International Journal of Renewable Energy Resources 11 (2021) 27-33
https://doi.org/10.22452/ijrer.vol11no1.3

POWER POTENTIALITY ANALYSIS OF PHOTOVOLTAIC MODULE WITH VARIATION OF TILT ANGLE IN BANGLADESH

Md. Fahim Faysal, Md. Sharif Hossain, Suman Chowdhury*
Electrical and Electronic Engineering Department, International University of Business Agriculture and Technology, Dhaka-1230, Bangladesh
*e-mail: suman@iubat.edu

Abstract
This paper explores the power potentiality analysis of PV modules to monitor the output power. Power potentiality analysis of the PV module is performed in the Bangladesh climate condition. The prominent factors are cell temperature, solar irradiance, clearness index, ideality factor, tilt angle and fill factor that are discussed in this paper. P-V and I-V characteristics of PV module are observed by MATLAB simulation and the power performance on various tilt angles are investigated by the experimental set up. From the experiment, it is seen that with the change of tilt angle the power has been changed significantly. For this reason data has been collected for a couple of days with set up of various angles of tilt. A perfect choice of tilt angle for the PV module can promote the performance to a great extent. Besides, the performance of module has been checked by MATLAB simulation taking consideration of performance factors like solar radiation, ideality factor. This paper finally tries to exhibit the role of tilt angle in promoting the output power of PV module. Tilt angle plays a vital role to promote power because the choice of proper tilt angle can track maximum solar radiation from the sun to produce optimum power from the PV module.

Keywords: Cell Temperature; Solar Irradiance; Ideality Factor; Fill Factor; Tilt Angle; Clearness Index

1. INTRODUCTION
For obtaining higher voltage level it is required to connect the PV (photovoltaic) cells in series and for increasing the current level it is needed to connect the PV cells in parallel. For targeting large power production the manufacturers are producing the solar module connecting 36 cells in series. For the important contribution of PV module in the power generation process to a great extent in mitigating the energy crisis, most countries are trying to produce power by the PV module for mitigating the energy problem. The costing of the PV module is highly depended on the efficiency of the PV module as well as the time span of the PV module (Tsai et al., 2008). The most important factors that affect the power generation of the PV module are tilt angle, solar irradiance, azimuth angle, cell temperature, ideality factor. These factors are directly connected in the analysis of the I-V and P-V curve of the PV module. According to STC (Standard test condition) the solar irradiance is 1000 W/m^2 & the PV cell temperature is 25°C (Chowdhury et al., 2012; Chowdhury et al., 2012). The PV system has earned a good reliability in power generation process for obtaining an alternative place for the energy demand. Already it has proved its ability to generate the power in remote places where grid line is not present for fulfilling the energy demand (Šály et al., 2015). With huge energy demand throughout the world the Photovoltaic system has increased its popularity to a great extent for mitigating the world energy crisis (Mostefaoui et al., 2018). Now the PV module has been introduced in the facades of the building rather than the roof space to ensure a huge power potentiality from the PV module is considered as the building integrated photovoltaic system. This system has a great challenge to meet the requirement of the materials that have been replaced by the PV modules in the building structure. In this way the PV module serves as a dual function as one is the electrical phenomenon and the other one is the building coating. The factors that affect the power generation of the PV module are fill factor, ideality factor, tilt angle, cell temperature, clearness index, azimuth angle, solar radiation (Chowdhury et al., 2012; Chowdhury et al., 2012).

The two main factors for affecting the ideality factor are central PN junction and metal semiconductor junction. Again as the temperature effect the ideality factor changes from 4.00 to 3.30 if the temperature changes from 20 to 80°C. This factor is also affected directly by carrier transfer and the recombination within the device which are the important factors for affecting the laser current density and efficiency of output power. A P-N junction diode has been considered as the series combination of rectifying junctions whereas the ideality factor of device is considered as the integration of the ideality factor of each junction representing the interpretation of the ideality factor larger than 2.0 for a diode. And this factor is highly affected by the shunt resistance of the device (Li et al., 2017; Shah et al., 2003). The solar modules should be placed in South direction in Northern hemisphere whereas the modules should be kept in North direction if the place is located in Southern hemisphere (Mohammed & Alibaba, 2018). Tilt and azimuth angle can do a favor in promoting output power of PV module in any location of earth. This angle can promote the gaining efficiency of the photovoltaic panel (Shareef, 2017). Due to the great influence of the tilt angle an experiment has been executed to observe the power performance from the PV module. As well as a good number of simulations have been done by MATLAB to observe the effect of various factors on output power of the PV module.

