Comparative Analysis of Solar PV Modules Performance for Up-scaling Green Electricity Contribution

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Abstract:
There are different types of PV modules available in the market. Among several types, the one, which generates electricity consuming optimal space with high efficiency and high yield, is recommendable to setup a solar power generation system. To plan for establishing the system, knowledge of solar insolation at a particular site location is essential to predict the possible electricity generation (PEG) for a defined area. At present simulation based predetermination of solar insolation and PEG at a particular site location is being practiced which could not establish the real engineering thrust. In this paper, an index termed as 'module preferable rank (MPR)' is introduced to compare six different types of PV modules. Solar irradiation at a site located at Latitude 13.6214^{O}N and Longitude 79.2903^{O}E is measured physically by using solar radiation sensor on the day just next to vernal equinox. PTBS methodology is proposed for calculating the solar insolation based on the physical irradiation data measured. The calculated solar insolation is used for evaluating the PEG by different PV modules that could be slotted in a vacant area at the concerned site and MPR for each type is evaluated. The PTBS methodology proposed could become real-time solar insolation calculation methodology. The MPR evaluated for different constraints could become reference for selecting appropriate PV module type by ultimate consumers. Choosing correct PV module among several could establish an enhanced green electricity contribution. The outcomes of this paper could establish the aforesaid statement.

Keywords:
Peripheral trio-block synthesis methodology (PTBSM); Module preferable rank (MPR); Solar Irradiation, Solar PV modules

I. INTRODUCTION

Energy is the major driving element for any machine or a livelihood. Effective extraction and utilization of that energy is of primary importance. One among the naturally available energy is solar energy. Abounded solar energy is available on the troposphere of the earth, which makes the humans to get survived. The rate of extraction of solar energy and the rate at which it is being utilized should get balanced to the extent possible. The extraction methods are completely relied on the developed technology being available, while utilization of the same depends on localized factors, like awareness and adoptability of the technology, availability of the system in the nearby market, economy, etc. It is well known fact that the amount of energy being invested to capture naturally available suns energy is very high and hence utmost care has to be taken by the consumers to properly utilize the later. The technology chosen by the consumer should not give a scope to lose the known amount of solar energy that can be captured optimally. It is possible by creating awareness about technology among the ultimate consumers who plays a key role in up scaling the green electricity contribution. The proposed paper addresses the same.

Passivated emitter and rear cell (PERC) silicon solar cell was developed in 1980s which set several efficiency records, but was not taken up commercially at that time. For decades, about 90% of global solar cell production has been of the aluminum back surface field design. There was about 25 year gap between development of the PERC and its wide spread commercial adoption. Several researchers and companies developed techniques that allowed low cost commercial fabrication of PERCs during the intervening years. The closeness of the current PERCs process and the older Al-BSF process has allowed a smooth and rapid commercial transition to the PERC [1]. Researchers also presented the evaluated performance of PERC solar cell technology [2], highlighted the improvements achieved and applications [3, 4, 5, 6]. Demonstrated the maturity of new Q.ANTUM technology concerning reliability and secured energy yield [7]. The potential for enhancing solar cell performance in the space environment was also evaluated [8].

Ongoing research also performed a modeling and simulation study to optimize the copper indium gallium diselenide (CIGS) thin film solar cell [9] and conducted a comparative evaluation on energy performance indicators of CIGS solar panels versus silicon (MC-Si) solar panels in the tropics in an urban environment. The study of work shown that the yield of CIGS solar PV panels are similar to that of MC-Si solar PV panels in urban tropics [10]. Researchers also performed a simulation study on the annual energy yield gain of solar modules [11] and performance comparison of different types of thin film modules [12] with regard to seasonal and meteorological conditions [13] and discussed a method to increase the efficiency of p-type monocrystalline silicon solar cells[14].

