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PV Performance Benchmarking in India. Results from the Project "Solar Mapping and Monitoring - SolMap"

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Abstract

Within the Jawaharlal Nehru National Solar Mission (JNNSM), India has installed a total of 2.2 GW_p PV capacity as of January 2014. The German GIZ (Gesellschaft für Internationale Zusammenarbeit) supports the Indian Ministry for New and Renewable Energy (MNRE) with the implementation of a countrywide PV Performance Benchmarking scheme, which presently includes 119 PV Power stations out of 12 Indian states with a total of 518 MW_p of installed capacity. This paper describes the approach for a structured monitoring, evaluation and feedback scheme for countrywide PV installations, gives some results of the present performance analysis and also provides an outlook for further objectives to be achieved.

Keywords: PV Performance, Solar Mission India, SolMap, Monitoring, Benchmarking

1. Introduction

Currently, little is known about the actual performance of photovoltaic (PV) plants under Indian conditions. Due to much different environmental conditions like high absolute humidity or high dust loads in the atmosphere, more challenging grid conditions and less experienced engineers familiar with solar technologies, the yield of the solar plants can differ much from what is known in Germany.

"Solar Mapping and Monitoring – SolMap" is a project under the Indo-German Energy Programme (IGEN) of GIZ. It is financed by the German Federal Ministry of Environment, Nature Conservation, Building and Nuclear Safety (BMUB) through the International Climate Initiative (IKI). It has the main goal to support Indian partners in accelerating the planning and implementation of solar power plants in India and to increase their power output. The German company, PSE AG has been commissioned by GIZ to deliver substantial consulting services to the SolMap project. Within the SolMap project, PSE AG is currently implementing a benchmarking system on technical performance of grid connected solar PV plants in India in close cooperation with MNRE and its associated organizations like Centre for Wind Energy Technology (CWET) and Solar Energy Corporation of India (SECI).

2. Approach

The idea of a countrywide PV performance benchmarking system in India is to collect PV plant operation data at a central location, do an automatic data analysis and calculation of plant comparison performance indicators, and distribute appropriate feedback information for plants to improve the performance.

Fig. 1 shows the structure of the currently developed benchmarking system:

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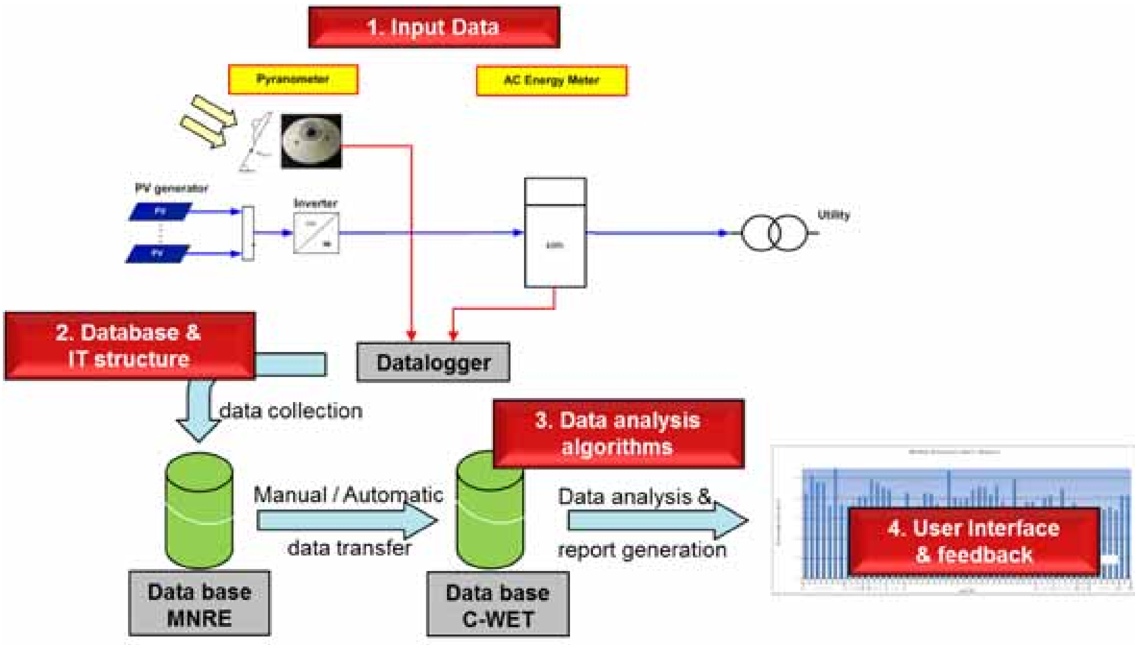

Fig. 1: Structure of PV benchmarking approach

Four main components are highlighted in red color and are described in detail below:

a. *Input data*

Input data are provided by PV Plant operators on a monthly basis, with daily time resolution. All data are first stored in data loggers at the sites and then transferred into a specific format by the plants individual SCADA system.

