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Effect of Ambient Temperature and Relative Humidity on Solar PV System Performance: A Case Study of Quaid-e-Azam Solar Park, Pakistan

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Abstract: This study synthesizes the output performance of solar PV system under variable conditions. Solar PV output depends upon the weather conditions which varies with time. This research has been carried out by observing the effects of the ambient temperature and the relative humidity, since for module efficiency of solar PV panel heavily depends upon the on these parameters. The primary data has been collected at different intervals of time at Quaid-e-Azam Solar Park located at Bahawalpur, Punjab, Pakistan. The statistical analysis has been carried out for correlation coefficient (R) for ambient temperature and relative humidity as 83% and 64% respectively, considering a confidence level of 90%. It is concluded that there exists a positive linear relationship of module efficiency with ambient temperature, whereas, an ordinary positive linear relationship with relative humidity. This conclusion provides an insight to the solar PV designers and the manufacturers in order to select appropriate modules for the selected areas in accordance with solar irradiation, humidity, and temperature level.

Keywords: Photovoltaic, Polycrystalline, Solar cell, Semiconductor, Power Efficiency, SPSS software, multiple regression models.

1. INTRODUCTION

Pakistan is facing a severe energy crisis,resulted in economic deceleration over the last decade (Valasai *et. al.*, 2017, Shakeel, 2015).Energy is the foundation for the economic development in the modern world. Subsequently, it becomes essential to have a continuous supply of energy to its consumers. The demand of primary energy in Pakistan has increased from 33 Million Tonnes of Oil Equivalent (MTOE) to 68 MTOE. Electricity is the secondary form of energy, widely used and the major sources to generate electricity are oil, natural gas and renewable energy resources. The government of Pakistan has initiated developing the coal power plants to meet the increasing demand of electricity. The installed generation capacity in the country is about 23,759 MW with a share of thermal 67%, hydel 29% and nuclear 3% (HDIP, 2015).

The increasing gap between the supply and demand of electricity is increasing due to a huge share of thermal power generation, which requires expensive and imported fossil fuel supply (Mirjat *et al.* 2017). On the other hand, the efficiency of thermal power plants is also decreasing against designated efficiency, due to ageing. According to NEPRA in 2014, the efficiency of thermal power plants has reduced by24-32%, i.e. more than 60% of input fuel is being gone into the atmosphere as waste heat.

2. ENERGY CRISIS SOLUTIONS

To deal with the electricity supply-demand gap, the following areas may be focused on:

- Energy savings by improving conversion efficiency, such as heat recovery processes in power plants.
- Reducing use of thermal power plant energy to boost up the economy and keep clean environment by replacing with solar PV module.
- Conserving energy through Demand Side
- Replacing existing energy sources with alternatives, like renewable.

Regarding solar energy utilization, Pakistan is one of the luckiest places in the world where the average sunshine hours on ahorizontal plane per year is around 1700-2200, and the range of average solar radiation is approximately 2000 kWh/m^2/year, whereas, at 30 degrees' slope facing south is measured as 2400 kWh/m^2 per year (PSC, 2016, Harijan *et al.* 2015). Besides the huge potential of solar PV and favourable irradiation, the efficiency and performance could further be improved by changing the ambient temperature around PV module (Fesharaki, *et al.* 2011). Solar modules work best in certain weather conditions, but due to constant changes in weather, the efficiency of PV modules will be reduced to the maximum extent, so that they do not work in normal operating conditions. The

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performance of a PV system depends not only upon its fundamental characteristics but also on environmental parameters such as ambient temperature (Siddiqui, and Bajpai, 2012). The performance of PV modules is influenced by the environmental parameters such as ambient temperature and relative humidity. The performance of the solar module differs from the actual location and the essential environmental conditions to which they are designedfor. The PV output performance varies with specific atmospheric properties. Since the intensity of solar irradiation is changing at every instant, it is evident that electricity generation by the solar cells will also be changing. It has been noted that the power failure by the PV systems is still a typical weather-related issue (Gxasheka, *et al.* 2005)

