International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Thermal Modeling of Opaque and Semi-Transparent Photovoltaic (PV) Module

Md. Meraj, M.E. Khan

Abstract*: *Photovoltaic (PV) module is one of the simplest technologies to convert the solar energy into the useful electrical energy. In the present paper, an attempt has been made to develop a simplified analytical expression for solar cell temperature and solar cell electrical efficiency of opaque and semi-transparent photovoltaic module in the terms of design and climatic parameters. Based on the energy balance of opaque and semi-transparent PV module, the performance parameters, namely, solar cell temperature, solar cell electrical efficiency, module efficiency and electrical power output have been evaluated for a typical clear day of May month of New Delhi climatic condition data taken from IMD (Indian Meteorological Department), Pune, India. The numerical simulations have been made on the MATLAB software. Based on the numerical computation, the effect of back cover opaque and semitransparent tedlar of module on the performance parameters has been investigated. From the results and discussion, it is found that the performance of photovoltaic module is very sensitive to the module temperature. Further, it is concluded that the semi-transparent photovoltaic module is more efficient than the opaque one. Thus, by the application of semi-transparent PV module in the design of stand-alone and rooftop PV system, the overall energy requirement and performance can be improved for same occupied area.

Keywords*: *Efficiency, Module, Opaque, Photovoltaic, Semi-transparent, Solar cell,

NOMENCLATURE:

A_m Area of module (m^2)
$\dot{E}_m$ Electrical power output of PV module (W)
h_o Heat loss coefficient from top of module to ambient (W/m^2)
hi Heat loss coefficient from bottom of module to ambient (W/m^2)
I(t) Solar intensity (W/m^2)
K_g Thermal conductivity of glass cover of PV module (W/m.K)
K_T Thermal conductivity of tedlar of PV module (W/m.K)
L_g Thickness of glass cover of PV module (m)
L_T Thickness of tedlar of PV module (m)
T_a Ambient temperature (^{o}C)
T_c Solar cell temperature (^{o}C)
T_0 Reference cell temperature for optimum cell efficiency i.e. 25 ^{o}C
U_b Overall heat loss coefficient from bottom of solar cell to ambient (W/m^2.K)
U_T Overall heat loss coefficient from top of solar cell to ambient (W/m^2.K)
U_L Overall heat loss coefficient of PV module
V Air velocity (m/s)
α_c Absorptivity of solar cell
α_T Absorptivity of tedler
β_0 Temperature coefficient of materials
β_c Packing factor of PV module
η_c Solar cell electrical efficiency
η_m Module efficiency
η_0 Module efficiency at standard test condition
τ_g Transmissivity of glass

Revised Manuscript Received on October 30, 2019.
***** Correspondence Author
Md. Meraj*, Mechanical Engineering Department, Faculty of Engg. & Tech., Jamia Millia Islamia, New Delhi, India. Email: md.meraj1221@gmail.com
M.E. Khan, Mechanical Engineering Department, Faculty of Engg. & Tech., Jamia Millia Islamia, New Delhi, India. Email: mekhan@jmi.ac.in

I. INTRODUCTION

Energy is the prime factor for social, economic and industrial development. It plays a vital role in our civilization. In these days, fossil fuels are the most widely used sources of energy to fuel vehicle, power plant, agricultural and various industrial sectors. In the present scenario, there is drastically increase in energy demand due to the fast growth in the world population. Hence, due to limited fossil fuel resources and environmental issues, more and more attention is being given to renewable energy sources. The solar energy is unlimited freely available to the earth atmosphere during day time. The solar energy is more reliable, sustainable, environmental friendly (free from CO_2 emission) and economically viable energy source. It is becoming an alternative for the limited fossil fuel resource.

Solar energy is the energy which is obtained from the Sun directly in from of sunlight, which comprises of electromagnetic radiation (a stream of photons) [1]. The simplest and most direct application of this energy is the conversion of solar radiation into electricity with the help of photovoltaic effect. The photovoltaic effect was first introduced by Alexander-Edmond Becquerel in 1839. After that, first practical photovoltaic cell, which works on photovoltaic effect, is commercially developed in 1954 by Bell Telephone Laboratories [2]. Further, a lot of researches have been performed in the field of photovoltaic technologies to improve its performance and design. According to the time of evolution, the solar cells are classified into the three generation, namely, first-generation consist of crystalline silicon solar cell, second-generation consist of thin film solar cell and third-generation consist of organic solar cells [3-6]. Many researchers have conducted their study to improve the performance of PV module.