In general, monitoring requirements are not absolute, but represent a trade-off between cost, effort, and potential benefits of the information. At present, a minimum number of parameters are measured to enable a basic evaluation of plant performance and to help identify the causes for performance differences. The input parameters which are collected at the PV power plants can be divided into two categories:

Meteorological Parameters

Currently, irradiation at the sites is measured by Si reference cells or pyranometers. The sensors measure the amount of radiation actually available to the PV modules, and are mounted in the same plane as the array (POA).

Other environmental conditions that are measured are basic weather parameters. Ambient air temperature is the most important of these, since it directly influences the module operating temperature. Wind is a significant cooling factor at some sites, and therefore its speed and direction is usually measured as well.

System Parameters

Plant energy production is the most important electrical parameter and is measured at the point of grid connection or billing using an AC energy meter. Furthermore, on the AC side, voltage is measured in order to diagnose possible outages or feed-in restrictions imposed by the grid.

b. *Database & IT structure*

The benchmarking system is accessing to two main databases:

- Central database located at MNRE in New Delhi
- Benchmarking database located at the Centre for Wind Energy Technology (C-WET) in Chennai

In a first step, all input data from the power plants are transmitted to the MNRE database. For reasons of safety, all relevant data required for the benchmarking analysis are transferred to a second database at C-WET. Currently, this data transfer is carried out manually: Data have to be downloaded from the MNRE server in Microsoft Excel file format and then uploaded to the benchmarking database. It is intended to automate this step in the future in order to be more efficient and to minimize the risk of possible errors.

c. Data analysis algorithms

PSE AG developed and implemented state of the art analysis- and evaluation software accessing to the benchmarking database. The data analysis presently focuses on two main performance indicators:

1. Final Yield Yf (kWh / kW_p): Ratio of energy to utility and rated PV array capacity
2. Performance Ratio PR (%): Ratio of actual and theoretical possible energy output of the PV plant

Additional analysis information:

- Grid availability

PV power plants can only feed energy into the grid when the grid is available. Periods of grid outages are recorded at the plant sites and the monthly grid availability is calculated by this information. Periods of grid-failures must be filtered out when calculating the performance ratio to avoid distortion of plant performance benchmarking results. Also the daily number of grid outages is recorded for each plant and provides useful information for the plant operators.

d. User interface & feedback

Monthly performance- and benchmarking reports for the individual Indian power plant operators can easily be generated by an automatic report generator via a user friendly interface developed by PSE AG. The reports provide comprehensive information about the individual monthly plant performance including the corresponding graphs. The values of individual monthly final yield and performance ratio are directly compared to the results of all other plants participating in the benchmarking scheme. Fig. 2 gives an example of a monthly performance ratio analysis that displays each plants performance under an anonymous plant ID, while the plants are grouped according to their federal state. The bar representing the individual plant is highlighted in yellow color. Hereby, the respective plant's performance can be easily evaluated in comparison to the others by the operator.

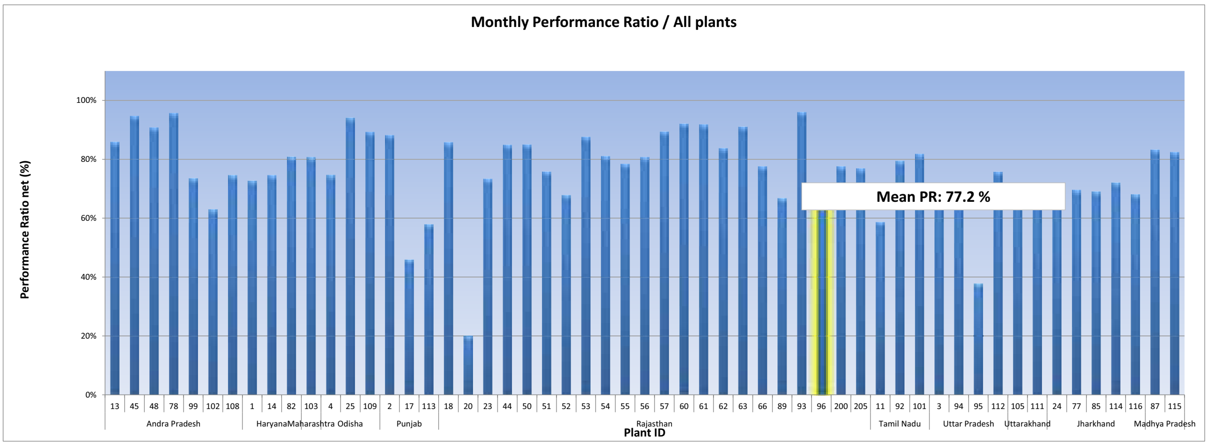

Fig. 2: Monthly PR values of the entirety of all PV power plants
[Source: data provided by operator and utility, graph PSE AG]

