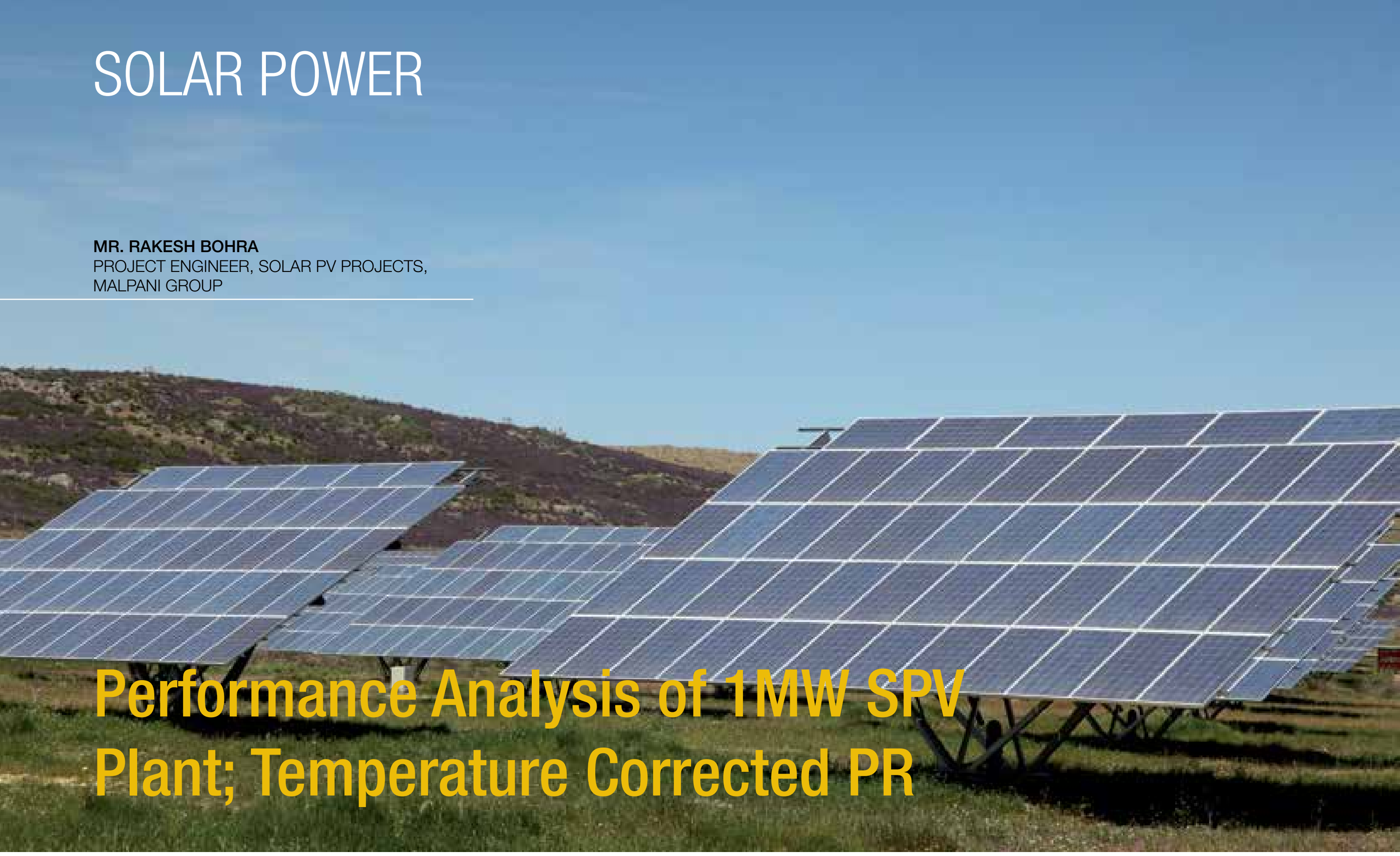


MR. RAKESH BOHRA
PROJECT ENGINEER, SOLAR PV PROJECTS,
MALPANI GROUP

Performance Analysis of 1MW SPV Plant; Temperature Corrected PR

Knowledge about the performance of solar power plants will result in correct investment decisions, a better regulatory framework and favorable government policies.