II. Different Types Of PV Modules

In order to identify the technology suitable for capturing maximum solar irradiance as possible, six different types of PV modules, whose specifications are furnished in Table 1, are considered. Their geometrical configurations are studied and accordingly the area required per kWp capacity of respective PV module is determined and also evaluated the possible efficiency of each module at STC conditions and furnished in Table 2 and the relative performance at STC is shown in Fig.1. An index termed as 'module preferable rank (MPR)' is introduced to compare various types of PV modules and is defined as the rank assigned to a particular type of PV module which projects an appreciable relative performance of a concerned parameter. For better ranking in view of performance, the efficiency of the module should be relatively high and area required per unit capacity should be relatively low. From the Table 2 and Fig.1, it is clear that MPR is one for mono crystalline PV module and two for PERC (poly) PV module and least for amorphous silicon PV module.

Table 1. Specifications of different PV Modules

Type of PV Module	Make	Pmax (Wp)	Voc (V)	Isc (A)	Vmp (V)	Imp(A)
PERC (Poly)	Nirvana Solar	165	21.6	8.8	17.82	8.6
Poly Crystalline	Junna Solar	150	22	9.09	17.60	8.50
Mono Crystalline	Vikram Solar	375	48.7	9.94	40.1	9.36
Amorphous Silicon	Alti Solar	90	96	1.6	70	1.29
Cadmium Telluride	First Solar	160	65.6	2.5	50.82	2
CIGS	Frontier	70	54	2.2	37.6	1.85

Table 2. Efficiency of different PV Modules

Type of PV Module	P_{max}	Effective Geometrical Configurations			Area per kW	Efficiency at STC	MPR
	Wp	Length (m)	Width (m)	Area (Sqm)	Sqm/kW	%	
PERC (Poly)	165	1.39	0.62	0.8618	5.223	19.146	II
Poly Crystalline	150	1.404	0.624	0.876096	5.841	17.121	III
Mono Crystalline	375	1.872	0.936	1.752192	4.673	21.402	I
Amorphous Silicon	90	1.38	1.08	1.4904	16.560	6.039	VI
Cadmium Telluride	160	1.39	1.07	1.4873	9.296	10.758	IV
CIGS	70	1.22	0.63	0.7686	10.980	9.107	V

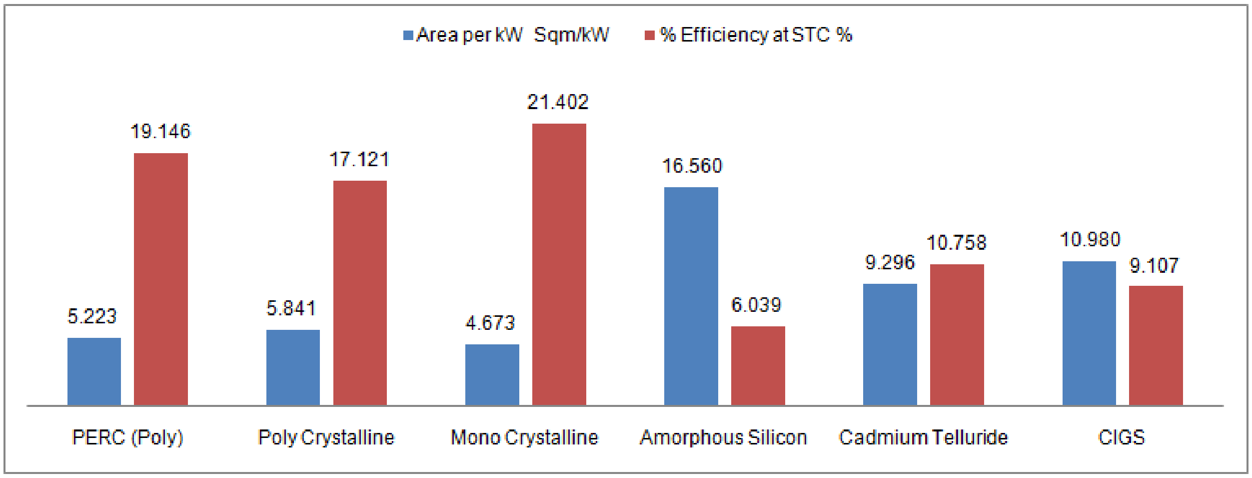

Fig.2. Efficiency and per unit area of different types of PV modules

III. Physical Measurement of Solar Irradiation

In this paper, solar irradiation at a site located at Latitude 13.6214^{O}N and Longitude 79.2903^{O}E is measured physically by using solar radiation sensor (SR 100V with SI 100) on the day just next to vernal equinox, i.e. on 21.03.2020. An equinox is an astronomical event that happens twice every year, once in spring and once in autumn when the tilt of the earth's axis is inclined neither away from the sun nor towards the sun. During equinox's the tilt of the earth with respect to the sun is about 0° and because of it, the duration of the day and the night are almost equal. The measurement was carried out for every minute with an average minute deviation about 18.48% during 9:37AM and 3:45PM covering peak sun duration. The effective total number of sampled time instants is 300. The variation of solar irradiation with respect to the time instants in minutes is shown in Fig2.