The location of installation of the PV panels also play an important role on the performance of the module due to variation of solar intensity, climatic condition, geographical positioning etc. [7-11]. The performance of PV panels can also be enhanced by the periodic removal of dust and pollutant from the surface of module [12-14].

Evan [15] has developed an expression for temperature dependent electrical efficiency of solar cell. It is found that at higher operating temperature the efficiency of PV module is lower due to rise in resistance between solar cells. The overall performance of PV panels can be improved by the withdrawal of heat either by flow of air or water which resulting cooling of solar cells or by the evaporative cooling of solar cells [16-18]. Some of the analytical and experimental work has been performed on the opaque and semi-transparent PV based module. Lately, a lot of work has been conducted to enhance the overall performance by introducing the different configuration of photovoltaic thermal collector [19-20].

Later, based on the preceding literature, it is found that a comparative performance analysis between opaque and semi-transparent PV module are in scarce. Hence, on the basis of energy balance of opaque and semi-transparent PV module, a comparative performance analysis in terms of solar cell temperature, solar cell electrical efficiency, module efficiency and electrical power output have been discussed in this paper.

II. SYSTEM DESCRIPTION

The cross-sectional cut views of a fully covered opaque and semi-transparent photovoltaic (PV) module are shown in Figure 1(a-b). The opaque PV module consists of a series connected solar cells sandwiched between the encapsulant ethylene-vinyl-acetate (EVA) and further, sandwiched between glass (on top) and opaque tedlar (on bottom) as shown in Figure 1(a). However, the semi-transparent PV module consists of a series connected solar cells sandwiched between the encapsulant ethylene-vinyl-acetate (EVA) and further, sandwiched between glass (on top) and transparent tedlar or glass (on bottom) as shown in Figure 1(b). In case of opaque PV module, some incident solar radiation available on the module is captured by solar cells and rest part is trapped in the module due to opaque tedlar [as shown in Fig. 1(a)]. While in case of semi-transparent PV module, a part of incident solar radiation available on the module is captured by solar cells and rest part is passed through the module due to transparent tedlar/glass [as shown in Fig. 1(b)]. In the both configuration, the area of module occupied by the solar cell is termed as packing area, while the area which is not covered by solar cell is named as non-packing area. Further, the ratio of packing area and total module area is known as packing factor, which play very important role in the design of module. A 2.1 m^2 module area of opaque and semi-transparent photovoltaic (PV) module has been considered for the present paper analysis. Later on, other design parameters of PV module have been given in Table 1.

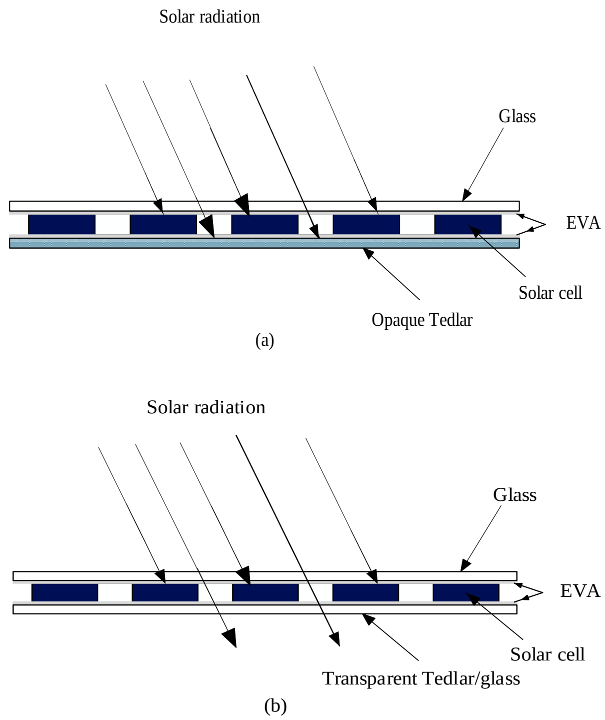

Fig. 1. A schematic representation of fully covered (a) opaque PV module and (b) semi-transparent PV module.

