Potential of Solar Radiation and Wind Speed for Photovoltaic and Wind Power Hybrid Generation in Perlis, Northern Malaysia

I. Daut, M. Irwanto, Y.M. Irwan, N. Gomesh, Rosnazri, N.S. Ahmad

Abstract-- **This paper presents analysis of the solar radiation and wind speed characteristics in Perlis, Northern Malaysia for the year of 2006. The characteristics consist of daily and annual mean solar radiation and wind speed. Peak sun hours (PSHs) of the solar radiation and PV power generation capacity are analyzed. The Weibull distribution function is applied to analyze the wind speed characteristics and used to calculate the wind power generation potential. Potential of PV and wind power generation is observed and analyzed during 24 hours (9th March 2011). The result shows that the annual total solar radiation in Perlis is 1831.45 kWh/m^2 which will generate a total electric energy of 237.7 kW/m2 per year of PV module, if all the lands in Perlis were filled with horizontal PV panels, nearly 189,29 GWh of electricity could be produced per year. This shows the big potential of solar radiation for PV power generation in Perlis. Based on wind speed data, the probability density of 81.06% and its wind speed is 1.01 m/s, it is important to choose a suitable wind turbine for a wind power generation. Observation during 24 hours ((9th March 2011), for a 24 V PV and wind power hybrid generation, the PV array gives big potential and the wind power gives 10% of its total output voltage.**

Index Terms—**solar radiation, wind speed, photovoltaic, hybrid system.**

I. Introduction

ENERGY is one of the essential inputs for economic development and industrialization. Fossil fuels are the main resources and play a crucial role to supply world energy demand. However, fossil fuel reserves are limited and usage of fossil fuel sources has negative environment impact. Therefore, management of energy sources, rational utilization of energy, and renewable energy source usage are vital [1].

Renewable energy has an increasing role in achieving the goals of sustainable development, energy security and environmental protection. Nowadays, it has been recognized as one of the most promising clean energy over the world because of its falling cost, while other renewable energy technologies are becoming more expensive [2].

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A. Solar radiation

Solar radiation is the result of fusion of atoms inside the sun. Part of the energy from the fusion process heats the chromosphere, the outer layer of the sun that is much cooler than the interior of the sun, and the radiation from the chromosphere becomes the solar radiation incident on the earth [3]. Wind energy is produced by continuously blowing wind and can be captured using wind turbines that convert kinetic energy from wind into mechanical energy and then into electrical energy [4].

When the solar radiation enters the earth's atmosphere (Fig. 1), a part of the incident energy is removed by scattering or absorption by air molecules, clouds and particulate matter usually referred to as aerosols. The radiation that is not reflected or scattered and reaches the surface directly in line from the PV module is called beam radiation. The scattered radiation which reaches the ground is called diffuse radiation. Some of the radiation may reach a receive after reflection from the ground, and is called the albedo. The total solar radiation on a horizontal surface of PV module consisting three components is called global irradiance. When the skies are clear and the sun is directly in line from the PV module, the global irradiance is about 1000 W/m^2 [5]. Although the global irradiance on the surface of the earth can be as high as 1000 W/m^2, the available radiation is usually considerably lower than this maximum value due to the rotation on the earth and climate condition (cloud cover), as well as by the general composition of the atmosphere. For this reason, the solar radiation data is the most important component to estimate output of photovoltaic systems [3], [6],[7]. Solar radiation is greater than 3 kWh/m^2 indicates that the sky is clear, its intensity very high and very good for PV application [8].

