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DETERMNATION OF WEIGHTED EFFICIENCY EQUATION FOR SB3000HF INVERTER

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This report is submitted in Partial fulfilment of Requirement for the Degree of Bachelor in Electrical Engineering (Power Industry)

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ABSTRACT

System yield is a mechanism used to predict the Return of Investment before installed the solar PV and also to estimate the customer profit. Inverter efficiency is one of the important elements in order to calculate system yield. However, Peak inverter efficiency was used and it is inaccurate because it only occurs at ideal condition of Standard Test Condition and this condition rarely achieved so it's not reliable to use. Thus, a better representation is weighted efficiency such as European efficiency and California Energy Commission (CEC) efficiency because weighted efficiency takes into account the inverter will behave in complete daily profile of irradiance. Anyhow European efficiency is most suitable for medium irradiation region and CEC efficiency for high irradiation region. Tropical Climate is unique, hence, this project aimed at developing a Tropical efficiency equation according to IEC 61683 standards. To do so a one year irradiance, G and temperature, T data of Malaysia was used and simulated by using PV simulator on SB3000HF inverter. The result shows that the tropical efficiency match the real system yield and the best in terms of validation if compared to Euro efficiency and CEC efficiency. This project also suggests an alternative method to produce Tropical Efficiency equation that is by using Multiple Linear Regression. The correctness of the alternative method was justified since that Coefficient of determination with the conventional method gives a value of more than 0.9.

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ABSTRAK

Sistem hasil adalah satu mekanisme yang digunakan untuk meramalkan Return of Investment sebelum dipasang PV solar dan juga untuk menganggarkan keuntungan pelanggan. kecekapan penyongsang adalah salah satu elemen penting untuk mengira hasil sistem. Walau bagaimanapun, kecekapan inverter Peak telah digunakan dan ia tidak tepat kerana ia hanya berlaku pada keadaan yang ideal bagi Standard Keadaan Ujian dan keadaan ini jarang dicapai supaya ia tidak boleh dipercayai untuk digunakan. Oleh itu, perwakilan yang lebih baik berwajaran kecekapan seperti kecekapan Eropah dan kecekapan California Suruhanjaya Tenaga (CEC) kerana kecekapan wajaran mengambil kira inverter akan berkelakuan dalam profil harian lengkap sinaran. Bagaimanapun kecekapan Eropah adalah yang paling sesuai untuk rantau penyinaran sederhana dan kecekapan CEC bagi rantau penyinaran tinggi. Iklim tropika adalah unik, dengan itu, projek ini bertujuan membangunkan satu persamaan kecekapan tropika mengikut IEC 61.683 taraf. Untuk berbuat demikian yang sinaran satu tahun, G dan suhu, data T dari Malaysia telah digunakan dan simulasi dengan menggunakan PV simulator pada SB3000HF inverter. Hasilnya menunjukkan bahawa kecekapan tropika sepadan hasil sistem sebenar dan yang terbaik dari segi pengesahan jika dibandingkan dengan kecekapan Euro dan kecekapan CEC. Projek ini juga mencadangkan kaedah alternatif untuk menghasilkan persamaan Kecekapan Tropical iaitu dengan menggunakan Multiple Linear Regression. Ketepatan kaedah alternatif adalah wajar kerana yang Pekali penentuan dengan kaedah konvensional memberikan nilai lebih daripada 0.9.

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LIST OF ABBREVIATIONS

AC	-	Alternating current
BIPV	-	Building integrated photovoltaic
CO_2	-	Carbon Dioxide
FiT	-	Feed in Tariff
GCPV	-	Grid connected photovoltaic
MPPT	-	Maximum Power Point Tracker
PR	-	Performance ratio
PV	-	Photovoltaic
RM	-	Ringgit Malaysia
ROI	-	Return on investment
RSM	-	Response Surface Methodology
SEDA	-	Sustainable Energy Development Authority
STC	-	Standard Test Condition
S.Y	-	System Yield
TNB	-	Tenaga Nasional Berhad

CHAPTER 1

INTRODUCTION

Nowadays, the world has been suffered from energy crisis. Energy crisis occurs due to the world's demand on the limited natural resources. Energy sources have been consumed for power generation of power plants. Before 1980's, Malaysia Government energy sector are mainly dependent on fossil fuels such as coal, oil and natural gas [1]. However, the usage of fossil fuels has contribute negative environment impact such as greenhouse gas problem and carbon dioxide emission [2]. Moreover, these natural resources are in limited supply and diminishing as demand rises. Due to the crisis, government has give incentives and concern to make the use of renewable resources as alternative energy to overcome the global problem. The energy crisis is something that is getting worse despite the many efforts and measures undertaken [3].

Renewable energy source has become a necessary energy sources and play a crucial role in achieving the goal of sustainable development [4]. Hence, it is also as important role to reduce the CO_2 emission that contributes by the fossil fuels [5]. Renewable energy sources are natural processes that are continuously renewed. This energy resource includes wind energy, hydro power, solar power energy and biomass energy which are producing clean and environmental friendly. Firstly, wind energy is energy resources that have zero emission and without fuel cost which is constantly distributes the energy. Hydropower energy is one of sources energy which uses energy of moving water to generate electricity [6]. Besides that, its process so environmentally way to gain electricity by the flowing water and has no any chemical or fuel cost. The process of hydropower based on simple concept. The flowing water turns the turbine works and its spin the generator so its produce the electricity [7]. While biomass energy is energy produced from plant materials such as wood and waste wood, leaves of plants, and agricultural waste. Its generate electrical power by burning biomass and the process will generate the emission likes the fossil fuels However, burning of fossil fuels has captured the carbon dioxide emission out the air. Besides, renewable energy sources are providing good solution to overcome the energy crisis [8]. However, due to Malaysia is located at the equatorial region and highly potential to receive good level of sunshine throughout the year, making it ideal place for application of solar energy.

Today, Solar Photovoltaic (PV) energy has become the most demand of energy sources among renewable sources. It is expected that it will the most important and significant renewable energy source until 2040 [9]. It is one of the renewable green energy that generates electricity in very clean, quiet, and re-usable. Moreover, solar power also generates great optimism energy in researchers [10]. Figure 1.1 shows the amount of energy produced by PV inverter depends on the sunlight produced. When the sunlight strikes directly to the solar, conversion of light into electricity occurred at the atomic level. The solar cell captured the neutron and generates electricity. Also, Solar Photovoltaic (PV) offers no noise and their operation cost is low. This is because PV modules absorbs the radiation from sun and converts them into electricity.

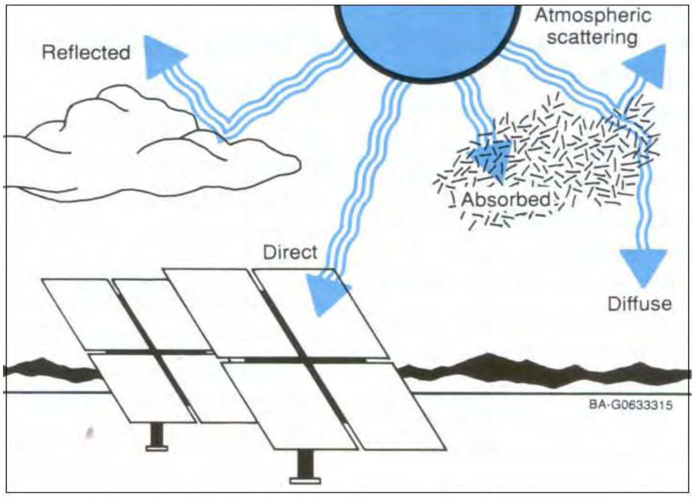

Figure 1. 1: How solar PV generates energy from the sun

However, solar photovoltaic (PV) energy is one of among renewable sources that promising the alternatives for the composition of a new energy in the world nowadays. It is expected that solar photovoltaic (PV) will be the important of renewable energy sources to the world until 2040 [9] . The conversion of solar energy to electrical energy shows that PV cells have better efficiency, longer lifespan and cheaper than others.

1.1 Motivation

Solar photovoltaic (PV) has set foot in Malaysia since 1980s with the purpose of providing electricity to rural areas. In 1998, an initiative given by Tenaga Nasional Berhad (TNB) to set up the grid connected PV system for national power utility which was inspired by the success of Japanese Sunshine Programs [6]. Solar Photovoltaic (PV) system is one of the most numerous throughout the Earth's surface and very simple of implementations. However, to ensure the system efficient, secure and environmentally sustainable supplies energy, Malaysia was developed National Energy Policy in 1979.

National Energy Policy was developed with long term objectives and guidelines to ensure efficient, secure and clean supplies energy. Not just that, it is the main policy in Malaysia in governs energy sector under Prime Minister's Department [7]. Development of national energy policy has opened up advantages of opportunities to renewable energy conservation. This growth enables of secure, affordable and reliable electricity sector in Malaysia.

However, National Renewable Energy Policy and Action Plan (2009) have a vision to enhance the utilization of indigenous renewable energy resources to contribute towards national electricity supply and sustainable socioeconomic development in Malaysia. By then, it has attracted many users towards renewable energy especially solar photovoltaic energy. Besides that, the Feed-in Tariff (FiT) has been implementing by Sustainable Energy Development Authority (SEDA) set quality prices for electricity generated from the renewable sources. It is crucial in ensuring the Mechanism Fit-in Tariff successfully implemented in Malaysia. Among of the main function of SEDA are to encourages and implementation of national policies for renewable energy. SEDA also monitor and review the Feed-in Tariff system so that it is compatible with the requirements of time and economy.

The introduction of Feed-in Tariff mechanism gives a good investment of renewable energy by the private sector or individuals. SEDA will constantly monitor the progress of each developer to make sure their project successfully. Figure 1.2 shows the fixed rate to the electricity for community for every kilowatt hour (kWh) of electricity generated and exported to the grid. The rate is provided under Fit as an incentive to the community to join of renewable green and clean energy. This rate is provided at a premium over the electricity rate that TNB (Tenaga Nasional Bhd) will pay for it according the latest rate. TNB will pay the current price for each day.

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)
(a) Basic FiT rates having installed capacity of :	01-JAN-2016
(i) up to and including 4kW	0.8249
(ii) above 4kW and up to and including 24kW	0.8048
(iii) above 24kW and up to and including 72kW	0.6139
(i) up to and including 4kW	0.9166
(ii) above 4kW and up to and including 24kW	0.8942
(iii) above 24kW and up to and including 72kW	0.7646
(i) up to and including 4kW	0.9166
(ii) above 4kW and up to and including 24kW	0.8942
(iii) above 24kW and up to and including 72kW	0.7222
(i) up to and including 4kW	1.0184
(ii) above 4kW and up to and including 24kW	0.9936

Figure 1. 2: Fit rates for Solar PV (community) by SEDA [7]

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For example, the seller generates a power of 4kW for every day while the current price according to FiT is 0.8249 RM/kWh and according to a study by the SEDA, an average “peak sun hours” ranging about 4-6 hours per day for good production and t is average about 5 hours per day only. So it will be calculated as the following:

Power generate = 4kW

Current rate RM/kWh = RM 0.8249

Peak Sun Hours = 5 hours

= (Power generate x Rate RM/kWh x Peak Sun Hour)

$1 \text{ kW} \times 4 \times 0.8249 \text{ RM/kWh} \times 5\text{h} = \text{RM } 16.498/\text{ day}$

So, for 30 day it will be RM 16.498 X 30 = RM 494.94/month

Since the FiT rate is higher than normally rate of electricity of TNB, it makes senses that this is a good investment since we can make some profit of selling the electricity generated from our PV panels to TNB.

1.2 Problem Statement

Inverter efficiency is one of the elements that have a crucial influence on the Performance Ratio of Photovoltaic (PV) plant and System Yield (S.Y) calculation to predict the Return of Investment for install PV. It can be simply that the higher the efficiency of the Photovoltaic (PV) inverters, the higher the Performance Ratio (P.R). The performance ratio is used commonly to access the quality installation on a daily, monthly or annually reported. It can be expressed in percentage by using this formula:

$$PR = \frac{Y_F}{Y_R} \tag{1.1}$$

While for the System yield, it is calculated by the following equation:

$$\mathrm{SY} = \mathrm{P_{array}} \times \mathrm{PSH_{period}} \times \text{No of Days} \times \text{Error} \times \mathrm{n_{inv}} \tag{1.2}$$

Where,

SY= PV yield of system (kWh)

Parray = power of the inverter

PSH_{period} = PSH value for the for the specified tilt angle over the period of interest

n_{inv}= inverter efficiency

The equation above shows that, inaccurate inverter efficiency value use will lead to inaccurate system yield, hence lead to misleading Return on Investment hence reduce the customer profit. Estimating the performance is very important to ensure the shortest Return on Investment (ROI). So, to ensure the shortest return-on-investment (ROI) as well as extending the lifetime of the system in good condition, estimating of the system performance is crucial and need to be considered [13]. The validity of existing efficiency formula is not accurate and not every country can use that formula. It is important because each country is very wide and there diverse climates between the states [9].

