DESIGN AND OPTIMIZATION OF REMOTE TELECOMMUNICATION STATION POWER SYSTEM USING SOLAR/WIND ENERGY.

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ABSTRACT

People in remote areas at present are beyond the coverage of conventional telecommunication networks. Telecommunication mobile markets have reached its saturation period and hunted for a new market. The conventional technology of telecommunication mobile networks nowadays is unable to reach the millions of rural user that ready to embrace it. The new technology introduced by WorldGSM is a new solution to reach the threshold of profitable mobile services in rural areas. The telecommunication station introduced is consumed at less than 50W which the whole system can be run alone on solar energy or wind/solar energy on selected site which is Cameron Highlands, Malaysia. The objective of this research is to design and optimize remote telecommunication power system using solar and wind energy.

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I hereby present my thesis entitled "Design and Optimization of Remote Telecommunication Station Power System using Solar/Wind Energy", in order to completely satisfy the requirements to graduate with a Master of Engineering Science in Renewable Energy Electrical Power System.

I declare that this thesis consists of my own work outside of where acknowledgements are given.

Yours sincerely,

(Nor Hanisah Baharudin)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Load BTS
Charger Controller
4 Batteries
5 Solar Panels
67.74 Ah/day
60.96 Ah/day

1.0 Introduction

For the last two centuries, global energy consumption has been powered primarily by carbon fuels; with nuclear power plants met some proportions of demand over the last five decades. Recently, a new era of increasing environmental concerns about global warming and the harmful effects of carbon emissions have created a new paradigm shift to green energy resources. Renewable energy sources such as wind, solar, sea, biomass and geothermal power do not cause any significant environmental pollution or substantial health hazards. Those are the pollution free sources with plentiful power. These resources are sustainable which are not depleted substantially by continued use. Furthermore, social injustices are not the issue as the resources are universal energy sources rather than dominated by certain countries.

Principally, the sun's radiation derives renewable energy resources directly and indirectly. Radiation and heat brought in by sunshine can be classified as direct solar energy whereas most of the other renewable energy resources belonged to indirect solar energy i.e wind, hydro and bio-energy power. Ancient people used all these energy sources for their daily life usage which hydropower for transportation and mills, wind power for sailing ships, mills and water pumping for farming, as well as solar power for heating, drying and lighting.

However, people in the western countries have realized the advantages of coals during the Industrial Revolution in the 18th centuries as a highly concentrated energy sources compared to renewable energy resources and more coals discovered in numerous amount. By end half of the 19th century, electric power generation stations powered by burning coals started to operate and became more popular globally. During the 20th century, it is become a norm of energy supply which electric power generated by coal fired power stations and electric power networks with long transmission lines. Electric powers generated by coal fired power stations are then partly replaced by oil and natural gas in the 20th century because of easy transportation and more concentrated but coals remain to be the core energy sources until today.

Nevertheless, fossil fuels cause environmental damage due to harmful emissions such as CO_2 and SO_2 which results global warming, acid rains and climate change. Since late 1700s of the industrial revolution, the carbon dioxide concentration in the earth's atmosphere was increasing slowly from 270 parts per million until the 20th century. Particularly for the last 50 years, CO_2 concentrations have grown rapidly which is shown in Figure 1 below. Besides, the present concentrations exceed 350 part per million which is higher than it has been in the last 160,000 years ago of 180 parts per million. The correspondence between CO_2 concentration and temperature over this period is shown in Figure 2.

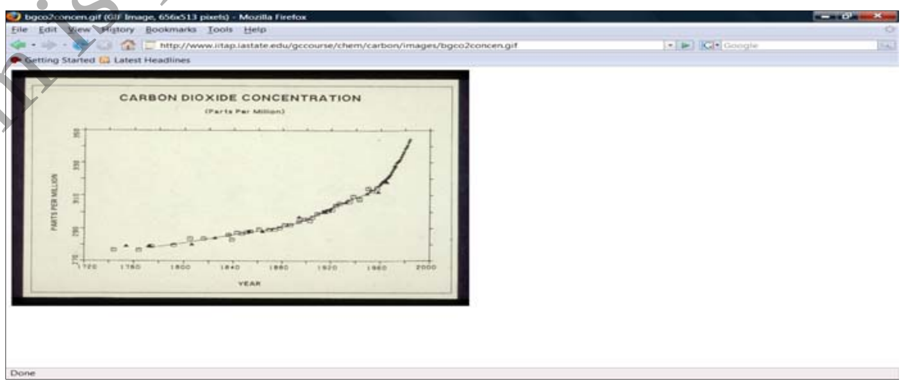


Figure : Atmospheric CO_2 since the beginning of the Industrial Revolution. (EPA.)