2. SOLAR IRRADIANCE

For a fixed location, solar radiation can be calculated by equation (1) (Alshushan & Saleh, 2013; Chowdhury et al., 2012; Chowdhury et al., 2012).

$$Gs = Gd + Gr \qquad (1)$$

Where G represents total solar radiation in kW/m^2. G_d is expressing direct portion of solar radiation in KW/m^2 and Gr is diffused portion of solar radiation in KW/m^2.

$$Gd = (H \cos\theta - \sin\theta \cos\alpha \sin\delta \cos\Phi n + \sin\theta \cos\alpha \sin\Phi n \cos w + \sin\theta \sin\alpha \cos\delta \sin w) * God \qquad (2)$$

Where H is representing the sun elevation, θ is showing oblique angle of the sun in radian, α is used for azimuth angle, δ is standing for the declination of the sun in radian, Φn is used for north latitude, w is hour angle (degree), G_{od} represents direct irradiation (radian).

$$Gr = Gor(1 + cos\theta)/2 + 0.2Go\,(1 - cos\theta/2) \qquad (3)$$

The sun elevation is given by (4) (Alshushan & Saleh, 2013)

$$H = sin - 1(cos\,L\,cos\,D\,cos\,T + sin\,D\,sin\,L) \qquad (4)$$

Where L is standing for latitude in degree; T is expressing hour angle in degree (Alshushan & Saleh, 2013; Chowdhury et al., 2012; Chowdhury et al., 2012).

3. CLEARNESS INDEX

The actual solar radiation trough the atmosphere is treated as the fact of the clearness index an important parameter for the PV system in comparison with the whole extraterrestrial radiation of the sun. The attenuation influence obtained from the world's weather and the cloud is totally involved with the clearness index. The clearness index can be identified through the ratio of two radiations as one is representing global sun radiation on horizontal surface at the ground state and the other one is the total extraterrestrial radiation of the sun. The range of the clearness index is considered as between 0 and 1. From three corners of views the clearness index is measured which are monthly, daily and hourly based average value (Nemes et al., 2018).

4. FILL FACTOR

To check the performance of the solar cell fill factor is considered as a very prominent factor. It may be calculated taking the facts of optimum power, open circuit voltage, short circuit current. The fill factor is represented by equation (5) (Thanakodi, 2009).

$$FF = Pmax/\,(Voc * Isc) = Vmp * Imp/Voc * Ioc \qquad (5)$$

Where Vmp represents voltage at maximum power point, Imp expresses current at maximum power point.

5. TILT AND AZIMUTH ANGLE

The tilt angle of PV module is the root way to get the optimum power from the PV module where the performance is optimum if the sun rays fall perpendicular to the solar array. The default value of the tilt angle is considered + 15 degree in the winter season and -15 degree for the summer season to get optimum power from the PV module. The solar irradiation falling on the PV array is determined by the two important factors which are tilt and azimuth angle. For the identification of the optimum tilt angle local latitude plays an important role. According to Beckman this angle is

$\beta opt = (\Phi + 15\,deg) \pm degree$ (where Φ is local latitude) (Chowdhury et al., 2012; Chowdhury et al., 2012; Tsai et al., 2008)

6. CELL TEMPERATURE

The solar modules exposed to high temperature is not good way to obtain maximum power output from the PV module. The relation between PV cell temperature and the clearness index is given by equation (6) (Mostefaoui et al., 2018).

$$Tc = Ta + (219 + 832\,Kt)\,((NOCT - 20)/800) \qquad (6)$$

Where Tc = PV cell temperature, Ta = the ambient temperature (°c); NOCT = normal operating cell temperature (°c).