Meteorological data such as solar radiation, relative humidity, and atmospheric temperature are reliable and widely accepted to measure the potential of solar energy. Researchers have considered several types of modules and arrays studied with different climates of different survey areas. The ambient temperature and relative humidity have been analysed for the current study. The specification given by the manufacturer does not give the accurate results for analysing the performance of the PV systems. According to the authors' knowledge, this study is first of its kind in the southern subtropical region of Pakistan. The PV system under study is installedon the premises of individual beneficiaries of rural and urban areas of Bahawalpur, Punjab by the government. PV installations are usually affected by the temperature, soiling, and so forth. However, the working of solar panels depends on the ambient variables also. (Midtgard *et.al* 2010) analysed the climate of Norway and experimented to analyse the performance of three different types of solar panels (monocrystalline, polycrystalline and amorphous silicon PV modules). They found that temperature effect on monocrystalline was moderate as compared to other PV modules (i.e. polycrystalline and amorphous silicon PV modules) and the average output, as well as the module efficiency of monocrystalline,was consideredbetter. (Mohammed *et al.* 2012) studied the accumulation of dust particles over the surface of 4 modules of polycrystalline and it resulted adecreasein efficiency of PVmodule to 50%. The decrease in efficiency was due to dust accumulation, water vapours on the modules, which caused wastage of the sunlight through refraction, diffraction, and reflection.Therated standard test conditions (global insolation 1000 W/m^2, PVmodule temperature of 25ºC and air mass ratio 1.5) based values are provided by the manufacturers, but in actual operating conditions these values may not be equal to the measured values due to variations in environmental parameters. (Tanima *et al.,* 2012) researched Tripura, India, where a single crystal silicon solar module was placed in different positions against the direction of the wind. He examined that there was an extreme effect ofwind speed on the performance of that crystal silicon module. At the same time, they noticed that the performance of that module was also disturbed by the change in ambient temperature. They focused on the difference between the efficiency of the PV module with temperature and wind speed. It was found that the temperature has the opposite impact on efficiency.

(Guenounou *et al.* 2012-2013) investigated the comparative performance of photovoltaic panels made of different technologies for exposing in the coastal areas of Mediterranean Sea in Algeria. The rated parameters of PV modules given by the manufacturer were based on standard test conditions (global irradiance of 1,000 W/m², module temperature of 25°C and air mass 1.5).

The values of these parameters may not in line with the measurement in actual operating conditions due to varying environmental factors.

(Olusegun *et al.* 2016) shown that the average temperature distribution throughout the year in hot climate region is 28±1ºC, while the relative humidity in the morning is about 80%. The efficiency of the modules decreases with the increase of module temperature. They investigated the performance of the PV module affected by the ambient temperature, relative humidity, and dust. A direct proportionality was found between ambient temperature and solar photovoltaic module efficiency.

3. SOLAR POWER POTENTIALIN PAKISTAN

Global average radiation falls to a horizontal surface in Pakistan is about 200-250 watts/m^2 in a day of about 1,700-2,200 hours' sunshine per year. The south-western province of Pakistan, Baluchistan, is rich in solar energy. It has an average global sunshine of 19-20 MJ/m^{2}per day (1.93-2.03 MWh/m^2 per year) with an average annual sunshine of 8-8.5h (Olusegun *et al.*1980).

4. SCOPE OF PV SYSTEM IN PAKISTAN

The government of Pakistan had set up around 18 solar PV stations, under Rural Electrification Programmed, in the remote rural areas in 1987-88. The installed capacity of PV system was nearly about 440kW, but these systems were no longer in operation after a few years of their deployment due to lack of adequate operation and maintenance (MNRE, The Government of India, 2012).However, over last 20 years, the field of alternative energy resources utilisation has witnessed improvement. Pakistan Council for Renewable Energy Technologies (PCRET) in collaboration with Alternative Energy Development

Board (AEDB) initiated the development and sustainability of solar PV in 2001-03.Unfortunately, the progress has not been satisfying due to inadequate financial assistance and non-availability of technical workforce.

National Electric Power Regularity Authority (NEPRA) has started a program of open-tariff for solar power plants. The stakeholders were invited to contribute and support the national grid. The first power station of 100 MW on solar PV wasinstalled by the Tebian Electric Apparatus, a subsidiary of Xinjiang Sun Oasis, at Quaid-e-Azam Solar Park, Bahawalpur in Punjab province. It started operation in May 2015. The planned capacity of this power station is 1000MW, remaining 900 MW capacity is to be installed by the Zonergy under China-Pakistan Economic Corridor (CPEC) Project. The other proposed solar power stations in Pakistan are shown in **(Table 1).**

Table 1: Renewable power generation plans in Pakistan

Power Station	Installed Capacity (MW)	Status
Thatta power plant	150	Proposed
Solar power plant	200	Proposed
Solar power plant	100	Proposed

