ECONOMIC EVALUATION OF A STAND ALONE PV SYSTEM FOR A RESIDENTIAL HOUSEHOLD IN MALAYSIA

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ABSTRACT

The price of crude oil has risen from a low of US$ 2 per barrel to a high of US$ 92.40 (as at 1st February 2008). This resulted in searching for an alternative energy source. Since Malaysia lies entirely in the equatorial region with an average daily solar radiation of 4,500kWh/m^2, with sunshine duration of about 12 hours, solar photovoltaic system is applicable to be used as an alternative primary energy to replace the conventional system. The purpose of this study is to investigate the cost per kilowatt hour for a stand-alone photovoltaic system supplying energy to a typical household of four applying life-cycle costing (LCC) method of analysis. RETScreen software is used to determine cost of developing a stand-alone photovoltaic system while taking into account the cost per watt of the photovoltaic cells, efficiency and all factors contributing to the output power generated from these cells while doing likewise to the balance of the system which includes the battery storage, charge controller and inverter. The temperature and irradiation effect towards the out power is interpreted using RETScreen. These data are obtained form the Meteorological Department in Petaling Jaya. The effects of which towards the various photovoltaic technologies are thoroughly studied. LCC is applied to determine the cost per kilowatt hour of energy generated more accurately taking into consideration the inflation and interest rates for the next 25 years. With this, a more reliable cost comparison between the cost of energy generated from stand-alone photovoltaic system and power supplied from Tenaga Nasional Berhad can be compared. From this investigation, although stand alone photovoltaic system provides several advantages from the environmental point of view, the major drawback is the fact that it costs ten times more than the cost of conservative energy. The price of energy for a standalone photovoltaic system ranges from RM 5.20/kWh for cadmium telluride to RM 5.32/kWh for amorphous silicon with an average of RM 5.26/kWh taking into account all five PV technologies.

ABSTRAK

Harga minyak di pasaran dunia meningkat secara mendadak sejak 1973 iaitu dari US$ 2 setong kepada US$ 92.40 setong (harga pada 1 Februari 2008). Perkara ini membawa kepada penjanaan tenaga elektrik menggunakan solar. Malaysia yang terletak di kawasan khatulistiwa mendapat pancaran cahaya suria sebanyak 4500kWh/m^2 sehari dengan cahaya matahari selama 12 jam sehari menjadikannya sangat sesuai untuk menggunakan tenaga solar sebagai sumber alternatif. Kajian ini dilakukan bertujuan mendapat penggunaan kos kitaran hayat (LCC) dalam menentukan kos per kilowattjam bagi sebuah sistem kendiri fotovolta untuk sebuah rumah teres yang penghuninya seramai 4 orang. Perisian RETScreen diguna bagi mentukan kos mendirikan sistem fotovolta tersebut dengan mengambil kira kos per watt bagi sel fotovolta. Data suhu persekitaran dan pancaran cahaya suria yang memberi kesan kepada kecekapan dan jumlah tenaga elektrik yang terhasil daripada sel fotovolta diperolehi daripada Jabatan Kaji Cuaca, Petaling Jaya dan data tersebut diintepretasikan melalui perisian RETScreen. Kesan suhu persekitaran dan kos per kilowattjam terhadap lima sel fotovolta yang berlainan teknologi disimulasi menggunakan perisian RETScreen. LCC digunakan untuk menentukan dengan lebih tepat kos per kilowattjam tenaga begi kelima-lima teknologi tersebut dengan mengambil kira kadar inflasi dan kadar faedah semasa untuk jangkamasa 25 tahun akan datang. Melalui kaedah ini, perbandingan kos per kilowattjam tenaga terjana melalui sistem kendiri fotovolta dibuat berbanding dengan kos menjana tenaga elektrik daripada Tenga Nasional Berhad untuk tempoh 25 tahun akan datang. Penyelidikan ini menunjukkan bahawa, walaupun sistem kendiri fotovoltta ini mempunyai banyak kelebihan dari segi pengurangan pencemaran alam sekitar, tetapi kos menjana per kilowatt tenaga elektrik adalah sepuluh kali ganda berbanding dengan kos menjana tenaga menggunakan kaedah konservetif. Kos per kilowattjam bagi sistem fotovolta kendiri adalah dalam lingkungan RM 5.20/kWh bagi teknologi cadmium telluride ke RM 5.32/kWh bagi teknologi amorphous silikon dengan purata kos diantara kelima-lima teknologi adalah RM 5.26/kWh.

