Evaluation of Underperforming Rooftop PV Plants in India – Moving from kW to kWh Part II

Phase I: Evaluation of 65 Rooftop PV Plants in India (Jammu, Uttar Pradesh, Gujarat, Maharashtra, West Bengal, Himachal Pradesh, Punjab and Kerala)

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List of abbreviations

AC	Alternating Current	**LTA**	Lender´s Technical Advisor
BOM	Bill of Materials	**LV**	Low Voltage
BOS	Balance of System	**MPP**	Maximum Power Point
CAPEX	Capital Expenditures	**MPPT**	Maximum Power Point Tracker
COD	Commercial Operation Date	**MV**	Middle Voltage
DC	Direct Current	**MWp**	Megawatt peak
DIF	Diffuse Horizontal Irradiance [Wh/m²]	**OE**	Owner´s Engineer
EL	Electroluminescence	**OPEX**	Operating Expense
EOW	End of Warranty	**O&M**	Operations and Maintenance
EPC	Engineering Procurement and Construction	**PAC**	Provisional Acceptance Commissioning
FAC	Final Acceptance Commissioning	**PCU**	Power Central Unit
FC	Financial Close	**PID**	Potential Induced Degradation
GHI	Global horizontal irradiation [Wh/m²]	**POA**	Plane of the Array
Isc	Short-circuit current	**PPA**	Power Purchase Agreement
IR	Infrared	**PR**	Performance Ratio
IV	Irradiation / Voltage	**PV**	Photovoltaic
KVA	Kilo-Volt-Ampere	**SPD**	Solar Project Developer
LCOE	Levelized Cost of Energy	**STC**	Standard Test Conditions
LID	Light Induced Degradation	**Voc**	Open circuit voltage

1. Executive Summary

The Government of India is aiming for an exponential increase in the installation of renewable energy systems in the country including 100 GW capacity of solar power by 2022 out of which 40 GW is targeted on rooftops. While the efforts are being directed towards substantially increasing the rooftop solar capacity, it is imperative to ensure that these systems perform with high yields.

Understanding the importance of ensuring that these installed rooftop solar systems perform optimally, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) undertook a technical study titled kWtokWh in 2019, the Part I of this mission. Under the Indo-German technical cooperation, the rooftop solar team at GIZ analysed the specific yields of various systems and found that many systems are performing sub-optimally. The technical advisory company PI Photovoltaik-Institut Berlin AG (PI Berlin) was contracted by GIZ to identify the causes of sub-optimal performance in 40 pre-selected rooftop PV plants, quantify those in terms of contribution to loss in generation and propose cost-optimal solutions to address the quality issues.

A website for the kWtokWh study Phase I (www.kwtokwh.in) has also been developed where the results of the Phase I of study have been uploaded. The findings of the initial part had a substantial impact on the Indian power sector considering the target of 40 GW of installed rooftop solar by 2022. Building on the knowledge gained in the earlier study, GIZ in partnership with the Ministry of New and Renewable Energy (MNRE) aims to conduct the Part II of the kWtokWh study. The focus on this next phase of the study will be to analyse additional sites along with delving into detailed causes for cell cracking by analysing the logistics aspects and mounting structures for the PV plants. The assignment will be conducted in two phases and a total of 65 sites will be evaluated. The broad scope for both phases shall remain the same.

The present report includes the results of 65 on-site inspections performed in the Indian states of Jammu, Gujarat, Maharashtra, Uttar Pradesh, West Bengal, Himchal Pradesh, Punjab and Kerala. The results of the evaluation of each of the PV plants presented in this study show that the low performance of the inspected PV plants is caused by a combination of (i) limited O&M, (ii) near shadings, (iii) high module degradation rates and (iv) module product defects. Module's underperformance stands out in this group, followed by mechanical damage in cells, disconnected circuits, and limited O&M (heavy soiling) and then self- and near shading. According to PI Berlin's calculations, the global losses at the system level caused by underperformance could exceed 15%, while the losses associated with soiling can widely exceed 25% during the dry season. In addition, in a few locations, some parts of the power plants were disconnected, due to a malfunctioning inverters and/or disconnected strings, generating losses ranging 1.5 - 50%.

PV modules are the core of a solar photovoltaic system. Hence, for the assurance of the Module quality of a PV plant, the best practices suggest performing in-factory supervision of production while PV modules are being manufactured. The purpose of this study regarding logistics was the evaluation of crack evolution from manufacturing until installation.

Even though transportation issues are known within the industry (cracks, scratches, broken glass), they are still a nuisance in project development, particularly during transportation. Furthermore, in the same way as lack of documentation available by plant owners (and in several cases, EPCs) is a frequent issue, the absence of after sales support by domestic module manufacturers limits development and confidence in local industry, creating a vicious circle. As part of the study, the consortium tried multiple times to approach the module manufacturers from the components under study. The purpose was requesting additional information regarding the manufacturing inline processes, such as Electroluminescence. However, the reluctance of the companies limits the development of the industry awareness of major issues such as pv module transportation, installation and handling malpractices. As described in the results for logistic evaluation, in some of the inspected PV Plants with severe mechanical damage at module level, the nominal power of the PV plant has been reduced by up to 8%.

One of the goals of the project is that future O&M contractors and developers can benefit from the knowledge and conclusions drawn from the evaluation of the PV plants presented in this study. In this sense, PI Berlin suggests 4 retrofitting actions that, depending on the status of each PV plant, might lead to a performance boost between 5% and 30%. Moreover, these actions do not require large investments in the OPEX.

The evaluation of the sites also includes an economic assessment regarding the retrofitting action on i) estimated energy boost after conducting the suggested retrofitting actions, ii) estimated costs of proposed retrofitting actions (CAPEX, OPEX), and iii) estimated retrofit cost per additional generation for remaining lifetime.

In regard to underperforming systems, modules with power performance under the expected values were discovered nearly at every PV plant. This issue shall be further addressed in cooperation with the developer, installer (EPC) and module manufacturer. Furthermore, if the situation warrants it (according to the specific installation contracts and the guarantees included), the proper claim could be initiated.

PI Berlin suggests 5 retrofitting actions to partially mitigate the negative consequences of the findings described throughout the report. The most important actions associated to these retrofitting actions are i) Improvement of module cleaning frequency, ii) Re-sorting of modules and strings, iii) Module replacement, iv) Increase of the albedo factor and v) create awareness of Module transport, handling and installation guidelines. Finally, PI Berlin has identified 10 prevention mechanisms to ensure the revenues and reduce the exposure to adverse technical, management, or environmental risks. These technical and commercial de-risking measures, for the next generation projects, are based on international standards, best practices, and PI Berlin's criteria beyond the norms.

2. Introduction and Background

The Government of India is aiming for an exponential increase in the installation of renewable energy systems in the country including 100 GW capacity of solar power by 2022 out of which 40 GW is targeted on rooftops. With this in mind, India's cumulative solar rooftop photovoltaic installations reached ca. 4.4 GW at the end of 2019 [Mercom]. While the efforts are being directed towards substantially increasing the rooftop solar capacity, it is imperative to ensure that these systems perform with high yields. The rooftop solar team at Gesellschaft für Internationale Zusammenarbeit (GIZ) has analyzed the specific yields of various systems and has found that many systems are performing sub-optimally. The technical advisory company PI Photovoltaik-Institut Berlin AG (PI Berlin) has been contracted by GIZ to identify the causes of sub-optimal performance, quantify those in terms of contribution to loss in generation and propose cost-optimal solutions to fix the quality issues.

Under the Indo-German technical cooperation, the Government of Germany is cooperating with India and has commissioned a project through the German Climate Technology Initiative (DKTI). The project Indo-German Solar Energy Partnership – Photovoltaic Rooftop Systems (IGSP-PVRT) is financed by the German Federal Ministry for Economic Cooperation and Development and implemented by GIZ in partnership with the Ministry of New and Renewable Energy (MNRE). The project aims to support MNRE in achieving the 40 GW targets announced for rooftop solar power plants under the National Solar Mission.

Building on the knowledge gained in the earlier study, GIZ in partnership with the Ministry of New and Renewable Energy (MNRE) aims to conduct the Part II of the kWtokWh study. The focus on this next phase of the study will be to analyze additional sites along with exploring into detailed causes for cell cracking by analyzing logistic and mounting structure aspects for the PV plants. The mission focuses on carrying out 60 on-site technical evaluations, in two phases, along with logistics monitoring of selected rooftop PV power plants in India. The approach of the current assignment will be to help improve the generation of the plants being studied and to help the Indian rooftop solar sector in improving actual generation.

The results will lead to synthesizing a solution, potentially in the form of business models for O&M companies. This report summarizes the results of the assessment of the 60 rooftop PV plants, located in of Jammu (Jammu and Kashmir), Ahmedabad, Anand, and Vadodara (Gujarat), Nagpur (Maharashtra), Lucknow (Uttar Pradesh), West Bengal, Himachal Pradesh and Punjab, as well as the outcomes of the evaluation of module handling and installation practices, for 5 additional PV sites (in construction phase during the study).

3. About PI Berlin

The Photovoltaik-Institut Berlin is a leading technical advisor, risk manager and quality assurance provider for PV power plants and equipment. With its experienced team of researchers, scientists and engineers, PI Berlin offers a wide range of design, testing and evaluation services with a focus on the risk management and quality assurance of PV equipment and complex PV power plants. PI Berlin has already supported 11 GW of PV power plants worldwide, with over 245 audits conducted on over 115 manufacturers producing more than 67 GW of PV equipment annually.

PI Berlin has an IEC 17025 accredited test laboratory at its Berlin location for evaluating the performance, reliability, and durability of solar modules. Another test laboratory is located in Suzhou, China. Modules are tested according to strict criteria that meet or exceed IEC standards.

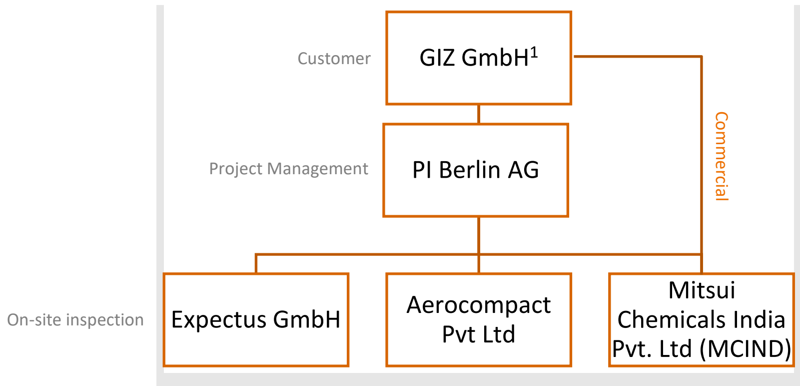
4. Description of the Inspection Methodology

This chapter summarizes the methodology that will be carried out for the fulfillment of the project objectives: (i) preparation phase, (ii) data acquisition, and (iii) postprocessing and reporting. The complete methodology (Inception report) can be found as appendix to this document.

For Phase II of the project kW to kWh, PI Berlin AG will act as project manager and coordinate the partners during all project stages. A weekly call was held (including GIZ) to discuss the project status, according to the amount and type of inspections and their preliminary results.

Stakeholders

The following graph described the relationship between the stakeholders within the project:



[1] Deutsche Gesellschaft für Internationale Zusammenarbeit

Preparation Phase

The preparation phase is mainly focused on selecting and securing the access to the roofs. The selection criteria agreed with GIZ and can be detailed as follows:

Identification of a broad list of 65 sites in at least 4 different locations as per the conditions below:

I. Installed capacity:

a. Between 1-5 kWp (at least 10% of sites)

b. 20 kWp and above

ii. Specific Yield:

a. Less than 1100 kWh/kWp (70% of sites)

b. More than 1200 kWh/kWp (30% of sites)

iii. Age of the plant:

a. More than one year old

b. Recent installations of less than one year old (at least 10 % of sites)

c. Ongoing installations (For logistics monitoring; refer to Task 3)

iv. Availability of reliable generation data

Data Acquisition

Ahead of each visit, the available documentation was reviewed in order to maximize the efficiency during the site inspection. By means of these documents, a digital App-based checklist will be prepared to maximize the accuracy during the on-site inspection.

MCIND Pvt Ltd and Aerocompact Pvt Ltd conducted the site visits spending one day per site. The site inspections focused primarily on aspects that have direct impact on the performance, such as (i) module cleaning, (ii) PV module degradation, (iii) shading situation, (iv) inverter unavailability, (v) logistic aspects, and (vi) O&M considerations. Safety issues, without a direct impact on the performance, were also documented.

Regarding logistics and installation, the assessment will cover i) Pre-shipment inspection criteria, ii) Module packaging characteristics, iii) Transportation, handling, delivery and pre-installation iv) Mounting structure design and robustness and vi) Storage space availability and characteristics. Furthermore, the specific retrofitting actions will be targeted to solve a) detailed causes of cell cracking, b) comparison between plants using dust cleaning robots (DCR) vs manual cleaning, c) appropriate cleaning mechanisms for selected plants, d) module handling practices and e) Module manufacturing quality.

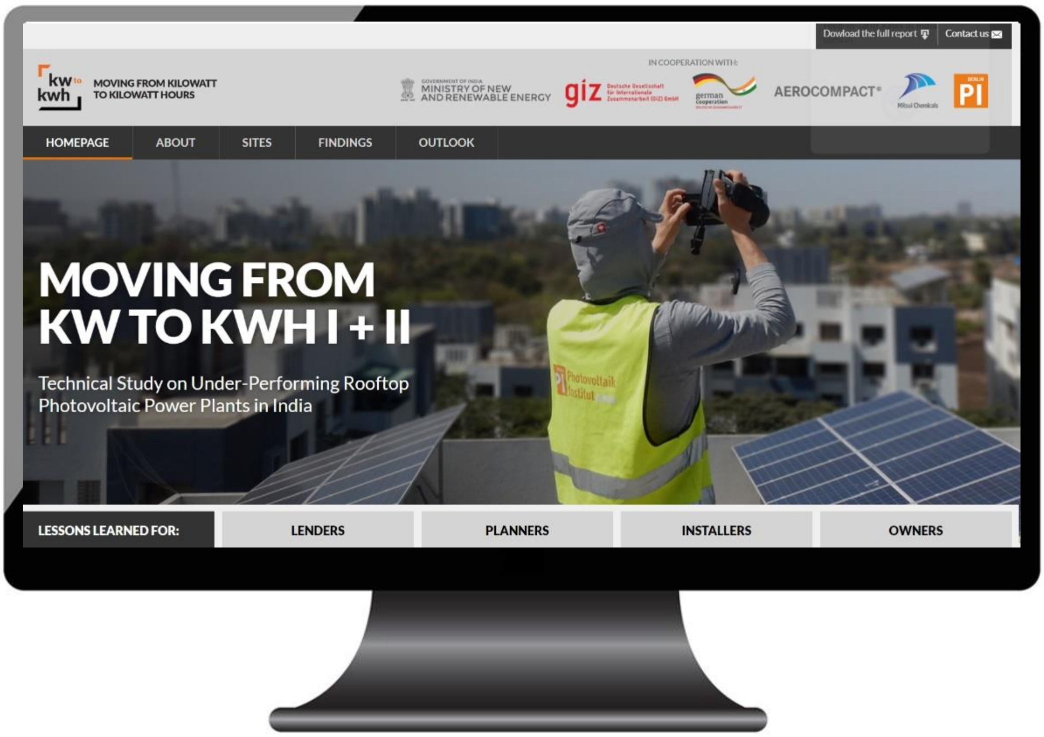
Post-processing and Reporting

The information gathered onsite was post-processed and combined with the results of the documentation reviewed ahead of the visit. Each of the findings responsible for performance drop has been, as far as possible, coupled to an estimated energy loss and feasible mitigation measures. The final statements of PI Berlin in regard to the quantification of the impact of the identified findings, are based on (i) PI Berlin's long-term experience in the PV sector, (ii) on-site data acquisition, and (iii) simulations using PVsyst software. The results achieved by PI Berlin will provide answers to the following questions:

1. Which findings have the highest impact on the PR values of the inspected roofs?
2. Which mechanisms are needed to avoid underperformance and ensure the revenues in the next generation projects?
3. Why is it important to prevent the issues discovered in the present study?
4. How can India benefit of this process?

Website

The website kwtokwh.in (showing the results from Phase I of this project) has been used to present the outcomes of phase II and were published after the approval of GIZ.



5. List of the Selected Sites

Jammu is the winter capital of the Indian union territory of Jammu and Kashmir. It is the largest city in Jammu district of the union territory and sits on the banks of the river Tawi. It has a humid subtropical climate with extreme summer highs reaching 46 ^{o}C and temperatures on winter falling below 4 ^{o}C.

Gujarat is the fifth-largest state by area in India and nineth-largest by population. With a 1,600 km coastline, it has a hot, semi-arid climate with average maximum temperature of 34 ^{o}C and with average minimum of 21 ^{o}C.

Nagpur is the third largest city and the winter capital of the Indian state of Maharashtra. Nagpur is named after the Great River Nag which flows through the city, and it has a tropical savannah climate what means an average highest temperature of 43 ^{o}C and average lowest temperature of 13 ^{o}C.

Lucknow is the largest city in and the capital of the Indian state of Uttar Pradesh. It has a dry-summer subtropical climate with average highest temperature of 42 ^{o}C and average lowest temperature of 19 ^{o}C.

West Bengal is the thirteenth-largest state by area in India and fourth largest by population. West Bengal's climates range from Tropical savanna climate to subtropical highland oceanic climate with average annual temperature of 31.3 ^{o}C and with average minimum of 20.1 ^{o}C.

Himachal Pradesh is one of the thirteen mountain states in India and is the northernmost state of India, shading borders with union territories of Jammu and Kashmir. It's climates range from humid subtropical climate to subarctic climate with average annual temperature of 16.1 ^{o}C.

Punjab is the nineteenth-largest state by area in India and sixteenth largest by population. Punjab has a humid subtropical climate with average annual temperature of 33.9 ^{o}C and with average minimum of 13 ^{o}C.

These regions provide different scenarios for the evaluation of systems exposed to challenging weather conditions. The selected sites under the scope of the project are shown in the following table:

Table 1: The selected sites under the scope of the project

PV Plant	Region	Installed capacity (kWp)	Average specific yield since COD
1	Jammu	200	628 kWh/kWp
2	Jammu	100	914 kWh/kWp
3	Jammu	50	970 kWh/kWp
4	Jammu	50	168 kWh/kWp*
5	Jammu	100	717 kWh/kWp
6	Jammu	140	801 kWh/kWp
7	Ahmedabad	35	1164 kWh/kWp
8	Ahmedabad	130	893 kWh/kWp
9	Ahmedabad	50	1331 kWh/kWp
10	Anand	200	1444 kWh/kWp
11	Ahmedabad	31	1253 kWh/kWp
12	Vadodara	63	927 kWh/kWp
13	Nagpur	100	1306 kWh/kWp
14	Nagpur	90	1234 kWh/kWp
15	Nagpur	15	1127 kWh/kWp
16	Ahmedabad	104	1356 kWh/kWp
17	Nagpur	670	746.7 kWh/kWp
18	Nagpur	80	637 kWh/kWp
19	Nagpur	20	1159 kWh/kWp
20	Nagpur	20	768 kWh/kWp
21	Mehsana	124	1090 kWh/kWp
22	Godhra	39	1322 kWh/kWp
23	Dholka	40	1440 kWh/kWp
24	Anand	39	1033 kWh/kWp
25	Gondal	348	1324 kWh/kWp
26	Bhavnagar	23	1245 kWh/kWp
27	Amreli	28	1374 kWh/kWp
28	Sarangpur	120	1216 kWh/kWp
29	Surendranagar	50	1230 kWh/kWp
30	Lucknow	109	678 kWh/kWp
31	Lucknow	10	1131 kWh/kWp
32	Lucknow	80	909 kWh/kWp
33	Lucknow	5	870 kWh/kWp
34	West Bengal	10	1039.6 kWh/kWp
35	West Bengal	5	526.8 kWh/kWp
36	West Bengal	10	1203.6 kWh/kWp
37	West Bengal	10	1044.3 kWh/kWp
38	West Bengal	20	1331.83 kWh/kWp
39	West Bengal	5	1100.8 kWh/kWp
40	West Bengal	10	1172 kWh/kWp
41	West Bengal	10	1099.7 kWh/kWp
42	West Bengal	10	894.7 kWh/kWp
43	Himachal Pradesh	349	942.7 kWh/kWp
44	Himachal Pradesh	29	1245.9 kWh/kWp
45	Himachal Pradesh	300	1190.1 kWh/kWp
46	Himachal Pradesh	160	759.1 kWh/kWp
47	Himachal Pradesh	300	894.7 kWh/kWp

48	Himachal Pradesh	6	1052.1 kWh/kWp
49	Himachal Pradesh	5	646.2 kWh/kWp
50	Punjab	120	906.8 kWh/kWp
51	Punjab	65	824.81 kWh/kWp
52	Punjab	500	839.97 kWh/kWp
53	Punjab	151	1081.97 kWh/kWp
54	Punjab	100	604.31 kWh/kWp
55	Punjab	90	1294.84 kWh/kWp
56	Punjab	80	1275.8 kWh/kWp
57	Punjab	71	1262.8 kWh/kWp
58	Punjab	399	1040.58 kWh/kWp
59	Punjab	72	664.65 kWh/kWp
60	Punjab	101	1194.66 kWh/kWp
61	Ahmedabad	2	Underconstruction
62	Gujarat	2	Underconstruction
63	Mumbai	2	Underconstruction
64	Kerala	33	Underconstruction
65	Gujarat	5	Underconstruction

* limited information provided concerning the energy production.

