

Chandra, Subhash; Agrawal, Sanjay; Chauhan, D. S.

Article

Soft computing based approach to evaluate the performance of solar PV module considering wind effect in laboratory condition

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Chandra, Subhash; Agrawal, Sanjay; Chauhan, D. S. (2018) : Soft computing based approach to evaluate the performance of solar PV module considering wind effect in laboratory condition, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 4, pp. 252-259, <https://doi.org/10.1016/j.egy.2017.11.001>

This Version is available at:

<https://hdl.handle.net/10419/187908>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>



Research paper

Soft computing based approach to evaluate the performance of solar PV module considering wind effect in laboratory condition



Subhash Chandra^{a,*}, Sanjay Agrawal^b, D.S. Chauhan^a

^a Department of Electrical Engineering, GLA University, Mathura U.P. 281406, India

^b School of Engineering and Technology, IGNOU, New Delhi 110068, India

ARTICLE INFO

Article history:

Received 22 August 2017

Received in revised form 28 October 2017

Accepted 15 November 2017

Keywords:

Photovoltaic

Energy

Wind

Performance ratio

Back propagation

ABSTRACT

Energy is the key factor for the growth of any country. Per capita energy consumption is the significance of the progress of any nation. With the increasing environmental impacts, world community is searching the way to shift towards sustainable energy sources. Recently the penetration of photovoltaic systems has increased to generate the electricity at grid or local level. Although this technology has improved a lot however the performance of these systems is site dependent. The experiment is conducted in laboratory of GLA University, Mathura, UP, India (hot and dry climate zone of India). Two PV modules of same electrical and mechanical specifications are taken for experiment. To analyze actual performance; different months of a year from various seasons are chosen including artificial wind. It has been observed that increased module temperature reduces performance but the cooling mechanism provided, bring down the module temperature due to which a net energy gain is 5.07% in considered time. Performance measure indices i.e. PR is improved by 3.4%. Experimental and Simulated energy is 431.28wh and 434.98wh for cooled module while for not cooled module experimental and simulated energy is 410.44wh and 439.7wh. Simulated values of energy are closer to experimental values for cooled module hence ANN avoids the underestimation of performance and overestimation of size, average simulated PR is also same as that of experimental PR i.e. 98.6%.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

In the current scenario of growing photovoltaic industry, it is essential to estimate high quality energy yield. In India the backbone of power sector is coal because it contributes maximum in power generation. India is aiming high to achieve the target of 175 GW installed renewable energy capacity by 2022 (Biroi, 2015). Since abundant amount of solar energy is available in India hence to supplement the target, government made a plan to generate 100 GW from solar photovoltaic systems, out of which 40 GW must be generated from roof top solar photovoltaic systems. State wise target of solar power is shown in Fig. 1 (Anon, 2017).

In order to generate electricity from non polluting energy sources, many efforts are being made to integrate different renewable energy sources. However PV systems are expected to play a key role for the sustainability of the future (Yang and Yin, 2011). Harnessing of electrical energy from solar energy depends upon geographical location, site conditions, characteristics of solar cell etc. i.e. the performance of PV system is highly climate dependent. Many researchers have already contributed a lot to improve the

efficiency, actual performance and sizing of PV system (Bizzarri et al., 2013; Gong and Kulkarni, 2005). Two well known parameters i.e. radiation and temperature affect the performance of PV system directly. Maximum electricity can be harnessed by maximizing radiation and minimizing temperature. Radiation is module orientation dependent and temperature depends on the semiconductor material used for manufacturing the solar cell. Although tracking methods can be used to get maximum radiation but due to limitations, they are not always beneficial. Since India is in northern hemisphere so generally the PV modules are placed facing due south (i.e. equator facing), as a thumb rule the tilt angle is fixed equal to the latitude of the location to maximize the solar radiation on a tilted surface. Seasonal variation in tilt angle is beneficial for better performance of PV system but in fixed roof top PV system the optimal tilt angle is equal to latitude (Gong and Kulkarni, 2005; Khatib et al., 2012; Dolara et al., 2012; Beringer et al., 2011; Kaldellis et al., 2012).

Solar cells are very sensitive to temperature; their power is significantly affected by temperature. For crystalline silicon the voltage temperature coefficient is about $-0.45\%/K$ and current temperature coefficient ranges between 0.04 to 0.09% K (Beringer et al., 2011). Manufacturers indicate the PV module efficiency under standard test conditions (STC), temperature of module 25 °C,

* Corresponding author.

E-mail address: 2003subhash@gmail.com (S. Chandra).

Nomenclature

STC	Standard Test Conditions
AM	Air Mass Ratio
PV	PhotoVoltaic
I	Irradiation, W/m ²
T_a	Ambient temperature, °C
W_s	wind speed, m/s
I_{sc}	Short circuit current of module, Amp.
$\tau \cdot \alpha$	Transmittivity and absorptivity product
PR	Performance Ratio
d_j	Target value of output
V_m	Maximum voltage of module, V
I_m	Maximum current of module, Amp.
P_m	Maximum power of module, Watt
β_{stc}	Temperature coefficient of power, /°C
NOCT	Nominal operating cell temperature, °C
T_{mb}	Module back side temperature, °C
V_{oc}	Open circuit voltage of module, V
H_w	wind convection coefficient
CUF	Capacity utilization factor
e_j	error between actual and desired value
Y_j	Actual value of output