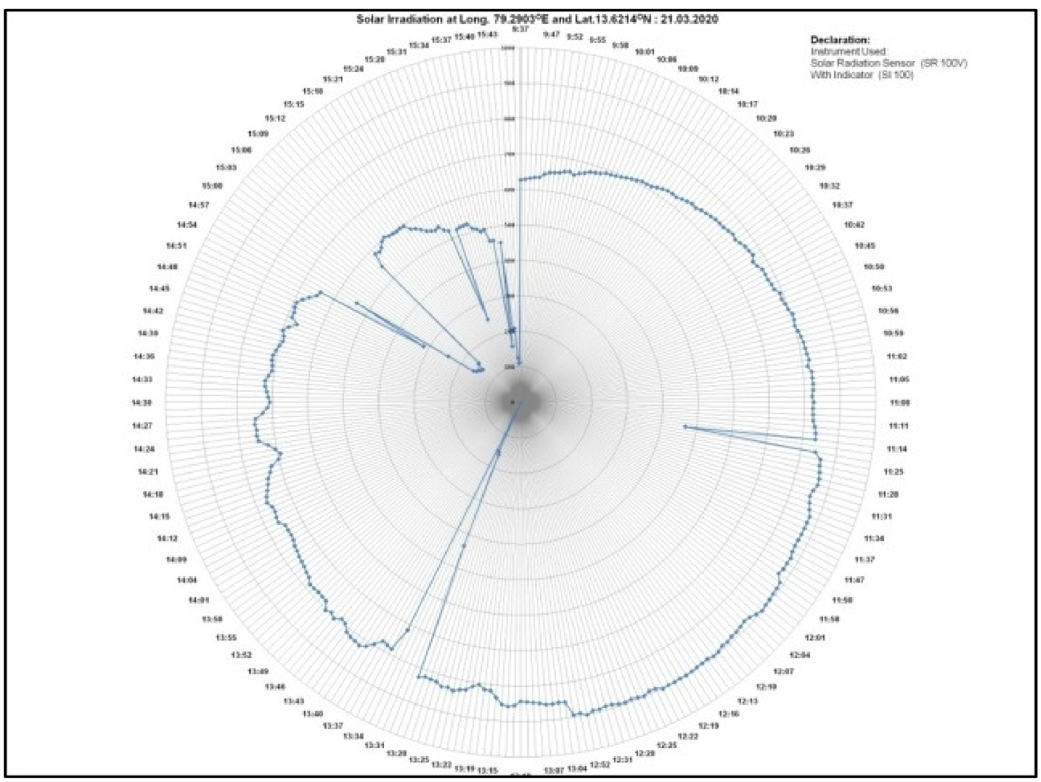

Fig2. Variation of solar irradiation

From Fig.2 it is clear that the solar irradiation is not uniform and is encountering sudden dips and fluctuations. It has been physically verified that, during passage of clouds, there was sudden dip in the irradiation, and during wind, the values of irradiation were floating. Passage of major clouds was observed during 11:15AM for about 4 minutes; 1:29PM for about 6 minutes; 2:56PM for about 11 minutes, during which irradiation was reduced from 540 to 160 and recovered back to 547 by 3:07PM. At 1:34PM the irradiation was drastically reduced to 02 from 819 which was at 1:29PM, and recovered to 717 at 1:35 PM and further to 823 at 1:41PM.The fluctuations in the curve was observed due to wind flow throughout the active measurement duration. However, severe dip was observed during passage of clouds. The value of solar irradiation is expressed in Watt/Sqm.

