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Research Article

Development of Statistical Model to Evaluate the Effect of Meteorological Parameters on the Performance of PV-Cell/Module

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I N F O

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A B S T R A C T

The growing need for energy by the human society, climate change and depletion of conventional energy sources demands a renewable, safe, illimitable and low-price energy source. One of the best applicable means to break the accountable world's activity crisis is to use the authority of the sun. Solar activity is clean, great and environment-amicable abeyant ability amid renewable activity options. Solar Photovoltaic (SPV) cells/ modules are composed of silicon or other semi-conductive materials. Semiconductor materials have negative temperature coefficient. The photovoltaic module power output/efficiency depends linearly on the operating temperature while operating temperature of photovoltaic module is depends on the meteorological parameters such as: wind speed, humidity, sky condition etc. In order to predict the energy production of photovoltaic (PV) modules, it's far compulsory to presage the PV module temperature as a function of ambient temperature, wind speed, wind direction, total irradiance, and relative humidity. This paper presents a statistical model to evaluate the effect of meteorological parameters on the performance of PV cell/module and predict the modules efficiency & module temperature.

Keywords: Photovoltaic Module Efficiency, Ambient Temperature (AT), Relative Humidity(RH), Wind Speed(WS), Solar Radiation (SR), Correlation, Regression

Terminology

1. TW - Trillion Watt
2. Tc - PV Cell Temperature, ^{0}C
3. RH - Relative Humidity
4. AT - Ambient Temperature, ^{0}C
5. WS - Wind Speed
6. SR - Solar Radiation, w/m^2
7. A_o, A_1, A_2, A_3, A_4 - Constant Values
8. I(t) - Solar Irradiation, 1000w/m^2

Introduction

The sun is only the source of renewable energy available on the earth surface whether it is direct or indirect. Whereas the energy obtained directly from the sun is largest among all other indirect form of renewable energy sources because of its cleanness and perennial availability. If we will be able to use a small part of the available solar energy (radiations), it will be enough to meet the world's energy requirement. Whereas, the sun radiation hits the earth atmosphere carrying $1.8x10^{17}$ Watt and assuming 60% of it is able to transmit through the earth atmosphere, $1.08x10^{17}$ Watt of energy reach to the earth surface.[1] If the irradiance falling on one percent of earth surface could be converted into electrical energy with PV cell of 10% efficiency, it would provide about 108 TW, whereas the total global energy needs for 2050 are projected 25-30 TW.[2] Further, on India's point of view sun is a great source of energy because 4–7 kWh/m^2 daily average solar radiations incident over India this is because of its location in the tropical region, lying between 8° and 37° north latitude, and has annual average temperature between 25 °C to 27.5 °C, with about 300 clear sunny days in a year.

India having a long coastal line gives inexhaustible breeze vitality consistently. Actually, Indian government is quick to improve sun oriented limit in coming 5 years by progressing decentralized and rooftop scale SPV power plant. The report prepared by TERI[3] estimated that potential for rooftop SPV power plant is 124GWp in the country. India has made considerable R&D efforts, in the last two decades of twentieth century to develop and manufacture indigenous solar PV panels. At first, in late-1970s Central Electronics Limited (CEL), a Public Sector Undertaking (PSU) has made advancement in the PV cell technology in the country and later getting encouraged by outcome of R&D efforts this PSU has started a pilot plant for production of solar PV cells and modules of 1MWp capacity under National Solar Photovoltaic Energy Development (NASPED) program by mid-1985 with average 12% cell efficiency.[4]

Since Government of India is committed to clean energy and to live up to his promise has started world's largest program for generating 100GWp of grid connected solar power by 2022.Presently, India stand 5th among the nations on the planet earth, who are striving to invest and meet their energy demand through renewable resources, only.[5,10] To meet this Himalayan target of 100GWp, Ministry of New and Renewable Energy (MNRE) has started a comprehensive program including R&D, demonstration & utilization, commercialization of the technology indigenous production of PV cell/modules and peripheral, and awareness for the promotion of PV technology.[6] Some of the semiconductors doped with the impurities are acts as photovoltaic converters which converts solar radiations of wavelength 0.38μm to 0.78μm falling on the surface of semiconductors directly converted into electrical energy.

