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Efficient Utilization of Different Solar PV Module Technologies for Maximum Power Extraction

Bharat Dubey*, Seema Agrawal**, Ashok Kumar Sharma**

*PhD Scholar
**Faculty
Department of Electrical Engineering, Rajasthan Technical University, Rawatbhata Road, Kota – 324010
(bharatdubey8888@gmail.com, seema10dec@gmail.com,aksharma_eck@hotmail.com,)

Abstract—*The huge demand of Energy is continuously increasing globally this enhances the utilization of available system resources efficiently. The Solar Energy is playing a very vital role in fulfilling the need, the set target of 500 GW by 2030 proves this demand to be fulfilled by the Solar resources. The heart of the Solar PV system is PV module and the inverter. The integration of the system as per the requirement is the most imperative part which directly influences the power generation of the PV solar plants. One of the most critical factors effecting the Solar PV system efficiencyis Temperatureof solar panels. The variance in output efficiency of technologies using the same wattages is caused by temperature change. For this variance in efficiency among the different numbers of available technologies with respect to ambient temp and module temperature for a specific instant is considered to perform this study. The SEC later known as the National Institute of Solar Energy (NISE), in Gurgaon, is where entire study is performed out on a test bed of nominal operating cell temperature (NOCT). The output via data logger from the NOCT test bedis opted for choosing the best technologies in the various regions of hot and cold climateswhen considering the impact of temperature into account.One of the requiredtest of IEC no 61215 is NOCT. The required output isfiltered and procedure is implemented to produce the result which is presented in appropriate graph form and is expressed in circumstances of efficiency with regard to temperature.Th e presented study compares two modules of the same wattages and differenct technologies monocrystalline (M-SI) and multicrystalline (mc-Si) that we use here to perform the test. Thisanalysisconcludes withultimate finding indicates that monocrystalline is more efficient than multicrystalline at a particular ambient temperature of the test site.As a result, monocrystalline technology is more productive then multicrystalline. As a result, we can speculate that multicrystalline technologies tend to be better suited for high-altitude places like the Himalayas, the Andes, etc., while monocrystalline technologies are more suitable for particular locations of Delhi-NCR. The entire study gives us the mainly helpful information for a PVplant's megawatt systems, in accordance with the technologies mentioned for a particular region to deliver the highestyield to the utilities.*

Keywords—NOCT, PV cell Temperature, High altitudes , Low altitudes, Solar Plant Efficiency, Multi and Mono Crystalline Module

