Effect of Solar Irradiance on Different Solar PV Module Technologies for Maximum Efficiency Extraction

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Abstract— **The future demand of clean energy which is increasing globally, In order to meet the demand, solar energy is playing a critical role. The goal of 500 GW by 2030 shows that solar resources can meet this demand. The PV module and inverter are the solar PV system's brains. The Irradiance is the main source to the power for PV based plant. The irradiance is one of the most significant elements affecting the efficiency for the solar based PV system. The variance in output efficiency of technologies using the same wattages is caused by changes in the solar radiation (direct and diffuse components). This study is being conducted in light of the efficiency differences between the various technologies in relation to irradiance for a particular instant. The entire investigation is being conducted at formerly it was SEC and now NISE Gurgaon, on a test bed with (NOCT) nominal operating cell temperature. This NOCT is one qualified tests that IEC-61215 specifies. The required output is filtered, a process is used to create the desired output, and the outcome is displayed in the proper graph shape and stated as efficiency with respect to solar radiation (direct and diffuse components) . In this study, two identically powered monocrystalline (M-SI) and multicrystalline (mc-Si) technology modules efficiency are compared with respect to the solar radiation availability for south-facing sloped surfaces at Gurgaon location and best efficient technologies is suggested for the composite zone of Delhi-National Capital Region (NCR). The (ECBC) Energy Conservation Building Code representing India specifies five different climate zones.**

in the cold, hot, dry, warm, and temperate climate zones of Srinagar, Delhi, Jodhpur, Mumbai, and Bangalore.

Keywords—solar radiation, module Efficiency, Multi and Mono Crystalline Module, NOCT

I. INTRODUCTION

The solar energy is free, clean, and abundant in many nations, converting it into electricity is a technique that has a lot of potential. The government of Indian is recently pushing more highlighting on environmental examining and set ambitious renewable energy targets for the next ten years. Under the direction of Honourable Prime Minister Mr. Narendra Modi, the Indian government has established a short-term objective of 175 GW of renewable power generation by 2022, comprising 100 GW via solar, 60 GW via wind, 10 GW via bio waste, and 5 GW via hydropower [1]. By 2030, the country wants to have 450 GW of green clean energy [2]. It is advisable to utilize a combination of push rules, pull mechanisms, and focused activities to further advancement in renewable energy technology. A few of the measures to increase the productivity through research and development (R&D) include tax advantages, sensible regulatory requirements, and technology developments [3]. A few of the good options for clean energy and environmental conservation that will ensure that clean energy resource centers are utilized in a timely and profitable custom include sensible regulatory guidelines, tax breaks, and initiatives to boost productivity through research and development (R&D) [3]. The article describes the scientific and economical efforts [4], strategy and monitoring framework, and educational training [5,6] that the government has put in place to encourage the growth and development of clean energy resources. The result is the demand for positions for technicians, contractors, and skilled labourers is taken into consideration. The result of the solar industry's growth and expansion increased demand for solar PV projects. The over-all applicability of solar PV modules at a specific location is determined using the 5 key components of solar PV modules: solar distribution, insulation, PV module efficiency with irradiance, yearly outdoor temperature, and dist ribution of solar spectrum.