The most popular solar cells are of crystalline silicon (mono-crystalline silicon solar cell or poly-crystalline silicon solar cell) and thin films solar cells, among them both mono crystalline & polycrystalline cells accept the solar radiation in a band of large wavelength for successful conversion in electrical energy and therefore these are used commercially.[9,10,11] Crystalline silicon based PV cells have high photovoltaic conversion efficiency in the range of 20% to 27% contrary to that the thin film has a conversion efficiency of 13-19%.[12,13]The parameters like: fill factor, short circuit current, open circuit voltage, conversion efficiency etcare used to evaluate the performance of PV cells.[7,8]

Primarily, the electrical energy produced by a PV cell is depend upon a type of semiconducting material is used as base material. The commercially available PV module has conversing efficiency in the range of 12-28%, which is additionally influenced by variables like orientation of the panel, shading effect, dust deposition and climatic conditions of the location such as wind speed, ambient temperature and precipitation[14] Particulate matters in the air and deposited dust particles on the PV modules limited the contact of incoming solar radiation with the PV cells, consequently lower the conversion efficiency of the PV cells. Such situation emerges for the most part in dusty, parched or semi-dry areas, or near highways.

Goossens et al.[15] reported that the high speed westerly winds in the afternoons, and southwesterly winds in the evenings mostly contribute to dust deposition on PV panels. Suspended dust particles in the air of diameter 0.3-0.6 mm mainly obstruct the incident solar radiations of visible range wavelength to reach the earth surface. E. Aguado measured the rate of dust deposition on PV modules in desert region for 34 days and reported that the rate of dust deposition per day on PV modules in the desert regions of Middle East was 0.36 g/m2, whereas 0.5 g/m2 and 0.17 g/m2 per day was found in the Negev Desert and Mojave Desert, respectively.[16] The incident infrared radiation present in the solar spectrum leads to significantly rise into the temperature of the PV modules consequently reduction into the efficiency of the PV modules/cells. The performance of PV modules/cells can be fully characterized by its electrical & optical characteristics and durability of the cell can be detected by mechanical evaluation tools .[9] Further the effect of outdoor conditions such as dust, shadow [17] and installing the PV modules at optimum tilt angle at particular location[18,19] is need to be assessed in terms of PV cell/module performance.

This paper discusses the photovoltaic modules power output depend linearly on the module temperature which in turn the outcome of the meteorological parameters like wind speed, humidity, solar radiations etc. A mathematical model was developed, based on the field monitored real time data of module temperature, ambient temperature, solar radiation, wind speed and relative humidity, to predict the surface temperature and efficiency of the module.

Objective of the Research Work

To analyze the performance of PV module in terms of

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energy produced, the surface temperature of the module is a significant parameter which in turns depends on the meteorological parameters like; ambient temperature (AT), wind speed (WS), wind direction (WD), total solar radiation (SR) and relative humidity (RH). Therefore, a computational technique is required to simulate the meteorological parameters, which can be used by engineers or project developers to anticipate the performance of SPV plant to be installed at particular location/locations with varied climatic conditions.

Site Details

Deenbandhu Chhotu Ram University of Science & Technology (DCRUST), Murthal is in northern hemisphere at 29.20°North latitude and 77.50°East longitude and at a height of 221 meter from sea level and average wind speed is recorded 0.5 m/s. During the summer, mercury raise to 47.2 °C and in the midst of winter it contacts to its uncommon low up to 4 °C and average annual variation in temperature is recorded between 31.4 °C and 18.8 °C.[10] At the rooftop of the one of the building of this university, 50KWsolar photovoltaic plant is installed, the technical specifications of PV modules are displayed in table-1.