I. INTRODUCTION

India will need a reliable source of energy that is more than twice as much as what it already uses to meet its fast-growing economy's energy demands. Utilizing energy from various renewable technologies Solar PV plants is one of the best solutions to fulfil the growing demand. The primary energy consumption of India today comes from renewable sources to the tune of about 38%. A nation's economic prosperity depends greatly on its energy division. The energy division in India is varied, utilizing both conventional sources of energyl like coal, oil, naturally gas, and hydropower as well as unconventional ones like solar, wind, and biowaste. Over the past few years, there has been a noticeable increase in the demand for electricity, and future growth is also anticipated.The state and central government keeps expanding capacity nationwide in an effort to provide electrical energy to eachresident of the nation. TheIndia consumes 162 kW hours of power per person, placing it third place around the world behind China and the UAE in terms of core energy utilization [1]. A requirement for a nation's economic development is the provision of increasing energy [2] too. The Nation energy Plan [NEP] of the MoP has created a 10-year comprehensive action plan with the intent of delivering energy throughout the nation[3]. It has also created a second plan to get moreconfident that power is prearranged to each citizen seconomically and affordably. Moreover one third of the world greenhouse gas emissions are caused by the three fuels that are used to produce electricity: coal, oil, and natural gas hence by providing cleaner and more dependable electricity, it is essential to raising people's standards of living [4].The Indian government has recently placed more emphasis on monitoring the environment and set ambitious renewable energy goals for the coming ten years. The government of India announced a short-term goal of 175 GW of clean energy capacity by 2022, with 100 GW sourced from solar, 60 GW through wind, 10 GW through biowaste, and 5 GW through hydropower[5]. The nation has a term goal of 450 GW from renewable energy sources by 2030 [6].A mix of push regulations, pull mechanisms and targeted initiatives should be used to push the expansion of clean and green renewable energy technology. Technology advancements sensible governing guidelines, tax breaks, and initiatives to boost productivity through Research and Development [7] a few of the good options for clean energy and environmental conservation that willpromises that renewable clean energy resource bases are utilized in a timely and profitable manner. The demand of positions for technicians, contractors, and skilled laborers are consequently considered, the article describes the scientific and economical efforts [8] policy and governing framework, as well as teaching and informativedeleveringprograms [9, 10] that the government has put in place to promote the growth and development of renewable clean energy bases.The outcome for the increase and expansion of the solar sector raised the demand for the solar PV projects. The five main factor of solar PV module are solar distribution, insulation, PV module efficiency with the intensity, ambient annual temperature, and distribution of solar spectrum are used to determine the general applicability of PV modules for a certain site. Standard Test Conditions (STC), which are artificially created in laboratories and which do not correspond to measurements of the outdoor performance of the modules.For the years 2009 and 2010, data from completed 24,000 SolarPVsetup installed at different places in Central of Europe were collected. In order to deliver adequate high-quality data was routinely tested and then it was modified at STC to compare empirical findings on the performance ofSolarPVelements at indoors.Data on the temperature and plant configuration was utilised to carry out this alterationsi.e. Efficiency of the inverter [11]Temperature and efficiency are key factors in this transition. This method is achievedto the actual ground working temperature PV module kinds under the real-world circumstances. The outdoor effect turn to proper study attest bed of NOCT. The cooling of PV module leads toraise in voltage and power output, this fact also points the influence of temperature.An effective cool down technique, however, is advantageous if the extra expenses remain less than the accumulated profit [12].This is why a passive coo-ling measureestablished on phase change of materials underwent an economic analysis of energy. At the same irradiance, data of two solar module that were each outfitted with a temperature-delicate materials were measured. A related study examines how the spot energy market changes depending on the time at the day, with more PV power being delivered in the forenoon because of the cooling impact [13].The Hawaii Natural Energy Institute (HNEI) points out that this is particularly interesting for electrical networks because PV plants already have a significant volume of uncooled air in them. The University at Hawaii has begun a PV test project that offers excellent quality of data to quantify module and array performance under varied geographical environmental situations. In this case,local impact of temperature is taken into account.When designing PV power plants, the estimated energy yield is calculated using the component performance. It's very much significant to calculate yield as accurately as possible. PV module efficiency muchoften stated at the STC. However, these circumstances only meets in test or research laboratory [12].At a specific site in Tripura, India, throughout the years of 2012–2013, Researchers have examined the effects of wind speed and temperature on the efficiency of monocrystalline silicon solar PV modules. Thestudywork beenperformed out due monitoring the differencein the module efficiency with wind speed and temperature. According to statistical analysis, the coorelating number between ambient-temperature and wind speed is of 96% for the former and 68% for the latter. [14].The temperaturewilleffectthe flow of power through an electric circuit's by altering the speed at which the electron travels [15]. The findings indicate that there a significant positive but linear correlation between modules efficiency and ambient-temperature andcomparatively weak positive but linear correlation between modulesproductivity and wind speed. Hence this study investigates the relationship between ambient-temperature and solar PV module productivity [14]. Investigations have shown that temperature causes a drop in performance ratio too with latitude. The cold temperatures at high-altitude locations, such as Antarctica, Andes, and the southern Himalayan region, have much higher performance ratios. PV crystalline modules thoseare very less sensitive to temperature should be used in areas with high temperatures, while PV modules more sensitive to temperature will perform better in areas with low temperatures.The geographic distribution of PV solar power potential is examined, taking into perspective how the performance of PV systems is impacted by ambient-temperature [16]. The above discussion states that the process of photovoltaic conversion is significantly influenced by ambient temperature. As a result, a PV module's power output is linearly related to operating temperature and cell temperature (Tc). To assess the entire losses caused by temperature impacts, PV crystalline solar system designers must evaluate the temperature at whichthe wholesystem would be operating in the field. In order to fulfill this purpose the International Electrotechnical Commission (IEC)

Standards for the qualification testing of modules that fact out at NOCT should be preferred as a suitable parameter. Since the NOCT examinations are referred to as quasi-fixed conditions, it is always necessary to provide an accurate and thorough explanation of the data because it can be challenging to interpret some clause standards precisely [17].

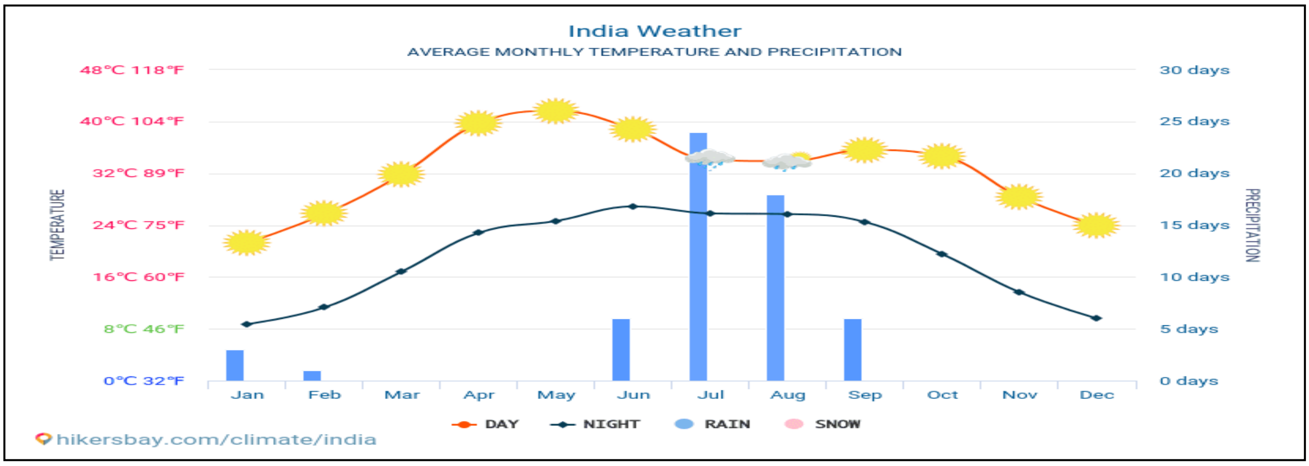

Fig.1.*The above figure represents the average periodicallytemperature and weather of India over the years 2015-2022, Source-hikersbay.com/climate/india*