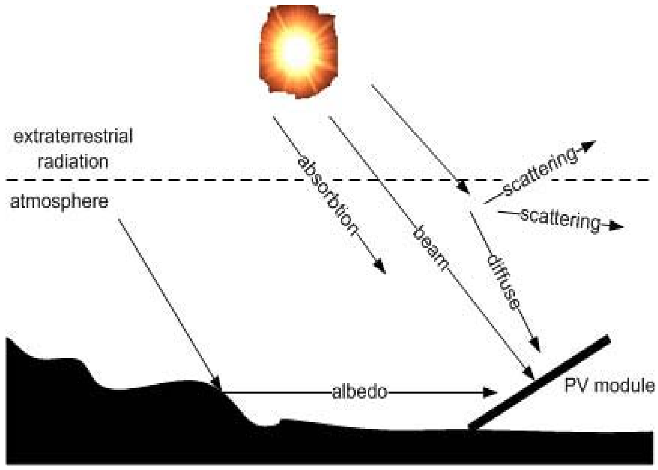

Fig. 1. Solar radiation in the earth's atmosphere

B. *Wind speed*

It is necessary to carry out long-term meteorological observation to accurately asses the wind power generation potential and its characteristics. Data of wind speed is needed to asses the potential. The wind speed is a random variable and variation wind speed over a period of time is represented by probability density function. Wind speed frequency distribution has been represented by various probability density function such as gamma, Rayleigh and Weibull distribution. However, in recent years Weibull distribution has been one of the most commonly used, accepted, recommended distribution to determine wind energy potential [1].

A lot of researchers have been studying the wind speed characteristics and its potential as a wind power generation in many countries worldwide. Analysis of the wind speed characteristics was done by [9] in Ras Benas city located on the east coast of Red Sea in Egypt using measured data (wind, pressure and temperature) and Weibull function. The result showed that the annual mean wind density is 315 kW/m^2 at a height of 70 m above ground level. The monthly and seasonal variation of the wind characteristics were investigated by [2] in term of wind energy potential using the wind speed data collected between 2002 and 2008 for four meteorological stations in Liguria region, in Nortwest of Italy, namely Capo Vado, Casoni, Fontana Fresca and Monte Settepani. The results showed that Capo Vado is the best site with a monthly mean wind speed between 2.80 and 9.98 m/s at a height of 10 m and a monthly wind power density between 90.71 and 1177.97 W/m^2, while the highest energy produced may be reached in December with a value of 3800 MWh.

This paper presents analysis of the solar radiation and wind speed characteristics in Perlis, Northern Malaysia for the year of 2006. The characteristics consist of daily and annual mean solar radiation and wind speed. Peak sun hours (PSHs) of the solar radiation and PV power generation capacity are analyzed. The Weibull distribution function is applied to analyze the wind speed characteristics and used to calculate the wind power generation potential. Potential of PV and wind power generation is observed and analyzed during 24 hours (9th March 2011).

II. Methodology

A. *Location description of meteorological station*

Base on Meteorological Station in Chuping Perlis, Perlis (6^0 $29'$ N , 100^0 $16'$ E) has about 795 square kilometers land area, 0.24% of the total land area of Malaysia, with a population about 204450 people [10], as shown in Fig. 2.

Fig. 2. Location of meteorological station in Chuping, Perlis, Malaysia

The solar radiation and wind speed data was measured as hourly during 2006 at a height of 21.7 m above ground level.

B. *Solar radiation*

B.1 Peak Sun Hours (PSHs)

Solar radiation data can be got from Meteorological Station, Chuping Perlis. Unit of solar radiation is Wh/m^2 or J/m^2, to convert a quantity given in Wh/m^2 to J/m^2, it should be multiplied by 3600 [2]. PSHs is the length of time in hours at a radiation level of 1000 W/m^2 needed to produce energy equivalent to the total energy in one day or it is ratio of solar radiation (Wh/m^2) to solar radiation level of 1000 W/m^2 [11]. The solar radiation and PSHs are needed to calculate a minimum size of PV module.

Solar radiation data for the year of 2006 is given and found the highest and lowest total daily average solar radiation, the monthly minimum, average and maximum solar radiation, distribution of the average annual daily solar radiation, and its PSHs.