Figure 1: Inspected sites: Jammu, Himachal Pradesh, Punjab, Gujarat, Nagpur, Lucknow, West Bengal, and Kerala. Source: Google Earth

Climate characteristics:

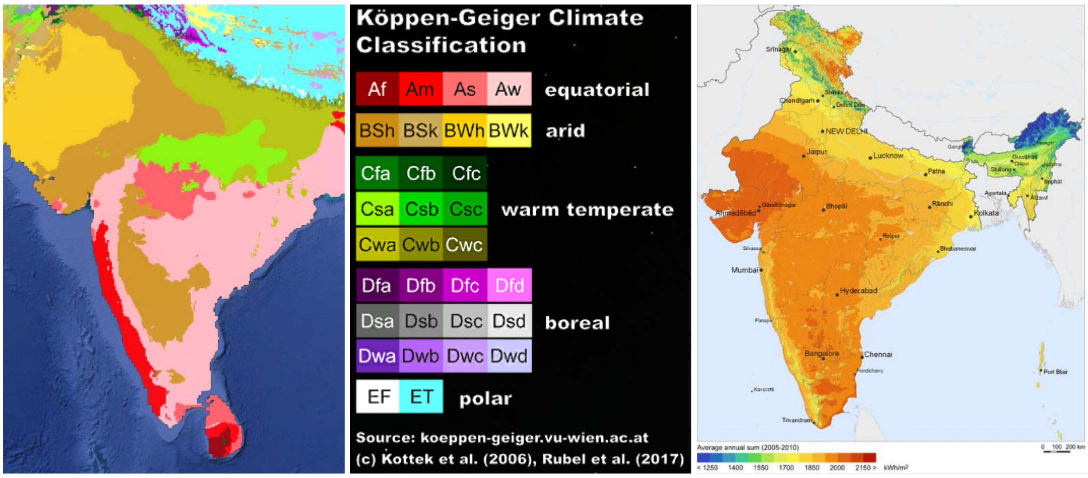


Figure 2: Köppen-Geiger climate classification map for India (1980-2016) [17]

Jammu

In Jammu, Jammu and Kashmir, the climate is warm and temperate. When compared with winter, the summers have much more rainfall. According to Köppen and Geiger, this climate is classified as Cwa. The average annual temperature in Jammu is 21.3 °C | 70.4 °F. About 1313 mm | 51.7 inch of precipitation falls annually. The driest month is October. There is 17 mm | 0.7 inch of precipitation in October. In July, the precipitation reaches its peak, with an average of 321 mm | 12.6 inch. May is the warmest month, with an average of 31.3 °C and December the coldest with an average temperature of 22.2 °C [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 1695 kWh/m² [source: SolarGIS].

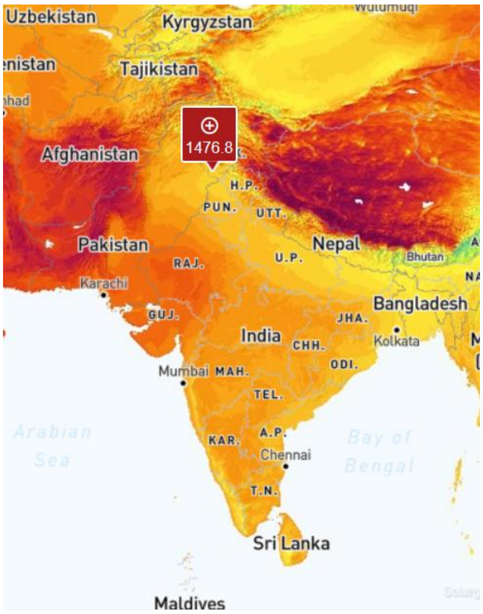


Figure 3: Global horizontal irradiation map of Jammu. GHI: 1695.4 kWh/m². Specific yield PVout 1477kWh/kWp) [source: SolarGIS]

Gujarat

The climate here is considered to be a local steppe climate. During the year there is little rainfall. The Köppen-Geiger climate classification is BSh. The temperature here averages 27.1 °C | 80.7 °F. About 757 mm | 29.8 inch of precipitation falls annually. The driest month is January, with 1 mm | 0.0 inch of rain. Most of the precipitation here falls in July, averaging 307 mm | 12.1 inches. May is the warmest month of the year. The temperature in May averages 33.0 °C | 91.4 °F. January is the coldest month, with temperatures averaging 20.4 °C | 68.7 °F. [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 2016 kWh/m² [source: SolarGIS].

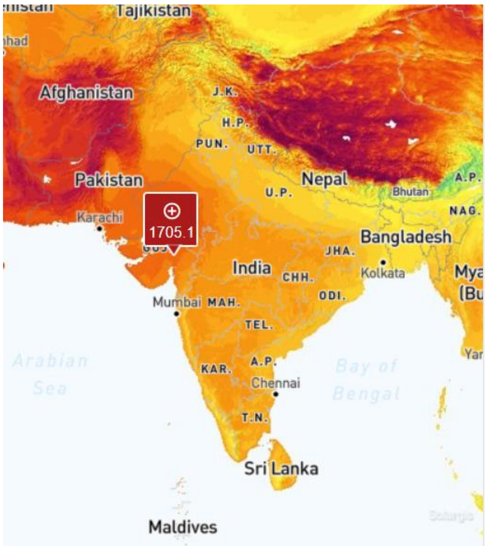


Figure 4: Global horizontal irradiation map of Gujarat. GHI: 2016 kWh/m². Specific yield PVout 1705kWh/kWp) [source: SolarGIS]

Nagpur

Nagpur, Maharashtra, has a tropical climate. In winter, there is much less rainfall than in summer. The Köppen-Geiger climate classification is Aw. The temperature here averages 27.0 °C | 80.7 °F. About 1128 mm | 44.4 inch of precipitation falls annually. The driest month is December, with 6 mm | 0.2 inches of rainfall. Most precipitation falls in July, with an average of 355 mm | 14.0 inch. The warmest month of the year is May, with an average temperature of 35.6 °C | 96.1 °F. In January, the average temperature is 21.1 °C | 69.9 °F. It is the lowest average temperature of the whole year. [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 1888 kWh/m² [source: SolarGIS].

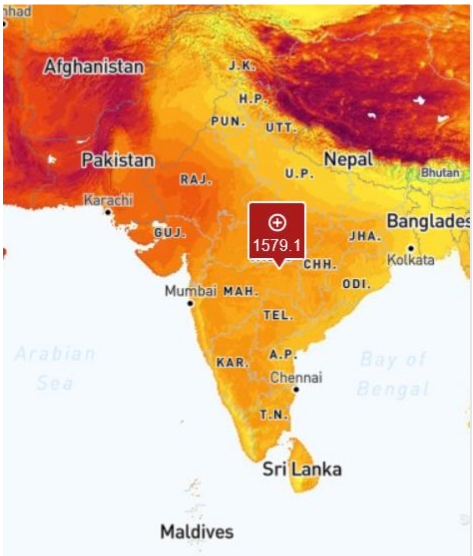


Figure 5: Global horizontal irradiation map of Nagpur. GHI: 1888kWh/m². Specific yield PVout 1579kWh/kWp) [source: SolarGIS]

Lucknow

Lucknow, Uttar Pradesh, has a dry-summer subtropical climate. In winter, there is much less rainfall than in summer. The Köppen-Geiger climate classification is Csa (Mediterran Climate). The temperature here averages 25.6 °C | 78.0 °F. About 1016 mm | 40.0 inch of precipitation falls annually. The driest month is November, with 2 mm | 0.1 inches of rainfall. Most precipitation falls in July, with an average of 310 mm | 12.2 inch. The warmest month of the year is May, with an average temperature of 32.8 °C | 91.1 °F. In January, the average temperature is 14.9 °C | 58.9 °F. It is the lowest average temperature of the whole year. [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 1754 kWh/m² [source: SolarGIS].

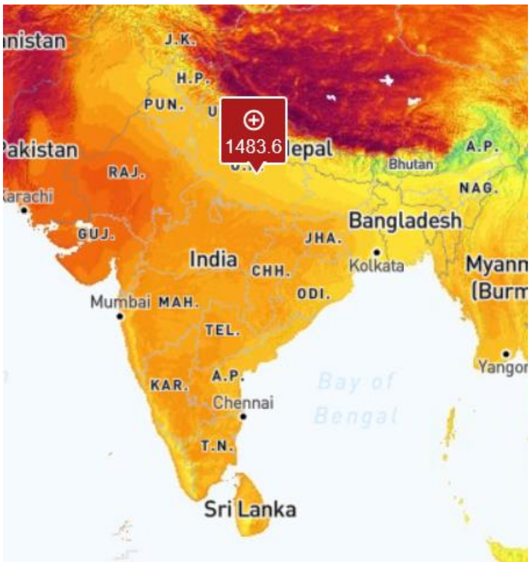


Figure 6: Global horizontal irradiation map of Lucknow. GHI: 1754kWh/m². Specific yield PVout 1484kWh/kWp) [source: SolarGIS]

West Bengal

West Bengal has a tropical climate. In winter, there is much less rainfall than in summer. The Köppen-Geiger climate classifications for the state range from Aw (Tropical savanna climate) to Cwb (Subtropical highland oceanic climate). The temperature here averages 26 °C | 78.8 °F. About 1656 mm | 65.2 inch of precipitation falls annually. The driest month is December, with 7.6 mm | 0.3 inches of rainfall. Most precipitation falls in July, with an average of 355.6 mm | 14 inch. The warmest month of the year is May, with an average temperature of 31.3 °C | 88.3 °F. In January, the average temperature is 20.1 °C | 68.1 °F. It is the lowest average temperature of the whole year. [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 1758 kWh/m² [source: SolarGIS].

Figure 7: Global horizontal irradiation map of West Bengal. GHI: 1758kWh/m². Specific yield PVout 1477kWh/kWp) [source: SolarGIS]

Himachal Pradesh

Himachal Pradesh has a dry-summer subtropical climate. In winter, generally there is much less rainfall than in summer. The Köppen-Geiger climate classification ranges from Cfa (Humid subtropical climate) to Dfc (Subarctic climate). The temperature here averages 16.1 °C | 61.0 °F. About 1876 mm | 73.9 inch of precipitation falls annually. Most precipitation falls in July. [source: climate-data.org].

The average Global Horizontal Irradiation (GHI) in the region is 1518 kWh/m² [source: SolarGIS].

Figure 8: Global horizontal irradiation map of Himachal Pradesh. GHI: 1518kWh/m². Specific yield PVout 1504kWh/kWp) [source: SolarGIS]

Punjab

Punjab has a humid subtropical climate. Summers usually receive slightly higher rainfall than winters, with much of the precipitation from thunderstorm and tropical cyclones. The Köppen-Geiger climate classification is Cfa (Humid subtropical climate). The temperature here averages 24.3 °C | 75.7 °F. About 698.5 mm | 27.5 inch of precipitation falls annually. The driest month is November, with 5.1 mm | 0.2 inches of rainfall. Most precipitation falls in July, with an average of 200.7 mm | 7.9 inch. The warmest month of the year is June, with an average temperature of 33.9 °C | 93.0 °F. The coolest month is January, with an average temperature is 13 °C | 55.4 °F. [source: weatherbase.com].

The average Global Horizontal Irradiation (GHI) in the region is 1738 kWh/m² [source: SolarGIS].

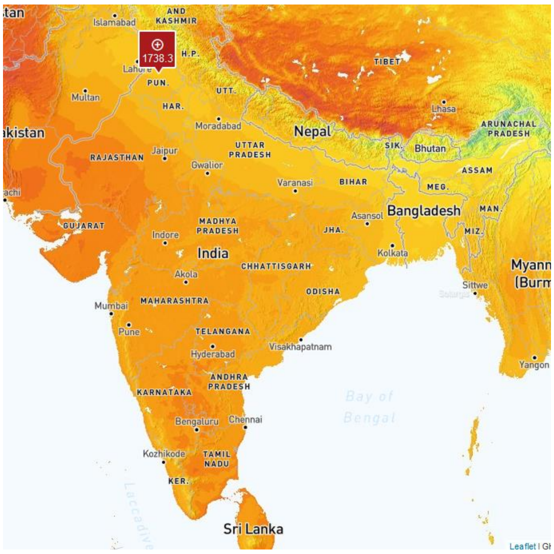


Figure 9: Global horizontal irradiation map of Punjab. GHI: 1738kWh/m². Specific yield PVout 1507kWh/kWp) [source: SolarGIS]

Kerala

Kerala has a tropical monsoon climate. The Köppen-Geiger climate classification is Am (Tropical monsoon climate). The temperature here averages 27.8 °C | 82.0 °F. About 2743.2 mm | 108 inch of precipitation falls annually in average. The driest month is January, with 22.9 mm | 0.9 inches of rainfall. Most precipitation falls in June, with an average of 566.4 mm | 22.3 inch. The warmest month of the year is September, with a maximum temperature of 38.9 °C | 102.0 °F. The coolest month is January, with an average temperature is 17.2 °C | 63.0 °F. [source: weatherbase.com].

The average Global Horizontal Irradiation (GHI) in the region is 1769 kWh/m² [source: SolarGIS].

Figure 10: Global horizontal irradiation map of Punjab. GHI: 1769kWh/m². Specific yield PVout 1424kWh/kWp) [source: SolarGIS]

6. Technical Background

This chapter serves as a guide for the better understanding of some of the module failures mentioned in the present study.

6. 1. Potential-Induced Degradation

The phenomenon of Potential-Induced Degradation (PID) is based on a power loss degradation caused by a negative potential of the solar cells towards earth, which leads to an accumulation of Na^+ located in the glass and migrating into the solar cells damaging the p-n junction responsible for the electron flow [14]. The degree of affection is highly dependent on the level of the potential (voltage stress). The first bibliographic references relate to the investigations carried out by Hoffman and Ross (JPL) in 1978 ("Impact of voltage-biased humidity exposure of solar modules on long-term stability") in which this physical effect was internationally presented for the first time. The PID effect was associated in the past principally to back contact cell technology, TCO corrosion in thin film modules and processes based upon band silicon. In recent years, the PID effect has also been linked to silicon technology; thus, this phenomenon has become more and more relevant due to the enormous amount of solar facilities built with this technology.

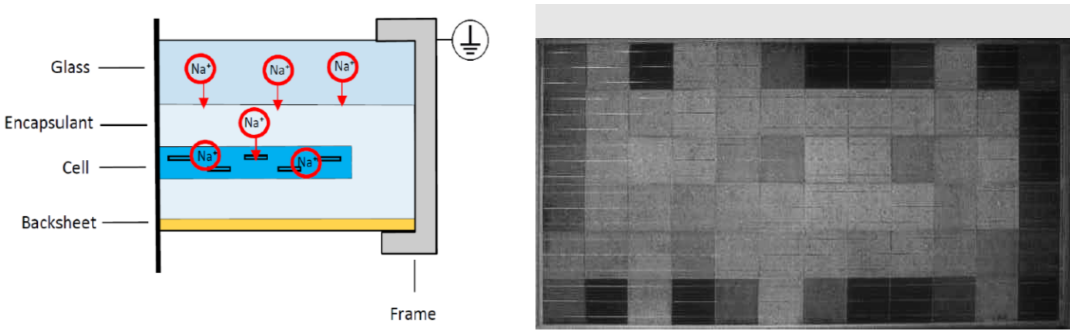


Figure 11: p-n junction damage (left) and typical PID pattern (right) [source: PI Berlin]

The necessary conditions for the appearance of PID in the field can be summarized as follows:

- High system voltage (has increased in the last years in order to minimize transport losses in the string)
- High relative humidity and high temperature
- Certain combination of materials (glass, encapsulate material, etc.)

The degree of PID of the PV modules decreases towards the positive pole, with the first modules of the negative pole being usually the most affected with power drops up to 95% in cases of advanced PID.

6. 2. Light and Elevated Temperature Induced Degradation

The Light and elevated Temperature Induced Degradation (LeTID) is a form of solar cell degradation (8-10% drop in relative efficiency) seen in the field and is accelerated by high irradiance at higher temperatures after hundreds of hours of light exposure.

The rear side passivation (PERC) is in most cases realized by a hydrogen-rich dielectrics, that when firing (manufacturing process), the released hydrogen reacts with the impurities of the silicon. With temperature and illumination, these bonds are easily broken, freeing the weakly bonded hydrogen at a faster rate, and thus leading towards degradation.

LeTID is the stronger degradation, if no countermeasures have been applied by the manufacturer, i.e., either by changing the cell process or by fast degradation/regeneration in the cell or module line. As the name suggests, LeTID is exacerbated by higher operating temperatures and higher light intensity. Unlike LID, LeTID can occur over a much longer period of time, showing that the development rate of LeTID in the cell is slower than any boron/oxygen combination process [REC].

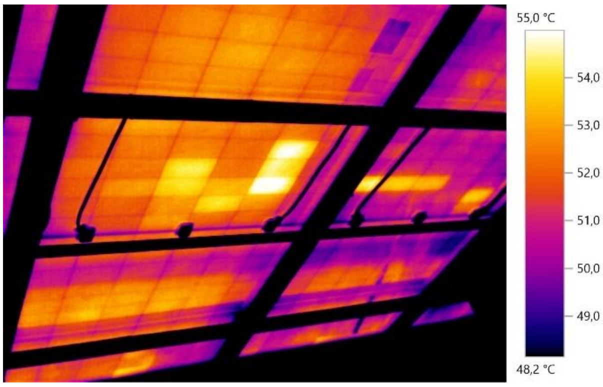


Figure 12: p-n junction damage (left) and typical PID pattern (right) [source: PI Berlin]

6. 3. Snail Trails

It is defined as a grey/black discoloration of the silver paste of the front metallization of screen-printed solar cells. In the PV module the effect looks like a snail trail on the front glass of the module and is visible to the human eye. The discoloration occurs along invisible cell cracks. The discoloration typically occurs 3 months to 1 year after installation of the PV modules. During the summer and in hot climates snail trails occur faster [1]. The area of the snail trail discoloration along the silver finger of the front side cell metallization shows nanometer-sized silver particles in the EVA above the silver finger. These silver particles cause the discoloration [5], [14]. The snail trails appear typically as branched trails across the cells and are a clear sign of hidden cell damages [15], [18].

Figure 13: PV module showing snail trails [source: PI Berlin]

6. 4. Hot Spots

A hot spot is defined as a localized region in a PV module whose operating temperature is very high in comparison with its surroundings. This can occur when a cell generates less current than the rest of cells connected in series as a result of partial shading, cell damage, mismatching or interconnection failure. As a result, the defective cell is reverse biased and behaves like a load that dissipates the power generated by the rest of the cells in the form of heat [14]. The protection against hot spots is also well-known and consists of connecting a bypass diode, with reverse polarity, in parallel with a group of cells, typically 12 or 18 for crystalline silicon modules. Thus, the defective cell is reverse biased to a point that causes the forward conduction of the bypass diode, which almost short circuits the group of cells and ensures that, in the worst case, the aforementioned cell dissipates nearly the power generated by the remaining cells in the group [12]. Hot spots present a potential risk of irreversible damage for PV modules. They can cause, for example, tedlar delamination, glass breakage, loss of electrical insulation or even fire [14].

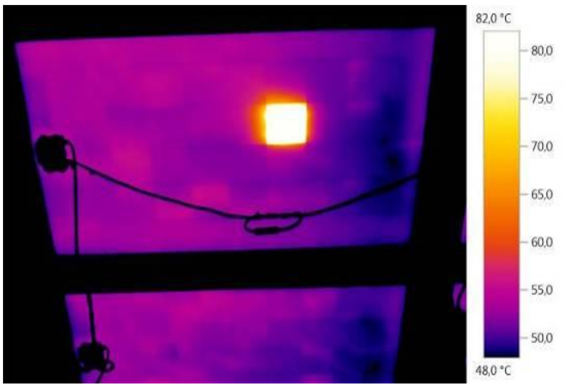


Figure 14: PV Module affected by a hot spot [source: PI Berlin],

6. 5. Inactive Cell Strings

In parallel to a certain number of solar cells, bypass diodes are integrated into the PV module. These bypass diodes reduce the power loss caused by partial shading on the PV module. Besides the power loss, the diode avoids the reverse biasing of single solar cells higher than the allowed cell reverse bias voltage of the solar cells. If a cell is reversed with a higher voltage than it is designed for, the cell may create hot spots that may cause browning, burn marks or, in the worst case, fire. Typically, Schottky diodes are used as bypass diodes in PV modules. Schottky diodes are very susceptible to static high voltage discharges and mechanical stress. So, they should be handled with care and human contact without grounding should be avoided [14]. Consequently, many bypass diode failures may occur. But it is difficult to find them because they only attract attention when the PV modules have severe mismatch in the individual IV characteristic of single cells, e.g., caused by shading or disconnected parts of a cell due to cell cracks [1].