7. MODELING OF THE PV CELL

The equivalent circuit diagram of a PV cell is shown in Fig.1.

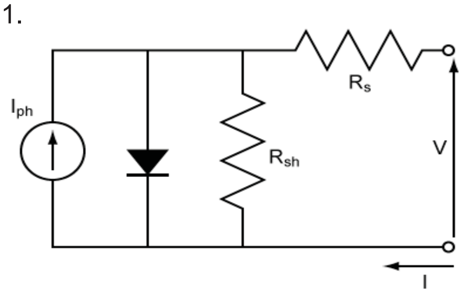

Fig.1 PV cell Equivalent circuit (Chowdhury et al., 2012).

The main equation that describes the I-V and P-V characteristics of the solar cell is shown in equation (7) (Chowdhury et al., 2012; Chowdhury et al., 2012; Tsai et al., 2008).

$$I = Iph - Is\,[exp\,(q\,(V + IRs)/KTcA - 1] - (V + IRs)/Rsh \qquad (7)$$

Where I_{ph} is standing for photo produced current, I_s is representing dark current saturation of cell, q (1.6×10^{-19}c) is charge of electron, K is a Boltzmann's constant (1.38×10^{-23} J/k), T_c is the working temperature of solar cell, A is ideality factor, R_{sh} is a shunt resistance. The photo produced current mainly relies on the solar irradiance and active temperature of cell which is described by equation by (8) (Chowdhury et al., 2012; Chowdhury et al., 2012; Tsai et al., 2008).

$$Iph = [Isc + Kt(Tc - Tref)]\,G/Gn \qquad (8)$$

Where I_{sc} is presenting the short circuit current of solar cell at 25°c, Kt is expressing the short circuit temperature coefficient, T_{ref} is presenting the reference temperature of cell and G is standing for the solar radiation in kW/m^2 and Gn is nominal solar radiation at STC in kW/m^2. Again the saturation current of cell is varied with temperature which is presented in equation (9) (Chowdhury et al., 2012; Chowdhury et al., 2012; Tsai et al., 2008).

$$Is = Irs\,(Tc/Tref)\,3\,exp\,(qEG\,((1/Tref) - (1/Tc)/kA) \qquad (9)$$

Where I_{rs} is representing the reverse saturation current of cell at the reference temperature, E_G is standing for band-gap energy of semiconductor material used in solar cell.

The cell's reserve saturation current is given by equation (10) (Villalva et al., 2009).

$$Irs = Isc/\,[exp\,(qVoc/kTcA) - 1] \qquad (10)$$

Where T_c is used for the cell's working temperature. V_{oc} is used for the open circuit voltage of PV cell, I_{rs} is used for the cell's reverse saturation current, I_{sc} is used for the cell's short circuit current , q (1.60 x 10^{-19} C) is electron charge, k is a Boltzmann's constant (1.38×10^{-23} J/K), A is ideality factor.
The taken PV module produces maximum power of 10W. To obtain power at particular voltage and current, the series and parallel connection of the PV panels are needed. The characteristics equation for the array is given by equation (11) (Chowdhury et al., 2012; Tsai et al., 2008).

$$I = Np * Iph - Np * Is * exp(q * (V./Ns + I * Rs/Np)/(k * Tc * A) - 1) - ((Np * V/Ns) + I * Rs)/Rsh \qquad (11)$$

Here Ns is number of series connected cells and N_p is number of parallel connected cells.

8. SIMULATION OF THE PV CELL AND MODULE

For simulation purpose, SF-10P solar model has been taken. The short circuit current (I_{SC}) and open circuit voltage (V_{OC}) of SF-10P solar cell is 0.65A and 21.6V respectively. The simulation of I-V and P-V curves of the PV cell and PV Module both for the variation of ideality factor are shown in figures: (2-3 for cell & 4-5 for module). Figure: 2-3 & 4-5 show that when ideality factors value increases, the power decreases.