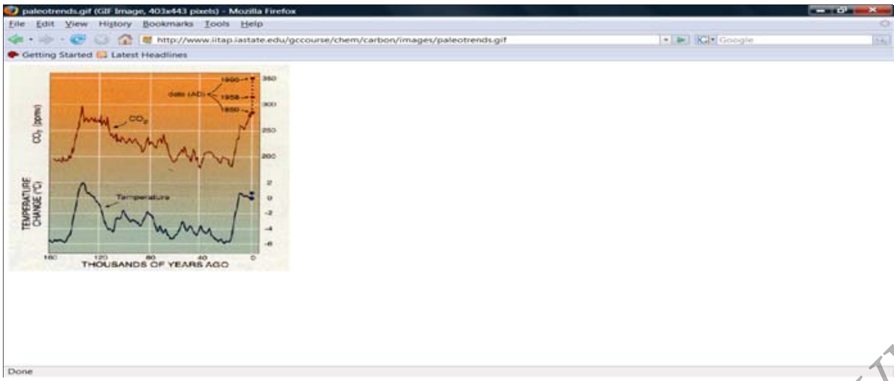


Figure : Changes in global atmospheric CO_2 and global surface temperature over the last 160,000 years. (U.S. Global Change Research Program.)

In addition, fossil fuel stocks are available in finite quantities and expected to deplete by continued use. Coals, oil and natural gas are expected to sustain for another 200 years, 40 years and 60 years respectively. Analysis of projected world production of oil and gas is presented in Figure 3. Historical data obtained until year 2000 whereas the dotted lines represent future projection of oil and gas production globally. Using ultimate recovery of 2000 billion barrels of conventional oil (including gas liquids), 750 billions barrel of non-conventional oil, and 2000 billion barrels oil equivalent of natural gas as a base. From the analysis, the projected peak in conventional oil supply occurs around 2005 while non-conventional oil peak supply arise approximately in 2015. Moreover, the projected peak of natural gas extends in 2030.

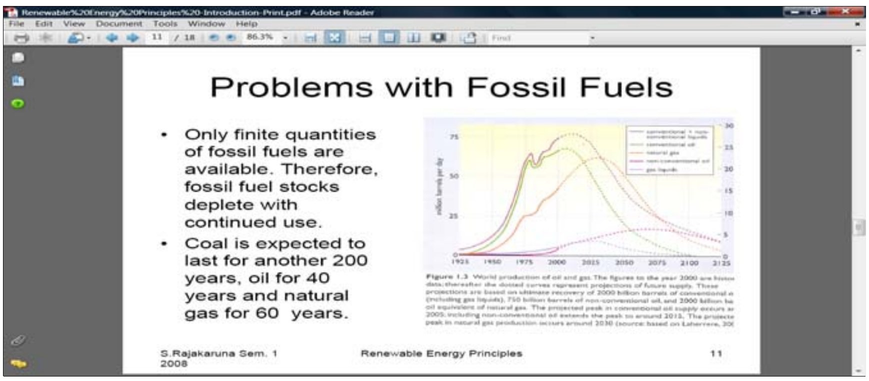


Figure : World production of oil and gas. (Laherrere, 2000)

On the other hand, high prices of fossil fuels which are due to limited number of countries with such resources have created oil crisis in 1970s and oil price hiked up again in 1990s. Besides, accidents involving oil tankers caused severe damages to marine life as an example, Exxon Valdez oil spill tragedy in 1989. Problems created by fossil fuels are then added up with power generation by nuclear reactors which started after World War II. Currently, the development of nuclear power plants are stalled because of high capital cost, well-known health hazard due to exposure to radiation during operation and accidents i.e. Chernobyl disaster as well as spread of nuclear weapons.