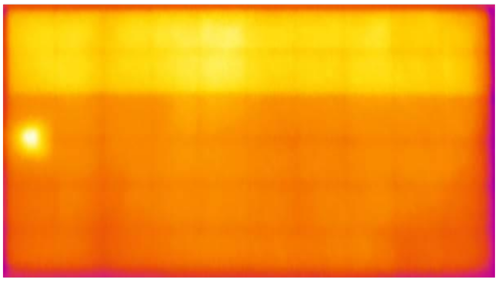


Figure 15: PV Module with an inactive cell string [source: PI Berlin]

6. 6. Cell Breakage and Microcracks

Photovoltaic cells are made of silicon. This makes the cells very fragile. Cell cracks are cracks in the silicon substrate of the photovoltaic cells that often cannot be seen by the naked eye. The cracks and microcracks can be detected easily with electroluminescence technique as shown in the picture below.

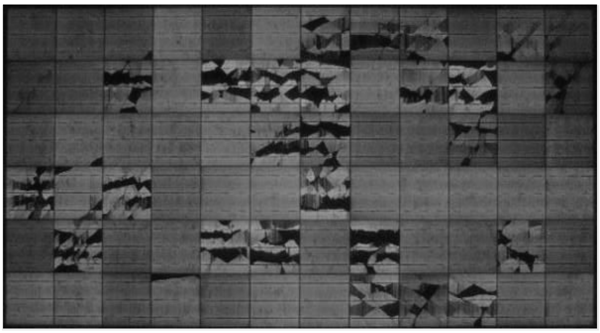


Figure 16: PV Module showing cracks and microcracks [source: PI Berlin]

Cell cracks can form in different lengths and orientations in a solar cell. [5],[14]. They are clearly recognizable as a dark line in the EL image and has no limitation in width. On one hand, a broken cell is a cell that has a crack from cell edge to cell edge, with both cell parts still electrically connected to each other. Furthermore, an isolated cell part is a cell piece which appears totally dark in the EL image due to the further development of a crack (break-off of the fingers). A cell part which shows only a reduction in EL intensity is normally not regarded as an electrically isolated cell area.

The associated power losses to the aforementioned phenomenon will depend on the size and depth of the crack, while the crack propagation is purely influenced by the site conditions (for instance, wind, temperature, and snow).

6. 7. Delamination

Solar panel delamination occurs when the bond between the plastics in the rear side and the front glass begin to separate. If cells are contaminated, for example by residues from the soldering flux, the EVA film does not adhere optimally, and it can come off. These signs of detachment are visible as gray areas in the module, but do not necessarily have an impact on the operation of the module. Significantly more critical are delamination phenomena that occur due to material defects in the EVA or defects in the lamination process. These can extend over the entire module surface and in the worst-case lead to insulation faults.

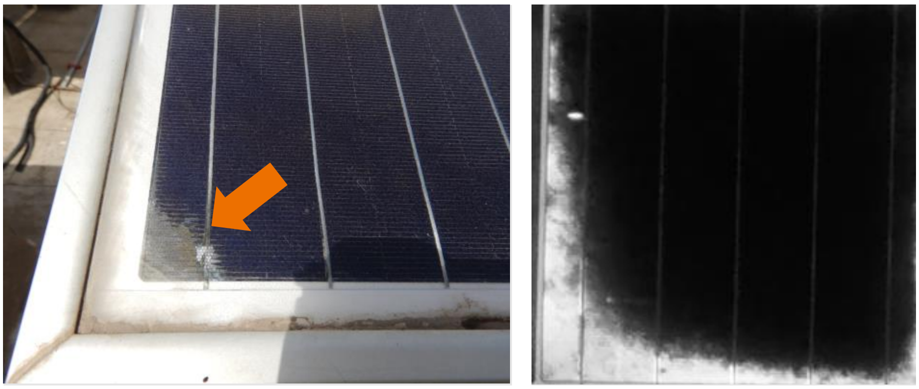


Figure 17: PV Module showing delamination. Left, VI, right, EL [source: PI Berlin]

6. 8. Quality Assessment of PV Modules and Structure

The PV modules are the core of a solar photovoltaic system. Hence, for the assurance of the Module quality of a PV plant, the best practices suggest performing in-factory supervision of production while PV modules are being manufactured. This includes experienced Quality Engineers deployed in the factory during production. The Engineers will supervise production to ensure that all required material, process and production controls are applied - and applied correctly.

When this process cannot be implemented or is not part of the scope or a Project[2], there are a few mitigation measures to uncover possible risks on an early stage of the projects. These are the so-called Pre-shipment Inspection, Post-Shipment Inspection (PSI) and Inspection During Installation procedures.

The Pre-shipment inspection is normally carried out on a sample basis and used to release modules for shipment (Manufacturing facility). During the Post-Shipment Inspection, a sample of modules is normally tested prior installation. Upon delivery of the modules to the Project site, and prior to the installation of the modules, Visual inspection (VI) and Electroluminescence (EL) imaging are performed once again. Here, the defect criteria defined in the supply agreement will be used (when available). During installation, the technical advisor will provide oversight of the installation of the modules and testing on a quantity of installed modules (VI and EL) and mounting structure (VI) to verify the quality of the installation work, including but not limited to: PV Module Handling & Storage and PV Module Mounting (EPC, different crews). Quality criteria as defined in the purchase is normally used, unless specified otherwise.

Logistic activities

For the sites for logistics assessment, the main reporting was on the evolution of the VI and EL failures in the modules from manufacturing, at warehouse (intermediate delivery), upon arrival and after installation, in a way that the 4 pictures evaluated are displayed so it is clear where the modules suffered most of the damages, i.e., Manufacturer/Warehouse - On-site delivery - After installation.

The purpose of this evaluation is to describe a common acceptance criterion for the Electroluminescence analysis (PI Berlin) for Poly-crystalline and mono-crystalline PV modules. PV Modules with critical defects are to be replaced after inspection by the owner/constructor, according to contractual criteria (with replacement modules being inspected under the same criteria).

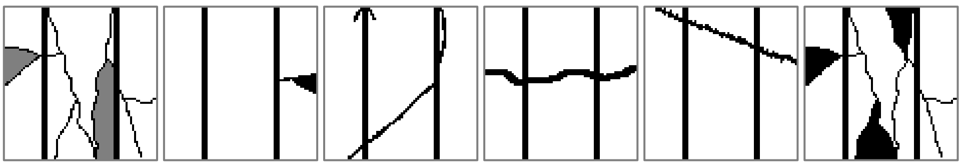


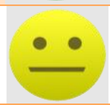
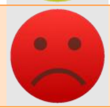
Figure 18: Cracks: branched, broken small, crack cross, crack perpendicular, scratch, broken multiple (PI Berlin)

Then, a more superficial evaluation of the sites in general (mounting structure, cabling, shadings, etc.) was performed.

[2] *That is the case of this Project whose scope of work includes only the quality assessment of PV systems with modules already manufactured.*

7. Results of the Analysis

The following section summarizes the outcomes of the investigations conducted by PI Berlin on the 65 rooftop PV plants. The following icons indicates the PV Plants' health:

Result	Average Specific Yield
	> 1200 kWh/kWp
	1000 – 1200 kWh/kWp
	< 1000 kWh/kWp

Although the logistic sites evaluated don't produce electricity yet, the general PV Module's health was weighed with the same icons to represent a good, average and bad condition.

1

PV plant: ***II.1***
Nominal capacity: ***200 kWp***
Average specific yield for last two years: ***628 kWh/kWp*** *(PVsyst estimation 1392 kWh/kWp)*

***Abstract**: The PV plant shows inhomogeneous amount of soiling. There is evidence of both partially open and broken connectors. Furthermore, the installed system is affected by near shading and the cabling is exposed to UV radiation and sharp edges. It is recommended to (i) replace to broken modules and cables, (ii) install an irradiation sensor (iii) practice frequent cleaning of the modules and the inverter-fan filters, (iv) re-stringing of shaded modules, and (v) yearly thermography inspection of the modules. The estimated production boost expected by the retrofitting actions lies between 5 and 10%.*

PV Plant's health

Main Findings

- Cable layout and labelling are in bad conditions. In addition, table and inverter labelling is missing. This makes maintenance work difficult and increase losses during O&M work on site.

Figure 19: Poor cable layout and labeling.

- String cables and MC4 connectors are not UV protected and with a high risk of water contact, resulting in isolation issues.
- The lightning protection is broken.
- Due to strong winds some clamps were pulled off, resulting in misalignment of modules.

Figure 20: Clamps missing.

- Modules were installed beyond the roof boundary this may cause higher wind loads in some parts resulting in uprooted modules.
- The minimum cable bending radius is not met.
- Broken, open and burned connector are found on-site.

Impact on Performance

- Modules are cleaned once a week with equipment in poor conditions. Some parts of the PV plant are heavily soiled due to bird dropping.

Figure 21: Soiling – bird droppings.

- The telephone tower close to the modules produces shading with a particular pattern resulting in hotspots.
- According to the number of cracks discovered via EL imaging; the system is not expected to have large power losses due to inactive areas.

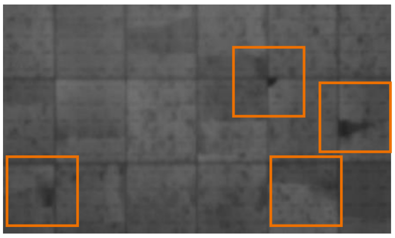


Figure 22: EL-Image with multiple cracks

- The underperformance of the inspected modules is 60%.

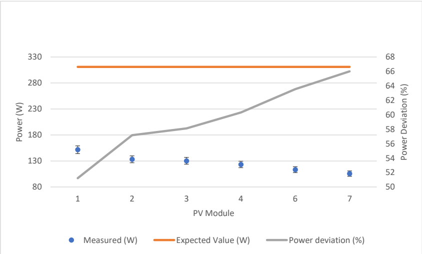


Figure 23: IV curve measurements

Proposed Solutions

- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Broken modules and cables should be replaced.
- UV protection measurements should be taken, it could be by using a suitable cable rack with roof or cable coating.
- Cable racks should be separated from the ground to avoid water contact.
- The cable layout can be optimized; the minimum bending radius is 10x times the cable diameter.
- Strings, Tables, and inverters should have a suitable labelling (UV-resistant if applicable).
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

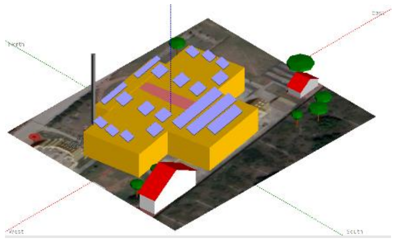


Figure 24: 3D model constructed in PVsyst.

- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.47 ₹/Wp, 0.20 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 6.9 ₹/kWh to 3.5 ₹/kWh

Picture Gallery

Figure 25: Shading due to cables.

Figure 26: General overview.

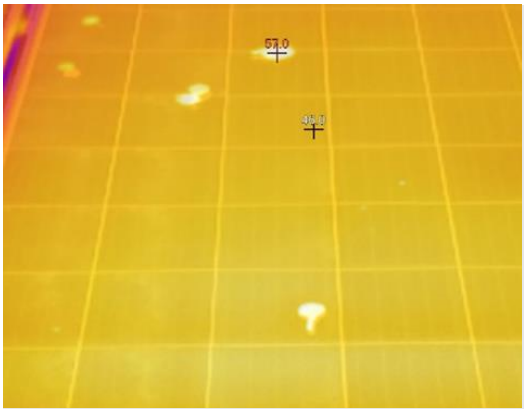


Figure 27: Hotspots - bird drops.

Figure 28: Broken MC4 connectors.

Figure 29: Poor cable management.

Figure 30: Shaded modules.

2

PV plant: ***II.2***
Nominal capacity: ***100 kWp***
Average specific yield for year 2020: ***914 kWh/kWp*** *(PVsyst estimation 1325 kWh/kWp)*

Abstract: *The PV plant is affected by near shadings caused by nearby trees, buildings, and a water tank; a soiling loss of 1% was determined via IV measurements; some modules present broken front glass, burnt marks and moisture damage; and modules were not properly fixed, and some fixing elements are rusted. It is recommended to (i) carry out a deep cleaning of contaminated modules, (ii) rearrange the strings based on shading categories, (iii) install an irradiation sensor on the tilted plane to compute and check the Performance Ratio, and (iv) replace damaged modules. The estimated production boost caused by the retrofitting actions lies between 10-15%.*

PV Plant's health

Main Findings

- Module washers, nuts and bolts are mostly rusted.
- Burnt cells due to moisture trapping into module.
- No module to earth connection.
- Modules are not properly aligned on rails/beams.

Figure 31: Modules with misalignment EW

- Snail trails on modules.
- Damaged modules with burnt busbars and broken glass are connected to the system.

Figure 32: Damaged module, Hotspots

- The PV plant is partly surrounded by buildings, trees and a water tank that cast shadows on the modules.
- Poor cabling management.
- Shading is mainly caused due to buildings and trees in the surroundings and a water tank on the rooftop.

Impact on Performance

- Shading can cause the main impact on the system performance. According to the simulation of the system, the near shading loss accounts for 3%.

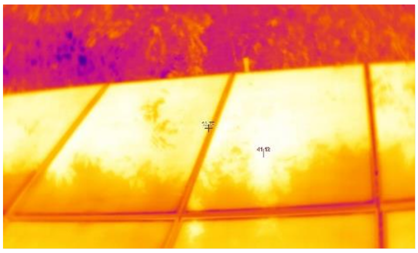


Figure 33: Shading caused by trees in the surroundings.

- Simulation showed that shading losses due to the surrounding trees is ca. 3.24%.

Figure 34: Module with broken glass

- Soiling is found on the modules. A soiling loss of 1% was determined from the IV curve measurement, which is likely to cause hot spots in the modules.

Figure 35: Cells with inhomogeneous temperatures, potential PID effect

- The under-performance of the measured modules is around 30.1%.

Proposed Solutions

- The broken/burned modules shall be replaced with new modules.
- The wet cleaning cycles shall also be included based on the results of the soiling study.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so to determine the performance of the system.
- A re-stringing of the modules from the shaded areas shall be conducted: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.
- PV modules showing power drops above the warranty conditions shall be replaced. If the replacement is not possible, the modules shall be regrouped in power classes within the same string and assigned to individual MPPTs.

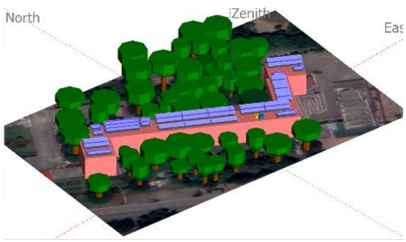


Figure 36: 3D modeling in PVSyst.

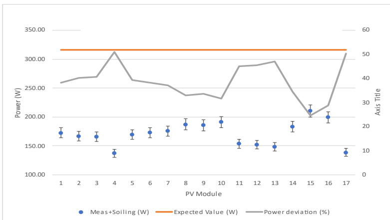


Figure 37: IV curve measurements results

Estimated energy boost after conducting the suggested retrofitting actions: 10% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.57 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.1 ₹/kWh to 1.4 ₹/kWh

Picture Gallery


Figure 38: Shade due to trees.


Figure 39: Potential sources of shading.


Figure 40: shading on module by LA.


Figure 41: Corrosion in busbars.


Figure 42: Poor cable management.


Figure 43: Cables exposed to UV loads.


Figure 44: Shading due to water tank.

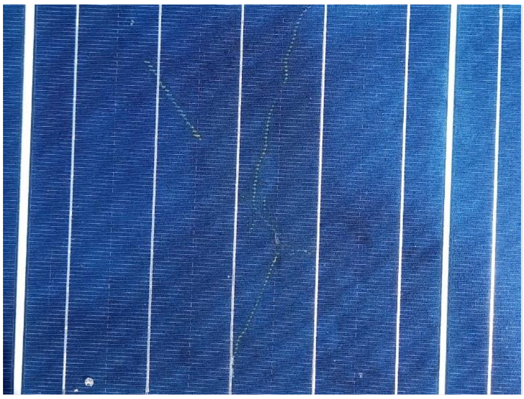


Figure 45: Snail trails.

3

PV plant: ***II.3***
Nominal capacity: ***50 kWp***
Average specific yield since COD (21.2.2018): ***970 kWh/kWp*** *(PVsyst estimation 1362 kWh/kWp)*

Abstract: *The PV plant has several broken modules. Some modules are installed in the risk wind zone. There is no lightning arrestor for on the roof. The building services vent directly under the modules. It is recommended to (i) replace to broken modules and rusty clamps, (ii) install a lightning arrestor (iii) continuous cleaning of the modules especially the bird drops (iv) restringing of shaded modules, and (v) yearly thermography inspection of the modules. The estimated production boost expected by the retrofitting actions lies between 5 and 12%.*

PV Plant's health

Main Findings

- There is no weather station, and hence no PR monitoring.
- Damaged modules are connected to the system, resulting in low generation.
- Exhaust ventilation system under module: the ambient temperature under or around the modules shall be kept as low as possible. An exhaust vent under modules will harm the module's life.

Figure 46: Exhaust ventilation under modules.

- Damaged modules due to mechanical impact, resulting in burned module.

Figure 47: Burned module

- Rusted clamps and structures are found all over the site
- No LA found on the roof.
- Modules were installed to close to the roof edge, having a distance not suitable for maintenance activities of 250mm. In addition, the wind loads are increased due to this reason.
- All module nameplates are washed away and model and producer cannot be read.

Impact on Performance

- Low generation due to heavy soiling and bird droppings. Modules are cleaned once a month.

Figure 48: Soiling on modules.

- Major Shading from nearby obstructions: Hotspots can be created due to shading from modules ahead of it.

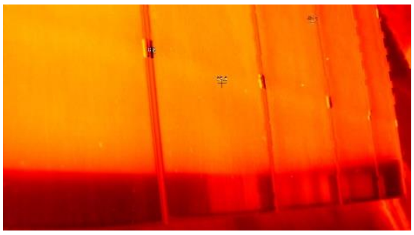


Figure 49: Module shading by IR imaging.

- Shadings due to soiling produces losses in the system performance.
- The measured soiling loses is 2%
- The underperformance of the measured modules is around 25.4%

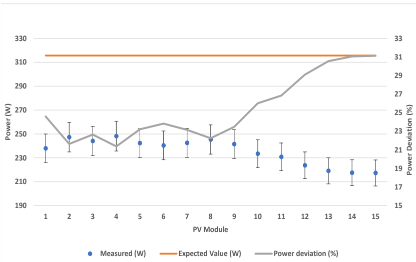


Figure 50: IV curve measurements results

Proposed Solutions

- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Burned modules should not be connected to the system to avoid further damages. It should be replaced or removed.
- The exhaust ventilation system should be redirected to the opposite direction, to avoid higher temperature under the modules.
- Rusted clamps and structure should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- It is recommendable to have lightning arrestor on the roof.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

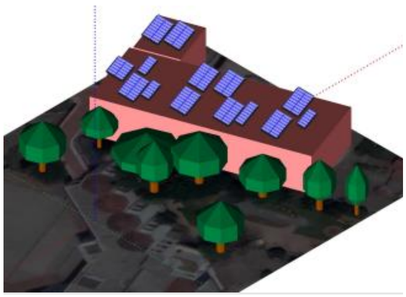


Figure 51: 3D model constructed in PVsyst.

- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 12%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.4 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 4.8 ₹/kWh to 2 ₹/kWh

Picture Gallery


Figure 52: Broken module due to mechanical impact.


Figure 53: Shading from nearby building.


Figure 54: Interrow shading.


Figure 55: Soiling by dry deposition.


Figure 56: Bent and loose clamps.


Figure 57: Missing cable fixation.

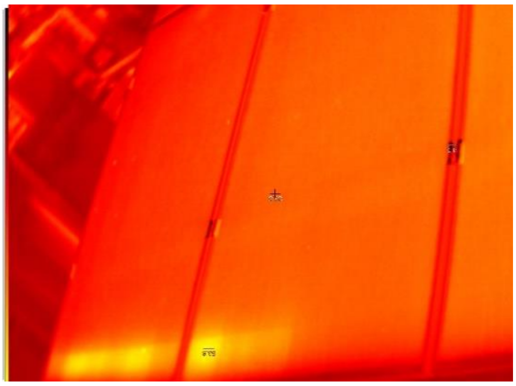


Figure 58: Soiling effect on lower edge (IR).

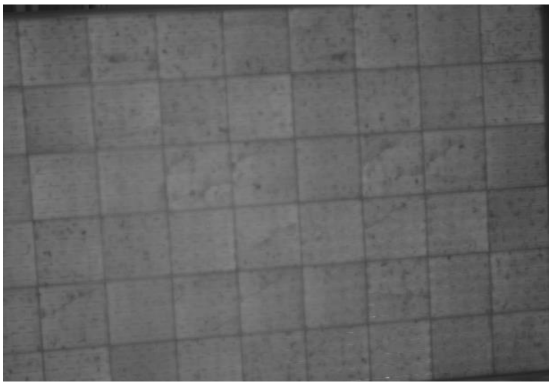


Figure 59: EL imaging of a module.

4

PV plant: ***II.4***
Nominal capacity: ***50 kWp***
Average specific yield since COD (21.09.2018): ***168 kWh/kWp**** *(PVsyst estimation 1304 kWh/kWp)*

Abstract: *The PV plant shows design failures such as self-shading, near shading, and the inadequate tilt angle. Vegetation has grown around and under the modules, which has caused hot cells on the system. No earthing between modules was found, the structure had no insulation coating, an inverter works under "UNGV" alarm, and leak current was present. It is recommended to: (i) increase the cleaning frequency, (ii) install an irradiation sensor on the tilted plane to estimate and check the Performance Ratio, (iii) ensure the operator's security, and (iv) a new method to fix the modules shall be used. The estimated production boost expected by the retrofitting actions lies between 5% and 15%.*

PV Plant's health

Main Findings

- No earthing connection between modules.
- No insulation coating on structure could represent a risk for maintenance workers and engineers while performing O&M works in case of current leakage.
- Existence of current on system after the inverter was turned off.
- Inverter is always under alarm "UNGV".
- Access to sites is complicated.
- Modules are not properly fixed to the ground and the wires used to fix them to the structure were damaged and rusted.