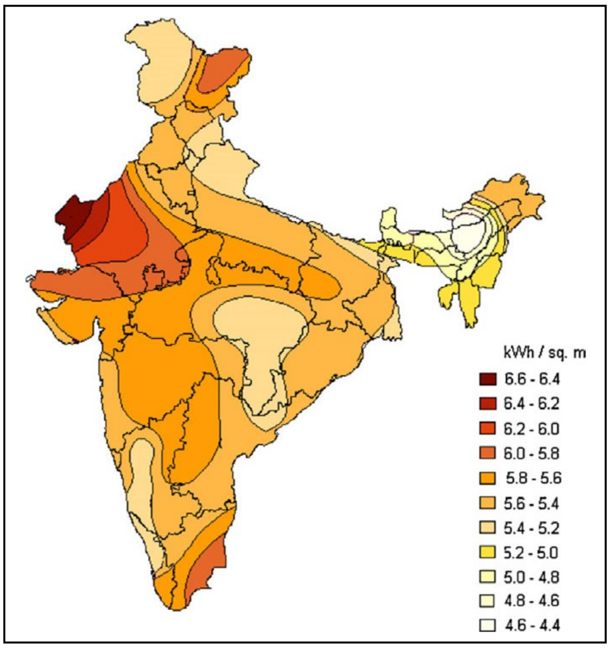

Fig.1. *solar insolation India map, Source [7]*

Standard Test Conditions (STC), which are fabricated in laboratories and don't match measurements of the modules outside performance. India is exposed to a large amount of solar radiation all year long. [9] and [10] both state that the average solar radiation which received is about two hundred MW/km2, with 250-300 fine sky days per year.

The figure showing the northeastern region is having the to much loss of the solar irradiance hence the thin film modules can be preferred for a generation. However, because of its enormous landmass, the intensity of solar energy varies widely, with the north-eastern portions receiving the least solar radiation and the western regions receiving the highest (Figure 1). In India, the average amount of solar energy received year is thought to be around 5000 trillion kWh [11]. Numerous solar-based applications can make use of this solar radiation potential [12,13]. The mainly prevalent examples that include solar purification, solar collector thermal, solar-operated cycles [14-17], Photovoltaic (PV) cells, daylighting, and heating for buildings. Increasing the quantity of usable power which can be collected from the received solar irradiation is thus a problem for scientists who are in the field of clean energy. Given that performance is correlated with the quantity of solar irradiation occurrence on a outside, it is thought that accurate set-up these PV solar designs can significantly alter performance. The performance of the aforementioned devices is mostly influenced by the climatology of irradiation, focus, tilt-viewpoint, and azimuth tilts in a particular environmental area. These modules are very less affected by solar irradiation that can be converted to electricity. The balance of the irradiation is converted to heat, which overheats the photovoltaic (PV) module and reduces its efficiency19], hence it makes the most important for the efficient utilization of the solar radiation (direct and diffuse components) to prevent the overheating of the PV modules the same may cause the loss in Efficiency and Generation Power too.

II. MATERIAL AND SYSTEM ARRANGEMENT

A. Test site city annual irradiance

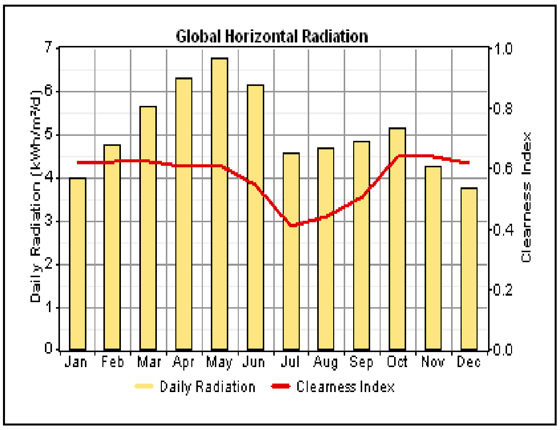

Fig.2. *Average monthly Irradiance of Delhi, source [8]*

At various locations across the country, the Indian Meteorological Department (IMD) gathers data regarding radiation from the sun along with other variables. IMD normally keeps records of statistics on the distributed solar radiation along a horizontal axis for the entire earth. The solar irradiation graphical data for New Delhi is shown in Figure 2 together with the clarity index of the solar radiation (at the lat. and long. are 28°36'N and 77°12'E, correspondingly). This shows the may month is the peak of the radiation achieved

B. Solar PV Module Specification

The first most important task is selection of PV module's of different technologies (Multi and Mono) because they are more commercialized and the testing is carried out at PV Test Facility-PVTF at indoor and NOCT at outdoor testbed at NISE, Gurgaon. This study the effect of solar radiation (direct and diffuse) on two solar PV modules of separate technology and of identical watt arrangement as listed in Table No- I. The design mentioned hereunder is same as cited at reverse of the modules by the maker. Though, the ambient temperature and solar radiation (direct and diffuse) data of outdoor placements is only measured for this study because the study is wholly based on the conclusion of solar radiation (direct and diffuse) on Solar PV module efficiency.