solar radiation of 1000 W/m² and air mass ratio AM = 1.5 (Deutsche Gesellschaft für Sonnenenergie, 2010). Large variations can be seen under outdoor conditions, therefore an important impact on efficiency and energy yield is observed. Module efficiency is temperature dependent (Skoplaki and Palyvos, 2009; Mattei et al., 2006; Evans, 1981). Although a lot of literature is available on PV cell temperature, which can be assumed to be same as that of PV module temperature but recently it is reported that wind speed provides natural cooling for PV module, which decreases the Module temperature hence improves the efficiency. Yet the effect of cooling by wind is not broadly applied that can be an important factor for estimating the true potential for large PV system (Gökmen et al., 2016; Bhattacharya et al., 2014; Schwingshackl et al., 2013). In order to collect the hot air, a channel can be made having inlet and outlet port and hot air from outlet port can be used for space heating i.e. utilization of both types of energy improves the efficiency of the system (Agrawal and Tiwari, 2011). In general the performance is assessed by measuring the actual output and comparing it with expected output. The ratio is called performance ratio (PR) usually employed to optimize the performance and for proper maintenance, a healthy system must have a certain PR value depending on the site, where the system is located (Padmavathi and Arun Daniel, 2015). Although CUF is an important metrics for performance measurement but it actually does not include various solar PV system parameters, hence less suitable in comparison to PR (Kumar and Sudhakar, 2017). Different Solar PV systems have PR value in the range of 0.6–0.9, depending upon site conditions. The inherent losses present in the system reduces the PR value, detailed losses are weak irradiation losses, temperature losses, DC cable losses, shading losses, dust and snow losses, inverter losses, and others if applicable. Although losses cannot be reduced to zero, however they can be minimized. In India very little literature is available on energy performance indicators hence a lot of documentation is required (Kumar and Sudhakar, 2017; Ayompe et al., 2011; Sharma and Chandel, 2013; Rawat et al., 2016). It is important to evaluate and forecast the site dependent performance of PV system before the installation, several soft computing based approaches like artificial neural network (ANN), genetic algorithm, fuzzy logic are playing key role in this. ANN's have many applications due to their reliability in forecasting; some tasks are

intelligently performed by them. They can be trained from examples which develop the ability to deal with non linear problems. Although ANN's are less efficient with high accuracy and precision as in arithmetic and logical operations but they are widely used in engineering, economics, adaptive control, robotics etc. (Ceylan et al., 2014; Kalogirousa et al., 2014; Kalogirousa, 1999).

This paper is intended to help investors and project planners to estimate the true potential of PV system by considering less module temperature due to wind cooling effect. The energy and instantaneous performance ratio are evaluated experimentally and ANN methods by considering wind effect, which is different from the literature available. Artificial wind is provided for cooling behind the PV module which also reduces the risk of PV cell damage by decreasing the temperature. An experiment is conducted in laboratory to analyze the comparative performance of two modules of similar characteristics, a fan is connected behind one module (cooled module), which is powered by module itself. Analysis is done for gain in energy by cooling mechanism during different months of various seasons of the year. Moreover this mechanism is beneficial in actual size estimation in large power plants and in BIPV applications. Fig. 2 is showing the mechanism for cooled module.

2. Experimental setup

An experiment is conducted in the solar energy laboratory in GLA University, Mathura, UP, India (27.4924° N, 77.6737° E). The Experimental setup is consisting two polycrystalline type PV modules of 0.353 m² areas as shown in Fig. 3. One of the PV modules is cooled by connecting a DC fan below it and powered by itself while another is not cooled. Two modules can be connected in series or parallel for different experiment. Keeping in mind the continuous consumption of energy by fan, a mechanism of adaptive cooling is chosen, this mechanism consist a temperature sensor and microcontroller. Temperature sensor is kept in touch with the back side of module, during programming of microcontroller reference temperature is set which decides the Turn ON and Turn OFF of the fan. Halogen lights are used to get the variable artificial radiation, to ensure uniform irradiance all the lights are connected in matrix form. Irradiance is measured by solar power meter TM 207. It indicates the range in W/m² and in BTU. It is high precision equipment and its operating temperature ranges between 5 °C to 40 °C. The instrument operates with a 9 V battery and below 2000 m altitude. Its dimensions and weight are 143 (l) × 74 (w) × 34 (h) mm, and 250 g respectively. A prototype of mini solar power plant kit has been used to measure the temperature, output voltage and current. This kit has two PV modules of same power rating which can be adjusted at desired latitude. The output of two modules can be measured individually or in series/parallel. AC/DC loads are available to conduct an experiment. Controlled switch are used for regulated irradiation; a digital anemometer AVM 06 is used to measure the speed of the wind. It has large screen LCD, backlight, auto power off and standard accessories. For checking the latitude an angle finder having magnetic base is used which can measure the angle 0–90° in any quadrant. Its accuracy is between $\frac{1}{2}$ to 1°. Data obtained from the experiment is processed with the MATLAB neural network tool to form the ANN for simulation work.

3. Methodology

The experiment is performed for four and half hours weekly with artificial irradiation in the month of March, May, September and December by keeping one module cooled while another not cooled. Weekly average values are taken to analyze the energy. In experiment, radiation and wind speed are two artificial parameters and controllable while ambient temperature is natural parameter.

