for HIT, Mono and TF systems

| Types of Solar Technology | Total Solar Irradiance ($Wh/m^2$) | Total Energy Generation (kWh) | Total Energy Yield (kWh/ kWp) | Performance Ratio (%) |
|---|---|---|---|---|
| TF | 45369 | 245.24 | 39.30 | 86.63 |
| HIT | 46306 | 216.01 | 38.30 | 82.71 |
| Mono | 46607 | 218.00 | 35.62 | 76.43 |

Table 4.7 shows the one week data collected from 3 March 2014 until 9 March 2014 of the total solar irradiance, energy yield and performance ratio for one week duration of system performance level for TF, HIT and Mono systems. The TF system has a better performance level with 86.63% and highest energy yield of 39.30 kWh/kWp. The highest solar irradiance which produces the least energy generation is the Mono system where it has a total solar irradiance of 46607 $Wh/m^2$ with an energy generation of 218.00 kWh.



According to Equation 3.11, the calculation for the performance ratio for Mono, HIT and TF systems can be represented by:

$$Performance\ ratio\ for\ Mono = \frac{218}{\frac{46607}{1000} \times 6.24} \times 100\%$$

$$= 76.43\ \%$$

$$Performance\ ratio\ for\ HIT = \frac{216.01}{\frac{46306}{1000} \times 6.24} \times 100\%$$

$$= 82.71\ \%$$

$$Performance\ ratio\ for\ TF = \frac{245.24}{\frac{45369}{1000} \times 6.24} \times 100\%$$

$$= 86.63\ \%$$

A one week data collection showed that the TF system had a performance ratio level of 86.63 %, followed by HIT and Mono, which were at 82.71% and 76.43 % respectively. The power output for the different types of solar PV systems can be estimated based on the performance ratio shown in Table 4.8. Thus, the estimated performance ratio for the TF system was 5.41kW, whereas for HIT and Mono systems, they were approximately 4.7kW each, as shown in Figure 4.6. The higher performance ratio of TF system is mainly driven by its lower temperature coefficient as compared to HIT and Mono systems.

Table 4.8: DC rated capacity and AC expected rated output for Mono, HIT and TF systems

| Type of Solar Technology | DC Rated Capacity (kW) | AC Expected Rated Output (kW) |
|---|---|---|
| HIT | 5.64 | 4.66 |
| Mono | 6.12 | 4.68 |
| TF | 6.24 | 5.41 |



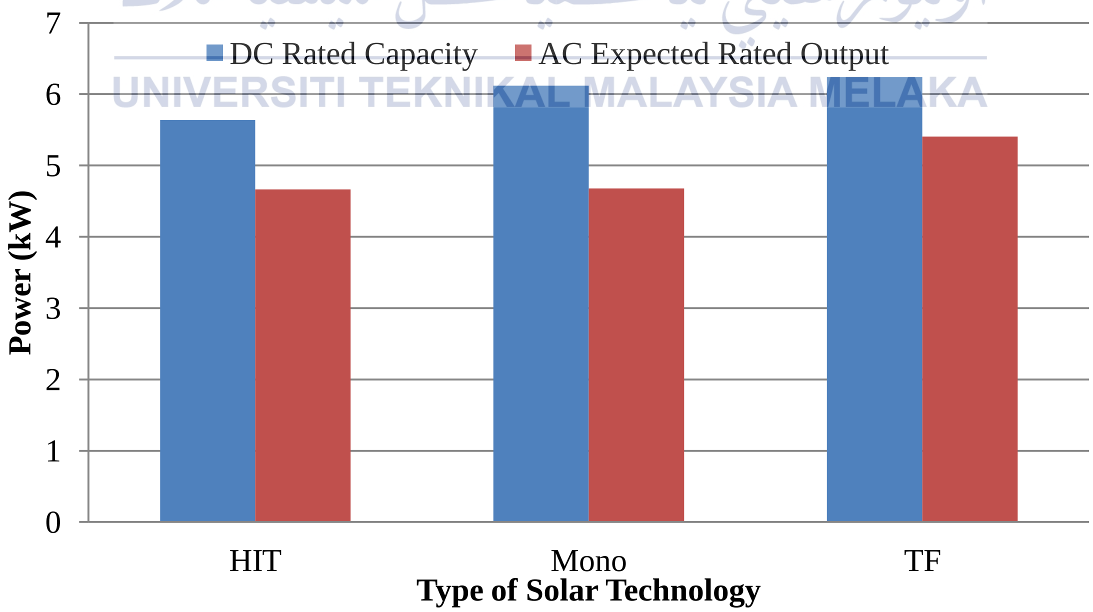


Figure 4.6: DC rated capacity and AC expected rated output for solar PV systems.

Figure 4.6 shows the DC rated capacity and AC expected rated output for Mono, HIT and TF systems for solar PV system. The higher performance ratio of TF system produces the highest AC capacity power compare to Mono and HIT systems.

### 4.2.3 Losses

There are several factors, such as cable losses, inverter losses, temperature losses, dust, mismatch, and etc, that were taken into consideration too as these losses affected the overall performance of the systems. After the evaluation on the overall level of performance for each systems found that the percentage of losses for TF, HIT and Mono systems were 13.37 %, 17.29 %, and 23.57 % respectively. This losses includes cable losses, inverter losses and temperature losses are shown in this section.

#### 4.2.3.1 Cable Losses

There are two types of cable losses consider in this section which are direct current (DC) cable losses and alternating current (AC) cable losses. The brand of the cable use is Leoni BETAflam Solar 125 RV flex FRNC with the size of 10mm$^2$ cable. From the data sheet shows in Appendix D, the resistance value was 1.95 mΩ/m. The analysis for each systems based on the cable length is assume to be 50m from the panel to the solar laboratory.



i. DC Cable Losses

The DC cable losses for the TF, HIT, and Mono systems were analysed according to Equation 3.12. The analysis taken form spread sheet data 23 March 2014 for every 5 minutes to perform the analysis of cable losses as shown in Figure 4.7. The cable losses is directly proportional to the current of each system. As the current of each systems increase, the cable losses also increases.

Table 4.9: DC cable losses for Mono, HIT and TF systems for March

| Parameters | Mono | HIT | TF |
|---|---|---|---|
| Total Current (A) | 14202.89 | 6369.69 | 7103.15 |
| Power Input (kW) | 453.20 | 456.06 | 527.30 |
| Cable Losses (kW) | 2.77 | 1.24 | 1.39 |
| Percentage Cable Losses (%) | 0.61 | 0.27 | 0.26 |

Table 4.9 shows the DC cable losses for the TF, HIT, and Mono systems were 0.26 %, 0.27 %, and 0.61 % respectively. The cable losses for Mono systems is double compare with HIT and TF systems due to the current carried by the Mono system was higher than the TF and HIT systems, it had higher losses. Generally, the DC cable losses contribute a small amount of losses which is less than 1 %.