TABLE I. PV MODULE SPECIFICATION FOR BOTH TECHNOLOGIES

Technology	**Multi Crystalline-Si**	**Mono Crystalline-Si**
Make	HBLPOWER SYSTEM LTD	R.E.I.L. Solar
Product Sr. No.	2011-75185	200952888
P_{max}	75 W	76 W

C. Information Gathering Procedure

The selected solar PV modules is tested under the STC conditions of IEC- 61215. The performed test under STC conditions comes out with the outcome as revealed in Table No.-II. Further, these results are undertaken for solar radiation (direct and diffuse) effect to study on both types of technology

PV module (Multi and Mono). After the successful performance in the indoor test lab and get the pass criteria, then modules are moved to outdoor NOCT testbed. In Fig. 3 clearly shows the placement of both modules at NOCT standard test bed setup for data recording the effect of solar radiation on different technology solar PV module of equal watt. The information collected with a single minute difference in the outside temperature, solar PV module temperature, and wind (speed along with the direction). Pyranometer instantaneous values (horizontal and slanted). The information gathered is filtered to meet the needs of the investigation.

TABLE II. INDOOR TEST RESULTS AT STC

Technology	Crystalline-Si Multi	Crystalline-Si Mono
P_{max}	76.6 W	76.5 W
PV Cell Efficiency [%]	15.3 %	14.4 %
STC Test Result	Pass	Pass
Solar Module Efficiency [%]	14.3 %	14.7 %

Fig.3. Placement of both Technology models at *NOCT Test Bed Setup*

D. NOCT Test bed placement and Procedure

The pre-prepared test bed setup is arranged of NOCT as per IEC 17025. The free space rack is placed to stand the test modules along with the pyranometer in the stated mode as shown in Figure 3 and 4.

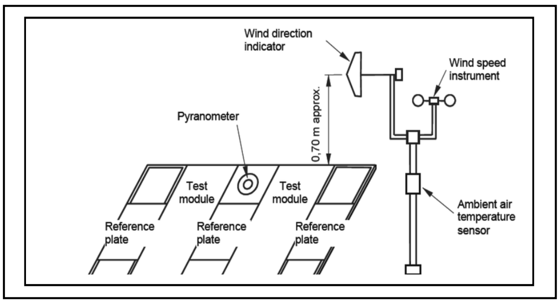

Fig.4 *The setup-diagram of NOCT Test bed, Source [19].*

The modules-placed test rack is to be twisted at 45° of ± 5° at the horizontally from the front side the same is faced toward equator. The mounting of the tilted pyranometer in the plane of the module and within 0.3m form the test array [19]. Anemometer is used to assess the speed of wind which is down to 0.25 ms−1 along with wind direction, the same is installed approx 0.7 m on the top of module and 1.2 m from the east or west. The outdoor temperature instrument is placed with a time constant that is equal or less than the module, which is installed inside the covered enclosure and ventilation is provided near the wind measuring device. The measurement of the module temperature the sensors are attached at the back end of the both modules one at the center and another at the corner of the module. The NOCT is the equilibrium mean temperature of the solar cell junction inside an open rack mounted module in the following standard reference environment (SRE), i.e. 45° tilt from the horizontal, Electrical load is zero (open circuit), wind speed is one metre per second. 800 W/m2 of total irradiance and a 20 °C ambient temperature. The collected data is filtered as per the above means of NOCT and processed as per methodology to conclude the findings.

III. METHODOLOGY

The data collected of NOCT test best by data measuring is designed for consideration the findings of of radiation effect on the multi and mono crystalline PV modules, the captured data is categorized and refer to follow the set procedure as detailed beneath. For one minute, the collected data includes immediate pyranometer measurements (both of which horizontal and inclined tilted), the outside temperature, module temperature, the speed of the wind, and direction of the wind. The specification of data log instrument and collection equipment are listed in detail beneath in Table number III and Figure no. 5 shows the NOCT testbed arrangement with data plotting unit placed at the outside NOCT test bed is illustrated.

