# APPLICATION OF SOLAR ENERGY IN MALAYSIA

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**FACULTY OF ENGINEERING**

**UNIVERSITY OF MALAYA**

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# APPLICATION OF SOLAR ENERGY IN MALAYSIA

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# ABSTRACT

Currently, countries continue to seek the best alternative energy sources for routine uses. Solar energy has continuously attracted attention since it is an available source of energy which does not require any extraction cost. In this study, the solar systems with inverter are analyzed technically through TRNSYS simulation and the economic analysis has also been made. Energy produced from this solar system will significantly cater to the need of energy consumption in the daily life of Malaysians. The data for solar energy was collected from Malaysia metrology department and software (Meteonorm as well as online GAISMA) was analyzed and used in TRNSYS. Two types of solar photovoltaic (PV) panels including Monocrystalline PV and Thin Film PV have been simulated in TRNSYS. At the same time, comparisons of both types of PV are also made for some selected regions in Malaysia such as Kota Bharu, Kelantan, George Town, Pulau Pinang and Petaling Jaya, Kuala Lumpur. Then, the energy outputs of the TRNSYS simulation were analyzed economically. Life Cycle Cost, LCC method has also been implemented in this economic analysis. The analysis will take into account the full cost of materials, operations, inflation rate, etc. to show the flow of future implementation. Using the results of energy output from raw data analysis, TRNSYS simulation, and LCC analysis on the economics of the solar system, this study will provide useful information for finding the sources of renewable energy and their implementation in meeting the demands of domestic consumers.

# ABSTRAK

Dalam masa di mana dunia terus mencari sumber tenaga alternatif yang terbaik untuk kegunaan seharian, tenaga solar terus mendapat perhatian dan merupakan sumber tenaga yang mudah didapati terus tanpa memerlukan sebarang pembayaran. Dalam kajian ini, sistem solar dengan pembolehubah dianalisa dari segi teknikal melalui simulasi TRNSYS dan juga pengiraan ekonomi analisa terhadapnya turut dilakukan. Tenaga yang terhasil dari system solar ini akan memenuhi keperluan penggunaan tenaga yang digunapakai dalam kehidupan seharian rakyat Malaysia. Data-data sumber tenaga dari matahari diambil dari pihak metrologi Malaysia, software (Meteonorm) dan juga dari aplikasi talian (GAISMA) dianalisa dan disimulasi dalam TRNSYS ke atas sistem solar dengan pembolehubah. Simulasi TRNSYS sistem solar ini akan dibandingkan dengan 2 jenis photovoltaic panel (PV) iaitu jenis monocrystalline dan juga thin film PV. Dalam masa yang sama, perbandingan hasil tenaga kedua-dua jenis PV ini juga turut disimulasi ke atas beberapa tempat terpilih di Malaysia iaitu Kota Bharu, Kelantan, George Town, Pulau Pinang dan juga Petaling Jaya, Kuala Lumpur. Kemudian, perbandingan tenaga yang terhasil daripada lain-lain jenis PV dan tempat-tempat berbeza ini akan dianalisa dari segi ekonomi. Life Cycle Cost, LCC kaedah akan digunapakai dalam menganalisa ekonomi sistem solar tersebut serta mengambil kira secara lengkap kos bahan, operasi, inflasi etc mengikut kira aliran masa mendatang. Dengan analisa data, simulasi TRNSYS, LCC ekonomi analisa ini keatas sistem solar ini, tenaga yang terhasil akan memberi ruang kepada semua pihak untuk mengimplikasi sumber tenaga baharu sistem ini bagi keperluan pengguna domestik.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| A | PV area ($m^{-2}$) |
| B | slope of the panel |
| $C_d$ | predicted monthly average daily PV output (MJ) |
| $C_i$ | $_i$th calculated data value |
| D | constant |
| DD | wind direction ($^{O}$) |
| D-RR | driving rain (mm) |
| d | diode completion factor |
| $d_1$ | empirical diode curve fitting factor |
| e | semiconductor bandgap (eV) |
| $e_I$ | error between measured and calculated insolation (%) |
| $e_{pv}$ | error between measured and predicted PV output (%) |
| FF | wind speed (m/s) |
| $G_b$ | beam radiation |
| $G_{bn}$ | beam component of the solar radiation ($W/m^2$) |
| G_Gh | mean irradiance of global radiation horizontal ($W/m^2$) |
| G_Dh | mean irradiance of diffuse radiation horizontal ($W/m^2$) |
| G_Gk | mean irradiance of global radiation, tilted plane ($W/m^2$) |
| G_Dk | mean irradiance of diffuse radiation, tilted plane ($W/m^2$) |
| G_Lin | mean irradiance of longwave radiation incoming ($W/m^2$) |
| G_Lv | mean irradiance of longwave radiation vertical ($W/m^2$) |
| G_Go | mean irradiance of extracted radiation horizontal ($W/m^2$) |
| G_Gn | mean irradiance of global radiation, tracked ($W/m^2$) |
| G_Bh | mean irradiance of direct radiation horizontal ($W/m^2$) |

| | |
|---|---|
| $G_{eff}$ | effective radiation ($W/m^2$) |
| $G$ | total irradiance |
| $G_T$ | total irradiance on the tilted surface |
| $I$ | current (A) |
| $I_{AM}$ | incidence angle modifier |
| $I_{AMb}$ | incident angle modifier for beam component of insolation |
| $I_{AMd}$ | incident angle modifier for diffuse component of insolation |
| $I_{AMg}$ | incident angle modifier for ground reflected component of insolation |
| $I_{bT}$ | beam component of in plane irradiance ($W\ m^{-2}$) |
| $I_D$ | diffuse component of global horizontal irradiance ($MJ\ m^{-2}$) |
| $I_G$ | global horizontal insolation ($MJ\ m^{-2}$) |
| $I_{dT}$ | diffuse component of in plane irradiance ($W\ m^{-2}$) |
| $I_L$ | photocurrent (A) |
| $I_{L,ref}$ | module photocurrent at reference conditions (A) |
| $I_{M,d}$ | measured daily total in plane insolation ($MJ\ m^{-2}$) |
| $I_{mp,ref}$ | current at maximum power point at reference conditions (A) |
| $I_{P,d}$ | predicted daily total in plane insolation ($MJ\ m^{-2}$) |
| Io | diode reverse saturation current (A) |
| $I_{o,ref}$ | diode reverse saturation current at reference conditions (A) |
| $I_{rT}$ | reflected component of in plane irradiance ($W\ m^{-2}$) |
| $I_{sc,ref}$ ` | short circuit current at reference conditions (A) |
| $I_T$ | in plane irradiance ($W\ m^{-2}$) |
| $I_{T,NOCT}$ | solar radiation at NOCT ($W\ m^{-2}$) |
| $I_{T,ref}$ | in plane irradiance at reference conditions ($W\ m^{-2}$) |
| $I_{Teff}$ | total effective insolation on array surface ($W\ m^{-2}$) |
| k | Boltzmann's constant ($J\ K^{-1}$) |

| | |
|---|---|
| $k_0$, $k_1$, $k_2$ | correlation coefficients |
| $k_T$ | hourly clearness index |
| Ld | diffuse lumninance (lux) |
| Lg | global luminance (lux) |
| $M_d$ | measured monthly average daily PV output (MJ) |
| $M_i$ | ith measured data value |
| Mx | mixing ratio (g/kg) |
| N | total number of data points |
| PAR | photosynthetically active radiation (W/m$^2$) |
| $P_{inv,n}$ | normalised inverter output power |
| $P_{inv,rated}$ | rated inverter input power (VA) |
| Ppv | input power to inverter (W) |
| Ppv,n | normalised inverter input power |
| $P_{PV,rated}$ | PV rated capacity (kWp) |
| q | electron charge (C) |
| R | mean irradiance of radiation balance |
| $R_{beam}$ | ratio of beam radiation |
| RH | relative humidity |
| RR | precipitation (mm) |
| $R_S$ | module series resistance (Ω) |
| $T_A$ | ambient temperature ($^o$C) |
| Td | dewpoint temperature ($^o$C) |
| Tp | wet bulb temperature ($^o$C) |
| $T_{A,NOCT}$ | ambient temperature at NOCT ($^o$C) |
| $T_{C\ PV}$ | module temperature ($^o$C) |
| $T_{C,NOCT}$ | module temperature at NOCT ($^o$C) |

$T_{C,ref}$ module temperature at reference conditions (K)

Ts surface temperature ($^oC$)

$U_{LS}$ thermal energy loss coefficient per unit array area (W $m^{-2}$ $K^{-1}$)

V voltage (V)

$V_{mp,ref}$ maximum power point voltage at reference conditions (V)

Voc open circuit voltage (V)

$V_{oc,ref}$ module open circuit voltage at reference conditions (V)

ρ air pressure (kPa)

$\rho_g$ ground reflectance factor

τα transmittance–absorptance product

$(\tau\alpha)_{normal}$ transmittance–absorptance product at normal incidence of incident radiation

$\eta_c$ cell efficiency at standard test conditions (%)

$\eta_{inv}$ inverter efficiency (%)

$\mu_{I,sc}$ temperature coefficient of short circuit current (A $K^{-1}$)

Φ solar altitude angle ($^o$)

$\theta_z$ zenith angle

# CHAPTER 1

# INTRODUCTION

## Overview

The world will need 53% of the total energy in the coming of year 2030. Thus, 70% of the value of that is used by developing countries (Oh et al, 2010). According to a research, Malaysian economy grew by 5% per annum and at the same time Malaysia is estimated to require energy consumption by 6% (Saidur et al, 2009). Total energy consumption is increasing in Malaysia; it will become more complicated because of declining energy resources every day. Among of those parts, productions of electricity require a high energy source and it has become the main area in Malaysian government planning (Jaafar, 2005). Pollution rates, rising of oil prices in every year, and looking forward through global incentives to go in the direction of green world have led Malaysian government to be aware of the need to find alternative energy sources which have the potential to be implemented. Many projects in Malaysia have utilized solar energy as renewable energy resources (Malaysia Department of Public Works, 2010). Solar energy is the answer for the replacement of other energy sources such as fossil fuels and coal (Hasnain et al, 1998). Solar energy, which does not have to be paid, can be used for the whole day and can be utilized by many parties. It is also not harmful to the environment like some other commercialization of energy today (EPRI, 2003). Even so, solar power is still considered as consuming a large cost of energy for its renewal. This is because at present only 1% of global electricity is generated from solar energy (Othman et al, 2010).

However, it has the potential to be developed after extensive research and new innovations continue to be conducted.

## 1.2 Problem Statement

Solar energy has turned into an alternative to traditional energy sources at the present time. These alternative energy sources are non-polluting and do not require any extraction cost in their availability. Nevertheless, high capital cost, especially for photovoltaic, has made its growth a slow one. In recent years, the capital costs of the advance materials' manufacture are decreasing as the world becomes more concerned about renewable energy use. The solar system is not complicated and can be built at the top of the houses of domestic users in Malaysia in order to provide an environmentally-sound source to be used for safe and clean energy production for that building. The solar system that is used to supply electrical energy source to domestic users can be utilized in both remote and urban areas. The energy output from the photovoltaic cell depends on the light intensity, the cell temperature, the panel's orientation, and its size, among others. The light intensity affects primarily the amount of current produced, making it proportional, while the cell temperature controls the voltage produced. As the cell temperature increases, the current produced remains the same but the voltage is reduced, which also reduce the output energy. All of these factors have to be taken into consideration to accurately predict the energy production. Besides that, even though there are numerous studies about solar application technologies that demonstrate the importance and need of them at present, the findings of this research are consequential to show the performance of the system and the capacity of it for more works and investments. This study is planned to become a reliable project; therefore, the main and even initial assessment of it is technical and economical in aspects. This study will provide useful information for finding the sources of renewable energy and their implementation in catering for the demands of domestic consumers.

## 1.3 Objectives of the study

Obstacles that need be overcome if renewable energy is to be used as an energy source are expensive initial costs for the purpose of renovation, development of infrastructure, maintenance and many other excessive extra costs (Argawal, 2006). Taking full advantage of solar energy could provide the best solution for the extension of modern energy services to remote and isolated communities (Eliasson, 2000). This is an added advantage to Malaysia because it has a tropical rainforest climate. This dissertation will analyze, make predictions, estimations, and also compare the energy (KWh/day) produced by simulation of thin film with the monocrystalline photovoltaic system, using TRNSYS simulation in seven consecutive days in selected areas in Malaysia to find out whether the application of solar energy consumption is worth the cost.

This study is carried out with the following objectives:

1. To investigate the energy produced from thin film photovoltaic with an inverter system in Kuala Lumpur, Pulau Pinang and Kota Bharu using TRNSYS simulation.
2. To investigate the energy produced from monocrystalline photovoltaic with an inverter system in Kuala Lumpur, Pulau Pinang and Kota Bharu using TRNSYS simulation.

3. To compare the energy output produced by thin film photovoltaic with an inverter system with monocrystalline photovoltaic with an inverter system in Kuala Lumpur, Pulau Pinang and Kota Bharu.

4. To analyze the 25-year life cycle economy of the highest energy output from photovoltaic with an inverter system.

The outcomes of the above goals allow performance of photovoltaic with an inverter system to be predicted and modeled and possible to be implemented when using solar energy.

## 1.4 Scope and limitation of the study

The scope of this study is to apply the solar monocrystalline and thin film's parameters from manufacturer and Kuala Lumpur's, Kelantan's and Pulau Pinang's weather data to modeling using software TRNSYS 16 to obtain solar energy for alternative energies. This study is only concentrating on monocrystalline and thin film solar photovoltaic panels with inverter output energy by using manufacturer parameters which based on their nominal power 24W, range of maximum power 170W-200W and 72 cells numbers. The simulation only utilized collected weather data on 7 consecutive days in Kuala Lumpur, Kelantan and Pulau Pinang. In the economic analysis, this study is only concentrating on the system which gives the highest energy output by using the Life Cycle Costing (LCC) method for 25-year life cycle. Properties will be collected from books, journals, and software (TRNSYS, Meteonorm as well as online GAISMA) to model and compare the energy output and their economic analysis on 25 years ahead.

## 1.5 Organization of dissertation

This dissertation consists of five (5) chapters and organized as follows:

**Chapter 1** is a brief introduction or overview of the research topic, discussing about issues on alternatives energy especially on solar energy. It continues about the significance of this study and the importance of switching to solar energy. Objectives, scope and limitations are listed after that.

**Chapter 2** provides a literature review of the study. Views of others on energy crisis and the importance of solar energy are shared. Recent studies on performances of solar energy and its application are reviewed and some of the important properties are selected and tabled. Studies on application of solar energy are also reviewed in this chapter.

**Chapter 3** explains the methodology of this project. In this chapter an explanation of methods that are applied to calculate incident radiation of solar energy, solar photovoltaic parameters, weather data, Life Cycle Cost (LCC) is provided.

**Chapter 4** presents all results that have been obtained from the input data and calculations on tables and graphs followed by detailed reasoning discussion, commented upon and comparing with literature reviews.

**Chapter 5** concludes the study and recommends some further works that can be performed.

# CHAPTER 2

# LITERATURE REVIEW

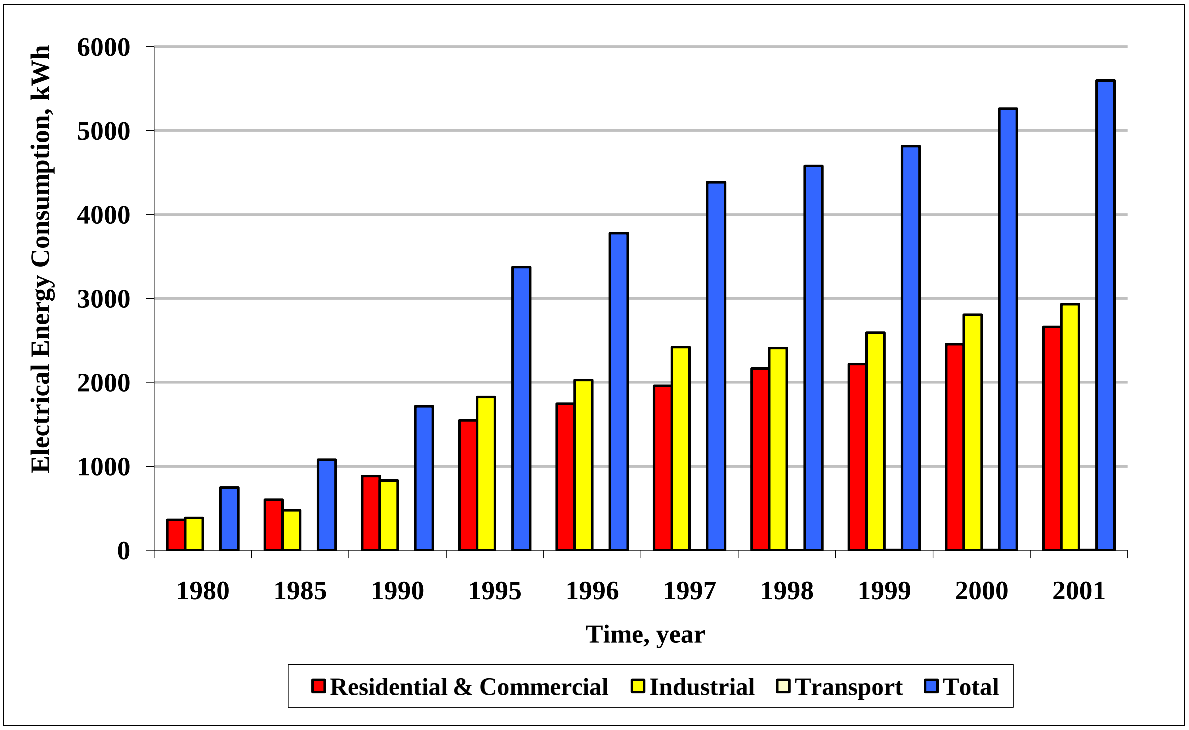
## 2.0 Solar Energy Application

## 2.1 Introduction

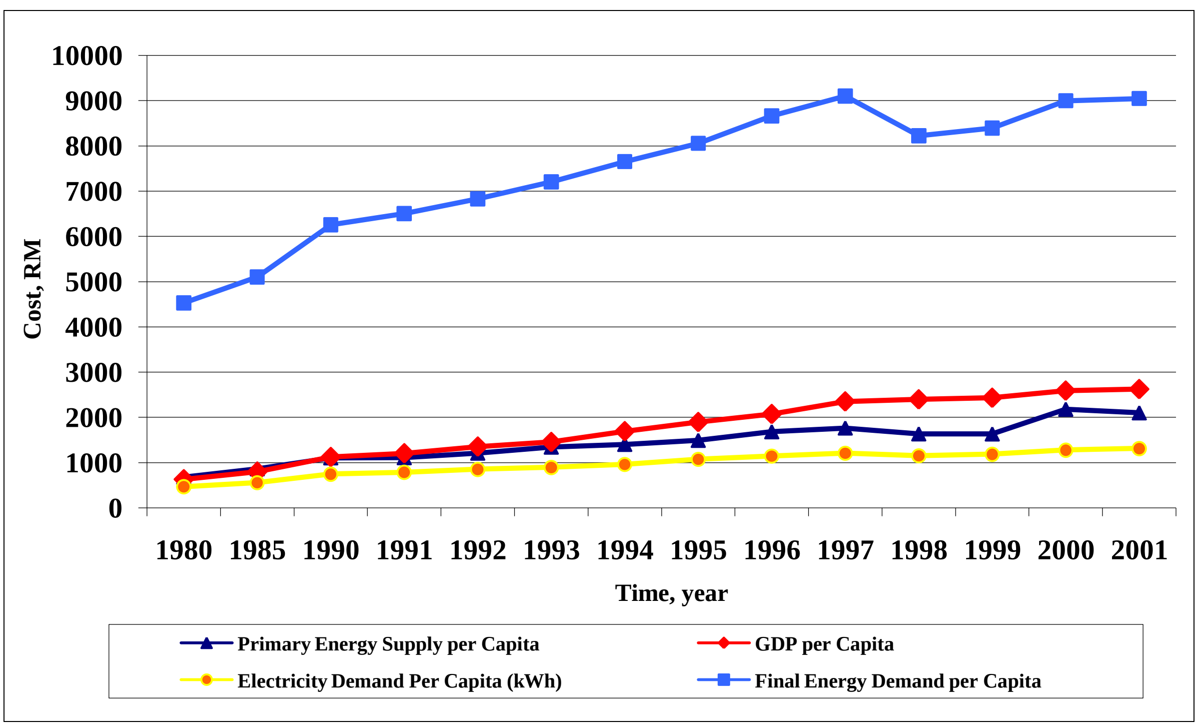
“The local power sector is currently one of the country's most highly subsidised industries. The price of natural gas has been fixed at RM6.40 per mmbtu since 1997. This represents a 76% discount to average US rates of US$6.39 per mmbtu converted at the prevailing exchange rate. Thus far, the discount has been borne by Petroliam Nasional Bhd (Petronas) in the form of loss of revenue” (Star, 3$^{rd}$ July 2004). In year 2000, electricity rates have been held in very small increment which leveling Malaysia's as the second-lowest in Asia. These rates pull towards foreign direct investment into Malaysia (TNB report, 2000). However, the bad result impacts on the industrial sub-sector which is greatly subsidised. The unfavourable implication lies in fact that the government will instantaneously bear Petronas to rework gas charge in consonance with international market rates which would have an adverse outcome on Malaysia's current competitive advantage (Griffin, 2001). Therefore, to overcome these matters is a solution is sought, which is utilizing the solar energy as a renewable-energy source.

### 2.1.1 Supply and Demand of Energy in Malaysia

Malaysia is a good location for solar energy application because it has a tropical rainforest climate. However, the usage of solar photovoltaic is still very small until now. One of the obstacles is the large capital investment required for utilizing solar PV systems. According to the journal "Solar Photovoltaic: Sunny Solution for Tomorrow" by Pusat Tenaga Malaysia in 2009, the range of unit cost of solar PV system is RM 24, 000 – RM 28, 000 per kWp. For a bungalow, the suggested PV capacity is typically 5 kWp which mean the capital investment is RM 120, 000 – RM 140, 000. According to MBIPV National Project accomplish by Ministry of Energy, Green Technology and Water (KeTTHA), the average PV system cost in March 2010 is approximately RM 19, 120 per kWp. This mean for 5 kWp of PV system capacity the capital investment is RM 95, 600. It shows that PV system cost decreasing about 32% in a year. If a house is energy efficient, then the portion of PV electricity generated for the same 5 kWp will contribute more significantly to the household electricity demand (Cen, 2008). The 9th Malaysia Plan, Malaysia Building Integrated Photovoltaic (MBIPV) Project was open to support extensive utilization of solar PV systems in the urban area. Solar PV is the best solution among renewable energy options. The cost of solar PV has decreased by more than 50% from 2000 to 2006. The price of solar PV is in tandem with economic scale which means that it will be decreasing within time. The tactic to obtain the cheaper price of solar PV is therefore to generate a market but unless the price decreases, the market is unlikely to shift (Cen, 2009). The simple approach to crack the deadlock is for government to get in the way.

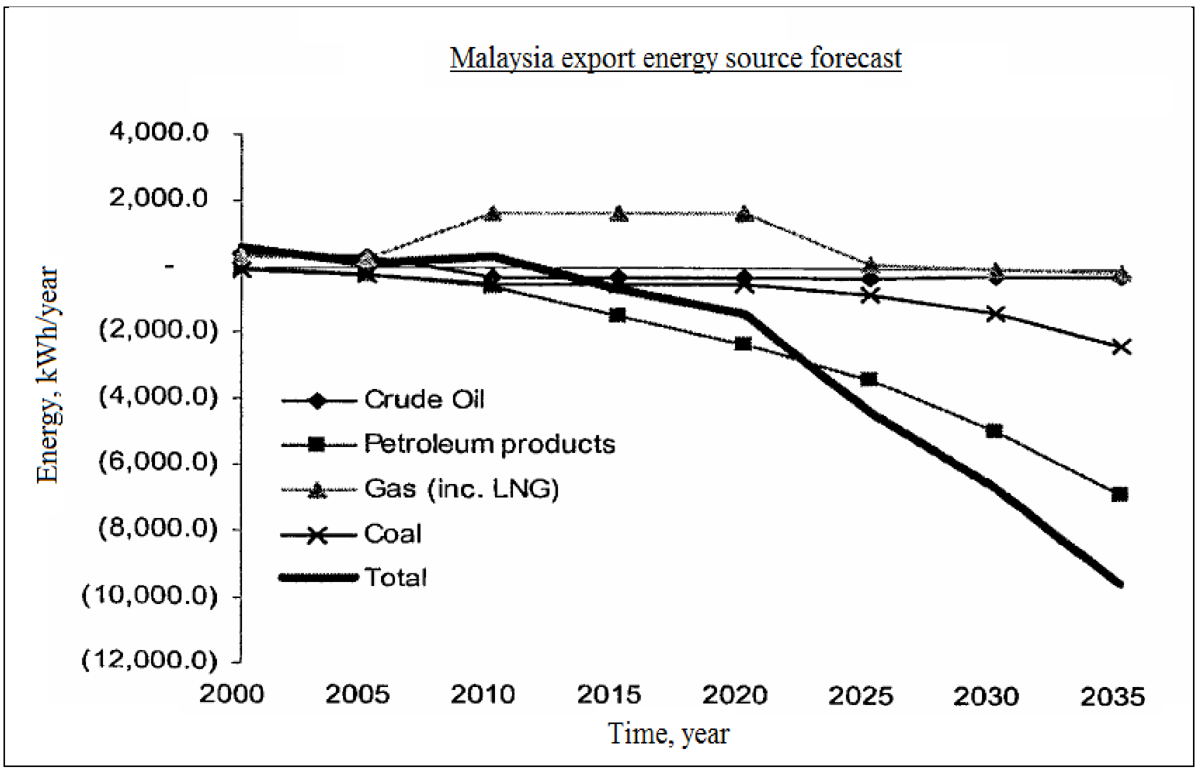



Graph 2.1: Electricity consumption by sectors in Malaysia in year 1980-2001 (Department of Electricity Supply Malaysia, TNB 2009)




Graph 2.2: Trends of Primary Energy Supply Per Capita, GDP Per Capita and Final Energy Demand Per Capita in year 1980-2001 (National Energy Balance, Ministry of Energy, Communications and Multimedia1980-2000)

Based on Graph 2.1 which is shown above, the commercial sector as well as residential consumers required about 48% of total electricity produced. With growing GDP, electricity demand will be enlarged but in various rates. In Graph 2.2, in each 1% growth in GDP, electricity consumption is growing by 1.5%. In simple words, Malaysian electricity-GDP elasticity is approximately 1.5 (Aun, 2004). An evaluation of the energy output use per capita had been made in 3 Asia countries. The result given is Malaysia's usage is approximately around 26 GJ/1000USD compared to Thailand's usage which is 20 GJ/1000USD and Japan's usage which is 7 GJ/1000USD (DANIDA, 1990). In conclusion, it is evident that Malaysia does not utilize the energy very efficiently.




Graph 2.3: Malaysia export energy source forecast in year 2000-2035 (Pusat Tenaga Malaysia, 2000)

According to the Graph 2.3 above, which shows the forecast of Malaysia's energy source, Pusat Tenaga Malaysia has predicted that Malaysia would turn into a net importer of energy within the year of 2010 and 2015. From the details above, engineers and researchers need to find ways to better utilize renewable energy in Malaysia. Once again, overcoming these matters can be done by discovering a way out which is applying the solar energy as a renewable energy source.

