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Weibull and Hargreaves Methods to Determine the Wind and Solar Energy – Case Study

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Abstract. This paper presents a case study of Weibull and Hargreaves methods used to determine the wind speed characteristic and solar radiation pattern in Perlis the northern part of Peninsular Malaysia. These two methods are then used to analyze the data of wind and solar that recorded using Davis Vantage Pro2 Weather Station. This paper also discusses the correlation of these two methods in determining the wind and solar energy. Through this case study, this paper conclude that these methods is highly recommended to determine and analyze the potential of wind and solar energy.

Introduction

According to Energy Information Bureau (EIB) Malaysia; wind energy growth in Asia is on the rise. Both India and China are leading the switch to with more installed capacity and manufacturing facilities. In Malaysia, wind energy conversion is a serious consideration. The potential for wind energy generation in Malaysia depends on the availability of the wind resource that varies with location. Understanding the site-specific nature of wind is a crucial step in planning a wind energy project [1]. Energy from wind is derived largely from solar radiation. Motion of the air mass in the atmosphere is caused by solar insolation and is reproduced. The disturbance of atmosphere air is reproduces at ground level as wind. Unlike solar energy, the wind availability is not cyclic and diurnal but intermittent, unpredictable and is not limited to daylight bourse [2].

Solar energy in one form or another is the source of nearly all energy on the earth. Solar radiation can be converted into electrical energy directly, without any intermediate process by the use of solar photovoltaic (PV) cells. PV generation of power is caused by radiation that separate positive and negative charge carriers in absorbing material. In the presence of an electric field, these charges can produce a current for use in an external circuit [3].

Weibull Methods

Wind is inconstant energy for inland area. Unlike the coastal region which most of the time the wind speed is above the minimum value to generate electricity. In particular case, a mathematical approximation is the best answer in determine the potential. Weibull function is a good mathematical approximation to determine the distribution curve of wind energy. The weibull function is:

$$\Phi = 1 - e^{-\left(\frac{v_w}{A}\right)^k} \quad (1)$$

where:

Φ = distribution function

v_w = wind velocity (m/s)

e = logarithmic base (normally the natural log, e = 2.781)

A = scaling factor

k = form parameter

Rayleigh distribution is a condition of Weibull distribution when the k = 2 is characterized for usual frequency distribution that assumed. The relative frequency is obtained mathematically from the cumulative frequency by differentiating with respect to the wind speed, v_w [4].

The availability of wind power is varies with the cube of the wind speed. Wind power density is a common unit of measurement or power per unit of area normal to the wind direction from the wind is blowing:

$$Pw = \frac{1}{2}\rho v_w^3 \tag{2}$$

where ρ is an air density at standard atmosphere (kg/m^3) [4].

Hargreaves Mehods

The orientation of the earth's orbit around the sun is such that the sun-earth distance varies only by 1.7 percent and since the solar radiation outside the earth's atmosphere is nearly of fixed intensities, the radiant energy flux received per second by a surface of unit are held normal to the direction of sun's rays at the mean earth-sun distance, outside the atmosphere, is practically constant throughout the year.

This is termed as the solar constant Isc and its value is now adopted to be 1367 W/m2. However, this extraterrestrial radiation suffers variation due to the fact that the earth revolves around the sun not in a circular orbit but follows an elliptic path, with sun at one of the foci. The intensity of extraterrestrial radiation Iext measured on a plane normal to the radiation on the nth day of the year is given in terms of solar constant (Isc) as follows:

$$I_{ext} = I_{sc}\left[1.0 + 0.033\cos\left(\frac{360\ n}{365}\right)\right] \tag{3}$$

Various equations are available for estimating Reference Crop evapotranspiration (ET0) and most important parameters in estimating ET0 are temperature and solar radiation [4]. From the equations define for ET0, Hargreaves Samani has recommended a simple equation to estimate solar radiation (Rs):

$$R_s = (K_T)(R_a)\sqrt{T_D} \tag{4}$$

where:

T_D = maximum daily temperature minus minimum daily temperature (°C) for weekly or monthly periods

R_a = extraterrestrial radiation (mm/day)

K_T = empirical coefficient

Extraterrestrial radiation is the solar radiation incident outside the earth's atmosphere. On average the extraterrestrial irradiance is 1367 W/m^2. This value is varies by ±3% as the earth orbits the sun.

$$R_a = \frac{1440}{\pi}\times SC\times\left(1+0.033\cos\frac{360n}{365}\right)\times\left(\cos\pi\times\cos\delta\times\sin\omega_s + \omega_s\sin\varphi\times\sin\delta\right) \tag{5}$$

where:

SC = solar constant (1367 W/m^2)

n = number day of year (DOY)

δ = solar declination

ω_s = sun set hour angle.