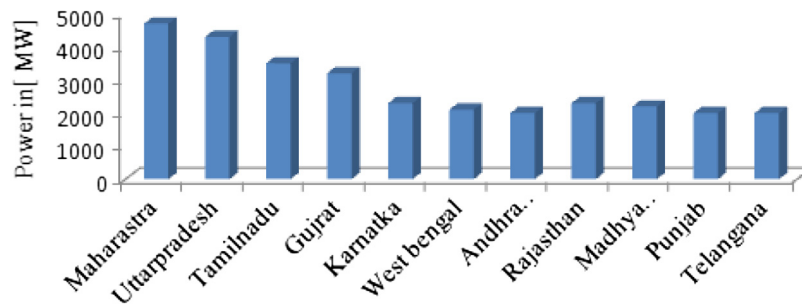


Fig. 1. State wise target of solar power.

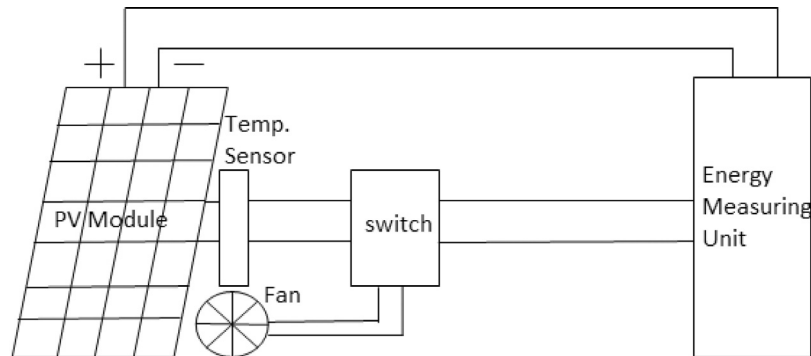


Fig. 2. Block diagram representation of cooled module.

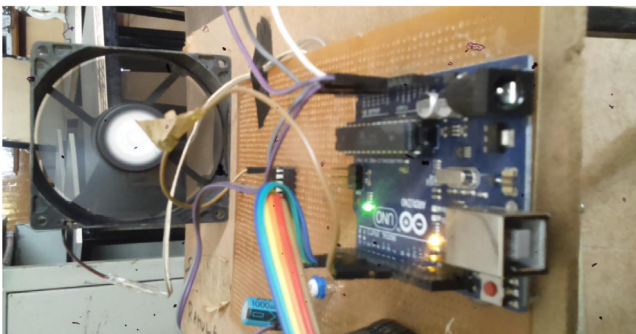


Fig. 3. Experimental setup.

First of all equal amount of irradiation (G) falls on both modules, which is varied from 50 W/m^2 to 500 W/m^2 in step of 50, at the same instant T_a , T_{mb} , V_{oc} and I_{sc} of individual PV modules are measured by mini solar power plant kit. After some time, the radiation is increased and measuring steps are repeated, this time T_{mb} of not cooled module is obtained higher than the T_{mb} of cooled module.

The concept behind cooling is that when T_{mb} is more than T_a , it is sensed by temperature sensor and signal goes to microcontroller which makes switch ON and fan starts cooling in order to bring down the T_{mb} . As soon as the T_{mb} becomes closer to or equal to T_a , microcontroller turns OFF the switch. Fan speed is also measured to observe its effect on solar cell temperature and thermal energy if collected. For not cooled PV module T_{mb} is theoretically calculated based on approaches given by various researchers and compared with the measured values, while for cooled module T_{mb} is theoretically calculated including wind effect and compared with measured values by temperature sensing device. To observe the effect of wind speed, module temperature is calculated by different approaches and measured also. Mathematical expressions for these approaches are

$$T_{mb} = T_a + (T_{NOCT} - T_{aNOCT}) * \frac{I}{I_{NOCT}} \quad (1)$$

Although this expression accurately determines the module temperature but it neglects the wind effect. In addition to the irradiance, temperature the wind effect is integrated thus considering wind effect T_{mb} is calculated as

$$T_{mb} = T_a + \frac{I}{I_{NOCT}} (T_{NOCT} - T_{aNOCT}) \frac{Hw_{NOCT}}{Hw} \cdot [1 - \frac{\eta_{stc}}{\tau \cdot \alpha} (1 - \beta_{stc} \cdot T_{stc})] \quad (2)$$

Above two equations are used to calculate theoretical T_{mb} of not cooled module and cooled module. Hence temperature dependent electrical efficiency of both modules can be calculated by

$$\eta_{el} = \eta_{stc} [1 - \beta_{stc} (T_{mb} - T_a)] \quad (3)$$

Now the measured value of T_{mb} is used to calculate the actual electrical efficiency by Eq. (3).

Table 1
Specification of PV module and setup.

Serial No	Parameter	Value
1	V_{oc}	22.32 V
2	I_{sc}	2.24 A
3	V_m	18.1 V
4	I_m	2.21 A
5	P_m	40 W
6	NOCT	47 °C
7	Operating Range	−20 °C to 90 °C
8	β_{stc}	−0.43%/°C
9	Fan rating	3 W
10	I_{NOCT}	800 W/m ²
11	T_{aNOCT}	20 °C
12	$\tau \cdot \alpha$	0.9
13	η_{stc}	11.3%
15	W_s	2 m/s
16	Module Area	0.353 m ²
17	DC fan rating	3 W, 12 V, 0.25 Amp.

Electrical energy of both modules is calculated by following equation.

$$E = \sum_{j=1}^n \eta_{ej} I_j t_j A \quad (4)$$

$$\Delta E = E_{\text{cooled module}} - E_{\text{notcooled module}} \quad (5)$$

$$PR = \frac{\text{Actual KWh}}{\text{Expected Kwh}} \quad (6)$$

Various parameters of a 40 W, polycrystalline photovoltaic module are given in Table 1 at STC ($I = 1000 \text{ W/m}^2$, $T = 25 \text{ °C}$, $AM = 1.5$). The tilt angle of modules is fixed to local latitude measured by angle finder. Flow chart for experimental procedure is shown in Fig. 4.