CHAPTER 1

INTRODUCTION

With the beginning of the Industrial Revolution, entailed a sharp growth in both population and in energy consumption per capita. Both gave way to an exponential growth in worldwide energy consumption of primary energies. A striking illustration of this is that until the 1970's, each decade saw a doubling of energy usage. In other words, every 14 years of humanity got through as much energy as in the whole of its previous history **(Solarcentury, 2008)**.

Compared with coal, oil is richer in energy, easier to transport and leaves fewer residues when burnt. The lowering of prices encouraged extravagant consumption, and externalization of costs reached its pinnacle giving rise to extensive pollution. The year 1973 saw the first oil embargo by the OPEC countries, which raised the price of crude oil from US$2 to US$13 per barrel *(US$1 is equivalent to RM3.3715 as at 1st February 2008)*. It was followed by a second embargo which raised the price again to US$32 per barrel. With the immergence of China and India as economic giants of the 21st century, the consumption of oil has increased exponentially raising the price to US$92.40 per barrel (as at 1st February 2008).

The present system cannot be maintained for more than one or two generations. Exhaustion of reserves, greenhouse gas effect, acidification of the water cycle and deforestation all pose threats to the world. All these gave way to an alternative source of energy, the sun.

1.1 Solar Energy as an Alternative

The Sun is the original source of almost all the energy used on the Earth. It provides the energy that drives our weather systems and so the energy sources of wind, water and waves are in fact a form of solar energy. Trees and other plant life are sustained by using sunlight to create stored chemical energy through the process of photosynthesis and it is this energy that is released when planet material is burned. Since this energy from the sun is in continuous supply these energy sources can be constantly replenished and hence are categorised as renewables.

Fossil fuels, which the world is at present so dependant on for energy, are deposits formed from the dead vegetation of millions of years ago (an indirect form of solar energy). There are two major issues with fossil fuels that make them an unsustainable energy source. Firstly, being finite, they are not renewable (except over geological timescales) and so will eventually run out. Secondly, when burned they release large volumes of carbon dioxide into the atmosphere. The increase in the atmospheric concentrations of carbon dioxide is the main cause of global warming, which is destabilising the planet's climate. The Royal Commission on Environmental Pollution's Report 'Energy – The Changing Climate' indicated that the UK needs to reduce emissions of carbon dioxide by 60% by the year 2050 and by 80% by the year 2100 (**Solarcentury, 2006)**.

A sustainable energy system must ultimately be based upon renewable energy sources, all of which are ultimately based upon solar radiation. Thankfully, the Earth receives a staggering amount of energy from the sun, as much energy falls on the planet each hour as the total human population uses in a whole year – that's about 1018 Kilowatt hours (kWh) **(Solarcentury, 2006)**.

1.2 Types of Solar Technology Application

There are several ways in which the solar energy the Earth receives can be used directly for heating and electricity generation. The various technologies are often classified as either 'passive' or 'active'. Passive solar systems do not involve the input of any other forms of energy apart from the incoming sunlight. Passive solar water heaters, for instance, have no pumps and may rely upon capillary action to pump water. Active solar systems use additional mechanisms such as circulation pumps. These mechanisms are typically powered by electricity and may have additional electronic or computerized automatic controls.

Electricity can be generated from solar energy in two ways. The first is to capture heat from the sun and use this to power a conventional turbine or generator. The other is to use the photovoltaic effect, which converts light directly into electricity using materials called semiconductors.

1.3 Types of Terrestrial Solar PV Applications

Terrestrial solar PV application could be generally divided into two categories as follows:

- Stand-alone application
- Grid-connected application

A brief comparison between the stand-alone application and grid-connected application is shown in Figure 1.1 and Table 1.1 below.