The graph clearly shows the average temperature for the month of April, May and June is more than 40℃ for the period of more than 25 days. This temperature really effects the generation of the PV plant throughout the India. Standard measurements at NOCT typically impose strong limitations on PV module mounting arrangements and measuring environments at universities like the ESTER laboratory at the University of the Rome Tor Vergata in place of NOST as the Nominal Operating Specific Temperature.At the upper end of the standard deviation of the temperature distribution, i.e., around 15℃, methodologies utilized in applications for engineering, such as nominal operating cell temperature and nominal module operating temperature, lose their accuracy [18]. So this effect of temperature study over PV solar modules of different technologies under real time will providethe effect on efficiency on different technologies for different region.

II. MATERIAL DETAILS

A. Test site city average Temperature

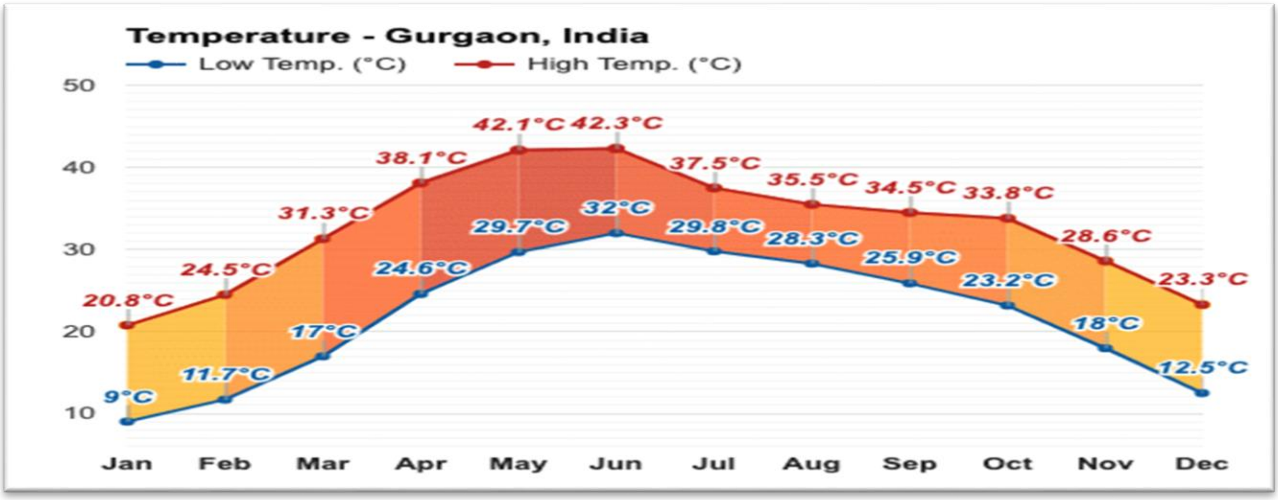

Fig.2. *Average monthly Temperature of Gurgaon, source-weatheratlas.*

Theabove graph clearly shows June (42.3°C) is the warmest month (with its highest average peak temperature). The month of January has the lowest average high temperature of (20.8°C) .

B. Specification of Modules

The internal testing isperformed at indoorPV Test lab Facility (PVTF) and the outdoor testing was performed at NOCT test-bedsetup at now NISE earlier SEC, Gurgaon.with this approach, we study the consequence of temperature on twoPV solar modules of another technology andapproxsame wattage specification is listed underthe Table-I.The specmentioned beneath is mentionedat the backward of panelvia manufacturer the samewe have considered during STC.However the temperature data of indoor and outdoor placements is only assessedduring the research because the impact of temperature is the sole focus of this investigation..Where in the Figure No.1 clearlyshows the average monthly temperature of the India, annually. The peak reaches more than the 40°C for three to four months.

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}	75W	76W
V_{oc}	21.0V	20.33V
I_{sc}	5.01A	1.01A

C. Collected data implementation method

Theselected module istested underthe STC conditions. The performed test under STC conditions produce theoutput resultto be referred in Table No.-II. These resultsareconsidered for effect of temperature study onbothtypes of technology PV module. Further, both modulesaremoved out to outdoor at NOCT bed. In Fig. 3clearly shows the placement of both module at NOCT standard test bed setupfor logging of the data to study the impact of the outside temperature on different semiconductor modules with identical wattages. The info loggedforthe difference of oneminute ofimmediate valuefor wind speed with direction,horizontal and tilted Pyranometer, ambient and module temperature.The accumulated data is now pass through a filterto limit the possibilities of the errors.