3. Status of the project

As of February 2014 a total of 119 grid connected PV power plants out of 12 Indian states with a total capacity of 518 MW_p were included in the benchmarking system of SolMap. This covers about ¼ of the total installed grid connected PV capacity of India. The majority of plants possess capacities between 1 – 5 MW_p but some are as big as 20 MW_p, as can be seen in Fig. 3. This work includes the plants installed under NVVN phase 1 batch 1, NVVN phase 1 batch 2, IREDA and Migration schemes up to December 2013.

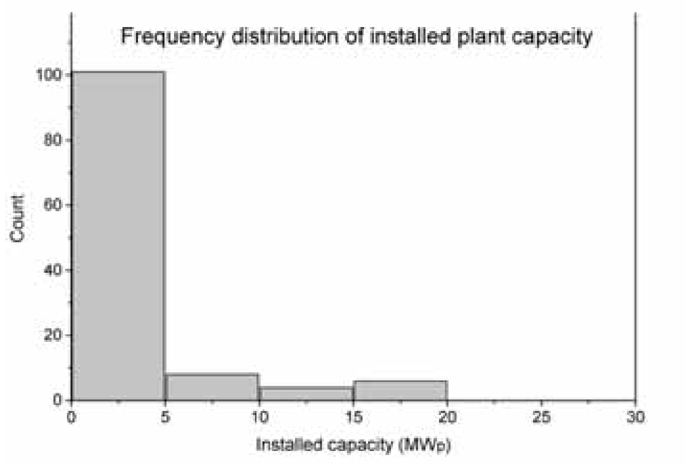

Fig. 3: Frequency distribution of installed capacity of PV plants in SolMap database

The geographical distribution of the PV power plant is depicted in Fig. 4:

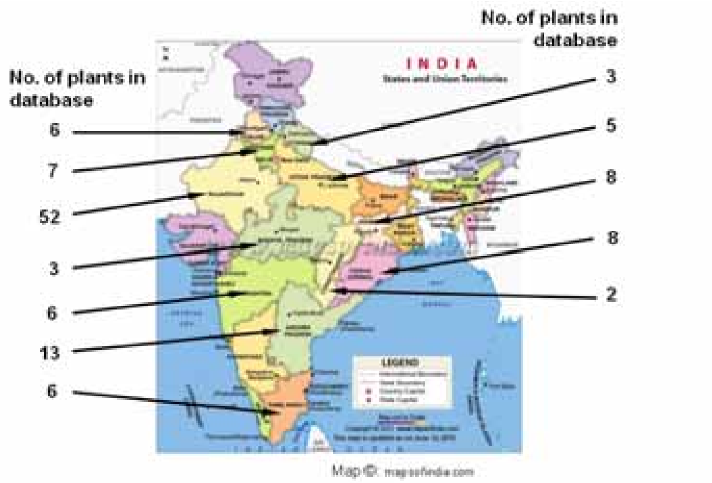

Fig. 4: Geographical distribution of PV power plants in SolMap database

Fig. 5 shows the data availability of the plants during the period under review. The fields highlighted in green indicate the availability of a full month of performance- and meteorological data, while the fields highlighted in white represent data gaps:

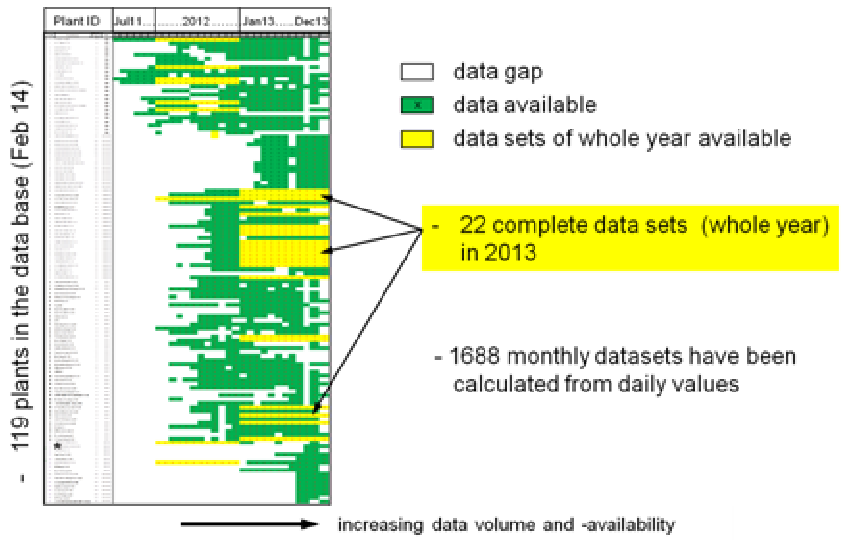

Fig. 5: Data availability

Starting from June 2011, the data volume and the data availability increased significantly. In spite of some data gaps, in 2013 there are already 22 complete data sets of a whole year available. It is expected that this number will further increase as missing data at the end of 2013 will be submitted by the plant operators subsequently.