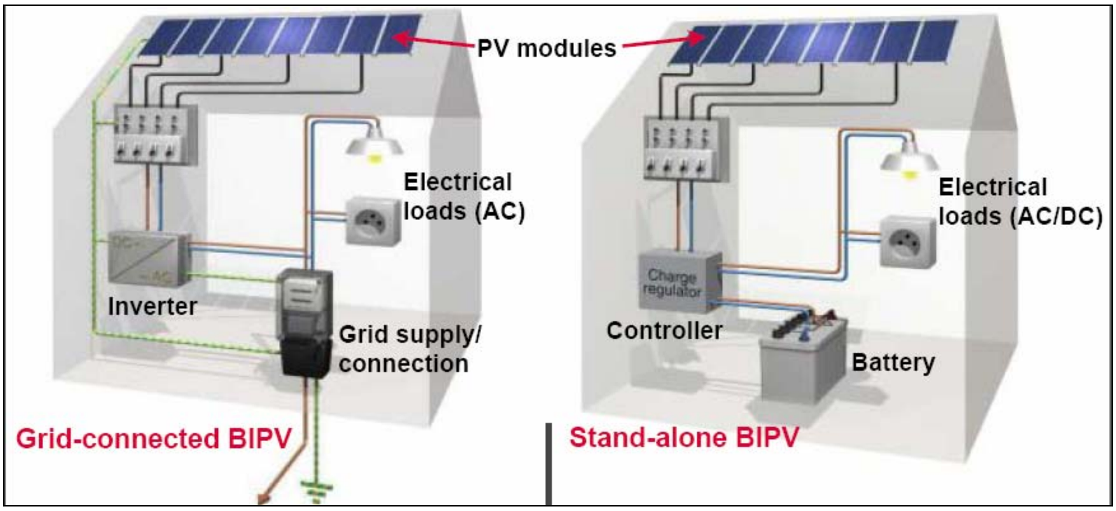

Figure 1.1: Building integrated photovoltaic (BIPV) application: grid connected vs stand alone

source: Installing BIPV: Process & Benefits
Impiana Hotel, K.L, 12th June 2004

Table 1.1: BIPV application: grid connected vs stand alone

Grid Connected BIPV	Stand Alone BIPV
Mostly applied in urban areas	Applied in remote areas, areas with no excess to the utility
Does not require battery (utility grid is used as battery source)	Requires battery (critical)
Inverter (critical) is used to convert D.C to A.C	Charge regulator or controller regulates the battery
Excess electricity is sold to utility	Can be connected to D.C load

Stand-alone domestic PV systems provide electricity to households in remote areas. The system provides basic electricity for lighting, refrigeration and other domestic electrical equipments. These application have been installed almost everywhere in the world, especially in rural areas of developing countries. The PV is often the most appropriate technology to meet the energy demand of isolated communities. Stand-alone PV systems generally offer an economic alternative to the extension of electricity distribution grid at distance of more than 1 or 2 km from existing power lines.

Consumer PV applications were the first commercial application for terrestrial PV system. They provide power for a wide range of application, such as watches, calculators, telecommunication, water pumps, navigation aids, aeronautical warning lights and etc. These are application where small amount of power have a high value, and thus PV price is competitive. Today, the PV's have also been applied to streetlights, parking meters and even cars.

The National Electricity Board (now Tenaga Nasional Berhad) initiated the use of PV system for rural electrification in the early 1980s. The first of these was the installation of stand-alone PV systems for 37 houses in Langkawi, followed by other projects in Tembeling (seventy houses) and Pulau Sibu (fifty houses) as observed in Figure 1.2 and Figure 1.3. Later in the 1990s two rural electrification pilot projects, of 10 kWp and 100 kWp respectively were implemented in Sabah with the support from the New Energy and Industrial Technology Development Organization (NEDO) of Japan. In the late 1990s the Ministry of Rural Development has undertaken the provision of photovoltaic system for rural electrification. It is estimated that the total capacity for stand-alone systems in Malaysia, including Sabah and Sarawak, in the year 2000 was 1.5 MWp, however, some of the installations have been dismantled **(Ahmad Hadri, 2003)**.

Figure 1.2: Solar PV for rural home, parking meter and street lamp

Figure 1.3: Stand-alone rural electrification

Distributed grid connected PV system is a relatively recent application where a PV system is installed to supply power to a building or other load that is also connected to the utility grid. The system usually feeds electricity back into the utility grid when electricity generated exceeds the building loads. Those systems are increasingly integrated into the built environment and are becoming commonplaces because of the huge economic potential. They are used to supply electricity to residential homes, commercial and industrial buildings. The PV capacity installed is usually dependent to the budget or existing space available as observed in Figure 1.4. Compared to the stand-alone applications, system costs are lower as energy storage (battery) is not required a factor that also improves system efficiency **(Ahmad Hadri, 2003)**.

Figure 1.4: Distributed and centralized grid connected PV system

These distributed applications also provide advantages such as:

- The distribution losses are reduced because the system are installed at the point of use
- No extra land is required for the PV system
- Costs for mounting systems can be reduced, and the PV array itself can be used as cladding of roofing material.

Centralized grid connected PV system have been installed for two main purposes:

- As an alternative to centralized power generation from fossil fuels or nuclear energy
- To strengthen the utility distribution grid

1.4 Present Status of Grid Connected Solar PV Applications

Traditionally solar PV is utilized in remote areas to provide basic electricity needs. However to make the efforts to reduce the green house gas effect more effective, it is becoming very rational to operate the solar PV in the urban area and connect it to the electricity grid. Currently the are many grid connected solar pV applications throughout the world especially in Japan, Europe and USA. For this application, solar PV is integrated into the building and houses, either as part of the building or retrofitting. Thus, the systems are known as building integrated PV or BIPV as seen in Figure 1.5.