The ratio of social acceptance of PV system in Pakistan as compared to its neighbouringcountries is precisely small. Pakistan lacks behind the neighbouring countries regarding the solar PV system based electricity generation. India has added annually 1100MW of power obtained from solar PV system to its energy production (Honghua, *et al.*, 2012) and similarly, China was producing about 3.2GW of power from renewable energy resources in 2012 as well Sanusi, *et al.*, 2014)

4. METHODOLOGY AND MATERIAL

An outdoor measurement system was installed at Quaid-e-Azam Solar Parkat Bahawalpur, Punjab. The PV modules were placed in different rows on the ground facing to ward the south-east. Each string from four lacs (400,000) panels consisted of twenty (20) modules in series at a fixed angle of 28ºC with horizontal. The modules specifications and measured values are encapsulated in **(Table 2 and Table 3).**

The secondary data for the year (2016), used for this study, is available at QASP Bahawalpur site area. The analysis has been done for twelve months to cover the seasonal effects.The adjustments of all equipment were handed over to the Pakistan Metrological Department at the beginning of work. The solar radiation monitoring system having a pyrometer was used to measure the solar irradiance in the form of energy (kWh) with the PV module. The solar irradiance was recorded after each hour. The characteristic parameters of PV modules were obtained from I-V curve, drawn by using variable resistance and multi-meters at QASP site area. After achieving all data for each day, the related performance parameters are calculated using the equations:

Solar irradiance

$$\text{Irradiance (W/m}^2\text{)} = \text{irradiance (kWh)}*1000/\text{hours} \quad (1)$$

Maximum power

$$P_{max} = V_{max} * I_{max} \quad (2)$$

PV module efficiency

$$\eta_{max} = (P\ max) / (S.I*A) * 100 \quad (3)$$

Table 2: Modules specifications and measured values

Specification	p-Si
Modules Dimensions	
Modules dimensions (L×W×H) (mm)	1650×991×40
Cell dimensions [mm×mm]	156×156
No. of cells in series	6×10
Total cells area (m^2)	1.460
Rated Values at STC	
Maximum power, P_{max} [W]	255
Maximum module efficiency [%]	15.59
Maximum current, I_{max} [Amp]	8.42
Maximum voltage, V_{max} [V]	30.29
Maximum power, P_{max} [W]	255
Maximum module efficiency [%]	15.59

Using all these parameters the efficiency is obtainedon a daily basis. All these calculations are further analysed on MS Excel evaluated to get final monthly efficiency to analyse the impact of temperature on efficiency using multiple regression analysis.

Table 3: Modules measured values

Measured values	
Avg. Ambient temp. [ºC]	25.786
Avg. Module voltage [V]	22.496
Avg. Module current [Amp]	3.88
Avg. Module power [W]	87.28
Avg. Module efficiency [%]	10.22

5. RESULTS AND DISCUSSION

During this study, the sunny days resulted in an average daily solar irradiance above 700W/m^2.The solar radiation increases linearly until noon and is lower in the evening. The maximum average solar irradiance was measured between 12:00 pm to 1:00 p.m. Similarly, the maximum average solar irradiance was measured in May, June, and July. The monthly average solar irradiance in summer was higher than January. The average solar irradiance for January, June, and July are respectively shown in **(Fig. 1).**

It can be concluded that the output power and efficiency of the PV module were higher during April, May, June, July, August and September compared to the other months of the year 2016. This is associated air occurred during the period, was caused by the high radiation intensity, and in turn, increased the temperature of the environment and reduced the relative humidity. Thisresulted in increased power generation and efficiency of the system. It further confirms that the output is determined by PV system efficiency, which in turn depends on the high solar radiation, high ambient temperatures and low relative humidity.

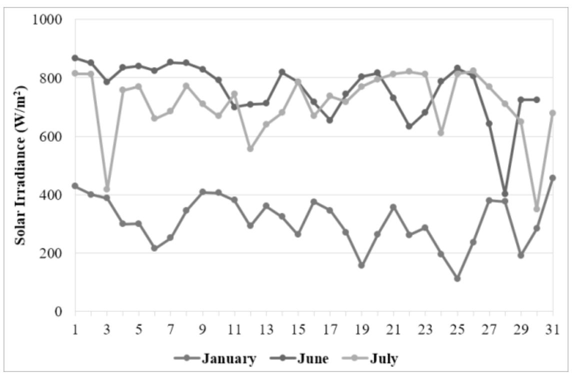

Fig.1: Monthly average solar irradiances of summer months

As the low efficiency recorded during the month of January-February, March, November, December and October related to under-current generated by the system because of low solar radiation, low temperatures and high relative humidity recorded. Thisis caused due to cloudcovering and rain and the presence of certain suspended particles in the atmosphere during the study period.

