Estimation of PV Output Power for Dhaka City

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Abstract
The daily output of PV panel has been estimated by calculating daily solar radiation. This calculation of solar radiation is necessary to estimate the PV output power on any particular day of the year for various applications. To run photovoltaic systems properly the estimation of PV output is also important. The output power of a PV panel can be estimated if the amount of solar energy incident on it, efficiency of the panel and its area are known. The area and the efficiency of a panel can be obtained from the manufacturer's data. So, in this paper, a procedure to calculate the daily solar energy for any day of the year in any place has been developed first, and then, the estimation process of the PV output power is described.
Keywords: PV System, Solar radiation,

1 Introduction

We can use solar power as an alternative source of power. We can use the solar power in producing electricity. The sun's energy is produced in the core of the sun through nuclear fusion of hydrogen atoms into helium, temperature 16×10^6 degree Celsius [1]. The outer surface of the sun is known as photosphere is much cooler and the temperature is around 6000 K [1]. This photosphere is the source of most solar radiation. It may be noted that radiation coming from the sun appears to be essentially equivalent to that coming from a black body at 5762 K [1].

Solar radiation travel all the way from sun to earth's atmosphere, within earth's atmosphere solar radiation gets attenuated by atmospheric different effects, before it reaches the surface. The sun, a "ball of fire" is sitting 150 millions of kilometers away from the Earth with a huge nuclear reactions going on. It is constantly giving off an enormous amount of energy and radiation uniformly in all directions. Traveling such a long distance, only 1/22-billionths of the emitted energy reaches the earth. In other words, in one hour, the Earth receives enough energy from the sun to meet its energy needs for nearly a year. The received energy density on the horizon of the Earth is about 1367 W/m^2, and on the surface its value is 1000 W/m^2 (at sea level and for 1 Air mass).

Dhaka, the capital of Bangladesh, is located between latitude 23.6^0 & 23.9^0 N and longitude 90.5^0 & 90.8^0 E [2]. With this geographical location Dhaka is endowed with a reasonable good solar energy potential. However the use of solar energy, as a commercial energy source as not yet received by popular acceptance in this region. The availability of reliable and well organized data on a solar insulation in the region is also limited. Investigation shows that only a few organizations are involved in collecting solar radiation data in Bangladesh. But we get huge solar energy in this region. If this huge amount of solar energy could be used efficiently, the energy demand of this country could be met forever. As a result, various ways of solar energy utilization have come out. Examples of direct utilization of solar energy on a comparatively large scale include photovoltaic and solar heating system. Wind, hydro electricity and wave power generations are considered as examples of derived forms of solar radiation.

2 Calculation of Solar Radiation in Dhaka

There are mainly two components of solar radiation, one is beam radiation and the other is diffuse radiation. Solar radiation means the summation of beam and diffuses radiations. Both the components contribute to the PV output power. To calculate the beam radiation, Hottel's empirical formula of atmospheric transmittance for beam radiation [3] has been used.. Hottel has presented a convenient method for estimating the beam radiation transmitted through clear atmosphere which takes into account zenith angle and altitude for a standard atmosphere and for four climate types. The atmospheric transmittance for beam radiation τ_b is G_{bn}/G_o and is given by the equation below

$$\tau_b = a_0 + a_1 e^{-k/\cos\theta_z} \qquad (2.1)$$

where, τ_b= atmospheric transmittance for beam radiation (G_{bn}/G_{on})
G_{bn} = beam radiation on the n^{th} day of the year
G_{on} = extraterrestrial radiation on the n^{th} day of the year
θ_Z = zenith angle

a_0, a_1 and k are constants. Considering the weather of Dhaka as mid-latitude winter and altitude 0.003km the values of the constants have been calculated and found as 0.122013711, 0.741522392 and 0.394685396 respectively [3]. The expression for extraterrestrial radiation [3] is

$$G_{on} = G_{sc}\left(1 + 0.033\ COS\ \frac{360\ n}{365}\right) \qquad (2.2)$$

where, G_{sc} = solar constant = 1353 W/m^2
n = day of the year

Now, multiplying equation (2.1) by equation (2.2), equation (2.3) can be obtained.

$$G_{bn} = G_{sc}\left(1 + 0.033\cos\frac{360\ n}{365}\right) \times \left(a_0 + a_1 e^{-k/\cos\theta_Z}\right) \qquad (2.3)$$

To calculate the value of G_{bn} for all day long, we have to replace θz of equation (4.3) by local time of the place where the beam radiation is to be calculated. For a horizontal surface θz = θ (incidence angle) and for inclined surface we have to use θz calculated for horizontal surface. There is a standard equation for the incidence angle [3], which is given below.