Furthermore, general rule of thumb in Europe where even 1% difference in inverter efficiency will lead 10% difference in price of Photovoltaic (PV) inverters. Even small differences of efficiency, it has a very large impact on the current price and at the same time affects the buyers [11]. For example, an inverter A with efficiency 94% would need to be 20% cheaper than inverter B with efficiency 96%. Its mean if inverter B cost about RM 10000, so inverter A should be RM 8000 only.

Besides that, different climate produce the different irradiation reading [12]. Climate determines the rate of degradation of the panel and the effect of temperature on efficiency. Also, Irradiation profile benchmark to irradiation region such as Europe regarded as benchmark for countries with medium irradiation level whereas California is regarded as benchmark for countries with high irradiance level. But there is no benchmarking yet for tropical climate. Thus, tropical climate should have its own PV inverter weighted efficiency equation. Since that climatic condition is known to have an effect on PV system performance, the research could be done in tropical climate.

1.3 Objectives

i. To determine the weighted efficiency equation of SB3000HF inverter by using a conventional method i.e. IEC 61683 standards as guideline.

ii. To determine the weighted efficiency equation of SB3000HF inverter by using an alternative scientific approach i.e. Multiple Linear Regression method.

iii. To compare the accuracy of the alternative with the conventional method

1.4 Scope

i. The inverter under study will only involve with the SB300HF.

ii. The raw data of irradiance for the simulation work will be gathered from UTeM's dedicated weather station from January 2014 to December 2014 of 5 minute sampling size.

iii. The Multiple Linear Regression method will be implemented by using MATLAB software.

iv. The accuracy of the alternative and conventional approach will be compared with R square method.

CHAPTER 2

LITERATURE REVIEW

2.1 PV System Configurations

There are two main configurations of PV system which are Grid-Connected Photovoltaic (GCPV) and Stand-Alone Photovoltaic (SAPV). Both configurations have their advantage and disadvantage in their application and uses. However, Stand-Alone Photovoltaic (SAPV) is preferable to be installed at rural area and in developing countries where the population is scattered. This system used the batteries and not connected to the power grid to store the power that generate by solar panel. In general, this system is an independent system and cannot maintain the energy supply when there is no enough sunlight unless energy storage is used. This system is much expansive than grid connected system since it used batteries.

While the Grid connected photovoltaic (GCPV) power system is actually a photovoltaic (PV) system which is connected to a utility grid. However, it is connected and supply power to a large independent grid. The panel of the grid is connected to inverter and main distribution for a complete system. Figure 2.1 shows the grid connected PV power system. In China, the solar PV will play as important role in power generation for their future energy supplied [13]. Grid-connected PV system usually applied conventional grid electricity is readily available in town or urban area [14]. There are two main types that related in grid connected photovoltaic system which are building integrated PV (BIPV) systems and terrestrial PV system. The generated electric power must be consumed within milliseconds of being generated at the scale of the entire interconnected electric power grid Not just that, GCPV system continued to be fastest growing in technology which is able to generate power with a 55% increase in cumulative installed capacity from 2.0 GW in 2004 to 3.1 GW [13].

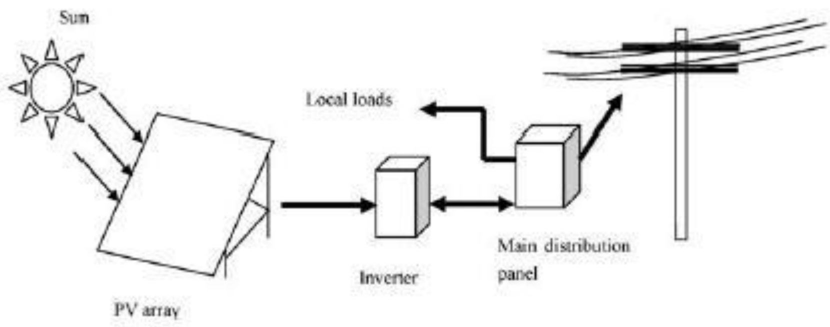

Figure 2. 1: Grid Connected PV power system [13]

Basically, grid-connected photovoltaic systems do not require battery system because it is connected to the grids which absorb the excess of electricity generated by the photovoltaic and export the electricity to the needed. Figure 2.2 shows the basic component of a grid-connected Photovoltaic (PV) system includes solar modules, metering, inverter and utility grid. The basic component of a grid-connected Photovoltaic (PV) system includes solar modules, metering, inverter and utility grid. Table 2.1 below shows the function of each component for GCPV system.

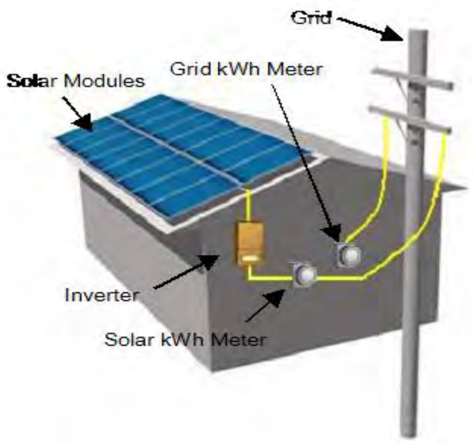

Figure 2. 2: The basic schematic GCPV system [15]

Table 2. 1: Specifications the basic component of the GCPV system

Component	Function
Solar photovoltaic Modules	Installed on the rooftop to generate DC power from sunlight
Inverter	DC power from the solar photovoltaic sent to the inverter and it is convert to alternating current (AC)
Metering	To record and monitor the PV electricity generated
Utility Grid	As interconnected network for delivering electricity from the supplier.

In general, the grid-connected Photovoltaic (PV) system can be categorized into two types which are Central grid connected PV system and Distributed grid PV system. The central grid system works when a large PV array is directly connected to the transmission line [14]. The range of this system installation can be as small as 50kWp up to 60MWp which has been succeed installed in Europe in recent years.

While distributed grid PV system is the system which is distributed through electricity grid. There are two types of distributed grid PV system which are commercial and residential system. Commercial system usually used more than 10kWp refers to those installed on factories, shopping centre and hospital and it is no excess power. While average residential is typically in range 4kWp – 5kWp refer to that installation on the rooftop. Basically, residential system is usually constructed as a Building Integrated Photovoltaic (BIPV) system because the PV modules is install as a part of the building itself. Moreover, GCPV system is a fastest technology in generating power with a 55% increase in cumulative installed capacity [13]

2.1.1 GCPV Inverter

Inverter technology is a key technology in which it has a security grid PV system. Inverter used to generate high-quality power to ac power with the low cost and it is a device which converts DC electrical energy into AC electrical energy [10]. The voltage generated from Photovoltaic (PV) array which is DC power is converted into AC power by using an inverter before delivered to the utility grid [16][14]. Inverter plays an important role in solar photovoltaic system. Hence, the inverters which used for GCPV system are diverse from other inverter that used in standalone PV system. It is also vary the output to match and synchronize with the utility AC, voltage and frequency. Besides that, output power from PV is varies according the meteorology of that location [17]. The grid inverter is different from a typical inverter because current drawn from the inverter is delivered to the utility at unity power factor [16]. Figure 2.3 shows the Grid connected photovoltaic solar inverter.

Figure 2.3: Grid-connected Photovoltaic inverter.

Also, there are four structure topologies of the inverter for Grid connected PV system which are module inverter, string inverter, multi-string inverter and central inverter. Therefore, module inverter is connected to the utility grid where an AC module consisting of single solar PV panel. This module removes the mismatch losses between PV modules and provides the optimal adjustment between the PV module and inverter. The second is string inverter where a single PV string is coupled to an inverter. This topology has minimum losses as well as increased of energy yield. Then, the multi-string inverters where several string are interfaced with their own DC-DC converter to a common DC-AC inverter. Next, the central inverter topology that where it is interfaced to a large PV array to the utility grid. The central topology was proposed as PV power conversion solution for large scale PV power plants [8].

Generally, grid connected PV system have two types of system which are those with transformer and without transformer. The transformer is used for stepping up or stepping down the voltage in the system. It is also providing the galvanic isolation for safety purpose. Without the galvanic isolation, a direct path can be formed for the leakage current to flow from PV to the grid. However, the use of transformer will reduces the efficiency of the entire PV system [18].

Nevertheless, the electrical transformer and inverters transformer perform the similar functions. Inverters usually include a modified transformer in their design. Based on the galvanic isolation, grid-connected photovoltaic (PV) inverter can be categorized into three types in terms of topologies which are Low Frequency transformer, High Frequency transformer and Transformerless. However, this inverter is factorized by different range of maximum efficiency as the following in Table 2.2 below.

Table 2. 2: Range of maximum efficiency between three topologies

Topology	**Maximum Efficiency**
Low Frequency transformer	< 95%
High Frequency transformer	95% - 96%
Transformerless	> 96%

For Low Frequency Transformer is used to step up the voltage and match grid-controlled inverters with the grid. This type of inverter is easily identified by their large size and weight. This type of transformer is cheaper and low frequency compared to High frequency and Transformerless frequency. However, the Low Frequency transformer has the matured energy since it has been used for long time. The transformer proposes the galvanic isolation between AC and DC sides for better protection [19]. The transformer used to overcome the limitation of input voltage. The disadvantage of this system is the losses in the transformer and bulky [20]. Figure 2.4 show the circuit diagram for low transformer inverter.

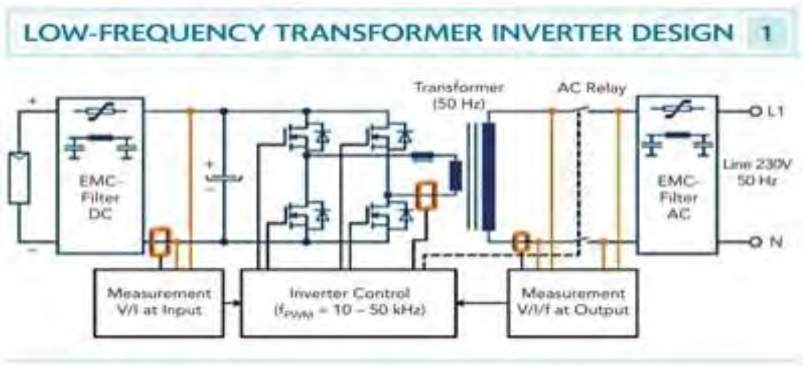

Figure 2.4: Inverter with low frequency transformer [21]

While for High Frequency Transformer is less power losses, small in size and also less expansive but have more complex circuitry circuit compared to Low Frequency transformer. The Figure 2.5 shows the transformer is located in boost chopper circuit. Even though the circuitry complex, it will be lighter because it has the smaller transformer inside the circuit and normally used for thin film panel

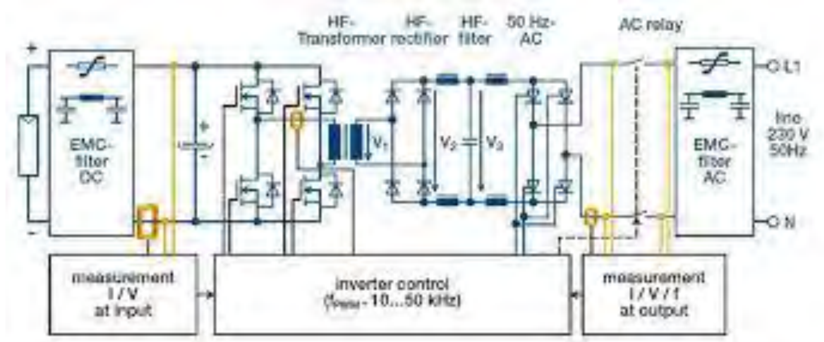

Figure 2.5: Inverter with High Frequency transformer [21]

Lastly, the transfomerless which has been chosen as the better one because of its advantages of higher efficiency compared with ones with transformer and no losses between the transformers. However, their safety issues need to be considering where there is no isolation between DC and AC sides of the inverter. Besides that, the leakage current needs to be addressed carefully for the safety [5][22]. It is also widely used in low-power photovoltaic (PV) grid connected system because the sizes are quite small and lighter. However, this type of inverter is quite expansive compared to Low Frequency transformer and High Frequency transformer.