It is a boon for India being located in the equatorial belt of the globe, thus receiving best radiation from the sun varies from 5.8- 6.8 kwh/m^2/day. The equivalent energy potential is about 6,000 million GWh of energy per year. The highest annual global radiation is received in Rajasthan and northern Gujarat. In these areas, a big part of land is barren and sparsely populated, making them best suitable for power generation by constructing Solar Power plants. Data for this study paper are from one of the SPV plant situated in Rajasthan only.

Yet all the insolation received is not converted to energy as the performance of such solar PV plants depends of variety of factors including losses in design system and other environmental factors. Performance of Solar PV Plants on globe is indexed generally on two parameters viz PLF (Plant Load factor) and PR (Performance Ratio). In fact nowadays variety of solar service providers are giving generation guaranty taking base of PR calculations.

In solar PV industry PLF (people also terms it as CUF, Capacity Utilization Factor) is not a parameter to be much taken into consideration .The reason behind it is time factor (24 Hours). For this reason, professionals find it better to consider PR to analyze the performance of a solar PV plant.

Objective of this study is to

- To provide industry a one year (2013-14) factual data of 1 MW SPV Plant (polycrystalline technology) constructed in Rajasthan

India is swiftly running in constructing solar farms, number of business groups are investing to harness sun, but the essential qualities of solar plant performance monitoring is still feel lacked

- To study effects of various parameters on performance evaluation of a SPV plant
- To compare conventional Performance Ratio methods that consider only radiation, and temperature corrected PR methods.

India is swiftly running in constructing solar farms, number of business groups are investing to harness sun, but the essential qualities of solar plant performance monitoring is still feel lacked. Apart from money making, it is always recommended to ensure the availability of well trained experts to record and frame such data for future references. Mega Watt scale solar industry is very new in India and there is a great scope of its development in future.

To analyze the performance of a PV system, one needs accurate weather data. The most important parameters to be recorded are:

1. Irradiance (GHI , POA & diffused when required)
2. Insolation/Intensity
3. Ambient temp. (Average calculation techniques to be used described later)
4. Module surface temp. (Average calculation techniques to be used described later
5. Wind Velocity

Generally this data is ignored but as the industry matures we believe the use of this data will gain more significance. An-other important point to be noted is that one needs to put temperature sensor on loaded module only (It should not be installed in any spare module out of the field). Further it is also recommended to install Met Station nearby DC Field only. It is essentially recommended to take intense care while calculating the average of data like intensity, plant availability and radiation calculation.

The basic Parameter to be calculated to analyze the performance of a SPV plant as mentioned in IEC 61724 is PR (Performance Ratio).

Other than that one can also refer PLF, energy yield (as per NREL/CP-520-37358) and Specific Yield (As per SolarPro) etc.

NREL= National Renewable Energy Laboratory

Study Base

The data collected to frame this study report is from a 1 MW (AC) SPV plant situated in Bap (Rajasthan). It is equipped with 4968 Nos. of polycrystalline modules each 240 Watts. The data has been recorded by SCADA system through the Met station installed in the plant premises and TVM meters.

As per MNRE study, the average DNI in Bap area lies between 6.5-6.8 kwh/m^2/day and average temperature lies between 30°C-40°C with almost 300 sunny days. Various parameters studied through this system includes following equations and specifications:

Specific Production

This parameter also referred as yield of a system is actually modules-to-metering end performance metric. It is the ratio of energy produced by the system (MWh AC) to the energy claimed by module manufacturer mentioned on spec sheet rating of the modules (MWDC-STC), which is usually expressed as MWh/MW.

Specific production = (1)

CUF (Capacity Utilization Factor)

This parameter often referred as PLF (Plant Load Factor) does not consider any environmental variations viz. irradiance , temperature or degradation of the PV modules. It also doesn't account the grid availability. Therefore it is not convincing that the CUF is a perfect parameter to be considered while claiming performance of a SPV plant. Moreover it also takes account of 24 Hours while it is a fact that solar power plant does not produce power for 24 Hours a day.