Figure 60: Poor mounting system.

- The tilt angle (10°) causes lost around 5.4% due to its deviation from optimal.
- Plants have grown under and around the modules due to no maintenance works since the commissioning of the site.

Figure 61: Poor vegetation management.

Impact on Performance

- The ballasts used as deadweights to hold the low heighted system and vegetation around it cast shadows on the modules resulting in hotspots.

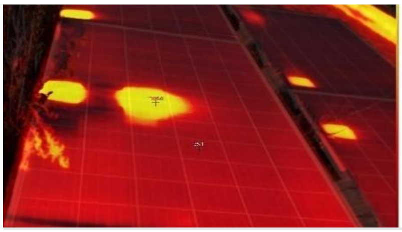


Figure 62: Hotspots due to shading.

- Soiling losses around 3% were measured on site.

Figure 63: Soiling on modules.

- Giving to the EL imaging, the system is not expected to have a large power loss.

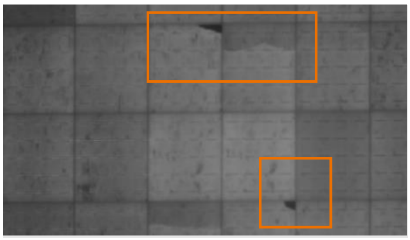


Figure 64: EL-Image showing cells with isolated parts.

- The underperformance of the measured modules is around 31%.

Proposed Solutions

- The cleaning cycles and a maintenance program shall be stablished based on the results of a soiling study that adjusts the cleaning needs to each season and vegetation growth.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.
- New methods shall be used to fix the modules to the structure.
- Earthing connections between modules shall be added.
- The operator's safety must be secured by isolating the structure and identifying and replacing of malfunctioning components in case of current leakage.

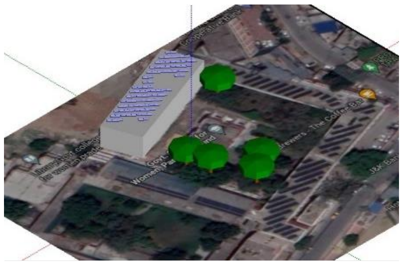


Figure 65: 3D model constructed in PVsyst.

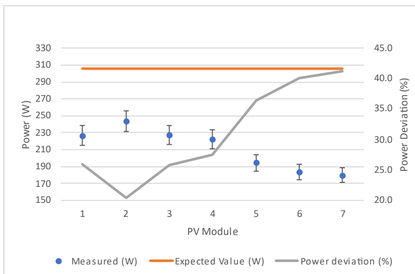


Figure 66: IV curve measurements results

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.3 ₹/Wp, 0.14 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 23.0 ₹/kWh to 7.9 ₹/kWh

Picture Gallery

Figure 67: Vegetation cast a shadow on the module

Figure 68: Hot spots due to shaded modules

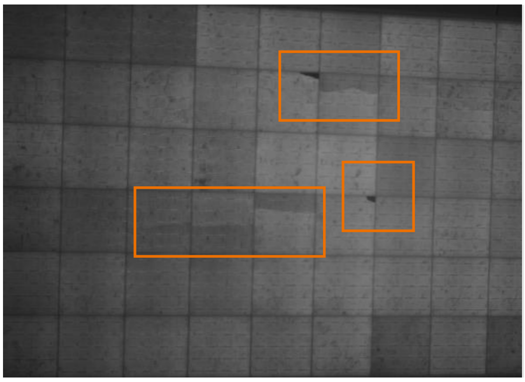


Figure 69: EL imaging shows isolated areas and microcracks.

Figure 70: Shading due to ballasts.

Figure 71: Poor mounting system/fixation.

Figure 72: Challenging access to site.

Figure 73: System overview.

Figure 74: PV system near shading.

5

PV plant: ***II.5***
Nominal capacity: ***100 kWp***
Average specific yield since COD (17.01.2018): ***717 kWh/kWp*** *(PVsyst estimation 1399 kWh/kWp)*

Abstract*: The PV plant makes no profit because it is not connected to the electricity meter. Furthermore, the installed system is affected by near shading. Some parts of the site are poorly ventilated. There are no walkways to carry out the O&M tasks. It is recommended to (i) connect the electricity meter, (ii) install an irradiation sensor (iii) continuous cleaning of the modules and the inverter-fan filters, (iv) re-stringing of shaded modules, and (v) trim surrounding trees. The estimated production boost expected by the retrofitting actions lies between 3 and 12%.*

PV Plant's health

Main Findings

- Poor Cable Management, which makes O&M activities more difficult.
- Cables and MC4 connector are exposed to UV, reducing their lifetime.

Figure 75: Cables and MC4 exposed.

- No walkways for maintenance: The array installed on the roof has an inclination of 20° and does not have a walkway for cleaning activities or maintenance work.

Figure 76: Array without O&M walkway.

- There is no weather station, and hence no PR monitoring.
- Short side clamping of modules is not advisable by the module manufacturers. This could result in damages of the module body during high wind loads.
- The installed metering system is not working. Therefore, no benefits from the site can be charged.

Figure 77: Non-functioning Meter.

Impact on Performance

- Heavy soiling and bird droppings: No maintenance work in the last 3 years, generation of plant is critical due to dirty modules
- Isolated parts were found by Electroluminescence analysis. This could indicate bad handling during installation or Maintenance.
- Parts of the system are insufficiently ventilated. This leads to an underperformance of the modules.

Figure 78: Insufficient Ventilation.

- More than half of PV array is shadowed by trees and buildings creating a pattern that damages the modules performance.

Figure 79: System surrounded by trees.

- The underperformance of the measured modules is around 27.3%.

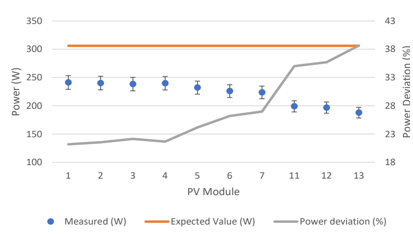


Figure 80: IV curve measurement results.

Proposed Solutions

- Cables should have suitable labelling and should be protected from UV.
- The metering system must be connected in order to gain any financial benefits from the site.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.
- The trees surrounding the system shall be trimmed if allowed. Otherwise, a re-stringing of the modules shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to one MPPT.
- The cleaning of the modules and inverter filter should be carried out frequently. Especially the elimination of bird drops could be implemented in the maintenance.
- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.
- The site should have walkways installed in order to carry out O&M tasks.

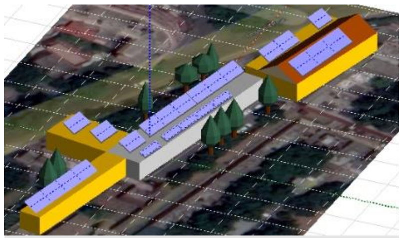


Figure 81: 3D Model created with PVSyst.

- Broken modules and cables should be replaced.

Estimated energy boost after conducting the suggested retrofitting actions: 3% to 12%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.53 ₹/Wp, 0.26 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 15.5 ₹/kWh to 4.0 ₹/kWh

Picture Gallery

Figure 82: Inverter overview

Figure 83: Soiling - bird dropping.

Figure 84: Modules Installed close to the boundary.

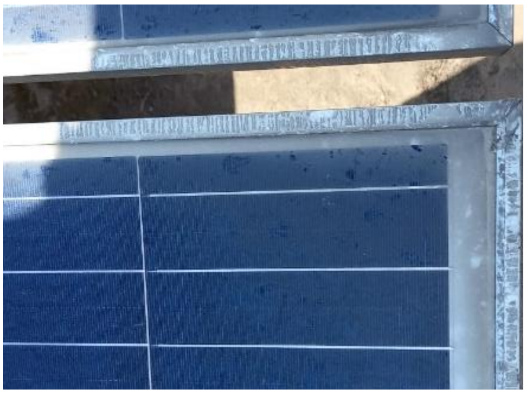


Figure 85: Soiling likely by hard water.

Figure 86: Near shading.

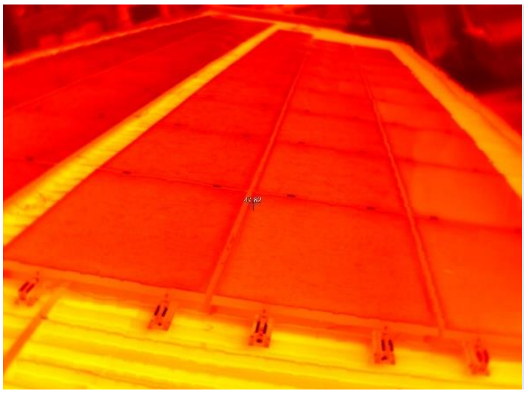


Figure 87: Insufficient Ventilation.

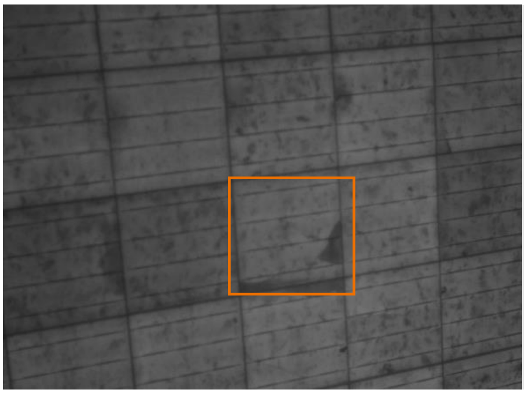


Figure 88: Module with micro-cracks.

Figure 89: Poor cable management.

6

PV plant: ***II.6***
Nominal capacity: ***140 kWp***
Average specific yield since COD (09.04.2018): ***801 kWh/kWp*** *(PVsyst estimation 1403 kWh/kWp)*

Abstract: *The PV plant is affected by near shadings caused by trees, walls, and cables. Furthermore, the modules show heavy contamination that has developed in hot cells. Additionally, the inverter of one rooftop (50 kWp) is not working. It is recommended to (i) carry out a deep cleaning of heavily contaminated modules, (ii) replace the malfunctioning inverter, (iii) trim trees and remove shading objects close to the system and (iv) replace or re-group modules with multi-cracks. The estimated production boost caused by the retrofitting actions lies between 9 and 30%.*

PV Plant's health

Main Findings

- Major portion of power plant is shaded due to low inter row spacing and trees surrounding the system.

Figure 90: Module shading due to trees.

- The 50 kWp system is not in operation since July 2020 and the inverter buttons are not working.
- Objects near the modules, such as a pole a cable, and nearby wall, cast shadow over the systems. Accounting for a shading loss around 4%, according to the simulation of the system.

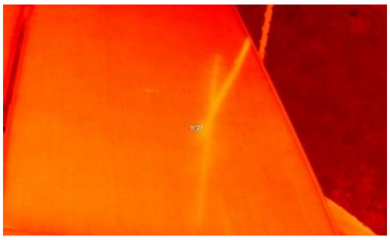


Figure 91: Hot spots due to module shading.

- No weather station was found on site.
- ACBD located next to non-working inverter was found broken and exposed to the environment.

Impact on Performance

- Heavy soiling is found on the modules. A soiling loss of 5% was determined from the IV curve measurement.

Figure 92: Soiling deposition on module.

- Some modules were identified with severe cracks and isolated areas.

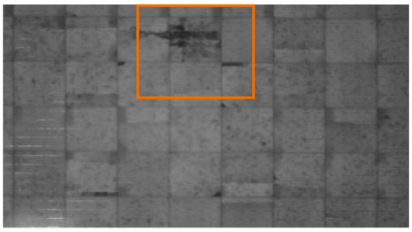


Figure 93: multi-cracks identified during EL imaging.

- Many modules have developed hot cells due to the shading of trees, the surroundings and heavy soiling.

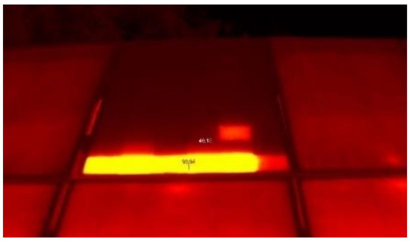


Figure 94: warm cells due to soiling.

- The average underperformance of the measured modules is around 24%.

Proposed Solutions

- Substitute or fix inverter of the 50 kWp system.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed to determine the performance of the.
- The trees surrounding the system shall be trimmed if allowed and the objects near the modules removed. Otherwise, a re-stringing of the modules shall be conducted according to their shading conditions to avoid shadowing losses.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Modules with highly damaged cells shall be replaced or grouped in the same string or at least assigned to one MPPT.

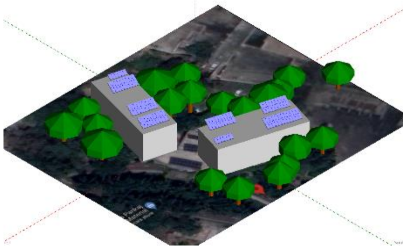


Figure 95: 3D model constructed in PVsyst.

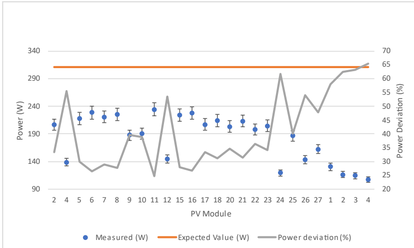


Figure 96: IV curve measurement results.

Estimated energy boost after conducting the suggested retrofitting actions: 9% to 30%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.3 ₹/Wp, 0.8 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 5.7 ₹/kWh to 1.7 ₹/kWh

Picture Gallery

Figure 97: Modules shaded by nearby trees.

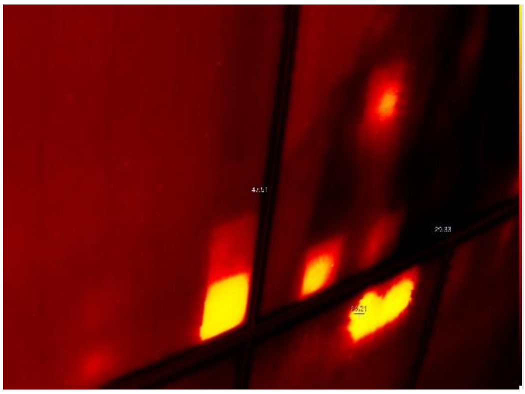


Figure 98: Modules with hot spots due to shading.

Figure 99: Heavy soiling, inhomogeneous distribution.

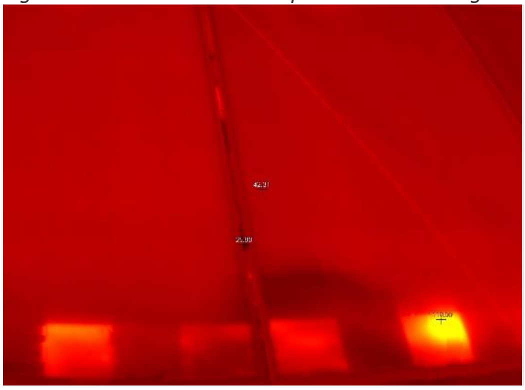


Figure 100: Hot cells due to shading.

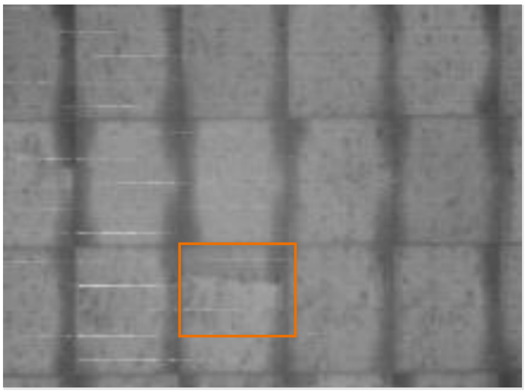


Figure 101: EI image of a module with few microcrack.

Figure 102: Modules shaded by nearby wall.

Figure 103: Water tank and tree shading the modules.

Figure 104: Shadow casted by nearby tree.

7

PV plant: ***II.7***
Nominal capacity: ***35 kWp***
Average specific yield since COD (29.03.2018): ***1164 kWh/kWp*** *(PVsyst estimation 1534 kWh/kWp)*

Abstract: *The PV plant is heavily soiled by pollution and bird droppings. Some modules with mechanical damages were detected (broken cells and snail trails). It is recommended to (i) increase the cleaning cycles, (ii) re-sort the modules according to the level of mechanical damage, (iii) install a new earthing system, and (iv) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the Performance Ratio. The estimated production boost expected by the retrofitting actions lies between 10% and 15%.*

PV Plant's health

Main Findings

- The modules are considered heavily soiled. Bird droppings were also found on the modules.

Figure 105: Heavy soiling - Bird droppings

- Some modules present snail trails.
- Poor management of grounding between modules: rusted, not connected, or gone.

Figure 106: Corroded PEB grounding between modules.

- Poor cable labelling.
- The labels of the modules are peeling off or already missing.
- The lightning protection is installed to close to the system and casts shadow on one module in the mornings. The contact point is rusted.
- No weather station was found on site.

Impact on Performance

- The lack of cleaning of the modules has developed hot cells on many modules.

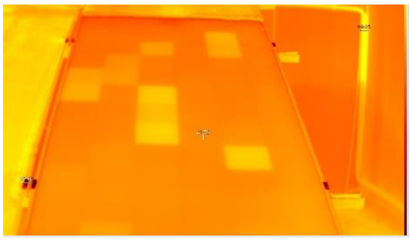


Figure 107: Hot cells due to long-term exposure to heavy soiling.

- Soiling losses were determined to be around 5.64% based on site measurements.

Figure 108: Modules heavily soiled.

- Based on the number of cracks and corresponding inactive areas, the power loss is not expected to be high.

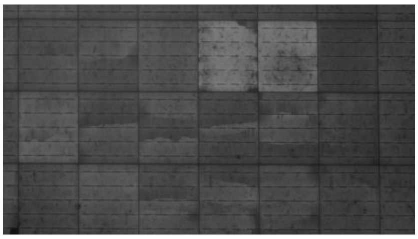


Figure 109: Broken cells discovered via EL imaging.

- The underperformance of the measured modules is around 5.9%.

Proposed Solutions

- Cleaning cycles shall be implemented and scheduled based on the results of a soiling study that adjusts the cleaning needs to each season.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed to properly determine the performance of the system.
- The rusted elements of the grounding shall be substituted, and all the connections have to be done to the grounding hole of the module frame.
- The damaged cable protecting tubes shall be substituted.
- Change the location of the lightning protection if possible.
- Modules with heavy cracks shall be grouped in the same string or at least assigned to one MPPT.

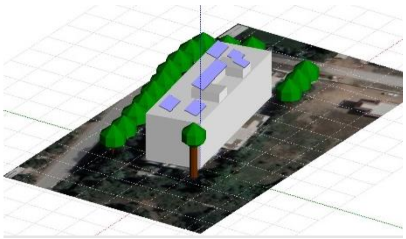


Figure 110: 3D model constructed in PVsyst.

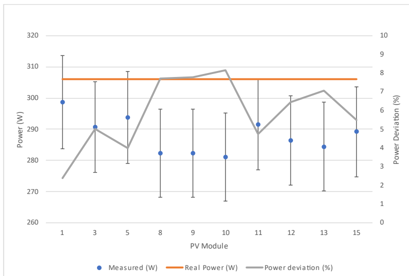


Figure 111: IV curve measurement results

Estimated energy boost after conducting the suggested retrofitting actions: 10% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.85 ₹/Wp, 0.38 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 4.0 ₹/kWh to 2.6 ₹/kWh

Picture Gallery

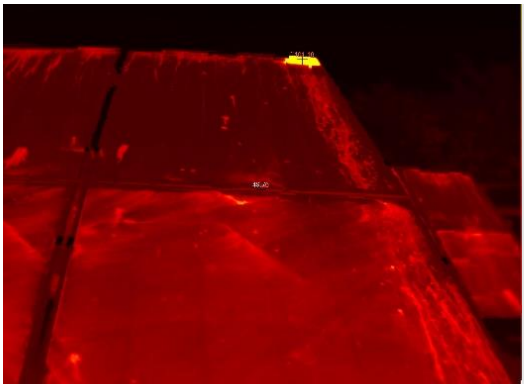


Figure 112: Hot spots due to bird droppings.

Figure 113: Shadow due to LPS.

Figure 114: Module after cleaning.

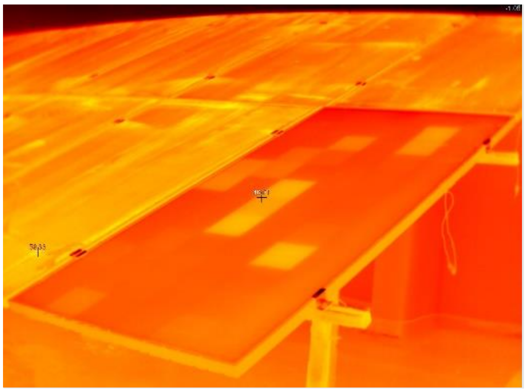


Figure 115: Inhomogeneous cell temperatures.