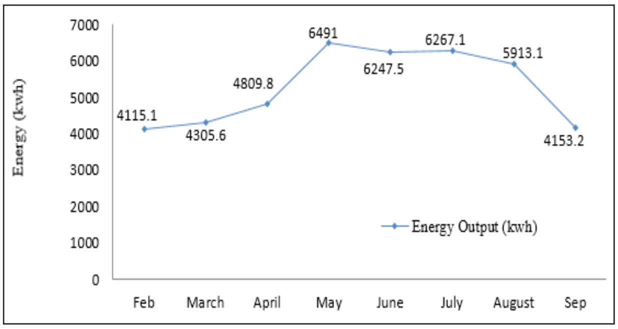

Figure 1.Month wise Energy Production of 50kW PV plant from Feb to Sep 2017

Research Procedure & Data Monitoring

A Solar Radiation Resource Assessment (SRRA) system installed at the rooftop of the university building is valuable to quantify the Solar Atlas i.e. global, direct and diffused radiation of the area. It consist of a tower on which a high resolution 'Pyranometer' is installed to record the radiation and also have a sensors to record atmospheric temperature, relative humidity. The wind speed and direction were measured by anemometer and wind vane. The data measured by SRRA were recorded in every 10 seconds and then averaged over 1-minute periods and displayed. The sensors/equipment's were regularly checked and calibrated. Data were manually validated to remove outlier events due to failure of instruments, power failure, etc. which is statistically analyzed. An Infrared Thermometer (temperature sensor) was used to measuring the temperature of top and bottom surfaces of PV modules at an interval of two & half hour daily starting from 09:00AM onward. To average the performance of the PV module round the year data recorded includes all the twelve months of the year. A four-blade propeller anemometer with a wind vane was used to measure wind speeds on the surface of the PV cell/module. A temperature probe was used for measuring the ambient temperature. The data was recorded for a period of one year (2017). As reported in literature the PV output decreases in summer months due to increase in ambient temperature and consequently PV module temperature. But the plant under study is located in composite zone which witnesses extreme cold, hot, hazy and humid environment as well as fog and dust storm during winter and summer, respectively. Therefore, to analyze the composite effect of weather parameters the data was recorded for complete one year. Figure 2 depicts the average intensity of ambient temperature and wind speed between January to December of the site.

Table 1.Technical Specifications of PV module

Electrical Characteristics	Specification	Material	Specification
Power	280Wp	Solar cell size	156mmX156mmX200micron
Voc	43V	Glass	3.2 mm low iron tempered and textured glass
Isc	8.68 amps	Module size (LxWxT)mm	(1960x990x42) mm
Vm	35V	EVA	STR FC 280 P, Etimex
Im	1.00 mps	Current temp. coeff.	+4.4 mA/K
Max system voltage	1000V	Voltage temp. coeff.	-0.23 V/K
No. of solar cells per module	72 (12x6) unit	Power temp. coeff.	-0.47%K

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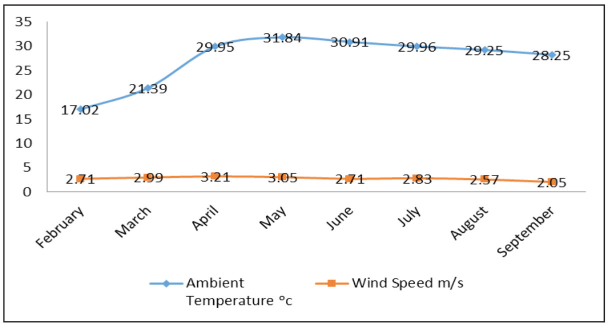

Figure 2.Month wise Energy Production of 50kW PV plant from Feb to Sep 2017

Measured Temperature of Modules

The amount of energy produced by specific PV plant is evaluated under standard test condition of 1000 W/m^2 of solar irradiance, 25°C atmospheric temperature, and 1.5 air mass. However, at different latitude & longitude and the different time of the day these conditions never met, consequently varied spectral irradiance and module temperature adversely affect the energy output from the PV modules. Mohammed et. al. [23,24] have conducted the field experiments on two types of roof; (a) green roof (PV-green) and (b) black roof (PV-black), for two years, to established the fact that the performance of PV module is influenced by its temperature. Researchers prove that PV module temperature can be monitored by choosing particular kind of roof. Gartland et. al.[25] reported that the ambient air above the roof is significantly impacted by roofing material and green roofs helps in keeping the module temperature below 50°C even during hot summer.