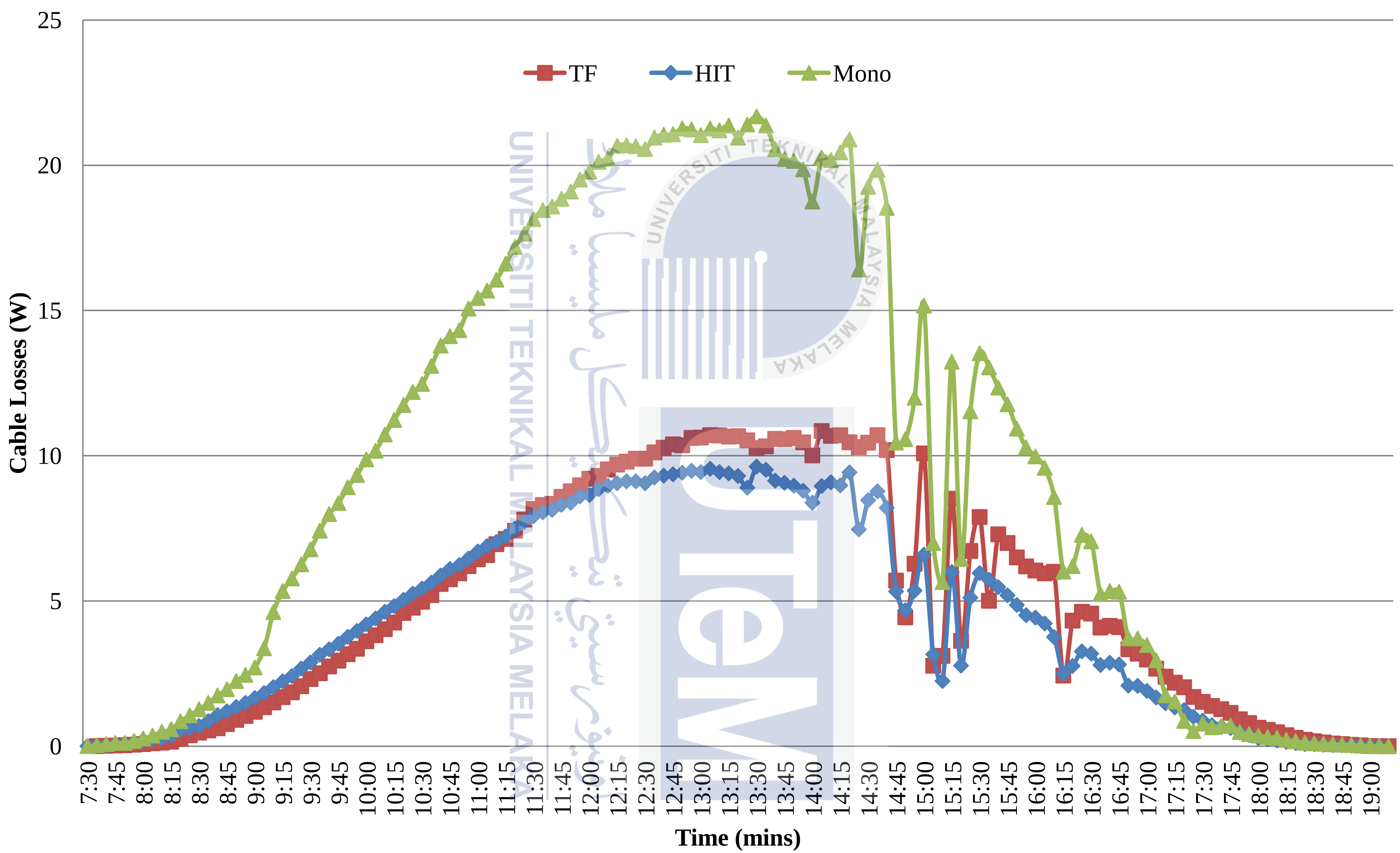


Figure 4.7: Cable losses for Mono, HIT and TF systems for March.

Figure 4.7 shows the cable losses for Mono, HIT and TF systems on March. From the line diagram, it indicates that the DC cable losses was higher at the peak time which is at 1.30pm. The cable losses fluctuate as the current of the systems vary. The highest cable losses is Mono system followed by HIT and TF systems due to the current carrying is higher. There is only slight difference in cable losses between HIT and Mono systems

ii. AC Cable Losses

The AC cable losses can be ignored because the AC output power was taken from the inverters before the AC cable was connected to the grid. In addition, there was no proper instrument that could be used to measure the losses.

#### 4.2.3.2 Inverter Losses

The main function of an inverter is to convert the DC power generated from the PV array into AC power, which is compatible with the utility grid. The power conversion efficiency is 95%, as published by the inverter manufacturer. The performance of the inverter was measured and compared with the data sheet in STC which is at 25℃ and 1000 $W/m^2$. Each of the solar PV system consisted of three inverters in grid connected system. The brand of the inverter used is SMA Sunny Boy 2000HF, and each has a power specification of 2 kW.



Figure 4.8 shows the graph of the inverter's efficiency against the solar array under direct current power on the 8th October 2013. At the beginning, the components of the inverters were not fully heated up, and the DC power was low. Before the efficiency of the inverters achieved 95%, there was a plunge in the percentage of approximately 15% due to the characteristics of the component. The overall efficiency of the TF inverter was 94.96 %, 94.07 %, and 92.94 %. By comparing to the spreadsheet data, there are little losses because of the characteristic of the component which may affect the performance of the system.

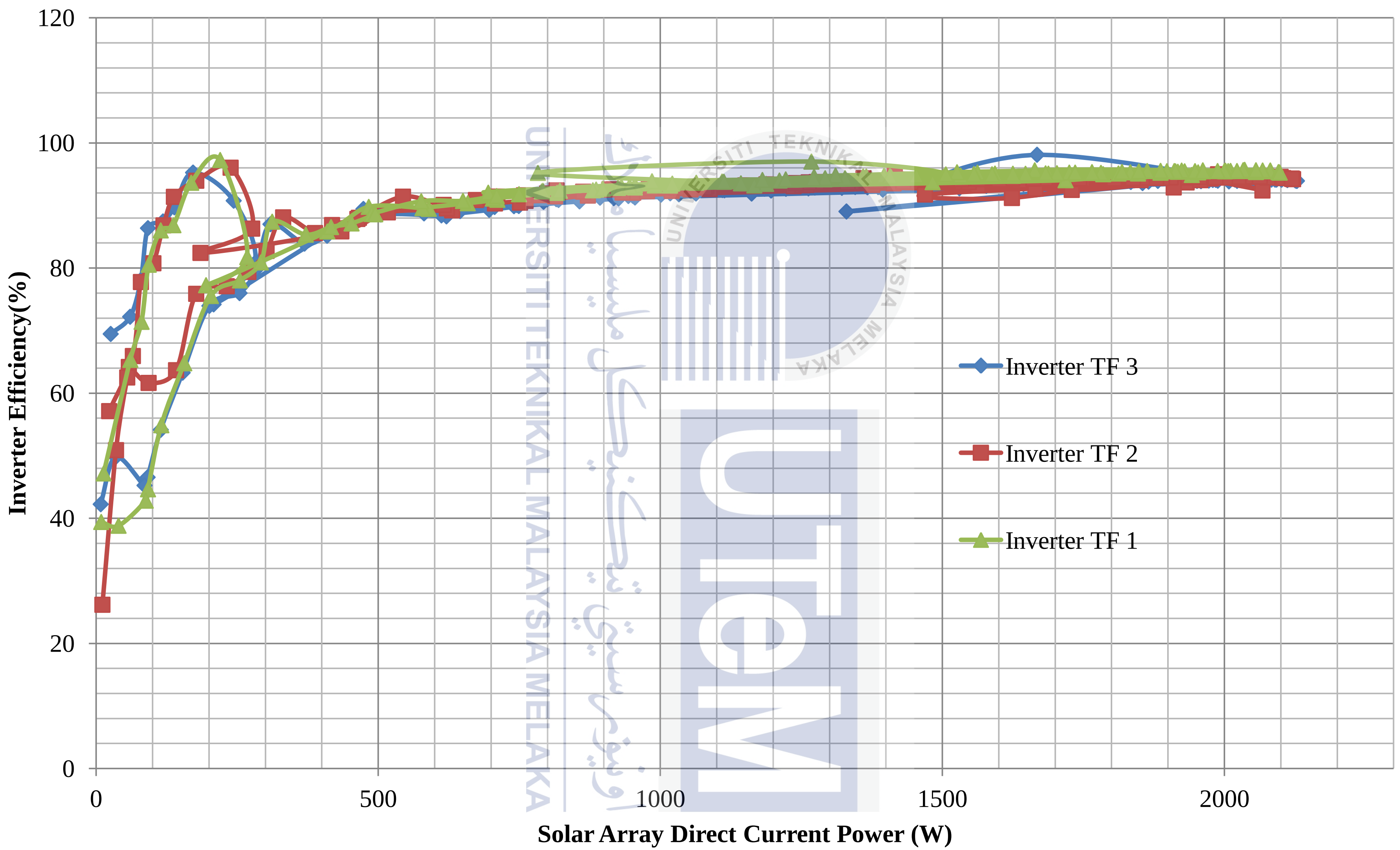


Figure 4.8: Inverter efficiency against solar array direct current power (W) on 8 October 2014.