Figure 116: cable ducting damaged.

Figure 117: Inverter and AC board.

Figure 118: Snail trails on module.

Figure 119: Module with detached label.

8

PV plant: ***II.8***
Nominal capacity: ***130 kWp***
Average specific yield since COD (02.01.2018): ***925 kWh/kWp*** *(PVsyst estimation 1470 kWh/kWp)*

Abstract: *The PV plant has several broken or damaged modules. O&M staff was spotted to walk on the modules. Some of the modules are extremely dirty. Objects laying under the modules have been found and some back sheets are extremely dirty. Some parts of the sites are affected by heavy near shading. It is recommended to (i) improve O&M activities and cleaning cycles, (ii) restringing of the shaded modules, (iii) install an irradiation sensor, and (iv) clean up the objects laying under the modules. The estimated production boost expected by the retrofitting actions lies between 11% and 17%.*

PV Plant's health

Main Findings

- Poor Cable Management, cables not tied up among the substructure which makes operation and maintenance activities more difficult.

Figure 120: Module cables hanging.

- Back sheet-Modules heavy soiled due to poor cleaning and maintenance.

Figure 121: Dirty back-sheet.

- Objects under PV-Array reduce the ventilation and this may increase the temperature of the modules.

Figure 122: Objects under PV-Array.

Impact on Performance

- Isolated parts and finger interruptions were found by Electroluminescence analysis.

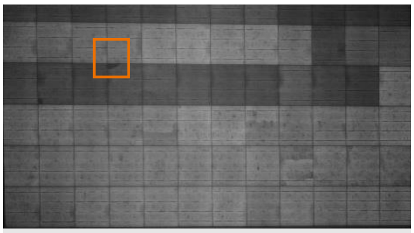


Figure 123: Isolated cell parts.

- Minimum bending radius not considered; this may damage solar cables sooner than its normal lifetime.
- Hot cells have been detected during the IR analysis.
- The measured soiling losses are 2.1%
- The underperformance of the measured modules is around 13%

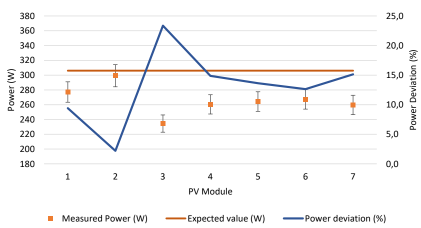


Figure 124: IV curve measurement results

- Disconnected modules affect the performance of complete strings.

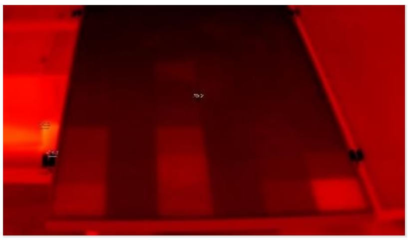


Figure 125: Potential PID effect on module.

Proposed Solutions

- Objects under the PV-Array should be removed to allow proper ventilation and avoid further risks.
- Solar cables should have a minimum bending radius to avoid early damages.
- The modules with major EL failures can be compared with the manufacturing catalogue and if applicable they can be replaced.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Cables should be tied up, have a suitable labelling, and should be protected from UV.
- The measured soiling loses is 2.1%. The cleaning cycle should be improved.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

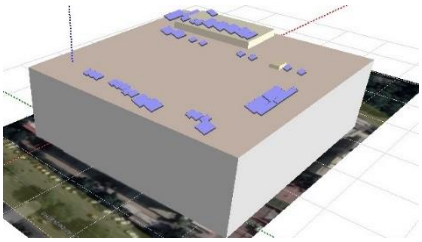


Figure 126: 3D Model created with PVSyst.

- Broken modules and cables should be replaced.
- The maintenance staff should be trained to handle the modules in a careful manner.

Estimated energy boost after conducting the suggested retrofitting actions: 11% to 17%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.3 ₹/Wp, 0.13 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.5 ₹/kWh to 0.9 ₹/kWh

Picture Gallery


Figure 127: Heavy soiling on modules.


Figure 128: Rusted fastener for PEB and foundations.


Figure 129: Poor cable management.


Figure 130: Dirty module from mechanical damage.


Figure 131: Module shading by near objects.


Figure 132: Missing PEB grounding between modules.


Figure 133: Minimum bending radius not considered.


Figure 134: Challenging access to site.

9

PV plant: ***II.9***
Nominal capacity: ***50 kWp***
Average specific yield from last two years: ***1287 kWh/kWp*** *(PVsyst estimation 1462 kWh/kWp)*

Abstract: *The PV plant is heavily affected by nearby and inter-row shading. Module with micro cracks and isolated parts were discovered through the electroluminescence sample. The used module clamps are rusty, and some are falling off. The module cables are hanging lose and in some parts the UV protection is missing. It is recommended to (i) improve O&M activities, (ii) change the module clamps, (iii) install an irradiation sensor, and (iv) re-string the shaded modules. The estimated production boost expected by the retrofitting actions lies between 5% and 10%.*

PV Plant's health

Main Findings

- Near shading is caused by trees and parts of the roof.

Figure 135: Near Shading.

- There is no weather station, and hence no PR monitoring.
- Poor cable management, cables not tied up, not labelled and no UV protection.

Figure 136: Poor cable management.

- There is no lightning arrestor installed.
- The earthing in between the modules is missing.
- The module clamps are rusted, and some are falling off. This leads to falling of modules.

Figure 137: Poor module fixation (loose module).

- Bird nest under the modules is indicating poor maintenance

Impact on Performance

- Modules with micro cracks and isolated parts have been discovered during EL Imaging.

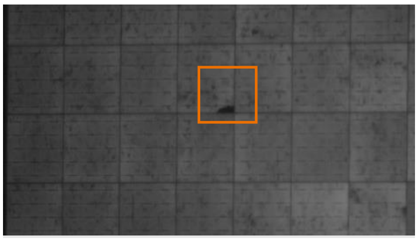


Figure 138: cell with isolated parts.

- Modules heavily affected by soiling, due to poor cleaning and maintenance, showed via IR analysis.

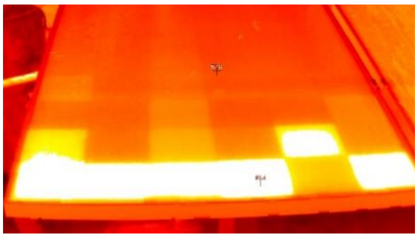


Figure 139: Soiling affected modules.

- Disconnected module being part of the PV Array, showed by IR analysis.
- Soiling losses were determined to be around 20% based on site measurements

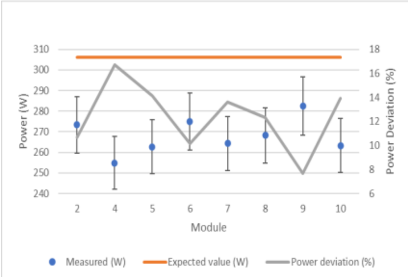


Figure 140: IV curve measurement results

Proposed Solutions

- Cables should be tied up among the substructure, have a suitable labelling and should be protected from UV.
- Modules with major EL failures can be compared with manufactures catalogue and can be replaced, if applicable.
- Trees surrounding the system shall be trimmed if allowed. Otherwise, a re-stringing of the modules shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to one MPPT.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

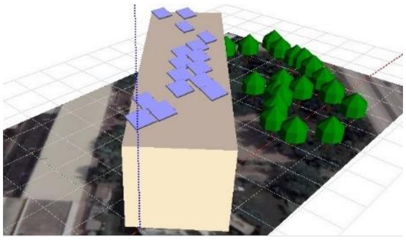


Figure 141: 3D Model created with PVSyst.

- The rusted module clamps should be replaced, and all screws of the clamps should be tight up.
- A lightning and earthing system should be installed.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.3 ₹/Wp, 0.8 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 5.1 ₹/kWh to 2.5 ₹/kWh

Picture Gallery

Figure 142: Disconnected module.

Figure 143: Bird nest under a module.

Figure 144: Incomplete cable UV protection.

Figure 145: Missing module PEB grounding.

Figure 146: Rusty and fallen module clamp.

Figure 147: Heavy soiling due to bird drops.

Figure 148: Interrow shading.

Figure 149: Near shading overview.

10

PV plant: ***II.10***
Nominal capacity: ***200 kWp***
Average specific yield since COD (28.03.2018): ***1444 kWh/kWp*** *(PVsyst estimation 1394 kWh/kWp)*

Abstract: *The PV plant shows heavy soiling. A considerable number of micro cracks and isolated parts were discovered through the electroluminescence sample. The module cables are extremely damaged, and some burned modules are found on-site. The modules have hand and shoe-prints. It is recommended to (i) Improve O&M activities, especially the cleaning, (ii) change the broken modules, (iii) install an irradiation sensor, and (iv) re-string the shaded modules. The estimated production boost expected by the retrofitting actions lies between 14% and 15%.*

PV Plant's health

Main Findings

- Near shading of telecom tower affecting module performance.

Figure 150: Near Shading

- Poor Cable Management, cables not tied up among substructure and exposed to UV. This makes Operation and maintenance activities more difficult and reduce the lifetime of solar cables.
- Burned modules are life threatening and the system performance is strongly affected.

Figure 151: Burned module

- Broken and poorly fixed module cables are found on-site. This lowers the system performance and is a high risk for human beings.
- The lightning arrestor is installed in a not functional way.
- No weather station or at least an irradiation sensor is installed.
- The module labels are falling of which makes the O&M tasks difficult.

Impact on Performance

- Isolated parts and micro cracks were found by Electroluminescence analysis

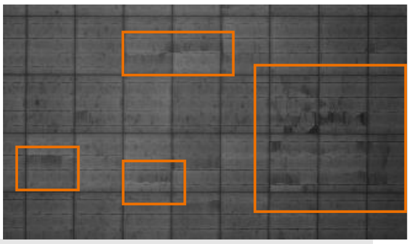


Figure 152: Module with several cracks via EL

- Modules with heavy soiling, due to poor cleaning and maintenance.
- Hot cells due to shading and soiling is impairing system performance.

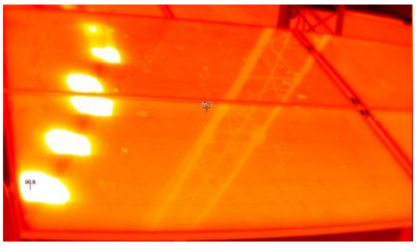


Figure 153: Warm cells due to shading

- Soiling losses were determined to be around 17.6% based on site measurements

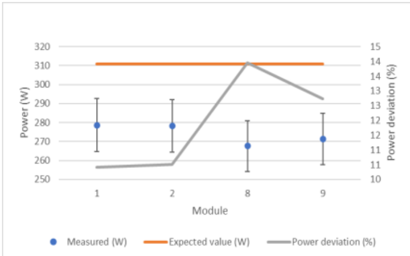


Figure 154: IV curve measurement results

Proposed Solutions

- The modules with major EL failures can be compared with the manufacture catalogue and if applicable they can be replaced.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Cables should be tied up among the substructure, have a suitable labelling and should be protected from UV.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

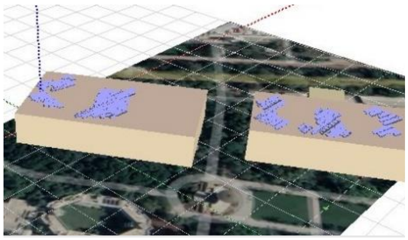


Figure 155: 3D Model created with PVSyst

- Burned, broken Modules and Modules with damaged cables should be replaced.
- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.
- The lightning arrestor should be installed in an adequate way.

Estimated energy boost after conducting the suggested retrofitting actions: 14% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.4 ₹/Wp, 1.0 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 5.1 ₹/kWh to 4.7 ₹/kWh

Picture Gallery

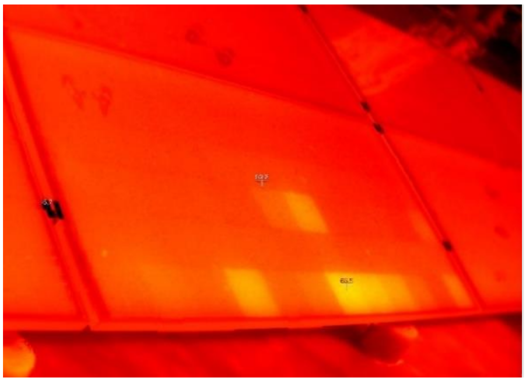


Figure 156: Inhomogeneous temperature due to soiling


Figure 157: Poor cable management

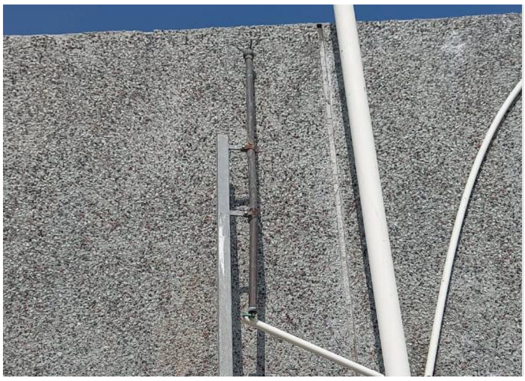


Figure 158: Incorrectly installed lightning arrester


Figure 159: On-site O&M personnel missing PPE

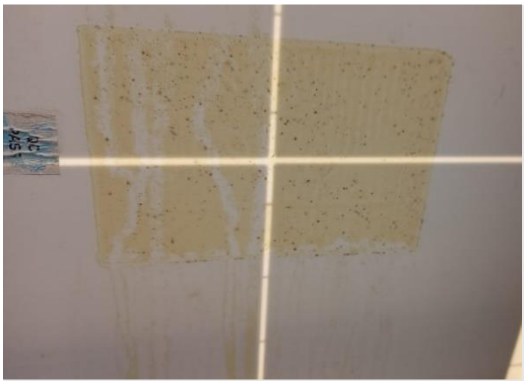


Figure 160: Module missing label


Figure 161: Minimum bending radius disregarded


Figure 162: Hand and footprints on the modules


Figure 163: Heavy soiling and bird drops

11

PV plant: ***II.11***
Nominal capacity: ***30,7 kWp***
Average specific yield since COD (30.03.2018): ***1253 kWh/kWp*** *(PVsyst estimation 1480 kWh/kWp)*

Abstract*: The PV plant is heavily affected by soiling and shading. Some of the modules are installed end to end. Footprints on the modules indicate a poor maintenance. Some of the connectors have been found open. It is recommended to (i) replace broken modules, (ii) perform a cabling check, (iii) continuous cleaning of the modules especially the bird drops, (iv) re-string shaded modules, and (v) yearly thermography inspection of the modules. The estimated production boost expected by the retrofitting actions lies between 5 and 10%.*

PV Plant's health

Main Findings

- Poor Cable Management, which makes operation and maintenance activities more difficult.
- Damaged module by mechanical impact.

Figure 164: Module with broken glass.

- PV-Array with disconnected modules is decreasing the system performance.

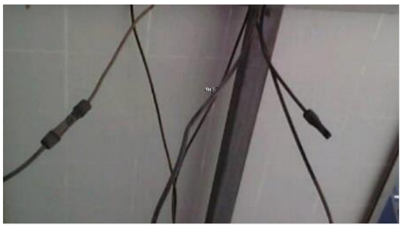


Figure 165: Disconnected modules.

- Labelling of strings are missing, and the UV protection of the cables is not sufficient.
- Shoeprints were found on the modules which indicates a poor maintenance handling.

Impact on Performance

- Isolated parts and micro cracks were found by Electroluminescence analysis.

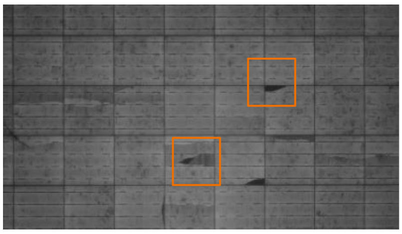


Figure 166: Isolated parts and micro-cracks.

- Modules with heavy soiling, due to poor cleaning and maintenance.

Figure 167: Heavy soiling and shading.

- The front part of PV array is shadowed by trees over one of the roofs of the site, creating a pattern which produces hot cells, impairing system performance.
- Soiling losses were determined to be around 22% based on site measurements

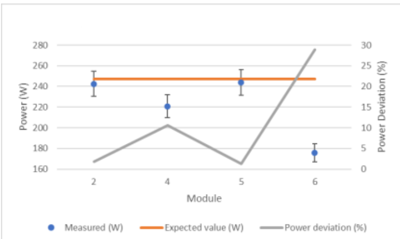


Figure 168: IV curve measurement results.

Proposed Solutions

- Missing or disconnected modules should be replaced to achieve the optimal system performance.
- The modules with major EL failures can be compared with the manufacture catalogue and if applicable they can be replaced.
- The trees surrounding the system shall be trimmed if allowed. Otherwise, a re-stringing of the modules shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to one MPPT.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Cables should have a suitable labelling and should be protected from UV.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.

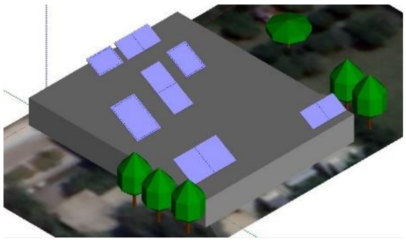


Figure 169: 3D Model created with PVSyst.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.5 ₹/Wp, 1.2 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 21.7 ₹/kWh to 10.9 ₹/kWh

Picture Gallery


Figure 170: Loose hanging module cables


Figure 171: Evidence of walking on the modules


Figure 172: Heavy soiling


Figure 173: Soiling - bird dropping.


Figure 174: Inconsistency in module orientation

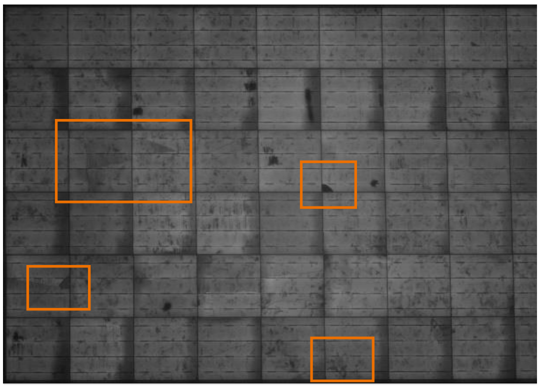


Figure 175: Microcracks, isolated parts & Inhomogeneity


Figure 176: Site overview.

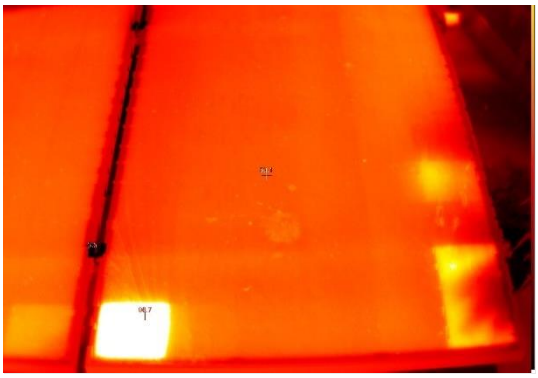


Figure 177: Hot cell due to soiling and shading

12

PV plant: ***II.12***
Nominal capacity: ***63 kWp***
Average specific yield since COD (04.01.2018): ***973 kWh/kWp*** *(PVsyst estimation 1498 kWh/kWp)*

Abstract: *The PV plant is affected by significant soiling due to pollution, near shadings caused by surroundings, and modules with cracked cells. A sub-array is disconnected, and damaged modules were found. Earthing, cabling, and structure are in poor conditions. It is recommended to: (i) increase the cleaning frequency, (ii) rearrange the strings based on the shading, (iii) re-sort the modules according to level of mechanical damage, (iv) install an irradiation sensor on the tilted plane to compute and check the Performance Ratio, and (v) replace damaged modules. The estimated production boost expected by the retrofitting actions lies between 20% and 30%.*

PV Plant's health

Main Findings

- Earthing strips used to connect the system for grounding were disconnected or broken.
- A 5 module sub-array was disconnected.

Figure 178: module sub-array disconnected

- Poor cable management. Some cables are exposed to weather and the cable conduits are degraded and broken.
- Hotspots due to heavy soiling were identified through IR imaging, resulting in some burn marks in the back of some modules.

Figure 179: Burn mark on module's back-sheet

- The bolts connecting the base of the structure to the foundation are rusted.
- A broken module was identified during the visit.
- No weather station was found on site.
- Several foreign objects were found on top of the modules.
- The inverter showed an Isolation Failure.

Impact on Performance

- A soiling loss of 19.3% was determined from IV curve measurements of a module before and after cleaning.

Figure 180: Heavy soiling on the system

- Shadows of nearby trees and walls of the buildings cast shadows on the system, creating hot cells on the module.

Figure 181: Hot cell due to near shading

- Footprints over the modules were found, which could have caused the significant number of cracks found during the electroluminescence.

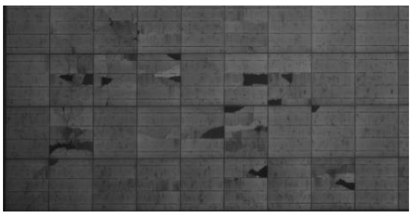


Figure 182: Module with multiple cracks and inactive areas

- The underperformance of the measured modules is around 7.2%.