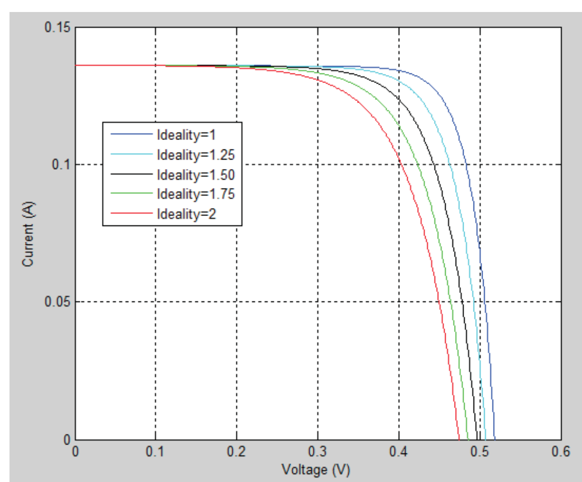

Fig.2 Solar cell characteristics (I-V) for change of the ideality factor.

The simulated I-V and P-V curve of the PV cell for the variation of solar irradiance are shown in figure:

(6-7 for cell & 8-9 for module). Figure: 6-7 & 8-9 show that, solar irradiance is directly influencing the output power of PV module.

Fig.2 clearly explains the effect of the ideality factor at the short circuit current of the solar cell. From this figure it can be said that with the decrement of the ideality factors the short circuit current output will increase at the maximum point of the PV cell.

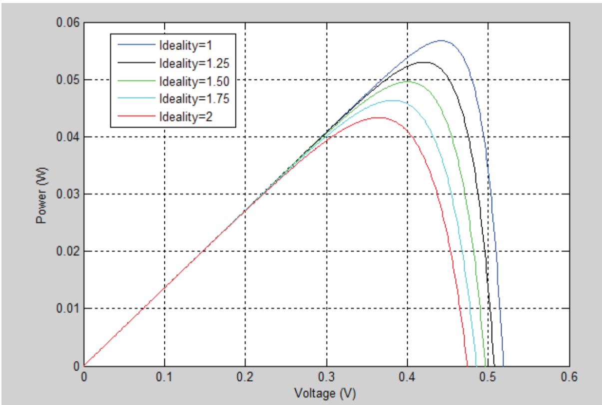

Fig.3 : Solar cell characteristics (P-V) for change of the ideality factor.

Fig.3 represents the power behavior of the PV cell for showing the influence of the ideality factor. From figure it is seen that with the decrement of the ideality factor the output power of the PV cell increase to a significant level.

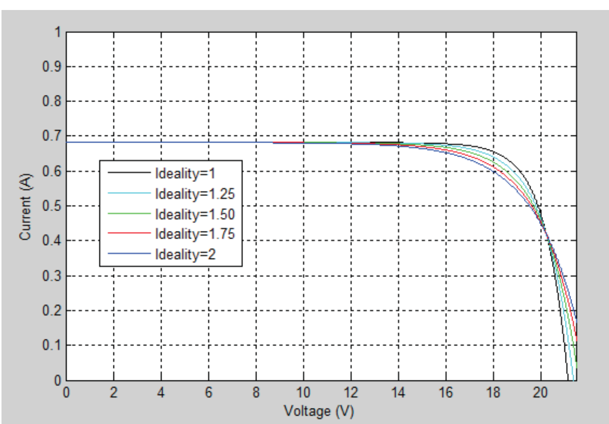

Fig.4 Solar module characteristics (I-V) for change of the ideality factor.

Fig.4 represents the current at maximum power point of PV module is increased with the decrement of the ideality factor. From the figure it is seen that the short circuit current is around 0.6 A at the maximum power point when the ideality factor is considered as 2 whereas this short circuit current is around 0.7 A when the ideality factor is considered as 1 as the lowest.

