Sampling guideline for inspection and testing of PV modules in the field

Module performance | Testing a sample of modules at an operational solar can help identify faults and underperformance in the wider plant, but which ones to choose? Authors from Mahindra Teqo describe a new methodology they have developed to Satish Pandey, Preetha Pillai, Sandeep Jadhav, Shyam Kumar, Gaurav Mishra, Rajesh Kumar Dhuriya

Solar photovoltaic (PV) system installations are increasing by leaps and bounds throughout the world. These systems are expected to produce clean, safe and reliable electricity over several decades of operation. However, PV installations are subjected to extreme environmental conditions that could result in deteriorating effects on the equipment's performance during their operational years. To ensure best performance and optimum ROI, these PV systems need periodic maintenance and testing throughout their operational phase. These practices can help to understand module degradation behaviour and provide essential information which can be used effectively to troubleshoot any problems arising within the system. Sampling for testing of PV modules comprises the procedures involved to select a part of PV modules from the entire solar PV plant for inspection and it should adhere to standard sampling methods IS2500/ISO-2859 and field-testing norms as per IEC 61215/61646 standards . The IS2500/ISO-2859 sampling plan has been designed mainly for the pre-dispatch module inspection at manufacturing facility. However, in field testing, the sampling needs to adopt the constraints of the field environment and limitation of the running plant. Accordingly, Mahindra TEQO has implemented the sampling plan with the stakeholders for whom the testing has been carried out.

Sampling selection criteria as per IS2500/ISO-2859

This sampling plan is a result of our expertise of handling a plus-3GW portfolio since 2012. The below mentioned sampling plan has been designed for electroluminescence (EL) testing, flash testing and visual inspection. Flash testing signifies the PV module maximum power output (P_{max}) at standard test conditions and helps to evaluate the comparative analysis with the rated power of the module. Flash testing is performed as per IS 14286/IEC 61215 and visual inspection of modules is performed as per IS14286:2015/IEC 61215:2016. Visual inspection can be done on a random basis and does not require any equipment for inspection. Hence it can be characterised as a general inspection. Similarly, a flash test and EL test are time consuming and costly, and thus cannot be done on many samples. In IS2500/ISO-2859 there are two categories – general inspection level and special inspection level. Based on our best practises we recommend General inspection Level-II for visual inspection and special inspection level S-4 for EL and flash testing, as given in Table 1. In the case of EL testing it interprets the existing micro-cracks, cracks and potential-induced degradation (PID) in the module, which affect the overall performance of the module. The IR thermographic inspection of PV modules is performed to detect non-conformities such as hotspot and diode failure. During thermographic inspection the evaluation will be performed on 100% of the plant modules or as per the respective requirement of the plant owner.

Sample selection methodology at PV plant

The sampling plan will apply to each module make respectively and the bottom-line approach is to not consider visually observed defective modules, which would give a false interpretation of average plant performance. If we have different module makes in the plant, then the sampling plan will apply as per the plant capacity but the total number of the samples will be distributed as per the weighted capacity of the modules at the plant. For example, consider a 10MW hypothetical plant with X make modules along with Y make modules and their

Sampling bracket	Plant size (MWp)	Number of modules in plant	Sample size for EL & flash test (as per special inspection level S4)	Sample size for visual inspection sampling (as per General Inspection Level II)
A	**Up to 0.0045MW**	2 – 15	2	2
B	**0.0045-0.008MW**	16 - 25	3	5
C	**0.0045-0.028MW**	26 - 90	5	13
D	**0.028-0.048MW**	91 – 150	8	20
E	**0.048-0.16MW**	151 - 500	13	50
F	**0.16-0.38MW**	501 – 1,200	20	80
G	**0.38-1MW**	1,201 to 3,200	32	125
G	**1-2MW**	3,201 to 10,000	32	200
H	**2-8MW**	10,001 to 35,000	50	315
J	**8-35MW**	35,001 to 150,000	80	500
J	**35-120MW**	150,001 to 500,000	80	800
K	**>120MW**	500,001 & above	125	1,250

Table 1. Sampling plan for field testing in solar PV plant as per IS2500/ISO 28591-1

Sample selected as per sampling plan					
Plant Capacity	**Samples selected**	**Module make**	**Proportion of modules in plant**	**Bracket**	**Make-wise number of modules selected**
10MWp	**32**	X	40%	E	13/32
		Y	60%	F	19/32

Table 2. Sample selection at PV plant with different module make

Plant Capacity	Number of modules	Sample size as per Table 1	Acceptable	Outlier
1MW	3,200	32	2	3

Table 3. Example for AQL

proportion in the plant is 40:60. Then, as per the sampling standard, the total number of modules to be selected for EL/flash testing will be 32 but these will be divided as per the weighted capacity of the manufacturer; thus, we must select 13 modules from X and 19 modules from Y.