Table 2.1: Electricity power consuming in a unit of Malaysian house (CETDEM Survey, 2004)

| **Item** | **kW** | **hrs/yr** | **kWh** | **kWh/m$^2$/yr** | **%** |
|---|---|---|---|---|---|
| Air Conditioner | 1.00 | 1440 | 1440 | 8.00 | 21 |
| Fan | 0.05 | 3600 | 162 | 0.90 | 2 |
| Fluorescent Lamps 18W | 0.22 | 576 | 64.51 | 0.36 | 1 |
| Iron | 1.00 | 180 | 180 | 1.00 | 3 |
| Radio | 0.25 | 72 | 18 | 0.10 | 0 |
| Refrigerator | 0.30 | 8760 | 2628 | 14.60 | 38 |
| Rice cooker | 0.65 | 360 | 234 | 1.30 | 3 |
| Television | 0.06 | 1080 | 64.80 | 0.36 | 1 |
| Water Heater | 2.70 | 360 | 972 | 5.40 | 14 |
| Washing Machine | 2.20 | 540 | 1188 | 6.60 | 17 |
| Vacuum Cleaner | 0.30 | 96 | 28.80 | 0.16 | 0 |
| **Total** | **8.73** | **17064** | **6980.11** | **38.78** | **100** |

Referring to Table 2.1 which is shown above, home consumption of energy would rely on the appliances installed, the hours of use and the efficiency of the equipment. Generally, in a typical Malaysian terraced house of about 180 m$^2$ size, the refrigerator has the highest electricity consumption. Meanwhile, the air-conditioned system will progressively become more essential as living standards grow (CETDEM Survey, 2004).

### 2.1.2 Solar Energy

The benefit of renewable energy sources such as solar, biomass, hydropower, tidal energy and wind energy is that it is CO2 free (Schnitzer et al, 2007 and Ernest et al., 2009).

Even though the general awareness of benefits that will be gained from application of renewable energy is increasing, in 2006 those sources of energy only assist about 1.5% of world energy demand (Abdelaziz et al, 2011). Solar energy is one of the greenest energy resources that are not harmful to the environment. Since the beginning of time, Humanity has been trying to find ways to exploit solar energy as the sun can radiate extra energy in one second. In general, solar energy is labelled as "alternative energy" to fossil fuel energy sources such as coal and oil (Mikhelef, 2010). At the present time, the solar energy is a good resource for most of renewable energy solutions. The straight forward employment of solar radiation gives high advantages to many parties in creating a relevant application.

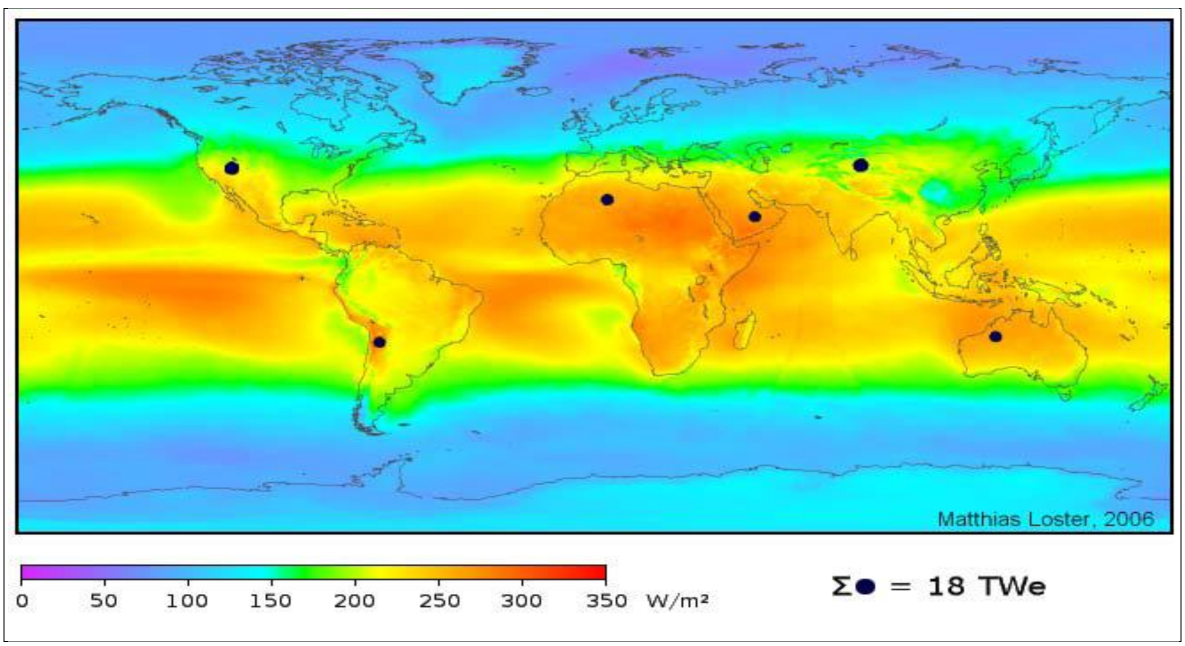



Figure 2.1: The local solar irradiance averaged in 24 hours per day from 1991 to 1993 (Total primary energy supply from sunlight, 2010)

From Figure 2.1 which is shown above, by an assumption conversion efficiency of 8%, the black dots in the maps possibly able to offer larger than the world's total primary energy demand (Naghavi, 2010). At the moment, the solar cells can possibly generate energy in the form of electricity which could substitute the current energy including heat, fossil fuels, etc. (Total primary energy supply from sunlight, 2010). In the year of 2050, solar photovoltaic application could provide for around 45% of world's energy demand (International Energy Agency (IEA), 2009).

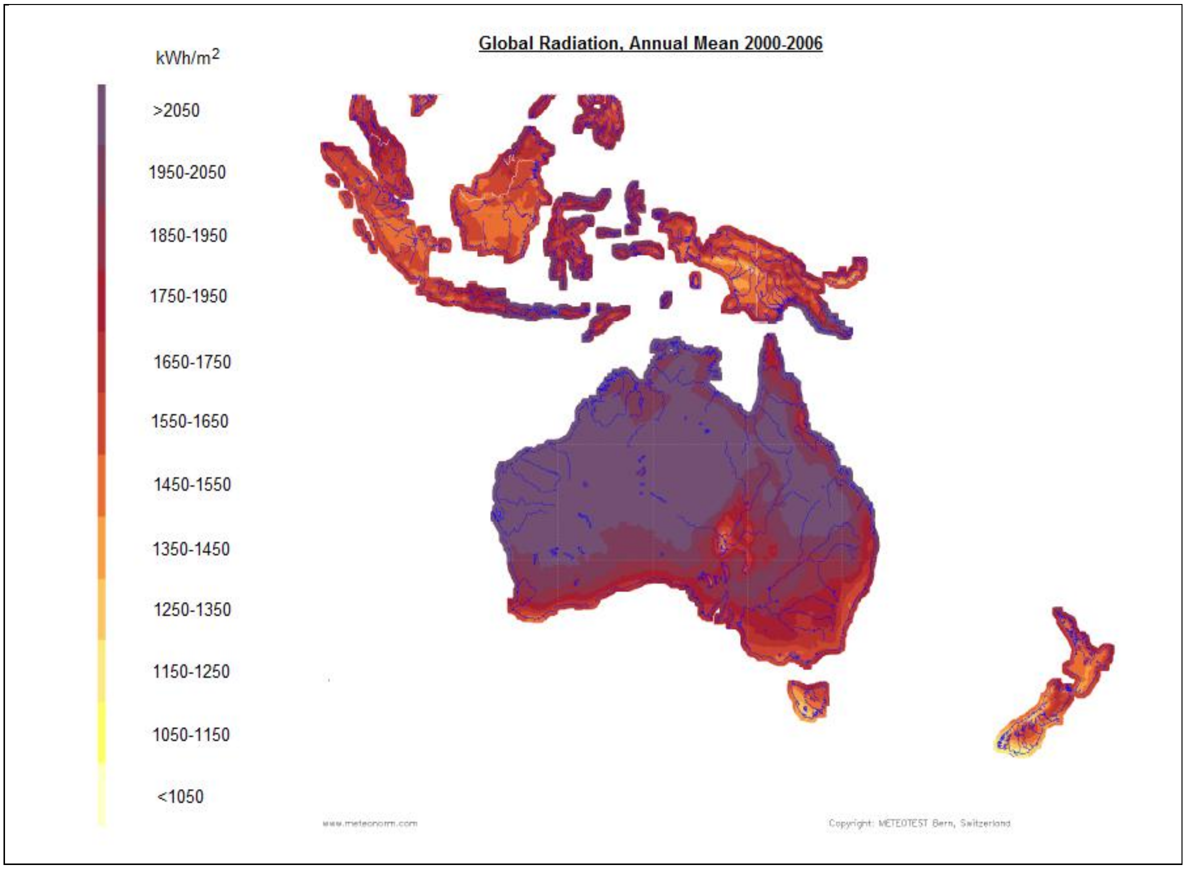



Figure 2.2: Asia global radiation (kWh/$m^2$) in 2000 to 2006 (Meteornorm, 2011)

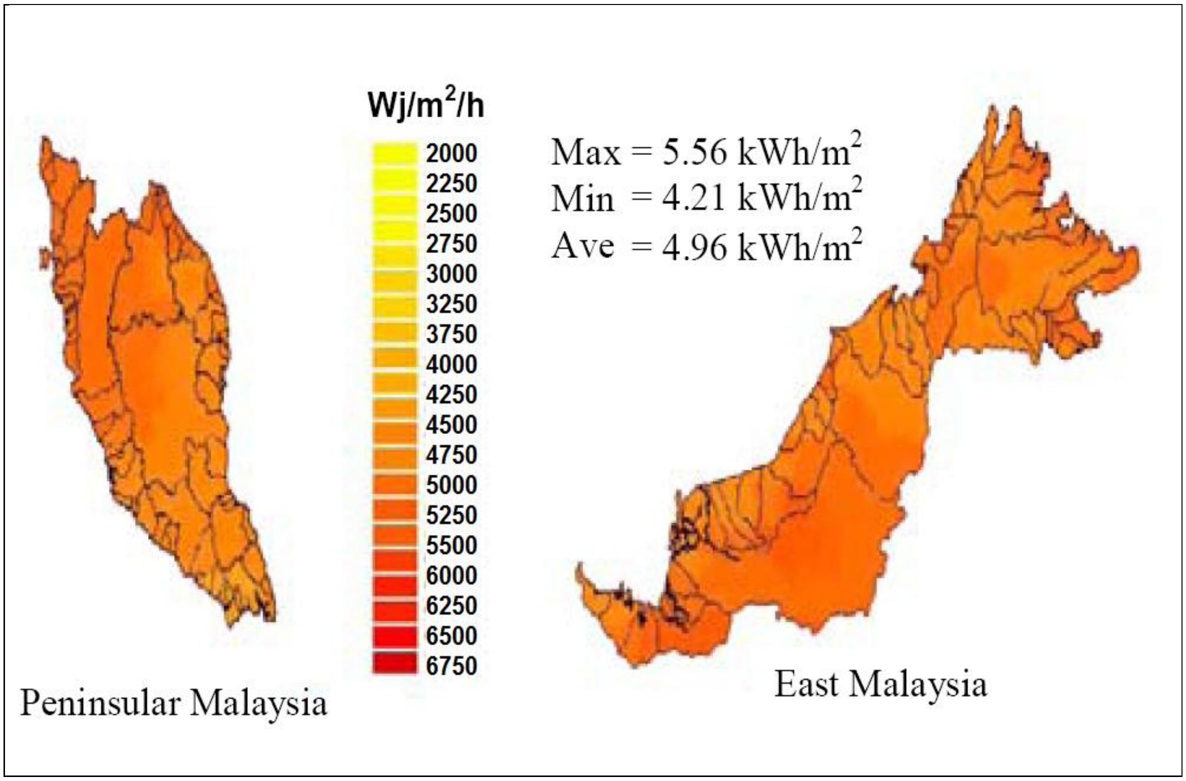



Figure 2.3: Annual average daily solar irradiation of Malaysia (Ayu, 2008)

From Figure 2.2 and Figure 2.3 which are shown above, Malaysia has an excellent resource of solar energy. There are about 1550-1950 kWh/m$^2$ per annum while the average daily irradiation is 4.96 kWh/m$^2$. This gives a lot of advantages to apply solar energy in Malaysia. It is a huge waste if solar energy application is not fully utilized in Malaysia.

### 2.1.3 Solar Energy by Photovoltaic Application

Normally, photovoltaic (PV) cells are worn for the extraction of solar energy to convert it into electrical energy. In practical science terms, a solar cell converts energy in the photons of sunlight then produces electricity using the method of a photoelectric phenomenon, originated in the few types of semiconductor materials such as silicon and selenium (Mikhelef, 2004). In principal means, a PV cell is to convert the solar energy which is cascading on the surface straight away then turning into electricity (Ivan et al, 2007).

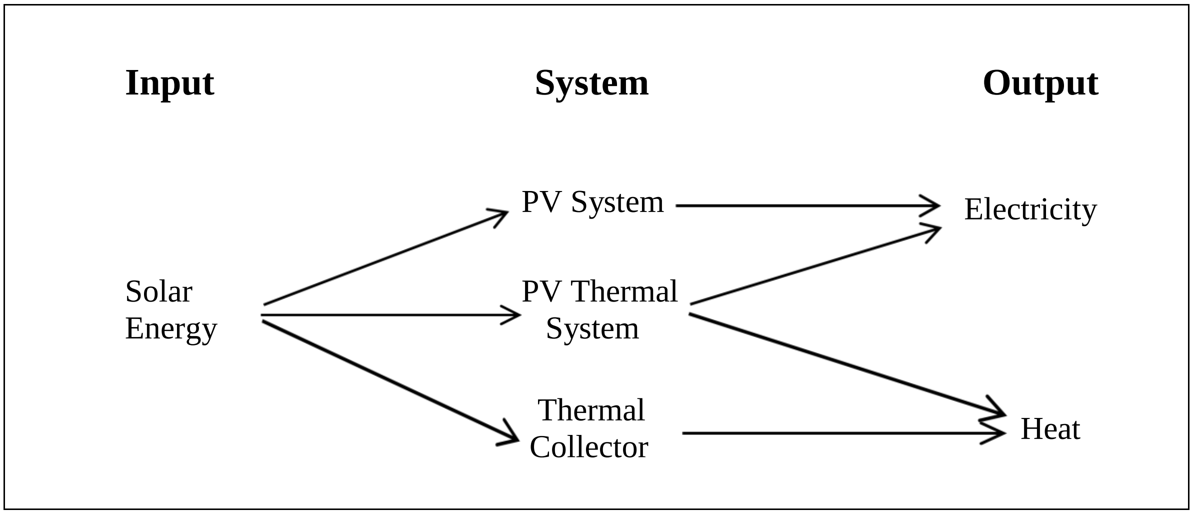



Figure 2.4: PV energy conversion process (Gadkari, 2005).

Figure 2.4 above shows the schematic process of solar energy. At present, just a small amount of the solar radiation is engaged in PV cells systems and then changed to electricity. This condition will cause the creation of waste heat in the cells. As a result, PV cell temperature increases. Therefore, the effectiveness of the module decreases. In order to overcome this, cooling processes; either natural or forced circulation, are necessary to diminish it. However, there is another solution which is employing the PV thermal system (PV/T). In the system, a PV cell is attached with heat extraction devices. In the previous study, the concurrent cooling of the PV module sustains electrical efficiency at the acceptable point (Gadkari, 2005).

In current technology, PV solar system is applied in stand-alone power systems in rural areas in most of the region in the world. Figure 2.5 presents the schematic flow chart of PV systems. Most of them are hybrid systems with diesel power generators. The main factor leading to this situation is the energy demand in third world countries towards a green environment condition. Standalone systems are in need when the area there has no connection with public grid. In another situation, standalone systems are in demand when the situation is involved with large cost in transmitting electricity to the remote places. The functions of standalone systems rely on the solar energy absorbed by the PV panels.

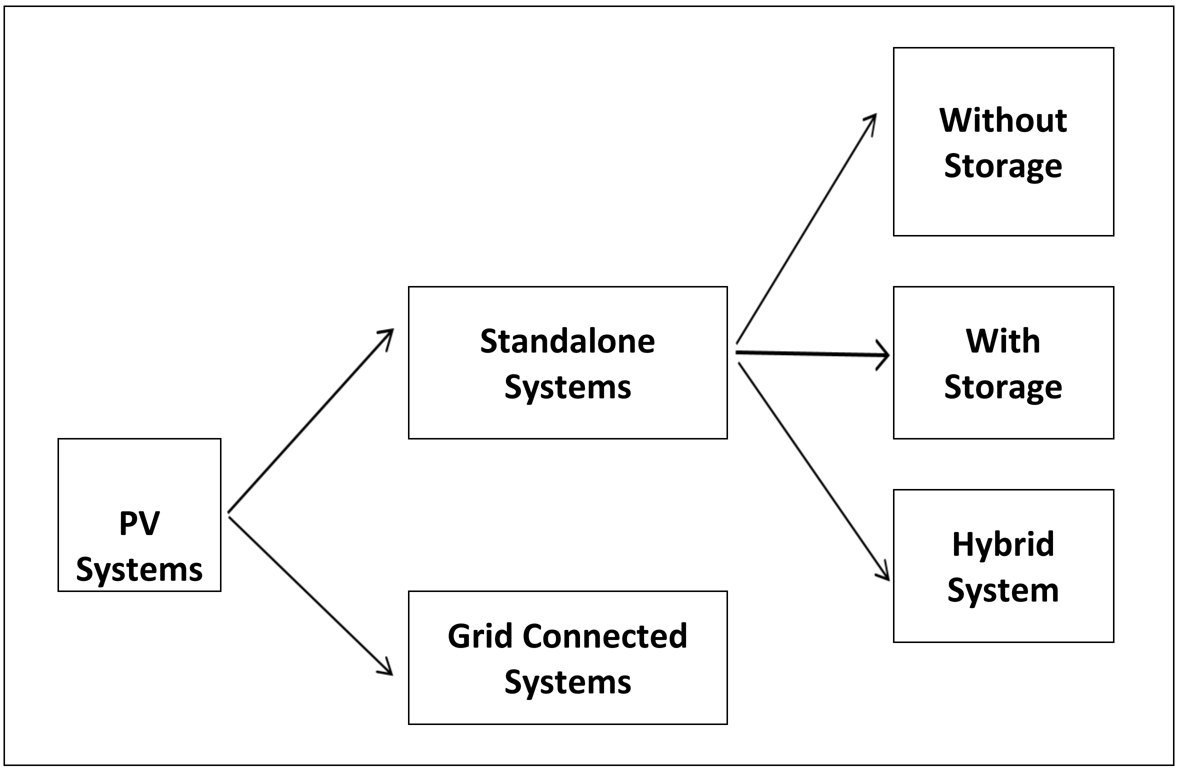



Figure 2.5: Types of PV systems (Saidur et al, 2009)

The implementations are different from watches, transportation, calculators or residential houses. In order for the load to be supplied independently, the power produced requires to be cushioned with a battery. If system's heaviness (e.g. high rise buildings) is not taken into account, lead acid batteries can be buffered with it. When it comes to a normal electric generation system (e.g. resident houses usage), alternative current (AC) is necessary. Therefore, the inverter has to be mounted into the system to convert the DC from the modules or batteries into AC. In order to keep away the damage of battery parallel to too much charging or discharging when optimizing the generated electric, a charge controller should be integrated in the system.

### 2.1.4 PV Cells

PV cells are made up of semiconductor material, such as silicon, which is currently the most common product in the market. When light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light has transferred by the semiconductor. Currently, there are eight commercial production technologies of PV cells (Patel, 2006). Here are some of Malaysian typical usages of PV cells:

· *Monocrystalline Silicon*: This is the oldest and more expensive production technique, but it is also the most efficient sunlight conversion technology available. Cell efficiency is averagely between 11% and 16%.

· *Polycrystalline or Multi-crystalline Silicon*: This has slightly lower conversion efficiency in comparison with single crystalline and manufacturing costs are minor. The average cell efficiency is between 10% and 13%.

· *Thin Film "copper-indium-diselenide"*: This is a promising alternative to silicon cells. It is much more resistant to the effect of shade and high temperature, and offers the promise of lower cost. Cell efficiency is about 8%.

· *Amorphous*: Material is vaporized and deposited on glass or stainless steel. The cost is lower than any other method. Cell efficiency is about 7%.

### 2.1.5 Comparison of Solar PV Cells

In this solar hybrid system, a type of Photovoltaic (PV) Cells has been chosen and installed in the project at various places in Malaysia. Therefore, the selection of right specification of solar has been done in particular. Many characters of PV are discussed in this chapter. Today, in Malaysia there are 3 major types of PV Cells that has been used in the industrial application. They are monocrystalline, polycrystalline, and thin film solar modules. The characteristics of these three PV are compared and at the end, the best PV is selected for the project of a solar hybrid system in Malaysia.

The nine (9) characteristics of PV Solar Modules (monocrystalline, polycrystalline and amorphous thin film) are compared. The characteristics are:

1) Market
2) Energy efficiency
3) Manufacturing process
4) Cost

5) Sunlight efficiency

6) Temperature limitation

7) Durability

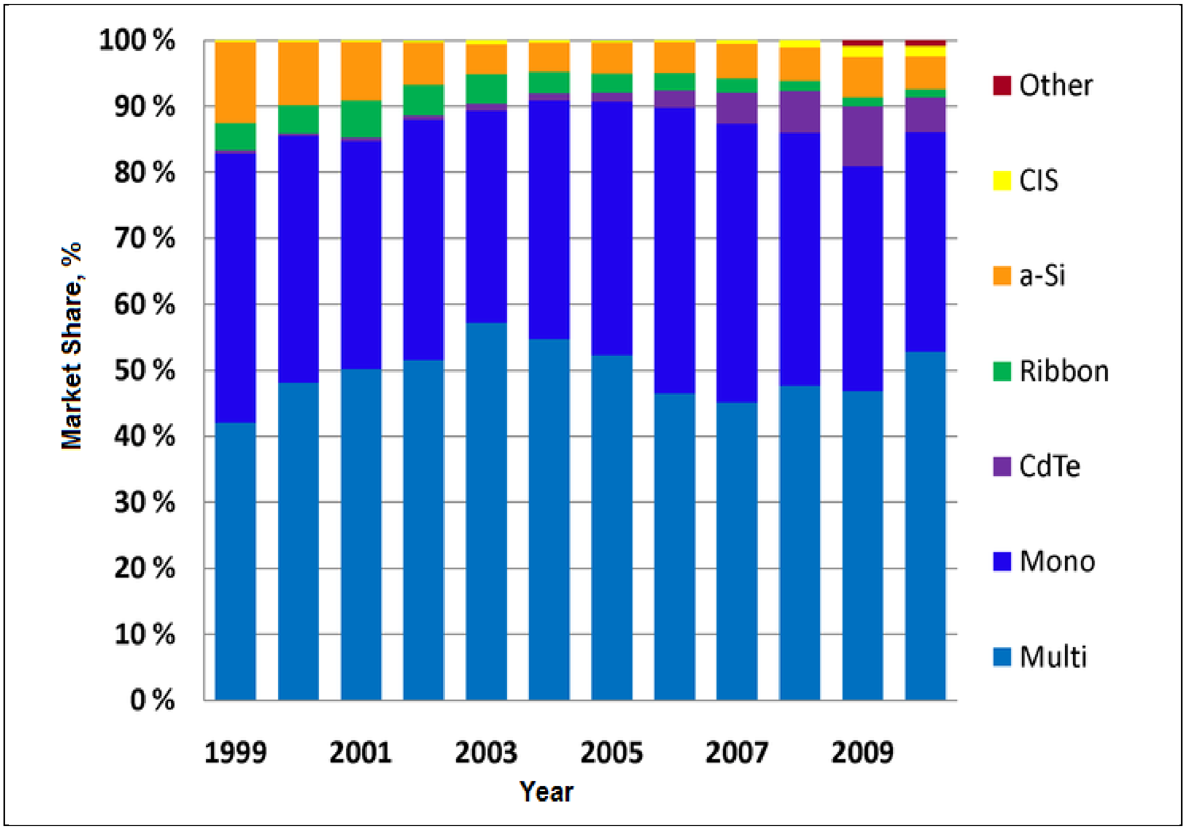
8) Space / area installation

9) Ease of installation

From results of the journals, academic papers, books, trusted websites, solar related organization etc. analysis, these characteristics are crucial in the decision to select the right PV to be used in the solar hybrid system project.

#### 2.1.5.1 Market

The availability of solar PV panels in Malaysia is a critical part in this solar hybrid system project. This is because if the PV panels are not available in Malaysian market, it will increase the transportation cost in the project.




Graph 2.4: Market share of the different photovoltaic technologies (Clean Energy Talk, 2011)

Graph 2.4 shows the market share of the different photovoltaic technologies from 1999 until 2009. The light and dark blue are multi- and mono crystalline silicon respectively; together they represented 87% of the market in 2010. This shows that the crystalline silicon made PV has a wider market in the world compared to others. Therefore, it is easier to get this type of PV cells rather than thin film.

I. *Monocrystalline:* Most widely used in the world, with over 50 years of technological development. This type of solar module is a go-to choice for many years, and is among the oldest, most efficient, and most dependable technologies in the solar industries. Now, it is already available and is considered as the most popular type of solar cell in the market today.

II. *Polycrystalline :* Furthermore, already available in the market today. It becomes a choice if it has more space for installation with less budget and fewer output requirements.

III. *Thin film:* Thin film is still relatively new technology, so it is still in the research and development to upgrade its efficiency. Therefore, it becomes a less attractive option compared to crystalline silicon. Maybe in the future, it will become a great choice of solar modules as the technology evolves and the price becomes lower.

**2.1.5.2 Energy efficiency**

I. *Monocrystalline:* This type has the highest power to size ratio, with efficiency within the range of 135-170 Watts per $m^2$. Now, some leading units of solar cell manufacturers have over 18% conversion efficiency. Its efficiency is the highest among other types on the market today. Monocrystalline is still leading the race of solar manufacture and makes it hard for the other types of solar cell to catch it up. It is hoped that engineers and scientists can find some solutions to beat the situation.

II. *Polycrystalline :* Polycrystalline has good efficiency at 120-130 Watts per $m^2$. The efficiency per square feet of this type of solar cell is lower than monocrystalline, but it is still higher than thin film solar cells.

III. *Thin film :* It has the lowest efficiency at 60-70 Watts/$m^2$ compared to crystalline silicon solar modules. But it can still be a choice if the requirements of energy output are small.

### 2.1.5.3 Manufacturing process

I. *Monocrystalline:* The process involved in their manufacturing is a complicated process. Each solar cell in the module has to be made from single crystal. This takes a longer time to grow and there is no room for error, which means every panel will cost a little more compared to polycrystalline and thin film solar cell.

II. *Polycrystalline:* Polycrystalline is composed of a number of smaller crystals or crystallites; it is like a metal flake in the solar cell. Therefore, it takes less time to fabricate it compared to monocrystalline. Different from monocrystalline which requires no room for error, this type of crystalline silicon solar panel is slightly less in the cost of manufacturing.

III. *Thin film :* Thin film solar cell also has the lowest embodied energy. The lowest embodied energy refers to the amount of energy required to manufacture and supply a product. It also means that high-voltage type solar cells can be formed at a high density on a single glass substrate, and that it is easy to produce them with larger surface areas. So the manufacturer can produce it in a large-scale amount.

### 2.1.5.4 Cost

I. *Monocrystalline :* Because they are made of just one crystal; not multiple crystals fused together, the process of making them is one of the most complex and costly ones. This is due to the fact that every panel will cost more. Even though they have higher efficiency, however, it is not always the best cost-friendly option considering the cost per watt. They often cost more per watt! However, if the space is not a concern, which is possible sometimes, these types are the best choice. They will give more watts per square feet compared to any other solar panel. However, that increased cost is giving additional efficiency, which means one panel will produce more power than the lower priced options.