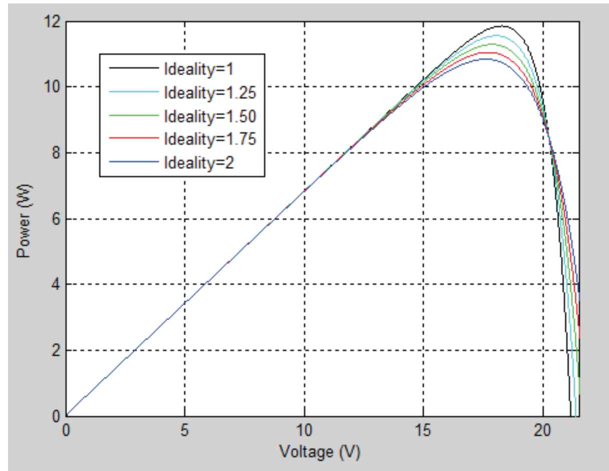

Fig.5 Solar module characteristics (P-V) for change of the ideality factor.

Fig.5 shows that the power is increasing with decrease of the ideality factor. From figure it is shown that the maximum power is around 11.9 W if the ideality factor is chosen as 1 as the lowest value of the ideality factor whereas the maximum power output is around 10.9 W for the ideality factor of 2.

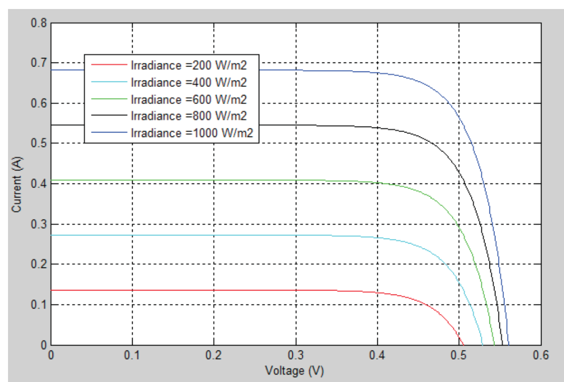

Fig.6 Solar cell characteristics (I-V) for change of the solar irradiance.

Fig.6 represents the current behavior of the PV cell for the variation of the solar irradiance. From the figure it is seen that the short circuit current level is increased rapidly with the increment of the solar irradiance.

Fig.7 exhibits the power behavior of the solar cell for variation of the solar irradiance. From the figure it is observed that the output power level is increased rapidly with the increment of the solar irradiance.

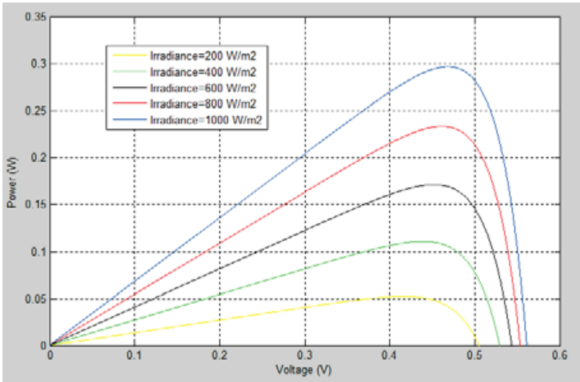

Fig.7 Solar cell characteristics (P-V) for change of the solar irradiance.

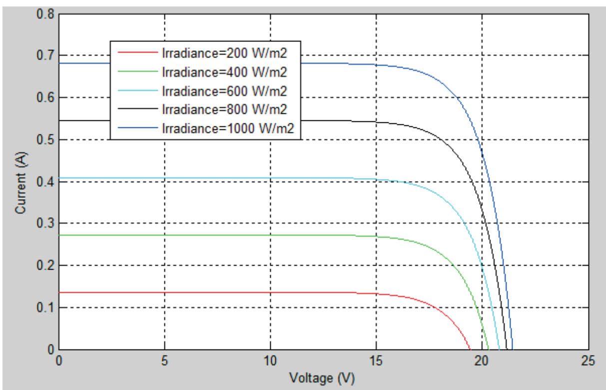

Fig.8 Solar module characteristics (I-V) for change of the solar irradiance.