4. Results and conclusions

An automatic analysis and report generating system was developed to provide monthly benchmarking results to the individual Indian power plant operators. Additionally, based on the available performance data between January 2012 and December 2013, statistical evaluations have been performed to get a first overview about the PV plant performance in India:

a. Analysis of final yield (Yf)

Fig. 6 shows the monthly final yield of all plants over the period under consideration. For each month, also the underlying number of available datasets is given. The monthly energy production of the individual plants varies considerably ranging from 0 kWh / kW_p up to a maximum value of 231 kWh / kW_p. The latter result was determined in case of a 5 MW_p PV power plant in Rajasthan in May 2013.

Fig. 6: Distribution of monthly Final Yield (Yf); Jan 12- Dec 13, all datasets

Fig. 7 shows the same distribution of final yield after applying a statistical analysis. The median, the 5th, 25th, 75th and the 95th percentile are depicted. The mean monthly Yf amounts to 124.6 kWh / kW_p and the median of the monthly Yf to 129.3 kWh / kW_p, respectively. The lower part of the diagram highlighted in red marks the zone of comparatively low energy production. The potential reasons for low final yield might be low irradiation, grid outages, but also malfunctions of the plants. This first indication of underperforming plants will be further examined in the following.

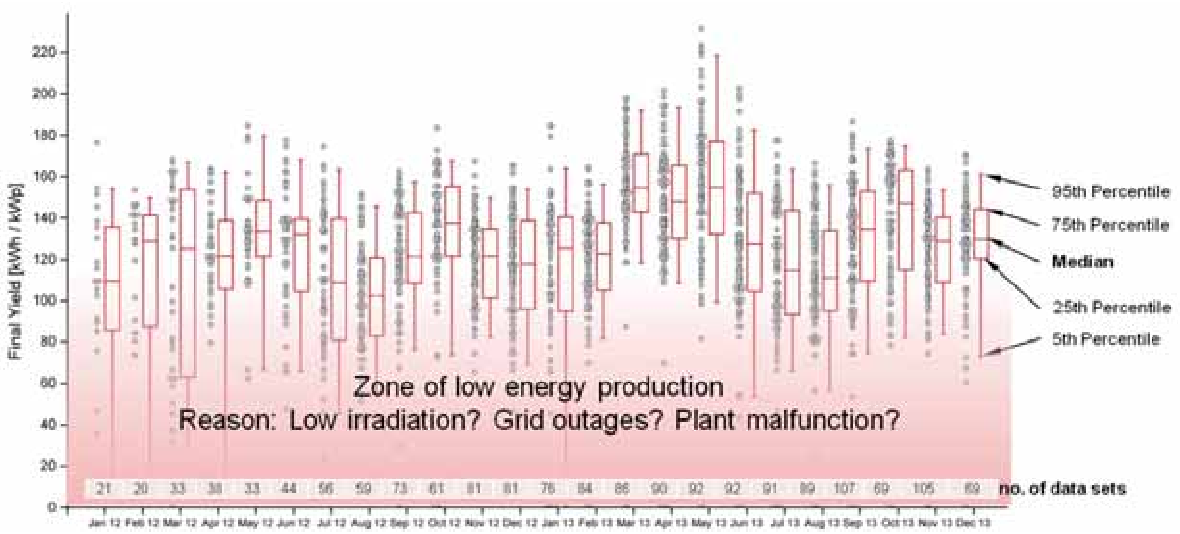

Fig. 7: Box- and whisker plot of monthly Final Yield (Yf); Jan 12- Dec 13, all datasets

In Fig. 8, the median of the monthly final yield distributions of the plants in the individual Indian states is depicted in red bars. The highest median of final yield was observed in the state of Rajasthan, followed by Tamil Nadu. The blue marks show the maximum monthly final yield that occurred in the period from Jul 11 to Dec 13.

