AN APPROACH PAPER ON DEVELOPING AN INSOLATION RATE TO COMPARE THE OPERATING PERFORMANCE OF DIFFERENT SOLAR PV PLANTS

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INTRODUCTION:

Solar PV Power Plants began to become cost-effective and popular in India from 2010. NTPC's foray into Solar Power started with the commissioning of 5 MW Solar Plant at Dadri in 2012 and the 5MW Solar Plant at Port Blair in 2013. The latest commissioned Solar Plant of NTPC is the 250 MW Ananthapuramu Ultra Mega Solar Power Plant, which was commissioned in May 2016. Today, the total installed solar capacity of NTPC is 360 MW, and two large Solar Plants (260 MW Bhadla Plant and 250 MW Mandsaur Plant) are scheduled to be commissioned shortly. NTPC has ambitious plans to reach 10000 MW Solar capacity by 2022.

Today, the total installed Solar Capacity of India is about 9000 MW. With the active policy initiatives of Government of India, this is poised to grow to 100000 MW by 2022. By 2030, Solar Plants are expected to contribute 30-35% of the total installed capacity of the Indian Grid.

While the installation and commissioning of a Solar Plant takes only 12 months from the date of handing over of Land and issue of LOA, the Plants will be in operation for the next 25 years. So the necessary O&M system of NTPC Solar Plants is being developed gradually.

PERFORMANCE INDICATOR:

One of the major concerns during the O&M phase is to measure and improve the **Operating Performance** of the Plants. If the tools of measurement are appropriate and significant, the results of the measurement will be truly representative of the quality of operation and maintenance. By comparing the appropriate performance measure of different Plants, the performance-gaps can be identified and corrected. In case of Thermal Plants, one single measure that can aptly describe the operating performance of a Plant is the **Heat Rate.** Operating performance of different Thermal Plants of different capacities can be aptly compared using the parameter of Heat Rate. This paper is an attempt to develop a similar measure for Solar Plants.

Presently, there are two parameters which are generally used to compare Solar Plants viz. (1) Capacity Utilization Factor (CUF) and (2) Performance Ratio (PR). While CUF is more commonly used in India, PR is more commonly used in Europe and USA.

Capacity Utilisation Factor (CUF):

This is also some times called Plant Load Factor (PLF). The formula for calculating the CUF or PLF of a Solar Plant is-

CUF or PLF = [(Actual Generation) / (Installed capacity of the Plant in kW x Time in hours)] x 100 %

Actual Generation = Export kWH as measured by the Commercial Class Energy Meter at the periphery of the Solar Plant.
Installed Capacity = Installed capacity of the Solar Plant in MW x 1000
Time = Period of Time, for which the CUF is being measured. For one day, it is '24 Hours', for one month, it is '24 hours x 30 days', for one year it is ' 24 Hours x 365' etc.

The CUF gives an exact measure of the Commercial Performance of the Solar Plant. It is an important indication on the actual Return on Investment, in the present model of NTPC's PPAs with the Discoms. Higher the CUF, better the commercial performance.

However, there are inherent technical characteristics of Solar Plants, that the CUF doesn't address. Even when the equipments are 100% available, the Generation varies with the Global Horizontal Irradiance (GHI) of the location and the Panel Temperature (which, in turn, depend on the Ambient Mean Temperature). The Day GHI in India varies from about 4.5 kWH/square metre in October to about 6.5 kWH/square metre in March. The Ambient Mean Temperature (AMT) in India varies from about 15 degrees in December to about 35 degrees in April. The GHI and AMT also varies from place to place. Any **Performance Measure**, which doesn't consider these two major factors will lead to wrong comparisons and will lead to wrong conclusions.

Hence, while CUF can measure the Commercial Performance of a Solar Plant, it fails to measure the quality of O&M Management of a Solar Plant. Hence it may not be an appropriate Performance Measurement, unless linked to the GHI.

Performance Ratio (PR):

Performance Raio (PR) of Solar Plants is the most popular performance measure in Europe and USA. Hence it is most popular on Google also.

The formula for calculating Performance Ratio is-
PR = (Output Energy in kWH)/ (Plane of array Irradiance x Area of the PV Panels x Efficiency of the Solar Panels)

The PR is most suitable for small Roof Top plants etc (of few kW capacity only). It works fine when only one type of Panels of the same manufacturer, and conforming to the same Data Sheet is installed in a Plant. It is suitable for the type of commercial agreement existing between small domestic 'Producers' and 'Utilities' in Europe etc.