The differences between Low Frequency and High Frequency transformer with the transformerless relate to the efficiencies, size, and functionality. Generally, the standard of inverter with the transformer operates at about 90% to 95% of efficiency. However, the transformerless with no transformer was operates at 98% of efficiency [20].

As the conclusion, transformeless is the best due its higher efficiency and the inverter becomes more compact and affordable without transformer. Besides that, it is also make marginally stronger electromagnetic fields than transformer-based inverters.

Table 2. 3: Comparison between three topologies with different features

No	Brand	Capacity	Topology	Maximum Efficiency	Weight
1	SB 3000TL	3200 W	Transformeless	97%	18 kg
2	SB 3000HF-30	3150 W	High Frequency Transformer	96%	26 kg
3	SB 3000LF	3200 W	Low Frequency Transformer	95%	32 kg

2.2 PV System

PV systems are made up of several solar modules with additional of a power converter to convert the DC power produce by the panels into AC electricity. Photovoltaic (PV) effect is the process of converting lights which is photons to electricity voltage. PV system are categorized into two which are grid-connected and stand alone system. However, solar energy of PV system is predicted as the biggest sources to generate electricity up to 60% of the total energy among of the other renewable energy. The principal reason for this is that the energy which converted into electrical energy from the sunlight is free, unlimited sources and available everywhere. Nevertheless, the PV system operation is low cost and do not produce noise.

On top of that, the Photovoltaic (PV) is a technology involving the direct conversion of solar radiation into electricity using solar cells. Therefore, PV is made up from the semiconductor material where the electricity is produced by conversion of photon. Usually, PV modules are made up from semiconductor material which is silicon. Besides, PV system has advanced materials of technology building which is more environmentally responsible [23] . There are several applications for PV system was already widely used nowadays. These are listed in the table below:

Table 2. 4: Typical applications of photovoltaic technology

Users	**Typical Application**
Phone Network Operators	Mobile phone local transmitters Telecoms repeater stations
Domestic Buildings	Lighting and generate power
Industrial Building	Lighting, general power and process equipment
Met Office	Weather stations

2.2.1 PV Inverter Efficiency

Figure 2.6 show the type of inverter efficiency which is has two branches which are Conversion efficiency and MPPT efficiency. However, conversion efficiency has two types which are Peak efficiency and weighted efficiency. Meanwhile, MPPT efficiency is divided into the static and dynamic conditions.

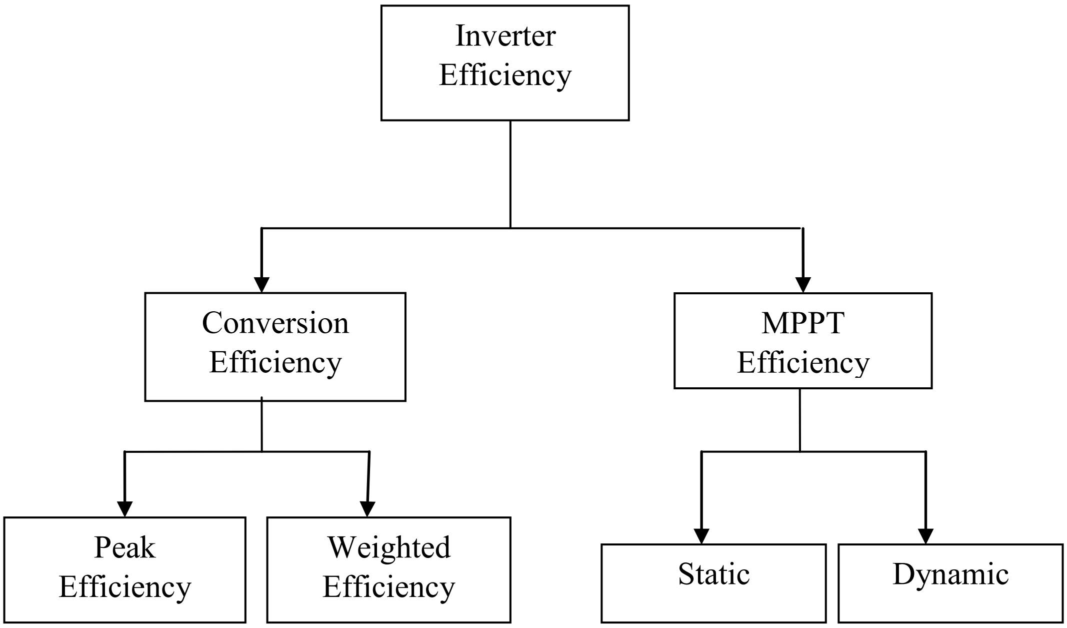

Figure 2.6: Inverter Efficiency breakdown structure

Conversion efficiency is the ratio of AC energy delivered to the DC energy input within a defined measuring period [24]. It is also depends under fluctuating over the input power of inverter. For conversion efficiency only weighted efficiency is considered because peak efficiency is not reliable to use. Peak efficiency refers to the ratio of output power over input power, (P_{out}/P_{in}) when the inverter is at its most ideal condition, i.e at Standard Test Condition (STC). STC refers to a condition where G = 1000 W/m^2 and Temperature = 25°C. This condition is rarely achieved; therefore peak efficiency is not the most reliable indicator performance [25]. Hence, more practical methods that can be use to give performance inverter is weighted conversion efficiency equation as described in IEC 61683 standard.

2.2.2 Weighted Efficiency

Weighted efficiency is introduced in order to standardize comparison between the inverters based on their efficiencies [26]. Weighted efficiency is calculated as the sum of the products of each power level efficiency and related weighting coefficient which are based on irradiance profile of related region [27]. In 1992, north-western Germany has been introduced the first weighted efficiency which is focused to the effect of irradiation outline on the inverter efficiency [28]. The method to determine weighted efficiency equation is based on IEC 61683 standards are described below.

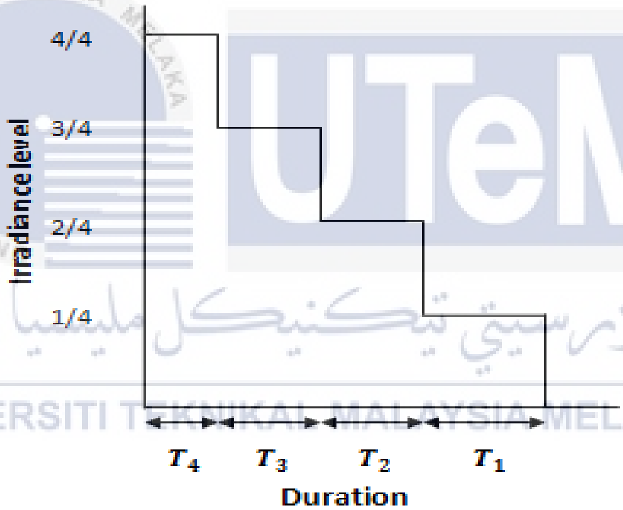

Figure 2. 7: Irradiance duration curve [27]

Figure 2. *7* above show how to develop weighted efficiency formula from the irradiance duration curve. The following formula as shown below:

$$n_{WT} = \frac{1T_1}{T_{WT}} n_{1/4} + \frac{2T_2}{T_{WT}} n_{2/4} + \frac{3T_3}{T_{WT}} n_{3/4} + \frac{4T_4}{T_{WT}} n_{4/4} \qquad (2.1)$$

Therefore the equation will consist of four elements by referring the equation, the first element of the equation means that the ratio of the irradiance of the first section will be multiplied by the efficiency reading of the inverter when it is operating at a 1/4 of its rated power.

Meanwhile, the second element of the equation means the ratio of the irradiance for second section will be multiplied by the efficiency reading of the inverter when it is operating at 2/4 of its rated power.

Then, the third element of the equation means the ratio of the irradiance for third section will be multiplied by the efficiency reading of the inverter when it is operating at 3/4 of its rated power.

Lastly, the fourth elements of the equation means the ratio of the irradiance for the fourth section will be multiplied by the efficiency reading of the inverter when it is operating at 4/4 of its rated power.

Therefore, the total weighted coefficient i.e. $T_{WT} = 1T_1 + 2T_1 + 3T_3 + 4T_4$ will be equal to 1. Hence, from the equation, in 1990 a weighted conversion efficiency factor was introduced by Dr. Rolf Hotopp and it is called as 'European Efficiency' [12]. To calculate the European Efficiency, the following six efficiencies values of irradiance based on weighted mean is used.

a. European Efficiency:

The European weighted average was defined based on concept of the data analysis of weather condition in Central Europe.

$$n_{EU} = 0.03_{n5\%} + 0.06_{n10\%} + 0.13_{n20\%} + 0.1_{n30\%} + 0.48_{n50\%} + 0.2_{n100\%} \quad (2.2)$$

This efficiency equation was defined by the calculation of weighted mean of six values for the irradiance. European is referred as a benchmark for inverter characterization for medium irradiation region. According to the [29], the European efficiency has been tested based on weather conditions of various location in central Europe which are Austria, Switzerland, Poland and Germany.

b. CEC efficiency:

$$n_{CEC} = 0.04_{n10\%} + 0.05_{n20\%} + 0.12_{n30\%} + 0.21_{n50\%} + 0.53_{n75\%} + 0.05_{n100\%} \quad (2.3)$$

CEC efficiency also one of the conversion efficiency which is defined by the California Energy Commission [30] with the same manner of European efficiency. CEC is referred as a benchmark for inverter characterization for high irradiation region. The equation of CEC efficiency has an additional nominal point at 75% irradiance is used for 0.53 weighing factor. It is shows that 75% nominal point is highly overrated. Besides that, the weighting factor of 100% irradiance is too small.

In this project, an alternative method to calculate equation of efficiency calculation will also be suggested i.e. Multiple Linear regression technique as describe in the next section.

Therefore, Maximum Power Point Tracking (MPPT) efficiency is also one of the parts of inverter efficiency. The MPPT efficiency can be divided into the static and dynamic conditions which is specify the actual amount of the theoretically PV generator power will be used by the inverter [31].

The static MPPT efficiency is describing the ability of an inverter to operate the generator at the MPP under steady state whereas the dynamic MPPT efficiency describes the accuracy of inverter to operate the generator at the MPP in case of variable conditions [29]. However, for overall of this research is not covered the MPPT efficiency but it is only focus on the weighted efficiency to determine the weighted efficiency equation based on IEC 61683 standards.

Thus, overall efficiency can be defined as the combination between conversion efficiency and MPPT efficiency

2.3 Multiple Linear Regression

To provide an alternative method and to measures the efficiency equation, RSM was used. Response Surface Methodology (RSM) is the collection of statistical and mathematical which is useful for the empirical model building and analysis of programs [32][33]. The main objective of RSM is to obtain an optimal the response. There are four mathematical models which are Multiple Linear Regression, Pure Quadratic, Interactions, and Full Quadratic was used to predict the tropical efficiency equation based on IEC 61683.

Therefore, RSM was used to develop and approximate the response. The approximating model for response is referred based on observed data. In general, the true response function, f was not known and it is the most problem in the RSM. Theoretically, the first order model with single independent variable was defined as linear regression while when there were a more than two independent variable known as multiple linear regression. The equations are as followed:

a) Multiple Linear Regressions

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \epsilon \qquad (2.4)$$

b) Pure Quadratic

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1^2 + \beta_5 x_2^2 + \beta_6 x_3^2 + \varepsilon \qquad (2.5)$$

c) Interactions

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 + \beta_3 x_3 + \beta_{4_{x_1 x_2}} + \beta_{5_{x_1 x_3}} + \beta_{6_{x_2 x_3}} + \varepsilon \qquad (2.6)$$

d) Full Quadratic

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{4_{x_1 x_2}} + \beta_{5_{x_1 x_3}} + \beta_{6_{x_2 x_3}} + \beta_7 x_1^2 + \beta_8 x_2^2$$

$$+\beta_9 x_3^2 + \varepsilon \qquad (2.7)$$

The multiple linear regressions were used to study the relationship between the independent variable and dependent variable. The second order was used because it more flexible. Therefore, there are a few functions as Interactions, Pure Quadratic and Full Quadratic.

From all the equation above, it shows where y_i was represented as the output or target variable of the equations. Whereas, the independent input of x_1, x_2, x_3 will determine this equation. Besides that, β_0 until β_6 is a constant variable which is output values obtained from analysis of MATLAB.

The overall equation, the formula is almost same but with different order of the variable. The different order of variable will generate the different accuracy of output to the different target. However, from the four of mathematical models which are Multiple Linear Regression, Pure Quadratic, Interactions, and Full Quadratic, the best model will be choose based on value of R^2 and Root Mean Square Error (RMSE) with the lowest value or closest to zero [34].