Currently, world energy sources are highly depended on burning fossil fuels, i.e natural gas, oil and coal which contribute 75.9% of overall energy sources. Another 5.7% is met by nuclear power and the rest of 18.4% are supplied by renewable energy sources. The correspondence data are shown in Figure 4. The main contributor for renewable energy sources is hydro power of 63.45% which is illustrated in Figure 5.

Trends of adapting renewable energy sources in power generation plants take place currently in the world throughout the nations as attempts to cut down greenhouse gas emissions by reducing fossil fuels consumption in power plants. Renewable energy sources that currently used for power generation plant are solar, wind, hydro, wave, tidal, geothermal power and biomass. It is highly expected that rapid development of renewable energy sources based power plant will result cheaper price of energy cost in the near future.

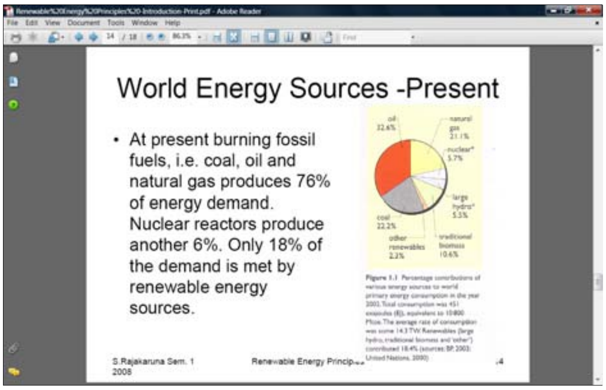


Figure : Percentage contributions of various energy sources to world primary energy consumption in 2002. (BP, 2003; United Nations, 2000)

Figure : World renewable energy 2005

1. Current State of Global Solar Power Development

Since 1970s, solar cells have been used to power the telephone system off the South-West coast of Skye and radio repeater stations in various parts in Scotland. Solar cells (photovoltaic diodes) convert the sunlight to direct current electricity. Solar cells are built from a single thin slice of crystalline silicone (semiconductor cells), generally several square centimetres in size. Based on the solid-state physics, the cell is basically a large area p-n diode with the junction placed closed to the top surface. These cells are commercially mounted and arranged in arrays to make up photovoltaic (PV) modules in order to supply required output power with the highest efficiency around 17%.

Solar cell technologies have been developed since 1960s to meet the requirement as reliable power sources for satellites. During the energy crisis in 1970s, these solar technologies have been started to adapt at ground level use [19]. However, high cost of PV modules production are due to crystalline silicones used for most of solar cells, which are the same semiconductor material to make integrated circuit (IC) chips. Presently, more researches carried out to reduce the cost and improve the efficiency of solar cells and arrays. Thus, the capital cost of PV modules per watt peak (Wp) of power capacity has reduced from more than USD$27/Wp in 1982 to around USD$4/Wp today. Nowadays, Japan becomes the largest country market and hosting the largest PV cell manufacturing companies which leads the world in PV price. The progression of price reduction for the last 10 years of 4 kWp residential solar system in Japan is shown Figure 6.

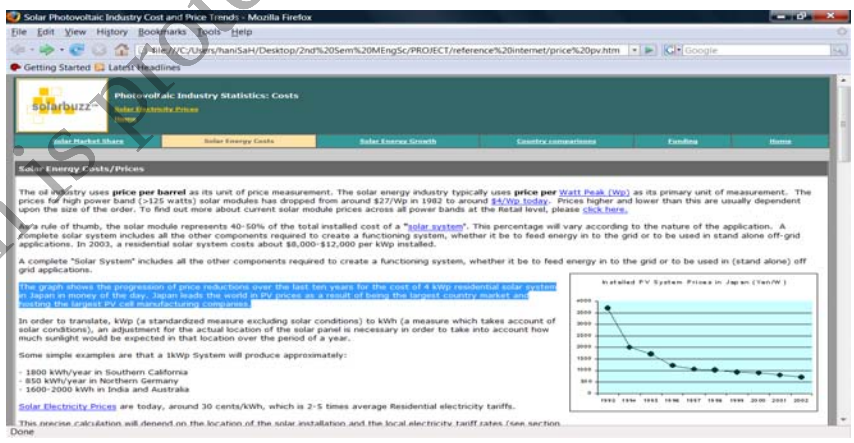
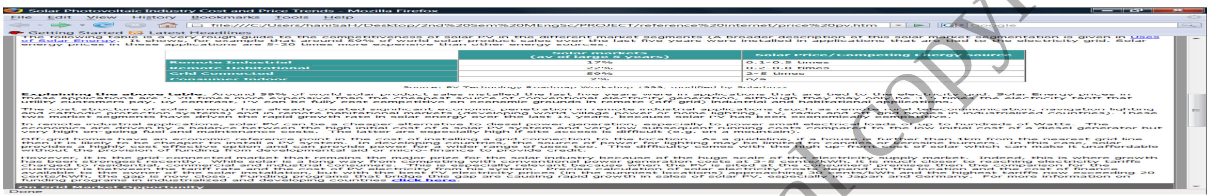