IV. Calculation Of Solar Insolation: PTBS Methodology

The possible solar energy that can be captured at the said location per day is calculated as per the procedural steps furnished in the flow chart shown in Fig.3. For the ease of convenience, the method proposed is named as 'peripheral trio-block synthesis methodology (PTBSM)'. It is so because, in this method, the irradiation versus time curve is synthesized into differential peripheral triangles and inherent blocks and then the area under the curve, resulting in solar insolation is calculated. The formulae used to attain solar insolation as per the flow chart shown in Fig.2 are presented in equations (1) to (6).

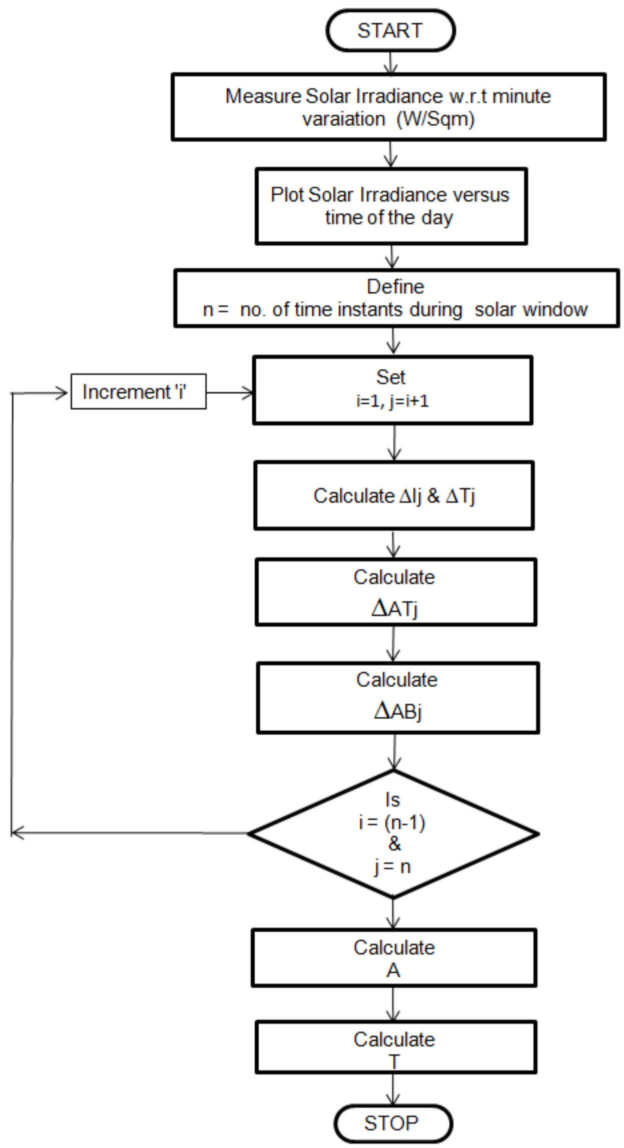

Fig.3. Flow chart of PTBSM for calculating solar Insulation

In the Fig.3

I = Solar Irradiance (W/Sqm)

ΔI_j = Change in solar irradiation during jth and ith instants (Watts/Sqm).

ΔT_j = Change in time during jth and ith instants (Minutes)

T = Total time duration (Minutes)

$\Delta_{AT\ j}$ = Area of jth peripheral triangle (Watt- Minute/Sqm)

$\Delta_{AB\ j}$ = Area of jth inherent strip (Watt-Minute/Sqm)

A = Solar Insolation (Watt-Minute/Sqm/Day)

$$\Delta T_j = (T_j - T_i) \quad \text{... (1)}$$

$$\Delta I_j = (I_j - I_i) \quad \text{... (2)}$$

$$\Delta_{AT\ j} = 0.5 \times \Delta I_j \times \Delta T_j \quad \text{... (3)}$$

$$\Delta_{AB\ j} = \Delta T_j \times I_i \quad \text{... (4)}$$

$$A = \sum_{\substack{j=i+1 \\ i=1}}^{\substack{j=n \\ i=n-1}} (\Delta_{AT\ j} + \Delta_{AB\ j}) \quad \text{... (5)}$$

$$T = \sum_{\substack{i=1 \\ j=i+1}}^{\substack{i=n-1 \\ j=n}} (T_j - T_i) \quad \text{... (6)}$$

By performing iterative calculations as per the procedural steps discussed in the flow chart, the solar insolation at the concerned site location is obtained as 271451 Watt-Minute/ Sqm/Day (or) 4.524 kWh/Sqm/Day.