FIGURE 1.5: BIPV applications

Another year of dramatic growth in installed PV capacity was reported by the IEA PVPS countries in 2004. The cumulative total grew by over 770 MW in the year, to just under 2,6 GW by the end of 2004. The vast majority (94 %) of this growth in capacity was installed in Germany, Japan and the USA and therefore care must be taken when interpreting the results, as most of the comments directly reflect the developments in these lead countries. Figure 1.6 below illustrates the growth of installed capacity since 1992 and the split of this capacity between the two primary applications for PV. Particularly with the recent levels of growth seen in IEA PVPS member countries, this installed capacity reported represents a significant proportion of worldwide PV capacity **(IEA-PVPS T1-14, 2005)**.

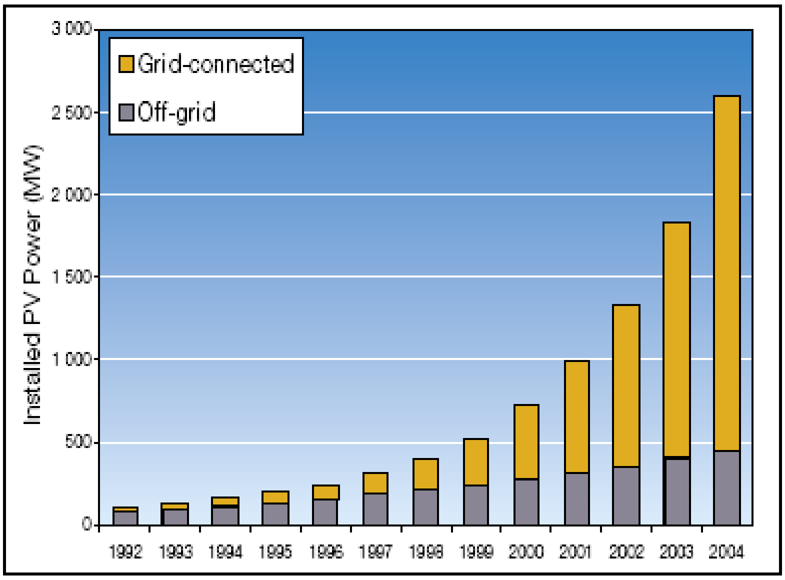

FIGURE 1.6: Cumulative installed grid connected and off grid PV power between 1992 – 2004

The cumulative market in IEA PVPS countries reached a new high growth rate of 42 % between 2003 and 2004, up from 37 % last year. In terms of annual sales the growth rate was even more spectacular rising from 44 % in 2003 to 55 % in 2004. Amongst the largest markets, the annual rate of growth in Germany (137 %) indicates that, if sustained, installed capacity in this country may meet that of Japan by the end of next year (if Japan's reported growth rate is maintained at 22 %). These extraordinary levels of growth continue to be driven by market support mechanisms that initially focused on grid-connected domestic applications in the urban or suburban environment. In terms of installed capacity per capita, Germany now leads the way at 10 W per capita, now ahead of Japan, Switzerland and the Netherlands at 9 W, 3 W and 3 W per capita respectively **(IEA-PVPS T1-14, 2005)**.

1.5 Photovoltaics Prospects in Malaysia

Malaysia lies entirely in the equatorial region with an average daily solar radiation of 4,500kWh/m^2, with sunshine duration of about 12 hours. Ambient temperature remains uniformly high throughout the year. Average ambient temperatures are between 27 to 33 °C. Most locations have a relative humidity of 80 – 88%, rising to nearly 90% in the highland areas, and never falling below 60% (**UNDP, 2004)**.

The Klang Valley (Kuala Lumpur, Petaling Jaya) has the lowest irradiance value, whereas around Penang (Georgetown, north-west coast) and Kota Kinabalu (East Malaysia) have the highest values measured. However, compared to Germany, an installation in Kuala Lumpur receives 1.3 times higher global solar irradiance. A solar PV installation in Malaysia would produce energy of about 900 to 1400 kWh/kWp per year depending on the locations. Areas located at the northern and middle part of the Peninsula and the coastal part of Sabah and Sarawak would yield higher performance. An installation in Kuala Lumpur would yield around 1000 - 1200 kWh/kWp per year **(UNDP, 2004)**.

According to the 9th Malaysia Plan period, the country's peak electricity demand is expected to increase at 7.8% per annum to slightly above 20,000 megawatt (MW) by the year 2010. From that capacity, 350 megawatt (MW) is expected to come from Renewable Energy (RE). This RE target is, however, lower than the 500 megawatt (MW) target in the 8th Malaysia Plan due to various reasons **(MGCC, 2007)**.