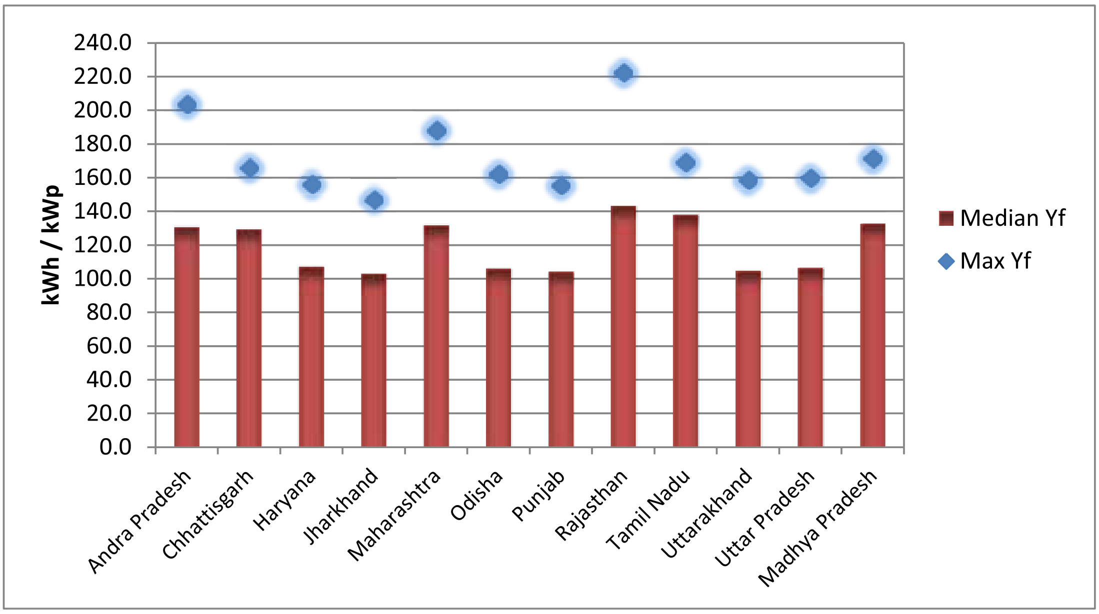

Fig. 8: median & max of monthly final yield / state wise;); Jul 11- Dec 13, all datasets

The majority of plants under investigation are installed in the federal state of Rajasthan, which is why some further analysis was performed only on these. As one example, the final yield of crystalline versus thin film module technology was looked at.

Fig. 9 shows that thin film modules performed slightly better than crystalline silicon modules. Possible reasons for the better performance of thin film technology may be a better performance at low irradiation, the positive effect of a lower temperature coefficient in the hot climate of Rajasthan and inaccurate nameplate D.C. power rating of the modules.

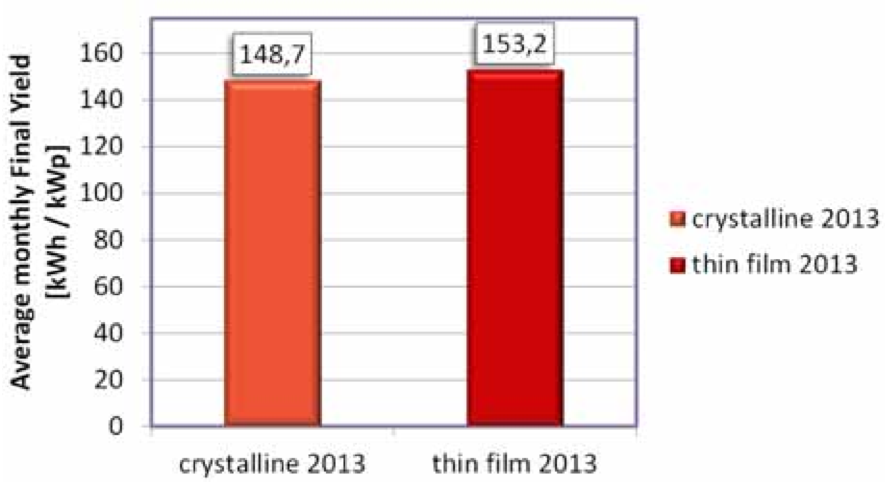

Fig. 9: Monthly Final Yield (Yf): crystalline versus thin film module technology in Rajasthan in 2013

The graphs in Fig. 10 show the monthly final yield of selected plants in Rajasthan during Apr 13 and Jul 13. Noticeable deviations from the general performance behavior indicate underperformance of plants ID 40 and 44 in Apr 13 and Jul 13, respectively.