II. *Polycrystalline:* There greatest advantage is that this type usually comes at a smaller price than monocrystalline. If the space is larger, this type ought to be considered as it can give more power per dollar. Therefore, in the market today it is marginally less expensive than monocrystalline.

III. *Thin film:* The high cost of crystalline silicon wafers had led the industry to look at less expensive materials to make solar cells. The selected materials have been strong, light absorbers. Therefore, thin film is the solution which only needs to be about 1 micron thick, which means material costs can be significantly reduced. In other words, it can be said that this type of solar cell has the lowest cost to manufacture and in the market today.

**2.1.5.5 Sunlight efficiency**

I. *Monocrystalline :* The amount of sunlight and the presence of shade, perhaps from nearby tree or other obstructions, are also important factors. This type of solar cell will lose far less efficiency in low light conditions and in the shade. This is because each solar cell is more sufficient itself and will continue to work even though other cells get less light, which makes the resistance lighter and it is easier to “push” the power through the solar cells and out of the solar panel itself. As a result, if the single large crystals like the ones found in monocrystalline panel don’t “shut off” easily, they are therefore better in the shady conditions.

II. *Polycrystalline :* A polycrystalline solar panel will suffer in low light conditions whereas a monocrystalline can still work on a reasonable efficiency. However, in low light and shady places this type is not the greatest. If this type of solar cells mounted in a place with a shade, it could lose up to 50% efficiency even though only 20% of the solar panel is in the shade. This is because of the extra resistance that occurs in each of the solar cells when some of the small crystals become inactive. This should not be of too much concern for solar panel, just remember not to install a polycrystalline where shade from trees, nearby buildings and bushes are present.

III. *Thin film :* The worst compared with monocrystalline and Polycrystalline PV cells.

**2.1.5.6 Temperature limitation**

I. *Monocrystalline :* The monocrystalline solar panels will have a reduction in a very hot temperature (50$^{o}$C or 115$^{o}$F) at about 12%-15%. These solar panels will lose some of their efficiency when they are heated over a certain temperature. Nevertheless, it has an outstanding performance in cooler conditions.

II. *Polycrystalline :* The efficiency of this solar cell at the temperature over than 50$^{o}$C or 115$^{o}$F is at a reduction about 14%-23%.

III. *Thin film :* These solar panels are good in overheated condition. At the temperature 50$^{o}$C or 115$^{o}$F and above, thin film/amorphous type will lose 0%. Thin Film solar panels have an optimal efficiency in hot weather, less effective in cooler conditions. Therefore, in a very hot country, this type of solar cells will become the best choice for solar application.

**2.1.5.7 Durability**

I. *Monocrystalline :* Usually monocrystalline comes with guaranteed lifetime-warranties of 25-30 years, and some of these panels are expected to last for up to 50 years if handled correctly. Nevertheless, there is still indirect effect which is they will still lose some efficiency over time and the average drop over a 50% year period is about 25%. It has an excellent life span or longevity. Monocrystalline has even withstood the rigours of space travel. The application of monocrystalline panels have been around for decades. Some monocrystalline panel installations in the 1970's are still cranking out power today.

II. *Polycrystalline :* The reliability of polycrystalline solar panels rival that of monocrystalline. It is also hard to find manufacturers that offer any kind of solar panels with a lifetime warranty of more than 25 years. Their drop of efficiency is also like monocrystalline, which is about 25% over 50 years period. Besides that, they are also as fragile as monocrystalline; therefore it is a must to install them with a rigid mounting to secure it from the effects of the wind.

III. *Thin film :* Thin film is still a relatively new technology. Its expected lifespan is less than crystalline panels. There is a 3-6 month ‘breaking in’ period where long term output is exceeded. Amorphous thin film is yet to prove itself in harsh conditions over a long period of time.

**2.1.5.8 Space / area installation**

I. *Monocrystalline :* Monocrystalline solar panels need far less surface/roof area - and roof space is a very valuable real estate when it comes to solar energy electricity related production. It is the best option for houses that have limited space on the roof.

II. *Polycrystalline :* It is ideal for small to medium sized roofs.

III. *Thin film :* In some instances, the project site has just enough roof space to deck it out in thin film panels; but what will happen later if it is to be upgraded? There are cases of home owners have had to rip up all their thin film panels and sell those at a loss in order to boost the size of their solar power system. These solar panels require 2-3 times more panels and surface area for the same output as crystalline.

**2.1.5.9 Ease of installation**

I. *Monocrystalline :* These panels are extremely fragile. A rigid mounting is a must.

II. *Polycrystalline :* The accessories of the installation of these solar modules are almost the same as monocrystalline.

III. *Thin film :* Some amorphous thin film panels actually need more mounting rails and take longer time to install; adding to the overall cost of the system. While thin film offers a lower level of embedded energy per panel, the fact that more panels are needed somewhat negates this aspect, especially given the extra mounting rails sometimes needed.

## 2.2 TRNSYS simulation program

TRNSYS is well-known software for a 'transient simulation' which can give convicting simulation result. Members of Solar Energy Laboratory in University of Wisconsin had developed TRNSYS which was then used worldwide until now (TRNSYS Manual, 1996). The program has various subroutines which can model subsystem components. Subsystem components have their own developed mathematical model in terms of differential or algebraic equations. TRNSYS has the ability to be integrated system components in assisting information output, every preferred approach, and work out with differential equations. It can resolve the whole difficulty of system simulation; simultaneously diminish the difficulty of every single recognized component that consists in the particular system (Kalogirou, 2004).

The first step starts by having the components of the system discovered and a mathematical explanation of every single component is offered. It is also required to assemble an information flow diagram for the system. The function of the information flow diagram is to smooth the progress of classification of the components and the flow of information. Every single component necessitates a number of constant PARAMETERS and time dependent INPUTS and produces time dependent OUTPUTS. Then, the

OUTPUT of the components can be employed as an INPUT to further components (TRNSYS Manual, 1996). In the flow diagram, a deck file has to be built to have information on each component of the weather data file, system and the output format (Kalogirou, 2004).

TRNSYS's subsystem components are comprised of auxiliary heaters, thermostats, solar collectors, pumps, differential controllers, heating and cooling loads, relief valves, hot water cylinders, pebble-bed storage, heat pumps etc. (Schwarzbözl, 2006). There are also subroutines for processing radiation data, performing integrations, and handling input and output. As simulation software, measured data by time steps down to 1/1000 h (3.6 s) can be applied for reading weather data. And this makes the program incredibly simple.

In order to verify the TRNSYS program as providing a convincing simulation program for a real system, model validation studies have been performed. In a previous study, the analysis result of these validation studies had declared that TRNSYS program offers results rate of successful between the TRNSYS simulation results and the calculated results on real operating systems is approximately 90% (Kreider et al, 1981). In other study, the simulation of TRNSYS of a thermosyphon SWH was nearly similar with the operating system output approximately 95.3% (Kalogirou, 2010). There is a lot of previous research about TRNSYS program. Some typical examples are in the modelling of a thermosyphon system (Kalogirou, 2010), modelling and performance evaluation of solar domestic hot water systems (Oishi et al, 201), modelling of industrial process heat applications (Kalogirou, 2010, Benz et al, 1996 and Schweiger et al, 2010), modelling and simulation of a lithium bromide absorption system (Florides et al, 2002), modeling the simulation of solar house (Serban et al, 2010), simulation of solar cereal dryer (Habtamu, 2007 and Morrison, 2009), investigation of the effect of load profile (Jordan et al, 2000) and many more.

## 2.3 Economic Analysis

### 2.3.1 Introduction

As mentioned before, solar systems generally come with the characteristic of high initial cost and low operational costs. This is different from conventional electric generation systems which are relatively high initial, operating and maintenance cost. The comparison between these systems is based on the direct financial outlay of the end users. At present, increasing daily pollution rates and rising oil prices in every year give a long-term benefit to produce electrical power from solar energy. To study the economic feasibility of a renewable energy system, Life Cycle Cost (LCC) could be used to estimate different figures of merit of the systems.

### 2.3.2 Economic and Technology Assessment

Renewable energy projects were studied globally, technically and economically for different systems and condition such as hybrid wind-solar systems, PV-wind-hydro-diesel systems and wind or PV in parallel with electricity grid, (Hossain, 1996, Islam, 1999, Kimura, 1996, Yang et al, 2009, Zhou et al, 2010 and Saheb-Koussa et al, 2009 ). Computerized evaluation tools had been developed to study habitable residence based on the technical feasibility and economic viability of a grid connected PV and PV/T energy conversion systems (Bakos et al, 2002). The method had developed to estimate the economic feasibility of the energy demand private investments on WECS installations (Karlis et al., 2001). Such privately owned generation system is still not proven to work in parallel with a large-scale network, thus the energy created by it is conveyed to the external grid system or supplied to meet local load needs (Reise et al, 2002 and Haris, 2001).

Currently, renewable energy systems are becoming an interesting subject to the researchers. The technical feasibility and economic viability of a hybrid solar or wind grid connected system for electrical and thermal energy production can provide the energy needs of a typical residence (Bokos et al, 2003). The payback period of the initial capital cost and Life Cycle Savings (LCS) method are used to analysis the economics of the planned system (Celik, 2003). There is also a study on the sizing and techno-economical optimization of a stand-alone hybrid PV/wind system with battery storage (Diaf et al. 2008). In Corsica Island, there is also a study on the outcome based on system size of the renewable energy potential value which characterized the most favourable dimensions of the system (Diaf et al, 2008). Furthermore, levelized cost of energy (LCE) had built up by taking into account an inclusive volume of model which can forecast the best system configuration. The simulation results are a sign that the renewable energy system or solar energy system is the greatest alternative for all the previous energy sources which had been thought about in this study. In Ethiopia, the alternative way of providing electricity from a solar energy system to an end user is separated from the main electricity grid (Bekele et al, 2010). The study has provided outcome of a list of feasible power supply systems and class following to net present cost. In another previous study, one project had predicted that the mainly appropriate expanse for a renewable energy system is closed to national electricity network. One well-known technique by the influences of dissimilar module temperature and dissimilar solar radiation dissimilar PV module type, and variety battery performance and wind turbine simulations is response surface methodology (RSM) (Erken et al., 2008). Another proven approach called loss of power supply probability (LPSP) is necessary to design solar energy systems with the use of battery banks. It is suggested as the best possible design model for estimating the system's most favorable configurations and it is guaranteed that the yearly cost of the systems is low (Yang et al., 2009). Generally, all studies above stated that there are three decision variables should be paid attention to in the solar energy development which are PV module number, PV module slope angle and battery capacity.

### 2.3.3 Life Cycle Concept

In a previous study, the economic analysis life-cycle theory is according to the principle of products and process life cycles (Duffie et al, 1980). Every phase of the life cycle such as an extracting and processing raw substances, fabricating, transportation, and delivery, recycling and waste management of products and processes works together with the environment. The environment is like raw materials which are mined, transformed, and further processed such as land is utilized and substances are emitted. There are many methods like modeling, life cycle tools, spreadsheet estimation and many others can be carried out to implement life-cycle thinking. The most universal method which had been used in evaluating energy system is the Life Cycle Assessment (LCA). LCA is an analytical formula for the efficient evaluation of the environmental aspects of a product, process, or service system during its life cycle (Elcock, 2007). There is also no limitation in using tools that can be implemented in combination with LCA method in any analysis such as an energy and material, material flow accounting, substance flow calculation, environmental risk evaluation, input/output assessment, life cycle costing, total cost accounting, environmental management accounting, and cost benefit analysis. The main objectives of these tools are to offer scientific information to assist and get better idea in a decision-making.

### 2.3.4 History of Life Cycle Assessment

According to economic history, from 1960s to 1970s, life-cycle methods were implemented to evaluate the usage of cumulative energy and also as prediction of delivery of raw substances and energy resources in the future. Life-cycle methods worked together with economic input-output models within their life cycles in evaluating economic costs and environmental emissions related with multiple energy technologies. In the early 1980s, United States found in such approaches to diminish the oil crisis besides awareness about pollution increased. Then, within the late 1980s and early 1990s, LCA consisted primarily of emission estimations and was utilized internally in estimating packaging alternatives evaluation. Simultaneously, in the early 1990s, LCA has also become an external method such as estimating marketing accounting. After that, significantly LCA has started to have a greater attention in regulatory focus. In dealing with multiple environmental issues, LCA was also permitted for the quantitative and structured comparison of alternatives to recognize environmentally preferred options (Elcock, 2007).

LCA tools also created many other methods which depend on the consideration and the way of an assessment project. In the renewable energy sector, the main function of LCA was to determine the environmental impact on products and services within their life cycle. LCA was an approach which could be used to estimate the impact of electricity generation on the environment. At the same time, LCA benefited the electric generation makers to compose better decisions towards environmental protection (Goralczyk, 2003). There was also another dynamic life cycle tool for renewable energy technologies (Pehnt, 2006). It has been proven that dynamic LCA suits all renewable energy chains. When it is compared with conventional system, the inputs of finite energy resources and emissions of greenhouse gases are very low. The study had been progressing within the past 30 years, to create an emphasis on scientific consensus creation and standardization in life cycle assessments. The challenge to create a closer collaboration and harmonization with the domain of energy analysis had been overcome. This will probably increase interest from the energy application side (Udo et al, 2007). By these findings, LCA has been developing to be used for estimating the energy payback time and environmental load (Nishimura et al, 2009). Therefore, at the present time the world has some main standards for life cycle assessment. The key players in this standardization were the Society for International Organization for Standardization (ISO), Environmental Toxicology and Chemistry (SETAC), and also the United Nations Environmental Program (UNEP). The ISO is a worldwide federation of national standards body, which, through various technical committees, prepares international standards for various topics. LCA's principles and framework had been described in ISO standard 14040 (Elcock, 2007).

### 2.3.5 Life Cycle Cost

Life-cycle costing (LCC) covers most of the entire part of economy analysis including process or movement, the entire life span of a product, and evaluates the entire life-cycle cost. Normally, LCC is utilized in the decision-making of design and further progress of products, processes, and further actions. Every part of internal costs gained during the life cycle of the object can be examined through LCC analysis. Among of the internal cost which can be investigated is operating, abandonment, initial investment, performance evaluation costs and capital, and hidden, fewer tangible, indirect company costs such as waste handling, licensing and environmental permitting, and reporting (Gary et al, 2005).

Generally the external costs are excluded in LCC. Examples of the external costs are government subsidies, general economic and environmental costs. Among other alternative options, LCC can be chosen to evaluate the net present value (NPV) either capital cost or operating expenses for whole life cycle of project. The tool is able to be employed while constructing the planning, conceptual, design, construction, and operating stages. Generally, the financial viability of renewable energy projects has been evaluated based on lowest amount of capital cost (Kablan, 2004). Larger total costs may come out if there is no attention to the possible higher noncapital costs. The solution had been formulated on the complexity and matter that elevates risks of results in LCC. The items that had been worked on are inconsistency of reported data, poor data availability, uncertainties regarding discount rate, asset life, estimation of future operating and maintenance costs (Elcock, 2007).

# CHAPTER 3

# METHODOLOGY

## 3.0 Introduction

In this report, technical characteristic, TRNSYS modeling and economic capacity of the proposed innovative system was assessed. The solar system was proposed to use by domestic consumers in Malaysia. The energy calculations were limited to the availability of meteorological data.

The methodology is needed for the study. It follows as below in Figure 3.1:

1. Literature review on thin film and monocrystalline photovoltaic solar systems.
2. Literature review on previous economic analysis works, particularly LCC method on renewable energy sources.
3. To find mathematical method for calculations and weather data of extractable energy from solar energy for 7 consecutive days of selected places to be used in TRNSYS.
4. To find best analysis procedure for economic assessment of the proposed system.
5. Modelling of thin film and monocrystalline photovoltaic solar system using TRNSYS.
6. Compute TRNSYS modeling of energy output based on meteorological data analysis and PV panel’s parameters.
7. Make a comparison between output energy results between monocrystalline and thin film with inverter system.

8. Evaluation of 25 years life cycle economic potential of sites based on energy output capacity.

9. Conclusions and recommendations.

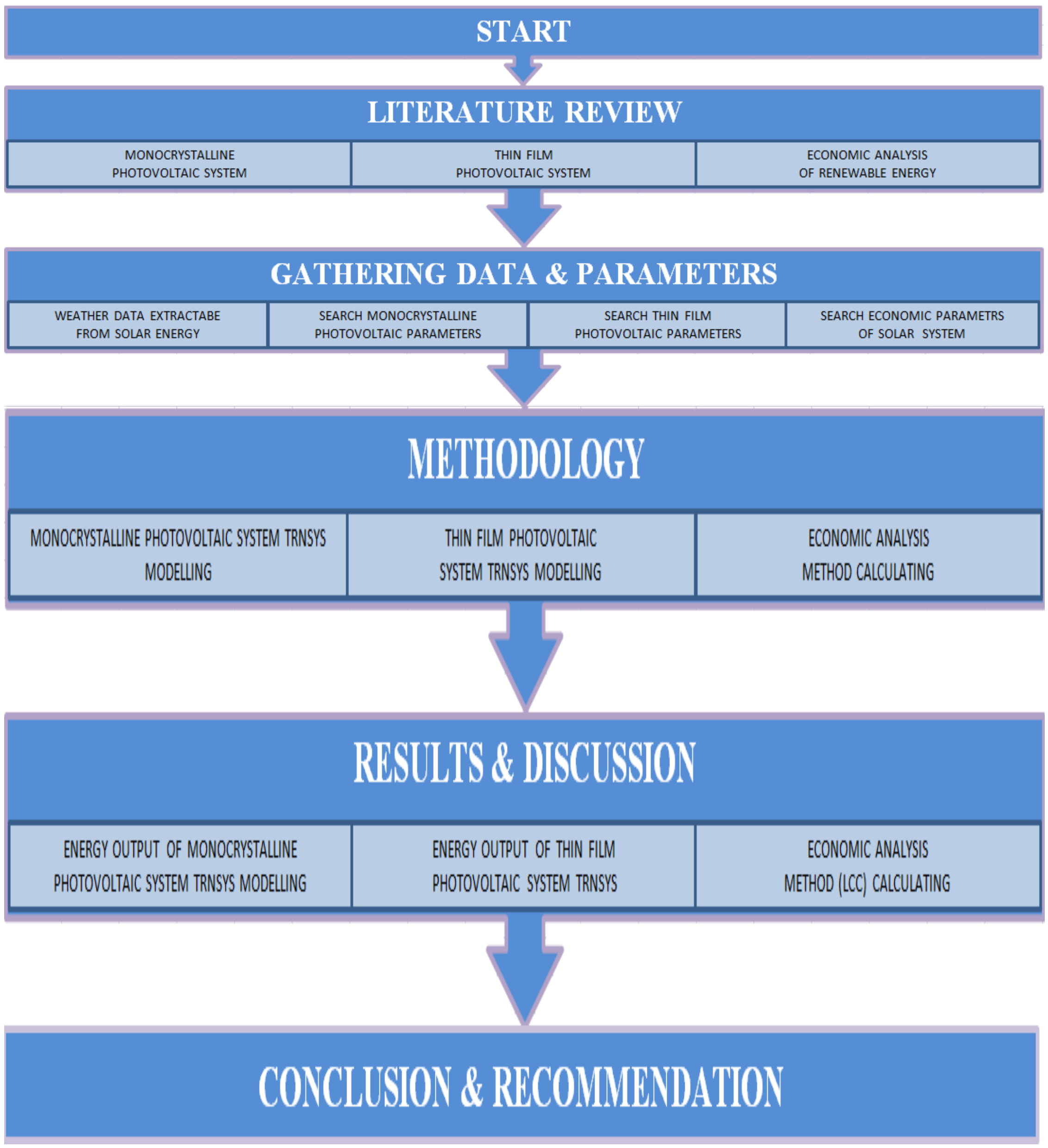



Figure 3.1: Methodology step in “TRNSYS Simulation and Economic Analysis”

## 3.1 Solar Data Simulation Modeling

In this study, TRNSYS, a transient simulation system were utilized to do the simulation of the Photovoltaic with inverter system to compute the energy output from monocrystalline and thin film photovoltaic type. TRNSYS had been escalated its competency in simulation of complex task with its modular structure, which offer flexibility in the system (Klein et al., 2006). In this TRNSYS simulation modeling, the input data file consisted of extractable solar data collected from Malaysia meteorology department and software (Meteonorm as well as online GAISMA).

### 3.1.1 Solar Energy

To find solar energy extractable data, some equations were considered to be used as well as had been utilized in TRNSYS simulation to give the best output results. The list shown below is some of the formulas that had taken part in this study to give a proven result.

### 3.1.2 Solar incident radiation

Irradiance draw from solar radiation is called insolation. Irradiance is the energy of solar radiation per unit area (radioactive flux) incident on a surface. Radiant emittance or radiant existence is the power per unit area radiated by a surface (Quaschning et al., 2003). The SI units for all of these quantities are watts per square meter ($W/m^2$). The total irradiance incident on a surface has its main components which are beam, diffuse, and ground reflected (Philibert et. 2008).

### 3.1.3 Beam radiation

The beam radiation (*Gb*), is the solar radiation delivered from the sun non-shattered by the atmosphere. *Gb* is also known as direct solar radiation. It can be calculated from Equation (1) given below:

$$G_b = G_{bn} \cos\theta_z \tag{1}$$

### 3.1.4 Diffuse radiation

The solar radiation once the scattering by the atmosphere, subsequently changed the direction. This radiation is known as diffuse radiation ($G_d$). $G_d$ also called as sky radiation or solar sky radiation. Pyranometer, a tracking device that could determine the diffuse radiation once shields the beam irradiance or if the total irradiance is known. A pyranometer can be employed to determine broadband solar irradiance on a planar surface. It can also be a sensor to determine the solar radiation flux density (W/m$^2$) from a field of view of 180 degrees (University of Oregon, 2006). Diffuse radiation calculated by Equation (2) given below:

$$G_d = G - G_b \tag{2}$$

In this study, the radiation processor utilized by weather data reader component in TRNSYS was applied to predict the total, beam and diffuse radiations of the in plane insolation from the total horizontal insolation (Soto, 2004). Two different global-diffuse correlation models were applied in the diffuse components of global horizontal insolation to be computed in TRNSYS modeling. This is given by Equation (3):

$$I_D/I_G = 1.020 - 0.254k_T + 0.012 \sin \Phi \quad for\ 0 \leq k_T \leq 0.3 \quad and\ I_D/I_G \leq 0.1$$

or

$$I_D/I_G = 1.400 - 1.749k_T + 0.177 \sin \Phi \quad for\ 0.3 \leq k_T \leq 0.78 \quad and\ 0.1 \leq I_D/I_G \leq 0.97$$

or

$$I_D/I_G = 0.486k_T - 0.082 \sin \Phi \quad for\ 0.78 \leq k_T \leq 0.1 \quad and\ 0.1 \leq I_D/I_G \tag{3}$$

Meanwhile, a site specific global-diffuse correlation model developed utilized long term hourly global and diffuse data to be modelled in TRNSYS were collected from Malaysia meteorology department and software Meteonorm as well as online GAISMA (Reindl et al, 1990). This is given by Equation (4):

$$I_D/I_G = 0.98 \quad for\ k_T \leq 0.2$$

or

$$I_D/I_G = 0.5836 + 3.625k_T - 10.171k_T^2 + 6.338k_T^3 \quad for\ k_T \leq 0.2 \tag{4}$$

### 3.1.5 Ground reflected radiation

Ground reflectance factor ($\rho_g$) of the surroundings becomes the important part for the ground reflected component to be reliant. In other words, it depended on the where the photovoltaic were to be located. The value of the ground reflectance factor normally differ from 0 (dark, non-reflective ground) to 0.7 (fresh snow on the ground). The ground reflectance factor can be computed together with the total irradiance on the tilted surface ($G_T$), the total horizontal irradiance ($G$), and the normal beam irradiance ($G_{bn}$). Equation (1) and Equation (2) also related and must be counted in to be computed in Equations (5) given below:

$$G_T = G_b \times R_{beam} + G_d \left[\frac{1 + cos(\beta)}{2}\right] + \rho_g \times G \left[\frac{1 - cos(\beta)}{2}\right] \tag{5}$$

If the total irradiance on the tilted surface could not be discovered, $\rho_g$ can be estimated. Most energy engineers can do the estimation based on their experience. In TRNSYS modeling, the incident insolation for an inclined surface was estimated using four tilted surface radiation models: one isotropic sky model (Liu et al., 2006) and three anisotropic sky models (Reindl et al., 2006, Hay et al., 2010, and Perez et al, 2010). A non-tracking mode was considered to compute insolation on the fixed surface. In this TRNSYS modeling, ground reflectance utilized is default to 0.2 in the system which is the located area is not covered by snow. In a previous study of ground reflected radiation, 0.2 as the default value to be used in TRNSYS modeling has shown to generate trustworthy results (Ineichen, 1990).

### 3.1.6 Effective radiation

There are 3 main important components to find the effective irradiance ($G_{eff}$) incident on a surface. These 3 components had been explained in above writing which is beam, diffuse, and ground reflected. $G_{eff}$ is reliant on the slope ($\beta$) of the surface with respect to the horizontal of earth position. $G_{eff}$ can be computed by Equation (6) given below:

$$G_{eff} = G_b \times R_{beam} \times K_{\tau\alpha} + (G_d \times K_{\tau\alpha}) \left[\frac{1 + cos(\beta)}{2}\right] + (\rho_g \times G \times K_{\tau\alpha}) \left[\frac{1 - cos(\beta)}{2}\right] \quad (6)$$

In this study, this component was extractable from Meteornorm software to be using in TRNSYS Modelling.