Proposed Solutions

- The cleaning cycles shall be increased based on the results of the soiling study that adjusts the cleaning needs.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed to properly determine the performance of the system.
- For shaded modules a re-stringing shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to one MPPT.
- The cables shall be protected from UV radiation by robust pipes or tubes.
- Modules with heavy cracks shall be grouped in the same string or at least assigned to one MPPT.
- Grounding system and structures shall be installed again.
- The broken module and that with hot spot mark shall be substituted.

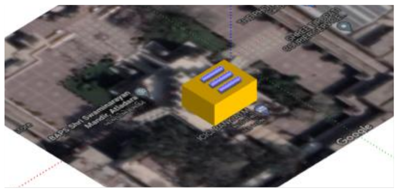


Figure 183: 3D modelling done on PVsyst

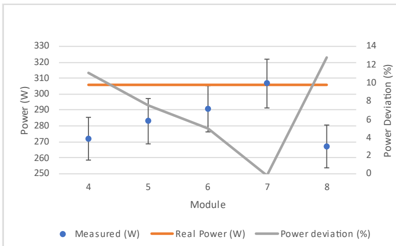


Figure 184: IV curve measurement results

Estimated energy boost after conducting the suggested retrofitting actions: 20% to 30%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.4 ₹/Wp, 0.22 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.5 ₹/kWh to 1 ₹/kWh

Picture Gallery

Figure 185: Rusted bolts in mounting structure

Figure 186: Footprints over module

Figure 187: Cable over module - shading

Figure 188: Grounding disconnected

Figure 189: Broken cable ducting

Figure 190: 3-meter wall in front of system (near shading)

Figure 191: Broken module

Figure 192: Hot cells developed on modules due to soiling and shadows on system

13

PV plant: ***II.13***
Nominal capacity: ***100 kWp***
Average specific yield since COD (26.03.2018): ***1218 kWh/kWp*** *(PVsyst estimation 1453 kWh/kWp)*

Abstract: *The PV plant has several broken or damaged modules. A considerable number of micro cracks and isolated parts were discovered through the electroluminescence sample. Some parts of the substructure are constructed unstable against heavy wind loads. The ventilation of some modules is very insufficient. It is recommended to (i) Improve O&M activities, (ii) reinforce the weak substructure, (iii) install an irradiation sensor, and (iv) replace the broken modules. The estimated production boost expected by the retrofitting actions lies between 10% and 14%.*

PV Plant's health

Main Findings

- Poor cable management: Cables and connectors loosely hanging from broken ties; the bending radius of the module cables was not regarded and could lead to power losses and cable breaking; cables run along sharp edges and show damage; and the wiring of the distribution boxes and inverters is not safe or clear. The sheathing of the cables is falling off.
- Hotspots due to shading or soiling have been identified.

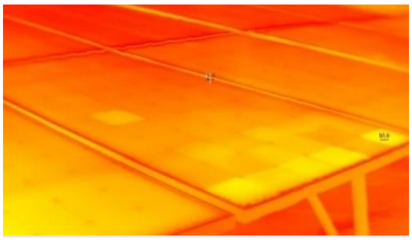


Figure 193: Hot Spots due to soiling.

- The grounding of some parts of the installation does not exist.
- Some modules have holes and burn marks or delamination.
- Footprints were found on modules. This can lead to broken cells and modules.
- Some parts of the construction are structurally questionable for wind loads.

Figure 194: Poor mounting structure installation.

- Online monitoring unit is burnt due to lightning strike for one year.

Impact on Performance

- Insufficient ventilation of the system is leading to overheated modules.

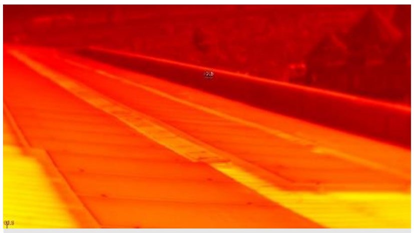


Figure 195: Insufficient module ventilation.

- Parts of the site are affected by close shading. This leads to a reduction in performance and hotspot formation.
- Some modules are delaminated, which can lead to a drop in performance and hot spots.
- Several modules with broken and inactive cells were found.

Figure 196: Broken cells via EL.

- The measured soiling loses is 2.5%.
- The underperformance of the measured modules is around 15%.

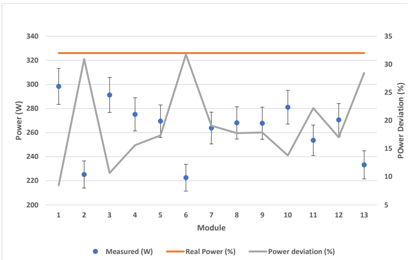


Figure 197: On site power measurement.

Proposed Solutions

- A weather station, or at least an irradiation sensor on the module plane, shall be installed.
- A re-stringing shall be conducted to have shaded modules in the same string or at least assigned to individual MPPTs.
- Broken modules should be replaced for new ones to ensure the safety of the site and increase the performance of the system.
- The maintanance staff should be trained not to step on the modules.
- The cleaning cycle could be improved to decrease the soiling losses.

Figure 198: 3D model constructed in PVsyst.

- The poor ventilated modules should be installed with some distance to the roof.
- The shading objects on the roof should be removed.
- The wide overhanging substructure should be fixed in order to be stable for any storms.

Estimated energy boost after conducting the suggested retrofitting actions: 10% to 14%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.25 ₹/Wp, 0.93 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 8.2 ₹/kWh to 5.8 ₹/kWh

Picture Gallery


Figure 199: Loose DC cabling


Figure 200: Minimum bending radius disregarded


Figure 201: Shoeprints on module.


Figure 202: cables in contact with sharp edges.


Figure 203: Broken Modules – hot spot.


Figure 204: Broken Module.


Figure 205: Main AC board overview.


Figure 206: On-site O&M personnel missing PPE.

14

PV plant: ***II.14***
Nominal capacity: ***90 kWp***
Average specific yield since COD (16.10.2017): ***1110 kWh/kWp*** *(PVsyst estimation 1357 kWh/kWp)*

Abstract*: The PV plant is heavily affected by soiling and shading. Some of the modules are installed end to end. Footprints on the modules indicate a poor maintenance. Some of the connectors have been found open. It is recommended to (i) replace to broken modules, (ii) do a cabling check, (iii) continuous cleaning of the modules especially the bird drops, (iv) re-stringing of shaded modules, and (v) yearly thermography inspection of the modules. The estimated production boost expected by the retrofitting actions lies between 5 and 10%.*

PV Plant's health

Main Findings

- Poor Cable Management, cables exposed to UV and not properly tied up. Risk of cable cut due to fastening with a screw.

Figure 207: Cables in contact with sharp edges.

- Broken und burned MC4 connectors indicate an isolation problem.

Figure 208: Broken and burned connector

- The installed irradiation sensor is facing shading during certain times of the day.
- Some screws of the system are corroded which can lead to serious damages.
- The grounding is not connected properly.
- The inverter wiring is not properly fastened and labelled.

Figure 209: Inverter cabling.

Impact on Performance

- Inter-raw shading and near shading are impairing the system performance.

Figure 210: Interrow shading.

- Irradiance sensor is installed but data logger is not working in the last 1.5 years, this means monitoring is not being carried out.

Figure 211: Data logger damaged.

- The measured underperformance of the inspected modules is 12.9%.

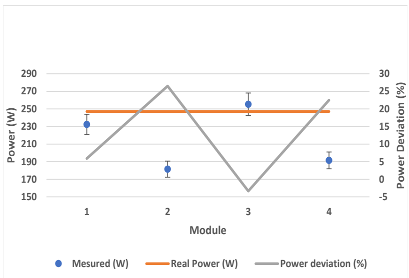


Figure 212: IV curve measurement results.

Proposed Solutions

- Cables should be tied up with plastic seals and protected from UV irradiation. Sharp edges should be avoided.
- If the data logger cannot be repaired then it should be replaced, in order to monitor the system properly.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season. This includes inverter fans.

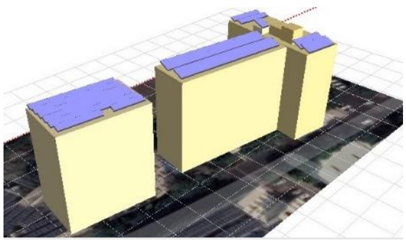


Figure 213: 3D Model created with PVSyst.

- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.
- The functionality of the grounding must be checked, and improper installations repaired.
- The broken modules should be replaced by new once to ensure the safety of the site and increase the performance of the system.
- The broken or burned connector should be replaced.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.8 ₹/Wp, 0.95 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 18 ₹/kWh to 9.4 ₹/kWh

Picture Gallery


Figure 214: Irradiation sensor on site.


Figure 215: Corroded screws.


Figure 216: Near shading on modules.


Figure 217: Welded grounding.

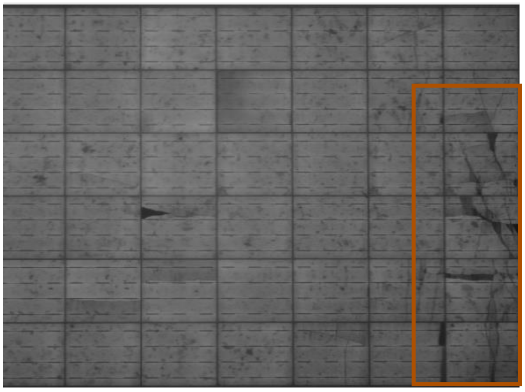


Figure 218: Cell with cracks and isolated parts.

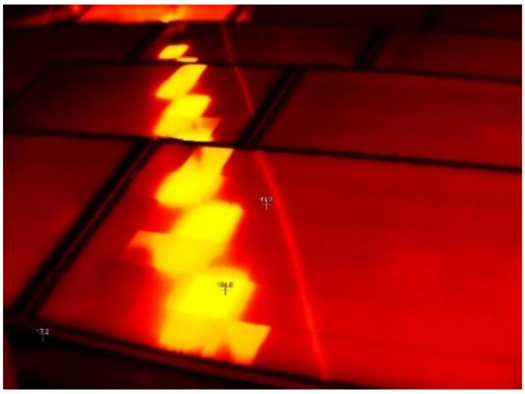


Figure 219: warm cells due to shading.

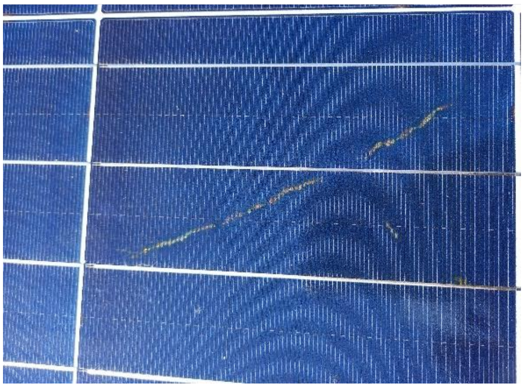


Figure 220: Module with snail trails.


Figure 221: Loose hanging cables.

15

PV plant: ***II.15***
Nominal capacity: ***15 kWp***
Average specific yield since COD (28.03.2018): ***1185 kWh/kWp*** *(PVsyst estimation 1400 kWh/kWp)*

Abstract: *The PV plant shows moderate levels of soiling. The system design disregarded near shading and self-shading losses. Poor cable management was found. Cracks of different severities were detected via EL inspection. It is recommended to (i) increase the cleaning cycles, (ii) trimming of trees surrounding the system if allowed by the authorities, (iii) install an irradiation sensor on the tilted plane to compute and check the Performance Ratio, (iv) re-sort the modules according to level of mechanical damage, and (v) rearrange the strings based on the shading situation. The estimated production boost expected by the retrofitting actions lies between 5% and 10%.*

PV Plant's health

Main Findings

- Poor cable management: Module cables are not attached to the frame or laying on the ground, and a broken cable was found.
- Self-shading due to a reduced inter-row distance.
- An antenna, a water tank, and building rods cast shadows on the system.

Figure 222: Near shading due to different objects

- The front row has a different tilt angle (15.8°) from the back rows.
- Self-shading accounts over 5.5% due to reduced inter-row distance.
- A junction box was found with a deformed lid.
- Evidence of local fauna walking over the system was found.
- Bonding between modules were not found.

Figure 223: PEB grounding missing between modules

- No weather station was found on site.

Impact on Performance

- A soiling loss of 21% was determined from IV curve measurements of a module before and after cleaning.
- A building is under construction at the South-East side of the site. According to the simulation, the near shading losses account for 4.11%.

Figure 224: Near shading due to building

- The modules present hot cells, likely due to inter-row shading.

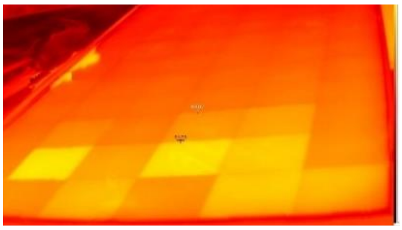


Figure 225: Hot cells on module

- According to EL imaging, the system is not expected to have a large power loss. Nevertheless, cells with multi-cracks were found.

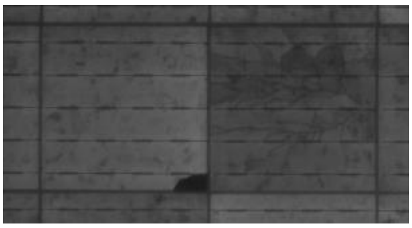


Figure 226: Multi-cracks and isolated area via EL imaging

- The underperformance of the measured modules is around 10.3%.

Proposed Solutions

- A weather station, or at least an irradiation sensor on the module plane, shall be installed to properly determine the performance of the system.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Module with damaged junction box shall be replaced.
- The trees surrounding the system shall be trimmed if allowed. Otherwise, a re-stringing of the modules with similar shading conditions shall be installed in the same string or at least assigned to one MPPT.
- Modules with heavy cracks shall be grouped in the same string or at least assigned to one MPPT. The grouping will be conducted based on infrared inspection.

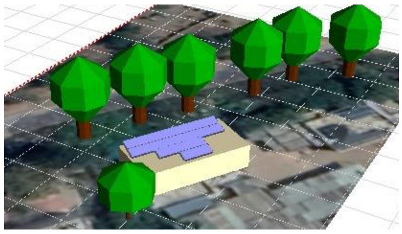


Figure 227: 3D model constructed in PVsyst

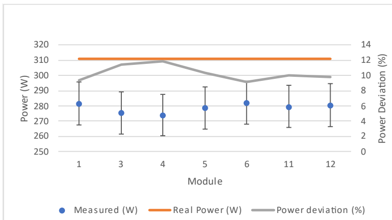


Figure 228: IV curve measurement results

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 4.6 ₹/Wp, 0.87 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 18.3 ₹/kWh to 9.2 ₹/kWh

Picture Gallery


Figure 229: Monkeys walking on modules


Figure 230: near shading due to construction rods


Figure 231: warm cells on modules


Figure 232: On-site O&M personnel missing PPE

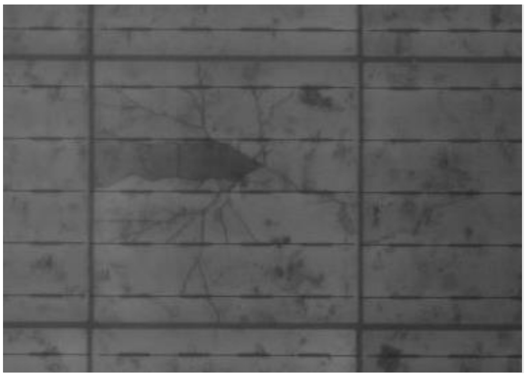


Figure 233: Cell with branched crack that will likely develop into inactive areas.


Figure 234: Poor cable management


Figure 235: PV plant overview


Figure 236: Inverter general view.

16

PV plant: ***II.16***
Nominal capacity: ***104 kWp***
Average specific yield: ***1356 kWh/kWp*** *(PVsyst estimation 1481 kWh/kWp)*

***Abstract**: The PV plant has several broken or missing modules due to high wind loads and poor mounting structure design. The cables don't meet the minimum bending radius and lack labelling. Two tables are oriented differently as the rest. Fixation method of the modules is rusted and bonding between modules is absent. It is recommended to (i) improve mounting structure, (ii) change broken modules, (iii) restring shaded modules, (iv) remove objects under modules, and (v) include inverter in cleaning activities. The estimated production boost expected by the retrofitting actions lies between 5 and 10%.*

PV Plant's health

Main Findings

- Poor cable management: The minimum cable bending radius is not considered and no string labelling was found.

Figure 237: Poor cable management and module misalignment.

- Modules are installed outside of roof edges in a high wind zone, resulting in damaged and missing modules.
- Two broken modules were found on site.
- Two tables have a different orientation from the rest of the tables.
- The table structure is fixed to the rooftops' perimeter wall with weak foundations and welded profiles for structural bonding between tables.

Figure 238: Poor structure management.

- Modules are fixed using rusted *J*-hooks and no clearance is found between modules.
- The LA is bent and casting a shadow over the system during the morning.
- PVC pipes stored under the modules can damage their back-sheet.
- An inverter presents heavy degrees of soiling, and its fan is very noisy, which might lead to break down.

Impact on Performance

- The on-site measured soiling losses were estimated in 6.0% from IV curve measurements.
- IR analysis indicates evidence of PID.

Figure 239: Potential PID-affected module.

- According to the number of cracks discovered via EL imaging; the system is not expected to have large power losses due to inactive areas.

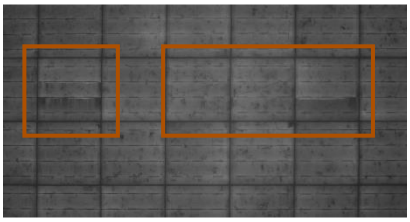


Figure 240: Microcracks on cells.

- The underperformance of the measured modules is around 17%.

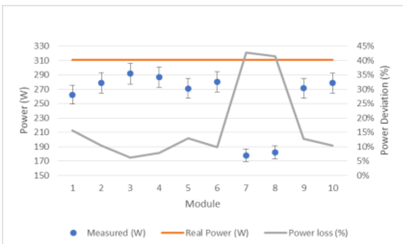


Figure 241: IV curve measurement results

- Several objects, such as, a water tank, walls, and the LA cast shadows over the system. According to the simulation of the system, the near shading losses account for up to 2.3%.

Proposed Solutions

- Broken and missing modules shall be replaced.
- The tables with different orientation shall be aligned with the rest of the tables towards true south.
- Solar cables should have a minimum bending radius to avoid early damages and string labelling should be included.
- The foundation and fixing method of the mounting structure must be improved to withstand the wind loads.
- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be connected in the same string or at least assigned to individual MPPTs.
- Include in the O&M practices the cleaning of the ventilation system of the inverters.
- The modules that might be affected by PID shall be resorted based on an IR sorting of the entire site.
- Objects under the PV-Array should be removed to prevent damage of the module's back-sheet.
- The module fixation method shall be improved including a bonding and clearance between the modules.

Figure 242: PVsyst constructed 3D model

- LA shall be repaired and relocated.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.9 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.8 ₹/kWh to 1.4 ₹/kWh

Picture Gallery


Figure 243: Table with different orientation.

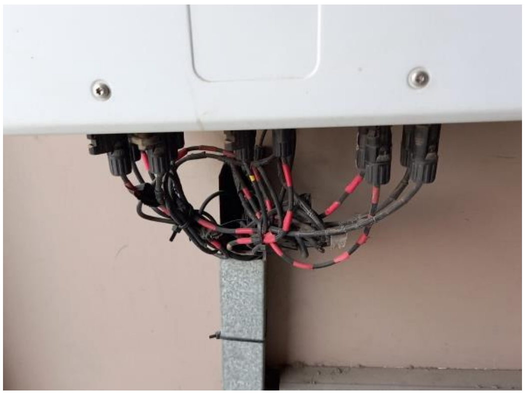


Figure 244: No string-labelling at inverter or module end.


Figure 245: Broken module.

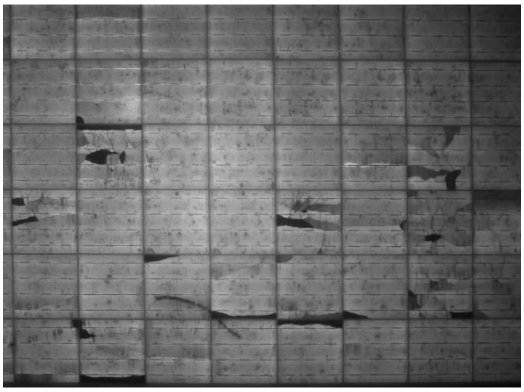


Figure 246: EL imaging of broken module.


Figure 247: Rusted J-hooks used as modules fixation.


Figure 248: Pipes stored under the modules.


Figure 249: Near shading objects.


Figure 250: Missing module.

17

PV plant: ***II.17***
Nominal capacity: ***80 kWp***
Average specific yield since COD (31.03.2018): ***661 kWh/kWp*** *(PVsyst estimation 1383 kWh/kWp)*

Abstract*: Some modules with mechanical damages were detected (broken modules). Cables hang under the modules were found. Interrow distance is insufficient. Structural earthing is incomplete and corroded. It is recommended to (i) increase the cleaning cycles, (ii) replace damaged modules and cables, (iii) retrofit the mounting structure, (iv) install a new earthing system, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the Performance Ratio. The estimated production boost expected by the retrofitting actions lies between 10 and 15%.*

PV Plant's health

Main Findings

- Inverters placed under the modules limiting air circulation.
- Base plates, connection bolts and most of the welded areas are rusted.
- There is no access to the front side of modules on the upper section for O&M activities.