$$\cos\theta = \sin\delta\sin\varphi\cos\beta - \sin\delta\cos\varphi\sin\beta\cos\gamma + \cos\delta\cos\varphi\cos\beta\cos\omega + \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega \qquad (2.4)$$

where, δ= sun declination
ω= hour angle
β= slope of the surface
γ= surface azimuth angle and
φ= latitude of the place

Considering the surface azimuth angle γ= 0 and the slope of the surface β = 0 (as we will first develop an equation for horizontal surface), equation (2.4) reduces to

$$\cos\theta = \sin\delta\ \sin\varphi + \cos\delta\cos\varphi\cos\omega \qquad (2.5)$$

The values of the parameters of this equation are

δ= sun declination = $23.45\sin(360\ \frac{284+n}{365})$

φ= latitude of Dhaka = 23.75°N

ω= hour angle = $\frac{720\ \text{min} - slt\ (\text{min})}{4}$

slt =solar time = Local time+4(L_{st}-L_{loc})+E

E = equation of time = 9.87 sin 2B – 7.53 cos B – 1.5 sin B, B = 360(n-81)/364

L_{st} = longitude based on which local time is calculated = 90.5° E (for Dhaka)

L_{loc} = longitude of Dhaka = 90.65° E

Putting all these values into equation (2.5) we can get $cos\theta$ in terms of local time and using this value into equation (2.3) we can calculate the beam radiation for any time of a particular day of the year. This calculated value is plotted in Fig. 1. But from this curve, it can be seen that the radiation changes abruptly at sunrise and sunset time, whereas the practically measured solar radiation changes gradually. This error occurs due to the constant term, a_0, in Hottel's equation (equation (2.1)) that does not depend on zenith angle θ_Z, i.e., due to this constant term some radiation will be available even at night, which is not possible. Hence, to overcome this abrupt change, Hottel's equation has been modified by multiplying the constant term by an exponential function, which is related to zenith angle. The modified equation (after multiplying by equation (2.2)) is shown below.

$$G'_{bn} = G_{sc}\left(1 + 0.033\cos\frac{360\,n}{365}\right)\times\left\{a_0\left(1 - e^{\xi_b COS\,\theta_Z}\right) + a_1 e^{-k/\cos\theta_Z}\right\} \quad (2.6)$$

where, G'_{bn} = modified beam radiation

ξ_b = a constant = 5

To calculate the diffuse radiation, Liu and Jordan's empirical formula for the transmission co-efficient of diffuse radiation (τ_d) [3] has been used. The equation is given below.

$$\tau_d = 0.2710 - 0.2939\,\tau_b \quad (2.7)$$

Multiplying equation (4.2) by equation (4.7), the clear sky diffuse radiation can be calculated as:

$$G_{dn} = G_{sc}\left(1 + 0.033COS\frac{360n}{365}\right)\times\left(0.2710 - 0.2939\tau_b\right) \quad (2.8)$$

where, G_{dn} = diffuse radiation on the n^{th} day of the year.

The empirical formula for τ_d has also been modified for some abrupt changes, as described for beam radiation. The modified equation is given below.

$$G'_{dn} = G_{sc}\left(1 + 0.033\,COS\,\frac{360\,n}{365}\right)\times \left\{0.2710(1 - e^{-\xi_d COS\,\theta_z}) - 0.2939\,\tau_b\right\} \quad (2.9)$$

where, G'_{dn} = modified diffuse radiation

ξ_d = a constant = 8.

The modified equation changes the diffuse radiation only at the sunrise and sunset time. The amount of energy lost (at sunrise and sunset time) depends on the value of the constant ξ_d. If the value of this constant is increased gradually the modified data will get closer and closer to the original value at sunrise and sunset time.

Finally, the solar radiation has been calculated by adding the beam and diffuses radiations as:

$$G'_{tn} = G'_{bn} + G'_{dn} \quad (2.10)$$

where, G'_{tn} = modified (total) solar radiation on the n^{th} day of the year.

The solar radiation for different months of year has been calculated by using the modified equation (2.10) and by original equations (2.3) and (2.8).

3 Calculation of the Output Power of PV Panel

Once the insolation, incident on a PV panel, is known, its output power (P_{pv}) can easily be estimated by the following equation.

$$P_{pv} = \Re \times \cos\theta \times \eta_m \times A_p \times \eta_p \quad (3.1)$$

Where, $\Re$ = solar radiation (W/m^2)

θ = angle of incidence calculated by considering β = 45°(declination of our panel)

η_m = efficiency of the MPPT = 96%

A_p = area of the PV panel = 8.505m^2

η_p = efficiency of the PV panel = 11% (at 25°C with a rate of change of -0.052%/°C)