Table- II: Design parameters of opaque and semi-transparent PV module

Parameters	Value
A_m	2.1 m^2
η_0	0.15
β_0	0.0045
β_c	0.89
α_c	0.9
α_T	1
τ_g	0.95
h_0	5.7+3.8v, v=0.5 m/s
h_i	2.8+3.0v, v=0.2 m/s
L_g(m)	0.003
K_g(W/m.K)	1.1
L_T(m)	0.0005
K_T(W/m.K)	0.033

III. THERMAL MODELING

In order to simplify the mathematical computations, the energy balance equations for fully covered opaque and semi-transparent PV module have been written on the basis of following assumptions:

- Systems are considered in quasi steady state condition.
- One-dimensional heat conduction is considered.
- In solar cells, ohmic losses are neglected.
- Heat capacity of materials used in the PV module has been neglected.

A. Energy Balance for Opaque PV Module

To analyze the performance of opaque PV module [as shown in Fig. 1(a)], followed by Gaur and Tiwari [21],

the energy balance equation can be written as follows:
[Rate of incident solar radiation absorbed by solar cells] + [Rate of incident solar radiation absorbed by opaque tedlar through non-pacing area] = [Rate of overall heat loss from top surface of PV modules to ambient] + [Rate of overall heat loss from back surface of PV modules to ambient] + [Rate of electrical energy generation by PV module]

$$\alpha_c\tau_g\beta_c I(t)A_m + (1-\beta_c)\alpha_T\tau_g I(t)A_m = U_T(T_c - T_a)A_m + U_b(T_c - T_a)A_m + \eta_c\tau_g\beta_c I(t)A_m \quad (1)$$

where, U_T and U_b are overall top and back heat loss coefficient respectively, which are given by:

$$U_T = \left[\frac{L_g}{K_g} + \frac{1}{h_0}\right]^{-1},$$

and

$$U_b = \left[\frac{L_T}{K_T} + \frac{1}{h_i}\right]^{-1}.$$

From the above equation (1), one can get the analytical expression for solar cell temperature of opaque PV module in terms of design and climatic parameters as given below:

$$T_c = \frac{T_a(U_b+U_T)+[\tau_g\{\alpha_c\beta_c+(1-\beta_c)\alpha_T-\eta_c\beta_c\}]I(t)}{U_L}, \quad (2)$$

or,

$$T_c = \frac{T_a U_L+[\tau_g\{\alpha_c\beta_c+(1-\beta_c)\alpha_T-\eta_c\beta_c\}]I(t)}{U_L} \quad (3)$$

or,

$$T_c - T_o = T_a - T_o\frac{[\tau_g\{\alpha_c\beta_c+(1-\beta_c)\alpha_T-\eta_c\beta_c\}]I(t)}{U_L} \quad (4)$$

Where, U_L is the overall loss coefficient of PV module, which is given as:

$$U_L = U_b + U_T \,.$$

The temperature-dependent electrical efficiency of solar cells of PV module given by [15, 22] is as follows:

$$\eta_c = \eta_o[1 - \beta_o(T_c - T_o)] \quad (5)$$

On substitution of Eq. (4) into Eq. (5), one can obtain the analytical expression for solar cell electrical efficiency of opaque PV module in terms of design and climatic parameters as follows:

$$\eta_c = \frac{\eta_0\left[1-\beta_0\left\{(T_a-T_0)+\left(\frac{\{\tau_g\alpha_c\beta_c+(1-\beta_c)\tau_g\alpha_T}{U_L}\right)I(t)\right\}\right]}{\left[1-\left(\frac{\eta_0\beta_0\tau_g\beta_c}{U_L}\right)I(t)\right]} \quad (6)$$

B. Energy Balance for Semi-transparent PV Module

Similarly, to analyze the performance of semi-transparent PV module [as shown in Fig. 1(b)], the energy balance equation can be written as given below:

[Rate of incident solar radiation absorbed by solar cells] = [Rate of incident solar radiation absorbed by opaque tedlar through non-pacing area] = [Rate of overall heat loss from top surface of PV modules to ambient] + [Rate of overall heat loss from back surface of PV modules to ambient] + [Rate of electrical energy generation by PV module]

$$\alpha_c\tau_g\beta_c I(t)A_m = U_T(T_c - T_a)A_m + U_b(T_c - T_a)A_m + \eta_c\tau_g\beta_c I(t)A_m \quad (7)$$

where, the expression for U_b for semi-transparent PV module can be given as follows:

$$U_b = \left[\frac{L_T}{K_T} + \frac{1}{h_i}\right]^{-1}.$$

In the same way, from Eq. (7) one can get the analytical expression for solar cell temperature and solar cell electrical efficiency of semi-transparent PV module in terms of design and climatic parameters as follows

$$T_c = \frac{T_a U_L+(\alpha_c\tau_g\beta_c-\eta_c\tau_g\beta_c)I(t)}{U_L} \quad (8)$$

$$\eta_c = \frac{\eta_0\left[1-\beta_0\left\{(T_a-T_0)+\left(\frac{\alpha_c\tau_g\beta_c}{U_L}\right)I(t)\right\}\right]}{\left[1-\left(\frac{\eta_0\beta_0\tau_g\beta_c}{U_L}\right)I(t)\right]} \quad (9)$$

Further, module electrical efficiency for opaque and semi-transparent PV module can be evaluated as given below:

$$\eta_m = \eta_c\tau_g\beta_c \quad (10)$$

Later on, with the help of Eq. (10), the rate of electrical energy output for the opaque and semi-transparent PV module can be estimated as follows:

$$\dot{E}_m = \eta_m A_m I(t) \quad (11)$$

or

$$\dot{E}_m = \eta_c A_m \beta_c \tau_g I(t) \quad (12)$$

IV. METHODOLOGY

In order to compute the performance parameters, namely, solar cell temperature, solar cell electrical efficiency, module efficiency and electrical power output for given design parameters of opaque and semi-transparent PV module for New Delhi climatic condition, following methodologies have been adopted.

- New Delhi climatic data such as ambient temperature and solar intensity available on horizontal surface for a typical clear day in the month of May have been taken from IMD, Pune, India. The total solar radiation [I(t)] incident on the opaque and semi-transparent PV module at the inclination of 30^o facing towards south has been estimated by using Liu and Jordan empirical relation. The hourly variation of solar radiation and ambient temperature have been given in Fig. 2.

- Corresponding to above climatic data and design parameters of opaque and semi-transparent PV module (as given in Table 1), solar cells temperature for both cases have been computed by using Eq. (3) and Eq. (8) respectively.
- With the help of above calculated parameters, Eqs. (6) and (9) have been evaluated to obtain the solar cell electrical efficiency of opaque and semi-transparent PV module respectively.
- After that, module electrical efficiency and electrical power output for both cases have been estimated by using Eq. (1) and (12) respectively.
- All numerical computations have been performed on the MATLAB R2015a software.

V. RESULT AND DISCUSSION

Fig. 2 shows the variation of total solar intensity and ambient temperature at a fixed interval of time i.e., 1h available on opaque and semi-transparent PV module inclined at 30^o facing towards south for a typical clear day of month of May for New Delhi climatic condition. It is seen in the figure that the highest solar intensity of 898.96 W/m^2 is incident on the module at 12:00 h, while highest ambient temperature of 38.5 ^{o}C is recorded at 17:00 h corresponding to 271.10 W/m^2 solar intensity.

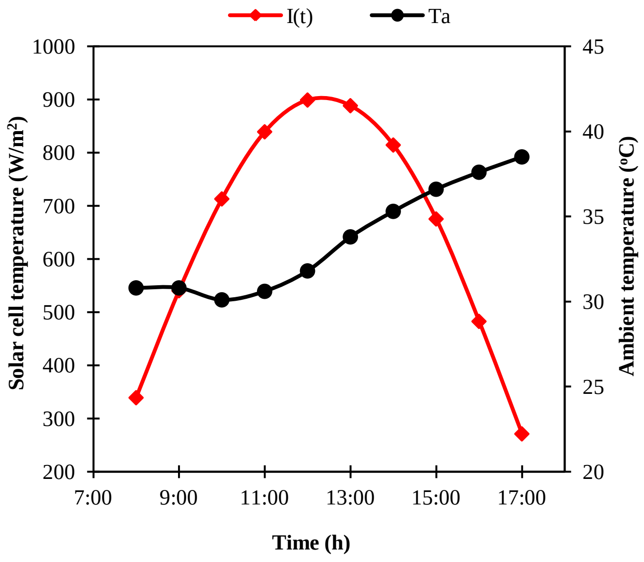

Fig. 2. Hourly variation of ambient temperature (T_a) and total solar intensity [I(t)] for a typical clear day of month of May for New Delhi.