#### 4.2.3.3 Temperature Losses

The fluctuation of the module cell temperature affected the performance of the solar PV systems. As the module temperature was high, the losses increased. From the module spreadsheet data shows that the temperature coefficient of maximum power for TF, HIT and Mono modules are -0.24 %/℃, -0.30 %/℃ and -0.45 %/℃ respectively. The analysis based on one week data  from 3 March 2014 until 9 March 2014. Power losses due to temperature effect of each solar PV systems as shown in Table 4.10.

Table 4.10: Power losses due to temperature effect of solar PV systems

| Panel Type | Temperature (℃) | | Power Losses due to Temperature Effect (%) | |
|---|---|---|---|---|
| | Lowest | Highest | Lowest | Highest |
| Mono | 25.40 | 59.70 | 0.18 | 15.62 |
| HIT | 25.40 | 59.70 | 0.12 | 10.41 |
| TF | 25.10 | 55.20 | 0.02 | 7.25 |



Table 4.10 shows the lowest and the highest power losses due to temperature effect for the different types of solar PV systems. The power loses due to temperature effect of the TF system was lower compared to Mono and HIT systems. The lowest and highest module temperature of TF system are 25.10 ℃ and 55.20 ℃ which is the lowest temperature compare to other systems.

# CHAPTER 5

# CONCLUSION

## 5.1 Conclusion

In conclusion, Mono, HIT and TF of solar PV technology were carried out studied and evaluated the best system energy performance of grid-connected solar PV systems. After the evaluation and analysis were done, all the objectives are fully achieved. Therefore TF PV system is suitable and it is a wise advice for customers to install the TF system rather than the HIT and Mono PV systems. The TF PV system performed better than the Mono and HIT PV systems based on the UTeM's climate condition, such as system performance, energy yield, and energy generation. Thin film is the best material used for solar PV system which is suitable for Malaysia climate condition but there is a limitation where it needs more space as compare to HIT and crystalline module. According to the data obtained, there are several rainy days and the solar PV system from thin film still produces the most energy compared to Mono and HIT systems. This is because thin film absorb two different types of solar wave which is red wave and blue wave. Therefore, thin film is encouraged to be chosen to be installed in utility scale power plant. Due to the high temperature environment, the TF PV system resulted in lower losses than the HIT and Mono PV systems. For the inverter to perform at a high efficient level, the TF PV system is recommended as its power has the lowest module temperature and is able to feed the solar inverter power window easily. The TF PV system has been proven to produce more energy in the tropical climate condition.

## 5.2 Recommendations

There are some improvement can be done to the solar PV system in order to get a better performance. Dust factor should be further evaluate which affect the system performance in term of energy generation and energy yield. However, due to the solar panel system located at a very high position, proper instruments should be provided for us to carry out the data collection properly.

In order to further study for megawatt power plant that will be installed at University Teknikal Malaysia Melaka (UTeM), this basic knowledge can be the initial platform for further advance for an evaluation on the system performance.

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# APPENDICES

## APPENDIX A- PUBLICATION

[1] H. S. Lew, C. K. Gan, and P. H. Tan, “The Performances of UTeM Solar PV Systems: An Evaluation,” in *The 2nd Power and Energy Conversion Symposium (PECS 2014)*, 2014, pp. 129–134.

The 2nd Power and Energy Conversion Symposium (PECS 2014)
Melaka, Malaysia
12 May 2014

# The Performances of UTeM Solar PV Systems: An Evaluation

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***Abstract*— Renewable clean solar energy can be utilized by using a photovoltaic (PV) system to convert solar energy into electrical energy. This helps to reduce global warming and save the environment as it enables the user to reduce the amount of energy utilization from electricity grid, and it can also supply back the additional energy into the grid. This paper presents the performances of the systems concerning mono crystalline silicon (Mono), thin film (TF), and heterojunction with intrinsic thin layer (HIT) grid-connected solar PV system, which are installed in the Faculty of Electrical Engineering of Universiti Teknikal Malaysia Melaka. The research was carried out based on the climatic condition in Malaysia. The performances of the solar PV inverters were also taken into consideration. The research was conducted at every 5 minutes interval, whereby the data were recorded and analysed to determine the system with the production of the highest energy yield. Several factors, such as inverter losses, cable losses, mismatch, and cloudy weather that influenced the solar PV system performance were also considered in this paper. After the data were analysed and the evaluation was done, it was found that the thin film (TF) system performed better than the heterojunction with intrinsic thin layer (HIT) and mono crystalline silicon (Mono) for the highest energy yield and system performance.**

***Index Terms*— heterojunction with intrinsic thin layer, mono crystalline silicon, thin film, energy yield, energy generation, performances of systems, losses**

## I. Introduction

The world global warming is in a critical stage. Scientists have estimated that the world's temperature will rise to another six degree Celsius if the emission of greenhouse gasses are not controlled [1]. The emission of the carbon dioxide gas that enters into the atmosphere has reached up to 90 million tons a day, and this increases the greenhouse properties that will lead to global warming [2]. Burning of forests and fossil fuels are some of the factors that cause global warming where it will lead to climate change. Hence, in order to reduce the emissions of these harmful gases into the atmosphere, the governments around the world need to support the development of clean energy sources, such as solar energy, for it is efficient and considered as cleaner fuels with multiple beneficial effects [3].

In Malaysia, the solar photovoltaic (PV) system has been implemented for a few years now, but they are still at the beginning stage due to the high initial cost of the PV system with the low solar electricity tariff rate [4]. Even though the PV system is not popular among Malaysians, there are a lot of researches that are being conducted. However, all relevant researches or articles are more focused on solar cell instead of the system itself. In general, there is no information regarding which Solar PV system is suitable to be installed due to lack of professionals in this field.

From the literature review, the solar PV system carries out system performance which affect the energy output, and meanwhile, energy output is affected by the module temperature and solar irradiance as well [5]. Dust, cable losses, and inverter losses are amongst the important factors that have an impact on the overall performance of the solar PV system [6]. The different types of solar panels have different levels of performances under different local climate conditions [7].

Besides, the importance of reducing the loss factor from the solar equipment also needs to be considered. Therefore, this project was carried out to evaluate the overall performance of mono crystalline silicon (Mono), thin film (TF) and heterojunction with intrinsic thin layer (HIT) solar PV systems based on UTeM's climate conditions.

## II. Methodology

The research was conducted to determine the best performance of the solar PV system. All relevant data were recorded based on real time data, which can be obtained from the solar laboratory. The data collected were only based on one inverter although each system has three inverters with ratings of 2 kW.