### 3.1.7 Data of Solar Energy

The example of the solar energy extraction data from online Gaisma based on the formula above is shown below. The data was collected through Meteornorm software and Gaisma online solar energy data. Refer Appendix A for more detailed information which shows all extractable solar data from online Gaisma and Meteornorm software for Kuala Lumpur, Pulau Pinang and Kelantan in 7 consecutive days as Table 3.1 below:

| | | | |
|---|---|---|---|
| Location | : | Kuala Lumpur | |
| Latitude | : | +3.16 | (3°09'36"N) |
| Longitude | : | +101.71 | (101.71°42'36"E) |
| Time zone | : | UTC 8 hours | |
| Local time | : | 22:20:18 | |
| Country | : | Malaysia | |
| Continent | : | Asia | |
| Sub-region | : | South-Eastern Asia | |
| Altitude | : | 60m | |

Table 3.1: Data of solar energy (NASA Langley Research Center Atmosphere Science Data Center, 2002)

| **Hour** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Insolation, kWh/m$^2$/day** | 4.29 | 5.06 | 5.22 | 5.33 | 5.08 | 4.91 | 4.87 | 4.99 | 5.04 | 4.83 | 4.21 | 3.77 |
| **Clearness, 0-1** | 0.45 | 0.50 | 0.50 | 0.52 | 0.51 | 0.51 | 0.50 | 0.50 | 0.49 | 0.48 | 0.43 | 0.4 |
| **Temperature, ºC** | 24.35 | 24.98 | 25.62 | 26.07 | 26.10 | 25.73 | 25.34 | 25.39 | 25.50 | 25.73 | 25.26 | 24.58 |
| **Wind Speed, m/s** | 3.56 | 2.97 | 2.61 | 1.61 | 1.58 | 2.58 | 2.58 | 2.78 | 2.17 | 1.72 | 2.58 | 3.56 |
| **Precipitation, mm** | 147 | 137 | 218 | 264 | 210 | 130 | 141 | 154 | 190 | 268 | 278 | 232 |
| **Wet days, d** | 14.80 | 14.60 | 17.20 | 19.60 | 16.20 | 12.30 | 14.20 | 15.40 | 18.20 | 22.10 | 24.80 | 21.10 |

## 3.2 Photovoltaic array with inverter output modeling

Photovoltaic array with inverter model in TRNSYS was utilized to predict the PV array output. The modeling of TRNSYS PV with inverter system in this study used the PV module the ‘four parameter’ equivalent circuit model, which considers a PV cell as an ‘‘ideal’’ irradiance dependent current source in parallel with a diode (Klein et al., 2006). The four parameters are module photocurrent at reference conditions ($I_{L,ref}$), diode reverse saturation current at reference conditions ($I_{o,ref}$), empirical diode PV curve fitting factor ($d_1$) and module series resistance ($R_S$) (Beckman, 2006). The total current (I) is calculated as the equation (7) as below (Townsend, 1989):

$$I = I_L - I_O \left[ exp \left( \frac{q}{d_1 k_T c} (V + IR_S) - 1 \right] \qquad (7)$$

I–V characteristic of the four parameters model is expressed by the above expression. PV cell that was used in this study employed unchanging values of the parameters $d_1$ and $R_S$. The photocurrent ($I_L$) is linearly proportional to the incident radiation. $I_L$ can be computed by Equation (8) given below:

$$I_L = I_{L,ref} \frac{I_T}{I_{L,ref}} \tag{8}$$

The reverse saturation current ($I_O$) is presented by the terms of material characteristics and PV module temperature ($T_C$). $I_O$ can be computed by Equation (9) given below:

$$I_O = DT_C^3 \exp\left(\frac{-q\varepsilon}{dk\,Tc}\right) \tag{9}$$

(Io) is also reverse saturation current. $I_O$ either can be computed by Equation (9) or Equation (10) given below:

$$I_O = I_{O,ref}\left(\frac{Tc}{Tc,ref}\right)^3 \tag{10}$$

By assumption the current and voltage at open circuit, current (I) is zero given by Equation (11).

$$0 = I_{L,ref} - I_{O,ref}\left[\exp\left(\frac{qV_{oc,ref}}{d_1kT_{C,ref}}\right) - 1\right] \tag{11}$$

By assumption voltage (V) is zero; short circuit can be calculated by Equation (12).

$$I_{SC,ref} = I_{L,ref} - I_{O,ref}\left[\exp\left(\frac{qI_{sc,ref}RS}{d_1kT_{C,ref}}\right) - 1\right] \tag{12}$$

The maximum power point can be calculated by Equation (13).

$$I_{MP,ref} = I_{L,ref} - I_{O,ref}\left[exp\left(\frac{q}{d_1 kT_{C,ref}}\right)(V_{MP,ref} + I_{MP,ref}RS) - 1\right] \quad (13)$$

By assumption the magnitude of the reverse saturation current ($I_o$) is very small, frequently of the order of $10^{-5}$ or $10^{-6}$. The term of $I_o$ can be neglected in previous Equation (7). By assumption the exponential term (exp) is very small. The term of exponential can be neglected in previous Equation (12). The parameter $R_S$ is found from the temperature coefficients of the open circuit voltage and short circuit current. The values of these temperature coefficients are obtainable from PV module parameters that had been given by manufacturer. The analytical derivative of voltage with respect to temperature at the reference open circuit condition is corresponding to the open circuit temperature coefficient of the voltage (APERC, 2000). By the assumptions of $I_o$ and exponential is neglected had been made, Equation (14), Equation (15) and Equation (16) come out as below:

$$I_{L,ref} \approx I_{SC,ref} \quad (14)$$

$$d_1 = \frac{q\,(V_{MP,ref} + I_{MP,ref}RS)}{kT_{C,ref}\ln\left(1 - \frac{I_{MP,ref}}{I_{SC,ref}}\right)} \quad (15)$$

$$I_{O,ref} = \frac{I_{SC,ref}}{\exp\left(\frac{qVo_{C,ref}}{d_1 kT_{C,ref}}\right)} \quad (16)$$

From iterative search routine in the Equation (13) till Equation (16), the computation of equivalent circuit characteristics parameters can be made. The incident angle modifier (IAM) is expressed as the ratio of the radiation absorbed by a PV array to the radiation that is perpendicular to normal incidence. Reflection loss due to the angle of incidence of radiation on the array surface had been considered in the equation of IAM. IAM can be calculated by Equation (17).

$$IAM = \frac{(\tau\alpha)}{(\tau\alpha)_{\mathrm{normal}}} \quad (17)$$

The total effective insolation on the array surface, $I_{Teff}$ is represented by Equation (18) as below:

$$I_{\mathrm{Teff}} = \tau\alpha \left(I_{\mathrm{bT}} IAM_{\mathrm{b}} + I_{\mathrm{dT}} IAM_{\mathrm{d}} + I_{\mathrm{rT}} IAM_{\mathrm{g}}\right) \quad (18)$$

In this TRNSYS PV with inverter system employed maximum power point tracking, the PV output was modelled at the maximum power point (MPP) as well produced the energy output (Wh/day). In this TRNSYS modelling, the PV module operating temperature is modelled in related to the nominal operating cell temperature (NOCT) (Duffie et al, 1991). PV module operating temperature can be calculated by Equation (19) given below:

$$T_{\mathrm{C}} = T_{\mathrm{A}} + \frac{I_{\mathrm{T}}}{I_{\mathrm{T,NOCT}}}\left(T_{\mathrm{C,NOCT}} - T_{\mathrm{A,\,NOCT}}\right)\left(1 - \frac{\eta_{\mathrm{c}}}{\tau\alpha}\right) \quad (19)$$

In this study, by taking into account correlation of measured module, ambient temperatures and incident insolation data in previous equation, a module temperature equation had been predicted. The module temperature equation is given by equation (20). It was found that there is a slight difference between module temperature equation calculation given by Equation (19) and Equation (19) (PV resources, 2000). In previous study, the Equation (19) is more selectable to give reliable output results (Meyer, 2000).

$$T_C = T_A + 0.031 I_T \quad (20)$$

### 3.2.1 TRNSYS Photovoltaic with Inverter Modeling

PV-module with inverter components utilized in TRNSYS can obtain the energy output of a photovoltaic array (SEL-UW, 2005). This component had a reliable calculation method which had been presented by previous comprehensive study (Soto et al, 2005). This component can also predict the power and current of array at specified voltage. In this study, this component will process and produce the energy output depended on the weather data which provided by weather data reader which had been discussed earlier in this chapter. The PV module and array characteristic parameters used in the study are shown in Table 3.3 below. In this study, these parameters were taken from PV manufacturer datasheet or catalogue of their product and some value of solar energy extractable data are used on TRNSYS modelling simulation. Refer to Table 3.4 and Table 3.5 for detailed manufacturer data of their monocrystalline and thin film PV. For the inverter, also refer to Appendix B for more details of its characteristic parameter. The characteristic of selecting PV module to utilize in this TRNSYS was based on the limitation of study as Table 3.2 below:

Table 3.2: Characteristic of selected PV module

| No | Parameter | Unit |
|---|---|---|
| 1 | Nominal voltage | 24V |
| 2 | Maximum power output range | 170W-200W |
| 3 | cells nos | 72 |
| 4 | CSI listed | - |

In this study, CSI listed module had only been chosen because they had gone through PCT. PCT is PVUSA Test Conditions; which has test and comparison process that should be gone through by PV systems. PTC is 1,000 Watts per square meter solar irradiance, 20 degrees C air temperature, and wind speed of 1 meter per second at 10 meters above ground level. PV manufacturers use Standard Test Conditions, or STC, to rate their PV products. STC is 1,000 Watts per square meter solar irradiance, 25 degrees C cell temperature, air mass equal to 1.5, and ASTM G173-03 standard spectrum (CEC, 2007). Actual solar systems will produce lower output due to soiling, shading, module mismatch, wire losses, inverter and transformer losses, shortfalls in actual nameplate ratings, panel degradation over time, and high-temperature losses for arrays mounted close to or integrated within a roofline. These loss factors can vary according to season, geographic location, mounting technique, azimuth, and array tilt (NREL, 2009).

Table 3.3: TRNSYS component's parameters characteristic of PV module with inverter

| No | Parameter Characteristic | Unit |
|---|---|---|
| 1 | Module short circuit current at reference conditions | Ampere (A) |
| 2 | Module open circuit voltage at reference conditions | Voltage (V) |
| 3 | Temperature at reference conditions | Kelvin (K) |
| 4 | Irradiance at reference conditions | Watt per meter square ($Wm^{-2}$) |
| 5 | Maximum power point voltage at reference conditions | Voltage (V) |
| 6 | Maximum power point current at reference conditions | Ampere (A) |
| 7 | Temperature coefficient of short circuit current | Ampere per Kelvin (AK-1) |
| 8 | Temperature coefficient of open circuit voltage | Ampere per Kelvin (AK-1) |
| 9 | Module temperature at NOCT conditions | Kelvin (K) |
| 10 | Ambient temperature at NOCT conditions | Kelvin (K) |
| 11 | Insolation at NOCT conditions | Watt per meter square ($Wm^{-2}$) |
| 12 | Transmittance–absorptance product at normal incidence | - |
| 13 | Semiconductor bandgap | (eV) |
| 14 | Number of cells in the module connected in series | - |
| 15 | Number of modules in series in each sub-array | - |
| 16 | Number of sub-arrays in parallel | - |
| 17 | Individual module area | Meter square ($m^2$) |
| 18 | Value of parameter at reference conditions | - |
| 19 | Value of $I_L$ at reference condition | Ampere (A) |
| 20 | Value of $I_O$ at reference condition | Ampere (A) |

Table 3.4: Parameter of Monocrystalline Photovoltaic from manufacturer

| Brand | MP-170WP (170W) Ningbo Maxsolar | 170/5ME (170W) mega solar | TSM-170DA01 (170W) TRINA SOLAR | WXS175S (175W) Wanxiang |
|---|---|---|---|---|
| **Electrical Characteristics** | | | | |
| **STC Power Rating** | 170W | 170W | 170W | 175W |
| **PTC Power Rating** | 149.7W | 151W | 150.6W | 157.6W |
| **STC Power per unit of area standard test condition** | 12.4W/ft$^2$ (133.2W/m$^2$) | 12.4W/ft$^2$ (133.2W/m$^2$) | 12.3W/ft$^2$ (132.9W/m$^2$) | 12.7W/ft$^2$ (137.1W/m$^2$) |
| **Peak Efficiency** | 14% | 13.32% | 13.30% | 13.71% |
| **Power Tolerances** | -1 | 0%/+3% | -1 | not available |
| **Number of Cells** | 72 | 72 | 72 | 72 |
| **Nominal Voltage (references)** | 24V | 24V | 24V | 24V |
| **current at max power point Imp** | 4.75A | 4.85A | 4.76A | 4.9A |
| **voltage at max power point, Vmp** | 35.8V | 35V | 35.8V | 35.71V |
| **short-circuit current Isc** | 5.05A | 5.2A | 5.25A | 5.5A |
| **Open-circuit voltage Voc** | 44.2V | 43.4V | 43.6V | 43.6V |
| **module temp NOCT** | 49.5°C | 48°C | not available | 48°C |
| **Temperature coefficient of Isc Temp. Coefficient of Power** | -0.47%/C | -0.44%/C | -0.45%/C | -0.5%/C |
| **Temperature coefficient of VocTemp. Coefficient of Voltage** | -0.168V/C | -0.148V/C | -0.153V/C | -0.144V/C |
| **Series Fuse Rating** | 15A | 10A | 9A | 15A |
| **Maximum System Voltage** | 1000V | 600V | 600V | 600V |
| **Mechanical Characteristics** | | | | |
| **Type** | Monocrystalline Silicon | Monocrystalline Silicon | Monocrystalline Silicon | Monocrystalline Silicon |
| **Output Terminal Type** | Multicontact Connector Type 4 | Multicontact Connector Type 4 | Tyco SolarLok Connector | Multicontact Connector Type 4 |
| **Frame Color** | Silver (Clear) | Silver (Clear) | Silver (Clear) | Silver (Clear) |
| **Length (mm)** | 1.58 | 1.58 | 1.581 | 1.58 |
| **Width (mm)** | 0.808 | 0.808 | 0.809 | 0.808 |
| **Depth** | 1.4in (35mm) | 2in (50mm) | 1.6in (40mm) | 1.6in (40mm) |
| **Weight** | 33.1lb (15kg) | 34.2lb (15.5kg) | 34.4lb (15.6kg) | 34.2lb (15.5kg) |
| **Warranty and Certifications** | | | | |
| **80% Power Output Warranty Period** | 20yrs | 30yrs | 25yrs | not available |
| **90% Power Output Warranty Period** | not available | 12yrs | not available | not available |
| **Workmanship Warranty Period** | 5yrs | 10yrs | 5yrs | not available |
| **CSI Listed** | Yes | Yes | Yes | Yes |
| **Module area (m$^2$)** | 1.28 | 1.28 | 1.28 | 1.28 |

Table 3.5: Parameter of Thin Film Photovoltaic from manufacturer

| Brand | SL-001-173 (173W) | SL-001-182 (182W) | SL-001-191 (191W) |
|---|---|---|---|
| **Electrical Characteristics** | | | |
| **STC Power Rating** | 173W | 182W | 191W |
| **PTC Power Rating** | 162.8W[1] | 171.4W[1] | 179.9W[1] |
| **STC Power per unit of area** | 8.2W/ft$^2$ (88.0W/m$^2$) | 8.6W/ft$^2$ (92.6W/m$^2$) | 9.0W/ft$^2$ (97.2W/m$^2$) |
| **Peak Efficiency** | 8.80% | 9.26% | 9.72% |
| **Power Tolerances** | -1 | -1 | -1 |
| **Number of Cells** | not available | not available | not available |
| **Nominal Voltage** | not applicable | not applicable | not applicable |
| **Imp** | 2.41A | 2.46A | 2.51A |
| **Vmp** | 71.7V | 73.9V | 76.1V |
| **Isc** | 2.75A | 2.76A | 2.77A |
| **Voc** | 95.2V | 96.7V | 98.2V |
| **NOCT** | 41.7°C | 41.7°C | 41.7°C |
| **Temp. Coefficient of Power** | -0.38%/C | -0.38%/C | -0.38%/C |
| **Temp. Coefficient of Voltage** | -0.276V/C | -0.28V/C | -0.285V/C |
| **Series Fuse Rating** | 23A | 23A | 23A |
| **Maximum System Voltage** | 600V | 600V | 600V |
| **Mechanical Characteristics** | | | |
| **Type** | Cylindrical CIGS | Cylindrical CIGS | Cylindrical CIGS |
| **Output Terminal Type** | Tyco SolarLok Connector | Tyco SolarLok Connector | Tyco SolarLok Connector |
| **Frame Color** | Silver (Clear) | Silver (Clear) | Silver (Clear) |
| **Length** | 71.7in (1,820mm) | 71.7in (1,820mm) | 71.7in (1,820mm) |
| **Width** | 42.5in (1,080mm) | 42.5in (1,080mm) | 42.5in (1,080mm) |
| **Depth** | 2in (50mm) | 2in (50mm) | 2in (50mm) |
| **Weight** | 68.3lb (31kg) | 68.3lb (31kg) | 68.3lb (31kg) |
| **Warranty and Certifications** | | | |
| **80% Power Output Warranty Period** | 25yrs | 25yrs | 25yrs |
| **90% Power Output Warranty Period** | not available | not available | not available |
| **Workmanship Warranty Period** | 5yrs | 5yrs | 5yrs |
| **CSI Listed** | Yes | Yes | Yes |

### 3.2.2 Inverter output modeling

In previous work, inverter efficiency is assumed to be constant (Klein et al, 2006) Meanwhile in real operating conditions, inverter efficiency is a function of input power to the inverter. Inverter output can be computed by Equation (21) and Equation (22) given below:

$$P_{inv,n} = k_0 + k_1 P_{pv,n} + k_2 P_{pv,n}^2 \tag{21}$$

$$where\ P_{pv,n} = \frac{P_{pv}}{P_{inv,rated}}\ and\ P_{inv,n} = \frac{P_{inv}}{P_{inv,rated}} \tag{22}$$

In this TRNSYS modelling system study, as taken from the correlation relating inverter efficiency as a function of fractional load to the inverter, the coefficients $k_0$, $k_1$ and $k_2$ were predicted to be -0.015, 0.98 and -0.09 (Jayanta, 2006). The input to this component was the predicted PV output obtained from the photovoltaic array component.

## 3.3 Photovoltaic energy Calculation methods

This is the most important part of this study. In this study, a formulation method had been used for electrical energy production by solar panels by using PV parameters characteristics from manufacturer then its simulation had been in TRNSYS. By applying the data of mean hourly global radiation and including factors related to PV panel characteristics which were collected from Malaysia meteorology department and software

(Meteonorm as well as online GAISMA), energy output was calculated and produced in TRNSYS.

### 3.3.1 TRNSYS Energy Calculation

The intensity, angle of the sun, the load matching for maximum power and the operating temperature become the main factors to give a great impact in designing the solar panel (Sajad, 2010). The calculation of PV power output has high level of difficulty and takes into account all information and factors. In this study, solar energy generation, *Esolar* was obtained, supported by the actual weather data mean daily global irradiances in 7 consecutive days for selected places. *Esolar* can be computed by Equation (23) as given below:

$$E_{\mathrm{solar}} = G_{\mathrm{s}} \times A_{\mathrm{s}} \times \eta_{\mathrm{ps}} \times K \tag{23}$$

After all data, parameter characteristic and equations were analyzed as described previously, the TRNSYS modelling was conducted to predict the energy output for Monocrsytalline and thin film PV with inverter system.

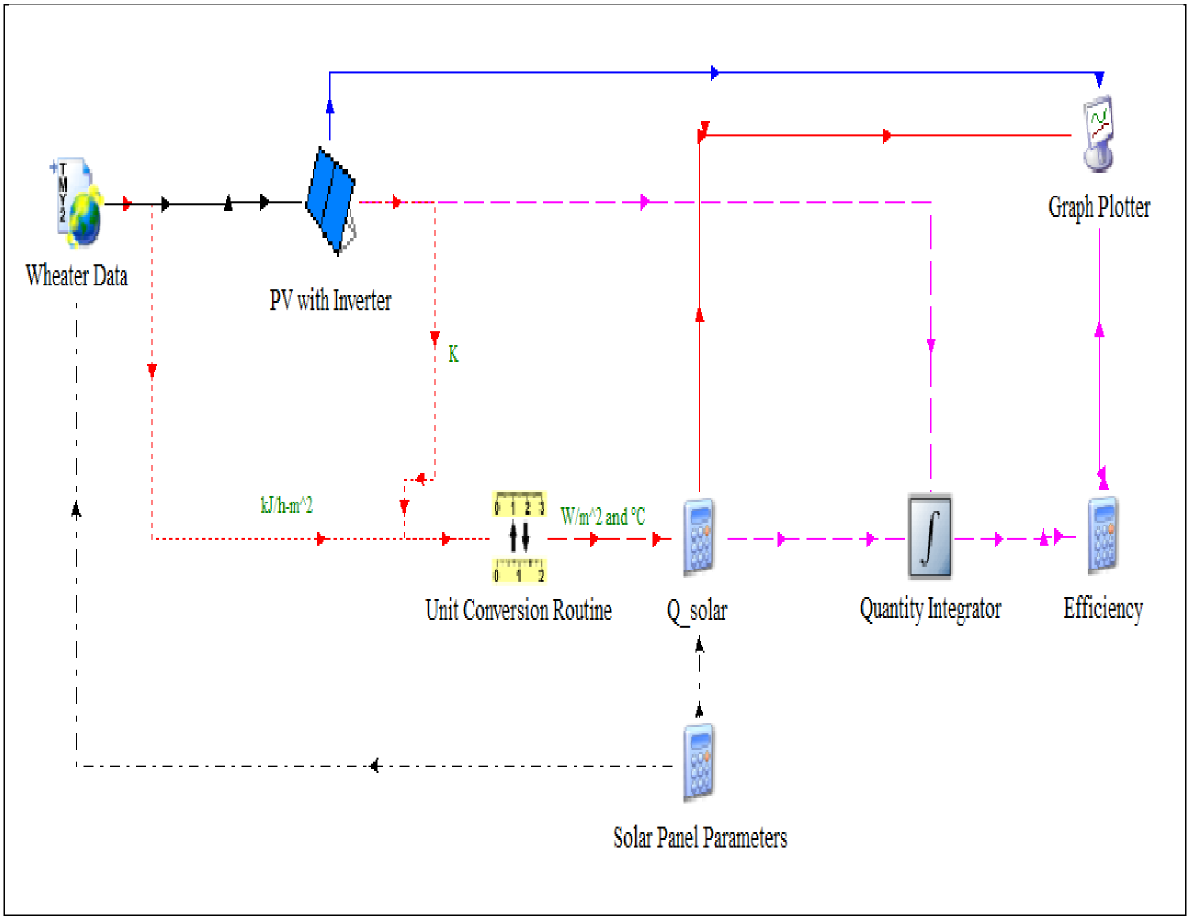



Figure 3.2: TRNSYS model of Photovoltaic with an inverter system

The Figure 3.2 above shows the TRNSYS simulation calculating the energy produced by a PV module with an inverter system which is being utilized in this study. In this model, PV modules and the inverter system will operate at a maximum power point for the given solar radiation condition.

## 3.4 Economic Analysis

At the present time, many economic criteria have been planned and used for assessment and optimization of the renewable energy systems (Chandrasekar, 2003, Dalimin 1994, Kablan , 1994 and Ozsabuncuoglu, 1995). To this day, there is no standard agreement on which method should be used. In this study, the characteristic of this analysis is the solar photovoltaic energy with inverter system parallel with urban grid of electrical. Initial capital and payback period for installation, maintenance and operation of the renewable energy system are the crucial factors to be considered by the domestic users.

In general, renewable energy systems usually have a high capital cost but very small operation costs compared to the existing energy system. The cost of the renewable energy development is necessary to include many factors such as interest rate on money, property and income taxes, equipment future value, maintenance, insurance, current and future rate of electricity and other maintenance costs. Government may allow a special tax credit to encourage the use of green energy (Jaafar, 2005). It is shown below the method of solar energy calculation for 25 years life cycle based on LCC method.

Photovoltaic savings (*PVS*) is the difference of the cost of a unit of produced energy (*CPE*) and domestic tariff rate (*DTR*) by Tenaga Nasional Berhad rate of electricity (TNB Report, 2009 and 2010) which is given in kWh by Equation (24) as stated below:

$$PVS = DTR - CPE \qquad (24)$$

The mortgage payment consists of principal payment and rate of interest of money in the future for system installation. In order to ensure the system is in a proper operation, there are periodic costs such as operation and maintenance, which are necessary to be paid. Income tax savings for the system can be calculated (Beckman et al, 1980) by Equation (25) as given below:

$$ITS = DTR \times (IP + PT) \tag{25}$$

In this study, the calculation of the present worth factor (*PWF*) was computed to obtain the total gain of the system. The considerations that had been made are, in every year, the payment is been compensated and inflates at an increasing rate. PWF of the payments can be calculated by Equation (26) as given below:

$$PWF\ (N, i\ , d) = \sum_{j=1}^{N} {(1\ + i)^{j-1}}\Big/{(1 + d)^{j}} \tag{26}$$

PV is used to return the value of the future payments or incomes on a given period to present value (Beckman et al, 1980). In this study, present value (*PV*) of payment or income was calculated for *Nth* period (year) in the future. PV can be calculated by Equation (27) as given below:

$$PV\ \frac{1}{(1+d)^{N}} \tag{27}$$

After that, the net present value (NPV) was computed to determine the sum of the present values of the domestic user cash flow of their investment. Before that, the sum of the geometric series should be done and solved. Refer to Appendix B for more detailed information on the calculation process. *NP* is the period when the initial capital is paid back by the system. After that, *N p* the payback period can be calculated as the Equation (28) as below:

$$Np = \frac{\ln\left[{}^{C_S i_F}/_{fLC_{F1}} + 1\right]}{\ln(1 + i_F)} \qquad (28)$$

Payback period is involved in a lot of different rationale function (PV resources, 2010). Some important times can be discovered by carrying out this economic analysis method. Among of that is the time needed for yearly cash flow to become positive and the cumulative PV saving reaches a minimum, the period of the cumulative energy cost savings to exceed the total initial capital, the period of the solar photovoltaic with inverter system savings to reach zero, the period of the cumulative solar photovoltaic with inverter system saving to the down payment and the period of the cumulative solar photovoltaic with inverter system saving to exceed the remaining debt principal. Refer to Appendix B for more detailed information on the calculation process. The LCC of Photovoltaic with inverter system in Pulau Pinang was evaluated for duration of 25-years. The total energy generation by the photovoltaic with inverter system was simulated by TRNSYS after being evaluated and is tabulated in Table 3.6 below.

Table 3.6: Total energy generation by the photovoltaic with inverter system

| **Pv Type / Place** | Kuala Lumpur | Pulau Pinang | Kota Bharu |
|---|---|---|---|
| Monocrystalline PV (kWh/day) | 1.805 | 3.618 | 3.611 |
| thin film PV (kWh/day) | 0.044 | 0.125 | 0.098 |

As shown by the Table 3.7 below, the total system cost approximately MYR 41634 and was 90% financed for period 25-years at an interest rate of 7%. In the period of the life cycle, it was predicted to compensate general operation and maintenance costing for system each year that increased by 5%.

Table 3.7: PV with inverter system costing

| **Item** | **Unit** | **Size** | **Price (MYR)** |
|---|---|---|---|
| PV monocrystalline | 170 x 8series x 5paralell | 6800 watt | 9747 |
| Inverter sunny boy 5000W | 5000W x 1 | 5000 watt | 11,388 |
| Controller | 1 | | 15,000 |
| Battery | | 24V | 3000 |
| **TOTAL** | | | **39,135** |

Table 3.8: Estimation of overall system costing for 25 year

| Item | **Cost (MYR)** |
|---|---|
| **Photovoltaic Array** | |
| PV cells and inverter and controller | 39,135 |
| Estimated installation | 2500 |
| **Estimated Capital Cost** | 41,635 |
| **Operation and maintenance (O&M)** | |
| PV O&M cost per kWh (RM/Wh) | 0.003 |
| PV O&M cost per day | 16 |
| **Estimated annual O&M costs** | 5,822 |
| **Estimated total cost** | 47,457 |

Complete details of costs are shown in Table 3.8 above. The complete details of interests are shown in Table 8 below. With respect to TNB website 2011, the cost of urban electricity for domestic user rated by Tenaga National Berhad (2008) was MYR 0.22 per kWh. Following to the TNB website in 2011, tariff rate is predicted to grow by 10% per annum. The extra property tax is predicted to be 2% of the total investment cost and it is predicted to grow with a general inflation rate of 4% per year. The effective income tax rate is predicted to be 45% through the period of analysis (Beckman et al, 1980).

Inverters and hybrid controllers need to be replaced after a certain period of time. Hence, they need to be replaced for every 5 years and their price is estimated to increase by 10% per annum (Energy pricing practices, 2010). If the market discount rate is 8%, then the Present Value (PV) of the Photovoltaic with inverter system was calculated for 25-years life cycle. The Table 3.9 below is showing the complete details of interests of PV with inverter system which is being calculated in this study. The loan period will be in the period of the lifetime of the system. Malaysian government supports the development of green energy projects, by reducing extra property taxes or deduction on the mortgage interest rate (Saidur, 2009). In Appendix B all these detailed information is included in the calculation process.