The value of R^2 can be determining by using the following equation:

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y}_i)^2}{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{2.8}$$

Where $0 \leq R^2 \leq 1$, values of R^2 highest or closest to one was the best model to determine the alternative method for tropical efficiency [4].

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, there is a flow of steps and procedure that were developed in order to complete this project. It is focuses primarily on providing information with the techniques used in the study process. For the methodology of this research, the set of procedures and method had been determined to ensure the work plan in progress as the planned.

3.2 Flowchart

Flowchart is one of the research steps that show the progress of a project from the beginning until the project is completed.

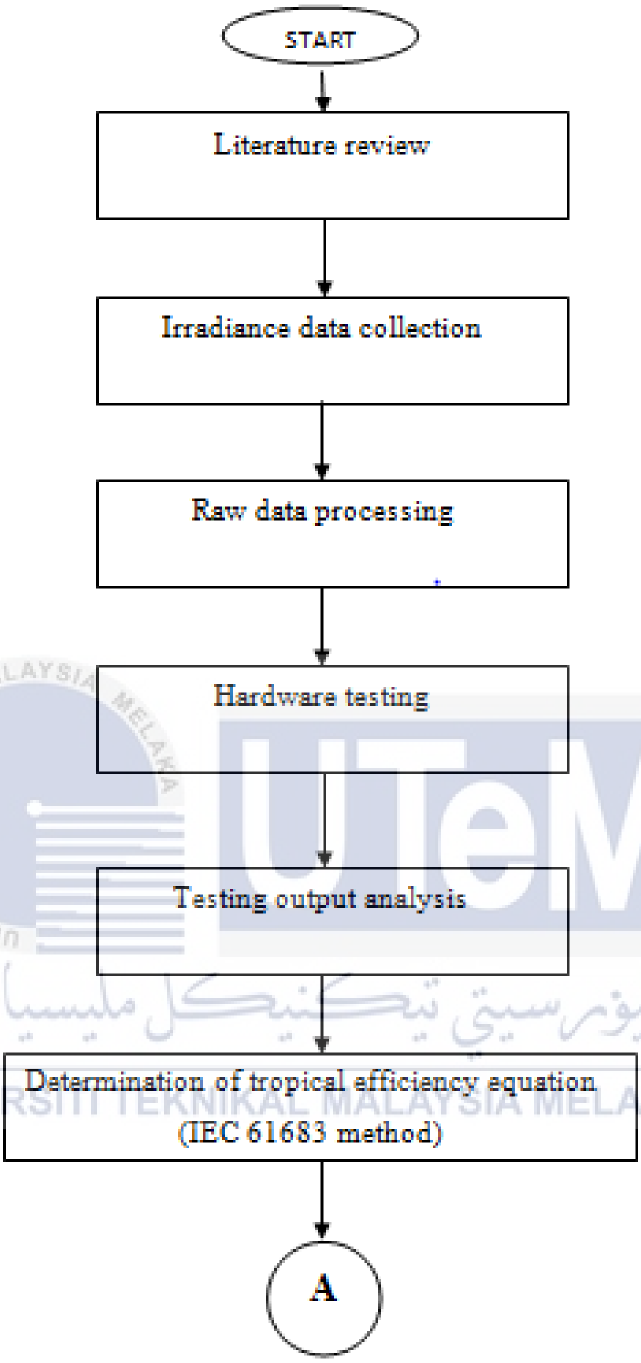

Figure 3. 1 (a): Flowchart of the project

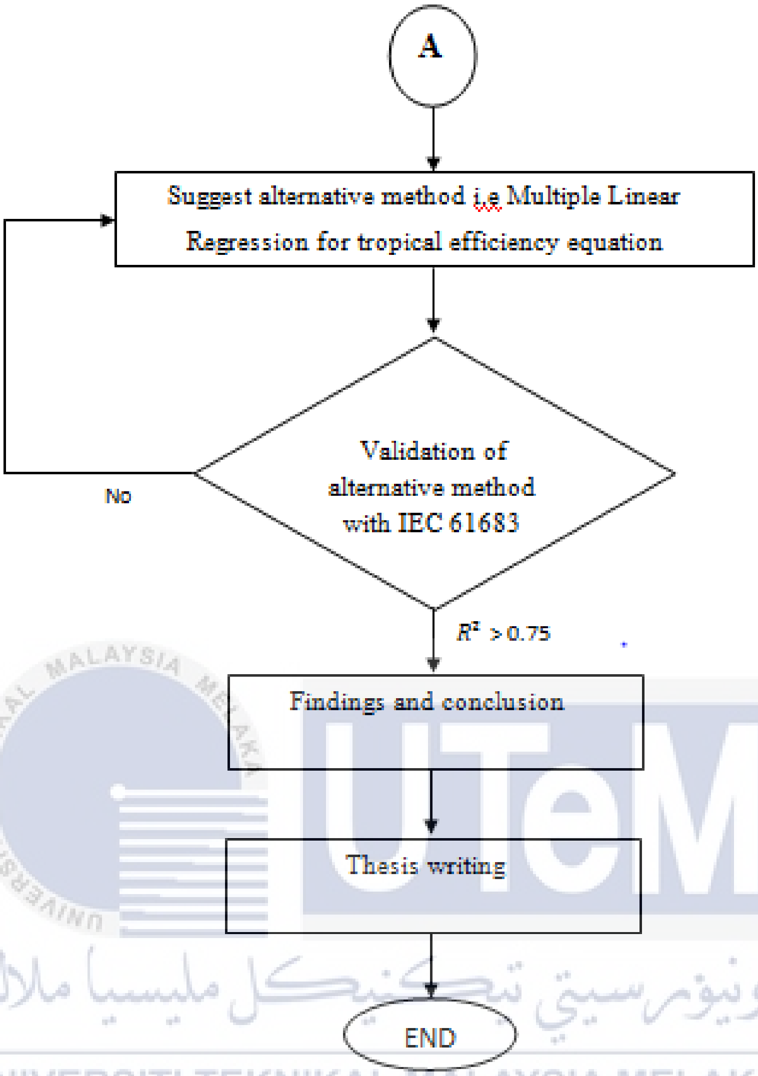

Figure 3. 2 (b): Flowchart of the project.

3.2.1 Literature Review

In this phase, it is focus the study on current of efficiency PV inverter and their equation for the tropical climate from the internet, journal, book and articles. Since the assumption and empirical research is used for the equation, a scientific approach with methodology is used to prove the equation. However, the purpose of this phase is to gain knowledge since it is crucial in order to develop the new equation of PV inverter for the tropical climate. This is due to through literature review; the important point could be identified.

3.2.2 Irradiance Data Collection

Second phase is irradiance data collection from UTem's weather substation for the simulation as shown in Figure 3. 3. The data gathered from January 2014 to December 2014 of 5 minute sampling size. A pyranometer in Figure 3. 4 were used to measure solar irradiance.

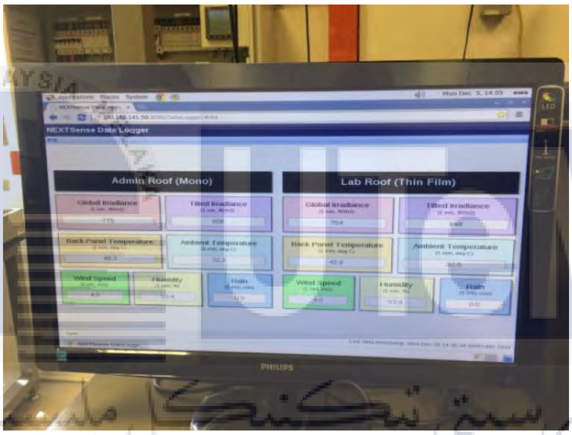

Figure 3. 3 :UTem's Weather Station Data Centre

Figure 3. 4: The pyranometer install at FKE building

3.2.3 Raw Data Processing

After that, based on the information gathered, a simple software (Microsoft Excel) is used to calculate the average the average for every month in year 2014. The data is presented in the curve shape to make it clearer.

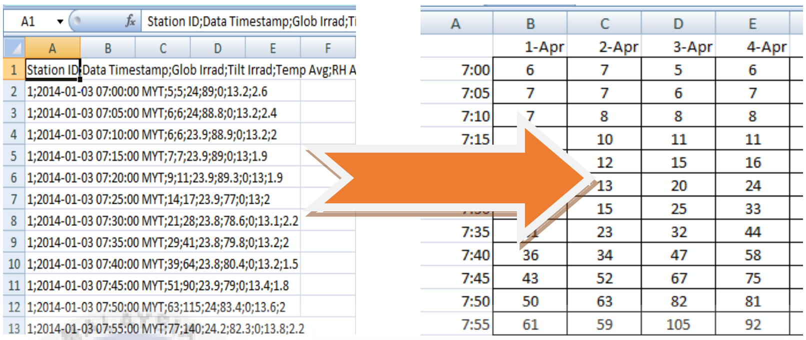

Figure 3. 5: The process of data by using Microsoft Excel

3.2.4 Hardware Testing

In this phase is hardware testing using DC/PV simulator. This testing will used the average data that have been calculate by using the Microsoft Excel as its input. The Figure 3. 6 shows the block diagram for the hardware testing that include the DC/PV simulator, power metering, and grid. The function of DC/PV simulator is to simulate the behaviour of solar module. The DC/PV simulator is connected to real PV inverter in this case of SB3000HF. The inverter works to convert the direct current (DC) power which is generated by photovoltaic (PV) panels into alternating current (AC) power to equivalent with the frequency and voltage of the grid. Then, the data of voltage and current was recorded by power meter. Lastly, the function of the grid and load is to emulate grid connected system.

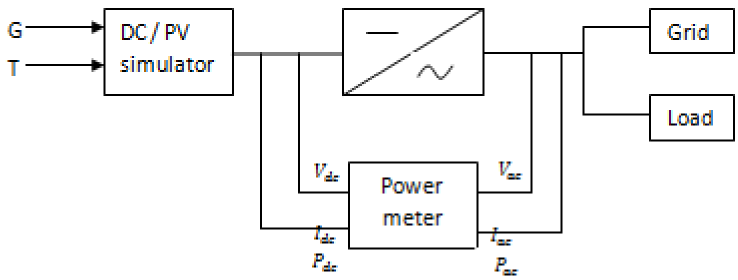

Figure 3. 6: Block diagram for hardware testing

3.2.5 Inverter under Test

3.2.5.1 Datasheet & Equipment

SB 3000HF-30	
Input (DC) Max. DC Power Max. DC Voltage Max. input current	 3150 W 700 V 15.0 A
Output (AC) Nominal AC power/max. AC power Max. output current	 3000 W / 3000 W 16.0 A
Efficiency Max. efficiency / Euro	 > 96% / > 95%

The Figure 3.7 shows the inverter SB3000HF which is High Frequency transformer that had been used for this study.

Figure 3. 7: SB3000HF inverter

3.2.5.2 Datasheet Pyranometer

Table 3. 1: Technical data of Pyranometer

Impedance	700 - 1500 Ohm
Tilt error	< 0.25% (beam 1000 W/m^2)
Operating Temperature	-40 C to 80 C
Sensitivity	Between 4 and 6 µV/ Wm^2
Irradiance	0-1400W/m^2 (max 4000 W/m^2)

Figure 3. 8: Pyranometer designed for measuring the irradiance.

3.2.6 Testing Output Analysis

Next phase is the testing output analysis by using MATLAB software. The output result from the hardware testing is used as the input variables for Multiple Linear Regression method by using MATLAB tool.

3.2.7 Determination of Tropical Efficiency Equation

This phase shows how to develop the tropical efficiency equation based on the IEC 61683 standard by using the output data of MATLAB. Besides that, the accuracy of the result will be compared to choose the best equation

3.2.8 Suggestion of Alternative Method

Based on the Response Surface methodology the suitable method for this research is using Multiple Linear Regression to produce the equation. This method is suggested because it s based on scientific and artificial intelligent approach, whereas the IEC 61683 is based on the statistic of the approach. The hypothetically this method should produce much simpler equation much compared to the IEC 61683 approach.

3.2.9 Validation of Alternative Method with IEC 61683

The verification method for tropical efficiency equation based on IEC 61683. The result from the IEC 61683 with the Multiple Linear Regression will be compared to determine the accuracy and correctness the alternative method.

3.2.10 Finding Conclusion

As the conclusion, it is predicted that the Multiple Linear Regression should produce a much simpler equation with and accuracy around 90%. Besides, the reading of tropical efficiency will be lower around 1% to 2% compared to European efficiency.

3.3 Gantt Chart

Table 3.1 shows the Gantt chart of overall final year project started from FYP 1 until FYP 2. Based on the timeline, literature review is most important task which is started from beginning until end of the project. Literature review is the fundamental part of research topic could be obtained. It is also the process of studying where the researcher to understand more on her research review.