Above study shows that the ambient temperature (AT) has direct impact on the module temperature, consequently power output effects accordingly i.e. higher the module temperature and lower the power output. In order to analyse the impact of ambient temperature on the top surface and flip side of the module temperature sensors were installed in the middle of underside surface of the three modules and top surface temperature of same modules was recorded with the help of hand held infra-red thermometer. The Ambient Temperature (AT), PV modules top surface temperature (MUST) and under side (flip side) temperature (MFST) was recorded between February 2017 and September 2017. Figure 3(a) shows the data for 09:00 am recording during the above said period and graph shows that the flip side surface of the module has higher temperature for whole period irrespective of the ambient temperature. Figure 3(b) depicts the data for the same period but time of record was 12;30 pm and exhibit the same behavior as of Figure 3(a). The probable reason for this was that roof was made of concrete and cement due to this the diffuse radiations from the roof surface added the extra heat to the lower side of the module which contributed to raise the flip side temperature of the modules.

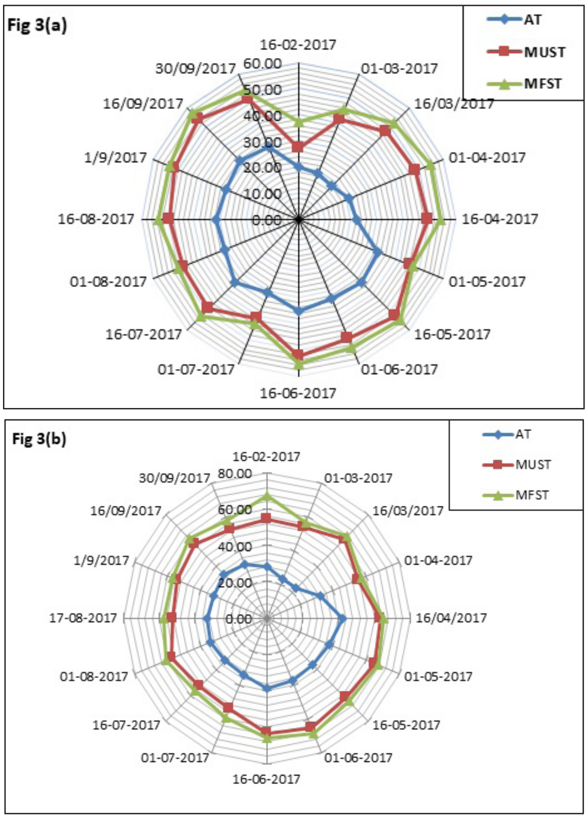

Figure 3(a-b).Measured temperature of top and flip side of modules at given ambient temperature

Statistical Analysis

In this study the ambient temperature, humidity, wind speed and solar radiation are considered as weather parameters, which causes significant effect on the efficiency of PVcells/modules by raising cells/modules temperature. To predict the module temperature in all weather conditions considering the above mentioned weather parameter a four variable linear regression approach was followed. In the present study, modules top surface temperature was addresses as dependent variable and humidity, temperature, wind speed and solar radiation were taken as independent variables &correlation was established among the dependent and independent variables.

Linear regression models are often fitted using the least squares approach to describe the linear association between quantitative variables. Regression is used to assess the contribution of one or more "explanatory" variables (called independent variables) in respect to "response" (or dependent) variable. It can also be used to predict the value of one variable based on the values of others.

For predicting the temperature of the PV module/cell based on measured weather parameters and the module temperature the following linear equation was developed

$$\text{Predicted Module's Temp} = Ao + A_1(AT) + A_2(SR) - A_3(RH) - A_4(WS) \quad (1)$$

In the above equation the PV module temperature was considered as dependent variable on the independent variables i.e. all weather parameters (AT, RH, WS, SR). Regression model helps to calculate the values of equation constants i.e. Ao, A_1,A_2, A_3 and A_4.