Apart from solar irradiance and temperature data, the temperature coefficient data for the respective PV system technologies were obtained from the manufacturer's specification sheet. The estimated power and losses formula are shown in equations (1) and (2), respectively [5]

$$P_{estimated} = P_{mp}\left(1 + \gamma_{coef}\left(T_{cell} - T_{stc}\right)\right) \quad (1)$$

$$P_{losses} = P_{mp}\left(\gamma_{coef}\left(T_{cell} - T_{stc}\right)\right) \quad (2)$$

Where:
$P_{mp}$ is the maximum power of the systems' capacity
$\gamma_{coef}$ is the temperature coefficient
$T_{cell}$ is the PV module cell temperature, ℃
$T_{stc}$ is the temperature at standard test condition, 25 ℃

The performances of the systems were evaluated and calculated based on the equations below. Energy yield is the amount of energy that can be produced in one hour with respect to the system power capacity.

$$Energy\ Yield = \frac{Energy\ Output}{System\ Power\ Capacity} \quad (3)$$

Inverter efficiency is to determine the power losses in the inverters in order to convert direct current (DC) to alternating current (AC).

$$Inverter\ Efficiency = \frac{Output\ Power}{Input\ Power} \times 100\% \quad (4)$$

Total energy production can be defined as the sum of power produced from PV array based on the performance of the system and irradiance in a week.

$$Total\ Energy\ Production = Power\ from\ Array\ Capacity \times Weekly\ Irradiance \times System\ Performance \quad (5)$$

Performance ratio is to determine the level of solar PV system performance.

$$Performance\ Ratio = \frac{Total\ Energy\ Production}{Weekly\ Irradiation \times System\ Power\ Capacity} \quad (6)$$

In order to calculate the losses that affect the performances of the systems, cable losses and temperature losses were calculated referring to Equations (6) and (7).

$$E = a \times R \times {I_b}^2 \quad (7)$$

Where:
E : energy losses in a wire, Watt (W)
a : number of line coefficient, a=1 for single line, a = 3 for 3-phase circuit.
R : resistance of one active line (Ω)
$I_b$ : current in Ampere (A)

The percentage of temperature losses is to determine the power losses from the module.

$$Percentage\ temperature\ losses = -\gamma_{coef}.\left(T_{cell} - T_{stc}\right) \times 100\% \quad (8)$$

Where:
$\gamma_{coef}$ is the temperature coefficient
$T_{cell}$ is the PV module cell temperature, ℃
$T_{stc}$ is the temperature at standard test condition, 25 ℃

Figure 1 shows the process flow on the evaluation of the performance of the solar PV system. The parameters of the data, such as the DC current, DC voltage, DC input power, energy generation, frequency, AC current, AC voltage, and AC output voltage were recorded from the inverter. At every 5 minute interval, the data were recorded and analyzed to determine the system with the highest energy yield. Module specification sheet and inverter spreadsheet were needed to perform the evaluation on the performances of the systems. In addition, system component losses and PV module degradation rate were considered before the evaluation on systems' performances could be carried out. In terms of the PV system performance metrics, the system energy yield (kWh/kWp) was the key indicator, which took into consideration the temperature coefficient, as well as the system degradation rate over the evaluation period of 21 years.

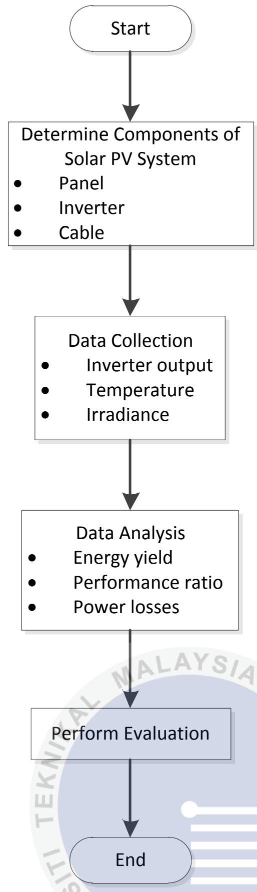


Fig 1: Process flow on the evaluation of the performance of the solar PV system

## III. System Description

Table I shows the various types of solar PV system in the grid-connected installed at the rooftop (free standing) of the Faculty of Electrical Engineering at Universiti Teknikal Malaysia Melaka with the solar PV technology, which are Mono, TF, and HIT, which were considered in this study.

TABLE I: VARIOUS TYPES OF SOLAR PV SYSTEMS

| | **System 1** | **System 2** | **System 3** |
|---|---|---|---|
| Panel Type | Mono | HIT | TF |
| System | 6.12kW | 5.64kW | 6.24kW |
| Quantity | 24 units | 24 units | 48 units |
| Location | Admin Rooftop | Admin Rooftop | Laboratory Rooftop |

Figure 2 shows the single line diagram of the PV configuration. The system capacities for the three different types of solar PV system were 6.12 kW, 5.64 kW, and 6.24kW. As for the PV module arrangement, 24 pieces of Mono and HIT PV modules were connected in series with 2 strings. The Mono system produced a system voltage of 753.6 V with the total current of 195.6 A, whereas the HIT system produced 1032 V and 131.52 A. The thin film PV module was connected in series with 4 strings which produced system voltage of 2212.8 V and 138.24 A.

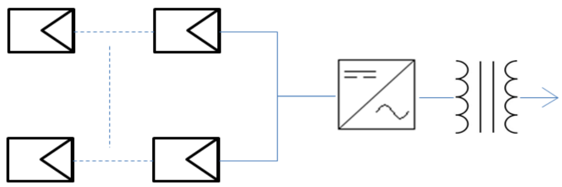

Fig 2: Single line diagram of PV configuration [5]

The technical characteristics of the module are shown in TABLE II. These characteristics indicate that TF had lower temperature coefficient compared to the Mono and HIT types of modules. This particular characteristic can have an effect on the overall performance of the systems, especially in a hot climatic tropical country, such as Malaysia.

TABLE II: MODULE CHARACTERISTICS

| **Characteristics** | **Mono** [8] | **HIT** [9] | **TF** [10] |
|---|---|---|---|
| Maximum power ($P_{max}$) | 255 W | 235 W | 130 W |
| Open-circuit voltage ($V_{oc}$) | 37.8 V | 51.8 V | 60.4 V |
| Short-circuit current ($I_{sc}$) | 8.66 A | 5.84 | 3.41 A |
| Maximum power voltage ($V_{mp}$) | 31.4 W | 43.0V | 46.1 V |
| Maximum power current ($I_{mp}$) | 8.15 A | 5.48 A | 2.88 A |
| Temperature coefficient of ($P_{max}$) | -0.45 %/°C | - 0.30 %/°C | - 0.24 %/°C |
| Temperature coefficient of ($V_{oc}$) | -0.30 %/°C | - 0.25 %/°C | - 0.30 %/°C |
| Temperature coefficient of ($I_{sc}$) | 0.004 %/°C | - 0.03 %/°C | 0.07 %/°C |

## IV. Results and Discussion

This section discusses the performances of the Mono, HIT, and TF PV systems. The results present the energy yield, performance ratio, and losses analysis at Standard Test Condition (STC) of irradiance of 1000 W/m$^2$ at 25 ℃ for the systems.

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### *A. Energy Yield*

From Table II, the Mono module has a higher temperature coefficient compared to the HIT and TF modules. This causes the Mono module to produce lower output power. Figure 3 shows the total energy generation and the total energy yield from September 2013 to February 2014. The energy generation and energy yield for the TF were 5445.24 kWh and 872.6346 kWh/kWp; higher than the HIT system by 802.30 kWh and 49.4218 kWh/kWp. The Mono system produced the lowest energy generation and energy yield among the three types of solar PV system. It was lower than the TF system by approximately 13.5% and 11.8% respectively. Hence, the results show that the TF system produced the best performance for energy yield. As shown in Figure 4, energy generation was directly proportional to energy yield.

