Comparative Analysis of Poly and Mono c-Si Solar PV Modules subjected to Shading and Spectral Variations

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Summary
Photovoltaic power generation replacing the fossil fueled power plants got height of interest for electrical power generation. Poly c-Si module and mono c-Si modules of solar PV technology are extensively used for solar PV generation. The two c-Si modules exhibit dissimilar and multipart performances when these are subjected to shadow and spectral bands of incidents lights. The experimental work is carried out to figure the performances of both types solar PV modules under parallel cells and series cells shading, also to investigate the effect of specific wavelengths of light and their combined effect on performance of both mono and poly c-Si outputs. Voc of mono c-Si module under complete 72 parallel cells shading gave 18.54 volts just lower the poly gave at 28 cells shading. For series cells shading, poly exhibited more Voc than mono but its current capacity was lesser than mono c-Si module under same number of cells shading. Exposing poly c-Si module to 495-575nm wavelength of light produced 34.53watts much lesser than mono c-Si module yielded with same band. Power output of poly and mono c-Si modules found highest with 575-780nm wavelength band but mono c-Si exhibited greater wattage than poly c-Si module. Mono c-Si module exhibited overall better wattage than poly c-Si under both series and parallel cells shading and also even in all color filters in visible band.

Key words:
Poly C-Si, Mono C-Si, Shading, Spectral Bands.

1. Introduction

The sustainability of modern economics depends on renewable energy production. Practically, basic needs and welfare of human like health care, education, sustainability, employment and agriculture centralizes at generation of power. The success ratio or economic stability of a nation can be evaluated in reflection to availability of energy resources. In the same time it is expected that three big continents upper America, Europe and Pacific Asia has 10, 57 and 40 years of reserves of fossil fuels. [1]

Renewable energy technologies unlike conventional energy resources are augmenting rapidly throughout the world. As per the REN21 statement, the 10% of global needs of energy in 2012 was fulfilled by renewable energy resources and their stake is likely to be enhanced at 15% by 2040. Global wind energy council states that the investment on annual basis in renewable technologies has elevated to 30% from 2004 to 2011. [2] Referring [3] researchers emphasize the solar and wind energy as robust, plenty and proficient among other renewables. Most of the countries switch to renewables from fossil fueled plants, in an article only Asia and china has fitted about 142 and 115 Giga watts wind energy. [4]

In a study it is highlighted that solar energy is significant margin of global energy demand offering 700*1012 MWh to earth. [5] Further solar power generation is the best solution to remote areas' electrical energy needs where grid supply does not exist. [6] In order to coup the demand in pollution free manner the investors are making notable contributions in commercializing renewable energy technologies at pretty wider scale. When it comes to renewable energy technologies two most important source are wind and solar. Solar energy is obtained from radiations of the sun. Photovoltaic cells generate electricity in translation to the light of sun. Solar energy has gained its attention at global level and is expanding with a faster rate. As per EPIA, solar photovoltaic has grown to 28% over the last decade, which has never been obtained previously. [7]

Despite of having huge potential and multiple advantages there are certain issues that limit the solar energy as a source of power generation. One of the focused issues is low power output even at peak hours of sunny day. The power output of a solar PV could be limited due to inappropriate position of a solar panel. Sometimes a tree or an obstacle limits the power output of a panel up to large extent. [8] In a work the study of power output against shadowing using parallel and series configuration was analyzed using MATLAB. It was concluded that the power output declined due to the shadowing conditions, furthermore the drop in power output was dependent on the way the cells are connected [9]. One study reveals reconfiguration analysis of PV arrays employing partial shading using MATLAB as a simulation tool. It was