Figure 251: No access to modules

- Object on the roof, possible near shading

Figure 252: Near shading

- Broken module.
- No string labelling on the inverter end.
- Burned inverter replaced by a refurbished one.
- No weather station on site.
- Poor cable management and bad bonding practice.
- Frame of some modules are bent; this can lead to micro-cracks.
- Inter-row shading due to proximity of the modules.
- Mounting structure is weak, diameter of structure is not ideal.

Impact on Performance

- Solar modules with defect on the ARC layer; the system is not expected to have large power losses due to this issue.

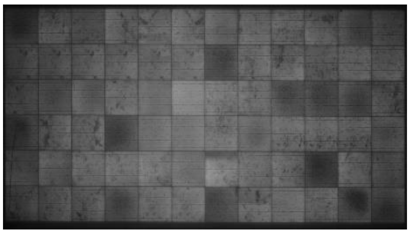


Figure 253: Module with manufacturing defect in the ARC layer

- The on-site measured soiling losses were estimated in 3.8%.
- Evidence of PID was found in the IR pictures

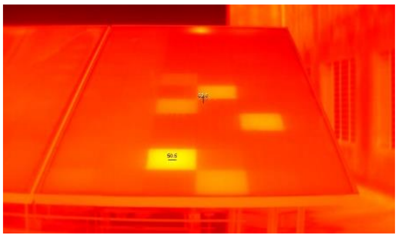


Figure 254: PID evidence in IR picture

- IR analysis showed that interrow shading developed hot cells in the bottom part of the modules. According to the PVsyst simulation, self-shading losses account for up to 5.36%.

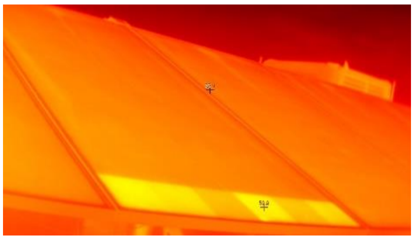


Figure 255: Module with hot cells due to inter-row shading

Proposed Solutions

- Broken module should be replaced.
- Change the location of the inverters in order to avoid hot spots.
- A weather station, or at least a irradiation sensor on the module plane shall be installed so the performance of the system can be properly determined.
- The cable layout can be optimized.
- Earthing connections between modules shall be added.
- A re-stringing of the modules from the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or at least assigned to individual MPPTs.
- Strings, Tables, and inverters should have a suitable labelling (UV-resistant if applicable).
- Rusted clamps and structure should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- In case it is possible, interrow distance shall be increased to avoid self-shading.

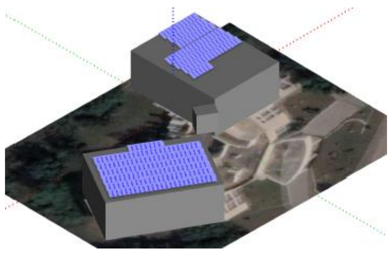


Figure 256: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 10% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.40 ₹/Wp, 0.16 ₹/Wp/a
Estimated retrofit cost per additional generationfor remaining lifetime: 3.4 ₹/kWh to 2.3 ₹/kWh

Picture Gallery

Figure 257: General plant overview.

Figure 258: General plant overview, interrow shading.

Figure 259: Inverter placed under the module.

Figure 260: Cleaning practice with water.

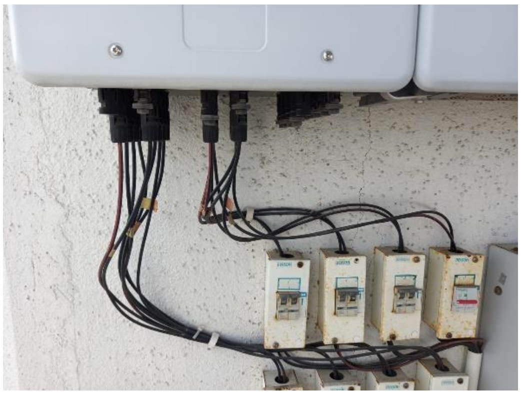


Figure 261: Inverter with no identification of strings.

Figure 262: Bad bonding practice.

Figure 263: Broken module.

Figure 264: Poor cable management.

18

PV plant: ***II.18***

Nominal capacity: ***20 kWp***

Average specific yield since COD: ***1159 kWh/kWp*** *(PVsyst estimation 1421 kWh/kWp)*

Abstract*: The PV plant is heavily affected by soiling due to the not functioning of a cleaning system. Many of the modules have back-sheet damage. Also, the plant capacity is overestimated by 1kW. It is recommended to (i) replace broken modules, (ii) find another cleaning system as the actual one causes permanent shading on the modules, (iii) install a new earthing system, (iv) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the Performance Ratio, and (v) retrofit the mounting structure. The estimated production boost expected by the retrofitting actions lies between 15 and 25%.*

PV Plant's health

Main Findings

- Clamping distance was found not to be appropriate, resulting in micro cracks on modules.
- Modules were installed beyond the edge area of the building.
- Modules have not been cleaned since commissioning date due to the fact that motors installed for automatic sprinklers have not worked. Heavy soiling observed.

Figure 265: Heavy soiling and bird drops on panels

- Commissioning certificate mentions 325 Wp panels whereas 315Wp panels were installed.
- No earthing connection between modules.
- Back-sheet damage on varies modules, bubbles and burned parts were found.

Figure 266: Back-sheet damaged

- Rusty mounting structure.
- Burned connections in Jbox observed.
- Bad cable management.
- No weather station was identified on site.

Impact on Performance

- The on-site measured soiling losses were estimated in 36%.
- Sprinklers were installed above the modules casting permanent shadow.
- Microcracks were observed on EL pictures.

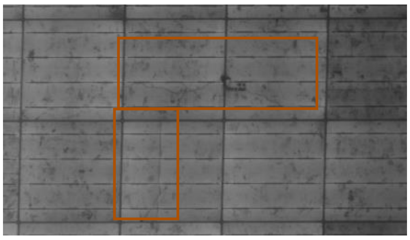


Figure 267: Microcracks on modules

- Manufacturing defects were found in some modules, the system is not expected to have large power losses due to this issue.

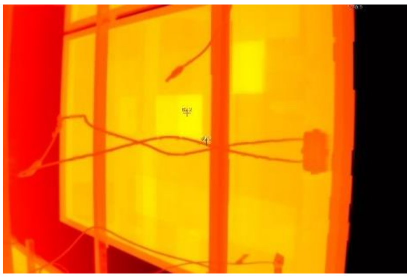


Figure 268:IR picture of a defective cell on module

Proposed Solutions

- Find another cleaning solution for the modules as the implemented sprinklers cast permanent shading. O&M practices with cleaning cycles in a weekly base should be implemented.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.
- The site should have walkways installed in order to carry O&M activities safely.
- In case it is possible, modules that are installed beyond the edge area of the building should be moved in order to reduce the wind loads.
- Burned modules should not be connected to the system to avoid further damages. It should be replaced or removed.
- Due to the fact that modules have less capacity than the planned, the plant capacity is reduced by 1kW.

Figure 269: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 15% to 25%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 3.67 ₹/Wp, 0.33 ₹/Wp/a
Estimated retrofit cost per additional generationfor remaining lifetime: 2.9 ₹/kWh to 1.7 ₹/kWh


Figure 270: Height of mounting structure


Figure 271: Overview of the power plant

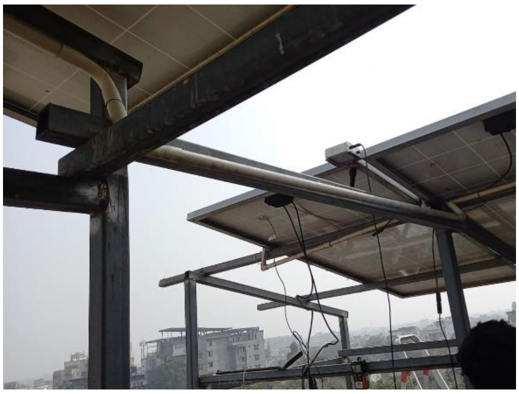


Figure 272: DC cable management and cables hanging


Figure 273: Sprinklers installed on modules

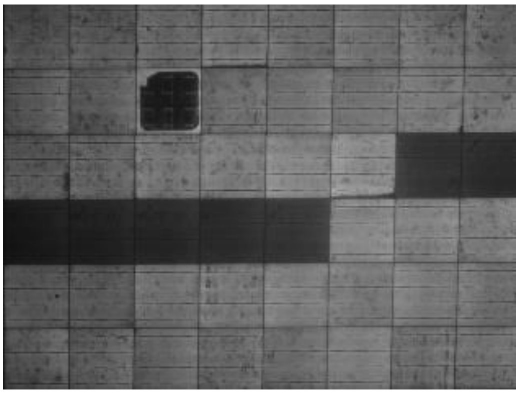


Figure 274: EL image of defective manufacturing

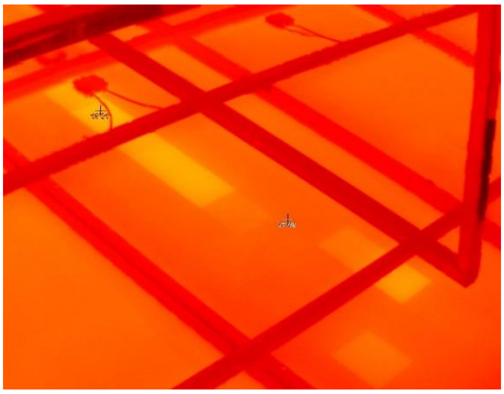


Figure 275: IR image of a defective manufacturing


Figure 276: Bad O&M practices


Figure 277: Very risky O&M practices

19

PV plant: ***II.19***
Nominal capacity: ***20 kWp***
Average specific yield for last year: ***1144 kWh/kWp*** *(PVsyst estimation 1454 kWh/kWp)*

Abstract: *Some modules with mechanical damages were detected (micro-cracks and burned cells). Cables hang under the modules. Interrow distance is insufficient. Structural earthing is incomplete and corroded. It is recommended to (i) increase the cleaning cycles, (ii) replace damaged modules and cables, (iii) retrofit the mounting structure, (iv) install a new earthing system, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the Performance Ratio, (vi) remove objects under modules. The estimated production boost expected by the retrofitting actions lies between 10 and 15%.*

PV Plant's health

Main Findings

- Modules have been installed over the edge limits of the building, increasing the wind load on the panels. Not possible to reach the panels for cleaning.

Figure 278: Panels beyond construction area

- Mounting structure is mostly rusted on welded areas and fasteners.

Figure 279: Rust in mounting structure

- Modules with burned cells
- Connectors are mostly soiled.
- J-boxes with burned contact were found.
- Bad cable management.
- No LA found on site.
- No weather station was found.
- Conduits rest in the mounting structure and the panel that may be cause micro cracks.
- The bonding between modules is absent.
- Different junction box found that indicates there is a different solar panel model.

Impact on Performance

- Microcracks were observed in the EL pictures

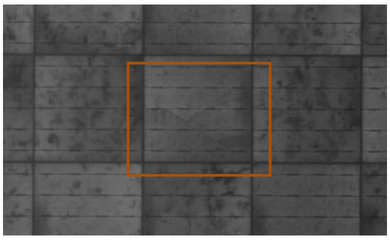


Figure 280: EL imaging

- Modules with manufacturing defect; the system is not expected to have large power losses due to this issue

Figure 281: Modules with manufacturing defect

- The on-site measured soiling losses were estimated in 11%.
- The underperformance of the measured modules is around 27%.

Proposed Solutions

- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.
- The site should have walkways installed in order to carry O&M activities safely.
- Modules with defective manufacturing problems, modules with burned back-sheet, and modules with moisture should be replaced.
- Earthing connections between modules shall be added.
- Based on the soiling calculated, the cleaning cycles shall be increased to a weekly base.
- In case it is possible, modules that are installed beyond the edge area of the building should be moved in order to reduce the wind loads.
- Rusted clamps and structure should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- The cable layout can be optimized.
- It is recommendable to have lightning arrestor on the roof.

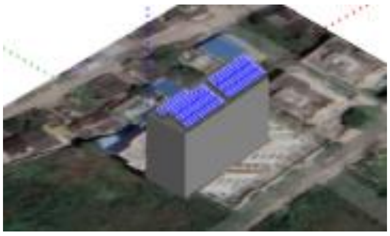


Figure 282: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 10% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.91 ₹/Wp, 2.14 ₹/Wp/a
Estimated retrofit cost per additional generationfor remaining lifetime: 12.6 ₹/kWh to 8.4 ₹/kWh

Picture Gallery

Figure 283: Scratch on the back-sheet.

Figure 284: Overview of part of power plant.

Figure 285: Hanging cables.

Figure 286: Bad O&M practices.

Figure 287: Junction box with melted contact.

Figure 288: Clean vs not clean modules.

Figure 289: PVC between rail and module.

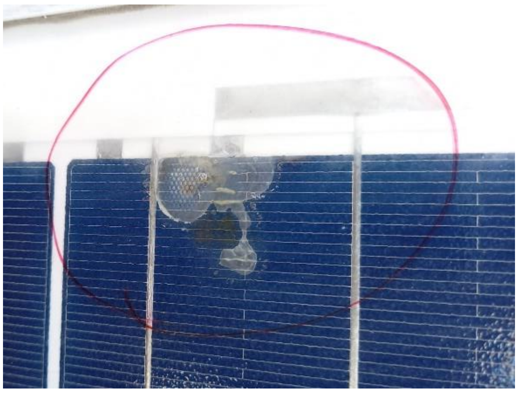


Figure 290: Module with delamination.

20

*PV plant: **II.20***
*Nominal capacity: **124 kWp***
*Average specific yield since COD (18.02.2018): **1090 kWh/kWp** (PVsyst estimation 1434 kWh/kWp)*

***Abstract**: Some modules with back-sheet scratches were detected. Cables loosely hanging from the modules were found. Module-to-module earthing is absent. It is recommended to (i) add earthing connections between modules, (ii) replace the cleaning equipment used, (iii) replace modules with back-sheet damage and melted connectors, (iv) replace rusted components of the mounting structure, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions lies between 7% and 9%.*

PV Plant's health

Main Findings

- Poor cable management: Cables loosely hanging from the structure and exposed to ambient. The minimum cable bending radius is not respected. In addition, table and string labelling are missing.

Figure 291: Poor cable management.

- One PV table with a 2-Portrait configuration was set up close to PV tables with 1-Portrait configuration. This causes shading on the 1-Portrait tables.
- The joints the mounting structures showed signs of rusting.
- A 3.5 m boundary wall casts shadow on the flat-roof installation during the morning, and the sheet-roof installation during the evening.

Figure 292: Shading on installations by boundary wall.

- Tables in one section of installation have bent structures in one end.
- Module-to-module bonding is absent.
- No weather station identified on site.

Impact on Performance

- The system performance was affected by soiling loss of 3.5%, estimated from IV curve measurements.
- IR analysis shows presence of hot cells from soiling.

Figure 293: Hot cells from soiling.

- The EL image reveals presence of micro-cracks and back-sheet scratches.

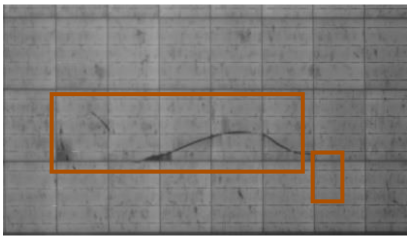


Figure 294: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 11% for the measured modules.

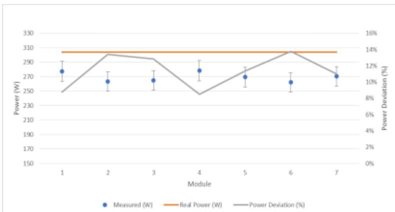


Figure 295: IV curve measurement results.

- According to the PVsyst simulations, the near shading losses account to 2.5%, and the module tilt used constitutes to 2.5% losses relative to optimal tilt.

Proposed Solutions

- Strings, tables, and inverters shall have suitable labelling (UV-resistant if applicable).
- The cleaning cycles shall be increased. Cleaning equipment shall be replaced to provide better cleaning and prevent module damage from cleaning.
- Modules with back-sheet scratches and deformed connectors shall be replaced to avoid safety threats.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least assigned to individual MPPT.
- A re-stringing shall be conducted to have shaded modules in the same string or at least assigned to individual MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Module tilt shall be changed to optimal tilt of 27°.
- If possible, installation that extend beyond the parapet shall be moved to reduce damage from wind loads.
- Earthing connections between modules shall be added.
- Rusted clamps and structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

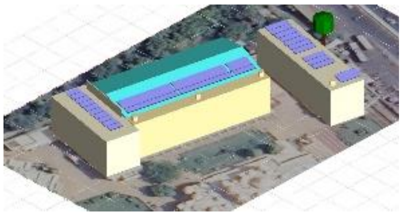


Figure 296: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 7% to 9%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.16 ₹/Wp, 0₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.3 ₹/kWh to 1 ₹/kWh

Figure 297: Bird droppings leading to hotspots.

Figure 298: Corroded joints.

Figure 299: 1.5m tall shading object.

Figure 300: Cables exposed to ambient.

Figure 301: Installation in high wind zones.

Figure 302: Uneasy plant access.

Figure 303: Poor cable management

Figure 304: Table with different orientation casting shadow.

21

PV plant: ***II.21***
Nominal capacity: ***39.04 kWp***
Average specific yield COD (1.11.2018): ***1322 kWh/kWp*** *(PVsyst estimation 1468 kWh/kWp)*

Abstract: *Cable layout with loosely hanging cables were found. Modules with cell breakage and burned cells were connected to the system. Modules were shaded by a taller room and water tank. It is recommended to (i) optimize cable layout, (ii) replace modules with broken glass and burned cells, (iii) re-sort lower performing modules, (iv) re-string shaded modules, and (v) install a weather station. The estimated production boost expected by the retrofitting actions lies between* ***4%*** *and* ***8%***.

PV Plant's health

Main Findings

- Poor cable management: The cables are observed to be loosely hanging and exposed to ambient. Cable conduits used are degraded.

Figure 305: Cable layout.

- Inverter fans and filters were found soiled.
- Damaged modules with broken glass and burnt cells were connected to the system.
- The LA found on site was broken and non-functional.
- Modules are shaded by objects like taller room and water tank.

Figure 306: Shading by taller room on the modules.

Impact on Performance

- Soiling losses of the modules were observed to be 3% as estimated from IV curve measurements.
- IR analysis indicates hot cells on modules, which may indicate irreversible cell damage.

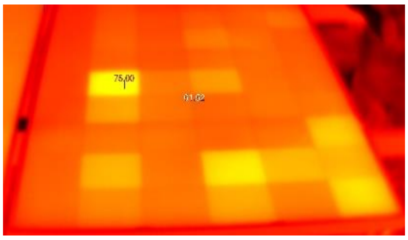


Figure 307: Hot cells from IR imaging.

- The EL image reveals isolated parts on the modules. Loss from mechanical damage is expected to be around 4%.

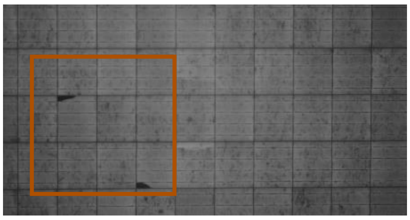


Figure 308: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 8.1% of the measured modules.

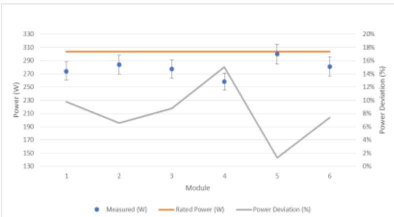


Figure 309: IV curve measurement results.

- According to the PVsyst simulations, the near shading losses account to 2.5%.

Proposed Solutions

- Loosely hanging cables shall be routed using appropriate tags. UV protection measurements shall be taken by a suitable rack with roof or cable coating.
- The inverter filters and fans shall be cleaned.
- Broken LA shall be replaced.
- Modules with broken glass and burned cells shall be replaced.
- A resorting of modules shall be done to have lower performing modules in the same string or at least same MPPT.
- A re-stringing of modules shall be conducted to have the shaded modules in the same string or at least same MPPTS.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

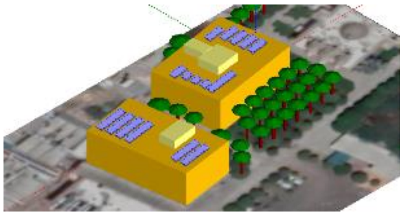


Figure 310: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 4% and 8%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 3.42 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 3.1 ₹/kWh to 1.5 ₹/kWh

Picture Gallery

Figure 311: Degraded conduit.

Figure 312: Broken LA on site.

Figure 313: Module with cell breakage.

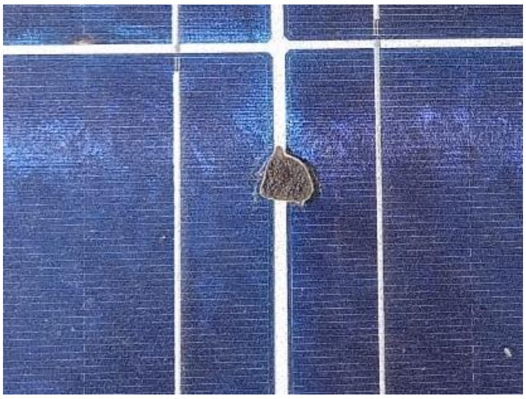


Figure 314: Module with burn on the cell.