Figure : Installed PV system prices in Japan (Yen/Watt). (Solarbuzz Inc)

In the mean time, solar electricity price today is 30 cents/kWh which is 2 – 5 times higher than average residential electricity tariff. Since the last five years, 59% of world solar product sales are grid connected which solar energy in these application is 5 to 20 times more expensive than the cheapest conventional power generation which is shown in Figure 7. However, the utility customer will pay only 3 – 5 times higher than the residential electricity tariff. On the contrary, solar energy is more cost effective at remote industrial (off grid) and habitational applications. Both of these applications have increased the growth of solar energy rapidly for the past 15 years because fully justified by its own economics.


Solar Photovoltaic Industry Cost and Price Trends - Mozilla Firefox

	Solar markets (av of large 5 years)	Solar Price/Competing Energy sources
Remote Industrial	17%	0.1-0.5 times
Remote Habitational	22%	0.2-0.8 times
Grid Connected	59%	2-5 times
Consumer Indoor	2%	n/a

Source: PV Technology Roadmap Workshop 1999, modified by Solarbuzz

Figure : Solar prices for different segments of solar market. (PV Technology Roadmap Workshop 1999, modified by Solarbuzz)

For remote industrial applications i.e. remote rural telecommunication, navigation lighting and cathodic protection system, as well as habitational applications i.e. to supply electricity in off-grid villages of developing countries, PV can be very cost competitive better than diesel generators. PV can supply small electrical loads to hundreds of watts with higher starting capital cost but low maintenance cost in the long run as compared to diesel generators which have low initial cost but high cost of operation due to fuels and maintenance. Geographical aspects such as mountain areas where the site access is difficult will increase more cost of operation for diesel generator. Nevertheless, the difficulty of high upfront cost can be made affordable by the provision of funding from government subsidies and micro-finance to provide loan.

Hence, it is grid connected that remains the wide gap opportunity because of the various range of electricity supply market. However, the strongest growth rate in solar energy presently is grid connected market. Even though solar energy production is a far apart from 3 cents/kWh of conventional power generation but it is proven that at the highest insolation (the sunniest location) where the PV system installed, the electricity price is 30 cents/kWh whereas the highest electricity utility tariff nowadays is 21.2 cents/kWh. Hence, the gap is getting narrower with the rapid growth sales of PV modules by government funding programs i.e. Japan and Germany as well as more low cost of PV cells and modules manufactured with improved efficiency to meet the growing demand.

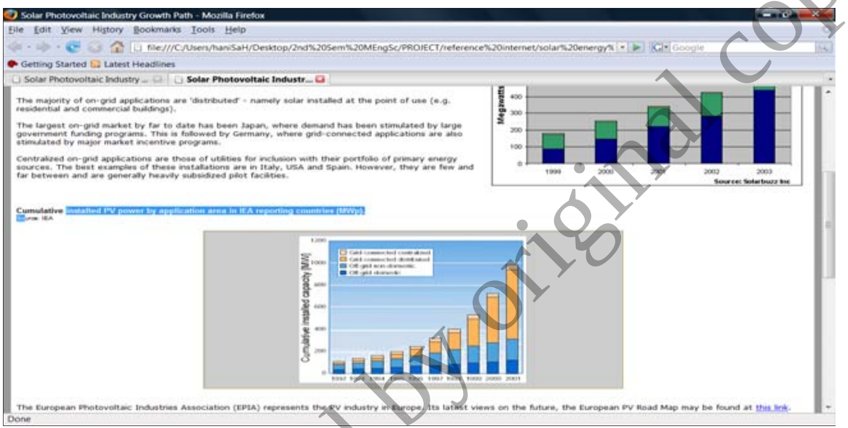


Figure : Cumulative installed PV power by application areas. (IEA)