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determined that the power output decreased due to partial shading and also generated several peaks. The bypass diodes contributed in reduction of peaks and Number place algorithm helped to elevate the output power, ultimately diminishing the effect of partial shading. [10] In tropical area, fluctuations in power output in response to effect of shading due to clouds were investigated. In experimental setup 16 panels, PV system having series connection was analyzed under various conditions like over cast, cloudy hours and clean sky. In addition a comparative analysis was carried out between thin film PV arrays and Poly c-Si PV arrays in terms of power deviation. It was found that the Poly c-Si PV arrays show huge power deviation than thin film arrays. [11] Oriel class AAA solar simulator was used to experimentally validate the MATLAB Simulink model. Black papers were kept on desired solar cells to shade. It was resulted that shading only 25% to 35% can reduce power output by 28% to 40%. [12] In a piece of study, Simulink model of PV array helped in comparative analysis between series parallel connected and total cross tied PV module under various operating conditions. Additionally, different shading patterns were compared like column, row and randomly stepped. It was observed that parallel series configuration fits row wise pattern as cells connection gets reduced, total cross tied fits for column wise pattern and step wise pattern improves efficiency and power output of a PV panel [13]. Experimental based work was conducted to examine the performance of PV system upon partial shading of cells. The study was carried on 90 watt photo voltaic model with both fixed and variable irradiance. In order to find the influence of solar irradiance at certain point, the shading was gradually increased from 0 to 80 percent. On fixed irradiation of 0.6 kilo watts/meter square and 25 percent shading, impact factor was found to be 1.25 and with 75 percent shading, impact factor declined to 0.86. The results show that, for every 100 watts per meter square increment in irradiation, the output power increased up to 3.890, 3.370, 2.270 and 2.020 watts at 0, 25.0, 50.0 and 75.0 percent shading respectively. The efficiency gain was found to be 0.290, 0.270, 0.250 and 0.220 percent at 0, 25.0, 50.0 and 75.0 percent shading respectively. Furthermore, a drop of 12.410 watts and 2.30 percent efficiency is observed for every 10% shaded area. Hence partial shading leaves a negative mark on PV system efficiency and power output. In one study, comparative analysis of different models of diodes has been established. The considered parameters were open circuit voltage, short circuit current, maximum delivered power and fill factor. The Simulink model was used as analysis tool. It was concluded that the suitable diode model is selected for various applications and shading criterion. [14] In another study, mono c-Si solar PV was analyzed under partial shading conditions. Upon shading to just 10 percent, the power production declined 12.41watts and efficiency by 2.3%. It was reported that shading 80 percent, Voc and Isc declined 3.29 V and 2.08A respectively. [15] In a piece of literature the performance of a solar panel is considered in terms of changing wavelength and color filters. The experimental results from case study of energy Centre at MANIT Bhopal (India) concluded that the performance of a solar panel is significantly dependent on wavelength of the incident light. In addition, red colored coverings resulted in augmented power output comparatively with other colors. [16] Solar PV's low efficiency was reasoned to utilize small portion of sunlight falling on PV surface. Sunlight available to solar PV is visible and infrared portions excluded ultra violet region which was rectified by ozone layer. In this study the optimal wavelength from radiations of the sun was analyzed. It was observed that the maximum output was traced at natural spectrum against other colors due to intensity loss from color filters. The elevated photon absorption and output power was obtained better with purple color because of being characterized by shorter wavelength 400nm. However the performance was found to decrease with neely color. [17] The impact of shifting of solar spectra was analyzed on poly c-Si PV panel performance. It has been shown that blue in visible range enhances the short-circuit current rather heating the panel as infrared did. [18] In an experimental work mono c-Si solar PV was taken to assess the effect of seven color filters (red, yellow, orange, green, blue and white-light). It was resulted that red color filter yielded more than rest excluding white-light. [19] In another study poly c-Si and CIGS thin film solar modules are examined by simulating passing clouds as shading on PV systems in tropic regions of Singapore. The study elaborated that poly c-Si power variations are ranging as 2.84%, 4.49% and 6.71% in response to overcast, clear and cloudy weather conditions respectively. The same was seen for CIGS thin film as 1.69%, 4.19% and 5.61%. [20] A comparative analysis was modeled in MATLAB to examine the performance of three different solar PV technologies poly c-Si, mono c-Si and amorphous-Si under effects of temperature and sun radiation. They concluded mono c-Si as the best among the others used. [21] The research was recently done to compare the power losses of mono c-Si, poly c-Si and CIS thin film PV modules due to partial shading in three cities of Cameroon. In Yagoua city, at 25 percent shading all the types showed same power losses, at 50%, mono c-Si and thin film gave same losses but lower than poly c-Si. In Tchollire city with one-fourth shading, the poly c-Si showed trivial move in results than mono c-Si and thin film, but half-sized shade, results of CIS and mono c-Si found higher than poly c-Si. In Tibati city with 25%, thin film made scarcer loss, whereas at half, poly c-Si and mono c-Si dropped same wattage but lesser than CIS. With null shade poly c-Si found better than others in Yagoua and

Tchollire cities while mono c-Si in Tibati city. Complete shading resulted same wattage outages for all three types in all three cities. [22]

In the previous research work the comparative studies were carried out in terms of shading of series and parallel cells of a solar PV module, also comparative analysis for power output and efficiency in response to spectral variations for a crystalline module. There should an extensive comparative analysis of poly and mono crystalline modules be done to see the effects of series, parallel cells shading, spectral response to single colour filter and combination of two different colour filters. In this research work, the main theme is to analyze the impact of shadow on series connected cells and parallel connected cells of mono and poly c-Si modules. Also the experimental study focuses the effect of four different wavelengths and combination of two wavelengths of incident solar spectrum on power output of poly c-Si and mono c-Si solar PV modules. The study could help the solar panel industry and investors to maximize profit even at same capital cost keeping in view few mentioned considerations. Furthermore concerns towards renewable energy resources are increased which ultimately result in pollution free environment.