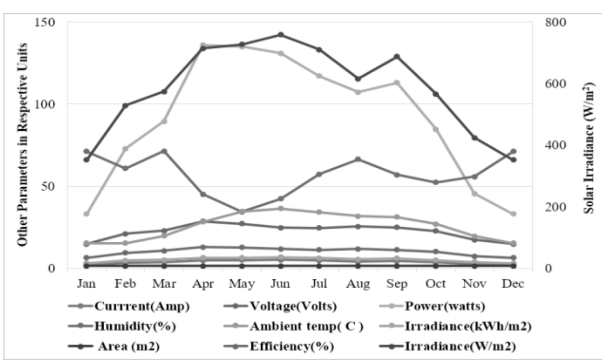

Fig. 2: Average monthly variations of electrical and Atmospheric parameters

(Fig. 2). shows average monthly variations in environmental parameters, and the **(Fig. 3)** shows average daily variations in electrical and atmospheric parameters for July. Higher solar irradiance in July and it decreases the relative humidity and increases ambient temperature that also decreases the power out of PV module.

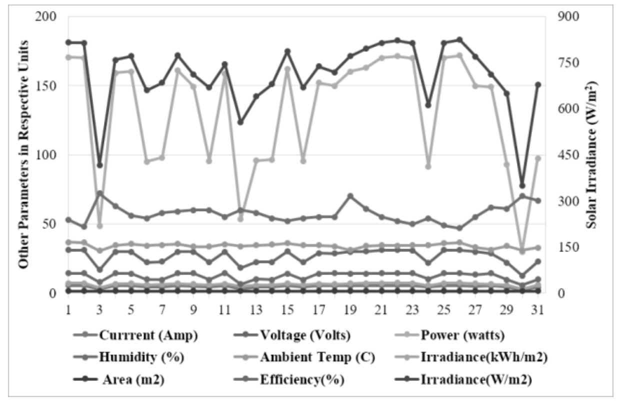

Fig. 3: Average daily variation in electrical and atmospheric parameters

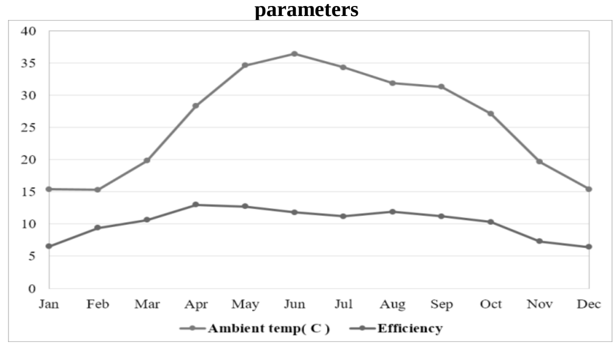

Fig. 4: Variations in monthly average values of environment ambient temperature and efficiency for the period from January 2016 to December 2016

(Fig. 4) shows the difference in the monthly average PV efficiency at ambient temperature for the study period. The chart shows that temperature and efficiency are related to one another. **(Table 4)** describes the variation of efficiency with ambient temperature and humidity.

Table 4: Variation of efficiency with ambient temperature and humidity for period of January 2016 to December 2016

Month	Humidity (%)	Ambient temp (ºC)	Efficiency (%)
Jan	71.258	15.387	**6.45**
Feb	60.793	15.325	**9.43**
Mar	71.378	19.806	**10.67**
Apr	45.2	28.333	**13.03**
May	34.483	34.622	**12.71**
Jun	42.433	36.4	**11.82**
Jul	57.387	34.303	**11.29**
Aug	66.451	31.854	**11.92**
Sep	56.933	31.266	**11.25**
Oct	52.387	27.103	**10.25**
Nov	55.966	19.65	**7.34**
Dec	71.258	15.387	**6.45**