With the declining prices and costs of PV system, solar electric demand has grown constantly by 20-25% annual rate during the last 20 years. The significant decline has been firmly determined by increasing efficiency of solar cells, improving technologies of manufacturing, and economics of scale. Furthermore, around 350 MW solar equipments were sold in 2001 to expand the existing solar equipments to generate clean energy. Nowadays, $37.1 billion revenues were generated globally for solar PV industry for its modules, associated equipments and installations. 1460 MW installed PV capacity in 2005 and increased to 1744 MW in 2006 for worldwide solar PV installation. World solar photovoltaic (PV) market installations reached a record high of 5.95 GW in 2008, representing growth of 110% over the previous year. Cumulative installed PV power by application areas are represented in Figure 8. Rapid growth of grid connected sales is doubled as compared to off grid customers in

2003 whereas solar PV for off grid markets is still the chosen energy supplies because of its cost competitiveness. The given data is shown in Figure 9.

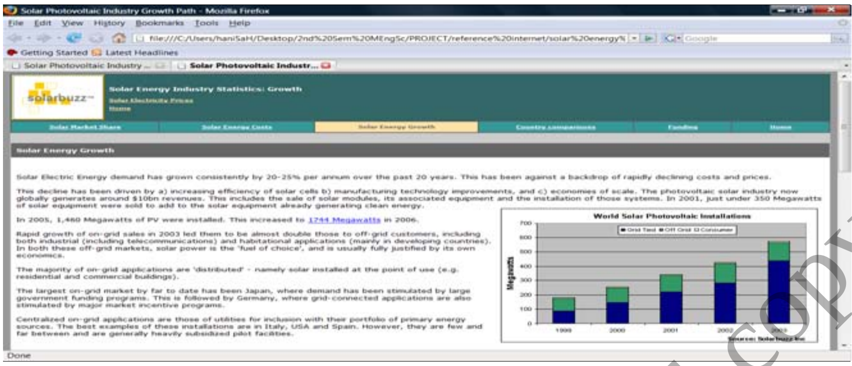


Figure World Photovoltaic Solar Installations (Solarbuzz Inc)

Currently, Japan is the largest grid connected market for ‘distributed’ type where PV installed at residential and commercial buildings. Large government funding programs have stimulated the increased growth in Japan. Germany is following as the second largest grid tied market which is also supported by major market incentive programs. Besides, centralized grid connected type installed in Italy, U.S, and Spain are few and far between and generally subsidized heavily as pilot projects. These correspondence data are shown in Figure 10. As the conclusion, government plays a significant role to stimulate the boost growth of solar PV industry globally.

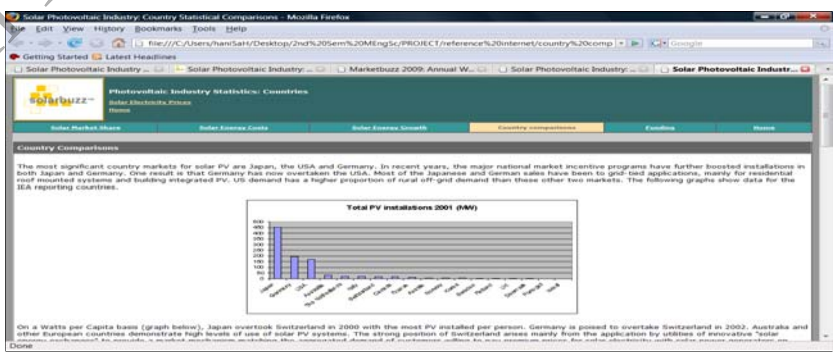


Figure : Total PV installations in 2001. (IEA)