Table 3.9: Complete details of interests of PV with inverter system

| Item | Value |
|---|---|
| Electricity price | MYR 218 |
| Down Payment | 10% |
| Interest rate of electricity price | 10% |
| Interest rate of controller price | 10% |
| Interest rate of inverter price | 10% |
| Interest rate of operation and maintenance | 5% |
| Interest rate of extra properties | 5% |
| Interest rate of principal | 7% |
| Discount factor | 8% |
| Extra property tax (Percentage of principal) | 2% |

# CHAPTER 4

# RESULTS AND DISCUSSION

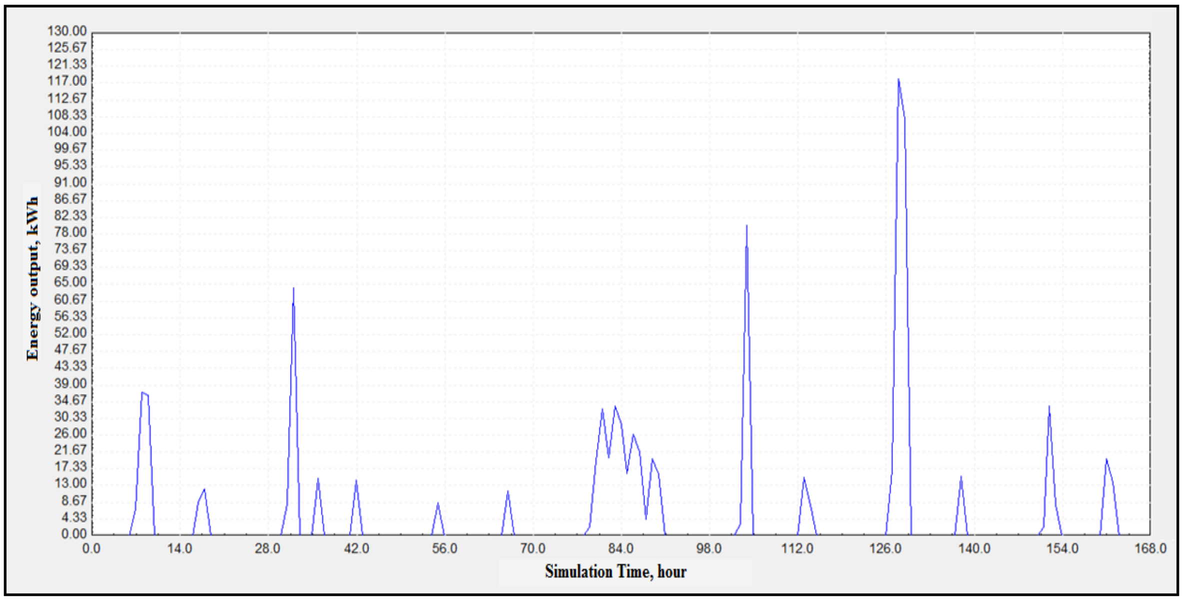
## 4.1 Introduction

This chapter will present all the results that had been obtained from the input data and simulation in TRNSYS which can be referred in the methodology chapter for system references, Appendix C for data references and graphs followed by detailed discussion reasoning, commented upon and comparing with another. The results of TRNSYS simulation's figures in section 4.2, 4.3 and 4.4 illustrated that at the beginning of every day, there was a minor time difference of output. This happened because the inverter began to seek for the maximum power point and waited to create its operation until input power to the inverter reached its threshold demand. Therefore, no PV power was measured at this interval, even though the simulation model predicts a small amount of power even at low insolation level (Jayanta et al, 2006).

## 4.2 Energy output from thin film photovoltaic with inverter system

In this section, the result is the energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in seven consecutive days at the selected places. Details of these results can be referred in Appendix C. The graphs below in this section answer the objective no 1 for this project. These results in this section will also be used to compare with the results of simulation of monocrystalline photovoltaic with inverter.

### 4.2.1 Energy output of thin film photovoltaic with inverter in Kuala Lumpur

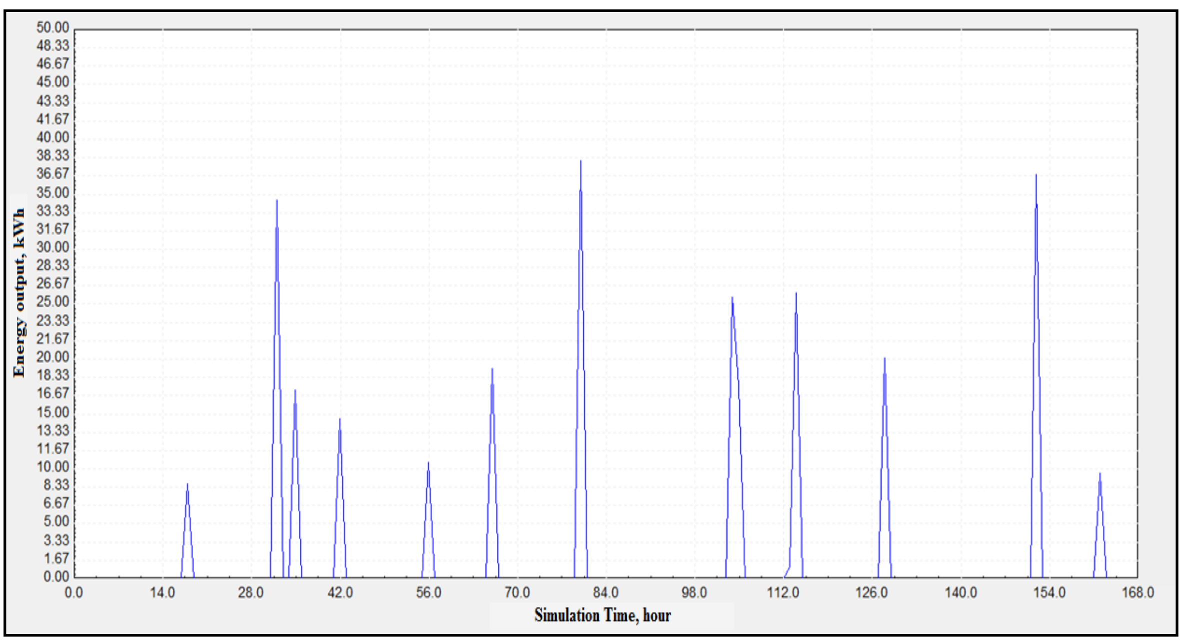



Graph 4.1: Energy output of thin film photovoltaic in Kuala Lumpur

Figure 4.1 shows energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter system using TRNSYS in seven consecutive days at Kuala Lumpur. In the first day, about 12 Wh/day was generated by the simulation which was the lowest energy output that obtained from the system which was lowest mean daily global irradiation. This is proven by other study, which reported lower energy output because of the intensity of the solar radiation is low (Serban et al, 2010). Another study also stated that the global irradiation; weather data can affect the energy output result (Chong et al, 2010). In the 2nd day, there was 72 Wh/day of energy produced by the system. On the next day, the energy produced by the system was 41 Wh/day. On the 4th day, the simulation gave only 27 Wh/day as an outcome of the thin film PV with inverter. In the 5th day, about

29 Wh/day was produced by the TRNSYS simulation. On 6th day, the highest energy produced by the thin film photovoltaic with inverter in Kuala Lumpur which reached 76 Wh/day. This highest energy produced by the TRNSYS simulation since the solar radiation, irradiation, temperature and sun insolation on that day was the highest in the Kuala Lumpur's weather data. This result was similar with other study which found that solar irradiation use to generate heat to be used by solar engine which can increase the output efficiency (Mikhelef et al, 2010). The last day result was 74 Wh/day. The entirety value for this energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in seven consecutive days at the selected place in Kuala Lumpur was 305 Wh/day. This means the average energy produced by thin film photovoltaic with inverter system in this project was 44 Wh/day.

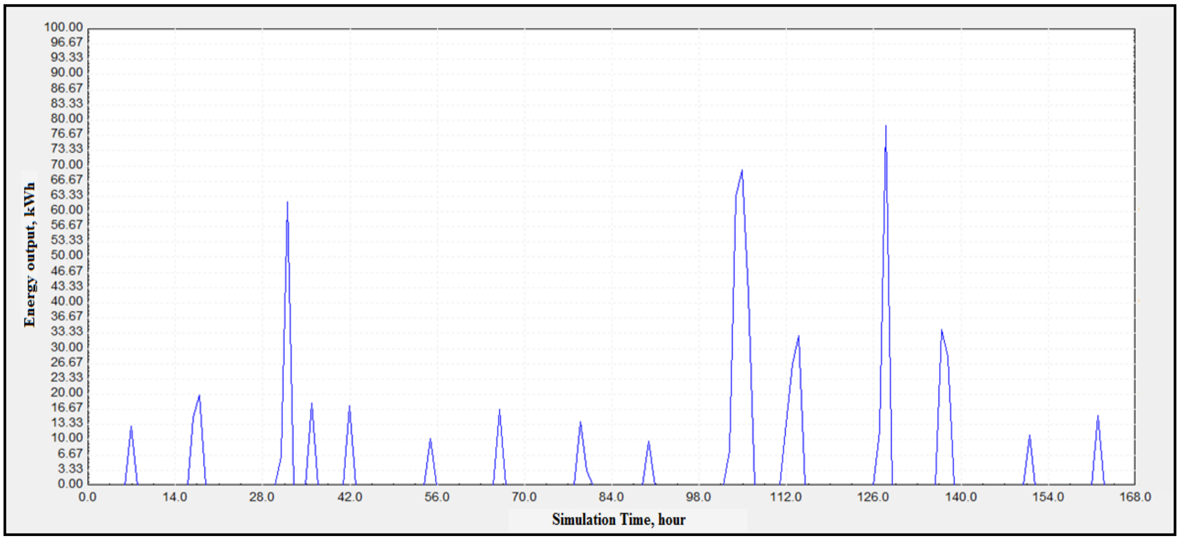
### 4.2.2 Energy output of thin film photovoltaic with inverter in Pulau Pinang




Graph 4.2: Energy output of thin film photovoltaic in Pulau Pinang

Figure 4.2 shows that energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in 7 consecutive days at Pulau Pinang. In the 1st day, about 94 Wh/day was produced by the simulation. In the 2nd day, there were 116 Wh/day of energy generated by the system. In the 3rd day, about 17 Wh/day produced by the TRNSYS simulation which was the energy that was obtained from the system. This happened because the weather data on that day also gave the lowest value in the solar radiation, irradiation, temperature and sun insolation compared to others (Ayu et al, 2008). The next day, the energy produced by the system was 150 Wh/day. On the fifth day, the simulation gave 138 Wh/day as a result of the thin film PV with inverter. On 6th day, the highest energy produced by the thin film photovoltaic with inverter in Pulau Pinang which reached 271 Wh/day. The last day result was 86 Wh/day. The total value for this energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in 7 consecutive days at the selected places in Pulau Pinang was 872 Wh/day. After calculation, the average energy per day generated in Pulau Pinang was 125 Wh/day. The above results can be compared with one of the thesis results which took Thailand as the selected place for solar application estimation. This result gave the similarity which it showed average energy output per day in Thailand was 114 Wh/day in March when they used same PV array like in this study (Jiratkwin, 2008).

### 4.2.3 Energy output of thin film photovoltaic with inverter in Kota Bharu



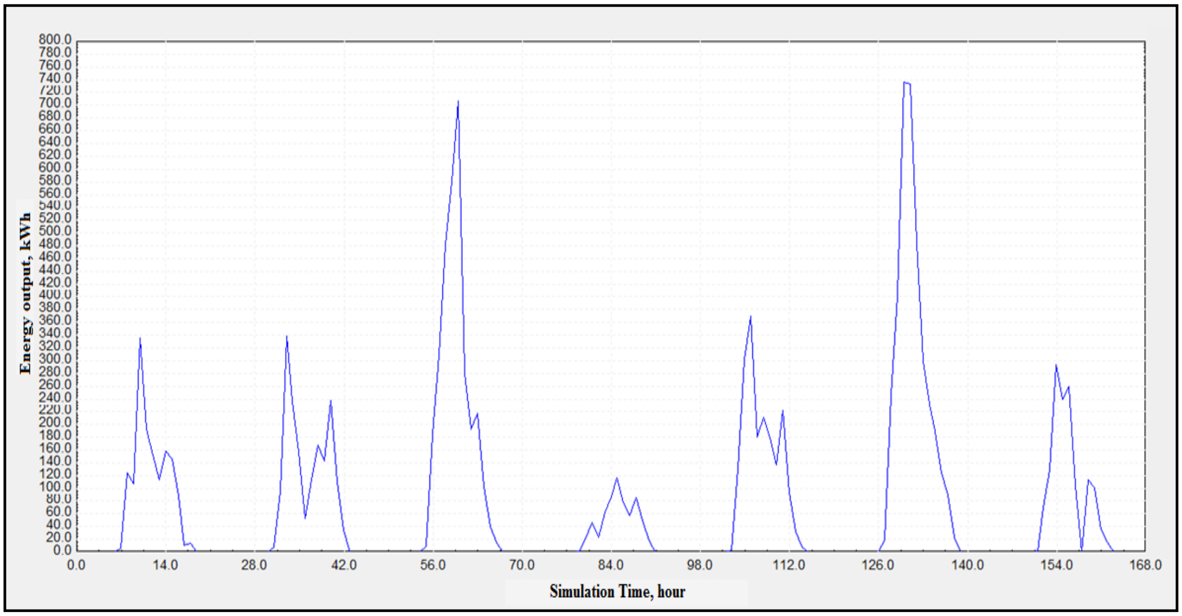

Graph 4.3: Energy output of thin film photovoltaic in Kota Bharu

Figure 4.3 shows potential energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in seven consecutive days at Kota Bharu. In the first day, about 39 Wh/day was produced by the simulation. In the 2nd day, there was 117 Wh/day of energy produced by the system. The next day, the energy produced by the system was 31 Wh/day. On 4th day, the highest energy produced by the thin film photovoltaic with inverter in Kota Bharu which reached 250 Wh/day. This highest energy produced by the TRNSYS simulation because the temperature and sun insolation on that day was the highest in the Kota Bharu's weather data (Solangi et al, 2011). On the 5th day, the simulation only gave 26 Wh/day as a result of the thin film PV with inverter which was the lowest energy that was obtained from the system. In the 6th day, about 181 Wh/day was produced by the TRNSYS simulation. The last day result was 41 Wh/day. The total value for this possible energy (Wh/day) which was produced by simulation of thin film photovoltaic with inverter using TRNSYS in 7 consecutive days at the selected place in Kota Bharu was 686 Wh/day. In other words, average energy produced by thin film photovoltaic with inverter system in this project was 98 Wh/day. This result gave the similarity in other study which showed average energy output per day in Thailand was 114 Wh/day in March (Jiratkwin, 2008).

## 4.3 Energy output of monocrystalline photovoltaic with inverter

In this section, the results were the possible energy (Wh/day) which was produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in seven consecutive days at Kuala Lumpur, Pulau Pinang and Kota Bharu. Details of these results can be referred in Appendix C. The graphs below in this section accomplish the objective no 2 for this project. These results in this section will also be employed to compare with the results of simulation of thin film photovoltaic with inverter which is in the above section.

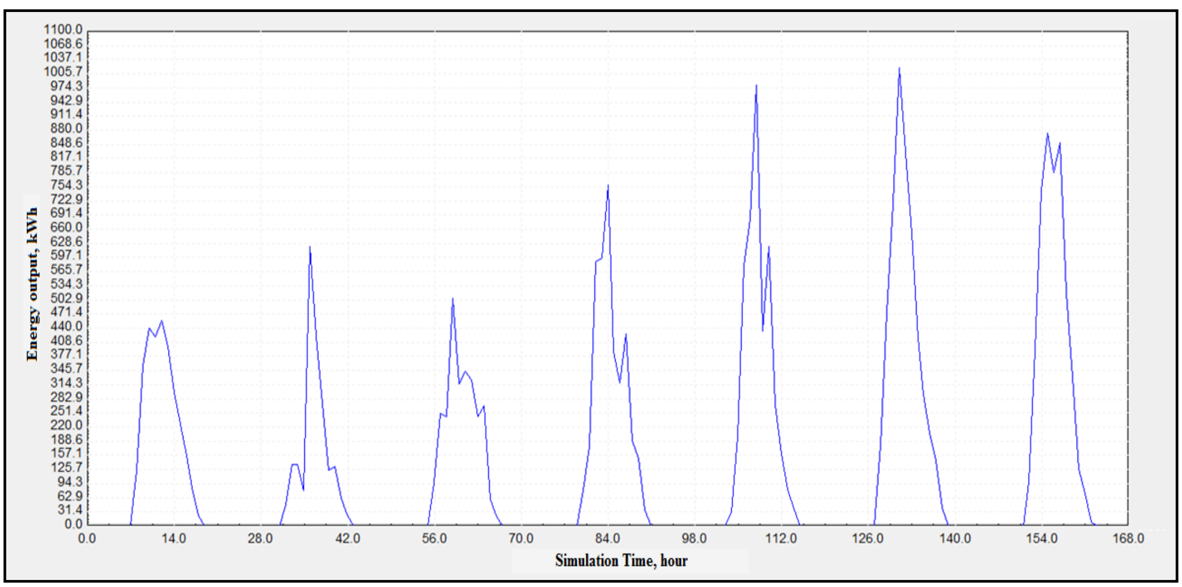
### 4.3.1 Energy output of monocrystalline photovoltaic with inverter in Kuala Lumpur




Graph 4.4: Energy output of monocrystalline photovoltaic in Kuala Lumpur

Figure 4.4 shows possible energy (Wh/day) which was produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in seven consecutive days at the selected place in Kuala Lumpur. In the 1st day, about 1145 Wh/day was produced by the simulation. In the 2nd day, there was 1396 Wh/day of energy produced by the system. The next day, the energy produced by the system was 2803 Wh/day. In the 4th day, about 524 Wh/day is produced by the TRNSYS simulation which was the lowest energy that was obtained from the system. This happened because the weather data on that day also gave a lowest value in the solar radiation, irradiation, temperature and sun insolation comparing to others (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). On the fifth day, the simulation gave 1473 Wh/day as a result of the monocrystalline PV with inverter. On 6th day, the highest energy produced by the monocrystalline photovoltaic with inverter in Kuala Lumpur which reached 4115 Wh/day. This highest energy produced by the TRNSYS simulation because the solar radiation, irradiation, temperature and sun insolation on that day was the highest in the Kuala Lumpur's weather data (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). The last day result was 1177 Wh/day. The total value for this possible energy (Wh/day) which is produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in 7 consecutive days at the chosen place in Kuala Lumpur was 12634 Wh/day. This means average energy produced in Kuala Lumpur was 1805 Wh/day. If the result extends its mean for a year it would generate 659 kWh/year. This is more than enough for a non-residential building electrical power consumption which is according need 987 $m^2$ Malaysian Standard MS1525:2001 for non-residential buildings sets an inferred standard of 130 $kWh/yr/m^2$ (Chan, 2004).

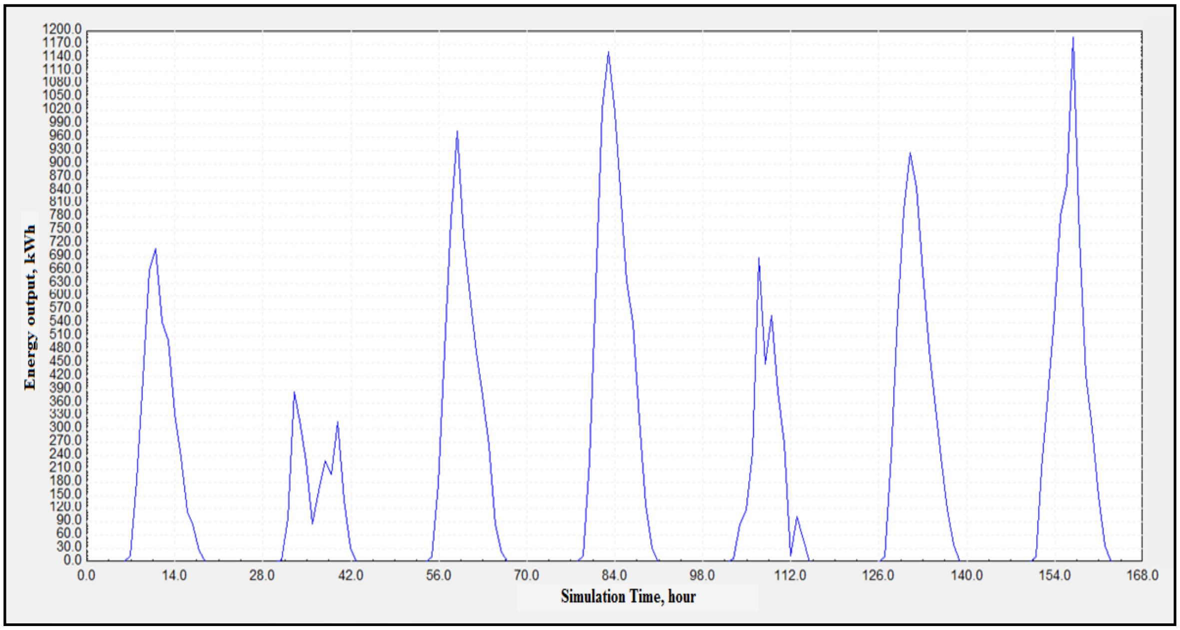
### 4.3.2 Energy output of monocrystalline photovoltaic with inverter in Pulau Pinang




Graph 4.5: Energy output of monocrystalline photovoltaic in Pulau Pinang

Figure 4.5 shows that possible energy (Wh/day) which produced by simulation of monocrystalline photovoltaic with inverter system using TRNSYS in 7 consecutive days in Pulau Pinang. In the first day, about 249 Wh/day was produced by the simulation. In the 2nd day, there was 2590 Wh/day of energy produced by the system. On the 3rd day, the simulation gave 2405 Wh/day as a result of the monocrystalline PV with inverter which was the lowest energy that was obtained from the system. This happened because the weather data on that day also gave a lowest value in the solar radiation, irradiation, temperature and sun insolation comparing to others (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). The next day, the energy produced by the system was 3610 Wh/day. In the 5th day, about 4326 Wh/day was produced by the TRNSYS simulation. On 6th day, the highest energy produced by the monocrystalline photovoltaic with inverter in Pulau Pinang which reached 5930 Wh/day. This highest energy produced by the TRNSYS simulation because the solar radiation, irradiation, temperature and sun insolation on that day was the highest in the Pulau Pinang's weather data (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). The last day result was 4410 Wh/day. The total value for this possible energy (Wh/day) which was produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in 7 consecutive days at the chosen place in Pulau Pinang was 25325 Wh/day. This means average energy produced by monocrystalline photovoltaic with inverter system in this project was 3680 Wh/day. If this result extends for a year it would generate 1343 kWh/year. This is more than enough for a non-residential building electrical power consumption which is according need Malaysian Standard MS1525:2001 for 987 $m^2$ non-residential buildings sets an inferred standard of 130 kWh/yr/$m^2$ (Chan, 2004).

### 4.3.3 Energy output of monocrystalline photovoltaic with inverter in Kota Bharu

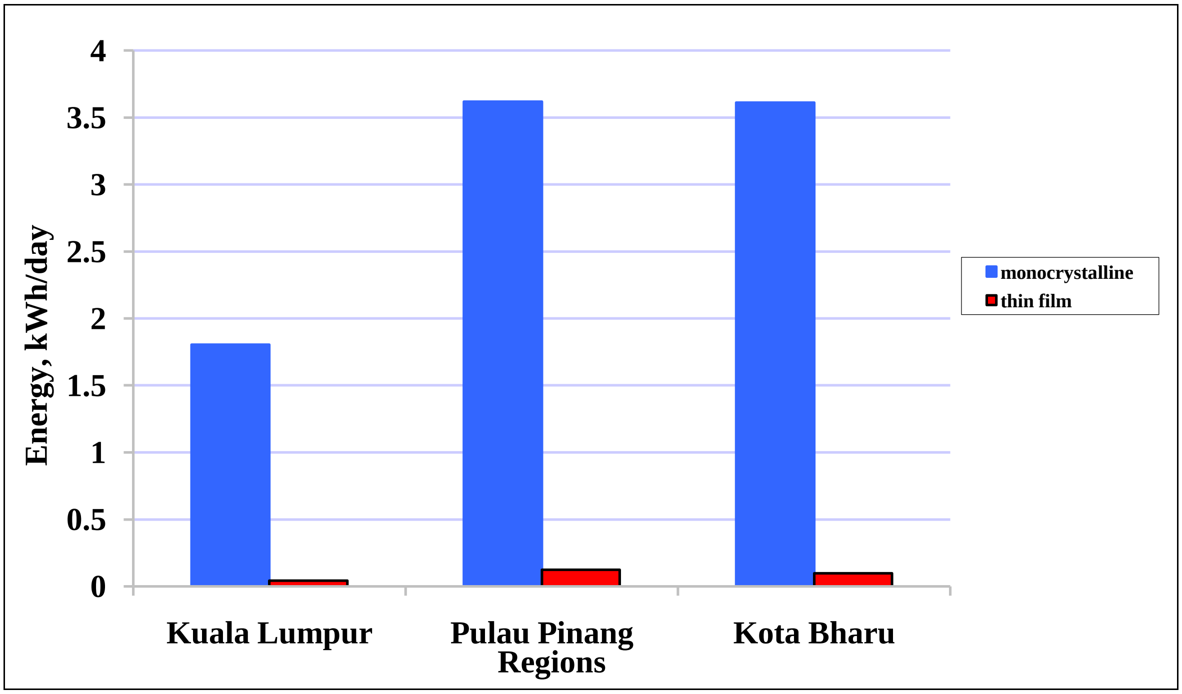



Graph 4.6: Energy output of monocrystalline photovoltaic in Kota Bharu

Figure 4.6 portrays potential energy (Wh/day) which was produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in 7 consecutive days at the selected place in Kota Bharu. In the first day, about 3573 Wh/day was produced by the simulation. In the 2nd day, there was 2809 Wh/day of energy produced by the system. The next day, the energy produced by the system was 4326 Wh/day. On 4th day, the highest energy produced by the monocrystalline photovoltaic with inverter in Kota Bharu which reached 5907 Wh/day. This highest energy was generated by the TRNSYS simulation because the solar radiation, irradiation, temperature and sun insolation on that day was the highest in the Kota Bharu's weather data (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). On the 5th day, the simulation gave only 2498 Wh/day as a result of the monocrystalline PV with inverter which was the lowest energy that was obtained from the system. This happened because the weather data on that day also gave the lowest value in the solar radiation, irradiation, temperature and sun insolation comparing to others (Mikhelef et al, 2010, Solangi et al, 2001, Chong et al, 2010, and Ayu et al, 2008). In the 6$^{th}$ day, about 3084 Wh/day was produced by the TRNSYS simulation. The last day result was 3082 Wh/day. The total value for this possible energy (Wh/day) which was produced by simulation of monocrystalline photovoltaic with inverter using TRNSYS in 7 consecutive days at the selected place in Kota Bharu was 25279 Wh/day. This means the average energy produced by monocrystalline photovoltaic with inverter system in this project was 3611 Wh/day.

### 4.4 Comparison energy output of photovoltaic system

In this section, the result is the comparison of possible energy (Wh/day) which was produced by simulation of thin film and monocrystalline photovoltaic with inverter using TRNSYS in 7 consecutive days at Kuala Lumpur, Pulau Pinang and Kota Bharu. The graph below fulfils the objective no 3 of this project.