Solar cell temperature of opaque and semi-transparent PV module has been evaluated by using the equation (2) and (8) respectively, and the results are illustrated on hourly basis in Fig. 3. From the graph of the figure, it is seen that the solar cell temperature is increased from morning to maximum at noon and further decreases in the similar trend of solar intensity as given in Fig. 1. It can also be observed clearly from the figure that the solar cell temperature of semi-transparent PV module is lower than the opaque one due to direct transmission of solar radiation through the non-packing area via transparent tedlar/glass of semi-transparent PV module [as shown in Fig. 1(b)]. In the other words, solar radiation is trapped in the opaque PV module due to opaque tedlar which resulting the rise in the temperature of solar cells. Further, the maximum solar cell temperature of 103 ^{o}C and 88.9 ^{o}C corresponding to solar intensity of 888.3 W/m^2 at 13:00 h for opaque and semi-transparent PV module has been recorded respectively. Later on, it is found that average solar cells temperature of semi-transparent PV is approximately 12.11% lower than opaque module.

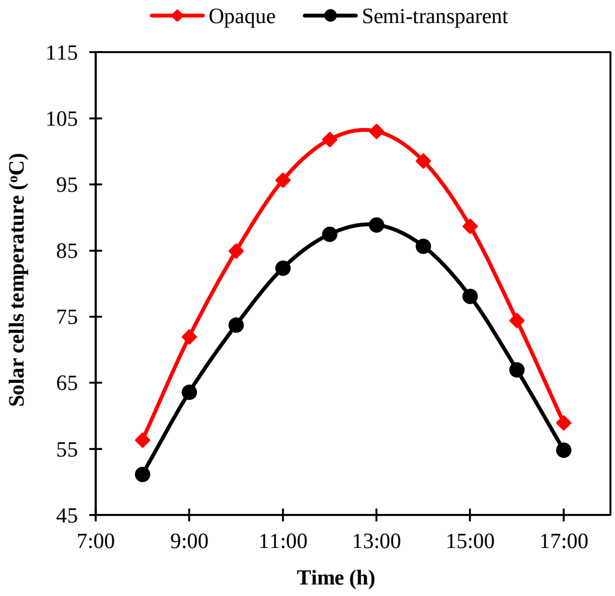

Fig. 3. Hourly variation of solar cell temperature for the opaque and semi-transparent PV module.

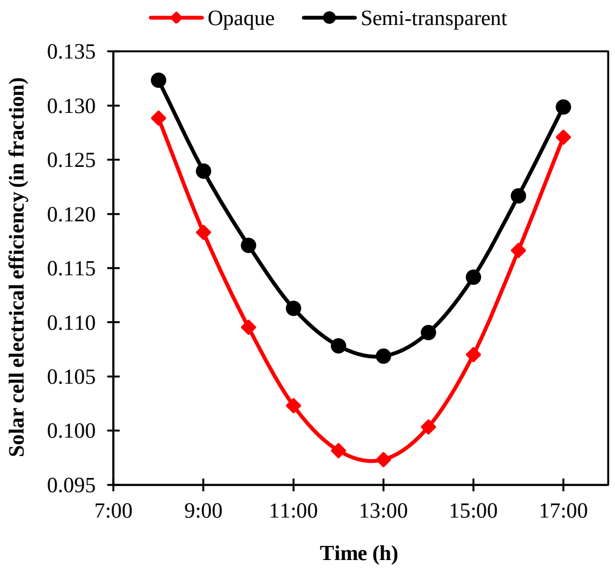

Fig. 4. Hourly variation of solar cell electrical efficiency for the opaque and semi-transparent PV module.