TABLE III. TESTBED NOCT DETAILED SPECIFICATION

Component	Total Number	Type	Specification
Data logger	1	NI CRio	
Anemometer	1	Young 015103V	Wind speed-0 to 100m/s,Direction-360[a], 355[b].
pyranometer	2(Tilted and Horizontal)	8101 DAN	Spectral Range 0.3 to 33μm72 element thermopile.
Thermocouples	4 (Two for each Multi and Mono)	K-Type	

The ambient temperature is the temperature at the outside, the module placed on the test setup are named as module 1 and module 2, wherein the record of the junction temperatures of module 1 of multicrystalline (mc-Si) technology and module 2 of monocrystalline (M-SI) technology.

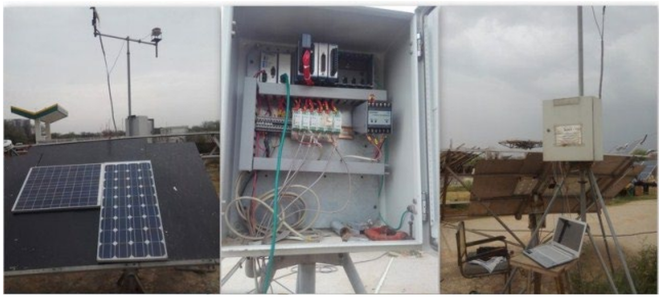

Fig.5. *NOCT setup with data logging and test specified module placed*

The data collected from the pyranometer placed horizontal, which provides the global data of irradiance (GHI), the pyranometer which is tilted provides the data of tilted angle 45^o at which the module is mounted as per Fig. 4 of IEC-61215 of the junction and wind speed is the velocity of the wind. The whole collected data is applied as per the procedure followed below.

A. Detailed Procedure followed

The earlier researches produce out many equations over the performance of irradiance and the temp. with respect to the proficiency of PV module which can be obtained by operating primary equations.

$$P_{max} = I_m V_m = (F.F.)\, I_{sc} V_{oc} \quad (1)$$

Eqn. (1) nomenclature as

i) F.F. is fill factor or squareness measure of module,
ii) I_{sc} - short ckt. current,
iii) $P_m = V_m I_m$ refer the max. power point of the solar PV module voltage and current curve.
iv) V_{oc} open ckt voltage, and

Once the F.F. and V_{oc} decrease substantially with temperature and during low irradiation too. (The thermally excited electrons begins to take over the electrical property of the semiconductor), while I_{sc} increases, only very marginally [18]. Thus, this effect take to form the linear relation in the form of

$$\eta_c = \eta_{Tref}\,[1-\beta_{ref}(T_c-T_{ref}) + \gamma \log_{10} I(t)] \quad (2)$$

The above equation "(2)," η_{Tref} is referred as module electrical effectiveness at solar irradiation of 1000 W/m^2 and source temperature T_{ref} of 25°C which is calculated at indoor PVTF lab at STC. The coefficient of temp is (β_{ref}) and the solar irradiation coefficient (γ) which is mainly the material property that it has value of about 0.12 and 0.004 K^{-1}, respectively for crystalline PV silicon solar modules [19]. Latter, however, it is more likely taken as "0" [20], and "(2)," which represents as and more lowers to "(3)," .

$$\eta_c = \eta_{Tref}\,[1-\beta_{ref}(T_c-T_{ref})] \quad (3)$$

This eqn. "(3)," represents linear expression of PV electrical effectiveness [21]. The practical quantities of module efficiency η_{Tref} which can be taken from the value of STC data. The definite value of temperature constant depends not only on solar module PV material but also on T_{ref} too. The same can be given by the ratio.

$$\beta_{ref} = \frac{1}{T_o - T_{ref}} \quad (4)$$

In the equation "(4)," which T_o is the (the highest point) measured temperature when a PV module's efficiency is zero [22]. This optimal temperature is 270 °C for solar cells made of crystalline silicon [23].