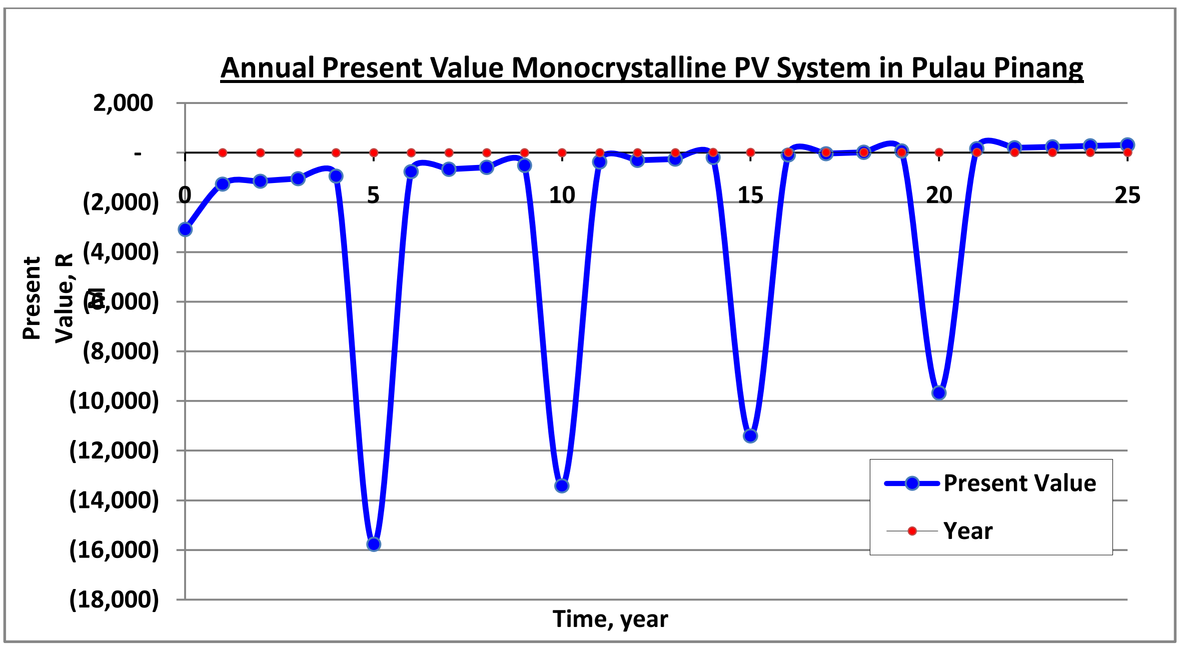

Graph 4.7: Comparison of average energy output per day of monocrystalline and thin film photovoltaic in Kuala Lumpur, Pulau Pinang and Kota Bharu

Figure 4.7 shows possible energy (Wh/day) which was produced by simulation of monocrystalline and thin film photovoltaic with inverter using TRNSYS in seven consecutive days at Kuala Lumpur, Pulau Pinang and Kota Bharu. As had been plotted, Pulau Pinang showed the highest energy output about 3618 Wh/day from monocrystalline with inverter production. Meanwhile the simulation for thin film PV with inverter in Pulau Pinang only gave 125 Wh/day. This happened because for most of the days, the weather data in Pulau Pinang was the highest compared to most places. Kuala Lumpur, with the often bleak weather, had empowered the lowest production of monocrystalline PV TRNSYS simulation which was 1805 Wh/day. According Renewable Energy in ASEAN website in 2005, Klang Valley (Kuala Lumpur, Petaling Jaya) had the lowest irradiance value, whereas the area around Penang (Georgetown, north-west coast) had the highest values measured. The significant difference energy production in (Wh/day) of monocrystalline PV compared to thin film PV is shown by the graph above. The difference of monocrystalline PV with inverter in Pulau Pinang compared with thin film PV is 96.55%. While in Kuala Lumpur it was at 97.59% and in Kota Bharu it was calculated as 97.29%. The significant difference can be caused by various factors that had been studied by many parties (Azah, 2007, Ahmad, 2006, Lim, 2002). Some of the causes are the efficiency of monocrystalline solar panel is within the range of 135-170 Watts per $m^2$, while thin film efficiency only 60-70 Watts per $m^2$ (Angus G, 2008). Among others, monocrystalline solar cell will lose far less efficiency in low light conditions and in the shade. This is because each solar cell is more self-sufficient and will maintain to work even though other cells get less light; this makes the resistance lighter and it is easier to "push" the power through the solar cells and out of the solar panel itself. A thin film solar panel will suffer in low light conditions whereas a monocrystalline can still work on a reasonable efficiency (Jiratkwin, 2008).

The results of TRNSYS simulation's figures illustrated that there was a huge difference of output. This happened because the inverter began to seek for the maximum power point and waited to create its operation until input power to the inverter reached its threshold demand. Therefore, no PV power was measured at this interval, even though the simulation model predicts a small amount of power even at low insolation level (Jayanta et al, 2006). For TRNSYS thin film PV simulation, this ineffectuality had happened and gives the result shown above as it can't create the maximum power point which needed by the Sunny Boy inverter to bring out the output. This deficiency can be improved by a better result by replace the type of inverter which can work along well with the thin film PV. Glavinich, 2006 are reported that, the inverter DC input parameters will determine the size and circuiting of the PV array given a particular PV module.

### 4.5 Economic analysis of the highest photovoltaic system output.

After all thin film and monocrystalline photovoltaic with inverter are simulated by using TRNSYS had been analyzed, Pulau Pinang had been found to give the highest output. Therefore, to meet the fourth objective of the project, the economic analysis was made on Monocrystalline photovoltaic with inverter system at Pulau Pinang. This economic analysis was based on several factors like inflation rate, tax, the system start-up capital, operation and maintenance cost etc. For more details of this economic analysis, it can be referred in table in the Appendix C.




Graph 4.8: Annual present value of Monocrystalline Photovoltaic system in Pulau Pinang

According to TRNSYS simulation which had been done in this project, Pulau Pinang's power output reached about 1.3MW per annum. According to TNB report in 2009, a domestic user only utilized 0.042MW annually. If the simulated system is implemented, it is more than enough to support the user power utility (TNB Annual Report 2009). After some arrangement has been made, the system is going to take a cost estimated about MYR30908. Required data has been searched and analyzed for 25 years. After the calculation, cumulative energy cost savings for the system (MYR30908) exceeded the initial capital in year 20. Meanwhile this system savings turn positive in year 18. When battery and inverter replacement are been made in year 20, again, system savings turn positive become negative in value. But after a year later, it will become positive again until year 25. After this economic analysis is completely done, it can be concluded that the solar system can be implemented in Malaysia like many other researchers have found out (Chong, 2010, Ahmad, 2006 and Masjuki et al, 2010).

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusions

The study focuses on energy produced from thin film photovoltaic and monocrystalline photovoltaic with inverter by utilizing solar energy extractable in Kuala Lumpur, Pulau Pinang and Kota Bharu using TRNSYS simulation for seven consecutive days.

Thin film photovoltaic with inverter system using TRNSYS in seven consecutive days at Kuala Lumpur produced average energy at approximately 44 Wh/day. While in Pulau Pinang, by using thin film photovoltaic average energy per day, the energy generated was 125 Wh/day. In Kelantan, average energy produced by thin film photovoltaic with inverter system in this project was 98 Wh/day.

By employing monocrystalline photovoltaic, the average energy produced in Kuala Lumpur was 1805 Wh/day. Meanwhile in Pulau Pinang and Kelantan, average energy generated by monocrystalline photovoltaic with inverter system in this study was 3680 Wh/day and 3611 Wh/day respectively.

LCC had estimated cumulative energy cost savings for the Pulau Pinang monocrystalline photovoltaic with inverter system (MYR30908) exceeded the initial capital in year 20. Meanwhile this system savings turn positive in year 18 and 20 years ahead.

From the results of this study, it can be concluded that it is possible to predict and model the performance of photovoltaic with inverter system and it is possible to implement the system using solar energy in Malaysia.

## 5.2 Recommendations for future work

This study only analyzes on performance aspect of the system using thin film photovoltaic and monocrystalline photovoltaic type. It is recommended that future research will focus on other types of photovoltaic that are available in the market at the moment.

This study only analyzes on energy production of the system using thin film photovoltaic and monocrystalline photovoltaic with inverter by using TRNSYS. It is recommended that future research will focus on other types of existing simulation software.

This study is a theoretical prediction of the energy production analysis of system using thin film photovoltaic and monocrystalline photovoltaic types. The actual data might be dissimilar from theoretical data and it is recommended to actually test it out when the equipments, technical and financial supports are prepared and available.

This study only analyzes on performance aspect of the system using Sunny Boy Inverter type. It is recommended that future research will focus on other types of inverter that are available in the market at the moment.

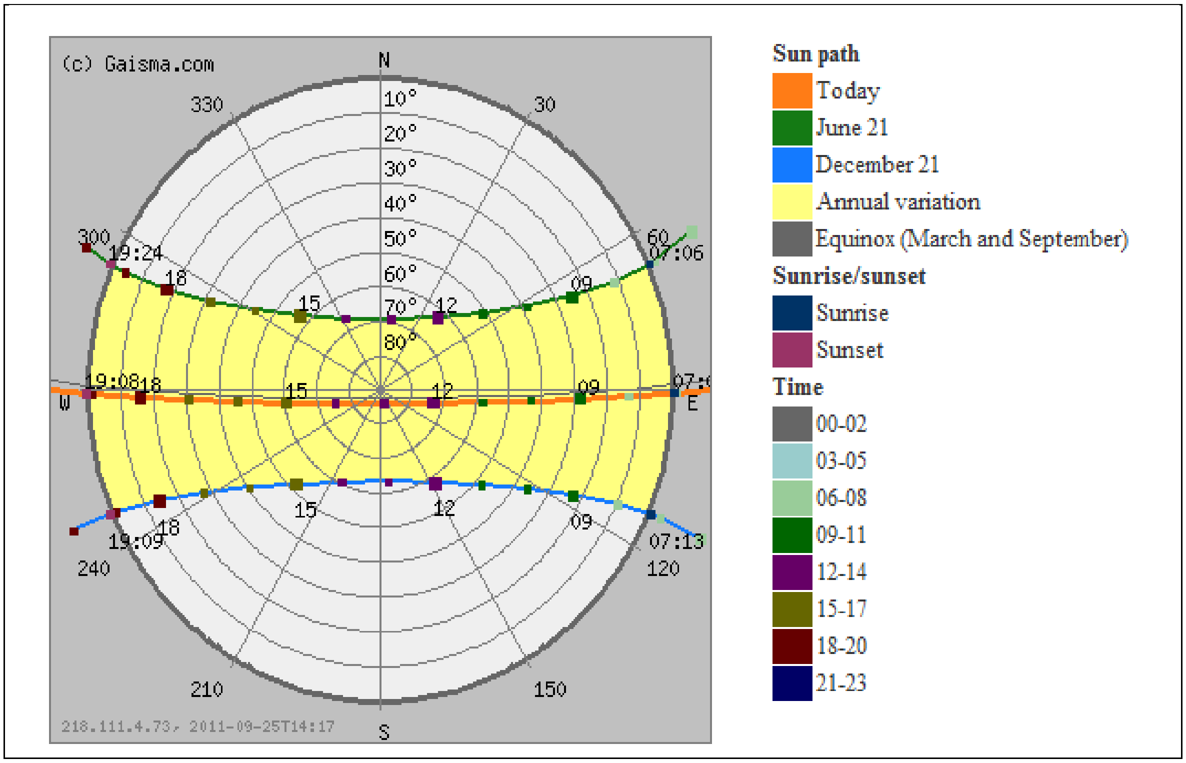
# APPENDIX A

## Appendix A.1 Kuala Lumpur Solar Data

| | | |
|---|---|---|
| Location | : | Kuala Lumpur |
| Latitude | : | +3.16 (3°09'36"N) |
| Longitude | : | +101.71 (101.71°42'36"E) |
| Time zone | : | UTC+ 8 hours |
| Local time | : | 22:20:18 |
| Country | : | Malaysia |
| Continent | : | Asia |
| Sub-region | : | South-Eastern Asia |
| Altitude | : | 60m |

Day light saving time, WWW.gaisma.com/en/location/kuala-lumpur.html <June 2011>

| **Date** | **Sunrise** | **Sunset** | **Length** | **Change** | **Dawn** | **Dusk** | **Length** | **Change** |
|---|---|---|---|---|---|---|---|---|
| **Today** | 07:02 | 19:08 | 12:06 | | 06:41 | 19:29 | 12:48 | |
| **+1 day** | 07:02 | 19:08 | 12:06 | 00:00 equal length | 06:41 | 19:28 | 12:47 | 00:01 shorter |
| **+1 week** | 07:00 | 19:05 | 12:05 | 00:01 shorter | 06:39 | 19:26 | 12:47 | 00:01 shorter |
| **+2 weeks** | 06:59 | 19:03 | 12:04 | 00:02 shorter | 06:38 | 19:23 | 12:45 | 00:03 shorter |
| **+1 month** | 06:57 | 18:58 | 12:01 | 00:05 shorter | 06:35 | 19:19 | 12:44 | 00:04 shorter |
| **+2 months** | 07:01 | 18:59 | 11:58 | 00:08 shorter | 06:39 | 18:21 | 11:42 | 00:06 shorter |
| **+3 months** | 07:14 | 19:11 | 11:57 | 00:09 shorter | 06:52 | 19:33 | 11:41 | 00:07 shorter |
| **+6 months** | 07:15 | 19:23 | 12:08 | 00:02 shorter | 06:55 | 19:49 | 12:49 | 00:01 shorter |




Sun path diagram, WWW.gaisma.com/en/location/kuala-lumpur.html <June 2011>

Data of solar energy (NASA Langley Research Center Atmosphere Science Data Center, 2002)

| **Hour** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Insolation, kWh/m$^2$/day** | 4.29 | 5.06 | 5.22 | 5.33 | 5.08 | 4.91 | 4.87 | 4.99 | 5.04 | 4.83 | 4.21 | 3.77 |
| **Clearness, 0-1** | 0.45 | 0.50 | 0.50 | 0.52 | 0.51 | 0.51 | 0.50 | 0.50 | 0.49 | 0.48 | 0.43 | 0.4 |
| **Temperature, $^o$C** | 24.35 | 24.98 | 25.62 | 26.07 | 26.10 | 25.73 | 25.34 | 25.39 | 25.50 | 25.73 | 25.26 | 24.58 |
| **Wind Speed, m/s** | 3.56 | 2.97 | 2.61 | 1.61 | 1.58 | 2.58 | 2.58 | 2.78 | 2.17 | 1.72 | 2.58 | 3.56 |
| **Precipitation, mm** | 147 | 137 | 218 | 264 | 210 | 130 | 141 | 154 | 190 | 268 | 278 | 232 |
| **Wet days, d** | 14.80 | 14.60 | 17.20 | 19.60 | 16.20 | 12.30 | 14.20 | 15.40 | 18.20 | 22.10 | 24.80 | 21.10 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| Day | G_Gh | G_Dh | G_Bn | G_Gk | G_Dk | G_ Lin | G_Lv | G_ Lup | G_ Ghr |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 180 | 97 | 125 | 180 | 97 | 412 | 442 | 463 | 35 |
| **2** | 203 | 109 | 134 | 203 | 109 | 415 | 445 | 467 | 41 |
| **3** | 206 | 121 | 118 | 206 | 121 | 416 | 449 | 471 | 41 |
| **4** | 200 | 113 | 122 | 200 | 113 | 416 | 445 | 467 | 40 |
| **5** | 195 | 103 | 133 | 196 | 103 | 417 | 450 | 472 | 39 |
| **6** | 188 | 107 | 116 | 188 | 107 | 415 | 446 | 467 | 38 |
| **7** | 189 | 118 | 100 | 189 | 118 | 419 | 447 | 467 | 38 |
| **8** | 187 | 114 | 103 | 187 | 114 | 417 | 447 | 467 | 37 |
| **9** | 188 | 103 | 121 | 188 | 103 | 413 | 444 | 463 | 38 |
| **10** | 191 | 103 | 121 | 181 | 103 | 414 | 444 | 463 | 38 |
| **11** | 172 | 107 | 92 | 172 | 107 | 417 | 442 | 459 | 34 |
| **12** | 170 | 101 | 107 | 170 | 101 | 415 | 443 | 461 | 34 |
| **Ave rage** | 189 | 108 | 116 | 189 | 108 | 416 | 446 | 466 | 38 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

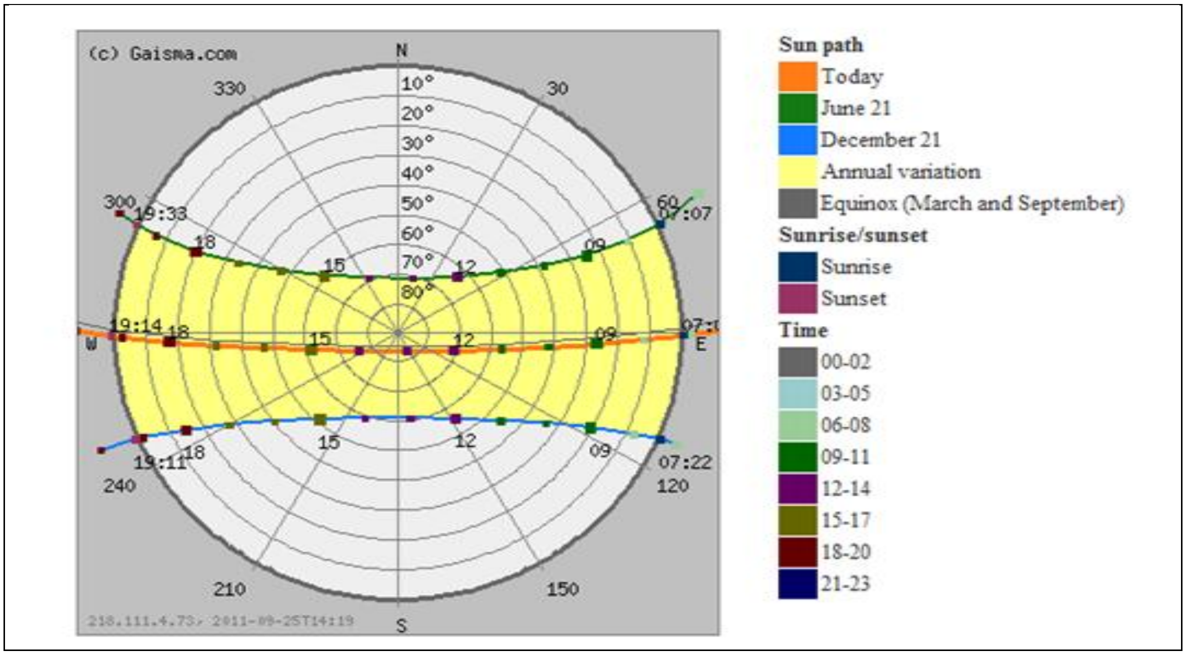
| Day | G_R | G_Go | Lg | Ld | G_Gn | Bh | UVA | PAR | RR |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 93 | 409 | 20190 | 12455 | 231 | 83 | 12 | 79.5 | 175 |
| **2** | 110 | 426 | 22671 | 14055 | 254 | 94 | 13 | 89.4 | 114 |
| **3** | 111 | 438 | 23119 | 15310 | 248 | 85 | 14 | 91.1 | 118 |
| **4** | 109 | 433 | 22589 | 14398 | 243 | 87 | 14 | 88.8 | 148 |
| **5** | 101 | 415 | 21967 | 13622 | 248 | 92 | 13 | 86.2 | 137 |
| **6** | 98 | 403 | 21174 | 13918 | 234 | 81 | 12 | 83.3 | 101 |
| **7** | 103 | 406 | 21258 | 14552 | 225 | 72 | 12 | 83.8 | 141 |
| **8** | 100 | 421 | 21042 | 14741 | 225 | 74 | 12 | 83.1 | 160 |
| **9** | 99 | 432 | 21186 | 13214 | 233 | 85 | 12 | 83.4 | 147 |
| **10** | 104 | 427 | 21491 | 13435 | 233 | 88 | 12 | 84.8 | 267 |
| **11** | 95 | 411 | 19439 | 13525 | 204 | 65 | 11 | 77 | 238 |
| **12** | 89 | 399 | 19119 | 12831 | 217 | 69 | 11 | 75.7 | 416 |
| **Average** | 101 | 418 | 21271 | 13839 | 233 | 81 | 12 | 84 | 177 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| Day | Ta | Td | Tp | Rh | Ts | Mx | D-RR | P | FF |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 27.2 | 22.4 | 23.7 | 75 | 27.3 | 17.6 | 65 | 995 | 1.9 |
| **2** | 27.7 | 22.0 | 23.7 | 71 | 28.0 | 17.3 | 30 | 996 | 1.9 |
| **3** | 28.1 | 22.7 | 24.2 | 73 | 28.6 | 18.0 | 28 | 995 | 1.8 |
| **4** | 28.0 | 23.4 | 24.5 | 76 | 27.9 | 18.7 | 34 | 996 | 1.8 |
| **5** | 28.5 | 23.7 | 25.0 | 75 | 28.7 | 19.1 | 36 | 996 | 1.8 |
| **6** | 28.1 | 23.2 | 24.4 | 75 | 28.0 | 18.5 | 21 | 995 | 1.9 |
| **7** | 27.6 | 22.9 | 24.2 | 75 | 27.9 | 18.1 | 22 | 995 | 1.9 |
| **8** | 27.7 | 23.0 | 24.3 | 75 | 27.9 | 18.2 | 32 | 996 | 1.9 |
| **9** | 27.5 | 22.8 | 24.0 | 76 | 27.4 | 18.0 | 31 | 996 | 1.8 |
| **10** | 27.2 | 22.8 | 24.1 | 77 | 27.3 | 18.1 | 59 | 995 | 1.9 |
| **11** | 27.1 | 23.1 | 24.1 | 79 | 26.7 | 18.4 | 67 | 996 | 1.7 |
| **12** | 27.0 | 22.7 | 23.9 | 77 | 27.1 | 17.9 | 122 | 995 | 1.7 |
| **Ave rage** | 27.6 | 22.9 | 26.4 | 75 | 27.7 | 18.2 | 46 | 996 | 1.8 |

## Appendix A.2 Pulau Pinang Solar Data

| | | | |
|---|---|---|---|
| Location | : | Georgetown | |
| Latitude | : | +5.37 | (5°22'12"N) |
| Longitude | : | +100.31 | (100.18°18'36"E) |
| Time zone | : | UTC +8 hours | |
| Local time | : | 22:22:15 | |
| Country | : | Malaysia | |
| Continent | : | Asia | |
| Sub-region | : | South-Eastern Asia | |
| Altitude | : | 0m | |




Sun path diagram, WWW.gaisma.com/en/location/kuala-lumpur.html <June 2011>

Data of solar energy (NASA Langley Research Center Atmosphere Science Data Center, 2002)

| **Hour** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Insolation, kWh/m²/day** | 5.61 | 6.04 | 5.92 | 5.64 | 5.08 | 4.97 | 4.91 | 4.71 | 4.65 | 4.49 | 4.74 | 4.97 |
| **Clearness, 0-1** | 0.60 | 0.61 | 0.57 | 0.54 | 0.51 | 0.51 | 0.50 | 0.46 | 0.45 | 0.45 | 0.50 | 0.54 |
| **Temperature, °C** | 25.41 | 26.15 | 26.44 | 26.44 | 26.51 | 26.36 | 26.11 | 26.10 | 25.86 | 25.65 | 25.36 | 25.06 |
| **Wind Speed, m/s** | 3.66 | 3.14 | 2.66 | 2.03 | 2.11 | 2.66 | 2.61 | 3.03 | 2.59 | 2.31 | 2.91 | 3.98 |
| **Precipitation, mm** | 97 | 103 | 159 | 230 | 259 | 194 | 224 | 234 | 325 | 412 | 282 | 149 |
| **Wet days, d** | 8.70 | 8.60 | 11.70 | 16.60 | 17.50 | 14.40 | 15.70 | 15.70 | 22.90 | 24.00 | 21.50 | 14.50 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| **Day** | **G_Gh** | **G_Dh** | **G_Bn** | **G_Gk** | **G_Dk** | **G_ Lin** | **G_Lv** | **G_ Lup** | **G_ Ghr** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 219 | 92 | 193 | 218 | 92 | 408 | 444 | 468 | 44 |
| **2** | 235 | 96 | 198 | 235 | 96 | 415 | 450 | 471 | 47 |
| **3** | 233 | 118 | 158 | 233 | 118 | 419 | 452 | 473 | 47 |
| **4** | 222 | 113 | 148 | 222 | 113 | 423 | 451 | 469 | 44 |
| **5** | 203 | 108 | 131 | 203 | 108 | 426 | 454 | 472 | 41 |
| **6** | 198 | 103 | 133 | 198 | 103 | 422 | 449 | 466 | 40 |
| **7** | 197 | 112 | 120 | 197 | 112 | 421 | 449 | 467 | 39 |
| **8** | 192 | 109 | 112 | 192 | 109 | 422 | 448 | 465 | 39 |
| **9** | 192 | 106 | 117 | 192 | 106 | 418 | 444 | 462 | 38 |
| **10** | 184 | 106 | 110 | 184 | 106 | 417 | 443 | 460 | 37 |
| **11** | 192 | 107 | 123 | 192 | 107 | 415 | 442 | 459 | 38 |
| **12** | 196 | 96 | 157 | 195 | 96 | 409 | 443 | 464 | 39 |
| **Ave rage** | 205 | 106 | 141 | 205 | 106 | 418 | 447 | 466 | 41 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

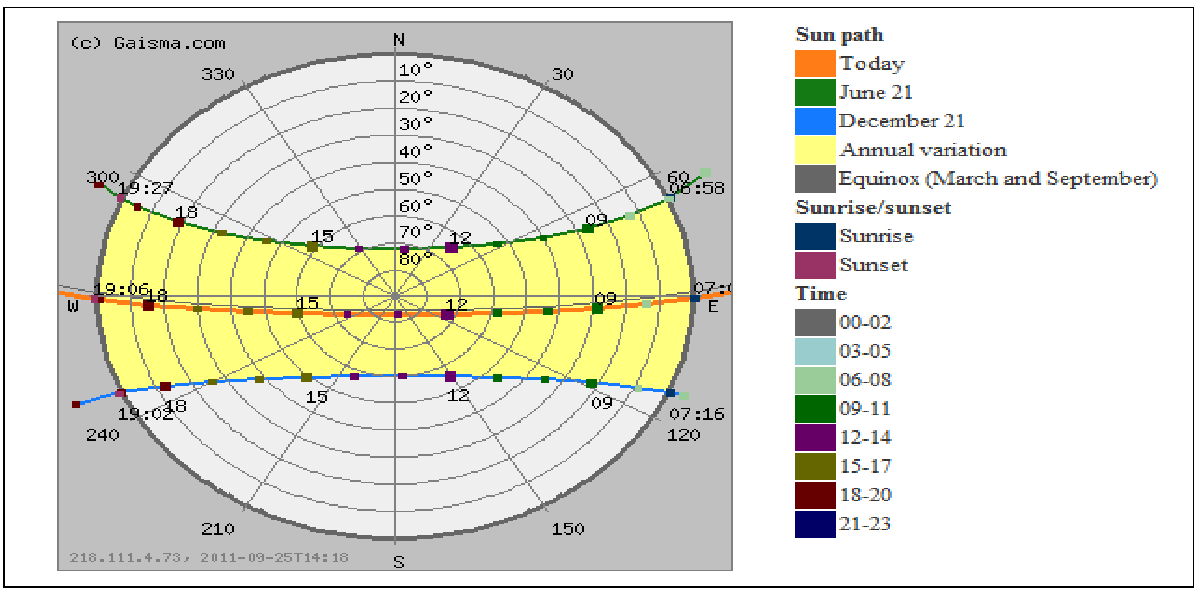
| **Day** | **G_R** | **G_Go** | **Lg** | **Ld** | **G_Gn** | **Bh** | **UVA** | **PAR** | **RR** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 115 | 396 | 24293 | 12107 | 302 | 127 | 14 | 94.8 | 68 |
| **2** | 132 | 419 | 26169 | 12715 | 310 | 139 | 15 | 102.0 | 79 |
| **3** | 132 | 435 | 26062 | 15635 | 290 | 115 | 15 | 102.1 | 114 |
| **4** | 131 | 435 | 25032 | 14395 | 270 | 110 | 14 | 97.8 | 146 |
| **5** | 116 | 423 | 22950 | 14117 | 250 | 95 | 13 | 89.8 | 205 |
| **6** | 113 | 412 | 22355 | 12980 | 244 | 95 | 13 | 87.6 | 154 |
| **7** | 111 | 414 | 22169 | 14407 | 240 | 86 | 13 | 87.2 | 159 |
| **8** | 110 | 426 | 21665 | 13923 | 228 | 83 | 13 | 85.1 | 221 |
| **9** | 110 | 432 | 21713 | 13661 | 230 | 86 | 13 | 85.3 | 250 |
| **10** | 105 | 422 | 20791 | 13602 | 223 | 78 | 12 | 82.4 | 403 |
| **11** | 110 | 401 | 21592 | 13977 | 240 | 85 | 13 | 85.5 | 223 |
| **12** | 101 | 387 | 21827 | 12750 | 259 | 100 | 12 | 86.8 | 132 |
| **Average** | 116 | 417 | 23051 | 13689 | 258 | 100 | 13 | 90.5 | 180 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| Day | Ta | Td | Tp | Rh | Ts | Mx | D-RR | P | FF |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 27.6 | 21.8 | 23.5 | 71 | 27.3 | 17.0 | 20 | 998 | 1.4 |
| **2** | 27.9 | 22.5 | 24.0 | 72 | 28.0 | 17.7 | 6 | 998 | 1.2 |
| **3** | 28.3 | 23.1 | 24.5 | 74 | 28.6 | 18.4 | 15 | 998 | 1.0 |
| **4** | 28.2 | 24.1 | 25.1 | 79 | 27.9 | 19.5 | 12 | 998 | 0.7 |
| **5** | 28.4 | 24.4 | 25.4 | 79 | 28.7 | 19.8 | 4 | 998 | 0.6 |
| **6** | 28.0 | 23.9 | 24.9 | 78 | 28.0 | 19.2 | 10 | 998 | 0.8 |
| **7** | 27.7 | 23.7 | 24.8 | 79 | 27.9 | 19.0 | 13 | 998 | 0.8 |
| **8** | 27.4 | 23.5 | 24.5 | 80 | 27.9 | 18.8 | 14 | 998 | 0.7 |
| **9** | 27.3 | 23.6 | 24.5 | 80 | 27.4 | 18.9 | 18 | 998 | 0.7 |
| **10** | 26.8 | 23.5 | 24.4 | 82 | 27.3 | 18.8 | 19 | 998 | 0.6 |
| **11** | 27.0 | 23.4 | 24.3 | 81 | 26.7 | 18.7 | 17 | 998 | 0.8 |
| **12** | 27.2 | 22.3 | 23.7 | 75 | 27.1 | 17.5 | 22 | 998 | 1.4 |
| **Average** | 27.7 | 23.3 | 26.7 | 77 | 27.7 | 18.6 | 14 | 998 | 0.9 |