2. Methodology

2.1 Instruments and Facilities Used

The setup consists of two solar PV modules-mono and poly-crystalline of same wattage, data logger, AC/DC power analyzer module, multi-meter. Black colored thick sheets were used for obstruction on desired cells for shading. The colors considered were Blue, yellow, green and red for simulating wavelengths. AC/DC power analyzer was used for DC voltage, current and power measurement. The analyzer can measure DC voltage above 200 volts and current up to 20 Amperes. To carry out the experiments in boundary of data sheets of solar PV modules, the data logger was used to measure light intensity and temperature of the panel. Its temperature measuring range is from -16 degree centigrade to +95 degree centigrade. The table 1 shows the data sheet of solar PV module.

Table 1: Data Sheets of Solar PV Modules

Poly Crystalline	SYM 90P	Mono Crystalline YJ 90	
Pmax	90 Watts	Pmax	90 Watts
Vpmax	18.37 Volts	Vpmax	18.0 Volts
Ipmax	4.90 Amps	Ipmax	5.0 Amps
Voc	22.05 Volts	Voc	21.12 Volts
Isc	5.15 Amps	Isc	5.30 Amps
Max. System Voltage	1000 Volts	Max. System Voltage	1000 Volts
STC	E=1000 W/m2 Tc=250c	STC	E=1000 W/m2 Tc=250c

2.2 Strategy for Shading Effect Analysis

The black paper sheets were pasted on the surface of the specific number of cells to shadow them, while other cells are exposed to sun. Series connected cells and parallel connected cells were shadowed separately and with help of AC/DC power analyzer electrical quantities were measured. This exercise was done for both the types of modules i.e. poly crystalline and mono crystalline.

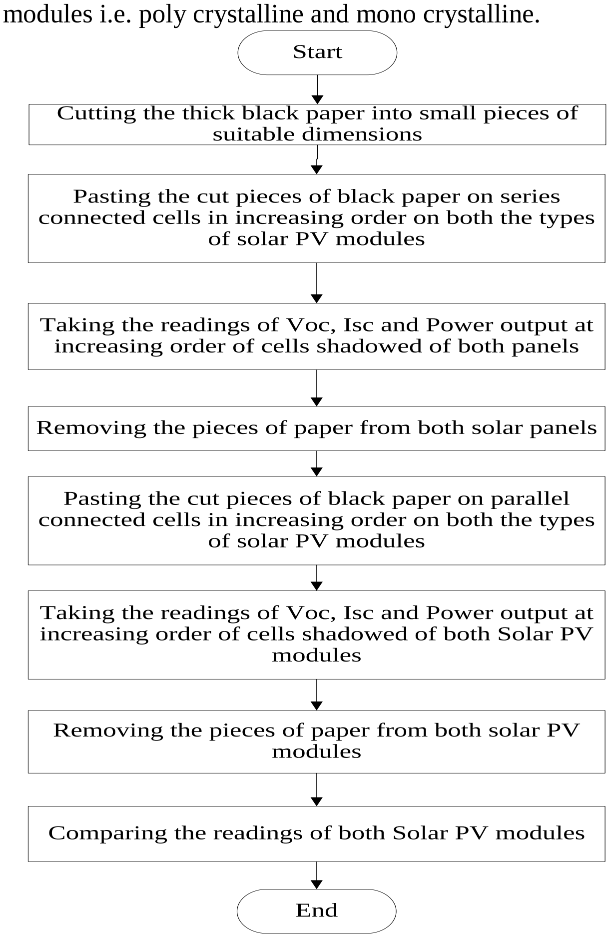

Fig. 1 Flow chart for shading analysis

2.3 Strategy for Color Effect Analysis

Poly Crystalline and Mono Crystalline PV modules were set in a way that they can be tilted to sun. Four colored cellophanes; blue, yellow, red and green were pasted on solar PV panel individually. In the next attempt two different cellophanes were used on Poly Crystalline and Mono Crystalline PV modules. The power analysis, open circuit voltage Voc and short circuit current Isc were recorded to trace the maximum power point