B. The followed Procedure of Operation on transformed data

The data of high accuracy is captured and projected on the process applied, as primarily to equation "(4)," equation the β_{ref} is to be calculated, T_o and T_{ref} as mentioned to taken as the module STC temperature of 25^0C. Hence next step is after collected data is applied to "(3)," equation as in T_c is the module cell temperature at the junction of multi and monocrystalline technologies and η_{Tref} this efficiency is at STC the same can be considered from Table No.- II, then η_c is replaced with the efficiency of PV module (η_m).

The aforementioned method is applied to both the temperature difference effects of various technological advancements in relation to ambient temperature. Equation (3) establishes the relationship between a cell's or module's efficiency with regard to temperature and the radiation impact. As a result, this process will have a predetermined outcome because the results will be displayed as graphs afterwards..

IV. Result and Discussion

The Four alternate days data was taken for the preparation of the final result and suggestion of the better technologies to their adoptions. The May month data was taken due to peak of radiation is found in the same month as per the Fig.2. The Applied procedure on filtered data, produces out the results in the form of the plots for the detailed discussion and result.

The representation of the data for the day 1 in under the Fig.6. Represents the efficiency of both modules to as 75 Watt, with respect to comparison of tilted radiation only not the global radiation , as the module placement is also tilted at an angle of 45^0 at which the module is mounted of different technologies.

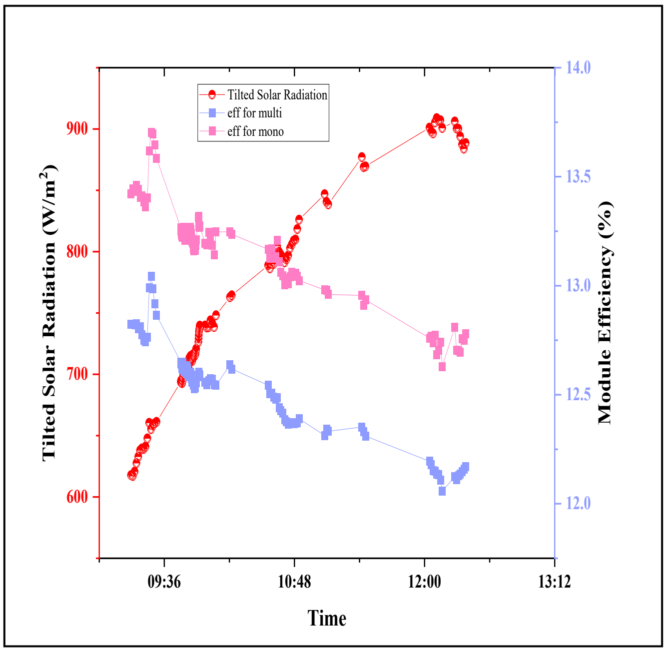

Fig.6. *The graphical plot of Radiation Vs Efficiency for day 1 outdoor performance*

The data was taken for the period of the 09:17 AM to 12:22 PM, which shows the peak of the radiation achieved on the day is at 12:06:44 Hrs. of 908.86 W/m2 the resultant efficiency achieved is of 12.13 % for Multi and 12.68 % for Mono is achieved.