Experimental and calculated energy is obtained, data is used to form neural network based on back propagation algorithm. Back propagation is an algorithm in which the network weights are moved along the negative of the gradient of the performance. A trained neural network is supposed to give reasonable answer for any new input. Here two layer feed forward neural network is created having log sigmoid and pure linear transfer function for layer 1 and layer 2 respectively. For faster convergence, steepest descent with momentum *traingdm* is used. Mean Square error (mse) is the performance function

$$F = mse = \frac{1}{N} \sum_{j=1}^N (e_j)^2 = \frac{1}{N} \sum_{j=1}^N (d_j - y_j)^2 \quad (7)$$

Following are the steps to create neural network

- 1 Assemble the data
- 2 Create the network
- 3 Train the network
- 4 Simulate the network for new inputs.

For not cooled module, inputs are irradiation I , ambient temperature T_a and output is calculated energy. In case of cooled module the inputs are irradiation I , ambient temperature T_a and wind speed w , again calculated energy is output. A two layer feed forward neural network is formed with the help of *mntool* in *matlab*. Simulated results are obtained for both types of modules and compared with calculated, experimental and target values to obtain the errors. Block diagram of back propagation algorithm is shown in Fig. 5.

Result and discussion

In order to consider the seasonal effect of temperature the experiment is conducted on every Sunday from 11:30 am to 4:00 pm in the month of December, March, May and September in year 2016. The mean value of temperature in each month is plotted

here. Artificial irradiance is varying from 50 W/m^2 to 500 W/m^2 while wind speed is constant during the experiment in each month. Forty samples are taken, first ten samples in December month, next ten in the march and similarly in the month of may and September as shown in Fig. 6.

Irradiance and ambient temperature values are imported which form an input matrix of order 2×40 . Output energy obtained from calculation in different months is used to form output matrix of 1×40 . The ANN contains one input layer, hidden layer and output layer. 70% data is used for training, 15% for validation and 15% for test. Simulated performance is shown in Fig. 7.

After obtaining the simulated values, these are exported and different values of energy are plotted in Fig. 8; it is observed that target energy has highest values always because it is based on standard efficiency by neglecting all types of losses. It is also observed that experimental energy is always less than others and average simulated energy is 7.12% higher than experimental energy; average calculated energy is 1.47% higher than experimental energy. Experimental energy is actually delivered by the module i.e. performance evaluation and size estimation is more accurate based on calculated values. Performance approximated by ANN is far from actual performance hence it is not better suitable for not cooled module.

In Fig. 9, error 1 is difference between target energy and experimental energy. Error 2 is the difference between calculated energy and experimental energy and error 3 is that difference between simulated energy and experimental energy. Observations are that error 1 and error 3 are to high during high ambient temperature that will lead to over estimation of size which will cost high payback period and more land area.

On the other side the data obtained from the module considering wind effect, is used to form neural network with three input variable irradiation, ambient temperature and wind speed as input matrix of order 3×40 . Calculated energy as output matrix of order 1×40 , the neural network is trained with these new values ensuring that 70% data for training, 15% for validation and 15% for test. The ANN simulated performance is shown in Fig. 10.

In comparison to Fig. 8, the observation in Fig. 11 is that, experimental energy has increased to significant amount because the thermal losses in experimental energy are compensated by artificial wind cooling. Average simulated energy is only 0.85% higher than the experimental energy while average calculated energy is 2.04% is less than experimental energy, thus performance is underestimated if system is designed based on calculated energy. Here ANN is more suitable method to evaluate performance and to estimate size of the system. For both types of modules calculated values are used to train the neural network while other parameters are kept same.

Here it is very interesting to note that error 2, which is the difference of calculated and experimental energy is negative i.e. actual energy delivered by the module is more than the calculated energy and close to the target energy with this difference of simulated and experimental energy is also very less in comparison in to Fig. 9. Thus ANN can evaluate better performance if applied with considering wind effect. See Fig. 12.

Instantaneous performance ratio decreases during the afternoon due to high module temp, although irradiance is having good values as shown in Fig. 13. The drop in *PR inst* is compensated by wind cooling effect. Among various months; the average running time for the fan is maximum in the month of May hence continuous cooling reduces the module temperature. The average *PR inst* for not cooled module is 95.2% while average *PR inst* for cooled module is 98.6% in the considered time.

Site dependent performance ratio is forecasted by ANN which is very close to the experimental values for cooled module. Although some abnormality is observed in simulated values due to data anomalies however average simulated *PR inst* is 98.6%. See Fig. 14.