TABLE II. INDOOR TEST RESULTS AFTERSTC

Technology	Multicrystalline-Si	Monocrystalline-Si
I_{sc}/I_{mp}	4.70/4.40 A	5.07/4.17 A
Efficiency of Cell	15.3 %	14.4 %
V_{oc}/V_{mp}	21.77/17.42 Volt	22.24/18.34 V
$P_{max\ at\ STC}$	76.6 Watt	76.5 Watt
F.F.	0.749 FF	0.678
STC Test Result	Pass	Pass
Efficiency of Module	14.3 %	14.7 %

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

D. NOCT Test bed placement and Procedure

NOCT test bedsetup is placed as standard per IEC17025. The open rack to bemounted to assistance the test modules and the pyranometer inthe requiredway as typicallypointed in Figures3 and 4.

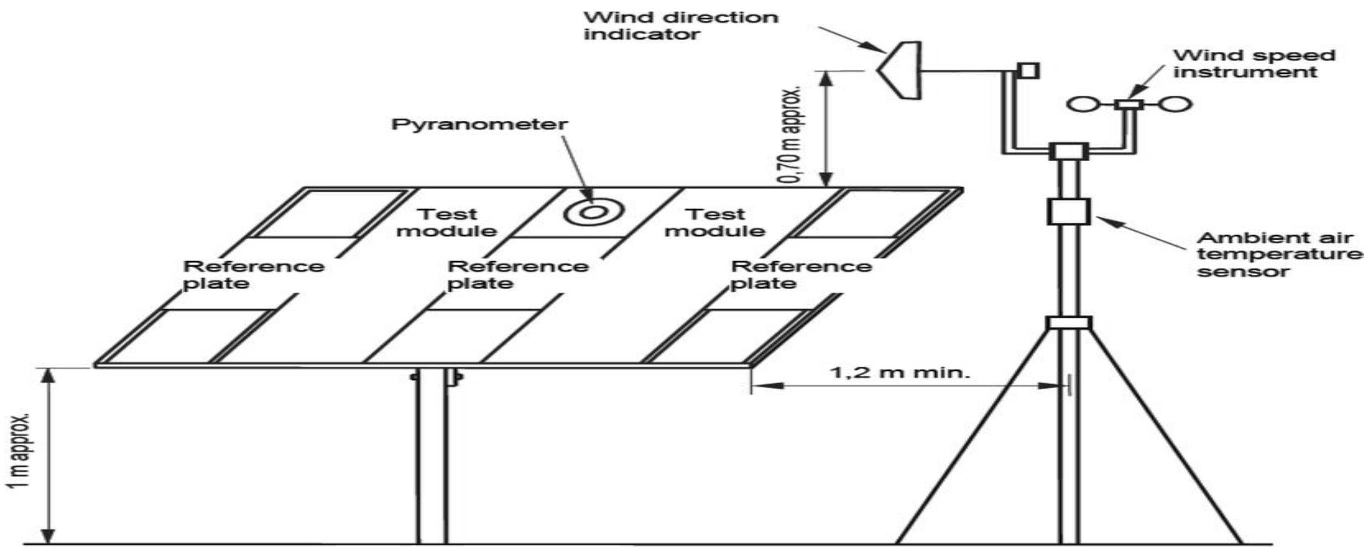

Fig.4 *NOCT bed plan diagram, Source [19].*

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The test rack is inclined at 45° ± 5° ofhorizontally along with the front of the rackpointed to equator. The mounting of the pyranometeristhe flatplaced module and inside 0.3m form the experiment array [19]. Instruments used to record the wind speed down to 0.25m s−1along with the wind direction, installed approximately 0.7 m overheadof the module and 1.2 m to the east or west. Near the wind sensors, the outside temperature sensor should have enough ventilation and be put in the shaded enclosure with a time constant which is equal to or below that of the module. Two solar cells one positioned at the center of each test modules and the other joined to the back with thermally sensitive adhesive or solder are used to detect the outside temperature of the cellsand another at the corner areplaced. The NOCT is characterised as the optimum mean of the photovoltaic cell junction temperatures within an open rack-mounted module in the following standard reference environment (SRE), i.e. Wind speed: 1 m/s1, no electrical load (open circuit), tilt angle of 45° from the horizontal. Irradiance total: 800 W/m2, temperature of outside: 20 °C. The collected data is filtered and processed as per methodology to conclude the findings.

III. Methodology

The captured data by the data recorder at the NOCT test bed are used for the consideration of difference in temperature,The approach is followed and the data is screenedas mentioned beneath. The data logged for the difference of one minute of immediate value for wind speed with direction, horizontal and tilted Pyranometer, ambient and module temperature. The description of data recorder and collection equipment are listed in detail under Table III and Fig. 5 NOCT setup with data logging unitat outdoor test bed is shown.