Fig. 4 represents hourly variation of solar cell electrical efficiency of opaque and semi-transparent PV module for given design parameters (as given in Table 1) and climatic condition (as shown in Fig. 2), which is computed by using the equations (6) and (9) respectively. From the plot of figure, one can observed that the solar cell electrical efficiency is maximum (0.1323 & 0.1288) at morning (i.e. 8:00 h) and gradually decreases to minimum (0.1069 & 0.0973) till 13:00 h and further increase onwards for both cases in order.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

This trend of electrical efficiency is just reciprocal of cell temperature. It is due to fact that at lower solar cell temperature at 8:00 h (as shown in Fig. 3), the kinetic energy of the electron and holes in the depletion band of solar cell become lower which prevents the collision and resulting lowest resistance in the solar cell. Hence, the solar cell electrical efficiency is lowest at 13:00 h due to maximum recorded cell temperature. Further, it seen in the graph, the semi-transparent PV module having higher efficiency than the opaque one throughout the working hours due to low operating cell temperature as discussed above. Later on, similar trends have been seen in the Fig. 5 for the module efficiency [Eq. (11)] for the both cases as per our expectation. It is found from the Fig. 4 and Fig 5 that the module efficiency is lower that solar cell efficiency as expected.

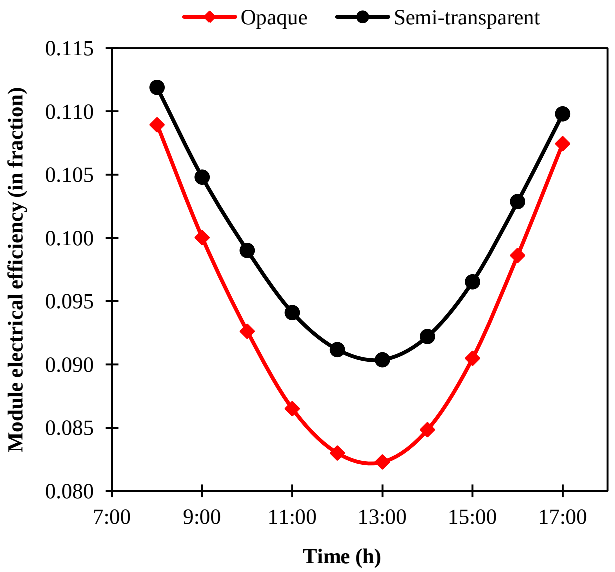

Fig. 5. Hourly variation of module electrical efficiency for the opaque and semi-transparent PV module.

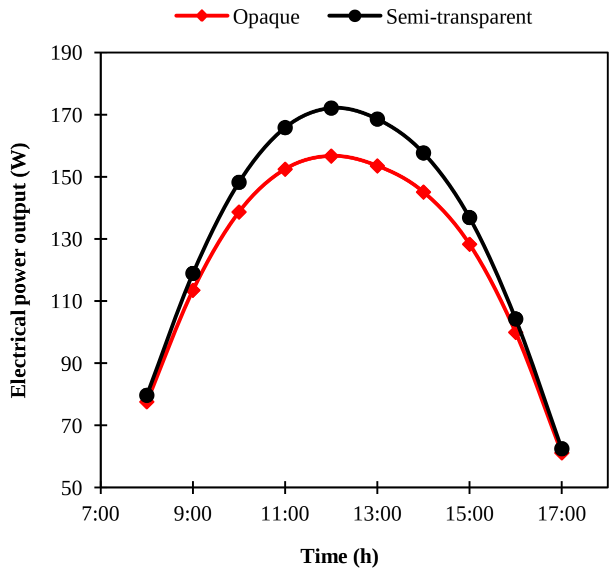

Fig. 6. Hourly variation of electrical power output for the opaque and semi-transparent PV module.

Fig. 6 shows the variation of electrical power output of opaque and semi-transparent PV module at fixed interval of time during working hours of 8:00-15:00 h, by computing the equation (11) or (12). The trends of graph is similar to the solar intensity, because it is the input energy to the module which resulting higher output at higher input radiation and vice-versa. As discussed in the above results that semi-transparent module having higher performance. Thus, the hourly variation of electrical power output of the semi-transparent module is higher than opaque one as shown in Fig. 6. Further, it is found that the overall daily electrical energy output of the semi-transparent PV module is 7.16% higher than the opaque one under the given design and climatic parameters. Later on, a comparative representation between daily electrical energy output for opaque and semi-transparent PV module has been shown in Fig. 7. The effect of packing factor on the daily electrical energy output for both cases has also demonstrated in this figure. It is clearly found from the plot of figure that the daily electrical energy output for semi-transparent PV module higher than opaque one at the same design and operating condition parameters. It is also observed that the output decrease with the decrease in the packing factor of module. It is due to fact that for a given design of PV module, as the packing factor reduced, the number of solar cells also reduced which resulting decrease in the energy output.