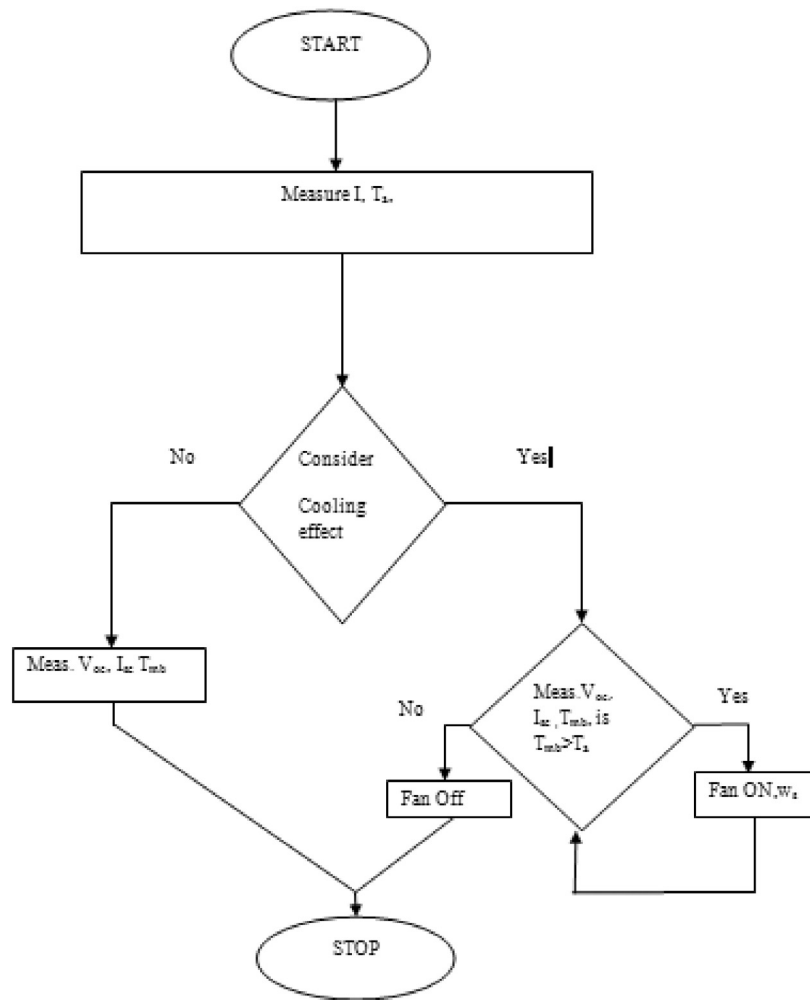


Fig. 4. Flow chart of experiment.

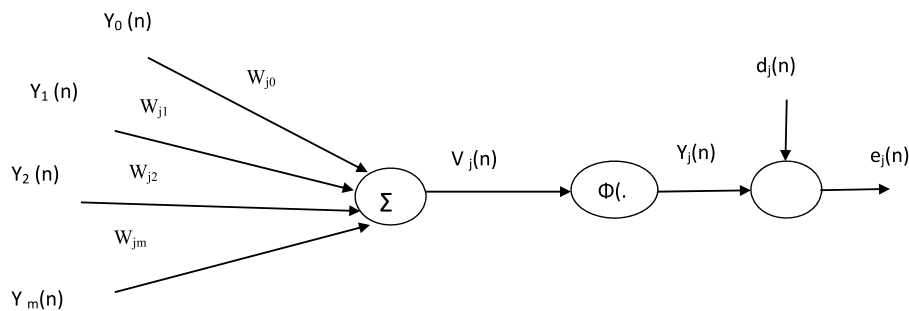


Fig. 5. Back propagation algorithm.

4. Conclusion

Ambient temperature is an important natural parameter for electrical efficiency drop due to thermal losses; wind can play a key role to boost the performance by reducing module temperature. At windy locations average wind speed must be considered before estimating the performance and PV system size that will reduce the cost and payback period. Module technology of high electrical efficiency can be suitable options for average high temperature & good windy locations in comparison to less efficient module technology having low power temperature coefficient. Experimental result show that even artificial cooling mechanism is beneficial in terms

of energy gain. In Cold regions, which are more suitable for BIPV systems because of light electrical load The BIPV system can have the mechanism of forced cooling and due to this generated thermal energy can be utilized for space heating, swimming pool, Bathroom hand drawer etc. Thus utilizing both types of energy system efficiency is improved. Site dependent performance evaluation with soft computing technique like ANN is better before installation of project. Generally due to temperature de rating it becomes difficult to estimate the actual size of inverter, because of variation in DC input side for a system without storage. This mechanism provides less variation in output voltage hence inverter size can be estimated near true value.

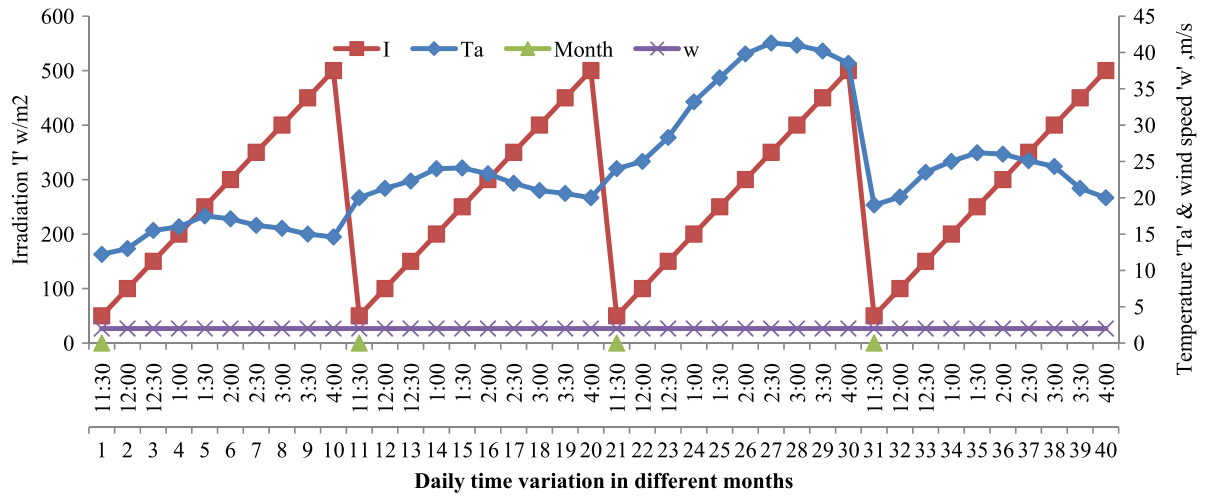


Fig. 6. Variation in artificial irradiation, wind and natural temp with time in different months of various seasons.