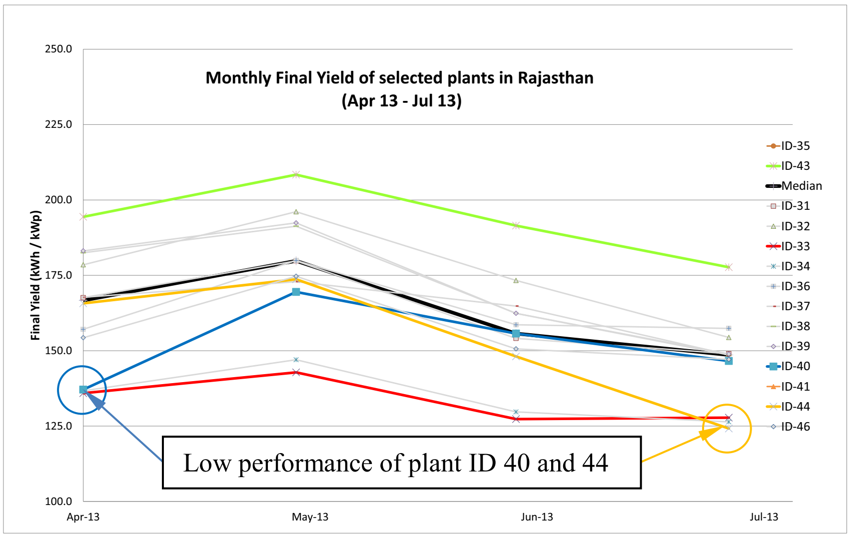

Fig. 10: Monthly Final Yield (Yf) of plants in Rajasthan (04/13 – 07/13)

Distribution of annual final yield in 2013

In order to obtain a first idea about the magnitude of annual final yield that can be expected in India, data from 22 PV power plants have been analysed. The plants are located in 6 Indian states: Rajasthan: 12, Andra Pradesh: 5, Odisha: 1, Jharkhand: 2 and Uttar Pradesh: 1; the total installed capacity amounts to 89.0 MWp.

A median of 1,718 kWh / kW_p was determined and the highest annual yield exceeded 2,000 kWh / kW_p, see Fig. 11. Nevertheless, in case of a few plants also low annual final yields have been detected. These plants should be further examined as comparatively low final yields indicate a high potential to improve the plant performances!

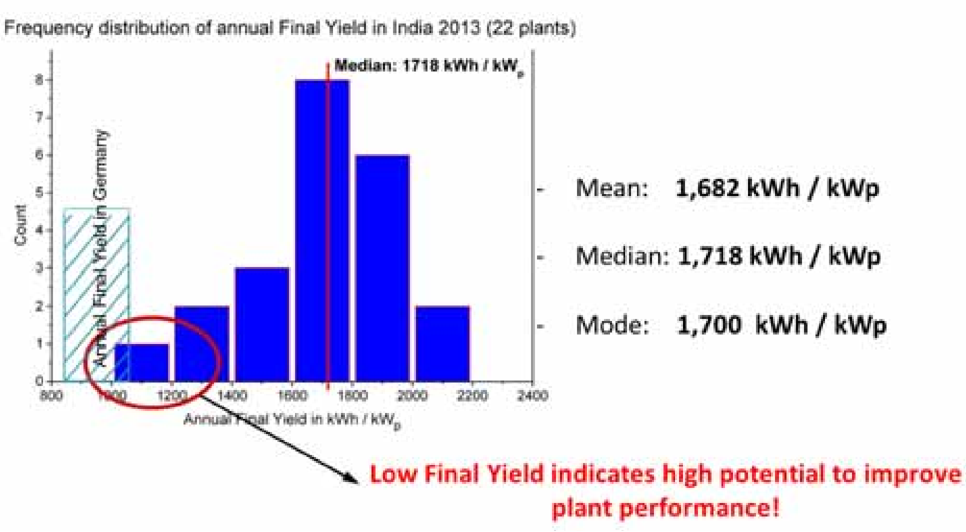

Fig. 11: Frequency distribution of annual final yield in 2013

b. Analysis of performance ratio (PR)

The assessment of PV plant performance by means of performance ratio proved to be a difficult process, as the quality of irradiation data from the plants was inadequate in many cases.

Fig. 12 summarises the range and the distribution of the monthly performance ratio. The monthly performance ratio of the individual plants varies considerably. While a high number of datasets shows PR values close to zero, on the other hand maximum values of around 180% were detected. This result raises the question how physically unrealistic PR values above 100% could occur.