B.2 PV Power Generation Capacity

In order to estimate the potential generating of PV module, it is necessary to estimate the area which is suitable for PV integration. The efficiency of PV module is an important figure for the estimation of PV output. A conservative value of 13 % for popular single crystalline silicon modules was used although higher efficiency modules are available [8]. The annual potential electricity generating capacity from PV systems, E_{out}, can be estimated by [8]

$$E_{out} = \left(\sum E_{solar,\ i}\right) x\ A_i\ x\ \eta_{pv}\ x\ f \tag{1}$$

where

$E_{solar,\ i}$ = available solar radiation on different orientation surfaces

A_i = area of orientation surface,i

η_{pv} = efficiency of PV modules

f = utilization factor

C. Wind speed

C.1 Weibull distribution

There are several probability density functions, which can be used to present the wind speed frequency curve. The Weibull distribution is the most commonly used statistical distribution for representing wind speed data.

The probability density function $f(v)$ indicates the percent of time for which the wind flows with a specific wind speed. It is expressed as [1],[12]

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

C.2 Wind power density

For a period of measurement the mean wind power density (the available power of wind per unit area) is given by the following expression [12]:

$$\overline{P} = \frac{1}{2}\rho \overline{v}^{3} \tag{3}$$

where ρ is the standard air density ($\rho = 1.225$ Kg/m^3 dry air at 1 atm and 15 ^{0}C).

D. PV and wind power hybrid generation

Potential of solar radiation and wind speed are observed and analyzed during 24 hours (9th March 2011) which measured using weather station (Fig. 3) installed in front of Electrical Energy and Industrial Electronic System (EEIES) cluster, University Malaysia Perlis.

The solar radiation and wind speed are taken by PV and wind turbine (Fig. 4) to produce direct current electricity. The output of PV and wind turbine are measured per minute using electrocorder.

Fig. 3 . Weather station

Fig. 4. PV and wind power hybrid generation

The PV and wind power hybrid generation consist of a PV array (8 units PV module, 2 units are connected in series and 4 parts are connected in parallel) and a wind turbine.

III. RESULT AND DISCUSSION

A. *Solar radiation potential*

A.1 Daily solar radiation

Fig. 5 describes the daily average solar radiation for the whole year of 2006. The highest total daily average solar radiation of 7238.89 Wh/m^2 was recorded on 7th March, and the lowest of 1130.56 Wh/m^2 was recorded on 20$^{th.}$ Daily average solar radiation values were high during the period of January to April. Average daily solar radiation for the whole year was 5031.45 Wh/m^2 per day and the annual total solar radiation in Perlis was 1831.45 kWh/m^2 per year.

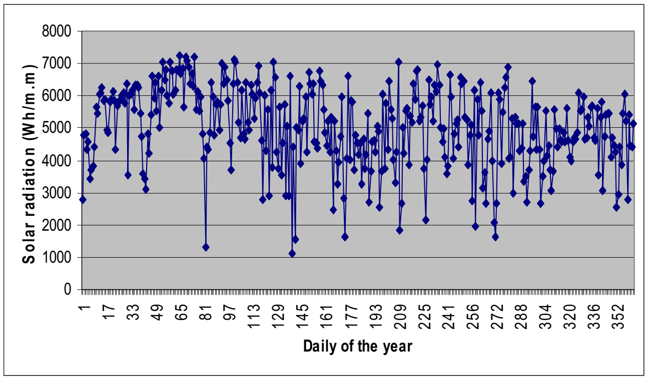

Fig. 5. Daily average of solar radiation throughout the year of 2006

Fig. 6 shows the distribution of the average daily solar radiation. The number of days with average annual daily solar radiation greater than 3 kWh/m^2 was 336 days, which indicates that the sky in Perlis was clear for 92.1 % of the days in a year and the solar radiation intensity was very high for these days. Solar radiation between 1 to 3 kWh/m^2 was 29 days or 7.9 % of the days in a year, still suitable for PV application. No solar radiation lower than 1 kWh/m^2, which indicates that no days in a year were absolutely cloudy days which were not good for PV application. Above analysis result shows that solar radiation in Perlis gives potential for PV power generation.