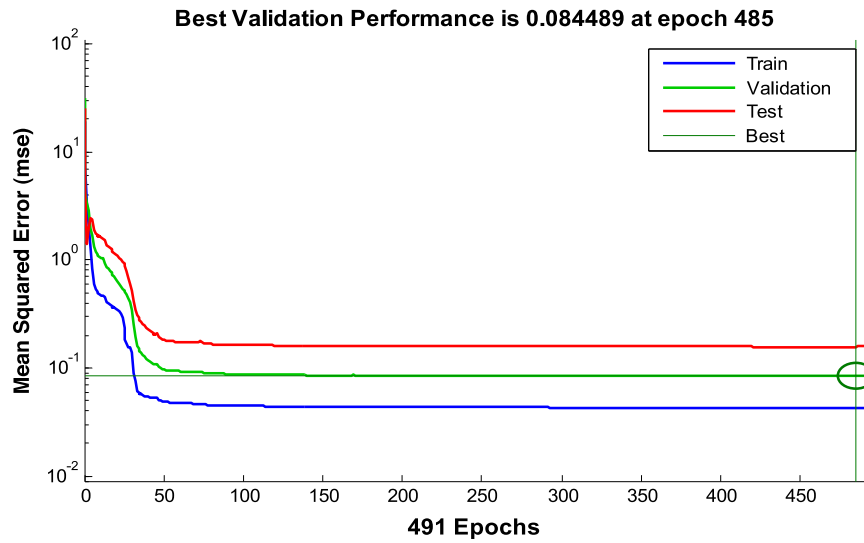


Fig. 7. ANN simulated performance of solar PV module without wind effect.

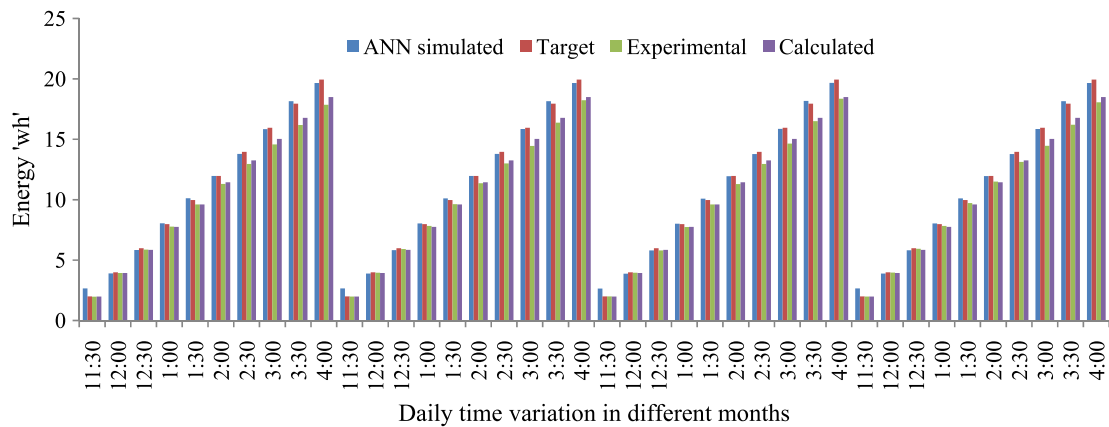


Fig. 8. Variation in energy with time in different months of various seasons without wind effect.

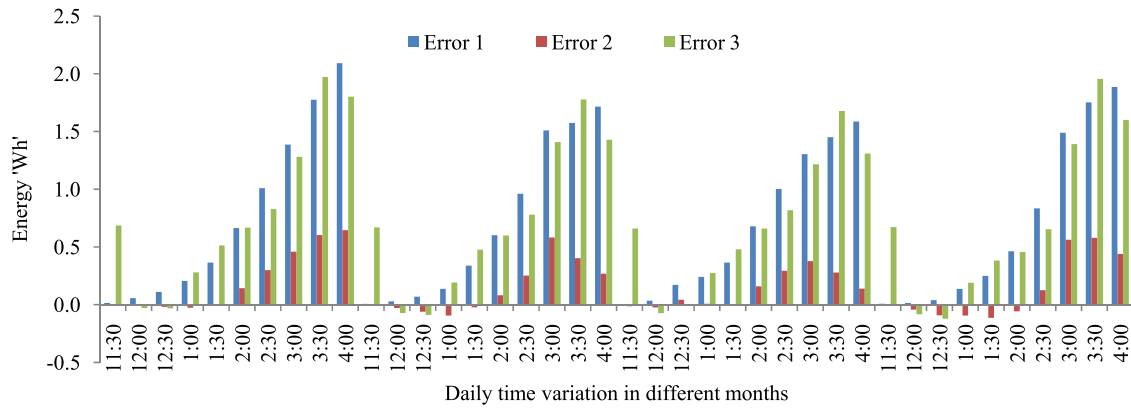


Fig. 9. Variation in error in energy with time in different months of various seasons without wind effect.