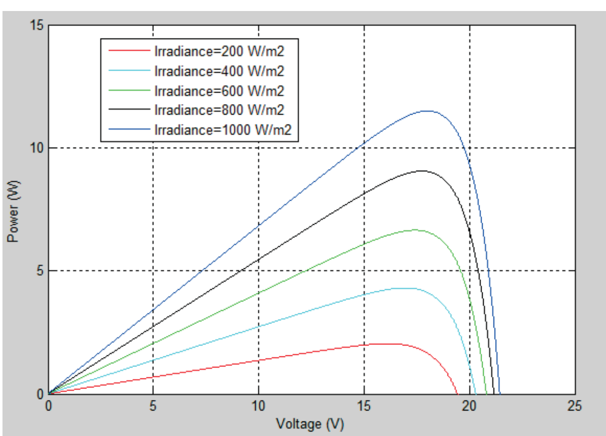

Fig.9 Solar module characteristics (P-V) for change of the solar irradiance.

Fig.8 presents the current behavior of the PV module for the variation of the solar irradiance. From the figure it is seen that the short circuit current level is increased rapidly with the increment of the solar irradiance. The maximum short circuit current is around 0.69 A for the irradiance level of 1000 W/m^2 whereas the short circuit current is around 0.14 A for the lowest irradiance level of 200 W/m^2.

Fig.9 shows the power behavior of the PV module for the variation of the solar irradiance. From the figure it is observed that the maximum power level is increased rapidly with the increment of the solar irradiance. The maximum output power is around 12 W for the irradiance level of 1000 W/m^2 whereas the short circuit current is around 2.2 W for the lowest irradiance level of 200 W/m^2.

9. EXPERIMENTAL INVESTIGATION

Fig.10 shows the experimental set up of PV module. According to experiment, Fig.11 represents ° the maximum output power is 8.81 W at the tilt angle of 22°. From Fig.12, it is observed that the maximum output power is 9.32 W when the tilt angle is 20°. Fig.13 explains that the optimum output power is 7.09 W when the tilt angle is 18°. Again Fig.14 shows that the maximum output power is 8.30 W when the tilt angle is 16°. And Fig.15 shows that the peak output power is 8.77 W at the tilt angle of 15°.

Fig.10 Solar panel, DC Ammeter, Voltmeter, Battery, & Charge Controller used for data collection.

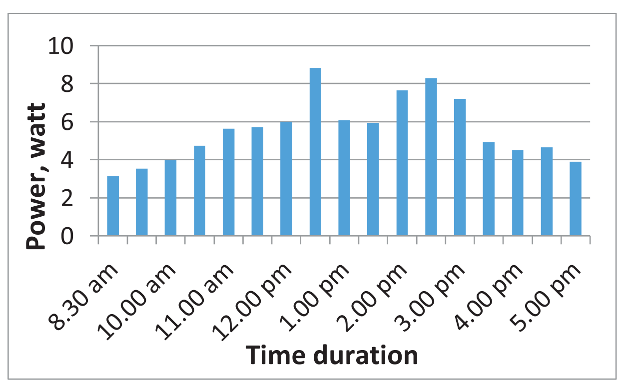

Fig.11 Practical data of Module power at tilt angle of 22° and at temperature of 24°C on 20-05-19.

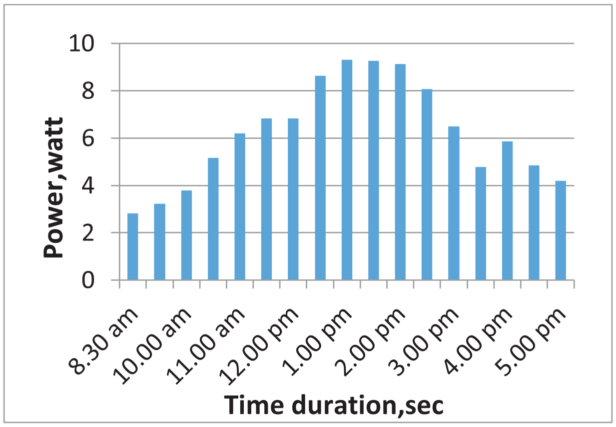

Fig.12 Practical data of Module power at tilt angle of 20° and at temperature of 22°C on 22-05-19.

Fig.10 exhibits the arrangement of the experiment for the data collection. From this figure it is clearly seen that an ammeter is used to calculate the output current and a voltmeter is connected to calculate the voltage of the PV panel. A charge controller is utilized to get the optimum power from the PV panel.