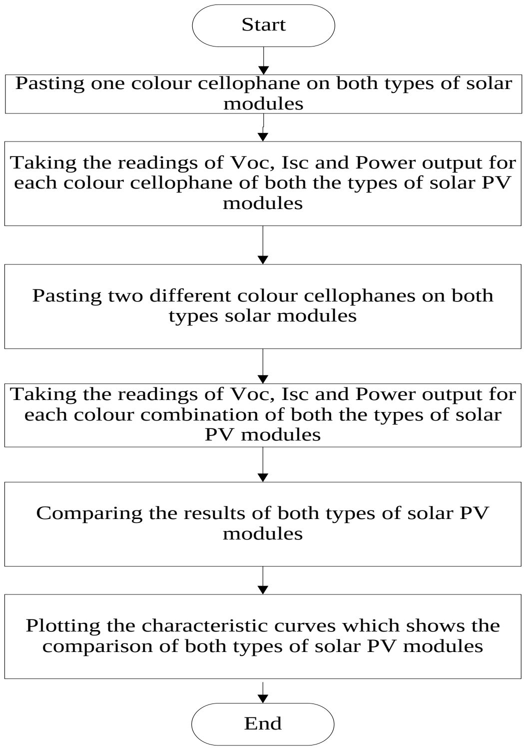

Fig. 2 Flow chart for color effect analysis

2.4 Data Acquisition

The Poly Crystalline and Mono Crystalline PV modules were fixed to an optimum tilt to face full sun. Current probe of AC/DC power analyzer was connected in series with the PV module whereas voltage probe was connected in parallel. The results were taken by varying the shadow on numbers of cells connected in series and parallel step wise. Cellophanes were used to absorb other wavelengths of visible band and exposing the solar PV modules to a specific spectrum of wavelength of their color.

3. Results and Discussion

The power outputs of the series-parallel shading of the cells were initially obtained from poly and mono crystalline modules. It was found that the mono crystalline modules have better performance when subjected to shading in series-parallel combination. In addition, the results of power output at different color filters were also obtained from the experimental setup. It was found that the yellow color yield maximum power output. Upon combination of two colors, best results were obtained in red-yellow combination irrespective of the type of module. The details of the results are discussed below:

3.1 Parallel cells Shading Response

In case of shading, output voltage and current of the solar PV module severely decreases. But it also depends on pattern of shadow of PV cells. In Figure 1, comparative results of parallel cells shadowing between poly and mono crystalline PV module is shown. The peak power output of 58.94 watts and 59.07 watts was observed when poly crystalline and mono crystalline modules were shaded 20 percent. It has been observed that up to 14 cells shadowing, the drop in open circuit voltage Voc and power output P are almost same in both Poly Crystalline and Mono Crystalline PV modules. When shadow exceeds 14 numbers of cells, the power output for mono crystalline cells is enhanced in comparison to poly crystalline cells. When shadow is subjected to 28 numbers of cells, mono crystalline gives 57.2 watts of power whereas poly crystalline has 41.3 watts. Upon shadowing 72 parallel cells poly and mono crystalline achieves power output of 35.6 and 37.3 watts respectively. Hence it is clear from the figure 3 that mono crystalline shows improved results comparatively even at shadowing conditions.

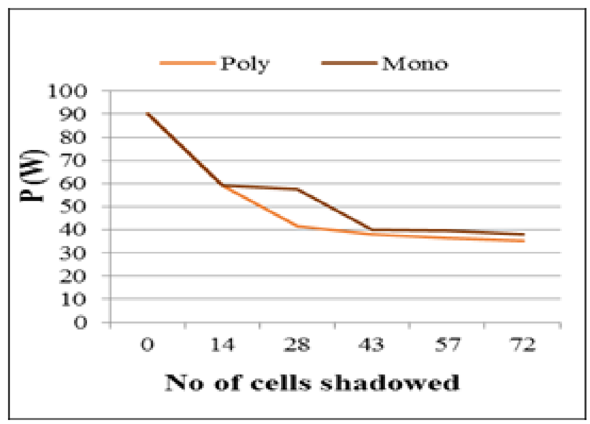

Fig. 3 Comparative power outputs of poly crystalline and mono crystalline PV panels under parallel cells shadowing

3.2 Series Cells Shading Response

When analysis of series cells shading is carried out, both poly and mono crystalline modules shows poor power output. The Shading of 4 serially connected cells produces power output of 4.76 watts in mono crystalline module while 2.04 watts were produced in poly crystalline module. In Figure 2, power comparison of poly and mono crystalline modules are shown. It is clear from figure 4 that power output is better for mono crystalline module when series cells are subjected to shading The cells connected in series under shadowing condition is analogous to a piece of load in the series circuit