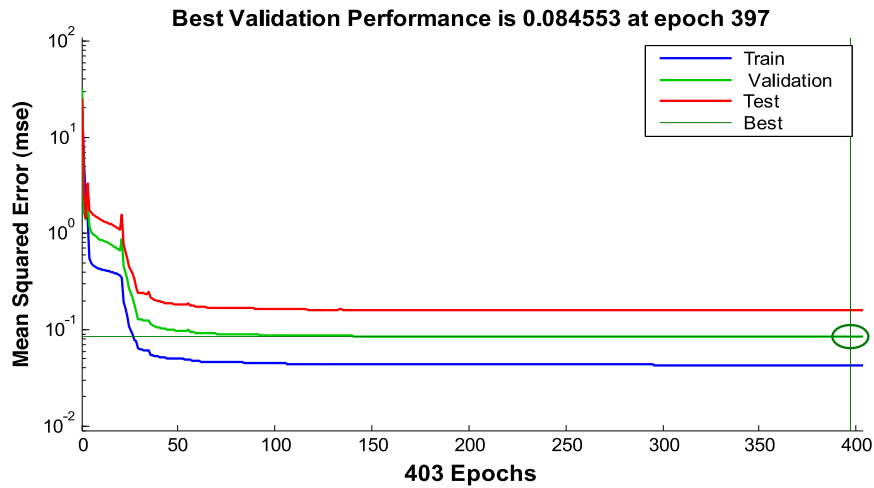


Fig. 10. ANN simulated performance of solar PV module considering wind effect.

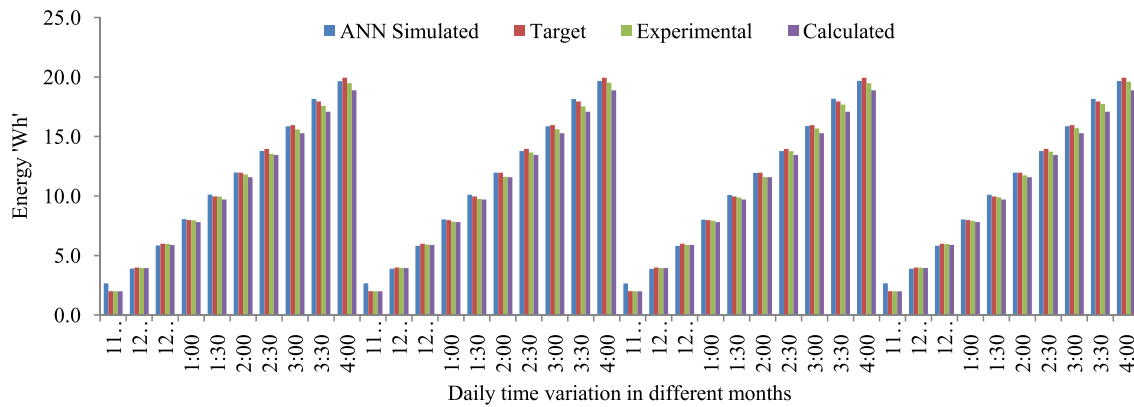


Fig. 11. Variation in energy with time in different months of various seasons considering wind effect.

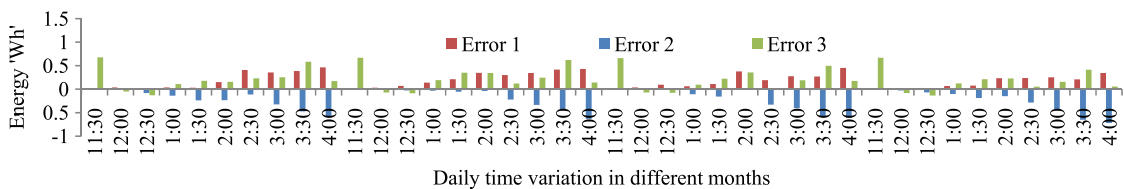


Fig. 12. Variation in error in energy with time in different months of various seasons considering wind effect.

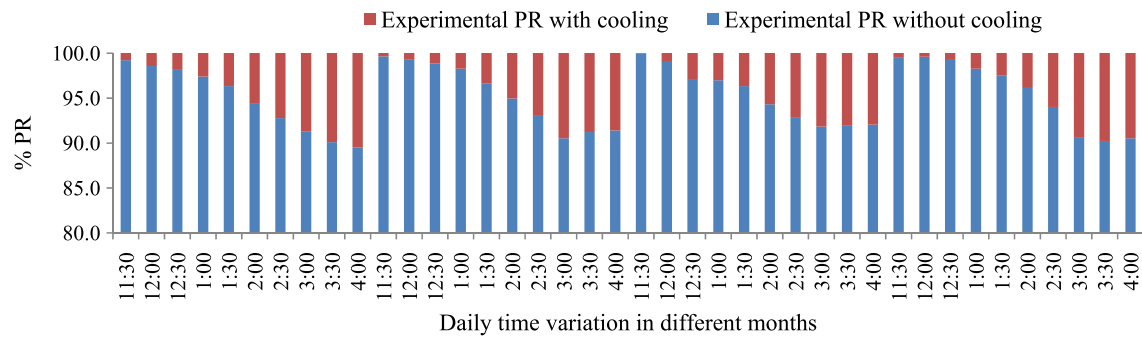


Fig. 13. Instantaneous performance ratio improvement in different months of various seasons.