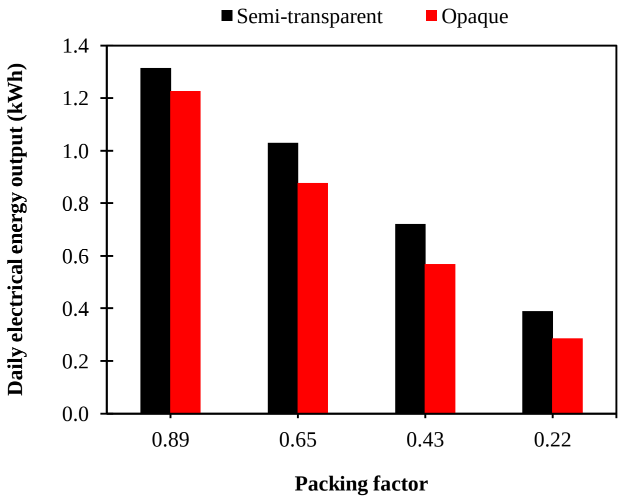

Fig. 7. Effect of packing factor on the daily electrical energy output of the opaque and semi-transparent PV module.

VI. CONCLUSION

Based on the above analysis, following conclusions have been drawn:

- The solar cells temperature (T_c) for the fully covered semi-transparent PV module is significantly lower than the opaque one throughout the working duration.
- The average solar cell electrical efficiency (η_c) and module efficiency (η_m) for the semi-transparent PV module is found to be approximately 6.47% higher than that of the opaque PV module throughout the day.
- For the electrical energy point of view, the fully covered semi-transparent PV module having higher packing factor is most suitable.

- For the overall performance enhancement of PV systems such as PV array, photovoltaic thermal collector, building integrated photovoltaic thermal system etc., the fully covered semi-transparent PV module with varying packing factor can be used.