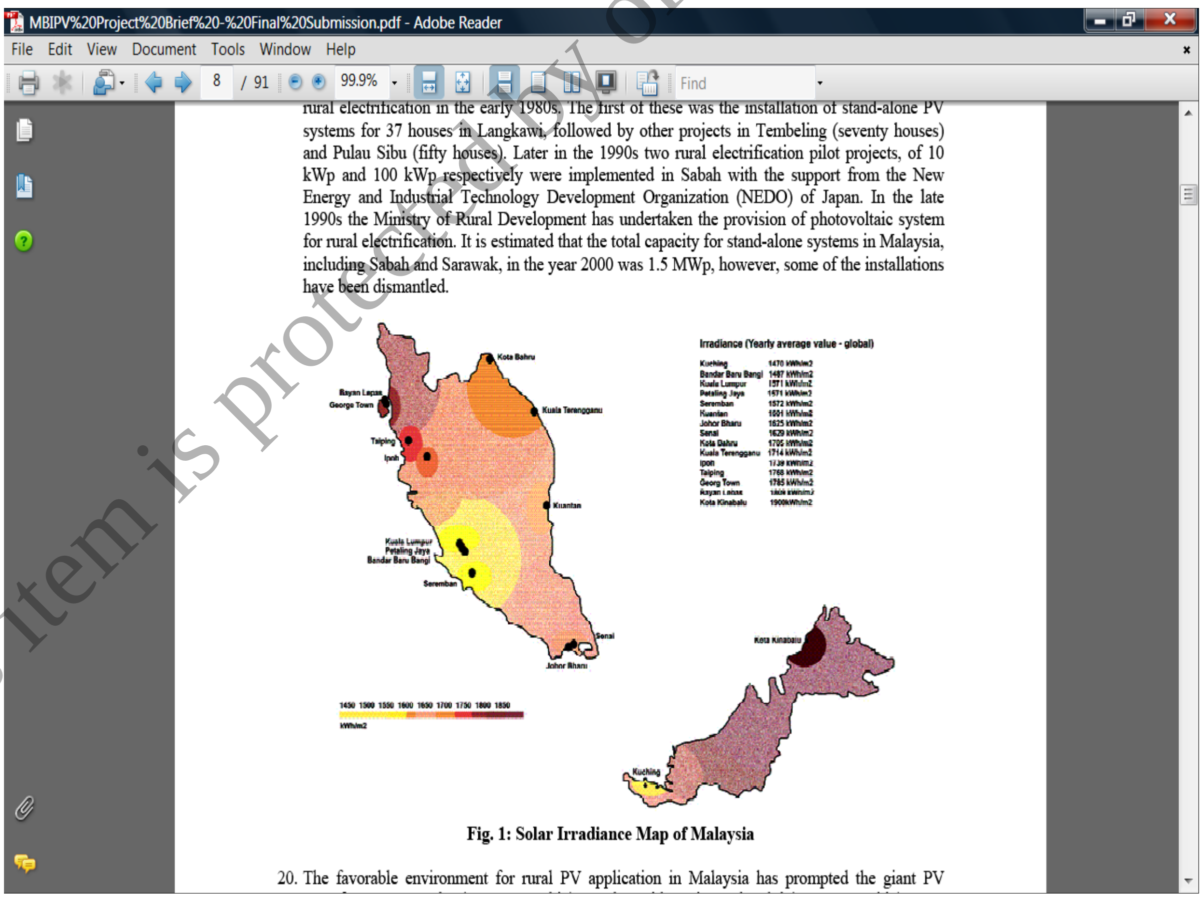
2. Solar Energy in Malaysia

Figure : Map of Malaysia. (World Factbook, 2005)

Malaysia is located near equator which the climate is entirely equatorial. The average ambient temperature is 27°C - 30°C and the annual rainfall exceeds 2000mm a year. Generally, Malaysia is being hot and humid throughout the year. There are two monsoons seasons occurs in Malaysia, the Southwest Monsoon (from late May to September) and the Northeast Monsoon (from November to March). More rainfalls occur in the Northeast Monsoon as compared to the Southwest Monsoon. The average solar insolation is 4500 kWh/m^2 with approximately 12 hours average daily sunshine period. The highest temperature recorded in Malaysia is 40.1°C which was recorded on 9 April 1998 at Chuping, Perlis. The average relative humidity is 80-88% in most locations and nearly 90% in highlands areas [18].