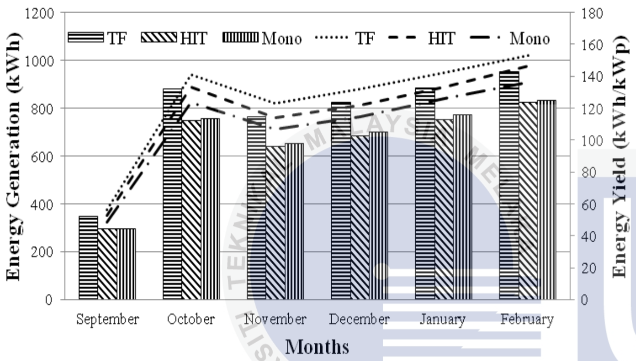


Fig 3: Total energy generation and total energy yield from September 2013 until February 2014

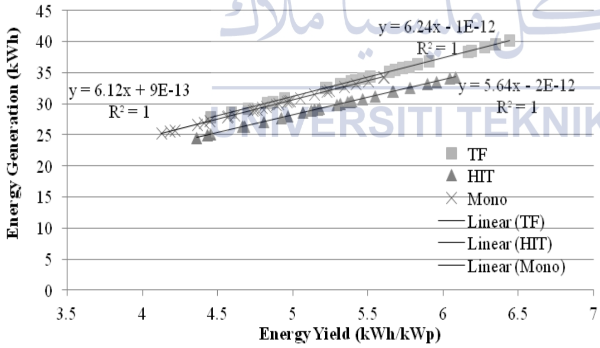


Fig 4: PV technology energy generation based on daily energy yield

### B. *The Performance Ratio of the PV systems*

System performance is the overall performance level of the system. As discussed earlier, the TF system produced the highest energy yield as compared to Mono and HIT systems. This is because the performances of the systems were affected by the solar irradiance and other factors. When the solar irradiance fluctuated, it affected the performance of the systems for power generation, as shown in Figure 5. Besides, Figure 6 shows the performance ratio against energy yield. A one week data collection showed that the TF system had performance ratio level of 86.63 %, followed by HIT and Mono, which were at 82.71% and 76.43 % respectively. The power output for the different types of solar PV systems can be estimated based on the performance ratio. Thus, the estimated performance ratio for the TF system was 5.41kW, whereas for HIT and Mono systems, they were approximately 4.7kW each, as shown in Figure 7. The higher performance ratio of TF system is mainly driven by its lower temperature coefficient as compared to HIT and Mono systems.

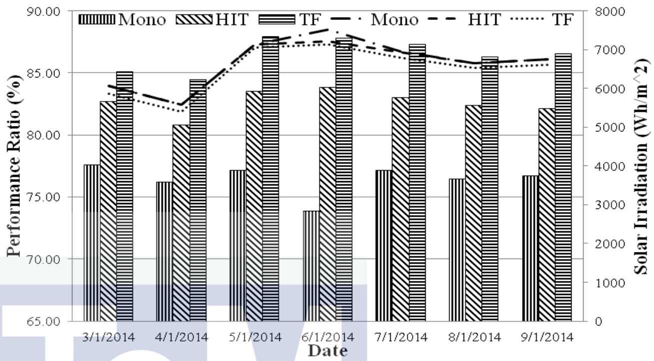


Fig 5: Performance ratio for solar irradiation

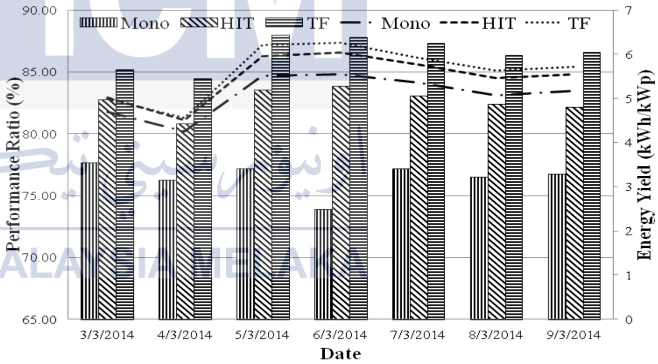


Fig 6: System performance ratio for energy yield

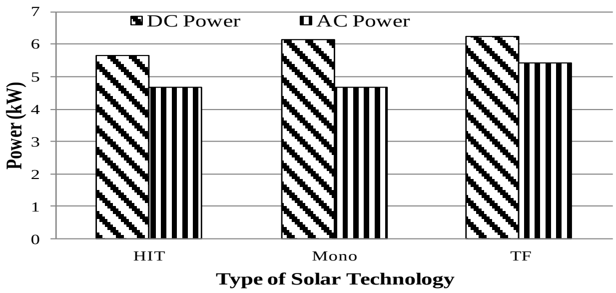


Fig 7: Power performance for solar PV system

*C. Losses*

There are several factors, such as cable losses, inverter losses, temperature losses, dust, mismatch, and etc, that were taken into consideration too as these losses affected the overall performance of the systems. The percentage of losses for TF, HIT and Mono systems were 13.37 %, 17.29 %, and 23.57 % respectively.

i. *Cable losses*

The length from the panel to the inverter room was assumed at 50m. From the spreadsheet data of the cable BETAflam Solar 125 RV flex FRNC, the resistance value was 1.95 mΩ/m. Therefore, the DC cable losses for the TF, HIT, and Mono systems were 0.13 %, 0.12 %, and 0.27 % respectively. As the current carried by the Mono system was higher than the TF and HIT systems, it had higher losses. The AC cable losses can be ignored because the AC output power was taken from the inverters before the AC cable was connected to the grid. In addition, there was no proper instrument that could be used to measure the losses.

ii. *Inverter losses*

The main function of an inverter is to convert the DC power generated from the PV array into AC power, which is compatible with the utility grid. The power conversion efficiency is 95%, as published by the inverter manufacturer. The performance of the inverter was measured with STC, which was at 25 °C and 1000 W/m$^2$. Each of the solar PV system consisted of three inverters in grid connected system. The brand of the inverter used was SMA Sunny Boy 2000HF, and each had a power specification of 2 kW. Figure 8 shows the graph of the inverter's efficiency against the solar array under direct current power on the 8th October 2013. At start, the component of the inverters was not fully heated up, and the DC power was low. Before the efficiency of the inverters achieved 95%, there was a plunge in the percentage of approximately 15% due to the characteristics of the component. The overall efficiency of the TF inverter were 94.96 %, 94.07 %, and 92.94 %.

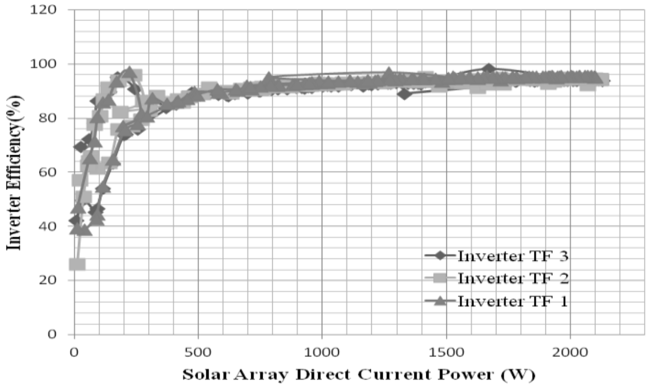


Fig 8: Inverter efficiency against solar array direct current power (W)

iii. *Temperature losses*

The fluctuation of the module cell temperature affected the performance of the solar PV systems. As the module temperature was high, the losses increased. Table III shows the lowest and the highest percentages of losses for the different types of solar PV systems. The percentage for temperature losses of the TF system was lower compared to Mono and HIT systems.

TABLE III: THE PERCENTAGE FOR TEMPERATURE LOSSES OF SOLAR PV SYSTEMS

| Panel Type | Temperature (°C) | | The Percentage for Temperature Losses (%) | |
|---|---|---|---|---|
| | Lowest | Highest | Lowest | Highest |
| Mono | 25.40 | 59.70 | 0.18 | 15.62 |
| HIT | 25.40 | 59.70 | 0.12 | 10.41 |
| TF | 25.10 | 55.20 | 0.02 | 7.25 |

## V. Conclusion

Based on the results and discussion, this paper has finalized that the TF PV system is suitable and it is a wise advice for customers to install the TF system rather than the HIT and Mono PV systems. The TF PV system performed better than the Mono and HIT PV systems based on the UTeM's climate condition, such as system performance, energy yield, and energy generation. Due to the high temperature environment, the TF PV system resulted in lower losses than the HIT and Mono PV systems. For the inverter to perform at a high efficient level, the TF PV system is recommended as its power has the lowest module temperature and is able to feed the solar inverter power window easily. The TF PV system has been proven to produce more energy in the tropical climate condition.

## Acknowledgment

The authors would like to acknowledge the funding provided by the Ministry of Education Malaysia under the research grant no. RAGS/2012/FKE/TK02/2 B00009.