TABLE III. NOCT SETUP SPECIFICATION

Components	**Total Number**	**Category**	**Description**
Anemo-meter	1	Young015103V	Speed of the wind-0 to 100m/s,Direction-360[a], 355[b].
Data recorder	1	NI CRio	
Pyrano-meter	2	8101 DAN	Range of spectral 0.3 to 33µm72 element thermopile.
Thermocouples	4	K-Type	

a-360^{o} Mechanical and b-355^{o} Electrical.

The collected datafrompyranometer horizontalwhich delivers the global horizontal irradianceGHI,the tilted pyranometer delivers the irradiance data of tilted angle 45^{0}module ismounted as shown in the Fig.4 according to IEC-61215, ambient-temperature is the outdoor environmental temperature,module 1 and module 2 named recordsthe joint temperature of the solar test PV module 1 of multicrystalline (mc-Si) technology, module 2 monocrystallinetechnology of the joints and wind speed mention the velocity of the wind.The entireaccumulated data is applied as per the procedure followed below.

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

A. Procedure followed

The someof the past researches produce out certain equations overthe effect of temperature and the use of elementary equations may result in PV module efficiency.

$$P_m = I_m V_m = (FF)\, I_{sc} V_{oc} \quad (1)$$

Equation (1) representation as

i) FF is fill factor,
ii) I_{sc} it is short circuit current,
iii) V_{oc} is the open circuit voltage, and
iv) $P_m = V_m I_m$ referthe maximum power point in the PV-module I-V curve.

Once the FF and voltage at open circuitwhich decrease substantially with the temperature. (As the thermally stimulated electrons establish to dominate the semiconductor's electrical properties), while I_{sc}increases, but very slightly [20].

Thus, the overall result yields a linear relationship of the form ofbelow equation

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

Where in "equation(2),"η_{Tref} is electrical efficiency of the PV module with the reference temperature-T_{ref} of 25°C and solar radiation of 1000 W/m^2 of STC.The temperature coefficient(β_{ref}) andradiation coefficient of the solar(γ) isprincipally material propertie that ithaving values of around0.12 and 0.004 K^{-1}, the samefor crystalline silicon PV modules [21]. however, at the later stage it is usually taken to zero [22], andequation "(2)," which generally represent after it reduces to "(3)," .

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

The equation"(3)," denotes the established linear representation for solar PV electrical efficiency [23].The quantities module efficiencyη_{Tref}can betaken from STC data as mentioned above. The actual temperature coefficient depends not only on PV material, but also onT_{ref}, as well. The same can be given by the ratio.

$$\beta_{ref} = \frac{1}{T_{\circ}\text{-Tref}} \quad (4)$$

In "(4)," which T_o is the (peak) temperature at which the efficiency of PV solar module drops to 0 [24]. For the crystalline solar PV cells this temperature reaches to 270˚C [25].

B. Procedure Implementation on filtered Data

The filtered and transformed data is implemented to procedure, as firstly formequation"(4)," $\beta_{ref}$is to be calculated, T_o is mentioned and T_{ref} is to be taken from STC hence it is 25^{0}C. Then after collected data is applied to equation "(3)," as in T_c is temperature of cell at junction of different technologies and η_{Tref} isthe efficiency of modules at STC where it can be taken from Table II, then $\eta_c$is replaced by efficiency of module (η_m).Mentioned procedure is applied to trace out the effect of both temperature difference effectsondifferent technologies in respect to efficiency and ambient temperature. Equation "(3)," gives the relation in between efficiency of cell or module with respect to temperature effect. Hence this procedure comes to a certain conclusion as later shown in the form of plots for four days.

IV. RESULT AND DISCUSSION

The applied methodology and procedureonthe filtered data,turns out the results in the form of the graphs with relation to effect of temperature on efficiency of the both multi and mono-technology typesmodule for the particular location of Gurgaon. The random data of Four days from the month of May is considered.

The graphical representation results for day 1st are as shown in Fig.6. represents the 75 Watt (W) module efficiency of output in relationship to the temperature across various technologies. The representation of the graphs shows timing schedule of data 09:36 AM to 01:12 PM is plotted, as it was a rainy day so the data of afternoon was filtered out, the graphical representation shows efficiency of the Mono is more in comparison to the multi hencein contrast to multicrystalline technologies, monocrystalline is more effective.