Predicted Module Temp at 09:00AM is:

Regression Statistics				
Multiple R	0.662430442			
R Square	0.43881409			
Adjusted R Square	0.388930898			
Standard Error	4.317010265			
Observations	50			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	4	655.7714149	163.9428537	8.796832607
Residual	45	838.6459931	18.63657762	
Total	49	1494.417408		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	20.75139877	5.65110644	3.672094835	0.000636238
Humidity	-0.030902191	0.015260662	-2.024957388	0.048829124
Temperature	0.512443916	0.170785435	3.000512987	0.00438341
Wind Speed	-0.535991967	0.425891524	-1.258517571	0.214695055
Global Radiation	0.020674188	0.005771228	3.582286008	0.000832172

From the regression analysis of the data recorded at 09:00AM the values of various equation coefficient obtained is;

Ao= 20.7514, A1=0.5124, A2=0.0206, A3= -0.0309, A4= -0.5359

Equation developed to obtain the module temperature under given weather condition can be expressed as;

Predicted Module Temp= 20.7514 + 0.5124 (AT) + 0.0206 (SR) + 0.0309 (RH) + 0.5359 (WS) (2)

Predicted Module Temp at 12:30 PM is:

Regression Statistics				
Multiple R	0.589244496			
R Square	0.347209076			
Adjusted R Square	0.309366123			
Standard Error	4.602886283			
Observations	74			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	4	777.5468072	194.3867018	9.174999726
Residual	69	1461.872787	21.18656214	
Total	73	2239.419595		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	47.68285446	5.270731357	9.046724493	2.45386E-13
Humidity	-0.037189746	0.013830703	-2.688926638	0.008979917
Temperature	0.20564256	0.145205739	1.416215094	0.161211193
Wind Speed	-1.010463814	0.386554272	-2.61402832	0.010977681
Global Radiation	0.008135791	0.003040489	2.675817123	0.009303688

From the regression analysis of the data recorded at 12:30PM the values of various equation coefficient obtained is;

Ao= 47.6828, A1=0.2056,A2=0.00813, A3= -0.0371,A4= -1.0104

Equation developed to obtain the module temperature under given weather condition can be expressed as;

Predicted Module Temp = 47.6828 + 0.2056 (AT) + 0.00813 (SR) + 0.0371 (RH) + 1.0104 (WS) (3)

Predicted Module Temp at 3:00 PM is:

Regression Statistics				
Multiple R	0.863531958			
R Square	0.745687442			
Adjusted R Square	0.729540613			
Standard Error	3.47041757			
Observations	68			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	4	2224.810572	556.202643	46.18166445
Residual	63	758.7592809	12.04379811	
Total	67	2983.569853		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	12.27839447	3.895568226	3.151887929	0.002483393
Humidity	-0.006770209	0.011122977	-0.60866879	0.544932485
Temperature	0.772551127	0.116948149	6.605928649	9.66841E-09
Wind Speed	-0.828874621	0.305718619	-2.711233695	0.008628346
Global Radiation	0.027486172	0.00293872	9.353110883	1.59303E-13

From the regression analysis of the data recorded at 3:00PM the values of various equation coefficient obtained is;

Ao= 12.27839, A_1=0.77255,A_2=0.02748, A_3= -0.0067,A_4= -0.8288

Equation developed to obtain the module temperature under given weather condition can be expressed as; Predicted Module Temp = 12.27839 + 0.77255 (AT) + 0.02748 (SR) + 0.0067 (RH) + 0.8288 (WS) (4)

Discussion of Results

A statistical model is developed in section-6.0 using multiple regression analysis. The model gives the correlation between the variable parameters and response. In this model to adjust the significance various terms like probability vales (P-value), variance ratio (F-vale), R-square and adjusted R square was calculated.