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**APPENDIX B- INVERTER DATA SHEET**

SUNNY BOY 2000HF / 2500HF / 3000HF

| Technical data | Sunny Boy 2000HF | Sunny Boy 2500HF | Sunny Boy 3000HF |
|---|---|---|---|
| **Input (DC)** | | | |
| Max. DC power (@ cos ϕ = 1) | 2100 W | 2600 W | 3150 W |
| Max. DC voltage | 700 V | 700 V | 700 V |
| MPP voltage range | 175 V - 560 V | 175 V - 560 V | 210 V - 560 V |
| DC nominal voltage | 530 V | 530 V | 530 V |
| Min. DC voltage / start voltage | 175 V / 220 V | 175 V / 220 V | 175 V / 220 V |
| Max. input current / per string | 12 A / 12 A | 15 A / 15 A | 15 A / 15 A |
| Number of MPP trackers / strings per MPP tracker | 1 / 2 | 1 / 2 | 1 / 2 |
| **Output (AC)** | | | |
| AC nominal power (@ 230 V, 50 Hz) | 2000 W | 2500 W | 3000 W |
| Max. AC apparent power | 2000 VA | 2500 VA | 3000 VA |
| Nominal AC voltage; range | 220, 230, 240 V; 180 – 280 V | 220, 230, 240 V; 180 – 280 V | 220, 230, 240 V; 180 – 280 V |
| AC grid frequency; range | 50, 60 Hz; ± 4.5 Hz | 50, 60 Hz; ± 4.5 Hz | 50, 60 Hz; ± 4.5 Hz |
| Max. output current | 11.4 A | 14.2 A | 15 A |
| Power factor (cos ϕ) | 1 | 1 | 1 |
| Phase conductors / connection phases | 1 / 1 | 1 / 1 | 1 / 1 |
| **Efficiency** | | | |
| Max. efficiency / Euro-eta | 96.3 % / 95.0 % | 96.3 % / 95.3 % | 96.3 % / 95.4 % |
| **Protection devices** | | | |
| DC reverse-polarity protection | ● | ● | ● |
| ESS switch-disconnector | ● | ● | ● |
| AC short circuit protection | ● | ● | ● |
| Ground fault monitoring | ● | ● | ● |
| Grid monitoring (SMA Grid Guard) | ● | ● | ● |

Figure B1: Inverter efficiency data sheet part 1.



| | | | |
|---|---|---|---|
| Ground fault monitoring | ● | ● | ● |
| Grid monitoring (SMA Grid Guard) | ● | ● | ● |
| Galvanically isolated / all-pole sensitive fault current monitoring unit | ●/– | ●/– | ●/– |
| Protection class / overvoltage category | I / III | I / III | I / III |
| **General data** | | | |
| Dimensions (W / H / D) in mm | 348 / 580 / 145 | 348 / 580 / 145 | 348 / 580 / 145 |
| Weight | 17 kg | 17 kg | 17 kg |
| Operating temperature range | -25 °C ... +60 °C | -25 °C ... +60 °C | -25 °C ... +60 °C |
| Noise emission (typical) | 38 dB(A) | 38 dB(A) | 38 dB(A) |
| Internal consumption: (night) | 1 W | 1 W | 1 W |
| Topology | HF transformer | HF transformer | HF transformer |
| Cooling concept | OptiCool | OptiCool | OptiCool |
| Electronics protection rating / connection area (as per IEC 60529) | IP65 / IP54 | IP65 / IP54 | IP65 / IP54 |
| Climatic category (per IEC 60721-3-4) | 4K4H | 4K4H | 4K4H |
| **Features** | | | |
| DC connection: SUNCLIX | ● | ● | ● |
| AC connection: screw terminal / plug connector / spring-type terminal | –/●/– | –/●/– | –/●/– |
| Display: text line / graphic | –/● | –/● | –/● |
| Interfaces: RS485 / *Bluetooth* | ○/● | ○/● | ○/● |
| Warranty: 5 / 10 / 15 / 20 / 25 years | ●/○/○/○/○ | ●/○/○/○/○ | ●/○/○/○/○ |
| Certificates and permits (more available on request) | CE, VDE 0126-1-1, Enel-GUIDA ED. 1.1, RD 1663, G83/1-1, PPC, AS4777, EN 50438*, C10/11, PPDS, UTE C 15-712-1 | | |
| | | | |
| | | | |
| * Does not apply to all national deviations of EN 50438 | | | |
| ● Standard features ○ Optional features – not available | | | |
| Provisional data, as of June 2011 – data at nominal conditions | | | |
| Type designation | SB 2000HF-30 | SB 2500HF-30 | SB 3000HF-30 |

Figure B2: Inverter efficiency data sheet part 2.

## APPENDIX C- MODULE DATA SHEET

I. Thin Film

SHARP

### NS-F130G5

Without frame "Glass-Glass" Panel.
Tandem structure with an amorphous and a microcrystalline silicon layer offering a stabilised module efficiency of 9.3 %.
Use of white glass, encapsulation material, weather protection film and a newly designed silver anodised aluminium frame for long-term use. This guarantees simple and safe installation.
Higher energy yields per watt at high temperatures.
Output: connection cable with waterproof plug connector.
Optimised for grid-connected roof mounting PV systems

**Description**

Without Frame "Glass-Glass" solar photovoltaic thinfilm panel

| General | |
|---|---|
| Nominal Output (Wp) | 130 |
| Module Efficiency (%) | 9.3 |
| Weight (kg) | 26 |

Figure C1: Thin film data sheet part 1.



| Physial Dimensions | |
|---|---|
| Cell type | Tandem structure of amorphous and micro-crystalline silicon cell |
| Dimensions (LxHxW) (mm) | 1402x1001x46 |
| **Electrical Characteristics** | |
| Open Circuit voltage Voc (V) | 60.4 |
| Short circuit current Isc (A) | 3.41 |
| Maximum power voltage Vpm (V) | 46.1 |
| Maximum power current Ipm (A) | 2.88 |
| System Voltage (V DC) | 1000 |
| **Thermal coefficients and characteristics** | |
| αPm (%/°C) | -0.24 |
| αIsc (%/°C) | 0.07 |
| αVoc (%/°C) | -0.30 |
| Operating temperature (°C) | -40 to +90 |
| Storage temperature (°C) | -40 to +90 |
| Storage air humidity (%) | up to 90 |

Figure C2: Thin film data sheet part 2.

II. Mono Crystalline Silicon (Mono)

SW-02-5153US 07-2012

# Sunmodule® ™
## SW 255 mono black / Version 2.0 and 2.5 Frame

### PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

| | | SW 255 |
|---|---|---|
| Maximum power | $P_{max}$ | 255 Wp |
| Open circuit voltage | $V_{oc}$ | 37.8 V |
| Maximum power point voltage | $V_{mpp}$ | 31.4 V |
| Short circuit current | $I_{sc}$ | 8.66 A |
| Maximum power point current | $I_{mpp}$ | 8.15 A |

*STC: 1000W/m², 25°C, AM 1.5

### PERFORMANCE AT 800 W/m², NOCT, AM 1.5

| | | SW 255 |
|---|---|---|
| Maximum power | $P_{max}$ | 184.1 Wp |
| Open circuit voltage | $V_{oc}$ | 34.0 V |
| Maximum power point voltage | $V_{mpp}$ | 28.3 V |
| Short circuit current | $I_{sc}$ | 6.99 A |
| Maximum power point current | $I_{mpp}$ | 6.52 A |

Minor reduction in efficiency under partial load conditions at 25°C: at 200W/m², 95% (+/-3%) of the STC efficiency (1000 W/m²) is achieved.