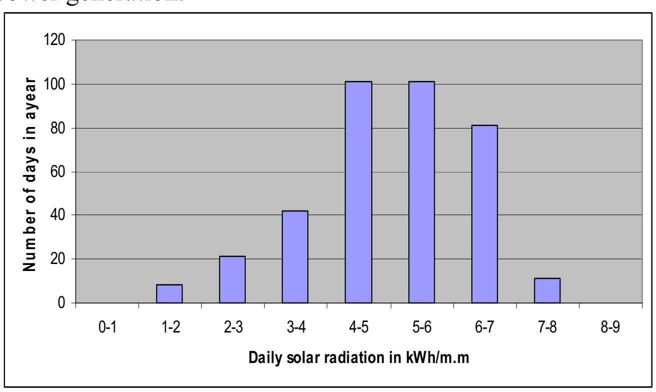

Fig. 6. Distribution of the average annual daily solar radiation in Perlis for the year of 2006

A.2 Peak sun hours (PSHs)

Peak sun hours (PSHs) for the year of 2006 is shown as Fig. 7. Month of July had the lowest PSHs of 4.37 hours and the highest of 5.93 hours was had by March. The average monthly solar radiation was 5.03 hours. It was greater than 3 hours, which indicates that PSHs in Perlis gives potential for PV power generation.

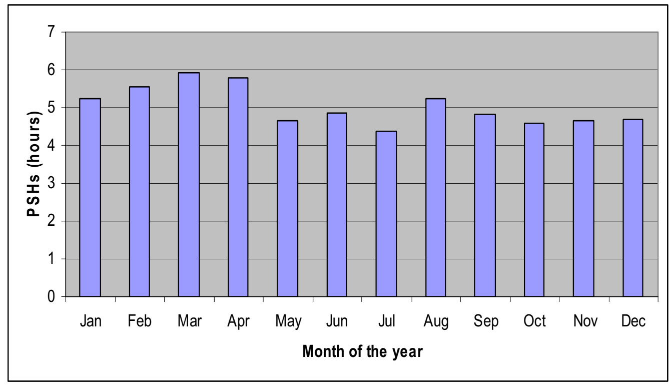

Fig. 7. Peak sun hours (PSHs) in Perlis for the year of 2006

A.3 PV Power Generation Capacity

Based on the average monthly solar radiation for the year of 2006, the annual total solar radiation in Perlis is 1831.45 kWh/m^2. If this amount of solar radiation is converted to electricity by PV technology with the its efficiency and utilization factor were 13% and 1, respectively, using equation (1) so will generate a total electricity energy as below.

$$E_{out} = \left(\sum E_{solar,\ i}\right) x\ A_i\ x\ \eta_{pv}\ x\ f$$

$$= 1831.45\ \ x\ 1\ x\ (0.13)\ \ x\ 1$$

$$= 238.1\ \ kW/m^2$$

It will generate a total electric energy of 237.7 kW/m^2 per year of PV module, provided that the PV module are horizontally installed.

If all the lands in Perlis were filled with horizontal PV panels, nearly 189,29 GWh of electricity could be produced per year. This shows the big potential of solar radiation for PV power generation in Perlis.

B. *Wind speed potential*

A.1 Daily wind speed

The daily wind speed for the year of 2006 is shown in Fig.8. The maximum, minimum and mean wind speed during the year are 2.4000 m/s, 0.3000 m/s and 1.1003 m/s.

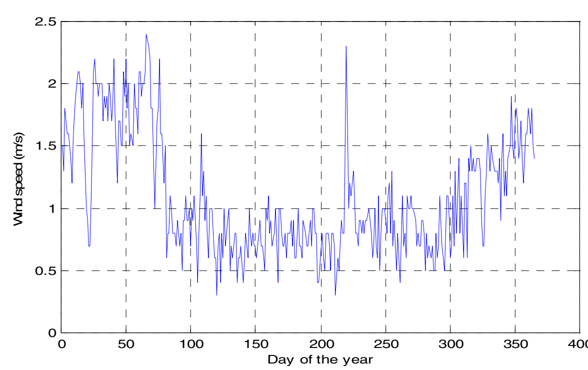

Fig. 8. Daily wind speed for the year of 2006

A.2 Wind speed distribution function

Weibull distribution function is usually used to describe the wind speed distribution of a given location over a certain period of time. In this paper, the annual Weibull distribution function are derived from the available data and are shown in Fig.9

The result shows that on 2006 has the probability density of 81.06% with the shape parameter, k of 2.49 and its wind speed is 1.01 m/s. Based on the above analysis of the Weibull distribution function, it is important to choose a suitable wind turbine for a wind power generation.