Since module temperature depends upon the meteorological parameters like RH, WS, SR and AT, these parameters are varying according to season. The area of study lies in a composite zone where sometime climate is very hot & dry, sometime hazy, sometime cloudy due to monsoon & sometime it is cold and foggy i.e., the effect of these parameters on the PV module temperature is varying throughout the day as well as year. To considered the effect of the weather parameters in a particular day three different hours i.e. 09:00AM, 12:30PM and 3:00PM were selected to record the data & consider the annual variation at different days of the month. Fig. 4(a) shows the module temp was found to be below 40°C in the month of February and for rest of the months from beginning of March to end

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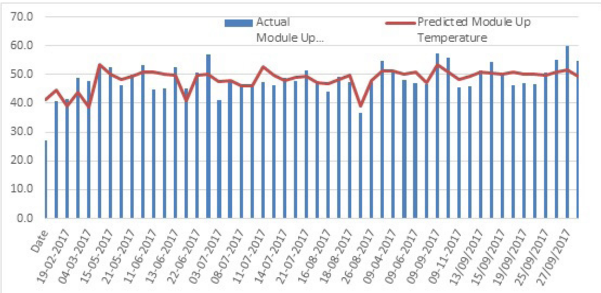
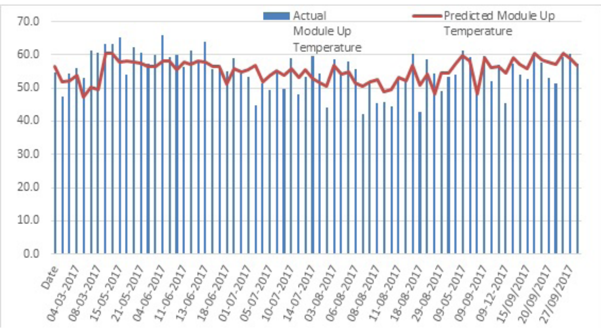
of September it was found to be average temperature lying between 40 to 50°C. These are the months when sun is located between the equator & tropic of cancer.

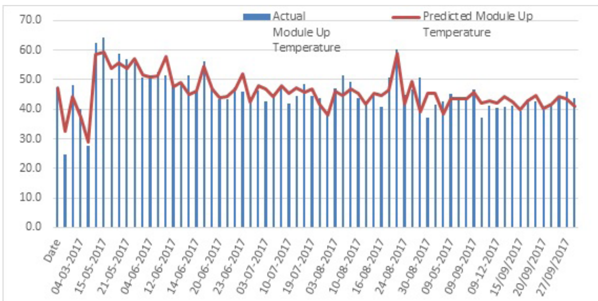
Whereas Figure 4(b) shows that at 12:30 PM the average temperature is lying between 50 to 60°C. The rise in temp is indicative of ground reflected radiation which results into rise in module temperature. Figure 4(c) sows that at 3:00PM temperature of the module is below 50°C or lying between 40 to 50°C except in the month of April, May & partially in June. The probable reason for this is that these are the hottest month at this latitude and ambient air which got heated during the first half of the day retains its temperature for longer duration.



(a)



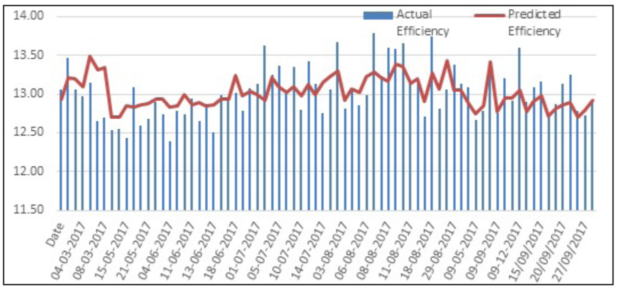
(b)



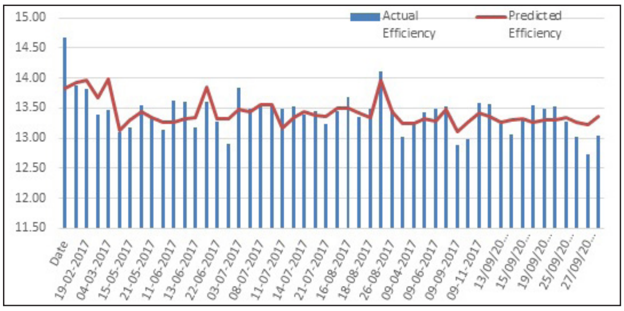
(c)