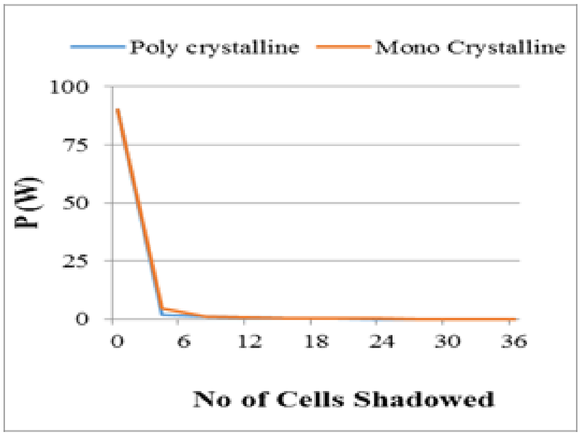

Fig. 4 Comparative result of power outputs of poly crystalline and mono crystalline under series cells shadowing

3.3 Series Cells Shading Response

The experiments were carried out by pasting one plain color cellophanes firstly and two different colors cellophanes secondly on pc-Si and mc-Si modules. Results of short circuit current open circuit voltage and power output were extracted.

3.3.1 One Plain Color

A comparative analysis of voltage and current between poly and mono crystalline PV panel has been shown in table 2.

Table 2: one color cellophane

Color Filter	Poly crystalline		Mono crystalline	
	Voc (V)	Isc(A)	Voc(V)	Isc(A)
Yellow	18.46	3.34	18.57	3.36
Red	18.35	2.95	18.53	3.32
Green	18.27	2.32	18.33	2.80
Blue	18.39	2.67	18.47	3.30

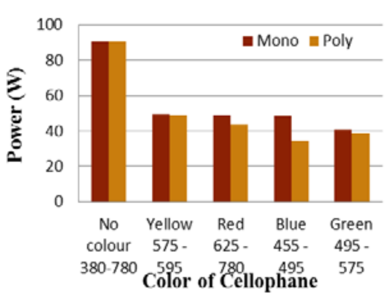

Fig. 5 Power comparison using one color cellophane

3.3.2 Two Color Filters

The Voc and Isc of poly and mono c-Si modules when combined with two different color filters are shown in Table 3. The combination of filters was pasted with fifty-fifty ratio on the cross section of modules. The peak power output of 41 watts and 49.44 watts was noticed when yellow- red grouping is taken for poly c-Si and mono c-Si module respectively. The color filters combined power comparison of both the type c-Si modules is presented in figure 6.

Table 3: voc and Isc of poly and mono c-Si modules

Color Combination	Poly crystalline		Mono crystalline	
	Voc (V)	Isc(A)	Voc(V)	Isc(A)
Yellow + Blue	18.55	2.58	18.61	3.46
Red + Blue	18.53	2.58	18.68	3.24
Blue + Green	18.39	2.78	18.36	2.77
Red + Yellow	18.61	2.77	18.70	3.55
Green + Red	18.40	2.25	18.56	2.76

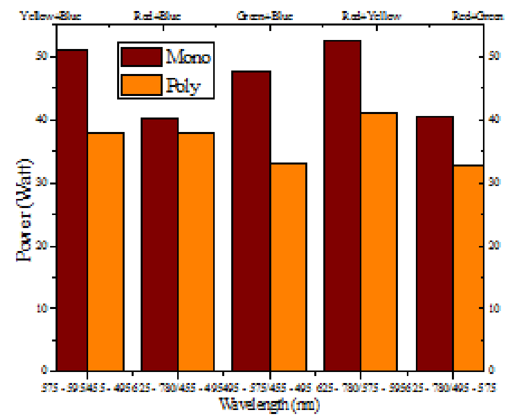

Fig. 6 color filters combined power comparison of both the type c-Si modules

4. Conclusion

Shading severely hits performance of solar PV modules of both types. Though it is concluded that number of cells and type of their connection shaded is the matter of analysis. Mono crystalline solar PV module has somehow better response than poly crystalline in term of series and parallel cells shadowing. Solar spectrum in its natural band has better performance than any specific wavelength in solar PV power generation. Exposing mono c-Si module to 575-595nm wavelength provides highest power than all other wavelengths incident to poly c-Si module. Mono c-Si module yielded 58.41% of rated power whereas poly yielded only 45.54% with exposure to same band of two wavelength ranging 575-595+625-780nm.

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