As a comparison, a solar PV installation in Kuala Lumpur will receive 1.3 times higher solar insolation than the same system installed in Germany. The lowest solar insolation is measured at the Klang Valley, Kuala Lumpur whereas the highest solar insolations are measured at Penang and Kota Kinabalu. The global solar irradiance map for Malaysia is shown in Figure 12. Generally, a solar PV installation in Malaysia will generate 900-1400 kWh/kWp annually. However, the higher solar energy can be produced at the northern and middle part of the Peninsular and the coastal part of Sabah and Sarawak.

Even though solar energy is abundant resource in Malaysia, the solar PV applications are limited to rural areas for off grid electricity supplies which heavily subsidized by funding from government. Furthermore, there are several small electrical load applications being promoted to use solar PV applications nowadays i.e. telecommunication systems, street and garden lightings and recently, for powering parking ticket dispensing machines.



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). 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.

Fig. 1: Solar Irradiance Map of Malaysia

20. The favorable environment for rural PV application in Malaysia has prompted the giant PV

Figure : Global Solar Irradiance of Malaysia. (UNDP)

Since early of 1980s, Tenaga Nasional Berhad (previously known as National Electricity Board) has established the solar PV applications for rural electrification.

The first project launched for stand-alone solar PV system for 37 houses in Langkawi, then followed by 70 houses in Tembeling and 50 houses in Pulau Sibu. Furthermore, another two pilot facilities for rural electrifications were executed in Sabah with capacity of 10 kWp and 100 kWp, in collaboration with the New Energy and Industrial Technology Development Organization (NEDO), Japan. Later in the late 1990s, the provision of photovoltaic system for rural electrifications have become under accountability of Ministry of Rural Development. Total installed solar PV systems for off grid rural electrifications are approximately 1.5 MWp in 2000 but some of the systems have been dismantled.

PV modules fabrication plant was launched in April, 2000 with share equity between the second largest PV manufacturer in the world, BP Solar (49%) and local company of Projass Sdn Bhd (51%). This PV plant favoured solar PV development for rural electrifications. At full capacity, this plant can reach up to 5MWp production annually and for the past 3 years, the plant have produced about 500 kWp per year.

Recently, government has funded several pilot grid tied solar PV projects through the Malaysia Electricity Supply Industry Trust Account (MESITA), Ministry of Science, Technology and the Environment (MOSTE) and Tenaga Nasional Berhad (TNB). However, these PV applications were add on PV technology rather than improved PV applications specifically such as Building Integrated PV (BIPV) projects. The main goal of these pilot facilities is to become as a platform for on-grid PV system instead of reducing the PV system costs. Since 1998, the annual grid connected PV installations in Malaysia reached about 90 kWp and increased rapidly to 450 kWp in 2003 for 14 grid tied PV applications.

Figure : 362 kWp grid-connected PV installations in Technology Park Malaysia. (Symbiosis online)

The cumulative grid-connected PV installations available in Malaysia from 1998 to 2003 are shown in Figure 14. The first government funded project installed in 1998 and raised rapidly in 2001 because of large scale PV installations at Technology Park Malaysia (TPM) with total capacity of 362 kWp. Solar PV installations at TPM consisted of 4824 fixed mounted roof modules; facing 15° in the Southern direction is the largest solar array facility in Malaysia and in the region of South East Asia.