Fig.11 shows the power data for the specific tilt angle of 22° at the temperature of 24°. From this figure it is seen that the power is at lower level at the morning and evening time due to the lower solar irradiance.

Fig.12 exhibits the PV panel power data for the specific tilt angle of 20° at the temperature of 22°. From this figure it is seen that the power is at lower level at the morning and evening time due to the lower solar irradiance. Again the power is better at the noon time of around 12.00 pm to 3.00 pm.

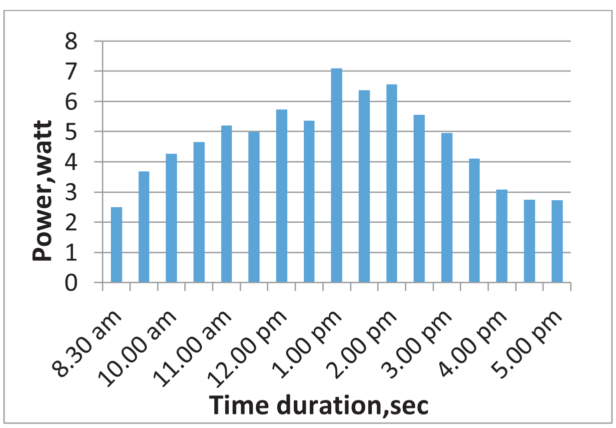

Fig.13 Practical data of Module power at tilt angle of 18° and at temperature 23°C on 23-05-19.

Fig.13 represents the output power data for the specific tilt angle of 18° at the temperature of 23°. From this figure it is seen that the power is at lower level at the early morning and late evening time due to the lower solar irradiance. Again the power is better from 10.00 am to 3.00 pm almost throughout the day.

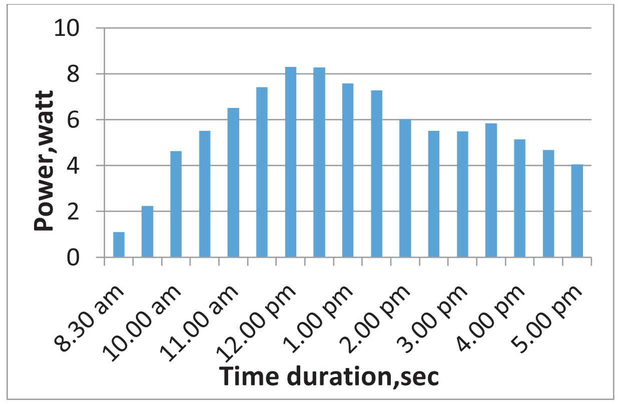

Fig.14 Practical data of Module power at tilt angle of 16° and at temperature 28°C on 26-05-19.

Fig.14 expresses the PV panel output power data for the specific tilt angle of 16° at the temperature of 28°. From this figure it is seen that the power is at lower level at the early morning whereas the power level is good throughout the whole day of remaining. Again the power is better from 10.00 am to 2.00 pm and the power is at medium level from 2.00 pm to 5.00 pm.

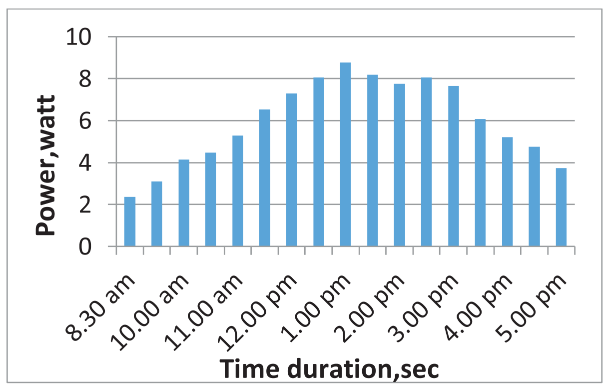

Fig.15 Practical data of Module power at tilt angle of 15° and at temperature 21°C on 27-05-19.

Fig.15 shows the PV module output power data for the specific tilt angle of 15° at the temperature of 21°. From this figure it is seen that the power is almost good throughout the whole day but better from 11.00 am to 4.00 pm. Here tilt angle plays a vital role for obtaining this optimum power rather than the other day.