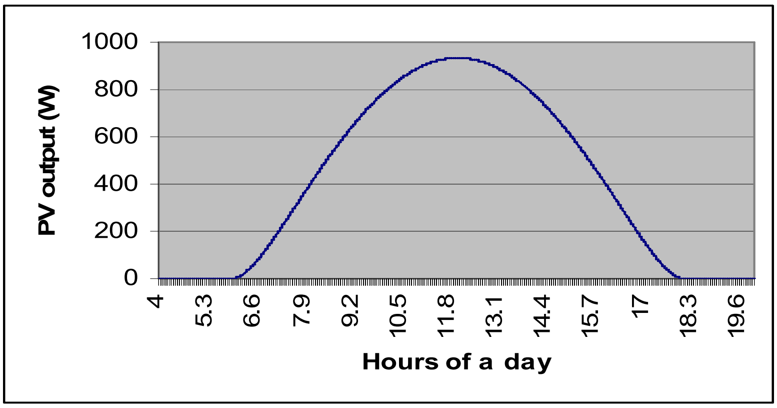

Fig.1. Estimated PV output power on 15th April 2010

Considering the given values of the above parameters, the PV output on a typical sunny day has been estimated. The results are presented in Figs. 4.1. Since, the value of η_p of equation (4.11) has been calculated by considering the average temperature of the day, the estimated P_{PV} gives the temperature compensated value.

4 Weather Dependent Characteristic of PV Output

Using the above method, PV output power can be estimated only in sunny (clear sky) weather. So, to do the same even in cloudy/rainy weather, we have studied the performance of the PV array in different weather conditions. From the Internet [4], the one-day-ahead weather forecast, given in three-hour intervals, has been recorded and the PV output has been measured for many days. The average values of η for

Table 1. Percentage of PV output in different weather conditions

Average value of η	Sunny	Cloudy	Rainy	Snow
Jan-Mar	76%	21%		11%
Apr-June	73%	28%	18%	
July-Sept	70%	30%	15%	
Oct-Dec	79%	35%	13%	18%

different Weather conditions have been considered for Japan as this system not yet been developed in Bangladesh (see Table 1). Now, it is possible to estimate the PV output power in any weather condition by multiplying the calculated clear sky PV output by the corresponding values of η according to the weather forecast.

The estimated clear-sky daily total PV output for different months of the year is shown in Fig. 2. In this calculation the average temperatures of different months have been considered and the efficiency of the PV panel has been considered. From

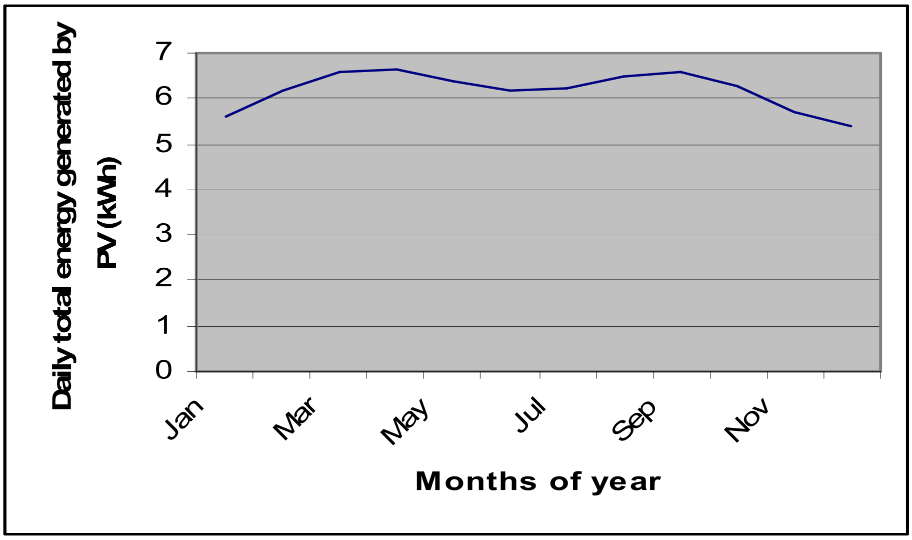

Fig.2. Daily total energy generated by the PV panel

this graph, it can be seen that the maximum PV output power can be achieved in the months of April and September (in Dhaka). On the other hand, the minimum output will be generated in the month of December

5 Conclusion

In this paper, a procedure to estimate the PV output power has been described. To calculate the daily solar radiation Hottel's and Liu-Jordan's equations have been used. However, to overcome the inaccuracy of these equations during the sunrise and sunset time, the equations have been modified. To verify the accuracy of the calculated radiation, they are compared with the practical data of 20 years. It is found that the calculated solar radiation always remain in the range of practically obtained data. Using this daily solar radiation the estimation procedure of PV output has been described.

Finally, to use the procedure in cloudy/rainy weather, the weather dependant characteristics of the PV panel has been studied and provided here.

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