Figure 4(a-c).Plot between Module Temperatures at Particular Day of The Month

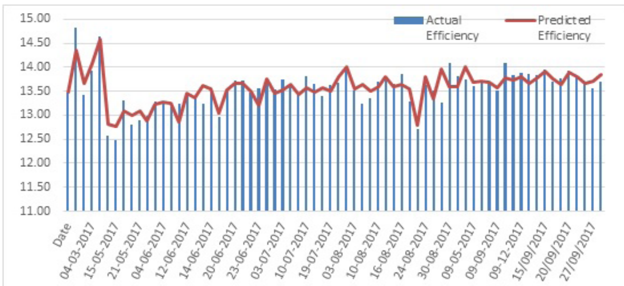
Figure 5, (a-c) show the plot of efficiency (actual & predicted) at different time of the day and year. It is evident from the plots that the output energy and conversion efficiency of SPV modules are affected by operating temperature. The plot in Figure 5(a) reveal that at low module temperature efficiency is high, however at 10:00AM the efficiency of the modules is lying between 13-13.5% whereas at 3:00PM it is lying above 13.5% except for the months; April, May & June, during these months the module temperature remains high. The probable reason for this high efficiency at 3:00PM is the availability of the higher solar radiation. By Clavadetscher and Nordman found that SPV modules had 1.7 to 5 % output decrease with an 8°C temperature expends over 20°C.[20] In another study, 12.7% efficiency decreases at surface temperature of 22°C (71°F) to 9 % conversion efficiency at surface temperature of 60°C.[21]



(a)



(b)



(c)

Figure 5(a-c).Predicted Efficiency & Actual Efficiency of the PV Cell/ Module

Concluding Remarks

Some study shows that the by cooling the PV Modules the temperature and stored heat inside the PV cells during operation can be reduced & in the industry, it becomes a common knowledge that PV modules efficiency can be improved by reducing the operating temperature. In the present study, a standard statistical equation was developed to correlate the actual and predicted values of temperature and efficiency of the PV module/cell all the leading weather parameters taking in consideration like solar radiation (SR), wind speed (WS), Relative Humidity (RH) and Ambient

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Temperature (AT), the performance of polycrystalline silicon modules have been studied. The obtained values of correlation coefficient and graphs developed thereof shows a good correlation with dependent and independent variable; and concluded that this developed standard statistical equation can be used to predicted temperature and efficiency of the modules merely knowing the weather parameters of the region.