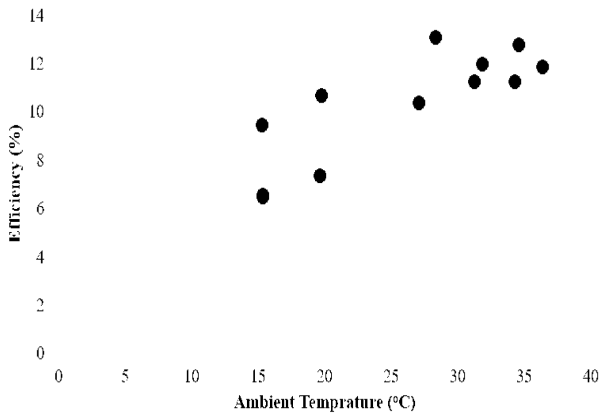

Fig. 5: Monthly average values of solar module efficiency and ambient temperature for the period from January 2016 to December 2016

Considering the temperature, statistical analysis found that the correlation coefficient (R) as 0.827, showing a vigorous, positive correlation between room temperature and efficiency. Regression equation obtained:

$$Y = 4.173 + 0.235 * X \qquad (4)$$

Where, X represents the independent variable for temperature, and Y shows the dependent variable for the efficiency of the solar power module. Again, the value of the determination coefficient (R^2) is 0.684, which indicates that 68.4% of the total variation in *Y* can be explained by the linear relationship between X and Y (as described by the regression equation). In other words, the regression line goes through almost all points that imply that there is a direct proportionality between the two variables. The **(Fig. 5)** shows the monthly changes in efficiency of PV modules compared to ambient temperature for the period of study.

Similarly, **(Fig. 6)**shows monthly changes in the efficiency of PV modules compared to relative humidity for the period of study. The linear regression equation provides results using multiple regression method on IBM SPSS 21 software. The model summary gives values of correlation coefficient (R) and coefficient of determination (R^2).

Considering the relative humidity, the coefficient of correlation (R) as 0.641, an ordinary positive correlation between relative humidity and efficiency. The regression equation obtained:

$$Y = 17.287 + 0.124 * X \qquad (5)$$

Where X indicates the relative humidity of the independent variable and Y represents the efficiency of the solar module dependent variable. In this case, the determination coefficient (R^2) comes 41.1%, which explains an ordinary linear positive relationship between the efficiency of the module and relative humidity, as 58.9% of the total variation in Y is unexplained. Different linear and nonlinear equations have been developed to include PV performance regarding electricity production at operating temperature. Sadok *et al.* Perform statistical analyses that show favourable conditions for the conversion of solar energy into electricity have been shown (Sadok, and Mehdaoui, 2008) However, in the recent study, statistical analysis is done in the concept of correlation concerning the confidence level of 90% for two different parameters, respectively ambient temperature and relative humidity.Also since Bahawalpur is a subtropical region where the ambient temperature largely changes in different seasons.

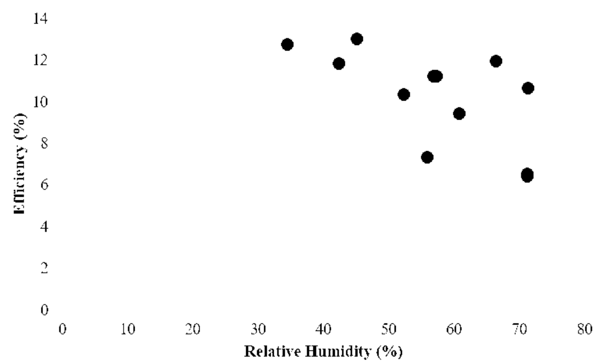

Fig. 6: Monthly average values of solar module efficiency and relative humidity for the period from January 2016 to December 2016

6. CONCLUSION

Under this study, the influence of temperature and relative humidity has been investigated to ensure the performance of a PV module. It has been observed that the correlation between efficiency and temperature is higher in comparison with the correlation between efficiency and relative humidity. The temperature correlation with the efficiency of the PV system is very strong and has a direct relationship with each other which indicates that the temperature plays a vital role in the performance. It is concluded that ambient temperature may be preferred to predict the performance of the PV module in relation to the relative humidity for the study area. When power plants are installed in different rural areas of the country, it is observed that, although the modules are faced to the south, the power generated does not reach the desired level. This may be due to the modules manufactured in standard testing conditions. Therefore, the divergence of the standard terms and condition influences the power generation and when designing green buildings, these environmental parameters should be considered instead of considering only the orientation of the photovoltaic modules.

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