To select modules from the plant Mahindra Teqo recommends following methodology:

1. If the PV plant is operational then the module selection should be made as per the inverter performance.
2. If the plant is not operational then the sample should be selected from a random pallet or module mounting structure/table.

For operational plants, the weighted numbers of each module make should be divided into least performing, average performing and maximum performing inverter.

- The selection of these inverters will be performed on a random basis with a stipulation of maximum three locations for each module make.
- After selection of the inverter, the next stage is to select the modules from the mounting table, which should be picked from the positive and negative end equally, and from the middle of the table. This helps to detect PID problems more accurately if they exist.

IEC standards 61215 and 61646 set out special testing requirements for crystalline silicon and thin-film modules respectively. Performance of a module at a site can be determined with the help of these standards. The flash test results should be interpreted as per the expected/guaranteed performance of the module make from the respective manufacturer/supplier. Also, if the corresponding results are not aligned with the expected performance values then a plant developer can reach to the PV module supplier/manufacturer as PV modules accounts for the 60% capex of the plant assets. This practice should be performed in accordance with the warranty agreements of the supplier/manufacturer.

Acceptance quality limit to be followed in compliance with ISO-2859

Acceptance quality limit (AQL) is an assessment criterion as per ISO-2589 in pre-dispatch statistical sampling plans. The notion behind including AQL in PV module assessment criteria is to bring it into alignment with the standard guidelines of ISO-2859. In field testing Mahindra Teqo has absorbed the AQL criterion primarily to validate the outlier selection during the assessment process. The outlier selection should be made through following the AQL 2.5 guidelines for major non-conformity as per ISO-2859. The AQL and the sample size code letter shall be used to obtain the sampling plan from Tables 1, 2, 3 or 4 (ISO-2589-1) attached at the end of the document. For a specified AQL and a given capacity of plant, the same combination of AQL and sample size code letter shall be used to obtain the sampling plan from the table for normal, tightened and reduced inspection.

As per AQL 2.5 of ISO-2589 two major conformities will be allowed for each module in acceptable range and if it is more than two it will be considered an outlier. Therefore, it will be removed from average calculation. The AQL process will be followed by the sampling process as proposed by Mahindra Teqo. For example, as given in Table 3.

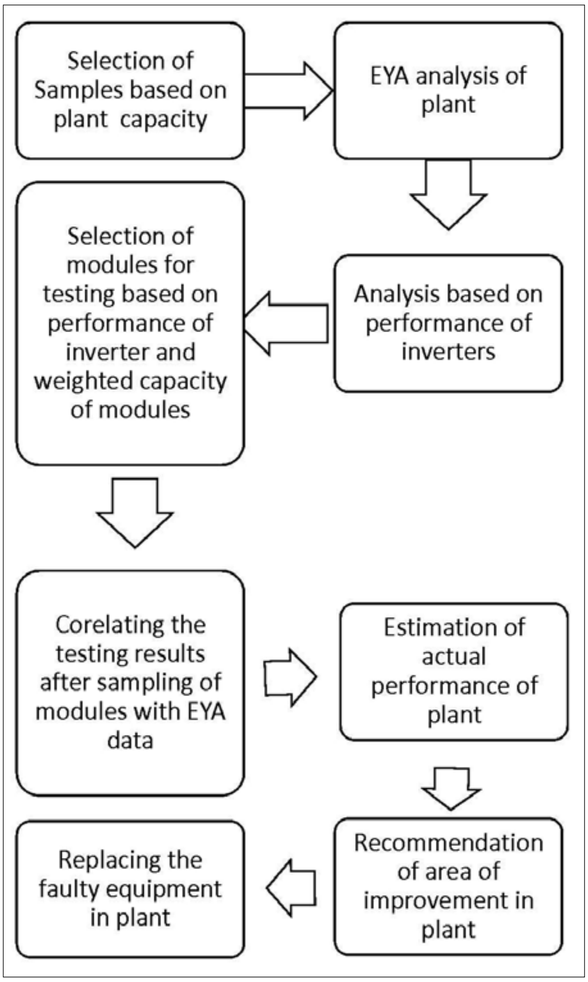

Figure 1. Sample selection to correlate EYA and field test data

Correlating energy yield data with field data

Mahindra Teqo has correlated the energy yield assessment (EYA) and samples tested on a PV plant to get the overall performance of the plant. This correlation is representative of the entire plant which is validating the sampling of modules.