### THERMAL CHARACTERISTICS

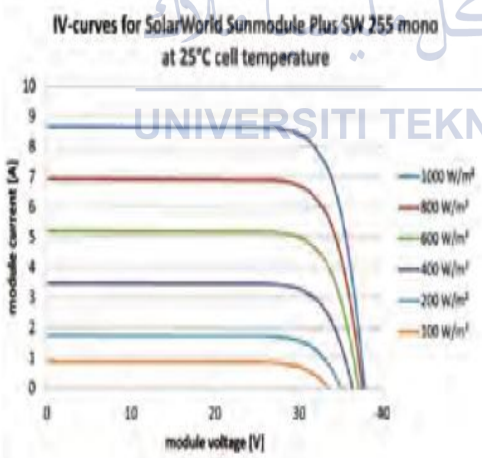
| | |
|---|---|
| NOCT | 48 °C |
| TC $I_{sc}$ | 0.004 %/K |
| TC $V_{oc}$ | -0.30 %/K |
| TC $P_{mpp}$ | -0.45 %/K |
| Operating temperature | -40°C to 85°C |

### COMPONENT MATERIALS

| | |
|---|---|
| Cells per module | 60 |
| Cell type | Mono crystalline |
| Cell dimensions | 6.14 in x 6.14 in (156 mm x 156 mm) |
| Front | tempered glass (EN 12150) |
| Frame | Black anodized aluminum |
| Weight | 46.7 lbs (21.2 kg) |

Figure C3: Mono crystalline silicon data sheet part 1.



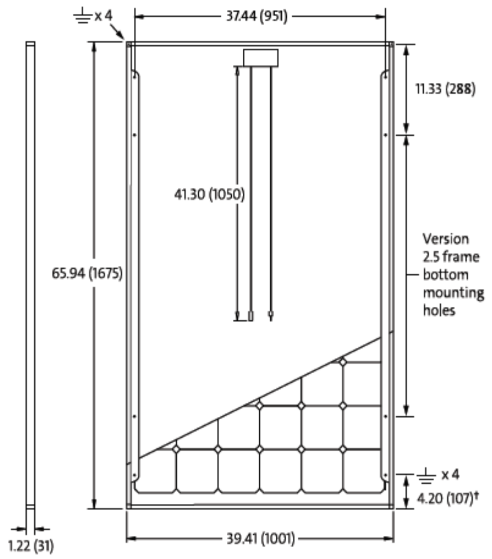



### SYSTEM INTEGRATION PARAMETERS

| | | |
|---|---|---|
| Maximum system voltage SC II | | 1000 V |
| Max. system voltage USA NEC | | 600 V |
| Maximum reverse current | | 16 A |
| Number of bypass diodes | | 3 |
| UL Design Loads* | Two rail system | 113 psf downward<br>64 psf upward |
| UL Design Loads* | Three rail system | 170 psf downward<br>64 psf upward |
| IEC Design Loads* | Two rail system | 113 psf downward<br>50 psf upward |

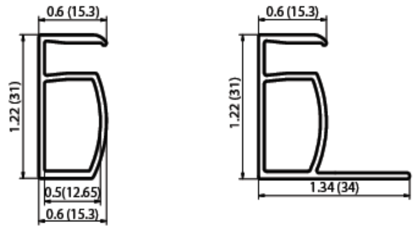
*Please refer to the Sunmodule installation instructions for the details associated with these load cases.

Figure C4: Mono crystalline silicon data sheet part 2.




## ADDITIONAL DATA

| | |
|---|---|
| Power sorting[2] | -0 Wp / +5 Wp |
| J-Box | IP65 |
| Connector | MC4 |
| Module efficiency | 15.21 % |
| Fire rating (UL 790) | Class C |




**VERSION 2.0 FRAME**
- Compatible with "Top-Down" mounting methods
- Grounding Locations: 4 corners of the frame

**VERSION 2.5 FRAME**
- Compatible with both "Top-Down" and "Bottom" mounting methods
- Grounding Locations:
  - 4 corners of the frame
  - 4 locations along the length of the module in the extended flange†

1) Sunmodules dedicated for the United States and Canada are tested to UL 1703 Standard and listed by a third party laboratory. The laboratory may vary by product and region. Check with your SolarWorld representative to confirm which laboratory has a listing for the product.
2) Measuring tolerance traceable to TUV Rheinland: +/- 2% (TUV Power Controlled).
3) All units provided are imperial. SI units provided in parentheses.

SolarWorld AG reserves the right to make specification changes without notice.

Figure C5: Mono crystalline silicon data sheet part 3.



III. Heterojunction with Intrinsic Thin Layer (HIT)

**HIT® Photovoltaic Module**

## Electrical and Mechanical Characteristics
## VBHN235SJ18

**Electrical data (at STC)**

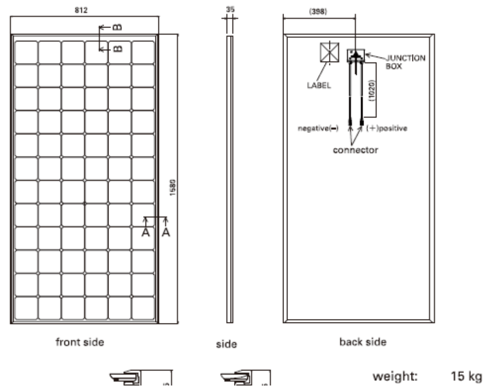
| | |
|---|---|
| Max. power (Pmax) [W] | 235 |
| Max. power voltage (Vmp) [V] | 43.0 |
| Max. power current (Imp) [A] | 5.48 |
| Open circuit voltage (Voc) [V] | 51.8 |
| Short circuit current (Isc) [A] | 5.84 |
| Max. over current rating [A] | 15 |
| Output power tolerance [%] | +10/-5* |
| Max. system voltage [V] | 600 |

Note: Standard Test Conditions: Air mass 1.5; Irradiance = 1000W/m$^2$; cell temp. 25°C
* All modules measured by Panasonic facility have output with positive tolerance.

**Temperature characteristics**

| | |
|---|---|
| Temperature (NOCT) [°C] | 46.0 |
| Temp. coefficient of Pmax [%/°C] | -0.30 |
| Temp. coefficient of Voc [V/°C] | -0.130 |

**Dimensions and weight**




weight: 15 kg

Figure C6: Heterojunction with intrinsic thin layer data sheet part 1.

section A-A section B-B unit: mm

### At NOCT

| | |
|---|---|
| Max. power (Pmax) [W] | 179 |
| Max. power voltage (Vmp) [V] | 40.5 |
| Max. power current (Imp) [A] | 4.41 |
| Open circuit voltage (Voc) [V] | 48.9 |
| Short circuit current (Isc) [A] | 4.70 |

Note: Nominal Operating Cell Temp.: Air mass 1.5 spectrum; Irradiance = 800W/m$^2$; Air temperature 20°C; wind speed 1 m/s

### At low irradiance

| | |
|---|---|
| Max. power (Pmax) [W] | 44.7 |
| Max. power voltage (Vmp) [V] | 41.0 |
| Max. power current (Imp) [A] | 1.09 |
| Open circuit voltage (Voc) [V] | 48.4 |
| Short circuit current (Isc) [A] | 1.17 |

Note: Low irradiance: Air mass 1.5 spectrum; Irradiance = 200W/m$^2$; cell temp. = 25°C

### Guarantee

Power output: 10 years (90% of Pmin), 25 years (80% of Pmin)
Product workmanship: 10 years
(Based on guarantee document)

### Materials

Cell material: 5 inch HIT cells
Glass material: AR coated tempered glass
Frame materials: Black anodized aluminium
Connectors type: KITANI

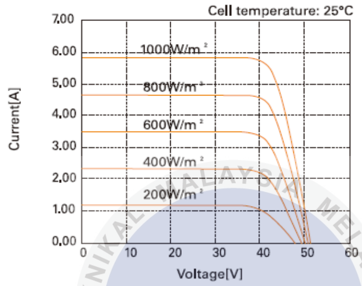
### Certificates

Module comply with the requirements of IEC61215, IEC61730-1, IEC61730-2.

JET: Japan Electrical Safety & Environment Technology Laboratories

Manufactured by SANYO Electric Co., Ltd.

### Dependence on irradiance




Please consult your local dealer for more information.

⚠ CAUTION! Please read the installation manual carefully before using the products.

Panasonic Australia Pty. Ltd.