REFERENCES

1. G.N. Tiwari, "Solar Energy: Fundamentals, Design, Modeling and application," New Delhi: Narosa Publishing House, 2002.
2. C. M. Chapin, C. S. Fuller, and G. J. Pearson, "A new silicon p-n junction photocell for converting solar radiation into electrical power," Journal of Applied Physics, 1954, pp. 676-677.
3. G.N. Tiwari, A. Tiwari, and Shyam, "Handbook of Solar Energy: Theory, Analysis and Applications," Singapore: Springer, 2016. doi:10.1007/978-981-10-0805-4.
4. G. Makrides, B. Zinsser, M. Norton, G.E. Georghiou, M. Schubert, and J.H. Werner, "Potential of photovoltaic systems in countries with high solar irradiation," Renewable and Sustainable Energy Reviews, vol. 14, 2009, pp. 754–762.
5. K. Vats, and G.N. Tiwari, "Performance evaluation of a building integrated semitransparent photovoltaic thermal system for roof and façade," Energy Build., vol. 45, 2012, pp. 211–218.
6. Y.B. Assoa, and C. Me´ne´zo, "Dynamic study of a new concept of photovoltaic–thermal hybrid collector," Solar Energy, vol. 107, 2014, pp. 637–652.
7. M.Z. Hussin, A. Omar, Z. Zain, and S. Shaari, "Performance of Grid-Connected Photovoltaic System in Equatorial Rainforest Fully Humid Climate of Malaysia," International Journal of Applied Power Engineering, vol. 2, 2013, pp. 105-114.
8. A.M. Humada, M. Hojabri, H.M. Hamada, F.B. Samsuri, and M.N. Ahmed, "Performance Evaluation of Two PV Technologies (C-Si and CIS) for Building Integrated Photovoltaic Based on Tropical Climate Condition: A Case Study in Malaysia," Energy and Buildings, vol. 119, 2016, pp. 233-241.
9. R. Muhida, A. Mostavan, W. Sujatmiko, M. Park, and K. Matsuura, "The 10 years operation of a PV-micro-hydro hybrid system in Taratak, Indonesia," Solar Energy Materials and Solar Cells, vol. 67, 2001, pp. 621-627.
10. P. Kamkird, N. Ketjoy, W. Rakwichian, and S. Sukchai, "Investigation on temperature coefficients of three types photovoltaic module technologies under Thailand operating condition," Procedia Engineering, vol. 32, 2012, pp. 376-383.
11. M.J. Ahmad, and G.N. Tiwari, "Optimization of Tilt Angle for Solar Collector to Receive Greatest Radiation," The Open Renewable Energy Journal, vol. 2, 2009, pp. 19-24.
12. J.K. Kaldellis, , M. Kapsali, and K.A. Kavadias, "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece," Renewable Energy, vol. 66, 2014, pp. 612-624.
13. M.T. Chaichan, B.A. Mohammed, and H.A. Kazem, "Effect of pollution and cleaning on photovoltaic performance based on experimental study," International Journal of Scientific and Engineering Research, vol. 6, 2015, pp. 594-601.
14. H. Jiang, L. Lu, and K. Sun, "Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules," Atmospheric Environment, vol. 45, 2011, pp. 4299-4304.
15. D. L. Evans, "Simplified method for predicting PV array output," Solar Energy, vol. 27, 1981, pp. 555-560.
16. Z.A. Haidar, J. Orfi, H.F. Oztop, and Z. Kaneesamkandi, "Cooling of solar PV panels using evaporative cooling," Journal of Thermal Engineering, vol. 2, 2016, pp. 928-933.
17. S. Chandra, S. Agrawal, D.S. Chauhan, C.S. Rajoria, "An Enhancement in electrical efficiency of photovoltaic module. IEEE 7th Power India International Conference (PIICON), Bikaner, India, 2016, pp. 1-5. doi:10.1109/POWERI.2016.8077375
18. A. Gaur, and G. N. Tiwari, "Performance of a-Si thin film PV modules with and without water flow: An experimental validation," Applied Energy, vol. 128, 2014, pp. 184–191.
19. G. N. Tiwari, Md. Meraj, M. E. Khan, R. K. Mishra, and Vihang Garg, "Improved Hottel-Whillier-Bliss equation for N-photovoltaic thermal-compound parabolic concentrator (N-PVT-CPC) collector," Solar Energy, vol. 166, 2018, pp. 203-212.
20. G.N. Tiwari, Md. Meraj, and M.E. Khan, "Exergy analysis of N-photovoltaic thermal-compound parabolic concentrator (N-PVT-CPC) collector for constant collection temperature for vapor absorption refrigeration (VAR) system", Solar Energy, vol. 173, 2018, pp. 1032-1042.
21. A. Gaur, G. N. Tiwari, "Performance of photovoltaic modules of different solar cells" Journal of Solar Energy, 2013. http://dx.doi.org/10.1155/2013/734581.
22. E. Skoplaki, and J.A. Palyvos, "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations," Solar Energy, vol. 83, 2009, pp. 614–624.

AUTHORS PROFILE

Md. Meraj is an eminent research scholar in Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India. He has been published some research papers in reputed international journals, conferences and book chapters in reputed publishers. He has been worked as guest faculty in Mechanical Engineering department and Community College, J.M.I. (India) in past few years. He has participated in many national and international conference, workshop and seminar. He has been completed his graduation and post-graduation from A.M.U. (India). He has research interest in the area of Solar Energy, Heat and Mass Transfer, Refrigeration and Air-conditioning etc.

Professor M. E. Khan is Head of the Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India. He has been published so many research papers in reputed international journals and no. of books and book chapters in reputed publishers. He has teaching and research experience of 34 years. He has guided more than 15 Ph.D. students. He is a member of NBA, Planning Commission of India and many selection committees. He has research interest in the field of Renewable Energy Systems, Clean Energy Systems, Heat and Mass Transfer, Life Cycle Analysis (LCA), Energy Conservation, Management and Auditing, Greenhouse Gases (GHG) Abatement, Energy recovery from Solid Waste, Environmental Engineering & Management etc.