Over the past decades alone, the Government has been continuously subsidizing the population's fossil fuels need. The fuel subsidy in 2005 alone was about RM25 billion, where RM9 billion were for power generation and RM16 billion were for the transport sector. Therefore, new and effective ways to reduce the overwhelming dependence on natural gas, as well as the energy subsidy, have to be found. One natural resource that Malaysia has in abundance and which is totally free is the sunlight **(MGCC, 2007)**.

In 2005, the Government launched the Malaysian Building Integrated Photovoltaic (MBIPV) Project, aimed at intensifying the usage of solar energy as an alternative source of electricity, contributing to environmental protection and to attract investments into the country in the areas of photovoltaic fabricated wafers, cells, modules, power management system, photovoltaic wires, connectors, mounting metal structures and inverters. The Malaysian Building Integrated Photovoltaic (BIPV) Technology Application Project (MBIPV) is intended to induce the long-term cost reduction of the non-emitting GHG technology via integration of the PV technology within building designs and envelopes **(UNDP, 2004)**.

The project's key success indicators are:

i. Total GHG emissions avoided from the power sector is about 65,100 tons CO2 over the lifetime of the installed BIPV capacity by the year 2010, relative to the baseline in the year 2005;

ii. Increase installed BIPV capacity by about 330% over the project implementation period, resulting from 1.5 MWp of new BIPV capacity by the year 2010;

iii. Reduce cost of BIPV technology by about 20% by the year 2010, relative to the baseline in the year 2005;

iv. About 30% annual growth of BIPV capacity and average 30% BIPV cost reduction, from year 2010 to 2020, made possible by the integration and implementation of National BIPV programs in the 10th Malaysia Plan (2011-2015).

An earlier assessment conducted by Pusat Tenaga Malaysia (PTM) indicated that by installing BIPV on most of our urban building roofs today, the country can have as much as 6,500 mega-watts (MW) of solar powered capacity in the country. This is almost half of Malaysia's maximum demand today. Even if Malaysia taps only 1% of that potential, the energy component is still significant.

The PV market is still considered to be very small and at its infancy in Malaysia. According to Ir. Ahmad Hadri Haris, National Project Leader for the MBIPV Project, at the current pace the country may reach the target of 2MW generated by PV by the year 2010, which is indeed a very small amount. He says that as a developed nation the country should generate approximately 100 MW through PV by 2020.

In the PV manufacturing industry in Malaysia, the current big name is First Solar, an American company with manufacturing facilities in Kulim High-Tech Park, Kedah. The majority of their products are manufactured for exports. German companies starting to make their presence noticeable on the Malaysian market are Solar World and Suntechnics **(MGCC, 2007)**.

1.6 Thesis Objective

Due to the high usage of non-renewable energy sources, environmental phenomena and the recent surge in oil and gas commodities, alternative sources are vital. Solar and wind are the alternative energy sources. Amongst a wide variety of renewable energy projects, photovoltaic systems are the most promising as a future energy technology.

The objective of the project is:

- Study the performance for different types of PV technologies
- Identify the parameters that affect the performances
- Perform cost analysis for various PV technologies
- Use Life Cycle Costing (LCC) to determine the cost per kWh

1.7 Scope of Work

The scope of the project comprises:

- Analyzing the thermal effect and irradiance effect at Ipoh for the application of stand alone PV systems
- Analyzing the accuracy of the energy efficiency models and the detailed cost analysis of the system components
- Analyzing using RETScreen software
- Analyzing the cost per kWh using LCC

1.8 Thesis Overview

This thesis comprises of five main chapters. Chapter 1 introduces solar energy as an alternative energy source and the types of terrestrial solar PV available. A brief outlook of the prospects of solar PV internationally and at national levels is presented.

Chapter 2 studies all the key components in developing from a solar cell right up to a solar array. Various types' solar PV cells and arrays are scrutinized together with the balance of the system involved in developing a stand alone PV application.

Chapter 3 details the load used to determine the PV array sizes in addition to costs breakdown of all key components involved in developing a stand PV system to supply power to a typical household of four.

Chapter 4 initially introduces RETScreen as a software used to analyze the cost of developing the PV system. There after, a detailed study on array losses, efficiency of the various PV arrays and balance of system are investigated. Finally, life cycle costing method is used to evaluate the cost per kWh energy for various PV technologies.

Lastly, Chapter 5 concludes the entire thesis and proposals for future works on PV systems are suggested.

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