To compare any SPV Plant performance indexes with other source of power generating plants like thermal, nuclear, wind etc.; PLF of SPV becomes irrelevant because solar plant is not working for 24 hours. One can calculate it for 12 hours taking it as a standard or to calculate the same with actual generating hours, but it is not yet adopted by global institutes.

PLF(CUF) % = X 100% (2)

PR (Performance Ratio)

This is the most important and most authentic metric to analyze the performance of a SPV Plant. It is defined in IEC 61724 and is a metric to measure how effectively the plant converts sunlight collected by the PV modules into AC energy despite of many de-rating factors viz. inverter inefficiency, cable losses, cell mismatch, module temperature, reflection from module glass surface, soiling losses, system down-time (grid failure), shading losses , and any component failures. Conventionally PR is calculated as equation (3) discussed ahead by the industry however this equation does not incorporate any aforesaid factors except irradiance. Yet it is very important to consider the effect of temperature and module efficiency along with PV area to calculate the corrected PR.

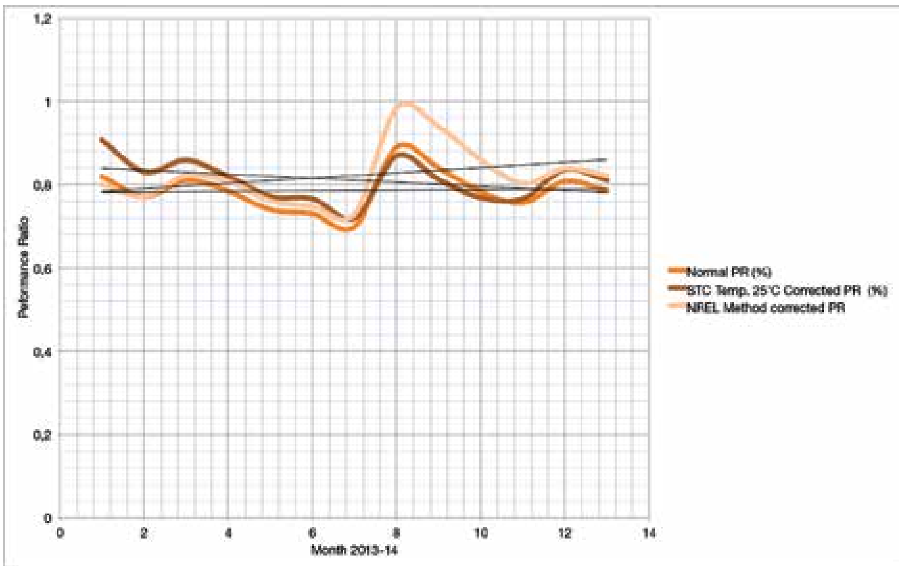
In a business model, nowadays contractual acceptance of guaranteed PR needs to be calculated and analyzed thoroughly before framing a conclusion. The contractor specifies a PR that is representative of the annualized performance at the site, but the calculation of the measurement is never defined, leading to unnecessary risk for both parties in future.

$$PR\ \% = (\text{Energy AC}_{KWh}) / (\text{Energy DC}_{STC} \text{ X Irr}_{kwh/m2/day})\ \%\quad (3)$$

Most notably, weather affects the PR by affecting the module temperature depending upon the location on globe. As per NREL report , The PV system electrical output changes as weather varies; for example, system output changes with temperature (typically ~ 0.5%/°C) referred as temperature coefficient , irradiance (typically can vary by as much as 5%–10%, especially for modules with high shunting or series resistance), and spectrum (typically varies by up to ~3%, depending on the difference in responses of the irradiance sensor and the PV module) depending upon the type of PV module technology.

Along with solar insolation, temperature also plays a big role in affecting the efficiency of a PV plant. Weather corrected report of NREL suggests that strong dependence of PR on temperature results in a large seasonal variation in PR, which can range from ±2% to ±10%.

PR is often corrected to a common temperature of 25°C (standard test conditions) as mentioned in equation (4) .But Correc-



Graphical representation of PR variation with different calculation/corrective methods.

tion to a cell temperature at 25°C usually results in a higher PR because modules more frequently operate at 25°C. Thus, while correction to 25°C essentially solves the problem of seasonal variations, it may claim increment in the actual performance but the value cannot be considerably justified as temperature varies constantly and on practical grounds modules does not produce power at 25°C the whole year.