■ 1 Innovation Road Macquarie Park NSW 2113 Australia
■ Tel: +61-2-9491-7400
■ Fax: +61-2-9491-7450
www.panasonic.com.au

Panasonic®


05/2012

Figure C7: Heterojunction with intrinsic thin layer data sheet part 2.

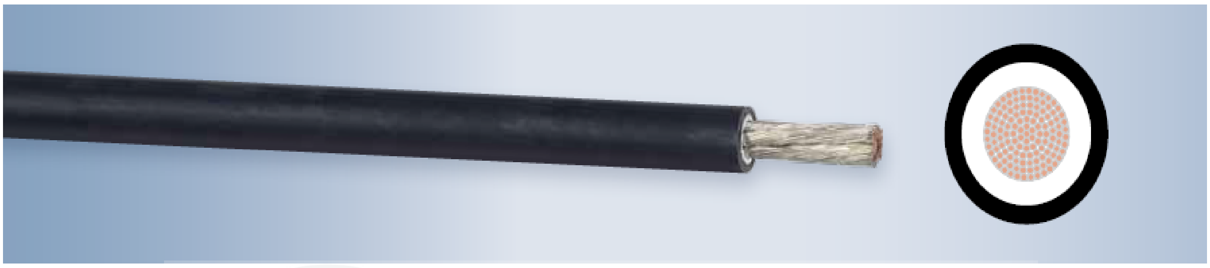
# APPENDIX D- CABLE SPREAD SHEET

## BETAflam® Solar 125 RV flex FRNC

Fotovoltaik-Kabel, halogenfrei, flammwidrig

## BETAflam® Solar 125 RV flex FRNC

Photovoltaic Power Cables, halogen free, flame retardant



**Anwendung**

Doppelt isolierte, elektronenstrahlvernetzte Leitungen für die Installation von Fotovoltaikanlagen. Mit reduziertem Durchmesser und integriertem Mantel.

**Aufbau**

- **Leiter:** Kupferlitze verzinnt, feindrähtig nach VDE 0295 / IEC 60228, Klasse 5
- **Isolation:** XLPO, flammwidrig, halogenfrei, elektronenstrahlvernetzt
- **Mantel:** XLPO, flammwidrig, halogenfrei, elektronenstrahlvernetzt, UV- und Ozonbeständig

**Application**

Double insulated, electron-beam cross-linked cables for Photovoltaic power applications. With reduced diameter and integrated jacket.

**Construction**

- **Conductor:** Tinned fine copper strands, according to VDE 0295 / IEC 60228, class 5
- **Insulation:** XLPO, flame retardant, halogen free, electron-beam cross-linked
- **Jacket:** XLPO, flame retardant, halogen free, electron-beam cross-linked, UV and ozone resistant

Figure D1: Leoni cable data sheet part 1.

- **Mantel:** XLPO, flammwidrig, halogenfrei, elektronenstrahlvernetzt, UV- und Ozonbeständig
- **Mantelfarbe:** Schwarz

Technische Daten

- **Nennspannung:** $U_0/U$ = 600 / 1000 V AC, 1000 / 1800 V DC
- **Prüfspannung:** 6500 V, 50 Hz, 5 min.
- **Betriebstemperatur:**
  – 40 °C bis + 125 °C
  – 40 °F bis + 257 °F
- **Umgebungstemperatur:** > 25 Jahre (TÜV)
  – 40 °C bis + 90 °C
  – 40 °F bis + 194 °F
- **Maximale Kurzschlusstemperatur:** 280 °C, + 536 °F
- **Biegeradius:**

| | | |
|---|---|---|
| ∅ <10 mm | Fest verlegt | > 4 × ∅ |
| | Gelegentlich bewegt | > 5 × ∅ |
| ∅ >10 mm | Fest verlegt | > 5 × ∅ |
| | Gelegentlich bewegt | > 7 × ∅ |

Materialeigenschaften / Normen

- **Brandverhalten:** IEC 60332-1, IEC 60332-3-24
- **Rauchemission:** IEC 61034; EN 50268-2
- **Geringe Brandlast:** DIN 51900
- **Zulassung:** TÜV 2 PfG 1169 02.2007 PV1-F
- **Anwendungsnormen:** UNE 21123; UNE 20.460-5-52, UTE C 32-502

- **Jacket:** XLPO, flame retardant, halogen free, electron-beam cross-linked, UV and ozone resistant
- **Jacket colour:** Black

**Technical specification**

- **Nominal voltage:** $U_0/U$ = 600 / 1000 V AC, 1000 / 1800 V DC
- **Test voltage:** 6500 V, 50 Hz, 5 min.
- **Temperature rating:**
  – 40 °C up to + 125 °C
  – 40 °F up to + 257 °F
- **Ambient temperature:** > 25 years (TÜV)
  – 40 °C up to + 90 °C
  – 40 °F up to + 194 °F
- **Max. short circuit temperature:** 280 °C, + 536 °F
- **Bending radius:**

| | | |
|---|---|---|
| ∅ <10 mm | Fixed installation | > 4 × ∅ |
| | Occasionally moved | > 5 × ∅ |
| ∅ >10 mm | Fixed installation | > 5 × ∅ |
| | Occasionally moved | > 7 × ∅ |

**Material properties / Standards**

- **Fire performance:** IEC 60332-1, IEC 60332-3-24
- **Smoke emission:** IEC 61034; EN 50268-2
- **Low fire load:** DIN 51900
- **Approvals:** TÜV 2 PfG 1169 02.2007 PV1-F
- **Application standards:** UNE 21123; UNE 20.460-5-52, UTE C 32-502

Figure D2: Leoni cable data sheet part 2.



Abmessungen, Gewichte / **Dimensions, Weights**

| Kabelaufbau Construction | Artikel-Nr. Part no. | Leiteraufbau Conductor construction | Leiter-∅ Conductor ∅ | Aussen-∅ Outer ∅ | Widerstand max. Resistance max. | Gewicht Weight | Brandlast Fire load |
|---|---|---|---|---|---|---|---|
| n × mm² | | n × mm | mm | mm | mΩ/m | kg / km | kWh/m |
| 1 × 2.5 | **304467** | 45 × 0.25 | 2.05 | 4.5 | 8.21 | 41 | 0.073 |
| 1 × 4 | **304468** | 52 × 0.30 | 2.55 | 5.0 | 5.09 | 57 | 0.088 |
| 1 × 6 | **304469** | 78 × 0.30 | 3.10 | 5.6 | 3.39 | 77 | 0.104 |
| 1 × 10 | **304471** | 75 × 0.40 | 4.10 | 6.7 | 1.95 | 119 | 0.132 |
| 1× 16 | **304472** | 119 × 0.40 | 5.50 | 9.70 | 1.24 | 217 | 0.295 |
| 1 × 25 | **304474** | 182 × 0.40 | 6.60 | 11.20 | 0.79 | 313 | 0.398 |
| 1 × 35 | **304475** | 259 × 0.40 | 7.70 | 12.30 | 0.56 | 415 | 0.454 |
| 1 × 50 | **304476** | 380 × 0.40 | 9.90 | 14.90 | 0.39 | 594 | 0.604 |

Figure D3: Leoni cable data sheet part 3.

**APPENDIX E- GANTT CHART OF FINAL YEAR PROJECT**

| Month / Task | FYP 1 | | | | FYP 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Task | September | October | November | December | January | February | March | April | May | June |
| Briefing | | | | | | | | | | |
| Preliminary Research | | | | | | | | | | |
| Introduction | | | | | | | | | | |
| Literature Review | | | | | | | | | | |
| Collecting Data | | | | | | | | | | |
| Writing Progress Report | | | | | | | | | | |
| Submission of Progress Report and Presentation | | | | | | | | | | |
| Repair report | | | | | | | | | | |
| Analysis Data | | | | | | | | | | |
| Report Writing FYP 2 | | | | | | | | | | |
| Presentation FYP 2 | | | | | | | | | | |
| Project Finalize and Checking | | | | | | | | | | |