## Appendix A.3 Kelantan Solar Data

| | | | |
|---|---|---|---|
| Location | : | Kota Bharu | |
| Latitude | : | +6.12 | (6°07'12"N) |
| Longitude | : | +102.24 | (102.24°14'24"E) |
| Time zone | : | UTC +8 hours | |
| Local time | : | 22:22:18 | |
| Country | : | Malaysia | |
| Continent | : | Asia | |
| Sub-region | : | South-Eastern Asia | |
| Altitude | : | 2m | |




Sun path diagram, WWW.gaisma.com/en/location/kuala-lumpur.html <June 2011>

Data of solar energy (NASA Langley Research Center Atmosphere Science Data Center, 2002)

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insolation, kWh/m²/day | 5.07 | 5.86 | 6.18 | 6.19 | 5.51 | 5.31 | 5.30 | 5.28 | 5.37 | 4.74 | 3.98 | 4.2 |
| Clearness, 0-1 | 0.55 | 0.59 | 0.60 | 0.60 | 0.54 | 0.54 | 0.53 | 0.52 | 0.52 | 0.48 | 0.42 | 0.46 |
| Temperature, °C | 25.02 | 25.28 | 26.14 | 26.98 | 27.26 | 27.26 | 27.02 | 27.12 | 26.83 | 26.38 | 25.97 | 25.42 |
| Wind Speed, m/s | 4.60 | 4.00 | 3.53 | 2.57 | 2.43 | 2.43 | 3.39 | 3.65 | 3.29 | 2.71 | 3.75 | 4.98 |
| Precipitation, mm | 204 | 84 | 93 | 81 | 143 | 143 | 171 | 199 | 242 | 293 | 537 | 558 |
| Wet days, d | 13.30 | 8.70 | 8.00 | 8.80 | 13.10 | 12.20 | 14.50 | 15.90 | 18.60 | 21.40 | 25.40 | 23.70 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| **Day** | **G_Gh** | **G_Dh** | **G_Bn** | **G_Gk** | **G_Dk** | **G_ Lin** | **G_Lv** | **G_ Lup** | **G_ Ghr** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 192 | 89 | 157 | 192 | 89 | 410 | 441 | 459 | 38 |
| **2** | 217 | 101 | 165 | 217 | 101 | 412 | 443 | 462 | 43 |
| **3** | 241 | 116 | 174 | 241 | 116 | 416 | 449 | 470 | 48 |
| **4** | 243 | 104 | 191 | 243 | 104 | 416 | 451 | 472 | 49 |
| **5** | 223 | 103 | 171 | 223 | 103 | 416 | 452 | 474 | 45 |
| **6** | 209 | 108 | 143 | 209 | 108 | 417 | 448 | 468 | 42 |
| **7** | 206 | 108 | 136 | 206 | 108 | 421 | 450 | 469 | 41 |
| **8** | 208 | 112 | 130 | 208 | 112 | 419 | 448 | 466 | 42 |
| **9** | 211 | 106 | 146 | 211 | 106 | 413 | 444 | 462 | 42 |
| **10** | 198 | 106 | 129 | 198 | 106 | 418 | 446 | 462 | 40 |
| **11** | 156 | 91 | 93 | 156 | 91 | 422 | 441 | 454 | 31 |
| **12** | 145 | 91 | 81 | 145 | 91 | 420 | 441 | 454 | 29 |
| **Ave rage** | 204 | 103 | 143 | 204 | 103 | 417 | 446 | 464 | 41 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| **Day** | **G_R** | **G_Go** | **Lg** | **Ld** | **G_Gn** | **Bh** | **UVA** | **PAR** | **RR** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 106 | 392 | 21523 | 11709 | 260 | 103 | 12 | 84.0 | 100 |
| **2** | 124 | 419 | 24274 | 13725 | 282 | 116 | 14 | 94.7 | 90 |
| **3** | 139 | 435 | 27039 | 15594 | 306 | 125 | 15 | 105.1 | 114 |
| **4** | 138 | 437 | 27406 | 14017 | 308 | 139 | 15 | 106.2 | 148 |
| **5** | 121 | 425 | 25157 | 14056 | 289 | 120 | 14 | 97.9 | 181 |
| **6** | 117 | 415 | 23583 | 13914 | 263 | 101 | 14 | 92.0 | 135 |
| **7** | 117 | 417 | 23127 | 14250 | 255 | 98 | 13 | 90.6 | 150 |
| **8** | 119 | 427 | 23404 | 14696 | 252 | 96 | 14 | 91.6 | 200 |
| **9** | 121 | 432 | 23799 | 14124 | 263 | 105 | 14 | 93.1 | 216 |
| **10** | 115 | 420 | 22371 | 13863 | 244 | 92 | 13 | 97.9 | 359 |
| **11** | 93 | 3698 | 17715 | 11880 | 190 | 65 | 10 | 69.8 | 226 |
| **12** | 82 | 383 | 16397 | 11484 | 176 | 54 | 10 | 65.0 | 215 |
| **Ave rage** | 116 | 416 | 22983 | 13609 | 257 | 101 | 13 | 89.8 | 178 |

Solar data (Meteonorm version 6.1.0.23 , 2011)

| **Day** | **Ta** | **Td** | **Tp** | **Rh** | **Ts** | **Mx** | **D-RR** | **P** | **FF** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 26.4 | 22.7 | 23.8 | 80 | 26.7 | 17.7 | 30 | 1013 | 2.1 |
| **2** | 26.7 | 22.9 | 23.9 | 80 | 27.1 | 17.8 | 10 | 1013 | 1.6 |
| **3** | 27.6 | 23.7 | 24.8 | 80 | 28.4 | 18.8 | 34 | 1013 | 1.6 |
| **4** | 28.5 | 24.3 | 25.3 | 78 | 28.8 | 19.4 | 27 | 1013 | 1.2 |
| **5** | 28.6 | 24.5 | 25.6 | 79 | 29.0 | 19.7 | 17 | 1013 | 1.0 |
| **6** | 28.1 | 24.0 | 25.0 | 78 | 28.1 | 19.0 | 7 | 1013 | 1.0 |
| **7** | 27.8 | 23.9 | 25.0 | 78 | 28.2 | 19.0 | 5 | 1013 | 0.9 |
| **8** | 27.5 | 23.8 | 24.8 | 79 | 27.8 | 18.8 | 14 | 1013 | 0.9 |
| **9** | 27.2 | 23.7 | 24.5 | 81 | 27.2 | 18.7 | 6 | 1013 | 0.9 |
| **10** | 27.0 | 23.9 | 24.7 | 83 | 27.1 | 18.9 | 16 | 1013 | 0.8 |
| **11** | 25.5 | 24.0 | 24.5 | 86 | 25.8 | 19.0 | 13 | 1013 | 0.8 |
| **12** | 25.2 | 23.3 | 24.1 | 84 | 25.9 | 18.3 | 59 | 1013 | 1.6 |
| **Average** | 27.3 | 23.7 | 26.9 | 81 | 27.5 | 18.3 | 20 | 1013 | 1.2 |

## APPENDIX B

Inverter Technical Data of Selected Inverter (Sunny Boy 5000TL, www.SMA.de, 2011)

| | |
|---|---|
| **Input (DC)** | |
| Max DC Power | 5300 W |
| Max DC Voltage | 550 V |
| PV voltage range, MPPT | 125 V-440 V |
| Recommended range at nominal power | 175 V-440 V |
| Max input current | 2 x 15A |
| Number of MPP trackers | 2 |
| Max number of strings (parallel) | 2 x 2 |
| **Output (AC)** | |
| Nominal AC output | 4600W |
| Max AC power | 5000W |
| Max output current | 22A |
| Nominal AC voltage / range | 220 V - 240 V / 180 V - 280 V |
| AC grid frequency / range | 50 Hz, 60 Hz / ± 5 Hz |
| Power factor (cos Φ) | 1 |
| AC Connection | single-phase |
| **Efficiency** | |
| Max effiency | 97.00% |
| Euro ETA | 96.50% |
| **Protective equipment** | |
| DC reverse polarity protection | Yes |
| DC load disconnecting switch ESS | Yes |
| AC short circuit protection | Yes |
| Ground fault monitoring | Yes |
| Grid monitoring (SMA grid guard) | Yes |
| Integrated all pole sensitive residual current monitoring unit | Yes |
| General Data | |
| Dimension (W / H / D ) in mm | 470 x 445 x 180 |
| Weight | 25 kg |
| Operating temperature range | 25 $^{o}$C - 60 $^{o}$C |
| Consumption : operating (standby) / night | < 10 W / 0.5 W |
| Topology | transformerless |
| Cooling concept | OptiCool |
| Installation : Indoor / Outdoor | Yes |
| **Features** | |
| DC connection : MC3 / MC4 / Tyco | Yes |
| AC connection : Terminals | Yes |
| Graphic display | Yes |

| | |
|---|---|
| Interfaces : Bluetooth / RS485 | Yes |
| Warranty | Yes |
| Certificates and Approvals | www.SMA.de |

**APPENDIX C**

## Economic calculation:

Procedure for calculation of economic values is described column by column based on the data of *Pulau Pinang (highest output) with 25-years* lifetime for year 1 (Table Appendix C):

**Step 1:** Annual energy generation in the site (Table 3.6):

*Solar energy generation per day X 365days/year =*
*3617.7234 Wh/day × 365days/year =*
*<u>1320.469041 kWh/year</u>*

**Step 2:** Cost of energy per kWh times to energy generation (in RM) according to TNB tariff

*Annual energy generation × Electricity price (per kWh) =1564.37*(RM/kWh)

| | | |
|---|---|---|
| First; | 200 (kWh) ×0.218 (RM/kWh)** = RM | 43.60 |
| 2nd; | 100 (kWh) ×0.334 (RM/kWh)** = RM | 33.40 |
| 3rd; | 100 (kWh) ×0.400 (RM/kWh)** = RM | 40.00 |
| 4th; | 100 (kWh) ×0.402 (RM/kWh)** = RM | 40.20 |
| 5th; | 100 (kWh) ×0.416 (RM/kWh)** = RM | 41.60 |
| 6th; | 100 (kWh) ×0.426 (RM/kWh)** = RM | 42.60 |
| 7th; | 100 (kWh) ×0.437 (RM/kWh)** = RM | 43.70 |
| 8th; | 100 (kWh) ×0.453 (RM/kWh)** = RM | 45.30 |
| 9th; | 421 (kWh) ×0.454 (RM/kWh)** = RM | 191.13 |

***(Based on the standard TNB tariff for domestic user)*

*Annual energy generation = <u>599 (RM)</u>**
**This value increases every year by inflation rate of 10%*

**Step 3:** Calculating annual extra mortgage payment by Eq. (10):

*PWF (N, i, d) = PWF (25, 7, 8) =11.654*
*(Based on the standard charts for PWF)*

*Annual extra mortgage =*
*Principal balance ÷ PWF =*
*(30907.95 × 90%) ÷ 11.654=*
*<u>2386.92 (RM)</u>*

**Step 4:** Calculation of interest in year, principal payment and principal balance:

*Interest in year 1 =*
*Interest rate × Principal balance =*
*0.07 × (30907.95× 90%) =*

*1947.20 (RM)*

*Principal payment =*
*Interest in year - Annual extra mortgage =*
*2386.92 - 1947.20*
*= 439.72 (RM)*

*Principal balance (in year N) =*
*Principal balance (in year N-1) - Principal payment =*
*(30907.95 × 90%) – 439.72 =*
*27,377.44 (RM)*

**Step 5:** Inverter and controller replacement cost

*Inverter and controller replaced every five years. At first year there is no need to change**

**The cost of inverter and controller increases by inflation rate of 4%*

**Step 6:** Operation and maintenance (O&M) cost (Table 3.8):

*Estimated annual cost =*
*PV O&M =*
*101.00 (RM)**

**The cost of O&M increases by inflation rate of 4%*

**Step 7:** Extra property tax calculated (Table 3.9):

*Estimated as 2% of initial capital =*
*30907.95 × 2% =*
*618.16 (RM)**

**The extra property tax increases by inflation rate of 4%*

**Step 8:** Income tax saving (*ITS*) calculated by using Eq. (9):

*ITS = ETR × (IP + PT) =*
*0.45 × (1947.20 + 618.16) =*
*1154.41 (RM)*

**Step 9:** Total energy saving (*TES*) of the system calculated by summing up of values of columns 3, 4, 8, 9, 10, 11 and 12 in Table in following Page 102:

*TES =*
*599 + (2,387) + 0 + 0 + (101) + (618) + 1,154 =*
*(1,353) (RM)*

**Step 10:** Present value of the system energy saving calculated by Eq. (11):

*Present Value =*
$TES \times 1/(1+d)^N =$
$(1{,}353) \times 1/(1+0.08)^1 =$

*(1,252.78) ($)*

**Step 11:** Calculation of cumulative energy saving, which is the summation of values of *TES*, from first year until the relevant year:

$$\textit{Cumulative energy saving in year } N = \sum_{i=1}^{N} TES_i$$

**Step 12:** Calculation of cumulative energy cost saving, which is the summation of costs of energy, from first year until the relevant year:

$$\textit{Cumulative energy cost saving in year } N = \sum_{i=1}^{N} (Cost\ of\ energy)_i$$

| Year | Energy Generation (kWh/year) | Cost of energy (RM) | Extra Mortgage Payment | Interest in year | Principal Payment | Principal Balance | Inverter repl. | Battery repl. | Maint. and Oper. | Extra Property tax | Income tax savings | Solar-Inverter System Saving | PV of System Savings | Cum. System Savings | Cum. Energy cost saving |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | 27,817 | | | | | | (3,091) | (3,091) | (3,091) | - |
| 1 | 1320.47 | 599 | (2,387) | 1,947 | 440 | 27,377 | - | - | (101) | (618) | 1,154 | (1,352) | (1,252) | (4,443) | 599 |
| 2 | 1320.47 | 659 | (2,387) | 1,916 | 470 | 26,907 | - | - | (106) | (649) | 1,154 | (1,328) | (1,139) | (5,771) | 1,259 |
| 3 | 1320.47 | 725 | (2,387) | 1,883 | 503 | 26,404 | - | - | (111) | (682) | 1,154 | (1,300) | (1,032) | (7,072) | 1,984 |
| 4 | 1320.47 | 798 | (2,387) | 1,848 | 539 | 25,865 | - | - | (117) | (716) | 1,154 | (1,268) | (932) | (8,339) | 2,782 |
| 5 | 1320.47 | 878 | (2,387) | 1,811 | 576 | 25,289 | (14,278.39) | (7,657.69) | (123) | (751) | 1,153 | (23,167) | (15,767) | (31,506) | 3,660 |
| 6 | 1320.47 | 965 | (2,387) | 1,770 | 617 | 24,672 | - | - | (129) | (789) | 1,152 | (1,188) | (749) | (32,694) | 4,625 |
| 7 | 1320.47 | 1,062 | (2,387) | 1,727 | 660 | 24,012 | - | - | (135) | (828) | 1,150 | (1,139) | (664) | (33,833) | 5,687 |
| 8 | 1320.47 | 1,168 | (2,387) | 1,681 | 706 | 23,306 | - | - | (142) | (870) | 1,148 | (1,083) | (585) | (34,916) | 6,856 |
| 9 | 1320.47 | 1,285 | (2,387) | 1,631 | 755 | 22,550 | - | - | (149) | (913) | 1,145 | (1,019) | (510) | (35,935) | 8,141 |
| 10 | 1320.47 | 1,414 | (2,387) | 1,579 | 808 | 21,742 | (18,223) | (9,773) | (157) | (959) | 1,142 | (28,944) | (13,407) | (64,879) | 9,554 |
| 11 | 1320.47 | 1,555 | (2,387) | 1,522 | 865 | 20,877 | - | - | (165) | (1,007) | 1,138 | (866) | (371) | (65,744) | 11,109 |
| 12 | 1320.47 | 1,710 | (2,387) | 1,461 | 926 | 19,952 | - | - | (173) | (1,057) | 1,133 | (773) | (307) | (66,518) | 12,820 |
| 13 | 1320.47 | 1,881 | (2,387) | 1,397 | 990 | 18,961 | - | - | (182) | (1,110) | 1,128 | (669) | (246) | (67,187) | 14,701 |
| 14 | 1320.47 | 2,070 | (2,387) | 1,327 | 1,060 | 17,902 | - | - | (191) | (1,166) | 1,122 | (552) | (188) | (67,739) | 16,771 |
| 15 | 1320.47 | 2,277 | (2,387) | 1,253 | 1,134 | 16,768 | (23,258) | (12,474) | (200) | (1,224) | 1,115 | (36,151) | (11,396) | (103,890) | 19,047 |
| 16 | 1320.47 | 2,504 | (2,387) | 1,174 | 1,213 | 15,555 | - | - | (210) | (1,285) | 1,106 | (271) | (79) | (104,161) | 21,552 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **17** | 1320.47 | 2,755 | (2,387) | 1,089 | 1,298 | 14,257 | - | - | (221) | (1,349) | 1,097 | (105) | (28) | (104,266) | 24,306 |
| **18** | 1320.47 | 3,030 | (2,387) | 998 | 1,389 | 12,868 | - | - | (232) | (1,417) | 1,087 | **81** | **20** | (104,185) | 27,336 |
| **19** | 1320.47 | 3,333 | (2,387) | 901 | 1,486 | 11,381 | - | - | (243) | (1,488) | 1,075 | **290** | **67** | (103,895) | 30,670 |
| **20** | 1320.47 | 3,666 | (2,387) | 797 | 1,590 | 9,791 | (29,684) | (15,920) | (255) | (1,562) | 1,061 | (45,080) | (9,672) | (148,975) | **34,336** |
| **21** | 1320.47 | 4,033 | (2,387) | 685 | 1,702 | 8,090 | - | - | (268) | (1,640) | 1,046 | **784** | **156** | (148,191) | **38,369** |
| **22** | 1320.47 | 4,436 | (2,387) | 566 | 1,821 | 6,269 | - | - | (282) | (1,722) | 1,030 | **1,075** | **198** | (147,115) | **42,805** |
| **23** | 1320.47 | 4,880 | (2,387) | 439 | 1,948 | 4,321 | - | - | (296) | (1,808) | 1,011 | **1,400** | **238** | (145,715) | **47,685** |
| **24** | 1320.47 | 5,368 | (2,387) | 302 | 2,084 | 2,237 | - | - | (311) | (1,899) | 991 | **1,762** | **278** | (143,953) | **53,054** |
| **25** | 1320.47 | 5,905 | (2,387) | 157 | 2,230 | 6 | - | - | (326) | (1,994) | 968 | **2,166** | **316** | (141,787) | **58,958** |
| | | | | | | | | | | | | **Sum** | **(60,141)** | | |

## APPENDIX D

**Pulau Pinang Thin Film PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 5.72 | 0 | | | | | |
| 7.86 | 36.11 | 2.14 | 36.11 | 77.28 | 38.64 | |
| 10 | 0 | 2.14 | 36.11 | 77.28 | 38.64 | |
| 15.73 | 0 | | | | | |
| 17.87 | 11.56 | 2.14 | 11.56 | 24.73 | 12.37 | |
| 18.59 | 0 | 0.72 | 11.56 | 8.32 | 4.16 | 93.81 |
| 30.03 | 0 | | | | | |
| 32.17 | 63.56 | 2.14 | 63.56 | 136.01 | 68.01 | |
| 32.86 | 0 | 0.69 | 63.56 | 43.85 | 21.93 | |
| 34.31 | 0 | | | | | |
| 35.03 | 14.44 | 0.72 | 14.44 | 10.40 | 5.20 | |
| 35.74 | 0 | 0.71 | 14.44 | 10.25 | 5.13 | |
| 40.03 | 0 | | | | | |
| 41.46 | 14.44 | 1.43 | 14.44 | 20.65 | 10.33 | |
| 42.18 | 0 | 0.72 | 14.44 | 10.40 | 5.20 | 115.79 |
| 53.62 | 0 | | | | | |
| 55.02 | 8.67 | 1.42 | 8.67 | 12.31 | 6.16 | |
| 55.74 | 0 | 0.72 | 8.67 | 6.24 | 3.12 | |
| 62.20 | 0 | | | | | |
| 62.92 | 10.11 | 0.72 | 10.11 | 7.28 | 3.64 | |
| 63.63 | 0 | 0.71 | 10.11 | 7.18 | 3.59 | 16.51 |
| 78.64 | 0 | | | | | |
| 81.50 | 33.22 | 2.86 | 33.22 | 95.01 | 47.50 | |
| 82.93 | 18.77 | 1.43 | 18.77 | 26.85 | 13.42 | |
| 84.36 | 33.22 | 1.43 | 33.22 | 47.50 | 23.75 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 87.22 | 15.89 | 2.86 | 15.89 | 45.44 | 22.72 | |
| 87.93 | 26 | 0.71 | 26 | 18.46 | 9.23 | |
| 90.79 | 4.33 | 2.86 | 4.33 | 12.38 | 6.20 | |
| 93.65 | 18.77 | 2.86 | 18.77 | 53.69 | 26.85 | 149.67 |
| 96.25 | 0 | | | | | |
| 102.23 | 0 | | | | | |
| 103.66 | 80.89 | 1.43 | 80.89 | 115.67 | 57.83 | |
| 105.09 | 0 | 1.43 | 80.89 | 115.67 | 57.83 | |
| 112.95 | 0 | | | | | |
| 114.38 | 15.89 | 1.43 | 15.89 | 22.72 | 11.36 | |
| 115.81 | 0 | 1.43 | 15.89 | 22.72 | 11.36 | 138.39 |
| 126.54 | 0 | | | | | |
| 128.68 | 118.44 | 2.14 | 118.44 | 253.47 | 126.73 | |
| 130.83 | 0 | 2.15 | 118.44 | 254.65 | 127.33 | |
| 137.23 | 0 | | | | | |
| 138.69 | 15.89 | 1.46 | 15.89 | 23.20 | 11.60 | |
| 139.40 | 0 | 0.71 | 15.89 | 11.28 | 5.64 | 271.30 |
| 150.84 | 0 | | | | | |
| 152.27 | 33.22 | 1.43 | 33.22 | 47.50 | 23.75 | |
| 154.42 | 0 | 2.15 | 33.22 | 71.42 | 35.71 | |
| 160.85 | 0 | | | | | |
| 162.28 | 18.77 | 1.43 | 18.77 | 26.85 | 13.42 | |
| 163.71 | 0 | 1.43 | 18.77 | 26.85 | 13.42 | 86.30 |
| | | 50.75 | | 1743.51 | 871.75 | |
| | | | | average per day | 124.54 | |

**Kuala Lumpur Thin Film PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 16.58 | 0 | | | | | |
| 18.03 | 8.33 | 1.44 | 8.33 | 12 | 6 | |
| 19.47 | 0 | 1.44 | 8.33 | 12 | 6 | 12 |
| 31 | 0 | | | | | |
| 32.45 | 35 | 1.44 | 35 | 50.40 | 25.20 | |
| 33.17 | 0 | 0.72 | 35 | 25.20 | 12.60 | |
| 34.61 | 0 | | | | | |
| 35.33 | 17.78 | 0.72 | 17.78 | 12.80 | 6.40 | |
| 36.77 | 0 | 1.44 | 17.78 | 25.61 | 12.80 | |
| 41.10 | 0 | | | | | |
| 42.54 | 13.89 | 1.44 | 13.89 | 20 | 10 | |
| 43.26 | 0 | 0.72 | 13.89 | 10 | 5 | 72 |
| 57.68 | 0 | | | | | |
| 59.12 | 37.78 | 1.44 | 37.78 | 54.40 | 27.2 | |
| 59.84 | 0 | 0.72 | 37.78 | 27.20 | 13.60 | 40.80 |
| 78.59 | 0 | | | | | |
| 80.03 | 25 | 1.44 | 25 | 36 | 18 | |
| 80.76 | 0 | 0.72 | 25 | 18 | 9 | 27 |
| 101.33 | 0 | | | | | |
| 102.77 | 10.56 | 1.44 | 10.56 | 15.20 | 7.60 | |
| 104.21 | 0 | 1.44 | 10.56 | 15.20 | 7.60 | |
| 108.77 | 0 | | | | | |
| 109.49 | 18.89 | 0.72 | 18.89 | 13.60 | 7 | |
| 110.21 | 0 | 0.72 | 18.89 | 13.60 | 7 | 28.80 |
| 126.9 | 0 | | | | | |
| 128.34 | 36.67 | 1.44 | 36.67 | 52.80 | 26.40 | |
| 129.06 | 0 | 0.72 | 36.67 | 26.40 | 13.20 | |
| 132.34 | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 133.78 | 9.443 | 1.44 | 9.44 | 13.60 | 6.80 | |
| 134.5 | | 0.72 | 9.44 | 6.80 | 3.40 | 76.80 |
| 150.7 | 0 | | | | | |
| 152.14 | 25.557 | 1.44 | 25.56 | 36.80 | 18.40 | |
| 153.58 | 0 | 1.44 | 25.56 | 36.80 | 18.40 | |
| 160.79 | 0 | | | | | |
| 162.23 | 26.11 | 1.44 | 26.11 | 37.60 | 18.80 | |
| 163.67 | 0 | 1.44 | 26.11 | 37.60 | 18.80 | 74.40 |
| | | 28.08 | | 609.61 | 304.80 | |
| | | | | average per day | 43.54 | |