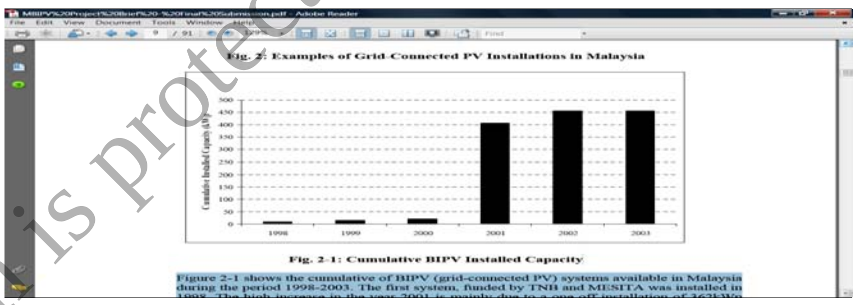


Figure : Total annual cumulative PV installations in Malaysia. (MBIPV)

3. Wind Power in the World

Since 5000 years ago, wind power was used to sail ships in the Nile and the European used it for pumping water and grinding grains since 1700s. In 1890, the first windmill for U.S rural electrification was installed, followed by the first wind electric power plant to generate hydrogen by electrolysis in 1891. By year 1940, thousands of wind power plants were executed to supply electricity for remote areas. However, wind power development downturn happened during 1940 till 1970 because of grid expansion and low oil prices.

Starting from 1970 onwards, oil crisis and financial support as well as regulatory incentives became the stepping stone for revival of wind power. These environments have grown interests of wind electric systems in U.S during 1970s until 1980s. Meanwhile, wind turbines performances were below expectations that declined the growth of wind power development in U.S. In addition, the wind power industry became stagnant when tax-credits were withdrawn from the U.S markets. In the other hand, European countries i.e. Germany, Spain and Denmark, preceded the development of wind power industry. By mid of 1990s, the interest of renewable energy resources specifically for wind power, increase immensely due to environmental concerns and oil price hiked up again. Hence, these European countries become the key players of wind turbine industry for wind power global markets. Today, large wind power plants are competing with utility grid to supply clean energy in the whole world. In 2008, total wind turbines installed worldwide are increased by 27,261 MW to 121,188 MW which is shown in Figure 15 [6]. This represented increment of 29% growth of rate in 2008. The total wind turbines installed capacities worldwide are expected to increase exponentially by 190,000 MW in 2010.

Figure : World Total Installed Capacity.(WWE Report 2008)

Nowadays, the wind energy becomes one of the most promising new sources of electrical power generation and it has continued as the most dynamically growing energy source in 2008. Large scale of wind energy generation cost reduced from 35 cents/kWh in 1980 to 4 cents/kWh today as shown in Figure 16. At this price, wind energy has become one of the least costs of electricity generation as compared to residential electricity tariff nowadays which is shown in Figure 17. The highest residential electricity tariff is 21.2 cents/kWh in Japan which wind energy power generation is more cost effective than any other renewable energy sources. This means that wind energy can compete strongly with conventional power generation and increase of renewable energy sources penetration in electricity share market. Main reasons that accelerate the growth of wind energy industry are high strength fibre composites for constructing large low-cost blades, price reduction of power electronic components, variable-speed operation of electrical generators to maintain optimum power, up to 95% plant operation availability as well as large scale of power plants.

Figure : Guideline electricity generation costs today (cents/kWh). (Solarbuzz Inc)

Figure : Residential Electricity Tariff 1999. (Energy Information Administration)

4. Potential of Wind Energy in Malaysia

Figure : 150 kW wind turbine installed in Terumbu Layang-Layang, Malaysia.

(Seagrass study: 25th March – 8th April,2004)

Malaysia consists of Peninsular Malaysia, Sabah and Sarawak. Malaysia is located on latitude 1°22`N and longitude 103°55`E which the climate changes depend on the Northeast and Southwest monsoons which blow alternately throughout the year. Generally, the wind blows in Malaysia are typically light. The strongest wind occurs in the East coast of Peninsular Malaysia during the Northeast monsoon because of the direct wind from the South China Sea. The pattern of the wind in Malaysia started with maximum speed in the afternoon and minimum speed occurs just before sunrise. This is due to convection in the surface boundary layer which the ground is heated by the sun's heat during the day and vice versa.

Wind turbine at Terumbu Layang-layang is one of success wind turbine installation in Malaysia. With 150 kW capacity, the wind turbine is used to harness the wind energy and convert it to electricity stored in batteries. Besides, the electricity generated is used to evaporate sea water for drinking water application. Furthermore, two 100 kW wind turbines were installed at Pulau Perhentian Kecil to facilitate part of the electricity needs of residents there.