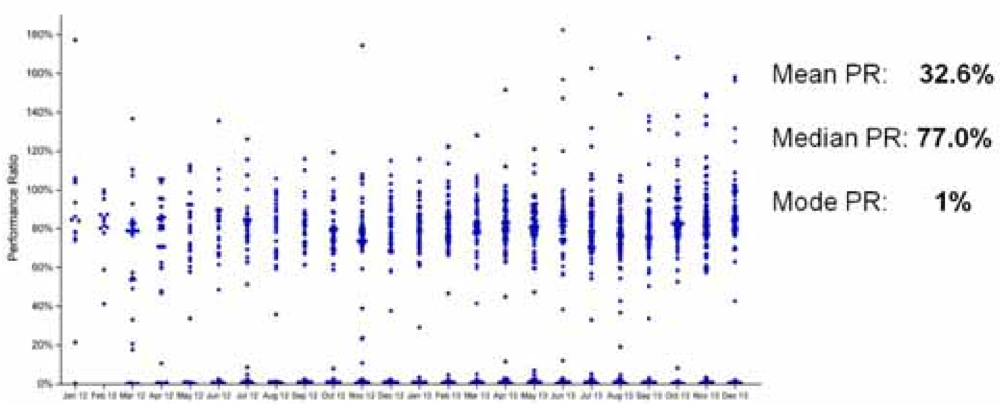

Fig. 12: Distribution of performance ratio (PR); Jan 12- Dec 13, all datasets, unfiltered raw data

First of all, it has to be remarked that for the PR analysis raw data were used and no quality control of the received performance data has been carried out by PSE AG. PR values above 100% indicate deficiencies in the reliability of the irradiation measurement. For example, a soiled irradiation sensor causes low irradiation measurement values which will in turn result in excessively high values of PR. In order to improve the quality of the irradiation data, a filtering of the physically unrealistic irradiation data was applied.

In Fig. 13, all data records of daily final yield are plotted against the plane of array irradiation. The upper limit of physically realistic daily irradiation values was assumed to be 11 kWh / m2. All measured values

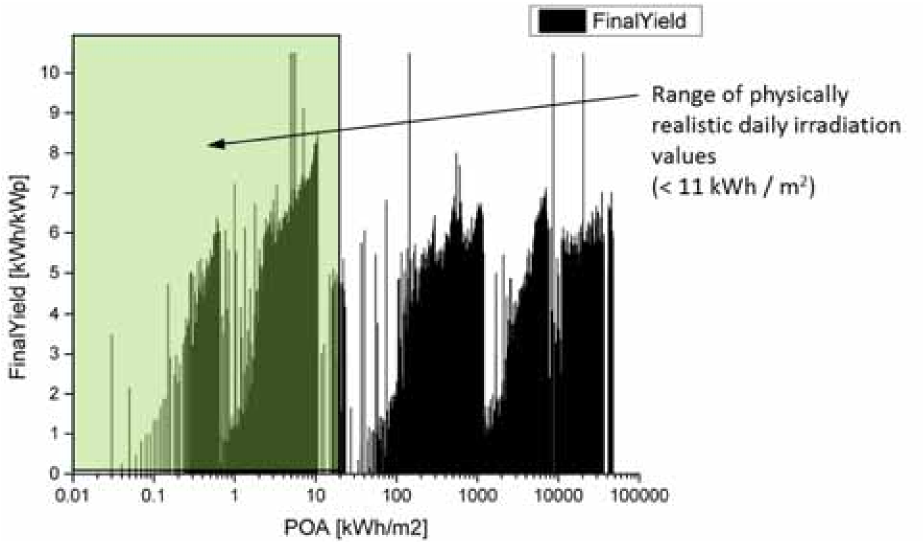

Fig. 13: Daily final yield plotted against plane of array irradiation, all datasets; unfiltered raw data

above that limit were filtered out (filter 1). The lower limit of physically realistic daily irradiation values was assumed to be 0.01 kWh / m2. All irradiation measurements below the lower threshold were also filtered out (filter 2). Finally, all PR values above 100% were filtered out by means of a third filter. The effect of the filtering on the distribution of the monthly performance ratio can be seen in Fig. 14. The values of monthly PR now range within a physical meaningful bandwidth:

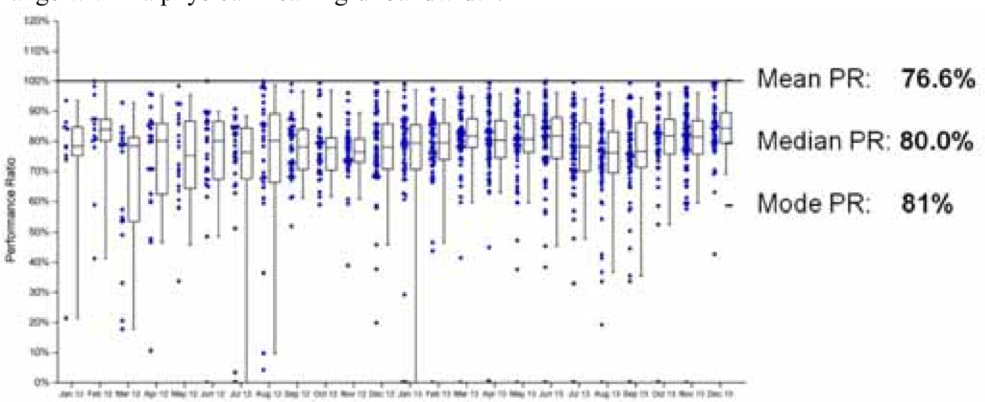

Fig. 14: Box- and whisker plot of performance ratio (PR); Jan 12- Dec 13, all datasets, filtered data

The resulting median PR of 80% seems also to be realistic. However, it has to be repeated that no quality control of the received irradiation data has been carried out and the absolute values of PR still need to be verified.