V. Results And Discussions

A physical site located at Latitude 13.6214^{O}N and Longitude 79.2903^{O}E considered for comparing different solar PV module performance extensively is shown in Fig.4. The effective area convenient for erecting the solar PV modules within the considered site location is measured as 1350Sqm. Trimble make Total-Station instrument is used for the previously mentioned purpose. For all the considered types of PV modules, the possible number of PV modules (PN) that can be erected within the identified area and corresponding total solar PV system (SPVS) capacity is furnished in Table-3. From the Table-3 it is clear that due to different module capacities, the dimensions of the panels are different and hence the number of modules is different. But the possible capacity of SPVS which depends on the dimensions of PV modules and the occupant area elevates the comparison strategy. So within the identified site location, with respect to the maximum possible capacity of SPVS that can be erected within the site location, MPR is one for mono crystalline PV module and the immediate next MPR goes to PERC (poly) PV module while the least rank is to amorphous silicon PV module.

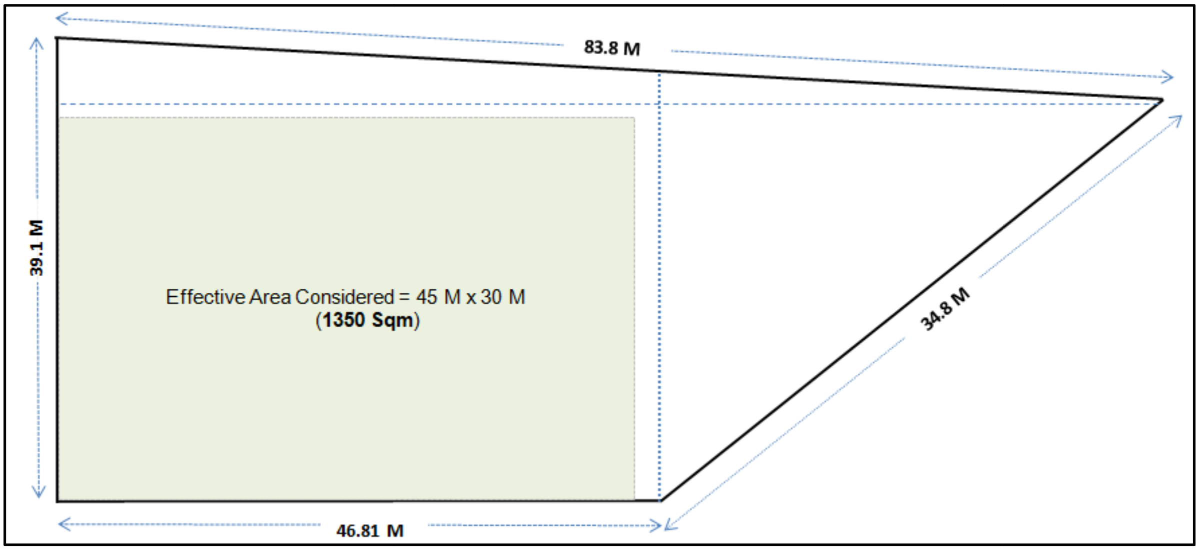

Fig.4. Site located at Latitude 13.6214^{O}N and Longitude 79.2903^{O}E

Table-3: Technology wise possible electricity generation

Type of PV Module	Module Capacity (Wp)	PN (No.s)	Possible Capacity of SPVS (kWp)	MPR
PERC (Poly)	165	1536	253.44	II
Poly Crystalline	150	1536	230.4	III
Mono Crystalline	375	768	288	I
Amorphous Silicon	90	864	77.76	VI
Cadmium Telluride	160	896	143.36	IV
CIGS	70	1704	119.28	V