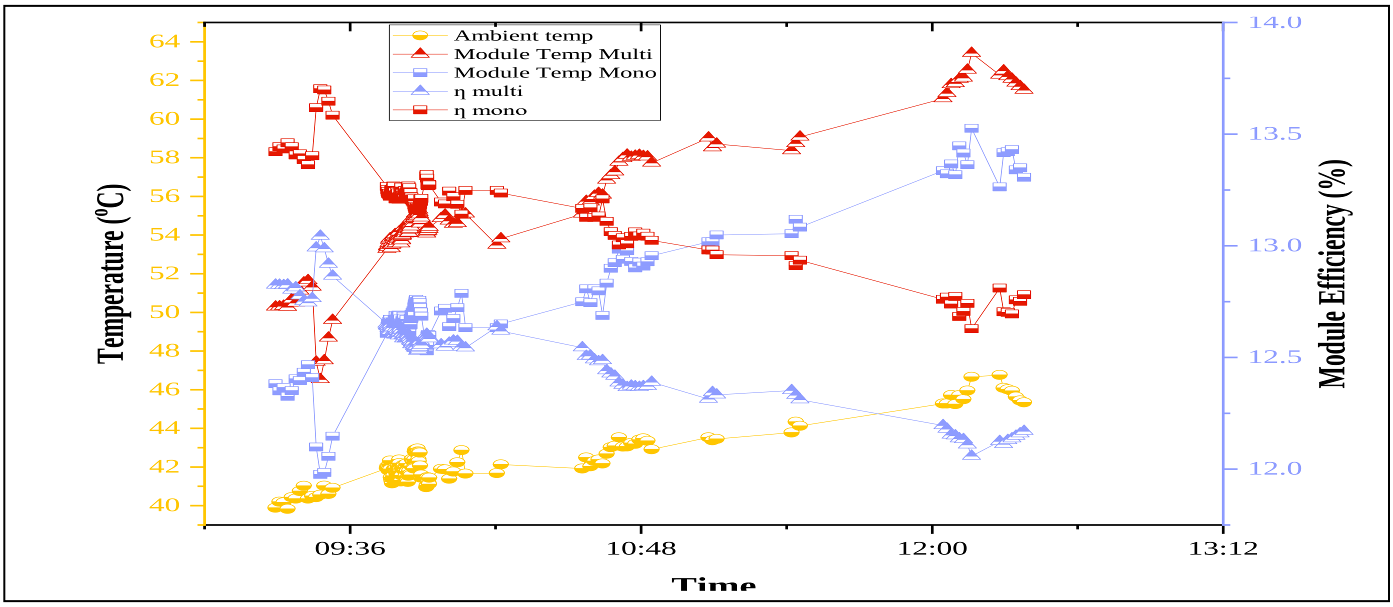

Fig.6*Image of graph for day one performance*9th May

Theabrupt decline in efficiency caused by a rise in temperature can be seen very easily at time of 12:16:43the peak ambient temperature reached of 46.76℃ with an efficiency of 12.12 % for multiand 12.81% for mono.

The graphical representation results for day 2nd are as shown in Fig.7. The output effectiveness of modules at 75 Watts (W) is shown in the graph, The representation of the graphs shows timing schedule of data 09:34 AM to 11:12 AM is plotted the data captured is for very less period to time due to bad weather, hence we have not considered the same graph for detailed analysis, However the changes in efficiency of both modules can be observed on the graph plot very easily.