Data from tested modules using this sampling methodology has been validated with the degradation obtained from the performance ratio (PR). A few examples of plants are shown in Figure 2. Plant A with 1.2MWp capacity was first analysed using daily generation data, where the module degradation based on the PR value is calculated. Then based on the plant capacity and performance of the inverter and watt peak rating of the module, flash testing is performed on modules. Based on the plant capacity the number of samples is selected as given in Table 1. It has been observed that in Plant A the degradation of modules obtained from flash testing is essentially the same as the yearly degradation obtained from PR, hence the sample selected for testing is representative of plant performance.

The PR calculation has the added uncertainty of other equipment such as inverters, cables etc., so calculation of the module degradation in the plant

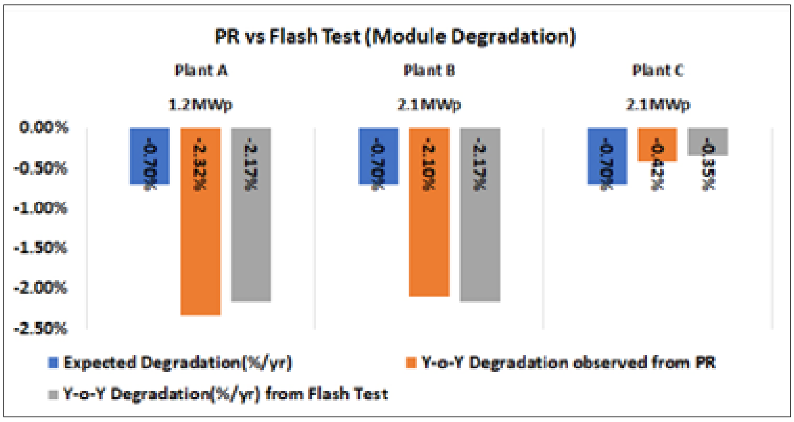

Figure 2. Module degradation obtained from PR versus tested module samples

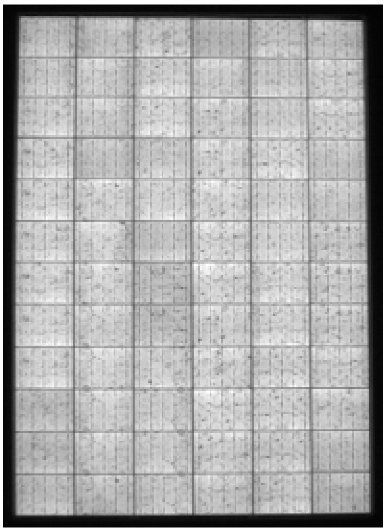

Figure 3. EL image of healthy module

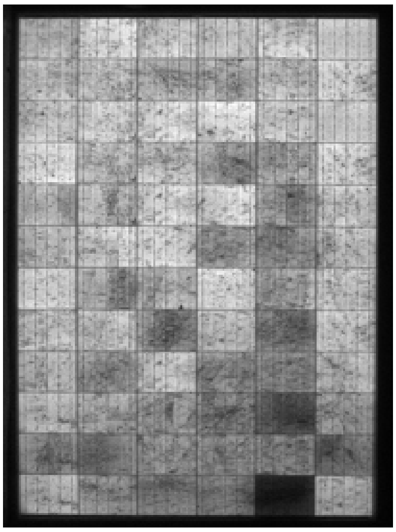

Figure 4. EL image with crack on module

is done by flash test, visual inspection, thermography and EL test of modules. This methodology is validated in the course of seven years of Mahindra Teqo's experience in the solar industry. Figures 3 & 4 show the EL testing of solar modules done on site, where the healthiness of solar module is checked. The samples for testing are selected as per the sampling guidelines recommend in this paper. Testing of sampled modules enables us to identify faults in the plant, apply corrective action and increase generation. If a 1MWp plant generates 1.70 million kWh/yr, then 1.5% extra module degradation can cause a loss in generation of 25,500kWh/yr. Based on a tariff of US$0.07/kW, this would result in a revenue loss of US$1,785/yr. Hence for a 100MW plant, which is quite common nowadays, the revenue loss will be 178,500 USD/yr – a significant amount. Therefore, identifying faulty modules through testing of selected samples can save revenue loss.

Conclusions

This sampling methodology can be used to ascertain the overall performance of a plant by testing sampled modules that represent the entire plant. There is no concrete guideline in a single standard available for field testing of PV modules in the market; to our knowledge, we are the first to standardise the whole process, and have prepared these guidelines based on our consultation with key stakeholders such as independent engineers, lenders, financial institutions, developers, EPC, manufacturer etc. This methodology is aligned with IS 2500/ISO 2859 sampling standards, which are defined primarily for pre-dispatch module testing; here IS standards have been incorporated as per field constraints. These guidelines will bring a coherency to field testing for PV modules, helping to standardise the process and will provide a common platform for every stakeholder to compare the results. ■

Authors

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Testing a meaningful sample of modules from a PV power plant can prevent potentially large financial losses