PR% = Normal PR (eqn 3) / (1 + μ(T_{CELL}–25ºC)) % (4)

μ= Temperature coefficient provided by module manufacturer (negative sign % / ºC).

But since one cannot judge the accuracy of PR value while considering the 25ºC i.e. STC; NREL has suggested more accurate equation that includes the average cell temperature of one complete year. To calculate with this method our plant needs to be equipped with an initial project file depicting range of module temperature for one complete year.

PR % = Normal PR (eqn 3) / (1–μ (T_{CELL} Avg–$T_{CELL[i]}$)) (5)

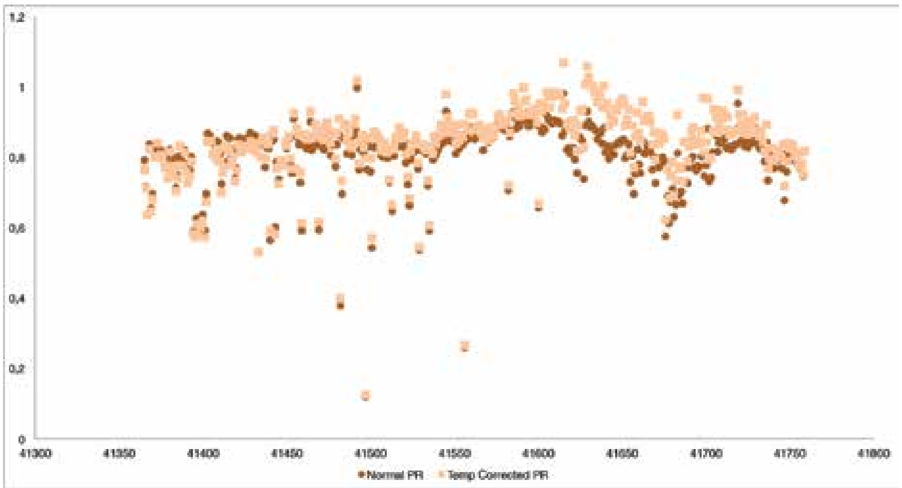
Where μ= Temperature coefficient provided by module manufacturer

T_{CELL} Avg = T_{Amb} + ( ) I (6)

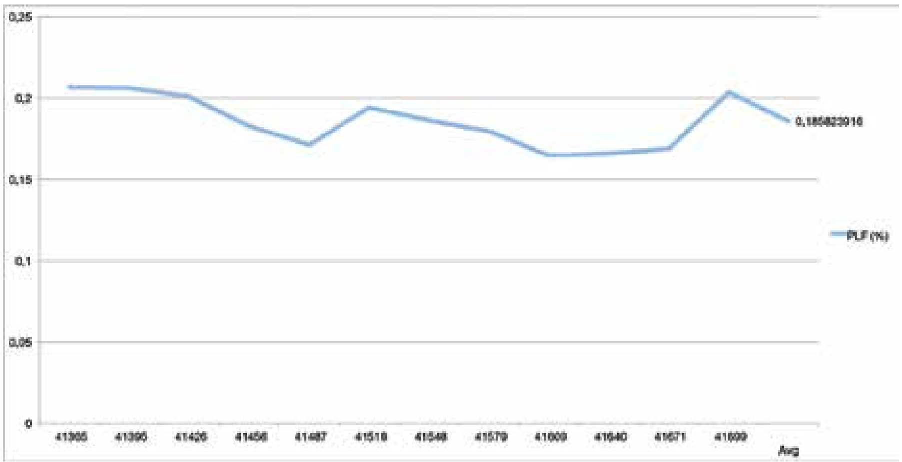
Where T_{NOCT} is Nominal Operating Cell Temperature provided by module manufacturer & I is intensity of solar light for the period.

$T_{CELL[i]}$ = Temperature of Cell/Module at the particular time instant

Yet it will definitely be a highest level of accuracy if one can correct the PR for every aspect of the weather, but here we have



Variation in Normal PR and temperature corrected PR on 365 days index, (On average Temperature corrected PR comes around 3-4 % more than normal PR).