However, in FYP 1 the focused is more on data collection and literature review in order to understand the fundamental of overall project. Meanwhile, FYP 2 was focused on the hardware testing to get the weighted equation result. Ten, the result was analyse and the thesis of the project was done.

Table 3. 2: The Gantt chart for FYP 1 and FYP 2

	PSM 1														PSM 2													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28
Briefing to the students	■																											
Selection of titles	■	■																										
Title registration and declaration		■																										
Meeting with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Identify objectives and problem of the research			■	■																								
Literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Data collection							■	■																				
Data processing									■	■	■																	
PSM 1 report							■	■	■	■	■	■	■	■														
Presentation of PSM 1														■														
Testing															■													
Analysis on the output of testing																■	■	■										
Findings and conclusion																		■	■	■	■	■						
Thesis writing																			■	■	■	■	■	■	■	■	■	
Submission report																											■	
Presentation report																												■

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

For this chapter, it is briefly explain about the data of irradiance that have been obtain gathered from UTeM's dedicated weather station from January 2014 to December 2014 of 5 minute sampling size. The result from this data collection will be proceed to FYP 2 and is used to determine the weighted efficiency equation for tropical climate

4.2 Preliminary Results

4.2.1 Yearly data collection

The Figure 4.1 until Figure 4.12 below shows the readings of irradiance from January until December 2014. The 5 minute intervals of irradiance reading were summed up for monthly average and then each monthly average of irradiance was average for one year. In fact, Malaysia is one of the countries that have high potential to apply Photovoltaic (PV) solar system due the climate and weather conditions. However, it is rarely to have full day with completely clear sky in Malaysia due to the cloudy day. The highest irradiance profile occurs in March with the reading more than 800 W/m^2 as shown in the Figure 4.3. This is because of hot and dry weather conditions have been usually experienced across the country in March. While the lowest reading of irradiance in September due to atmospheric dust scattering, clouds and haze and due to the current situation where Malaysia has been hit by a very severe haze that covered the cloud.

However, based on the Figure 4.13 the curve started increasing after 11:00 until its reach the peak reading then begins to decline from 14:30 until 19:00. The average of the irradiance shows in Figure 4.13 does not exceed to 1000 W/m^2 because the data were measured at five minutes interval. According to the global irradiance, when the skies are clear and the sun directly in line from the PV module, the irradiance will reach about 1000 W/m^2. However, the available radiation is usually lower than maximum value of global irradiance due to the rotation of earth and climate condition.

Anyhow, this study was testing the inverter under tropical climate i.e tropical irradiance and tropical temperature with constant at 2   C as suggested in BS EN 50530

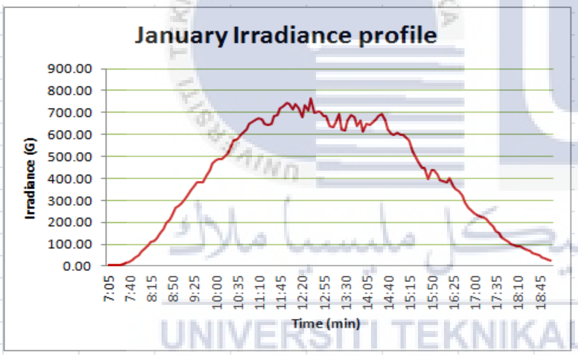

Figure 4. 1: Average data irradiance in January

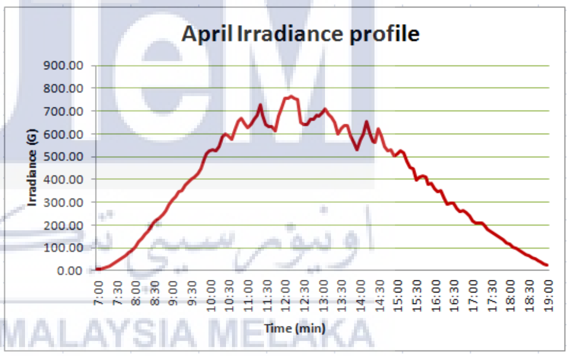

Figure 4. 2: Average data irradiance in April

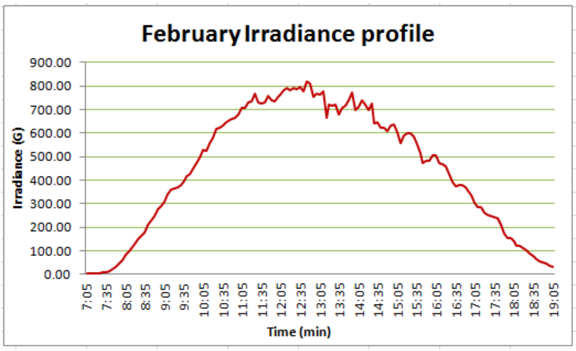

Figure 4. 3: Average data irradiance in February

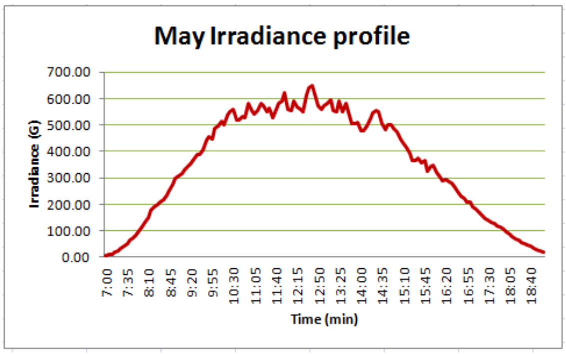

Figure 4. 4: Average data irradiance in May

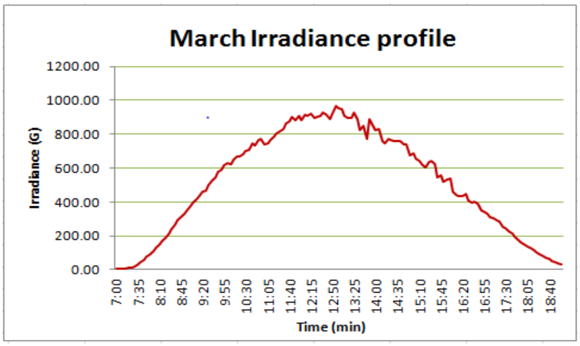

Figure 4. 5: Average data irradiance in March

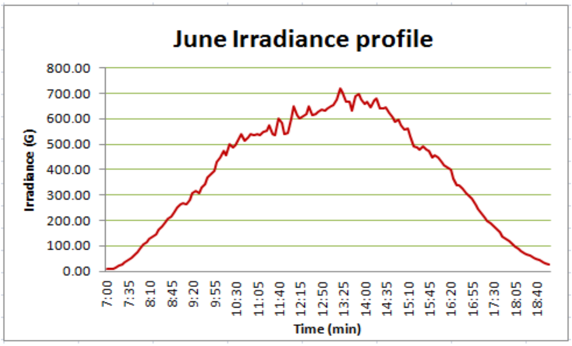

Figure 4. 6: Average data irradiance in June

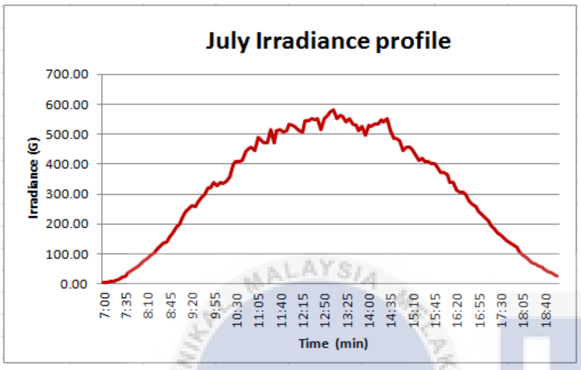

Figure 4. 7: Average data irradiance in July

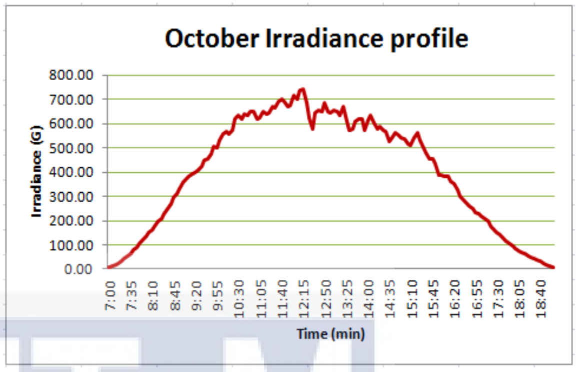

Figure 4. 8: Average data irradiance in October

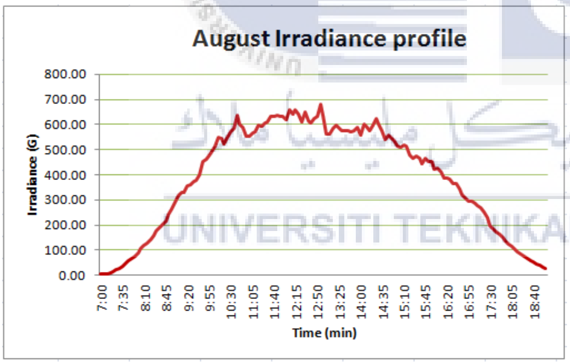

Figure 4. 9: Average data irradiance in August

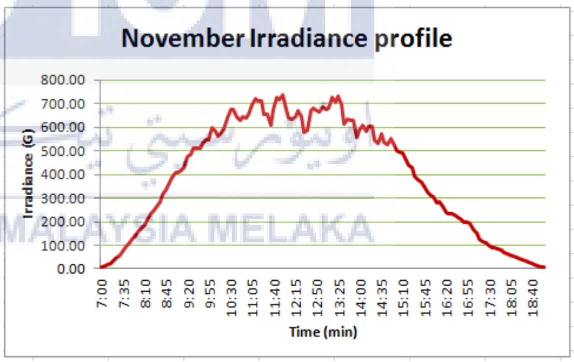

Figure 4. 10: Average data irradiance in November

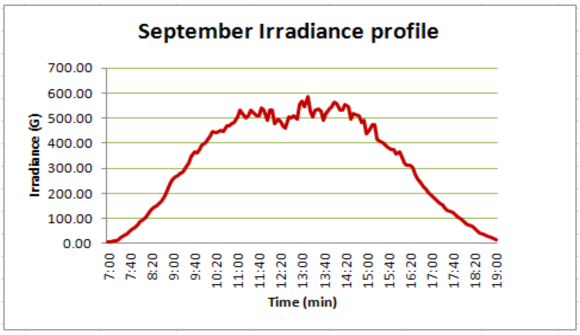

Figure 4. 11: Average data irradiance in September

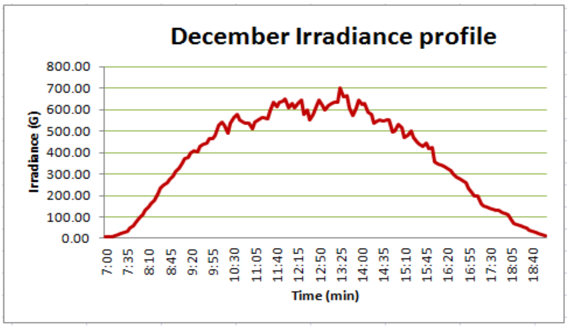

Figure 4. 12: Average data irradiance in December

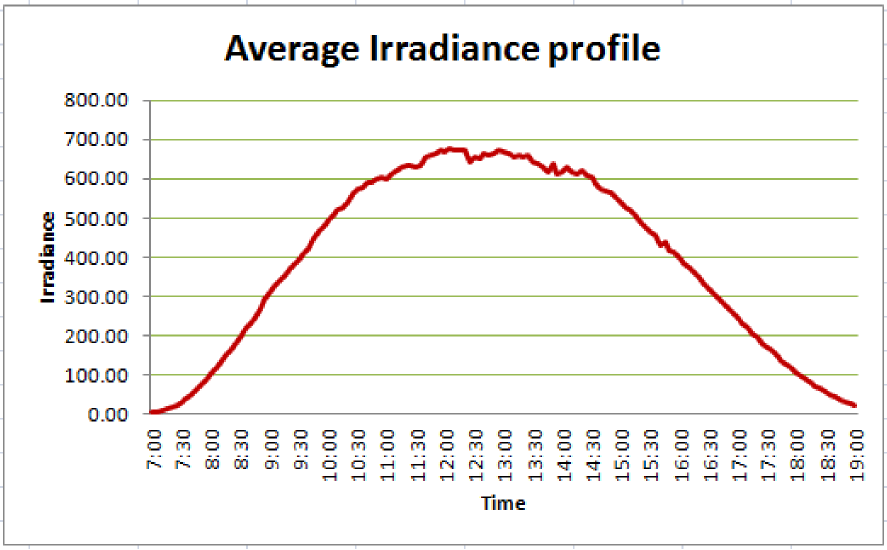

Figure 4. 13: Average of irradiance profile from January to December

4.3 Test Result

4.3.1 Result Experiment

Table 4. 1: The test result

Time	G	G/Gsum	Pin/Pin R	P1 [W]	P4 [W]	Efficiency
8:05	136.07282	0.00044	0.02274	30.49395	71.62456	0.42575
8:06	138.85058	0.00045	0.03292	64.54916	103.70150	0.62245
8:07	141.48223	0.00046	0.03678	88.85799	115.85050	0.76701
8:08	144.99846	0.00047	0.03788	96.61321	119.31670	0.80972
8:09	147.89782	0.00048	0.04009	103.74770	126.27990	0.82157
8:10	151.01000	0.00049	0.04253	111.34420	133.98220	0.83104
8:11	154.61032	0.00050	0.04478	118.43930	141.04700	0.83972
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
↓	↓	↓	↓	↓	↓	↓
17:56	84	0.000272	0.019243	39.7975	60.61493	0.656563
17:57	83	0.000267	0.012629	35.45927	39.78093	0.891364

Table 4.1 shows the result of the experiment that has been tested from UTeM's weather station. However, Table 4.1 shows the testing result with 6 difference outcome with G represent for irradiance, G/Gsum represent for irradiance over the total irradiance, Pin/Pin R represent for Pin over Pin rated, P1 represent for Pac and P4 represent for Pdc. The data start from 8:05 until 17:57 with 593 points of total data. This result is used to determine weighted for tropical efficiency equation. Then, the 593 points of the efficiency data have been categorized according to the range as shown in the table M below. The range of data is depending on the value of Pin/Pin R.