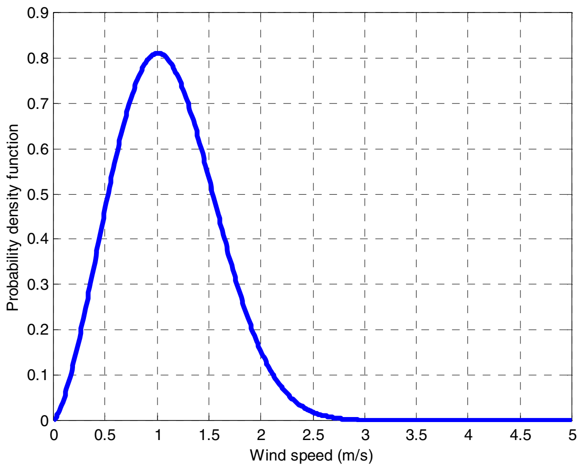

Fig. 9. Wind speed probability density

A.3 Wind powerdensity

The evaluation of the wind power and energy per unit area are an importance information of wind power project assessment. During 2006, the wind speed data at 21.7 m above ground level is evaluated to obtain the monthly mean wind power density as shown in Fig. 10. The highest monthly mean wind power density is 3.8847 W/m^2 occur on January and the lowest one is 0.2367 W/m^2 occur on July. The annual mean wind power density is 0.8668 W/m^2 .

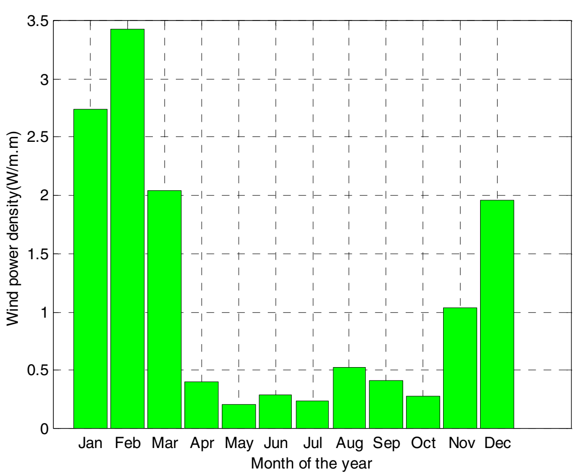

Fig. 10. Monthly mean wind power density

C. PV and wind power hybrid generation

Solar irradiance and wind speed are observed and analyzed during 24 hours (9th March 2011).

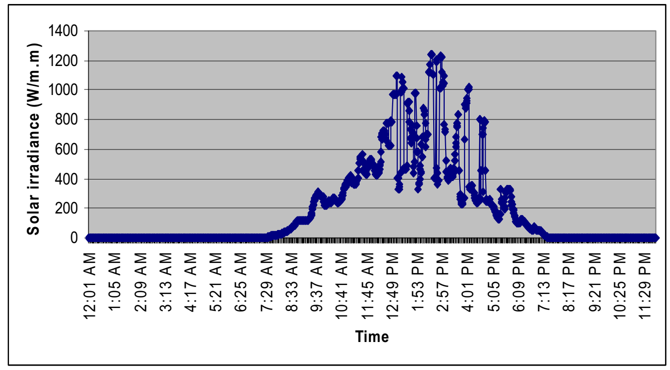

Fig. 11. Solar irradiance on 9th March 2011

Solar irradiance during 24 hours is shown in Fig. 11. The sunrise and sunset are 7.25 am and 7.35 pm. The minimum, maximum and average solar irradiance during this time are 3 W/m^2, 1243 W/m^2 and 378.5 W/m^2.