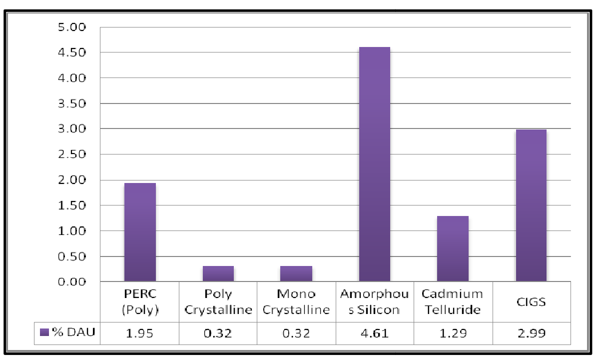

Fig.5. Percentage deviation in utilized area

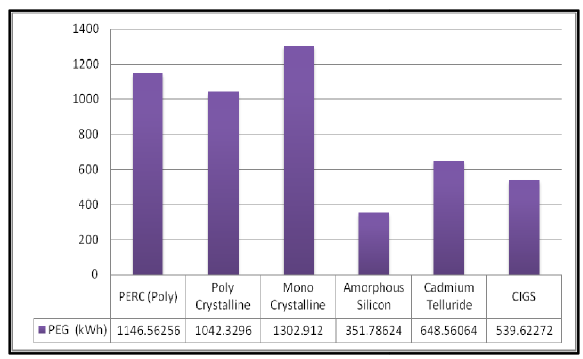

Fig.6. PEG by different PV modules at the identified site location

Percentage deviation in the area utilized by placing various types of PV modules with respect to the identified available area (%DAU) is shown in Fig.5. From the Fig.5 it is clear that, %DAU is relatively high for amorphous silicon PV modules while less for both mono and poly crystalline PV modules. The corresponding value is relatively less for cadmium telluride PV module as compared to PERC (poly) PV module. It is also evaluated that the specific energy yield (SEY) at the considered site location is 4.524 kWh/kWp, and is found constant for all the types of PV modules considered.

The possible electricity generation (PEG) by considering different PV module types is shown in Fig.6. From the Fig.6 it is clear that MPR is one for mono crystalline PV module (1302.91kWh) and two for PERC (poly) crystalline PV module (1146.56 kWh). Besides, cadmium telluride (648.56 kWh) is superior to CIGS (539.62 kWh) while amorphous silicon is inferior to CIGS (539.62 kWh). With respect to MPR-1 module, PEG by MPR-2, 3 and 6, modules are substandard by 156.34 kWh, 260.58 kWh and 951.12 kWh respectively. Considering sale price at Rs.6/- per kWh, with respect to MPR-1 module there is a considerable price implication (loss) about Rs.938.10/-, Rs.1563.49/- and Rs.5706.75/- by using MPR-2, 3 and 6, modules respectively. By this, it is clear that, just by varying the type of PV module, PEG per day is getting changed drastically with accountable price implication. Hence to upscale the green electricity contribution, it is indispensable to choose the PV module with high MPR.

VI. CONCLUSION

An index termed as ‘module preferable rank (MPR)’ is introduced to compare the performance of different PV modules. In this paper, total six different types of solar PV modules are considered and their efficiency and area required per kWp is evaluated. A physical site with an effective area about 1350 Sqm located at Latitude 13.6214^{O}N and Longitude 79.2903^{O}E is considered to allocate and compare different solar PV module performance extensively. To carryout extensive performance comparison among different types of solar PV modules, solar irradiance and insolation are desired quantities. Solar irradiation at the concerned site is measured physically by using solar radiation sensor. The measurement was carried out for every minute with an average minute deviation about 18.48% covering peak sun duration. By using the proposed ‘peripheral trio-block synthesis methodology (PTBSM) the solar insolation at the concerned site location is obtained.. It has been found that MPR, in view of efficiency, area required per kWp capacity, maximum possible capacity of SPVS that can be erected within concerned site location and possible electricity generation is relatively high for monocrystalline followed by PERC(poly) PV modules, and it is relativelely less for amorphous silicon PV module. Just by varying the type of PV module, PEG per day is getting changed drastically with accountable price implication. Hence during planning stage of a solar PV power system, by selecting the type of PV module with high MPR, uncaptured energy due to low MPR modules can be recaptured thereby upscaling the yield of green electricity generation to the extent possible.

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