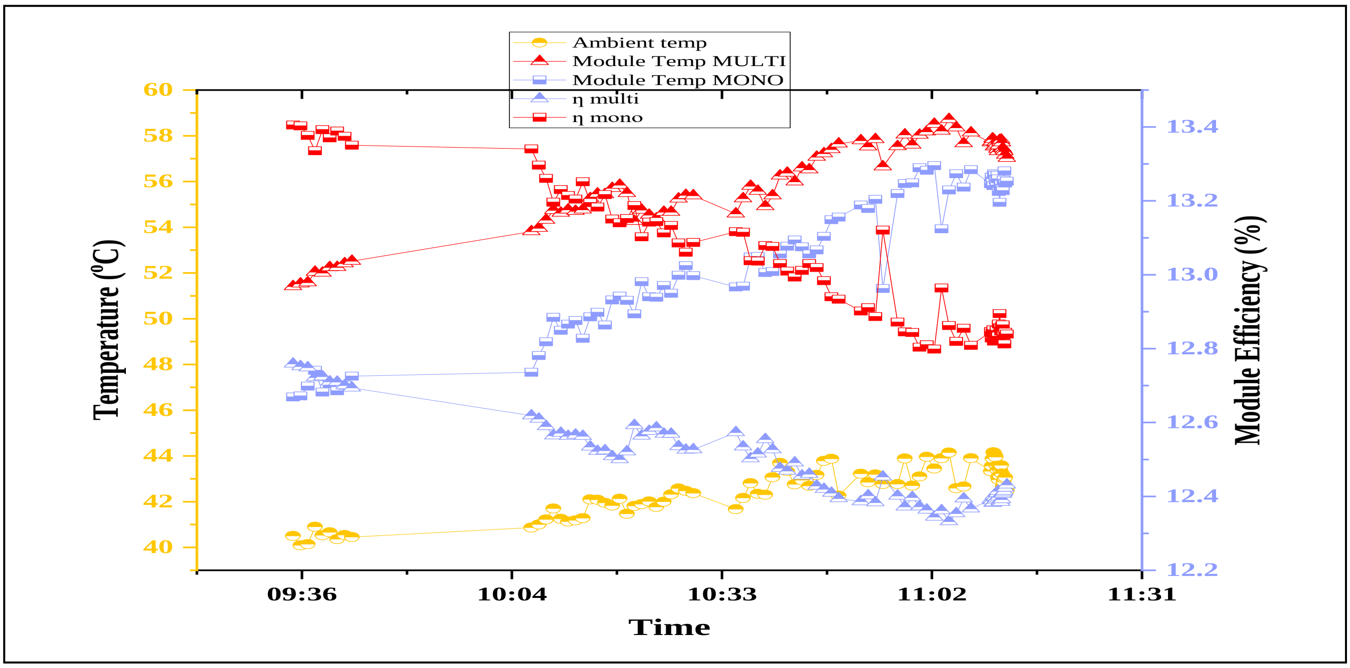

Fig.7*Image of graph for day two performance*10th May

The experimaental setup was again performed after six days interval, where in thegraphical representation results for day 3rd are as shown in Fig.7. The representation of the graph plot shows for the 09:06 AM to 16:32 PM timing schedule data plotted, the graph very clearly shows the efficiency of mono crystalline module is much better in comparison to multi crystalline.Consequently, at an identifiable ambient temperature, monocrystalline technology is superior thanmulticrystalline technology.

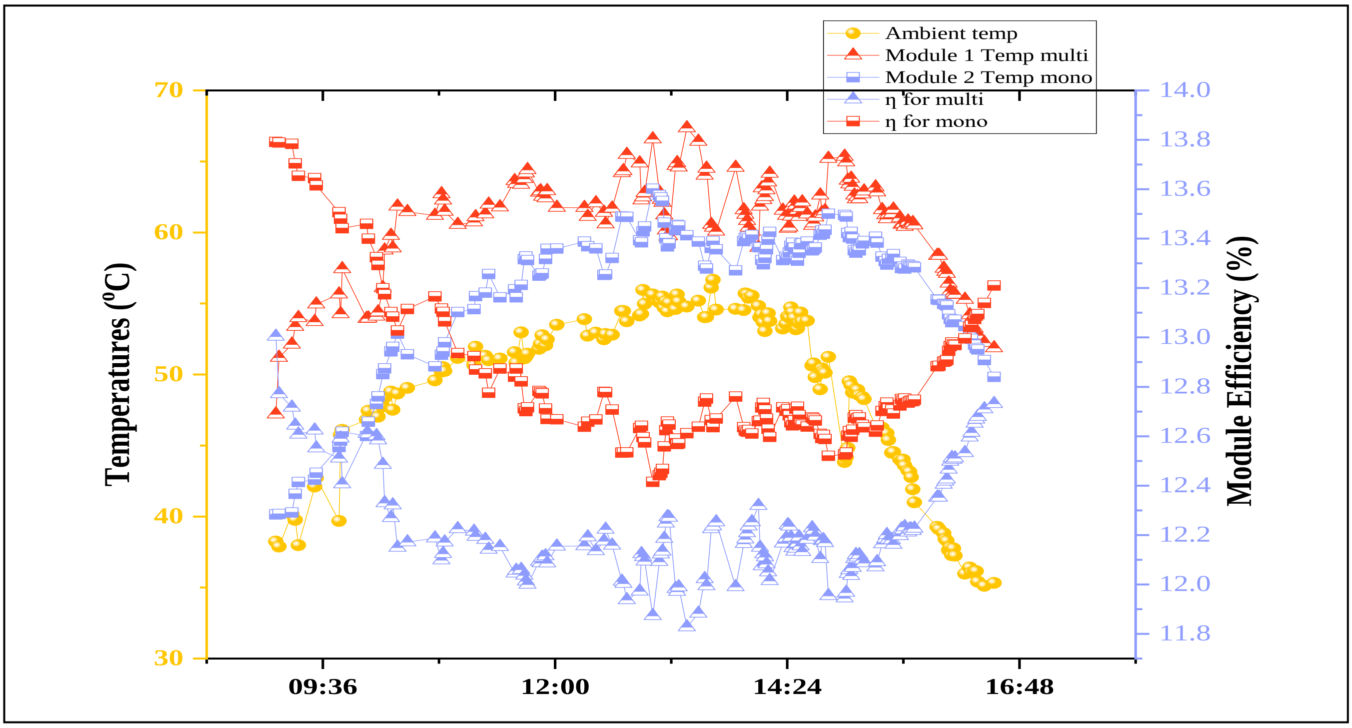

Fig.8*Image of graph for day three performance*17th May

The peak ambient temperature noticed on the same day is at 13:37:56 Hrs. of 56.67℃ with an efficiency of 12.23 % for Multi and 12.63% for Mono and lowest noticed is of 35 .12℃ at 16:26:15 Hrs., with the efficiency of 12.71% of Multi and 13.13% for Mono.