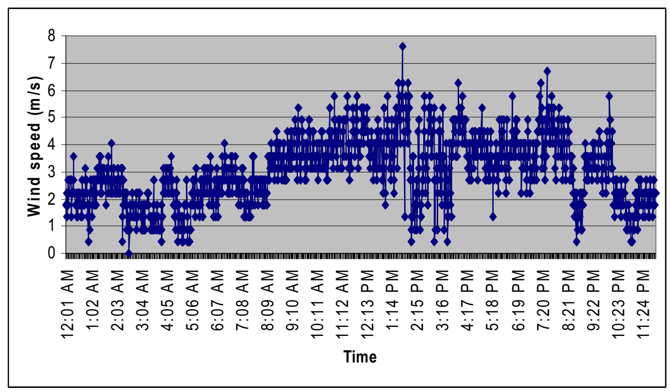

Fig. 12. Wind speed on 9th March 2011

Wind speed during 24 hours is shown in Fig. 12. The maximum and average wind speed during this time 7.61 m/s and 3.03 m/s.

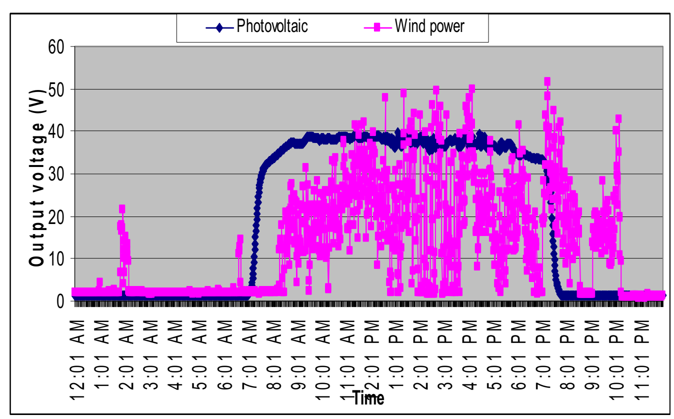

Fig. 13. Output voltage of the PV array and wind power

The solar irradiance and wind speed are applied to the PV array and wind power. Output voltage of the PV array and wind power are measured using eloctrocorder as shown in Fig. 13. According to the result, for a 24 V PV and wind power hybrid generation, the PV array gives big potential and the wind power gives 10% of its total output voltage

IV. Conclusion

According to research result can be concluded that:

1. Based on solar radiation data for the year of 2006, the average monthly solar radiation was 5036.252 Wh/m^2. It was greater than the normal solar radiation (3 kWh/m^2), which indicates that the sky in Perlis was clear and very high solar radiation intensity for the months in the year. The annual total solar radiation in Perlis is 1831.45 kWh/m^2 which will generate a total electric energy of 237.7 kW/m2 per year of PV module, if all the lands in Perlis were filled with horizontal PV panels, nearly 189,29 GWh of electricity could be produced per year. This shows the big potential of solar radiation for PV power generation in Perlis.
2. Based on wind speed data for the year of 2006 has the probability density of 81.06% with the shape parameter, k of 2.49 and its wind speed is 1.01 m/s. Based on the above analysis of the Weibull distribution function, it is important to choose a suitable wind turbine for a wind power generation.
3. According observation during 24 hours ((9^{th} March 2011), for a 24 V PV and wind power hybrid generation, the PV array gives big potential and the wind power gives 10% of its total output voltage.

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VI. Biographies

Ismail Daut received his B. Applied Science in Electronic Industry from University of Science Malaysia in 1980 and MSc in Electrical and Electromagnetic Engineering from University of Wales, College of Cardiff, United Kingdom in 1984 and PhD in Energy Conservation and Power Engineering from University of Wales, College of Cardiff, United Kingdom in 1991. His research interest includes energy conversion, electrical machine design and high voltage. He has authored and co-authored more than 200 technical papers in the national, international journal and conferences.

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