Table 4.2 : Nominal points and irradiance strength range according to Hotopp [12]

Nominal point	5%	10%	20%	30%	50%	100%
Range (Pin/ Pin R)	0%-7.5%	7.5%-15%	15%-25%	25%-40%	40%-75%	>75%

Figure 4.14 show the result after classification the number of point according to the range. It is illustrate that at 50% is the highest number of point which is 239/593. This is because most of the time the inverter operates at ranges 40% to 75% of its rated performance which force under 50% of nominal point. Whereas, the lowest number of point is at 10% which is 51 points. Not just that, at 5%, 20%, 30% and 100% are 59 points, 57 points, 81 points and 109 points respectively.

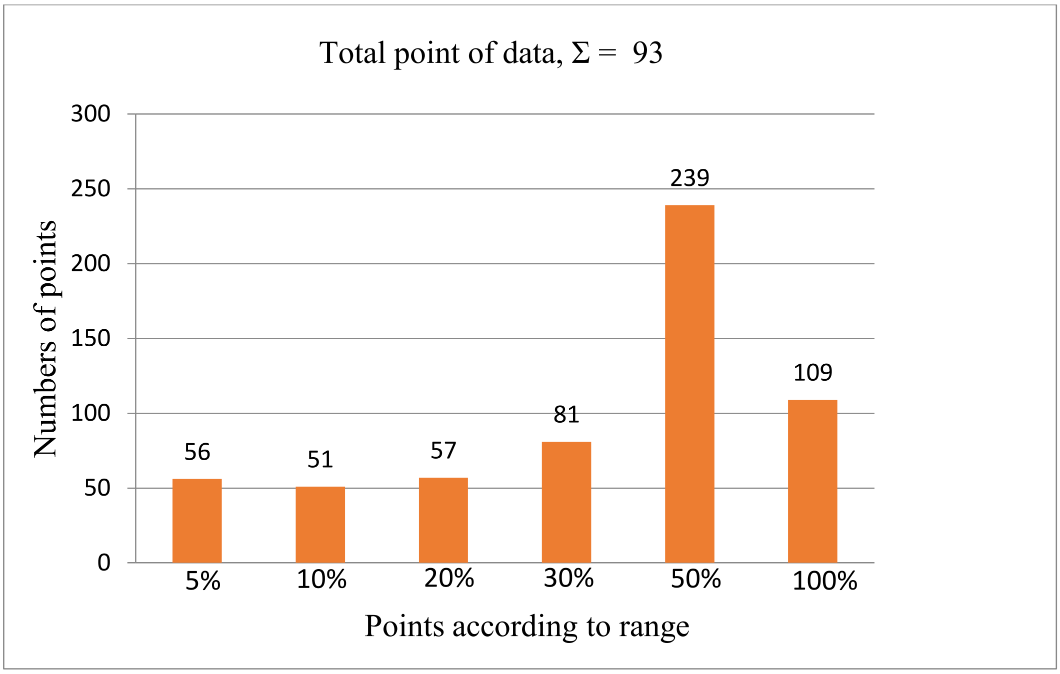

Figure 4. 14: Classification the number of point according to the range.

However, show the weighting factors for Tropical efficiency in terms of percentage. The figure illustrated that about 9% from 593 points is located in range (0%-7.5%) and (15%-25%) which are at 5% and 20% of nominal point respectively. Besides that, about 8% is into account range (7.5% - 15%) which is at 10% of nominal point. However, at 50% of nominal point in range (40%-75%) shows the highest percentage which is about 43% from 593 points. Not just that, for range (25%-40%) at 30% nominal point, there is 13% of 593 points while there is about 18% from 593 points at 100% of nominal points in range (>75%).

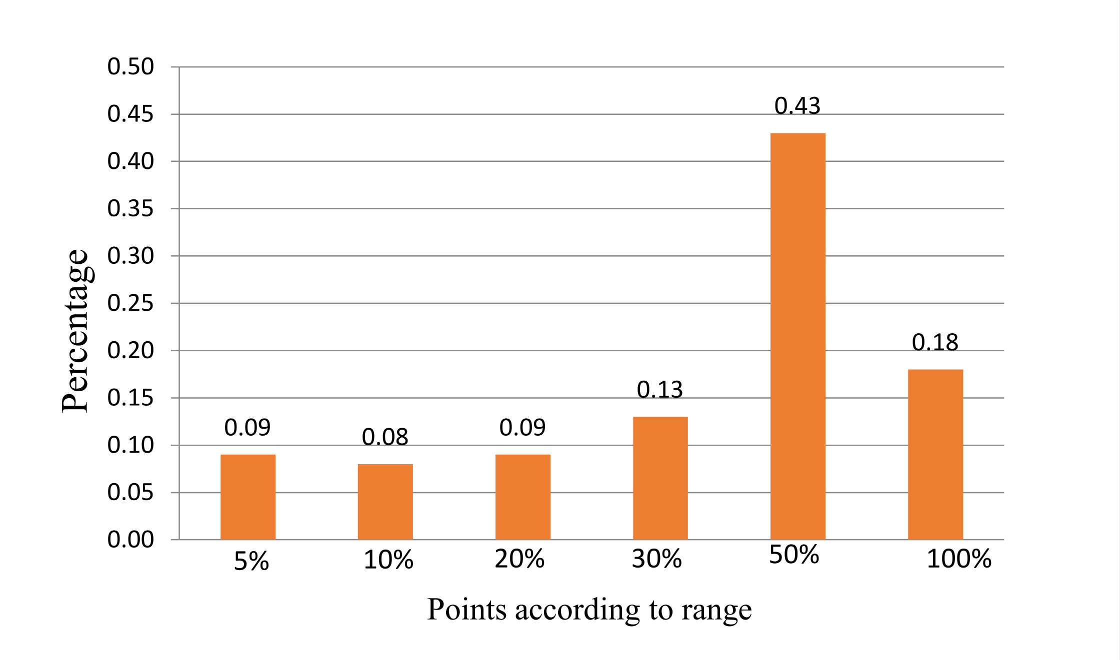

Figure 4. 15: Weighting factors for Tropical efficiency

From the result above, the tropical efficiency was calculated by using the following weighting factors as shown below:

Tropical efficiency = [0.09 x n5%] + [0.08 x n10%] + [0.09 x n20%] + [0.13 x n30%] + [0.43 x n50%] + [0.18 x n100%] (4.1)

Through the experiment, the inverter gives an efficiency reading of 0.09% when operating at 5% of its rated power, 0.08% at 10% of its rated operation, and 0.09% at 20% of its rated power, 0.13% at 30% of its rated power, 0.43% at 50% of its rated power and 0.18% at 100% of its rated power. Hence, the overall weighted tropical efficiency can be determined as in equation below:

Tropical efficiency = [0.09 x 81.83] + [0.08 x 92.45] + [0.09 x 94.84] + [0.13 x 95.8] + [0.43 x 95.97] + [0.18 x 95.77] (4.2)

Thus, after the calculation it shows that the topical efficiency is 94.256%. Anyhow, Table 4.3 shows the difference of the weighted between Euro efficiency and Tropical efficiency.

Table 4. 3: Difference between Euro efficiency and Tropical efficiency

	5%	**10%**	**20%**	**30%**	**50%**	**100%**
Euro	0.03	0.06	0.13	0.1	0.48	0.2
Tropical	0.09	0.08	0.09	0.13	0.43	0.18
Difference	0.06	0.02	0.04	0.03	0.05	0.02

The Table 4.3 shows the differences of the weighted efficiency between Euro and Tropical efficiency. The difference of its weighted is due to the difference in terms of profile irradiance for Euro and Tropical efficiency. Hence, the difference of weighted produces the difference efficiency.

4.3.2 Validation Result

For the validation part, there are 3 types of efficiency is used which were Euro efficiency, Tropical efficiency, and Peak efficiency. The efficiencies were compared by year, month and week.

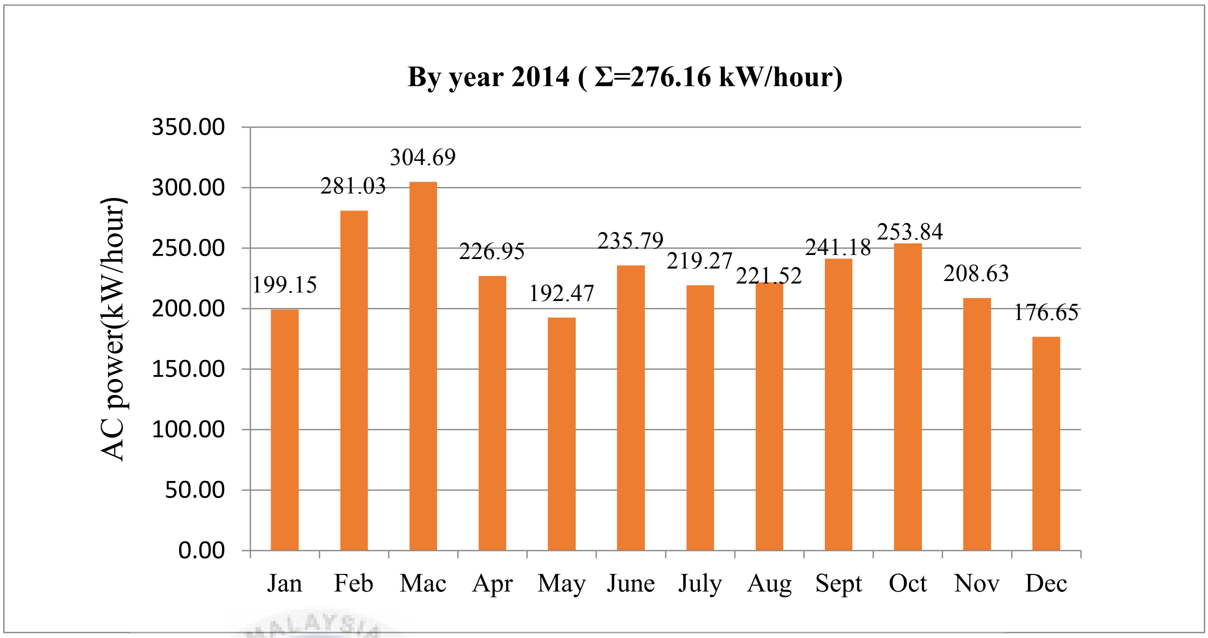

Figure 4. 16: Real value of AC power inverter from January to December in year 2014

Table 4. 4: System Yield calculation for year 2014

Table year 2014 (SYreal = 2761.16 kW/h)			
Type of efficiency	AC power value by calculation (kW/hour)	Difference with real (kW/hour)	Difference with real (%)
Peak	2834.70	73.55	2.66
Euro	2802.39	41.23	1.49
Tropical	2770.08	8.92	0.32

The bar chart illustrates the real value of AC power of inverter from January to December in year 2014 as shown in Figure 4.16. It is measured in kilowatt per hour. It can be seen that the highest AC power value is 304.69 kW/h for the month of March because of hot and dry weather conditions have been usually experienced across the country in March. However, the lowest is 176.649 kW/hour for the month of December which is in the wet North-East monsoon season and might be due to rain and higher air mass. The average of AC power for year 2014 is quite constant which 230.096 kW/h is. Meanwhile, the yearly system yield real value for 2014 is SYreal = 2761.16 kW/h.