It is not suitable for large Solar Plants (of MW Capacities), having different types of Panels by different manufacturers and conforming to different Data Sheets. Also, once installed, measuring the total area (actual) of a PV Plant with millions of PV Panels is almost impossible.

It can be seen that, the Capacity of the Plant (MW) doesn't appear in the formula for PR at all. In the PPA model being practiced between NTPC and Discoms, and in the data being furnished to RLDCs, the MW capacity is the most important specification of a Solar Plant. The daily Declared Capability (DC) submitted to the RLDC s are also based on MW Load. Hence, any performance calculation that doesn't include MW Capacity is irrelevant.

MW capacity of a Plant is firm (except for the annual de-rating) and clearly specified in the EPC Contracts. However, some of the parameters, base on which the PR is calculated, like the **Total area of**

the Panels, efficiency of the Panels etc., are not mentioned in the EPC Contracts and hence not contractually enforceable. Hence PR suffers from the inability of being non-enforcable.

PR takes into account the Total Generation and the Total GHI of the measuring period (a day, or a month, or a year). This gives a 85-90% accurate tool of comparison. However, there is a strong correlation between **Generation** and **Panel Temperature**, which is not captured in the PR calculations. So, for the same GHI, the calculated PR of a cold month (November / December / January in India) will be different from the calculated PR of a hot month (March/ April/ May in India). This may lead to wrong conclusions if we compare the PR of different months, even for Plants located in the same geographical area.

Hence, PR is not an appropriate and accurate measurement of the performance of an operating PV Plant. Hence, there is a need to develop a Measure, which will ensure that we are comparing Apples to Apples.

A new Measure for performance of Solar Plants: INSOLATION RATE.

The attempt here is to develop a Performance Measure to compare Solar PV Plants of different installed capacities, located at different locations, and valid for any month of the Year. It has to be having clear linkage with (1) Installed capacity of the PV Plant, as clearly mentioned in the EPC Contract (2) Net energy generated, as measured by the Commercial Energy Meter (3) GHI, as measured by an accurate and calibrated Pyranometer (4) Mean ambient temperature of the location of the PV Plant in different months of the year. This will make the Measure SMART.

Based on the above parameters, a Performance Measure of INSOLATION RATE is worked out-
Insolation Rate = 1000 x [(CUF /GHI) x LCF]

Where GHI = Global Horizontal Irradiance for the measuring period in kWH/square metre, as measured by the accurate Pyranometers installed at the PV Plant.
CUF = (Net Export Energy of the PV Plant as measured by the Commercial Energy Meter at the PV Plant) / (Installed capacity of the Plant x Time period in Hours)
LCF = Locational Correction Factor = A figure varying from month to month from 1.00 to 1.50 and derived from the design GHI and Generation figures mentioned in the EPC Contract.

Installed capacity of the PV Plant and Time period are static data. Net Energy Generated is an authentic data from the Commercial Energy Meter, which is authenticated by the State Discoms also. GHI is accurately measured by a high resolution Pyranometer (of Resolution less than +/- 1%).

Locational Correction Factor (LCF) is a figure which is based on the 30 year temperature and other weather data of that location/ region, and is clearly mentioned in the EPC Contract. For calculating the Locational Correction Factor, we take the design data of GHI and Generation of each month. Take the Generation per GHI for each month. Then take the maximum of this ratio as 1.00 and take an index for the other months, with this figure as base.

From the EPC Contract document of Anantapur Solar, the LCF for Anantpur area is derived as below-

Sl.No.	Month	Design GHI (as per Contract)	Design Generation for a 50 MW Plant (as per Contract)	Generation per GHI	LCF
01	January	166.7	7546.476	45270	1.020
02	February	176.1	7408.226	42068	1.097
03	March	208.3	7668.926	36817	1.254
04	April	201.6	7264.050	36032	1.281

05	May	199.4	7210.726	36162	1.276
06	June	159.8	5885.500	36830	1.253
07	July	154.8	5747.250	37127	1.243
08	August	157.0	5940.800	37839	1.220
09	September	159.1	6011.900	37787	1.222
10	October	143.3	5638.626	39266	1.176
11	November	144.7	6385.176	44127	1.046
12	December	145.1	6697.626	46159	1.000