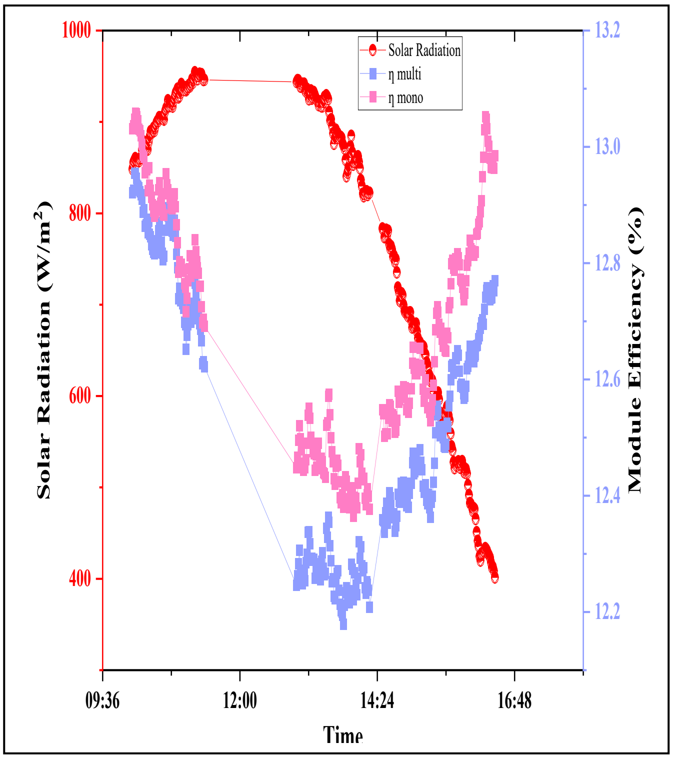

Fig.7. *The graphical plot of Radiation Vs Efficiency for day 2 outdoor performance*

The representation of the data for the day 2 is plotted as Fig.7. The data seems to be mission for a short period of time is because the day is rainy day, the point to be noticed the fall in radiation does not affect the efficiency of the module too much, the graph is plotted for the period of between 10:07 AM to 16:27 PM the peak achieved is during the time of 11:12 AM with the radiation of 954.27 W/m2 and the efficiency achived if of 12.76% for Multi and 12.84 % for Monocrystalline PV modules, During the point of the peak radiation the efficiency of the both modules does not make any difference on rainy day the temperature would be also.

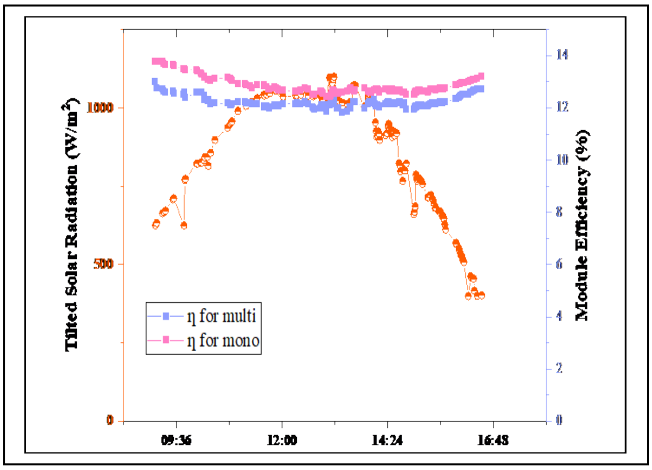

Fig.8. *The graphical plot of Radiation Vs Efficiency for day 3 outdoor performance*

The representation of the data for the day 3 is plotted as Fig.7. The data seems to be very good the graphical illustration as plotted for the period of time between 09:06 AM to 16:32 PM. The peak radiation archives at 13:10:43 Hrs. of radiation 1100.29 W/m2 and efficiency of 12.27 % for Multi and 12.64 % for Mono crystalline can be seem from the obtained data, the irradiation also keeps a certain linearity at 650 W/m2 for majority of time.

V. Discussion on Outcome/Conclusion

The study of result graphs, comes to a conclusion the monocrystalline is one of the most effective technology at high radiation in comparison to multicrystalline solar PV technology the talk for output efficiency, though at the low radiation both mono and multi crystalline have the approximate same efficiency, but the mono seems to slightly at higher side. Hence at the project site test place at Delhi-NCR the monocrystalline solar PV module is most suitable and outperformed as the results, shows the low effect of low radiation on multicrystalline efficiency. This study on different types of modules of same wattages produces the results which provide output the most useful information to the plants installation in capacity of megawatts because they need to meet the guaranteed generation clause to avoid the penelties form time to time.

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