**Kelantan Thin Film PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 5.92 | 0 | | | | | |
| 6.66 | 13.33 | 0.74 | 13.33 | 9.86 | 4.93 | |
| 7.40 | 0 | 0.74 | 13.33 | 9.86 | 4.932 | |
| 16.28 | 0 | | | | | |
| 18.50 | 20 | 2.22 | 20 | 44.40 | 22.20 | |
| 19.24 | 0 | 0.74 | 20 | 14.80 | 7.40 | 39.46 |
| 31.08 | 0 | | | | | |
| 33.30 | 62.22 | 2.22 | 62.22 | 138.13 | 69.06 | |
| 34.04 | 0 | 0.74 | 62.22 | 46.04 | 23.02 | |
| 35.52 | 0 | | | | | |
| 36.26 | 17.78 | 0.74 | 17.78 | 13.16 | 6.58 | |
| 37 | 0 | 0.74 | `17.78 | | | |
| 40.70 | 0 | | | | | |
| 41.44 | 16.67 | 0.74 | 16.67 | 12.34 | 6.17 | |
| 42.93 | 0 | 1.49 | 16.67 | 24.84 | 12.42 | 117.25 |
| 53.29 | 0 | | | | | |
| 54.77 | 14.44 | 1.48 | 14.44 | 21.37 | 10.69 | |
| 56.25 | 0 | 1.48 | 14.44 | 21.37 | 10.69 | |
| 64.39 | 0 | | | | | |
| 65.13 | 8.89 | 0.74 | 8.89 | 6.58 | 3.29 | |
| 66.61 | 0 | 1.48 | 8.89 | 13.16 | 6.58 | 31.24 |
| 76.97 | 0 | | | | | |
| 79.93 | 68.89 | 2.96 | 68.89 | 203.91 | 101.96 | |
| 82.15 | 0 | 2.22 | 68.89 | 152.94 | 76.47 | |
| 88.07 | 0 | | | | | |
| 91.03 | 32.22 | 2.96 | 32.22 | 95.37 | 47.69 | |
| 92.51 | 0 | 1.48 | 32.22 | 47.69 | 23.84 | 249.95 |
| 101.39 | 0 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 102.13 | 10 | 0.74 | 10 | 7.40 | 3.70 | |
| 102.87 | 0 | 0.74 | 10 | 7.40 | 3.70 | |
| 107.31 | 0 | | | | | |
| 108.79 | 16.67 | 1.48 | 16.67 | 24.67 | 12.34 | |
| 109.53 | 0 | 0.74 | 16.67 | 12.34 | 6.17 | 25.90 |
| 125.81 | 0 | | | | | |
| 127.30 | 78.89 | 1.49 | 78.89 | 117.55 | 58.77 | |
| 128.78 | 0 | 1.48 | 78.89 | 116.76 | 58.38 | |
| 135.44 | 0 | | | | | |
| 136.92 | 34.44 | 1.48 | 34.44 | 50.97 | 25.49 | |
| 139.14 | 0 | 2.22 | 34.44 | 76.46 | 38.23 | 180.87 |
| 149.50 | 0 | | | | | |
| 150.98 | 11.11 | 1.48 | 11.11 | 16.44 | 8.22 | |
| 151.72 | 0 | 0.74 | 11.11 | 8.22 | 4.11 | |
| 160.60 | 0 | | | | | |
| 162.08 | 15.55 | 1.48 | 15.55 | 23.01 | 11.51 | |
| 164.30 | 0 | 2.22 | 15.55 | 34.52 | 17.26 | 41.10 |
| | | 42.2 | | 1371.55 | 685.78 | |
| | | | | average per day | 97.97 | |

**Kuala Lumpur Monocrystalline PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 6.16 | 0 | | | | | |
| 7.28 | 120.93 | 1.12 | 120.93 | 135.44 | 67.72 | |
| 8.40 | 0 | 1.12 | 120.93 | 135.44 | 67.72 | |
| 9.52 | 334.88 | 1.12 | 334.88 | 375.07 | 187.54 | |
| 12.88 | 0 | 3.06 | 334.88 | 1024.75 | 512.37 | |
| 14 | 158.14 | 1.12 | 158.14 | 177.12 | 88.56 | |
| 16.8 | 0 | 2.800 | 158.14 | 442.79 | 221.40 | 1145.30 |
| 29.68 | 0 | | | | | |
| 31.92 | 344.19 | 2.24 | 344.19 | 770.98 | 385.49 | |
| 34.16 | 0 | 2.24 | 344.19 | 770.98 | 385.49 | |
| 35.84 | 167.44 | 1.68 | 167.44 | 281.30 | 140.65 | |
| 36.96 | 0 | 1.12 | 167.44 | 187.54 | 93.77 | |
| 38.08 | 232.56 | 1.12 | 232.56 | 260.46 | 130.23 | |
| 40.32 | 0 | 2.24 | 232.56 | 520.93 | 260.46 | 1396.09 |
| 52.64 | 0 | | | | | |
| 58.24 | 697.67 | 5.60 | 697.67 | 3906.97 | 1953.49 | |
| 59.36 | 0 | 1.12 | 697.67 | 781.39 | 390.70 | |
| 61.04 | 204.65 | 1.68 | 204.65 | 343.81 | 171.91 | |
| 63.84 | 0 | 2.80 | 204.65 | 573.02 | 286.51 | 2802.60 |
| 76.16 | 0 | | | | | |
| 78.40 | 55.81 | 2.24 | 55.81 | 125.02 | 62.51 | |
| 78.96 | 0 | 0.56 | 55.81 | 31.26 | 15.63 | |
| 81.76 | 120.93 | 2.80 | 120.93 | 338.60 | 169.30 | |
| 84 | 0 | 2.24 | 120.93 | 270.88 | 135.44 | |
| 85.12 | 83.72 | 1.12 | 83.72 | 93.77 | 46.883 | |
| 87.36 | 0 | 2.24 | 83.72 | 187.54 | 93.77 | 523.53 |
| 99.68 | 0 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 103.04 | 409.30 | 3.36 | 409.30 | 1375.25 | 687.63 | |
| 103.60 | 0 | 0.20 | 409.30 | 81.86 | 40.93 | |
| 104.72 | 204.65 | 1.12 | 204.65 | 229.21 | 114.60 | |
| 106.40 | 0 | 1.68 | 204.65 | 343.813 | 171.91 | |
| 107.52 | 204.65 | 1.12 | 204.65 | 229.21 | 114.60 | |
| 110.88 | 0 | 3.36 | 204.65 | 687.63 | 343.8 | 1473.49 |
| 123.20 | 0 | | | | | |
| 127.68 | 734.88 | 4.48 | 734.88 | 3292.28 | 1646.14 | |
| 134.40 | 0 | 6.72 | 734.88 | 4938.42 | 2469.21 | 4115.35 |
| 146.72 | 0 | | | | | |
| 150.08 | 288.37 | 3.36 | 288.37 | 968.93 | 484.46 | |
| 151.20 | 0 | 1.12 | 288.37 | 322.98 | 161.49 | |
| 151.76 | 251.16 | 0.56 | 251.16 | 140.65 | 70.33 | |
| 153.44 | 0 | 1.68 | 251.16 | 421.95 | 210.98 | |
| 155.12 | 111.63 | 1.68 | 111.63 | 187.54 | 93.77 | |
| 157.92 | 0 | 2.80 | 111.63 | 312.56 | 156.28 | 1177.30 |
| | | 76.62 | | 25267.35 | 12633.67 | |
| | | | | average per day | 1804.81 | |

**Pulau Pinang Monocrystalline PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 6.95 | 0 | | | | | |
| 9.85 | 442.53 | 2.9 | 442.53 | 1283.33 | 641.67 | |
| 10.43 | 0 | 0.58 | 442.53 | 256.67 | 128 | |
| 11.59 | 455.17 | 1.16 | 455.17 | 528 | 264 | |
| 17.96 | 0 | 6.37 | 455.17 | 2899.45 | 1449.72 | 2483.72 |
| 30.70 | 0 | | | | | |
| 33.02 | 126.44 | 2.32 | 126.44 | 293.33 | 146.67 | |
| 34.76 | 0 | 1.74 | 126.44 | 220 | 110 | |
| 36.50 | 619.54 | 1.74 | 619.54 | 1078 | 538 | |
| 42.29 | 0 | 5.79 | 619.54 | 3587.14 | 1793.57 | 2589.24 |
| 54.46 | 0 | | | | | |
| 59.09 | 505.75 | 4.63 | 505.75 | 2341.61 | 1170.80 | |
| 59.67 | 0 | 0.58 | 505.75 | 293.33 | 146.67 | |
| 61.99 | 341.38 | 2.32 | 341.38 | 792 | 396 | |
| 66.04 | 0 | 4.05 | 341.38 | 1382.58 | 691.30 | 2404.76 |
| 78.77 | 0 | | | | | |
| 83.42 | 658.62 | 4.65 | 658.62 | 3062.59 | 1531.30 | |
| 85.74 | 0 | 2.32 | 658.62 | 1528 | 764 | |
| 86.90 | 382.24 | 1.16 | 382.24 | 443.40 | 221.70 | |
| 90.37 | 0 | 3.47 | 382.24 | 1326.38 | 663.19 | 3180.18 |
| 103.70 | 0 | | | | | |
| 107.75 | 986.21 | 4.05 | 986.21 | 3994.14 | 1997.07 | |
| 108.91 | 0 | 1.16 | 986.21 | 1144 | 572 | |
| 110.07 | 606.90 | 1.16 | 606.90 | 704 | 352 | |
| 114.70 | 0 | 4.63 | 606.90 | 2809.93 | 1404.96 | 4326.03 |
| 127.45 | 0 | | | | | |
| 131.50 | 1024.14 | 4.05 | 1024.14 | 4147.76 | 2073.88 | |
| 139.03 | 0 | 7.53 | 1024.14 | 7711.76 | 3855.88 | 5929.76 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 151.78 | 0 | | | | | | |
| 155.83 | 859.77 | 4.05 | 859.77 | 3482.07 | | 1741.03 | |
| 156.41 | 0 | 0.58 | 859.77 | 498.67 | | 249.33 | |
| 159.31 | 834.48 | 2.9 | 834.48 | 2420 | | 1210 | |
| 162.21 | 0 | 2.9 | 834.48 | 2420 | | 1210.00 | 4410.37 |
| | | 78.79 | | 50648.13 | | 25324.06 | |
| | | | | average per day | | 3617.72 | |

**Kelantan Monocrystalline PV**

| time (hr) | power (W) | total hour | power (W) | hr X W | exact energy (Wh/day) | Energy (Wh/day) |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | |
| 7.05 | 0 | | | | | |
| 11.75 | 663.45 | 4.70 | 663.45 | 3118.21 | 1559.10 | |
| 17.82 | 0 | 6.07 | 663.45 | 4027.13 | 2013.56 | 3572.67 |
| 31.72 | 0 | | | | | |
| 34.07 | 413.41 | 2.35 | 413.41 | 971.52 | 485.76 | |
| 36.42 | 0 | 2.35 | 413.41 | 971.52 | 485.76 | |
| 38.77 | 220.69 | 2.35 | 220.69 | 518.62 | 259.31 | |
| 39.94 | 0 | 1.17 | 220.69 | 258.21 | 129.10 | |
| 41.12 | 821.24 | 1.18 | 821.24 | 969.06 | 484.53 | |
| 43.47 | 0 | 2.35 | 821.24 | 1929.92 | 964.96 | 2809.43 |
| 55.80 | 0 | | | | | |
| 59.33 | 736.31 | 3.53 | 736.31 | 2599.17 | 1299.59 | |
| 67.55 | 0 | 8.22 | 736.31 | 6052.47 | 3026.23 | 4325.82 |
| 79.89 | 0 | | | | | |
| 84 | 1058.62 | 4.11 | 1058.62 | 4350.93 | 2175.47 | |
| 91.05 | 0 | 7.05 | 1058.62 | 7463.28 | 3731.64 | 5907.11 |
| 104.56 | 0 | | | | | |
| 108.67 | 589.55 | 4.11 | 589.55 | 2423.05 | 1211.53 | |
| 109.26 | 0 | 0.59 | 589.55 | 347.83 | 173.92 | |
| 110.43 | 551.72 | 1.17 | 551.72 | 645.52 | 322.76 | |
| 112.78 | 0 | 2.35 | 551.72 | 1296.55 | 648.28 | |
| 113.96 | 96.55 | 1.18 | 96.55 | 113.93 | 56.97 | |
| 115.72 | 0 | 1.76 | 96.55 | 169.93 | 84.97 | 2498.41 |
| 127.45 | 0 | | | | | |
| 131.58 | 551.72 | 4.13 | 551.72 | 2278.62 | 1139.31 | |
| 138.63 | 0 | 7.05 | 551.72 | 3889.65 | 1944.83 | 3084.14 |
| 150.96 | 0 | | | | | |
| 157.43 | 551.72 | 6.47 | 551.72 | 3569.65 | 1784.83 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 162.13 | 0 | 4.70 | 551.72 | 2593.10 | 1296.55 | 3081.38 |
| | | 78.94 | | 50557.89 | 25278.95 | |
| | | | | average per day | 3611.28 | |

# REFERENCES

Abdelaziz EA, Saidur R, Mekhilef S. A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews 15 (2011) 1:150–68

A. H. Haris, W. F. Anwar. “Experiences in Conducting Research on Pilot Grid Connected Solar Photovoltaic Systems in Malaysia”, 17th European PV Solar Energy Conference, Munich, Germany, 2001

Ahmad Hadri Haris. National Project Leader, MBIPV Project, Pusat Tenaga Malaysia, Grid Connected And Building Integrated Photovoltaic: Application Status & Prospect For Malaysia, Master Builders, 3rd Quarter 2006

Annual report. Tenaga Nasional Berhad (TNB). 2009. <http://www.tnb.com. my/investors-media/annual-reports.html> [August 2011]

Annual report. Tenaga Nasional Berhad (TNB). 2010. <http://www.tnb.com. my/investors-media/annual-reports.html> [August 2011]

Ayu Wazira Azhari, Kamaruzzaman Sopian,Azami Zaharim, Mohamad Al Ghoul. A New Approach For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia, WSEAS Transactions on Environment and Development, Mar. 27, 2008

Azah Ahmad, Vincent Tan, Wei Nee, Daniel Ruoss. Milestone Report for 9.9 kWp BIPV System Installation at Damansara Utama Shoplots, Building Integrated Photovoltaic (MBIPV) Project, IEA PVPS Task 10, Activity 4.1 – 9.9 kWp (Malaysia), 2007

Bahagian Tenaga Baharu. Jabatan Kerja Raya Malaysia (JKR). 2010. < http://www.jkr.gov.my/> [August 2011]

Bakos GC, Tsagas NF. Technical feasibility and economic viability of a smallscale grid connected solar thermal installation for electrical-energy saving. App. Energy 72 (2002) 621–30

Bakos GC, Soursos M, Tsagas NF. Techno economic assessment of a building-integrated PV system for electrical energy saving in residential sector. Energy Build 35 (2003) 757–62

Bekele G, Palm B. Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia. App. Energy 87 (2010) 487–95

Celik AN. Long-term energy output for photovoltaic energy systems using synthetic solar irradiation data. Energy 28 (2003) 479–93

CETDEM. “Making Malaysian Homes Energy Efficient – Stakeholder Workshop” Impiana Hotel Kuala Lumpur, 2004

CETDEM. “Working with the Community on Energy Efficiency at Household Level in Petaling Jaya” A CETDAM Study on Energy Efficiency, 2006

Chan Seong Aun. Energy Efficiency Designing Low Energy Buildings Using Energy 10, Pertubuhan Arkitek Malaysia, CPD Seminar, 2004

Chandrasekar, B., Kandpal, T.C. Techno-economic evaluation of domestic, 2003

C. Reise, T. Erge. Solar Irradiation and Energy Yields for Photovoltaic Systems in Kuala Lumpur“, Fraunhofer ISE, (on behalf of NLCC Architects), 2002

C. Şerban, E. Eftimie and L. Coste. Simulation Model in TRNSYS of a solar house from brasov, Romania, Department of Renewable Energy Systems and Recycling, Transilvania University of Braşov, , 2010

Dalimin, M.N. Renewable energy update: Malaysia. 0960-1481 (99) 00070-0, 1994

Department of Electricity Supply Malaysia, Ketua Merinyu Electric Sarawak, TNB, SESco, SEBSB and GDB (M) Department of Static Malaysia. National Energy Balance 1980-2000, Ministry of Energy, Communications and Multimedia, 2000

Diaf S, Notton G, Belhamel M, Haddadi M, Louche A. Design and technoeconomical optimization for hybrid PV/wind system under various meteorological conditions. App. Energy 85 (2008) 968–87

Duffie J, Beckman W. Solar engineering of thermal processes. 1st Edition, New Jersey: Wiley (1980) 453–74

Duffie, J. and Beckman, W. Solar Engineering of Thermal Processes, 2nd Edition, John Wiley & Sons, Inc., New York, 1991

Domestic pricing & tariff. Tenaga Nasional Berhad. 2010. <http://www.tnb.com.my/tnb/business/for-domestic/pricing-tariff.html> [October 2011]

Ekren O, Ekren BY. Size optimization of a PV/wind hybrid energy conversion system with battery storage using response surface methodology. App. Energy 85 (2008) 1086–101.

Elcock D. 2007, Life-cycle thinking for the oil and gas exploration and production industry. Argonne National Laboratory; <www.evs.anl.gov/pub/ dsp_detail.cfm?PubID=2154> [July 2011]

Eliasson, B. The Road to Renewable: Opportunities and Challenges, World Renewable Energy Congress VI, Brighton, 1 - 7 July, (2000) 64-68

Energy pricing practices. Asia Pacific Energy Research Centre (APERC). 2000. <http://www.ieej.or.jp/aperc/final/pricing.pdf> [July 2011]

EPRI. Potential Health and Environmental Impacts Associated With the Manufacture and Use of Photovoltaic Cells, Technical Report, Final Report, Public Interest Energy Research Program (PIER), 2003

Florides G, Kalogirou S, Tassou S, Wrobel L. Modelling and simulation of an absorption solar cooling system for Cyprus. Solar Energy 72 (2002) 1:43–51

Gary, H.P., Prakash, J. Solar energy: Fundamentals and applications. Tata McGraw-Hill Publishing company limited. (2004) 412-417

http://www.ecmag.com/?articleID=6888&fa=article/ Thomas E. Glavinich, 2006, PV Inverter Technology, Department of Civil, Enviromental and Architectural Engineering, University of Kansas <January, 2012>

Habtamu Tkubet Ebuy and Abebayehu Assefa. Simulation of solar cereal dryer using TRNSYS, Addis Ababa University, Ethiopia, 2007

Hasnain SM, Elani UA, Alawaji SH, Abaoud HA, Smiai MS. Prospects and proposals for solar energy education programs. App. Energy 52 (1995) 307–14

Hossain. “Wind Energy Study- Progress and Preliminary Findings” – First Seminar of Wind Energy Study (WEST) Project, Prepared by BCAS/LGED/ETSU, Bangladesh Atomic Energy Commission (BAEC), 1996

International Energy Agency (IEA). World energy outlook. (Paris: OECD/IEA), 2009

Ineichen P, Guisan O, Perez R. Ground-reflected radiation and albedo. Solar Energy 44 (1990) 207–14

Jaafar, Z. The Way Forward, Malaysia’s Energy Plan, Malaysia Energy Center, 2005

Jayanta Deb Mondol, Yigzaw G. Yohanis, Brian Norton. Comparison of measured and predicted long term performance of grid a connected photovoltaic system, School of the

Built Environment, University of Ulster, UK and Dublin Institute of Technology, Ireland, 2006

Jiratkwin Rakwichian. PV-Bio Diesel from Farmer Diesel Engine for Hybrid Solar Home System (PV-Bio FDE for HSHS), Energy Technology at the Faculty of Electrical Engineering, University of Kassel. Kassel Jan, 2008

Jordan U, Vajen K. Influence of the DHW load profile on the fractional energy savings: a case study of a solar combisystem with TRNSYS simulations. Proceedings of Eurosun' 2000 on CD-ROM, Copenhagen, Denmark, 2000

Kablan, M.M. Techno-economic analysis of Jordanian solar water heating system. Renewable Energy 29 (2004) 1069-1079

Kalogirou S, Papamarcou C. Modelling of a thermosyphon solar water heating system and simple model validation. Renewable Energy 21 3/4 (2000) 471–93

Kalogirou S. The potential of solar industrial process heat applications. App. Energy 76 (2004) 337–61

Karlis AD, Dermentzoglou JC, Papadopoulos DP. Wind energy surveying and techno economic assessment of identifiable WEC system installations. Energy Convers Manage 42 (2001) 49–67

K.H. Solangi, M.R. Islam, R. Saidur, N.A. Rahim, H. Fayaz. A review on global solar energy policy, Centre of Research UMPEDAC, University of Malaya, Malaysia, Renewable and Sustainable Energy Reviews 15 (2011) 2149–2163

Kimura Y, Onai Y, Ushiyama I. A demonstrative study for the wind and solar hybrid power system. Renew Energy 9 (1996) 895–8

Klein SA, Beckman WA, Duffie JA. TRNSYS - A transient simulation program. ASHRAE Trans 82 (1976) 623–33

Kreider JF, Kreith F. Solar energy handbook. New York: McGrawHill, 1981

Lim Chin Haw, Elias Salleh and Philip Jones. Renewable Energy Policy and Initiatives in Malaysia, ALAM CIPTA, Intl. J. on Sustainable Tropical Design Research & Practice, Vol. 1 (Issue 1) December (2006) 33-40

Liu BYH, Jordan RC. Daily insolation on surfaces tilted towards the equator. Trans ASHRAE 67 (1962) 526–41

Malaysia inflation rate. Trading Economics. 2010. <http://www.tradingeconomics.com/economics/inflation-cpi.aspx?symbol=myr> [June 2011].

Malaysia Energy Centre, Ministry of Energy, Water & Communications of Malaysia: "National Energy Balance Malaysia 2001". www.ktkm.gov.my <July 2011>

Malaysia : Energy Efficiency and Renewable Energy Applications in Non-Residential Buildings. Codes of Practice. SIRIM MS 1525, 2001.

Meyer EL, Van dyk EE. Development of energy model based on total daily irradiation and maximum ambient temperature. Renewable Energy 21 (2000) 37–47

Meteonorm version 6.1.0.23. Global Meteorological Database for Solar Energy and Applied Meteorology, Meteotest, 2010

Ms Chen Wei-Nee, Solar Photovoltaic: Sunny Solution for Tomorrow, Pusat Tenaga Malaysia. BEM's The Ingenieur, Dec Issue, 2008

Ms Chen Wei-Nee, Solar Photovoltaic: Sunny Solution for Tomorrow, Pusat Tenaga Malaysia. BEM's The Ingenieur, Feb Issue, 2009

NASA Langley Research Center Atmosphere Science Data Center, 2002, New et al, www.gaisma.com/en/location/kuala-lumpur.html <June 2011>

National Renewable Energy Laboratory (NREL). December. *A consumer guide: heat your water with the sun.* For the US Department of Energy's Office of Energy Efficiency and Renewable Energy, 2003, Retrieved from http://www.nrel.gov/docs/fy04osti/34279 <August 2011>

Oh, T.H., Pang, S.Y. and Chua, S.C. Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth Renewable and Sustainable Energy Reviews 14 (2010) 4:1241-52

Oishi M, Noguchi T. The evaluation procedure on performance of SDHW system by TRNSYS simulation for a yearly performance prediction. Proceedings of Eurosun'2000 on CD ROM, Copenhagen, Denmark, 2000

Othman AK, Jakhrani AQ, Abidin WAWZ, Zen H, Baharun A. 2010, Malaysian Government Policy. Renewable Energy: Solar PV System, World Engineering Congress, C.o.N.R.a.G. Technology, Editor. The Federation of Engineering Institutions of Islamic Countries: Kuching, Sarawak, Malaysia, 2010

Ozsabuncuoglu, I.H. Economic analysis of flat-plate collectors of solar energy. 0301-4215) 00063-1, 1995

Patel, M. S., and T. L. Pryor. Monitored Performance Data from a Hybrid RAPS System and the Determination of Control Set Points for Simulation Studies, ISES 2006 Solar World Congress, Adelaide, Australia, 2006.

Perez R, Reed R, Hoff T. Validation of a simplified PV simulation engine. Solar Energy 77 (2004) 357–62

Photovoltaic economics. PV resources. 2010. <http://www.pvresources.com/ en/economics.php> [September 2011].

Pusat Tenaga Malaysia. Biogen, 2000 http://www.ptm.org.my/biogen/index_new.htm <July 2011>

Reindl DT, Beckman WA, Duffie JA. Evaluation of hourly tilted surface radiation models. Solar Energy 45 (1990) 9–17

Saheb-Koussa D, Haddadi M, Belhamel M. Economic and technical study of a hybrid system (wind-photovoltaic-diesel) for rural electrification in Algeria. App. Energy 86 (2009) 1024–30

Saidur, R., M. R. Islam, N. A. Rahim, and K. H. Solangi. Renewable Energy Research in Malaysia, Centre of Research UMPEDAC Faculty of Engineering University of Malaya, Malaysia, 2009

Saidur, R., Rahim, N.A., Masjuki, H.H., Mekhilef, S., Ping, H.W. and Jamaluddin, M.F. End-use energy analysis in the Malaysian industrial sector Energy 34 (2009) 153-8

Saidur R, Islam MR, Rahim NA, Solangi KH. A review on global wind energy policy. Renewable Sustainable Energy Rev 14 (2010) 7:1744–62

Schnitzer H, Christoph B, Gwehenberger G. Minimizing greenhouse gas emissions through the application of solar thermal energy in industrial processes. Approaching zero emissions. Journal of Cleaner Production 13–14 (2007) 1271–86

Schwarzbozl P, Eiden U, Pits-Paal R. A TRNSYS model library for solar thermal electric components. A Reference Manual, German Aerospace Agency (DLR), Koln, Germany, 2002

Schweiger H, Mendes JF, Benz N, Hennecke K, Prieto G, Gusi M, Goncalves H. The potential of solar heat in industrial processes. a state of the art review for Spain and Portugal. Proceedings of Eurosun Copenhagen, Denmark on CDROM, 2000

S. Mekhilef, R. Saidur, A. Safari. A review on solar energy use in industries, Faculty Engineering, University of Malaya, Malaysia, 2010

S. Mekhilef. R. Saidur. Energy use, energy savings and emission analysis in the Malaysian rubber producing industries. Applied Energy 87 (2010) 8: 2746–58

TRNSYS 16 Program Manual. Solar Energy Laboratory, University of Wisconsin, Madison, USA, 1996

TRNSYS User’s Manual. Laboratory of Solar Energy. University of Wisconsin Madison: USA, 2004

Widalys De Soto. Improvement and Validation of a Model for Photovoltaic Array Performance, Solar Energy Laboratory, University of Wisconsin-Madison, 2004

Widalys De Soto, A. Klein, and W. A. Beckman. Improvement and Validation of a Model for Photovoltaic Array performance, Solar Energy Vol. 80 (2006) 1:71-80.

W.T. Chong , M.S. Naghavi, S.C. Poh, T.M.I. Mahlia, K.C. Pan. Techno-economic analysis of a wind–solar hybrid renewable energy system with rainwater collection feature for urban high-rise application, University of Malaya, Malaysia, 2011

www.firstsolar.com. 00801_FL_NA_07MAR11 Copyright, First Solar, Inc, 2011 <July 2011>

Yang H, Zhou W, Lou C. Optimal design and techno-economic analysis of a hybrid solar wind power generation system. App. Energy 86 (2009) 163–9

Zhou W, Lou C, Li Z, Lu L, Yang H. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. App. Energy 87 (2010) 380–9