Graphical Representation of Monthly PLF fluctuation.

attempted to correct PR only for environmental variations that indeed affect the temperature of module and so its efficiency.

Plant Performance Degradation

Generally it is assumed that only the PV modules are accountable for the performance degradation of the SPV plants; however while evaluating the performance it is recommended to look at the weather data and the BOS (Balance of system).

As per a study report of Fraunhofer Institute performed on thin film modules

1MW PLANT YEAR 2013-14

Month	Installed DC Capacity (KW)	Monthly Generation at ABT Meter of H-Pole (kWh)	Avg Generation Per MW (kWh)	Avg Irradiation Global Tilt	Module Temp. (Dg C)	Amb Temp.	PLF (%)	Normal PR (%)	STC Temp. 25'C Corrected PR (%)	NREL Method corrected PR
Apr-13	1193,00	177320	5910,67	6,04	47,33	32,94	21%	82,03%	91%	80%
May-13	1193,00	183065	5905,32	6,41	48,93	37,43	21%	77,22%	83%	77%
Jun-13	1193,00	172598	5753,27	5,95	42,72	36,21	20%	81,05%	86%	82%
Jul-13	1193,00	161995	5225,65	5,58	39,04	33,43	18%	78,50%	82%	81%
Aug-13	1193,00	151893	4899,77	5,55	35,62	30,87	17%	74,00%	77%	76%
Sep-13	1193,00	166750	5558,33	6,38	35,53	31,02	19%	73,03%	77%	75%
Oct-13	1193,00	165303	5332,35	6,39	36,96	30,24	19%	69,95%	72%	73%
Nov-13	1193,00	154264	5142,13	4,84	32,12	23,55	18%	89,05%	87%	98%
Dec-13	1193,00	146083	4712,35	4,70	18,88	16,03	16%	84,04%	81%	94%
Jan-14	1193,00	147170	4747,42	5,08	16,41	13,69	17%	78,33%	77%	86%
Feb-14	1193,00	136319	4868,54	5,39	20,57	17,16	17%	75,71%	77%	80%
Mar-14	1193,00	174857	5640,55	5,85	28,25	23,41	20%	80,82%	84%	84%
AVG		161468	5308,03	5,68	33,530	27,17	19%	79%	81%	82%

Table No.1 : Various Parameter recorded and used in this study paper.

that were delivered in 1984 and tested in 2009 it was found that ,18 out of the 20 modules tested, showed an average power output of 7% below the nominal output listed by the manufacturer on delivery, even after 25 years of use.

As per a study conducted by NREL to figure out degradation on 2 different mono crystalline and 2 different polycrystalline modules, the average degradation rate for the all 4 of modules was 0.71% per year. Study also concluded that for crystalline silicon modules, it will be more reasonable to assume a figure of less than 0.5% for degradation per year.

Conclusions drawn from the study

- PRTemp Corrected value on average last year comes around 3% more than normal PR (yet it depends on various geographies)
- The normal methods of performance parameter calculation specifically Performance Ratio as mentioned in IEC 61724 can also be amended and the values can be corrected by methods as derived in equation no. 4 & 5.

Factor	Range of effect
Temperature	1-10 %
Module tilt angle	1-5%
spectral distribution	0- -3 %
uncertainity in manufacturer rating	0-5%
ageing	5% over lifetime
mismatch	2%
soiling	0-15%
snow & shadding	depends on location
diodes & cabling	3%

- Approx 1% to 10% of variation into PR value can be seen with respect to temperature corrective method on different geographies.
- Weather parameters and solar power production are very uncertain. This makes it necessary to preserve historical data which can be analyzed to improvise the system efficiency.
- Temperature correction in PR taking account of STC i.e. 25°c is not feasible round the globe, hence it should be done with calculating TCELL Value. Try to maintain highest accuracy levels while calculating this value.
- It is quite evident that the performance of SPV plant not only depends on irradiance but also on other factors like temperature (Ambient and Cell) wind velocity, soiling , dusting, snow, element failure, grid unavailability ,design flaws etc

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Disclaimer

The data used in this study are purely practical data extracted from plant system. Any deviation from expected may involve the factors viz. grid unavailability, element failure, defects in modules or any other equipment. However the calculations are best to author's practical experience and domain knowledge.