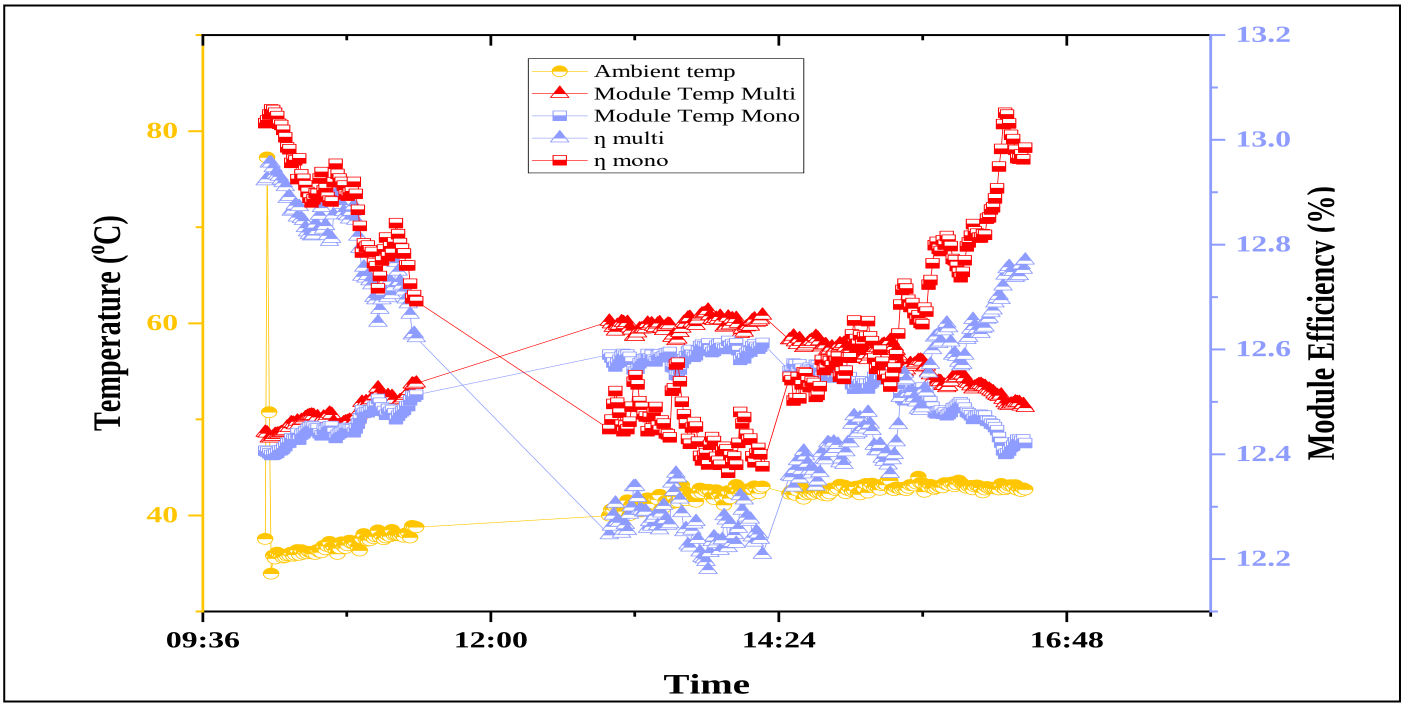

Fig.9*Image of graph for day four performance*20th May

The above graphical representation results for day 4th are as shown in Fig.9. The representation of the graph plot shows for the 10:07 AM to 16:27 PM timing schedule data plotted, the graph very clearly shows the efficiency of mono crystalline module is too much better in contrast to multi crystalline, An additional point to note is that mono is more sensitive to temperatures than multi, as demonstrated by the abrupt spike and decrease in efficiency shown in figure. The day was observed with the with the peak of ambient temperature is 44.01℃ at 15:33:54 Hrs., with the module efficienvcy of 12.48% for Multi and 12.66 % for Mono.

The effect of water, rainy dayand low irradiance as per Fig. 6. Shows the low effect on efficiency of multicrystalline PV module, Hence the multicrystalline is excellent in performingefficiently under the certain conditions too.

V. Conclusion

With this research theresults can be concluded with respect to the study of the graphs the mono-crystalline is furthermostefficient at peak of temperature or we can say in hot regions inassessment to multi-crystalline technology as ofyield efficiency shows in study.
At the particular region ofNCR Delhi the mono-crystalline is most appropriate technology to be adopted, since, if we move forward to conclude it scientifically, the plot demonstrates that high temperatures have little impact on the output efficiency of modules. If we correlate the sameresult with the regions one more significant fact can be traced easily, The region of high altitude and region of low altitude can be compared when incorporating into consideration the impacts of higher temperature and lower temperature on multiple technology, and it is possible to determine that monocrystalline technology is extra efficient than multicrystalline the region someplace the test setup arrangement exists. Furthermore considering the differentregions of the nation the high altitude regions like Himalayan, Ande and etc. the suggestedmost appropriate technology is the multicrystalline because of the technology more sensitivity to the temperature hence at the cold regions multi will perform good and for a test bedplace at NCR- Delhi the monocrystalline is mosteffective.

The whole results and conclusions offer the aforementioned relevant information for the megawatt plant installation, during the selection of technology for a given region to provide the utmostefficient output power.

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