Nevertheless, the filtered data already allow the detection of underperforming PV power plants. In order to determine these plants, the frequency distribution of the filtered monthly PR values has been calculated. Low performing plants can now easily be determined by identification of conspicuous low PR values, as can be seen in Fig. 15:

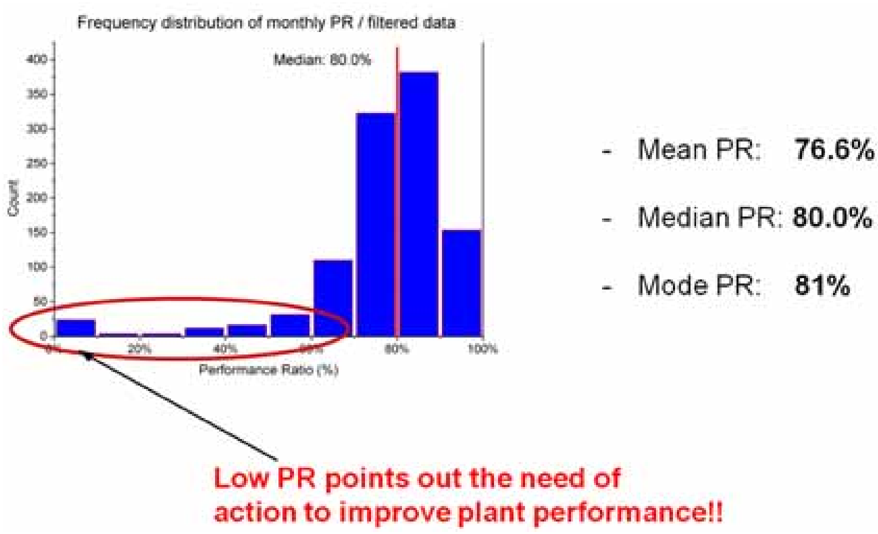

Fig. 15: Frequency distribution of monthly performance ratio (PR); Jan 12- Dec 13, filtered datasets

c. Conclusion and outlook

An automatic analysis and report generating system was developed to provide monthly benchmarking results to the individual Indian power plant operators. Additionally statistical evaluations were performed to analyse the mean plant performance in different Indian states. While the majority of plants operate well, the analysis of the performance ratio indicates that there are some plants which have potential for performance improvement. In a few cases a general lack of attention towards adequate performance monitoring has been observed. Further results can be summarized as follows:

- Data of 119 PV power plants (517.8 MWp) have been uploaded to the benchmarking performance database.
- The database represents PV plants in 12 Indian states covering schemes of IREDA, NVVN phase I, batch 1, NVVN phase I, batch 2 and Migration
- Many plants show a good performance with a highest monthly final yield of 231 kWh / kWp (CUF= 31%) in the case of a plant located in Rajasthan.
- The analysis of PR indicates that a certain percentage of plants shows a potential for performance improvements. A performance improvement of the bottom 10% underperforming plants would result in a significant increase in annual energy production in India!
- The comparison of PV plants with crystalline and thin film modules in Rajasthan shows a slightly higher energy production in case of the thin film technology.

A big challenge is the improvement of the data quality obtained from the PV plants, in particular the quality of irradiation data. The basis of a reliable performance monitoring and benchmarking is an adequate measurement of irradiation at site. The quality of these data has a direct influence on the quality of performance analysis results. Thus, a standard for instrumentation has to be introduced and adhered for all participating plants. Furthermore, it is intended to implement gap filling- and performance data validation algorithms. In the field of data analysis, it is planned to implement further analysis algorithms such as:

- Implementation of additional filter such as inverter-technology, geography, size, and time of installation
- Evaluation of long term degradation (individual plants and statistical evaluation)
- Evaluation of individual plant performance timelines (development of regression equations)
- Evaluation of correlation of effects (e.g. high auxiliary losses with poor PR).

One main focus of PSE's upcoming activities will be in any case on building up capacities in the relevant Indian institutions to enable a reliable and sustainable operation of the implemented benchmarking scheme.