From the EPC Contract document of Bhadla Solar, the LCF for Bhadla area is derived as below-

Sl.No.	Month	Design GHI (as per Contract)	Design Generation for a 65 MW Plant (as per Contract)	Generation per GHI	LCF
01	January	128.7	9340574.1	72576	1.00
02	February	136.8	8715287.1	63708	1.14
03	March	181.7	9610725.8	52893	1.37
04	April	195.7	9202131.9	47022	1.54
05	May	211.5	9513474.1	44981	1.61
06	June	199.9	8990486.7	44975	1.61
07	July	173.5	8013050.5	46185	1.57
08	August	169.1	8057405.2	47424	1.53
09	September	169.9	8373823.9	49287	1.47
10	October	160.5	9195449.9	57293	1.27
11	November	128.3	8661672.5	67511	1.08
12	December	118.0	8546150.6	72425	1.00

Similarly, the LCF of different Plants/ Regions can be worked out once from the EPC Contract's Design Data. The value will vary over the months from 1.00 to 1.30 for the **'Andhra/ Karnataka/ Telangana Solar Region'** and from 1.00 to 1.60 for the **'Rajasthan/Gujarat/M.P. Solar Region'**. For other regions, it can be calculated and frozen.The Insolation Rate for different 50 MW Blocks of Anantpur Solar for the months of October, November and December are worked out as below-

	October 2016 (LCF = 1.176)	November 2016 (LCF = 1.046)	December 2016 (LCF = 1.000)
P2 (Tata)			
Net Generation MU	7.501	7.523	6.925
Actual CUF (%)	20.16	20.89	18.62
Actual GHI (kWH/m2)	181.54	160.08	145.97
Insolation Rate= 1000 x (CUF/GHI)x (LCF)	**130.569**	**136.553**	**127.53**
P3 (LANCO)			
Net Generation MU	7.523	7.037	6.647
Actual CUF (%)	20.22	19.55	17.868
Actual GHI (kWH/m2)	179.99	159.56	144.7
Insolation Rate= 1000 x (CUF/GHI)x (LCF)	**132.079**	**128.148**	**123.485**

P4 (BHEL)			
Net Generation MU	7.443	7.143	7.021
Actual CUF (%)	20.00	19.84	18.87
Actual GHI (kWH/m2)	181.13	160.29	146.77
Insolation Rate= 1000 x (CUF/GHI)x (LCF)	**129.852**	**129.485**	**128.593**
P5(Sterling)			
Net Generation MU	7.488	7.251	7.051
Actual CUF (%)	20.129	20.14	18.95
Actual GHI (kWH/m2)	182.80	159.79	148.61
Insolation Rate= 1000 x (CUF/GHI)x (LCF)	**129.444**	**131.854**	**127.544**

The above Table indicates that higher generation and higher CUF alone does not indicate the good performance. Higher Generation and the higher CUF is only due to higher GHI, which is an Act of God. The achievement of higher GHI is not exactly attributable to the Quality of O&M Management. However, whenever there is a higher Insolation Rate, it is an **exact indication of better O&M Management.**

It can be clearly inferred from the above that the **Insolation Rate** is the best indicator to judge the quality of O&M and real performance of the plant. The strength of this indicator is that it is based on declared, verifiable, and authenticated data. Hence, it is the best Performance Measure to compare the operational efficiency of a PV Plant, mitigating the influence of various variables such as GHI, Mean Temperature etc.

The adoption of this indicator keeps a check on the tendency to go into self-congratulatory mode, on Cold Sunny days, for better Generation due to higher GHI and lower temperature. GHI and Temperature are uncontrollable variables (God's gifts) and higher generation on account of good GHI cannot be attributed to the efforts of O&M Team and vice versa is also applicable. The predominant effect of such uncontrollable variables is nullified in the calculation of Insolation Rate thus providing a good indication of the quality of maintenance/upkeep. Thus, better Insolation Rate indicates true efforts of the O&M Team (100% availability, better maintenance practices, better Water-Washing, better Grass-cutting etc.)

In view of the above, the **Insolation Rate** can be adopted as the Performance Measure to compare different Solar PV Plants.

Future: Focus should be laid more on optimizing the generation with the controllable variables and future studies should focus more on developing a set of parameters as a single parameter cannot judge the performance of a solar plant in view of numerous variables involved.

References: Based on Operating Experience of Anantapuramu Solar Plant (250 MW)

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