References

1. Bandyopadhyay B, Gupta MK, Vashistha RD. Solar radiation assessment over India" in Ä Solar future for India, edited By G M Pillai, *World Institute of Solar Energy* 2011, ISBN:81-902925-2-8:349-363.
2. Goswami DY. Global energy system and solar energy. in Ä Solar future for India, edited By G M Pillai, *World Institute of Solar Energy* 2011, ISBN:81-902925-2-8:1-16.
3. Sundaray S, Mann L, Bhattacharjee U et al. Reaching the sun withrooftop solar. New Delhi: TERI; 2014.
4. Bhargava B.," Photovoltaic Technology in India: A historical perspective" in A Solar future for India, edited By G M Pillai, World Institute of Solar Energy 2011, ISBN:81-902925-2-8:364-383.
5. The UN Environment (UNEP). Global Trends in Renewable Energy Investment report 2016.
6. MNRE (Ministry of New and Renewable Energy). Commissioning Status of Grid Connected Solar Power Projects. [http://mnre.gov.in/file-manager/UserFiles/grid-connected-solar-power-project-installedcapacity], 2015a.
7. Al-Khazzar A. Behavior of four Solar PV modules with temperature variation. *International journal of renewable energy research* 2016; 6(3).
8. Berwal AK, Kumari N, Kaur I et al. Investigating the Effect of Spectral Variations on the Performance of Monocrystalline, Polycrystalline and Amorphous Silicon Solar Cells.*Journal of Alternate Energy Sources and Technologies*, ISSN: 2230-7982, 2016; 7(3): 28-36.
9. Meyer EL. Assessing the Reliability and Degradation of Photovoltaic Module Performance Parameters. *IEEE Transactions on Reliability* 2004; 53(1): 83-92. doi:10.1109/TR.2004.824831.
10. Berwal AK, kumar S, Kumari N et al. Design and analysis of rooftop grid tied 50 kW capacity Solar Photovoltaic (SPV) power plant. *Renewable and Sustainable Energy Reviews* 2017; 77: 1288-1299.doi.org/10.1016/j.rser.2017.03.017
11. Kadyan H, Berwal AK. Design of a 12 kWp grid connected roof top solar photovoltaic power plant on school building in the Rohtak District of Haryana. *International Journal of Applied Engineering Research*, 2018; 13(13) : 11354-11361, ISSN 0973-4562.
12. Green MA, Emery K, Hishikawa Y et al. Solar cell efficiency tables (Version 45). Progress in photovoltaics: research and applications, 2015; 23(1): 1-9. 10. DOI: 10.1002/pip.2573
13. https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.20191105.pdf, "Best Research-Cell Efficiency Chart – NREL", 2015.
14. Deb D, Brahmbhatt NL. Review of Yield Increase of Solar Panels Through Soiling Prevention, and a Proposed Water-free Automated Cleaning Solution. *Renewable and Sustainable Energy Reviews*, 2017; 82(P3): 3306-3313, DOI: 10.1016/j.rser.2017.10.014.
15. Goossens D, Offer Z, Zangvil A. Wind tunnel experiments and field investigations of eolian dust deposition on photovoltaic solar collectors, *Solar Energy* 1993(50): 75-84.
16. Aguado E. Effect of advected pollutants on solar radiation attenuation: Mojave Desert, California, Atmospheric Environment. Part B. *Urban Atmosphere.* 1990;24: 153-157.
17. Ibrahim A. Effect of Shadow and Dust on the Performance of Silicon Solar Cell. *Journal of Basic and Applied Sciences Research,* ISSN 2090-424X, 2011; 1(3): 222-230.
18. Elminir HK, Ghitas AE, El-Hussainy F et al. Optimum Solar Flat-plate Collector Slope: Case Study for Helwan, Egypt. *Energy Conversion & Management,* 2006; 47(5): 624-637.
19. Ibrahim A. LBIC Measurements Scan as a Diagnostic Tool for Silicon Solar Cell. *Journal of Applied Sciences Research,* ISSN 2090-424X,, 2011; 1(3): 215-221.
20. Nagengast A. Energy Performance Impacts from Competing Low-slope Roofing Choices and Photovoltaic Technologies. Carnegie Mellon University, 2013. Dissertations (Paper 192).
21. Meral ME, Dinçer F. A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems. *Renewable and Sustainable Energy Reviews* 2011; 15(5): 2176-2184.
22. Chattariya Sirisamphanwong, Nipon Ketjoy,Chatchai Sirisamphanwong. The effect of average photon energy and module temperature on performance of photovoltaic module under Thailand's climate condition", 11th Eco-Energy and Materials Science and Engineering (11th EMSES), doi: 10.1016/j.egypro.2014.07.168.
23. Alshayeb M, Chang JD. Photovoltaic Energy Variations Due to Roofing Choice. International Conference on Sustainable Design, Engineering and Construction (2016), doi: 10.1016/j.proeng.2016.04.143
24. Mohamed H, Chang JD, Alshayeb M. Effectiveness of High Reflective Roofs in Minimizing EnergyConsumption in Residential Buildings in Iraq. Procedia Engineering, 2015; 118: 879-885.
25. Gartland L. Heat islands: understanding and mitigating heat in urban areas. 2010: Routledge publication, ISBN-10:1849712980 and ISBN-13:978-1849712989.

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