However, for validation purpose, the value of System Yield has been calculated by using equation (1.2). The result of the calculation is shown in Table 4.3 where Peak efficiency, Euro efficiency, and Tropical efficiency are 2834.70 kW/h, 2802.39 kW/h and 2770.08 kW/h respectively. From the comparison between the real and calculation value, Peak efficiency has the highest difference with real which is 73.55 kW/h (2.66%) and Tropical efficiency has smaller difference which is only 8.92 kW/h (0.32%). Thus, the tropical efficiency is the most acceptable efficiency for validation because its value is nearer to the real value.

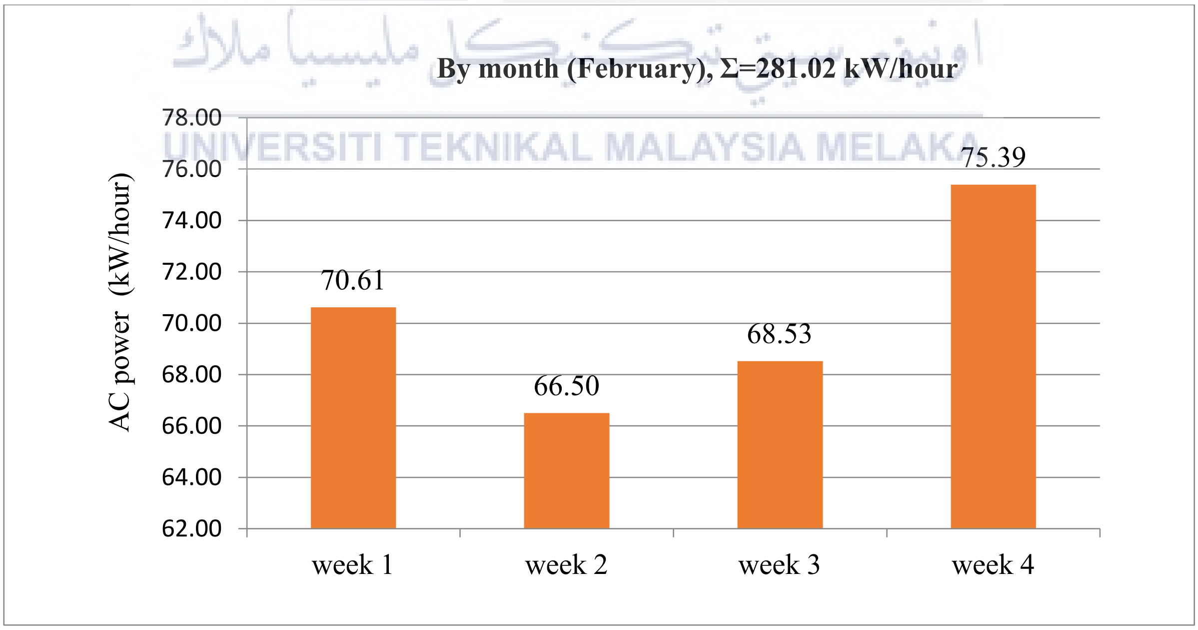

Figure 4. 17: Real value of AC power inverter in February 2014

Table 4. 5: System Yield calculation for February

Table month February (SYreal = 281.02kW/h)			
Type of efficiency (calculation)	AC power value by calculation (kW/hour)	Difference with real (kW/hour)	Difference with real (%)
Peak	286.72	5.691	2.03
Euro	283.45	2.423	0.86
Tropical	280.18	0.845	0.30

Then, this validation also compares the value between calculation and real value for every month. Figure 4.17 shows the real value of AC power in February from week 1 until week 4. The bar chart was recorded that week 4 has the highest AC power value which is 75.39 kW/h while week 2 66.50 kW/hour is the lowest value. However, the monthly system yield for February, SYreal_month is 281.02kW/h and the average value is 70.26 kW/h. The month of February was randomly chosen for this validation.

However, for validation purpose, the value of System Yield has been calculated by using equation (1.2). The result of the calculation is shown in Table 4.4 where Peak efficiency, Euro efficiency, and Tropical efficiency are 286.72 kW/h, 283.45 kW/h and 280.18 kW/h respectively. Hence, from the comparison between the real and calculation value, Peak efficiency has the highest difference with real AC power which is 5.691 kW/h (2.03%) and Tropical efficiency has smaller difference which is only 0.845 kW/h (0.30%). Thus, the tropical efficiency is the most acceptable efficiency for validation because its value is nearer to the real value. This proves that tropical efficiency is suitable to use and this validation is acceptable.

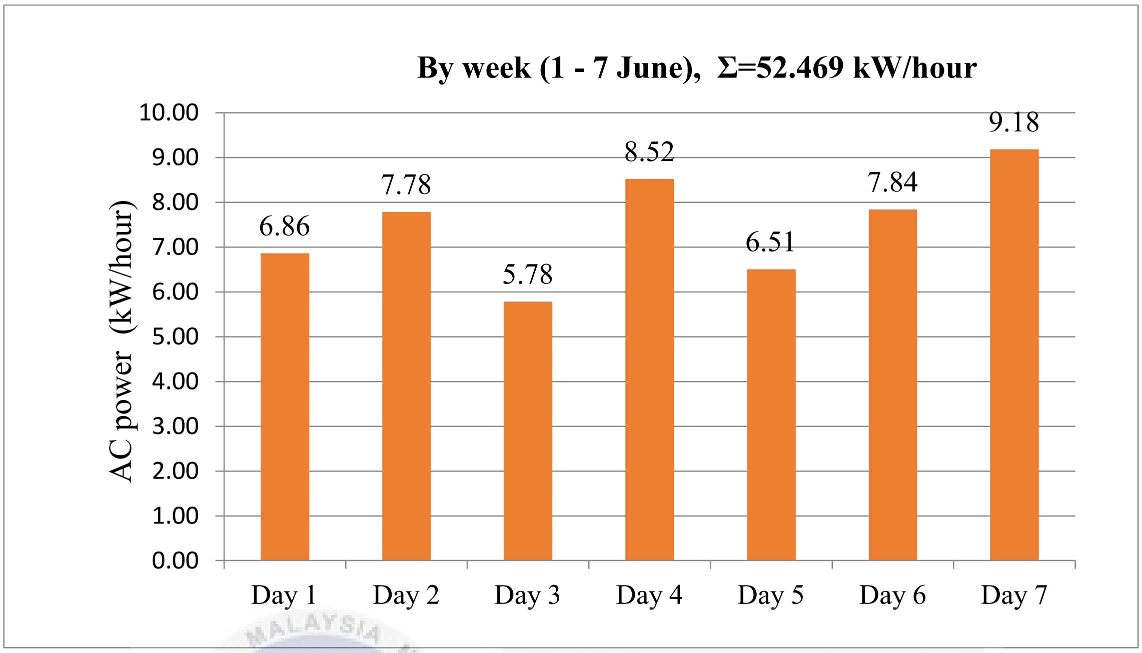

Figure 4. 18: Real value of AC power inverter in first week of June

Table 4. 6: System Yield calculation in first week of June

Table week (1 – 7 June) (SYreal =52.469 kW/hour)			
Type of efficiency (calculation)	AC power value by calculation (kW/hour)	Difference with real (kW/hour)	Difference with real (%)
Peak	72.08	19.619	37.39
Euro	71.27	18.798	35.82
Tropical	70.45	17.976	34.26

Next, this study also compare the value of real AC power by week. The bar chart shows the value of real Pac in the first week of June which 1 June to 7 June 2014. It is shows that day 3 has the lowest AC power value which is 5.78 kWh and the highest is 9.18

kWh in day 7. However, the weekly system yield, SYreal_week is 52.469 kW/h with an average is 7.495 kW/h. The month of February was randomly chosen for this validation.

However, for validation purpose, the value of System Yield has been calculated by using equation (1.2). The result of the calculation is shown in Table 4.5 where Peak efficiency, Euro efficiency, and Tropical efficiency are 72.08kW/h, 71.27 kW/h and 70.45kW/h respectively. Hence, from the comparison between the real and calculation value, Peak efficiency has the highest difference with real AC power which is 5.691 kW/h (37.39%) and Tropical efficiency has smaller difference which is only 17.976 kW/h (34.26%). Thus, the tropical efficiency is the most acceptable efficiency for validation because its value is nearer to the real value. This proves that tropical efficiency is more suitable to be used and this is confirmed by the validation works done.

4.3.3 Financial Impact on the Usage of Different Efficiency Value

Feed-in Tariff is a program that a payment made to producers that generate their own electricity and it is proportional to the amount of power generated. Feed-in Tariff also promotes long term contracts (21 years) and guaranteed pricing to the producers. Feed-in Tariff will pay for every kilowatt hour of power exported to the grid for 21 years. However, the used of different efficiencies values give the financial impact to the seller as it is influence on the calculation of system yield and performance ratio which is used to estimate the Return of Investment (ROI). The System yield is calculated by the following equation (1.2).

While Feed-in tariff is calculated by using the formula:

$$\text{Feed-in-Tariff} = (\text{Power generate} \times \text{Rate RM/kWh} \times \text{Peak Sun Hour}) \quad (4.3)$$

Where the power generates and peak sun hour is from the system yield calculation. Then, the system yield value for 1 year is multiplying the current rate price which is 0.8249 RM/kWh. Table below shows the result of estimation total cost return on investment for 1 year and after 21 years by using Feed-in Tariff formula. It has shown that there are differences between the three types of efficiency. However, according to the real value of system yield, the cost will be as 2761.16 kW/h x 0.8249 RM/kWh = RM 2277.68 and after 21 years, the total cost is RM 2277.68 X 21 years = RM 47831.29.

From the Table 4.6 it shows that Tropical efficiency is most acceptable to use as prediction cost because it is nearer to the actual value. This is because if the peak efficiency and Euro efficiency are used, the prediction by installation for System Yield (SY) calculation is inaccurate. This is shown by the Table 4. 7 where the Peak efficiency in SY calculation shows the error of 2.66% where the difference cost with actual is RM

1273.93. Whereas, if the Euro efficiency is used of the error is 1.49% and the difference cost with actual value is RM 714.23. Then, the Tropical efficiency has the lowest error which is 0.32% with RM 154.53 difference with actual cost. Thus, it is shows that Tropical efficiency is most suitable and accurate for prediction by installer.

Table 4. 7: Difference total cost between calculation values and real value

Real value after 21 years (RM 47831.29)				
Type of efficiency	**Total cost for 1 year**	**Total cost for 21 years**	**Differences with real (RM)**	**Differences with real (%)**
Peak	RM 2338.34	RM 49105.22	RM 1273.93	2.66
Euro	RM 2311.69	RM 48545.52	RM 714.23	1.49
Tropical	RM 2285.04	RM 47985.82	RM 154.53	0.32

4.3.4 Alternative Method (RSM)

In this part, MATLAB was used in Response Surface Methodology in terms of Multiple Linear Regression in order to obtain the value of B_0, B_1, B_2, and B_3. The result will be applied in the following equation:

$$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \quad \varepsilon \qquad (4.4)$$

Where, X is called as independent variable or predictor variable while Y as response variable. Moreover, B_0 is the intercept of line and B_1, B_2, and B_3 are the slope of line which is one of important quantities in any linear regression analysis.

The Table 4. 8 shows the data of irradiance (X_1), DC power (X_2) and AC power (X_3) that will be used as input data and weighted efficiency as target data in Multiple Linear Regression model to predict the output result. The following figures shows step by step procedure to obtain output data in MATLAB software by using Response Surface Methodology in terms of Multiple Linear Regression model.

Table 4. 8: The input data and target data used in MATLAB software

Input data			
Irradiance (X_1)	DC Power (X_2)	AC Power (X_3)	Weighted Efficiency (Target)
136	71.62456	30.49395	0.000187
139	103.7015	64.54916	0.000279
141	115.8505	88.85799	0.00035
145	119.3167	96.61321	0.000378
148	126.2799	103.7477	0.000392
151	133.9822	111.3442	0.000404
155	141.047	118.4393	0.000418
⋮	⋮	⋮	⋮
84	60.61493	39.7975	0.000178
83	39.78093	35.45927	0.000238

Firstly, the data were saved as Target.txt for weighted efficiency and Input.txt for irradiance (X_1), DC power (X_2) and AC power (X_3) in Notepad file before it is used as input in MATLAB. Then, the data will be called back by using simple coding in MATLAB as shown in the Figure 4. 19.