10. CONCLUSION

The power potentiality analyses of PV module application are studied in the reference of Bangladesh environment condition. The most prominent factors for developing the power performance are azimuth angle, tilt angle, clearness index, ideality factor etc. This paper discusses influence of tilt angle on generation of maximum power on PV module practically. According to the experiment it is seen that when tilt angle is 20° on that time the output power is reached to maximum. But still more experiments are needed to reach out the proper decision on tilt angle because the data taken on various days are not in the same temperature. To observe proper output power from PV module, temperature must be taken as constant in the case of tilt angle variation. Also a record of solar radiation needs to be observed for doing this experiment since solar radiation plays a vital role in promoting the output power from the PV module.

REFERENCES

Alshushan, M. A. S., & Saleh, I. M. (2013, 16-21 June 2013). *Power degradation and performance evaluation of PV modules after 31 years of work.* Paper presented at the 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC).

Chowdhury, S., Al-Amin, M., & Ahmad, M. (2012, 20-22 Dec. 2012). *Performance variation of Building integrated photovoltaic application with tilt and azimuth angle in Bangladesh.* Paper presented at the 2012 7th International Conference on Electrical and Computer Engineering.

Chowdhury, S., Al-Amin, M., Sanjari, S., Tasnim, S., & Ahmad, M. (2012, 18-19 May 2012). *Performance parameter analysis of grid connected building integrated photovoltaic application in Bangladesh.* Paper presented at the 2012 International Conference on Informatics, Electronics & Vision (ICIEV).

Li, X., Wang, H., Qiao, Z. L., Guo, X., Liao, Y. P., Zhang, Y., . . . Liu, C. Y. (2017). *Raman-tailored photonic crystal fiber for telecom band photon-pair generation.* Paper presented at the IEEE Photonics Conference (IPC).

Mohammed, M., & Alibaba, H. (2018). The effect of photovoltaic (PV) panel tilt angle for best energy generation in hot climate. 185-196.

Mostefaoui, M., Neçaibia, A., Ziane, A., Dabou, R., Rouabhia, A., Khelifi, S., . . . Sahouane, N. (2018, 26-27 April 2018). *Importance cleaning of PV modules for grid-connected PV systems in a desert environment.* Paper presented at the 2018 4th International Conference on Optimization and Applications (ICOA).

Nemes, C., Ciobanu, R., & Rugina, C. (2018). *2018 Smart City Symposium Prague (SCSP).* Paper presented at the IEEE.

Šály, V., Váry, M., Packa, J., & Perný, M. (2015, 20-22 May 2015). *Electrical characterization of PV modules after three years of operation.* Paper presented at the 2015 16th International Scientific Conference on Electric Power Engineering (EPE).

Shah, J., Li, Y. L., Gessmann, T., & Schubert, E. (2003). Experimental analysis and theoretical model for anomalously high ideality factors (n >> 2.0) in AlGaN/GaN p-n junction diodes. *Journal of Applied Physics, 94*, 2627-2630. doi:10.1063/1.1593218

Shareef, S. J. M. (2017). The Impact of Tilt Angle on Photovoltaic Panel Output. *ZANCO Journal of Pure and Applied Sciences, 29*(5), 112-118. doi:10.21271/ZJPAS.29.5.12

Thanakodi, S. A. L. (2009). *Modeling and simulation of grid connected photovoltaic system using matlab / simulink.* (Master of Engineering (Electrical-Power)). Universiti Teknologi Malaysia, Universiti Teknologi Malaysia. Retrieved from http://eprints.utm.my/id/eprint/12050/6/SureshThanakodiMFKE2009.pdf

Tsai, H.-L., Ci-Siang, T., & Yi-Jie, S. (2008, October 22 – 24). *Development of generalized photovoltaic model using MATLAB/SIMULINK.* Paper presented at the Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA.

Villalva, M. G., Gazoli, J. R., & Filho, E. R. (2009). Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays. *IEEE Transactions on Power Electronics, 24*(5), 1198-1208. doi:10.1109/TPEL.2009.2013862