The extraterrestrial radiation is differing for each of latitude.

Weibull Distribution Analysis

From the Eq. 1 and Eq. 2 for the Weibull distribution above, the data collected through weather station is applied. From the analysis, a graph is plotted as shown in Fig. 1 below.

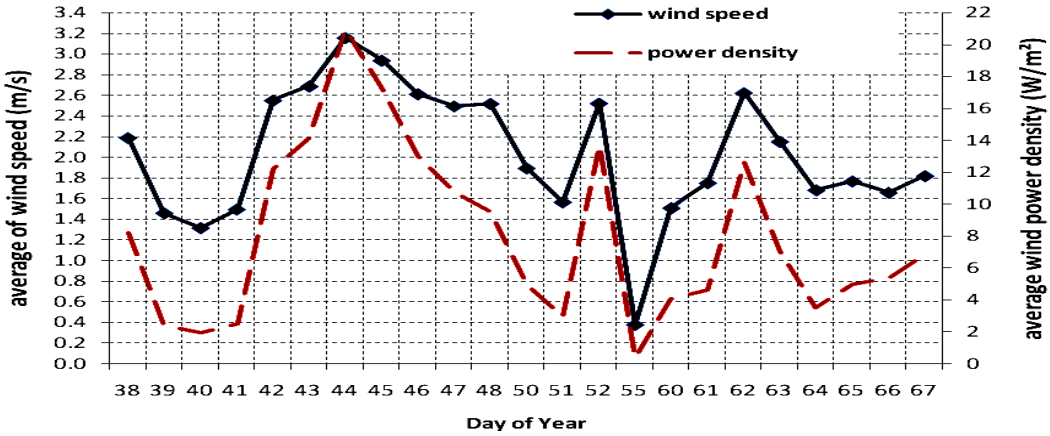

Fig. 1: Correlation of wind speed and power density using Eq. 1 and 2.

The graph in the Fig. 1 is shows that the Weibull distribution function able to illustrate the wind energy potential through mathematical approximation. The wind speed collected using weather station is successfully analyzed to determine the wind power density as show in Fiq. 1 above. This shows that even the location is inland; the wind energy is potentially to develop in Perlis with suitable of wind turbine compared to coastal regions.

Hargreaves Methods Analysis

Hargreaves method that applied in this analysis is using the temperature recorded from the weather station. The temperature of certain areas is corresponding to the Hargreaves equations. From the Eq. 3 until Eq. 5 is used to determine the solar radiation in Perlis as shown in Fig. 2 below.

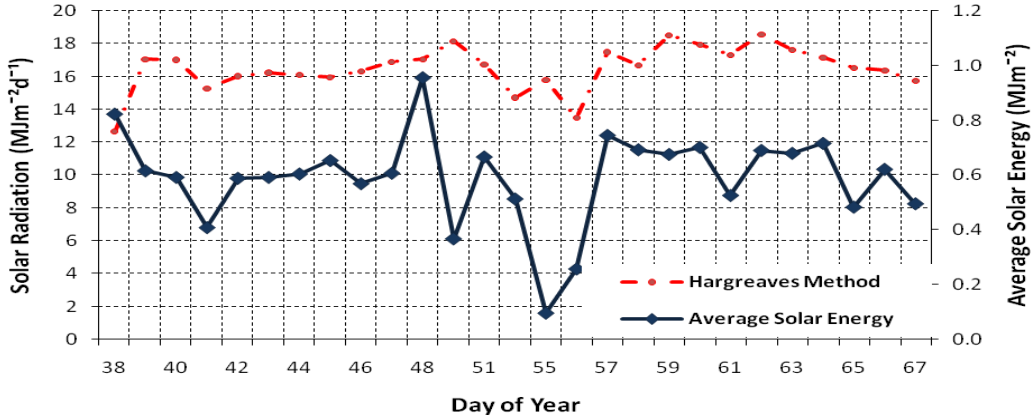

Fig. 2: Solar radiation using Hargreaves method analysis with average of solar energy.

Fig. 2 illustrated the outcome graph using Hargreaves method to show the pattern of solar radiation. The line for average of solar energy is plotted as references line for Hargreaves method. The average of solar energy plotted is collected from weather station. However, from the both line shows that the Hargreaves method is above the average of solar energy and the pattern of solar radiation is valid.

Summary

From the overall of this case study, the authors found that these two methods is valuable and useful to determine the potential of wind and solar energy in Perlis. From this paper, the next process is in progress to develop in Perlis. Since both of energy is highly potential to apply in Perlis and authors is start to overview the type of wind turbine and angle of solar panel to harvest the high energy as alternative power.

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