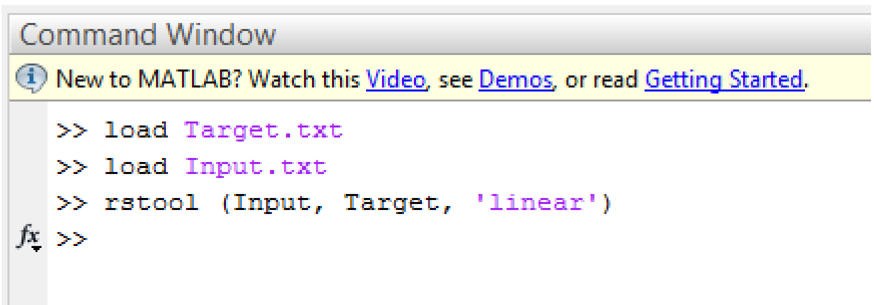

Figure 4. 19: Simple coding in MATLAB

After that, the MATLAB will display as the following Figure 4. 20.

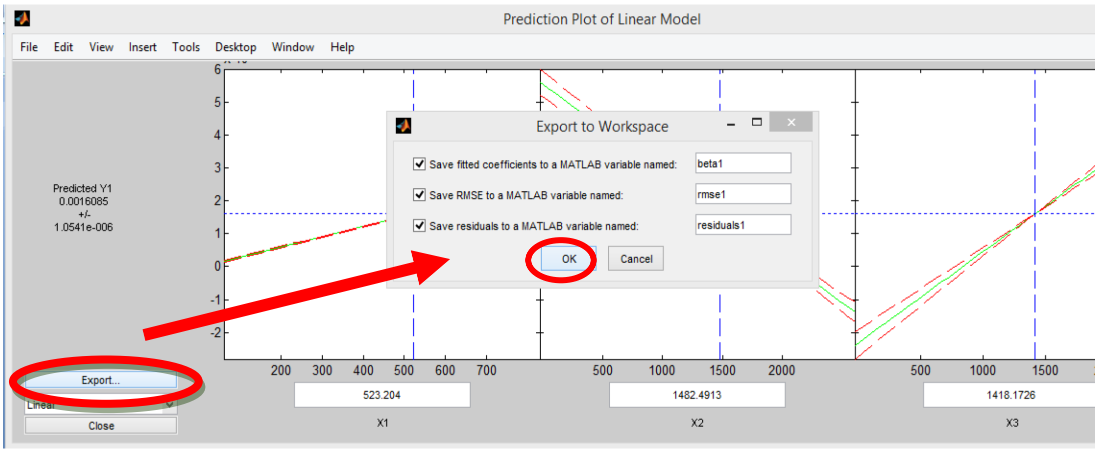

Figure 4. 20: Prediction Plot of Linear Model

In this part, the linear model was selected. Next, the Export's button and OK's button on Export to Workspace windows was click and the result of beta, residuals and rmse were display in Workspace windows as shown in the Figure 4. 21. However, the rmse value which is represent for the root mean square error and it is frequently used to measure the differences between values that predicted by a model. In this study, the error shows the smallest value which is only 0.000008307 and this result is acceptable to use.

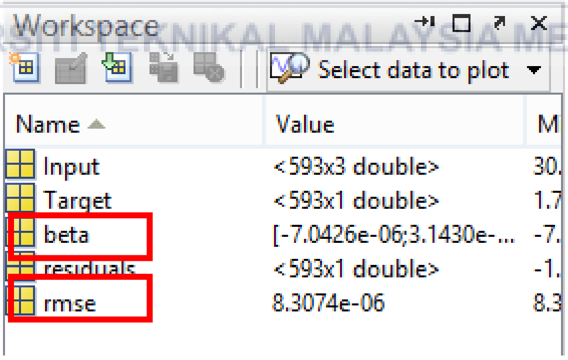

Figure 4. 21: Result from MATLAB

The data result of beta is used to calculate the output result by using the following equation:

$$\text{Output, } y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \qquad (4.5)$$

Where Beta represents the value for B_0, B_1, B_2, and B_3 and the input data which are irradiance, DC power and AC power were represents for X_1, X_2, and X_3. The value of Beta from the simulation is shown in Figure 4. 22

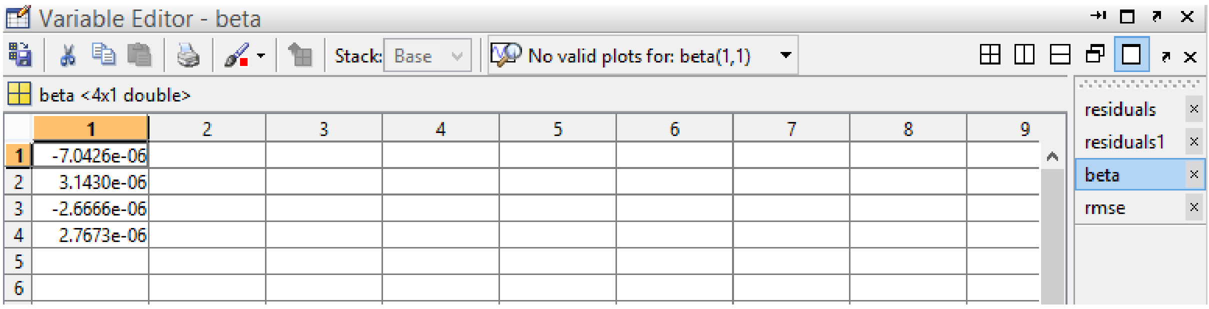

Figure 4. 22: The beta value from simulation in MATLAB

Table 4. 9: The output result of the calculation by using the beta value

Input data				
Irradiance (X_1)	DC Power (X_2)	AC Power (X_3)	Weighted Efficiency (Target)	Output
136	71.62456	30.49395	0.000187	0.000314
139	103.7015	64.54916	0.000279	0.000331
141	115.8505	88.85799	0.00035	0.000375
145	119.3167	96.61321	0.000378	0.000398
148	126.2799	103.7477	0.000392	0.000408
151	133.9822	111.3442	0.000404	0.000418
155	141.047	118.4393	0.000418	0.000431
• • •	• • •	• • •	• • •	• • •
84	60.61493	39.7975	0.000178	0.000207
83	39.78093	35.45927	0.000238	0.000245

The output result was calculated by using the beta value and input value as shown in the following steps:

$$\text{Output, } y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$$

Where,

y = Output

B_0 = -7.04E-06, B_1 = 3.14E-06, B2 = -2.67E-06, B3 = 2.77E-06

$X_1 = 136$, $X_2 = 71.62456$, $X_3 = 30.49395$

Hence, the output value was obtained as the following calculation below:

$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$

y= (.7.04E-06) + (3.14E-06) (136) + (-2.67E-06, B3) (71.62456) +

(2.77E-06) (30.49395)

y= 0.000314

Input data				
Irradiance (X_1)	DC Power (X_2)	AC Power (X_3)	Weighted Efficiency (Target)	Output
136	71.62456	30.49395	0.000187	0.000314

Figure 4. 23 show the relationship between output and target data in Multiple Linear Regression method and it is shows the result of coefficient determination, R^2. The R^2 value is the value that tells how much the variation is explained by the model. The predicted R^2 indicating how well a regression model predict the response. The results shows the filled like follow the data very nicely and the R^2 value is 0.9999 which is very fantastic that reflects the perfect model. However, Figure 4. 23 also shows that the different error between target and output. For coefficient determination, R^2, any value of $R^2 > 0.75$ or more than 75% shows an acceptable different between targets and output. In this case the different is very low which indicates that the alternative equation for weighted tropical efficiency by using Multiple Linear Regression of RSM is accurate.

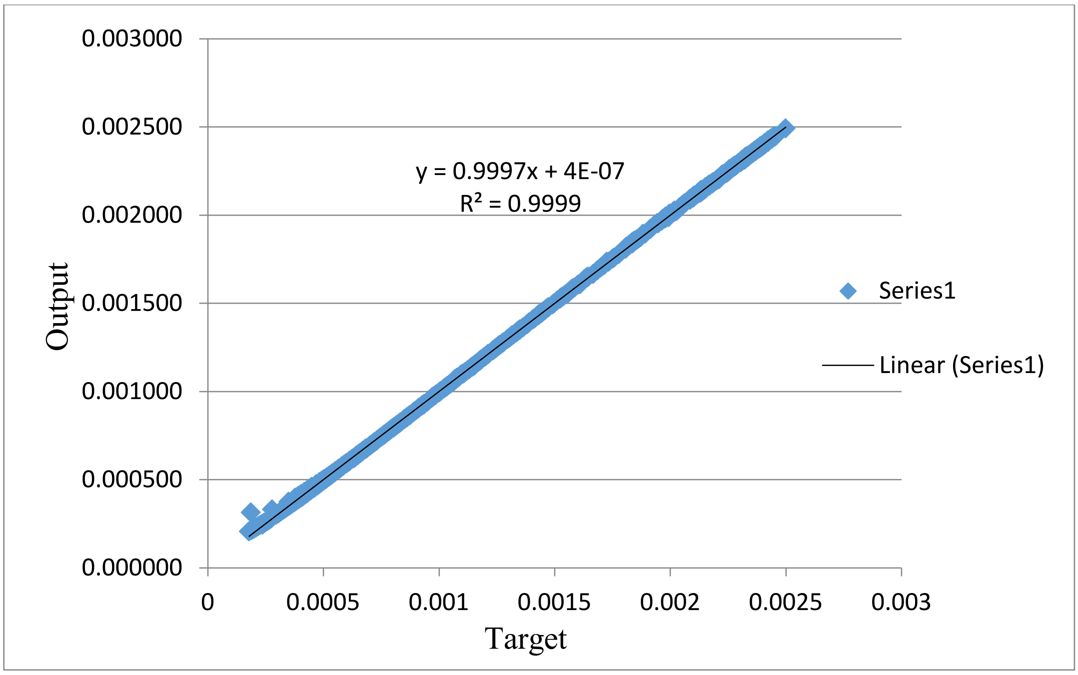

Figure 4. 23: Relationship between Output and Target

4.4 Summary

This chapter presented the System Yield analysis for three type of efficiency to identify the most suitable efficiency for tropical climate. Further, the analysis was done for SB3000HF inverter that has been installed in Utem's weather station. In the performance analysis section, the main focus is to calculate and analyze the System Yield produced by each type of efficiency and to determine their estimate cost for 1 year and after 21 years. Based on validation purpose, Tropical efficiency shows the most acceptable because its value is nearer to actual value of AC power of inverter.

Besides, Response Surface Methodology (RSM) which is Multiple Linear Regression is used as alternative way to form an accuracy of the equation forming as suggested in IEC 61683 standards. The coefficient determination, R^2 between target and output is 0.999 which is more than 0.75. This is shows that the alternative equation for weighted Tropical efficiency by using Multiple Linear Regression is accurate.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter will discuss conclusion for the overall project and the recommendation for the purpose of improvement in future research.

5.2 Conclusion

In this study, the inverter was testing under tropical climate i.e tropical irradiance and tropical temperature with constant at 2 C as suggested in IEC 61683. The result of the inverter test experiment shows that the weighted efficiency of the inverter is difference from the weighted efficiency as suggested in European efficiency equation. This shows that the weighted Euro efficiency is unsuitable for benchmarking PV inverter operation in tropical climate. Hence, the more accurate Tropical efficiency is suggested.

In terms of financial impact, if we continue to use Peak efficiency instead of the suggested Tropical efficiency in the system yield calculation the consumer will bear the losses in the long run. The validation result has shown that the usage of Tropical efficiency is more accurate if compared with the usage of Peak and Euro efficiency.

This study also shows that Response Surface Methodology (RSM) through Multiple Linear Regression method can be use as alternative way to form an accurate equation as compared to the one suggested in IEC 61683 standards. This is because the coefficient determination, R^2 between target and output is 0.999 which is more than 0.75.

This is shows that the alternative equation for weighted Tropical efficiency by using Multiple Linear Regression is accurate.

5.3 Recommendation

It is suggested that the experimental work to be performed on the inverter with other technology as well such as Transformerless with low frequency inverter as this will give more accurate representation on how PV inverter will operate under tropical climatic condition.

Experimental work should also include testing on inverter with difference sizes. The alternative method to produce an alternative equation for Tropical efficiency equation some other RSM method can be consider such as Full Quadratics, Pure Quadratics and Interactions.

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