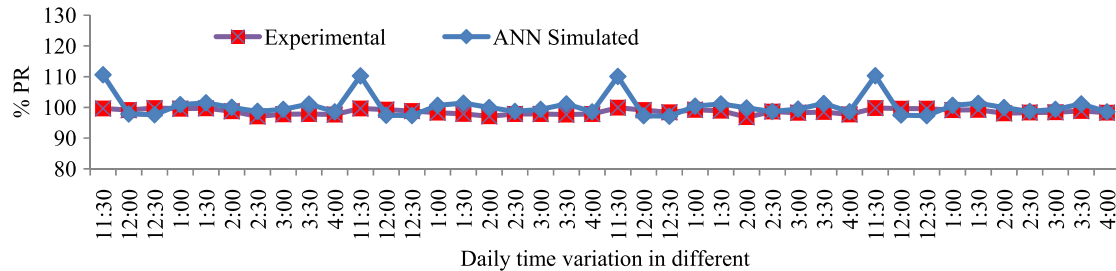


Fig. 14. Instantaneous performance ratio obtained by different methods considering wind effect.

References

- Agrawal, S., Tiwari, G.N., 2011. Energy and electrical energy analysis of hybrid micro-channel photovoltaic thermal module. *Sol. Energy* 85, 356–370.
- Ayompe, L.M., Duffy, A., McCormack, S.J., Conlon, M., 2011. Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy Convers. Manage.* 52, 816–825.
- Beringer, S., Schilke, H., Lohse, I., Seckmeyer, G., 2011. Case study showing that the tilt angle of photovoltaic plants is nearly irrelevant. *Sol. Energy* 85, 470–476.
- Bhattacharya, T., Chakraborty, A.K., Pal, K., 2014. Effects of ambient temperature and wind speed on performance of monocrystalline solar photovoltaic module in Tripura, India. *J. Sol. Energy* 2014.
- Biroi, Fatih, 2015. India energy outlook: World energy outlook special report.
- Bizzarri, F., Bongiorno, M., Brambilla, A., Gruosso, G., Gajani, G.S., 2013. Model of photovoltaic power plants for performance analysis and production forecast. *IEEE Trans. Sustain. Energy* 4, 278–285.
- Ceylan, Ilhan, Erkamaz, Okan, Gedik, Engin, Gurel, Ali Etem, 2014. The prediction of photovoltaic module temperature with artificial neural networks. *Case Stud. Therm. Eng.* 3, 11–20.
- Dolara, A., Grimaccia, F., Leva, S., Mussetta, M., Faranda, R., Gualdoni, M., 2012. Performance analysis of a single-axis tracking pv system. *IEEE J. Photovolt.* 2, 524–531.
- Deutsche Gesellschaft für Sonnenenergie, , 2010. Photovoltaische Anlagen, fourth ed. Berlin Brandenburg e.V., Berlin, Chap. 3 (in German).
- Evans, D.L., 1981. simplified method for predicting photovoltaic array output. *Sol. Energy* 27 (6), 555–560.
- Gökmen, Nuri, Hu, Weihao, Hou, Peng, Chen, Zhe, Sera, Dezso, Spataru, Sergiu, 2016. Investigation of wind speed cooling effect on PV panels in windy locations. *Renew. Energy* 90, 283–290.
- Gong, X., Kulkarni, M., 2005. Design optimization of a large scale rooftop photovoltaic system. *Sol. Energy* 78, 362–374.
- Kaldellis, J., Kavadias, K., Zafirakis, D., 2012. Experimental validation of the optimum photovoltaic panels tilt angle for remote consumers. *Renew. Energy* 46, 179–191.
- Kalogirou, S.A., 1999. Applications of artificial neural network sinenergy systems: a review. *Energy Convers.* 40, 1073–1087.
- Kalogirou, S.A., Mathioulakis, E., Belessiotis, V., 2014. Artificial neural networks for the performance prediction of large solar systems. *Renew. Energy* 63, 90–97.
- Khatib, T., Mohamed, A., Sopian, K., 2012. A review of solar energy modeling techniques. *Renew. Sustain. Energy Rev.* 16, 2864–2869.
- Kumar, B.S., Sudhakar, K., 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Reports* 1, 184–192.
- Mattei, M., Notton, G., Cristofari, G., Muselli, M., Poggi, P., 2006. Calculation of the polycrystalline PV module temperature using a simple method of energy balance. *Renew. Energy* 31, 553–567.
- <http://mnre.gov.in/file-manager/grid-solar/100000MW-Grid-Connected-Solar-Power-Projects-by-2021-22.pdf>.
- Padmavathi, K., Arun Daniel, S., 2015. Performance analysis of 3 MW_p grid connected solar photovoltaic power plant in India. *Energy Rep.* 184–192.
- Rawat, Rahul, Kaushik, S.C., Sastry, O.S., Singh, Y.K., Bora, B., 2016. Energetic and exergetic performance analysis of CdS/CdTe based photovoltaic technology in real operating conditions of composite climate. *Energy Convers. Manage.* 110, 42–50.
- Schwingshackl, C., Petitta, M., Wagner, J.E., Belluardo, G., Moser, D., Castelli, M., Zebisch, M., Tetzlaff, A., 2013. Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation. *Energy Procedia* 40, 77–86.
- Sharma, Vikrant, Chandel, S.S., 2013. Performance analysis of a 190 kW p grid interactive solar photovoltaic power plant in India. *Energy* 55, 476–485.
- Skoplaki, E., Palyvos, J.A., 2009. On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations. *Sol. Energy* 83, 614–624.
- Yang, D., Yin, H., 2011. Energy conversion efficiency of a novel hybrid solar system for photovoltaic, thermoelectric, and heat utilization. *IEEE Trans. Energy Convers.* 26, 662–670.