Figure 315: Taller building cast module shading.

Figure 316: Broken LA on site.

Figure 317: Soiled inverter fans.

Figure 318: Soiled inverter filters.

22

PV plant: ***II.22***
Nominal capacity: ***39,7 kWp***
Average specific yield since COD (1/2/2018): ***1033,7 kWh/kWp*** *(PVsyst estimation 1326 kWh/kWp)*

***Abstract**: Some shaded and heavily soiled modules were found. A module with glass breakage was found to be connected to the system. It is recommended to (i) replace broken parts of the cabling and connectors, (ii) replace the rusted screws, (iii) change the module tilt to the optimal value, (iv) re-string the shaded or broken modules, (v) increase the cleaning cycle, and (vi) install a weather station or at least an irradiation sensor. The estimated production boost expected by the retrofitting actions lies between **17%** and **20%**.*

PV Plant's health

Main Findings

- Some modules have slipped due to improper mounting.

Figure 319: Shifted modules.

- The screws used in the mounting structures showed signs of rusting.
- Some parts of the modules were installed underneath roofs and have significant shading.

Figure 320: Shading on installations.

- A module with a broken glass is still connected.
- No weather station identified on site.
- Access to the second part of the roof is difficult, which makes module cleaning and maintenance difficult.
- Shoe-prints were found on some modules.

Impact on Performance

- The system performance was affected by soiling losses of 10.9%, estimated from IV curve measurements.
- The Thermographic examination indicates irreversible cell damage due to shading.

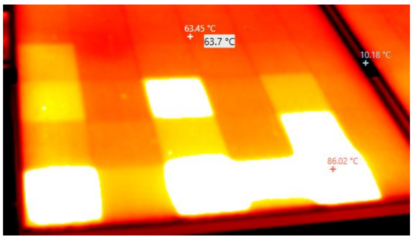


Figure 321: Hot cells

- The EL image reveals presence of micro-cracks and isolated parts, which are representative of poor handling during installation or maintenance.

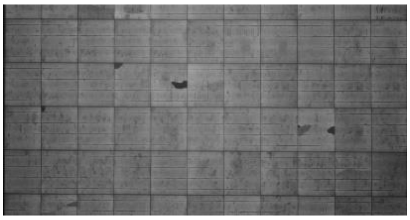


Figure 322: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 8.5% from the measured modules.

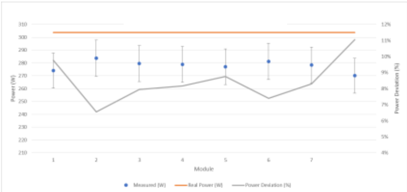


Figure 323: IV curve measurement results.

- According to PVsyst simulations, the module tilt deviates about 5° from the optimal position, which leads to about 1.6% losses.

Proposed Solutions

- If there is sufficient space on the roof, the module tilt shall be adjusted.
- A re-sorting of modules shall be conducted to have lower performing modules in the same string or at least same MPPT.
- A re-stringing of modules shall be conducted to have shaded modules in the same string or at least same MPPT.
- Damaged or burnt connectors must be replaced.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- A proper O&M plan including training shall be established. This helps in improved performance and safety of the plant.
- A weather station, or at least an irradiation sensor on the module plane shall be installed so that the performance of the system can be properly determined.
- Modules with broken glass shall be replaced since they pose a safety risk and impact the performance.
- Rusted screws should be replaced if possible.

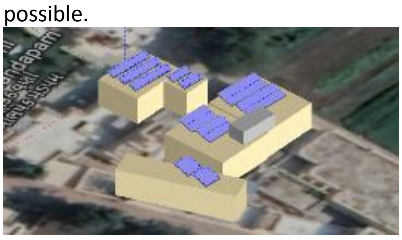


Figure 324: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 17% to 20%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.54 ₹/Wp, 0.33 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.5 ₹/kWh to 2.2 ₹/kWh

Picture Gallery


Figure 325: Soiling condition.


Figure 326: Burned connector.


Figure 327: Broken modules.


Figure 328: Footprints on the modules.


Figure 329: Shading due to trees.


Figure 330: Dangerous roof access.


Figure 331: Rusted screws.


Figure 332: Site overview.

23

PV plant: ***II.23***
Nominal capacity: ***348 kWp***
Average specific yield for last two years: ***1324 kWh/kWp*** *(PVsyst estimation 1430 kWh/kWp)*

Abstract*: Several modules with cell breakage and isolated cell parts were detected. Cables and connectors were exposed to ambient without any UV protection, they also display signs of abrasion and cuts. Several clamps were improperly fixed, and many were faulty. It is recommended to (i) optimize the cable layout (ii) replace rails that offer better ventilation (iii) restring the modules with cell breakage, and shaded module to dedicated strings, and (iv) install a weather station or at least an irradiation sensor to monitor performance ratio. The estimated production boost expected by the retrofitting actions lies between* ***6%*** *and* ***10%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables and connectors are degraded from exposure to ambient conditions. The cables also showed signs of abrasion and cuts, and low bending radius.

Figure 333: Cable layout.

- 30 mm rail used in flush mount causes higher operating temperatures.
- Open shaft holes found on site.
- Walkway installed over landscape module, casting permanent shading on the module and reducing string production.

Figure 334: Module shading from walkway.

- Clamp fixations at several locations show improper application leading to misalignment and imbalanced loading.
- Clamps used to fix walkways are rusted.
- Fans and filter in an inverter were heavily soiled.
- Some modules are shaded by a taller section of the building.
- Shoeprints found on modules.

Impact on Performance

- The system performance was affected by soiling loss of 3.5%, estimated from IV curve measurements.
- IR analysis shows presence of hot cells.

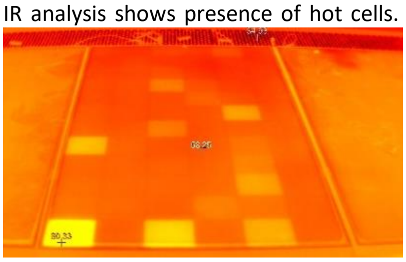


Figure 335: Hot cells from IR imaging.

- The EL image reveals cracks and isolated parts from broken cells. All modules tested for EL revealed isolated parts. Power loss estimated from mechanical damages is expected to be around 8%.

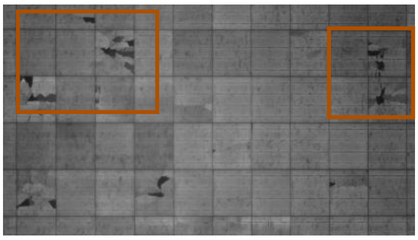


Figure 336: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 7.7% for the measured modules.

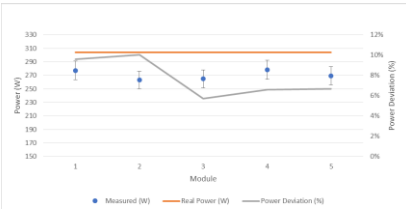


Figure 337: IV curve measurement results.

- Simulations from PVsyst revealed near shading losses to be 1.95%, and a 1.34% loss from reduced heat dissipation.

Proposed Solutions

- The cable layout shall be optimized, the minimum bending radius shall be 10x the cable diameter, and cable racks shall be used.
- Rails used currently of around 30 mm height shall be replaced with ones that offer an effective clearance of 100 mm to facilitate better air flow and improve system performance.
- Open shaft holes shall be covered since they pose a several threat to the O&M personnel.
- A proper O&M plan shall be established that includes instructions on module handling.
- A re-sorting shall be conducted to have modules with isolated parts in the same string or at least same MPPT.
- A re-stringing of modules shall be conducted to have shaded modules in the same at least same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed so that the performance of the system can be properly determined.
- Faulty clamp fixations shall be properly fixed, and clamps with faulty threads shall be replaced. Rusted clamps should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

Figure 338: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 6% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.01 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 0.6 ₹/kWh to 0.4 ₹/kWh

Picture Gallery


Figure 339: Hot cells on module.


Figure 340: Open shaft in installation area.


Figure 341: Soiling and cement particles from roof drain pipe directly above the module.


Figure 342: Shoe prints on module.


Figure 343: Cables with cuts.


Figure 344: Misalignment from clamp fixation.


Figure 345: Degraded conduit.


Figure 346: Shading from taller section of building.

24

PV plant: ***II.24***
Nominal capacity: ***46.08 kWp***
Average specific yield since COD (11.02.2017): ***1244.8 kWh/kWp*** *(PVsyst estimation 1459 kWh/kWp)*

***Abstract**: Some shaded modules and, loosely hanging cables were found. The substructure has inferior workmanship in some places. It is recommended to (i) fix and protection of the cables and connectors (ii) replace the rusted screws, (iii) change the module tilt to its optimal position, (iv) re-string the shaded or broken modules, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions lies between **12%** and **15%**.*

PV Plant's health

Main Findings

- Poor cable management: Cables loosely hanging from the structure and are exposed to ambient. The minimum cable bending radius is not respected.

Figure 347: Loosely hanging cables and low bending radius.

- Objects under the modules can lead to insufficient rear ventilation.
- The screws used in the mounting structures showed signs of rusting.
- On the south side of the roof edge are superstructures that shade parts of the plant.

Figure 348: Shading on installations by boundary wall.

- Some of the unused plugs on the inverters are not closed, which can lead to moisture ingress.
- No weather station identified on site.
- The fans of the inverters are slightly soiled.
- Difficult access to some installations.

Impact on Performance

- The system performance was affected by soiling losses of 4%, estimated from IV curve measurements.
- IR analysis shows presence of hotspots due to broken cell and soiling. The pattern is indicating a possibility of PID issues.

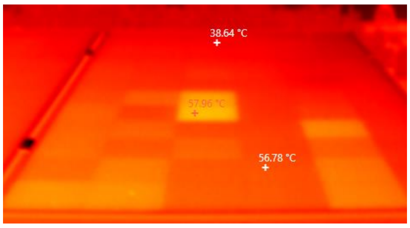


Figure 349: Hotspot from soiling.

- The EL image reveals presence of micro-cracks and isolated parts.

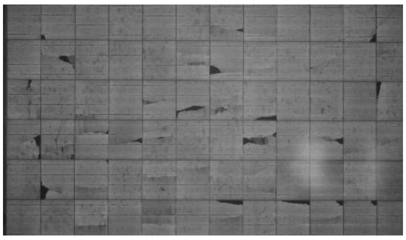


Figure 350: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 4% for measured modules.

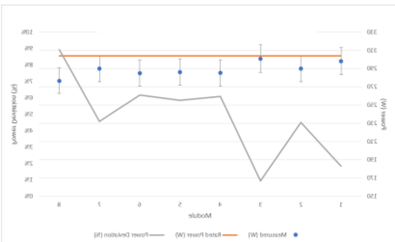


Figure 351: IV curve measurement results.

- According to PVsyst simulations, the near shading losses account to 1.7%, and module tilt 1.6% relative to optimal tilt.

Proposed Solutions

- The cable layout shall be optimized by using a suitable cable rack with roof or cable coating.
- In order to be able to clean the modules on steles that are difficult to access, the cleaning staff should be equipped with the appropriate tools.
- Modules tilt shall be changed to an optimal value.
- Modules shall be investigated further for PID, and if necessary, the system should be equipped with an anti-PID box.
- A re-sorting of modules shall be conducted to have lower performing modules in the same string or at least same MPPT.
- A re-stringing of modules shall be conducted to have lower performing in the same string or at least same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed so that the performance of the system can be properly determined.
- Rusted screws shall be replaced.

Figure 352: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 12% to 15%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.26 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 0.7 ₹/kWh to 0.6 ₹/kWh

Picture Gallery


Figure 353: Dirty inverter fans.

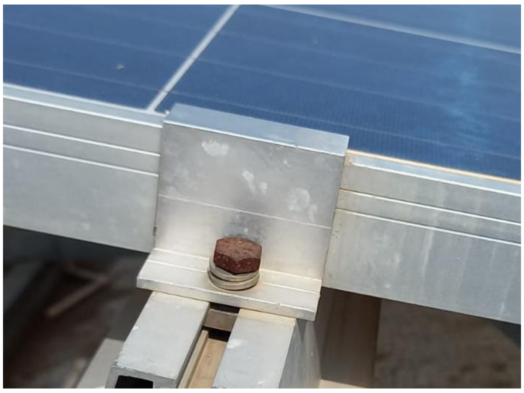


Figure 354: Rusted screws.

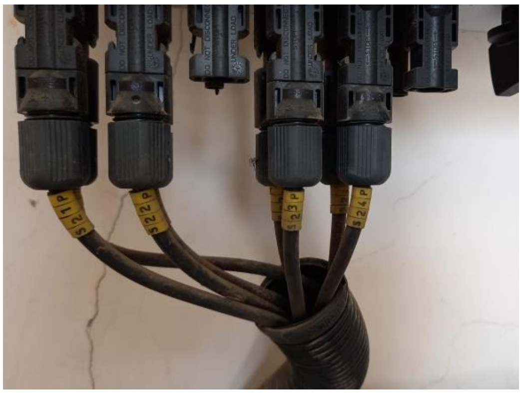


Figure 355: Open inverter connectors.


Figure 356: objects under the module.


Figure 357: Base Plate unhinged at one end.


Figure 358: Broken ballast blocks fixation.


Figure 359: Degraded conduit.


Figure 360: Bending radius of the cables is too low.

25

PV plant: ***II.25***
Nominal capacity: ***27.5 kWp***
Average specific yield COD (31.3.2018): ***1374 kWh/kWp*** *(PVsyst estimation 1456 kWh/kWp)*

***Abstract**: Cable layout with loosely hanging cables were found. Modules with manufacturing and other defects were found on site. Several structure related problems were observed. It is recommended to (i) optimize cable layout, (ii) replace defective modules, (iii) re-sort and restring modules, (iv) replace faulty and unsuitable clamps and structures, and (v) install a weather station. The estimated production boost expected by the retrofitting actions lies between 5% and 7%.*

PV Plant's health

Main Findings

- Poor cable management: The cables were observed to be loosely hanging, without string labelling, and exposed to ambient.

Figure 361: Cable layout.

- Many modules were dislodged and lost due to a cyclone incident. Replacement modules of different power rating and dimensions were mounted onto the same structure.
- Inverter fans and filters are soiled.
- Module defects such as broken back-sheet, sealant on cell, moisture ingress, and sealant gap around junction box found.
- The connections between structure purlins in a table was established by varying screws per plate.
- Clamps of different types were used in the same table, also causing an imbalance in the load on the modules.

Figure 362: Clamp variations.

Impact on Performance

- Soiling loss of 1% were estimated from IV curve measurements.
- IR analysis indicates hotspots and hot cells on modules due to sealant on cell and broken cells.

Figure 363: Hotspot by sealant on cell.

- The EL image reveals several isolated parts, which may have caused from handling issues, the cyclone incident, or imbalanced loading.

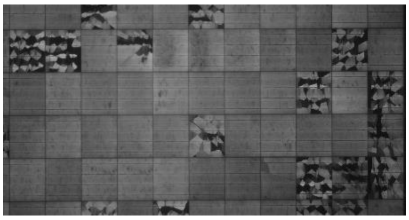


Figure 364: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 12.3% for the measured modules.
- According to the PVsyst simulations, the near shading losses account to 1.31%, and 1.5% tilt loss relative to optimal tilt.

Figure 365: IV curve measurement results.

Proposed Solutions

- Loosely hanging cables shall be routed using appropriate tags. UV protection measurements shall be taken by a suitable rack with roof or cable coating.
- The inverter filters and fans shall be cleaned.
- Manufacturing defects shall be investigated for possible warranty claim.
- Modules with broken back-sheet and sealant gap pose performance and safety threats, which shall be replaced.
- A re-sorting of modules shall be conducted so that the lower performing modules are in the same string or at least in the same MPPT.
- A re-stringing of modules shall be conducted so that the shaded modules are in the same string or at least same MPPT.
- Module tilt shall be changed to optimal tilt of 25°.
- Clamp variations used in the same table shall be replaced with appropriate clamps of same type. The structure and components shall be replaced or retrofitted to sustain any future damages from cyclones.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

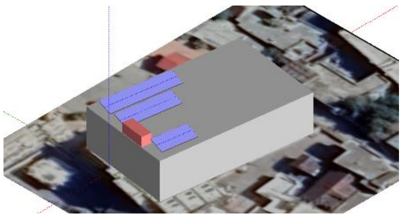


Figure 366: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 7%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 3.1 ₹/Wp, 0₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.1 ₹/kWh and 1.5 ₹/kWh

Picture Gallery


Figure 367: Taller room that cause shading.


Figure 368: Sealant gap around junction box.


Figure 369: Damaged module frame.


Figure 370: Broken back-sheet.


Figure 371: Sealant on cell.


Figure 372: Purlins joined by screws and connecting plate.


Figure 373: Moisture ingress.


Figure 374: Damaged and corroded connecting plates.

26

PV plant: ***II.26***
Nominal capacity: ***50 kWp***
Average specific yield since COD (12.08.2017): ***1230 kWh/kWp*** *(PVsyst estimation 1431 kWh/kWp)*

Abstract: *Cables loosely hanging and layout with low bending radius were found. Module misalignment was observed across the installation. It is recommended to (i) optimize cable layout, (ii) carry out cleaning more effectively to remove cementing, (iii) provide better ventilation in the inverter room, (iv) provide safety railings for safer and easier access for the O&M team to modules close to the slopes, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions lies around 5% and 7%.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables from the structure. The minimum cable bending radius is not respected.

Figure 375: Loosely hanging cables and low bending radius.

- Inverter fans are soiled.
- Ballast blocks used are of varying dimensions due to improper casting, causing module misalignment.
- Tilt inhomogeneity greater than 2 degrees found across the installation.
- Modules are clamped at 560 mm from the edge, which does not align with the manufacturer guidelines.
- Inverter room was without proper ventilation.
- Slope of roughly 20 degrees on both sides of the roof makes the access risky to the end modules for the O&M team.

Figure 376: Risky access to table ends for the O&M team.

- Unsafe access to the roof.

Impact on Performance

- The system performance was affected by soiling loss of 2%, estimated from IV curve measurements.
- IR analysis shows presence of hotspots from soiling.

Figure 377: Hotspot from soiling.

- The EL images reveal that the modules are essentially free from defects that can impact the module performance.

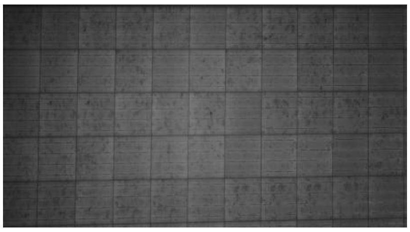


Figure 378: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 3.8% for the measured modules.

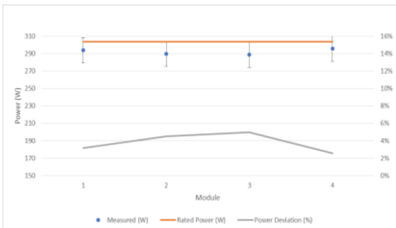


Figure 379: IV curve measurement results.

- According to PVsyst simulations, the self-shading losses account to 2.25%.

Proposed Solutions

- The cable layout shall be optimized; the minimum bending radius is 10x times the cable diameter.
- The cleaning shall be carried out more effectively, since soiling is present on the module edges after cleaning.
- If possible, the ballast blocks used to fix the mounting structure shall be replaced with proper dimensions, and properly aligned to reduce module misalignment.
- The module tilt shall be increased to the optimal value of 25°.
- The table pitch used shall be increased to reduce self-shading losses.
- The ventilation in the inverter room shall be improved.
- A weather station, or at least an irradiation sensor on the module plane shall be installed so that the performance of the system can be properly determined.
- Modules shall be clamped according to manufacturer guidelines.
- Safety railings shall be provided to reduce safety risks on area close to slope roofs.

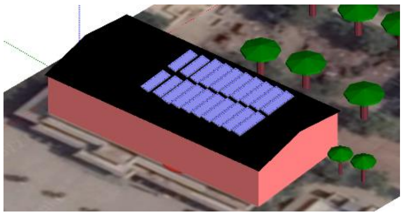


Figure 380: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 5% to 7%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.28 ₹/Wp, 0₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1 ₹/kWh to 0.7 ₹/kWh

Picture Gallery


Figure 381: Installation overview


Figure 382: Uneasy roof access.


Figure 383: Improperly cast ballast blocks.


Figure 384: Inverter fans soiled.


Figure 385: Poorly ventilated inverter room.


Figure 386: Modules with cementing.


Figure 387: Spikes of lightning arrester damaged.


Figure 388: LA casting shading.

27

PV plant: ***II.27***
Nominal capacity: ***109 kWp***
Average specific yield since COD (21.07.2017): ***678 kWh/kWp*** *(PVsyst estimation 1271 kWh/kWp)*

Abstract*: Heavy soiling was observed. Cables with bite marks and missing string labelling were found. Several modules show presence of PID. It is recommended to (i) increase cleaning cycles, (ii) replace the cleaning equipment used, (iii) install anti-PID box to mitigate damages from PID, (iv) re-sort PID affected modules, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions is expected to be around* ***35% to 40%.***

PV Plant's health

Main Findings

- Poor cable management: The minimum cable bending radius is not respected. In addition, table and string labelling are missing. Cables showed signs of bite marks.

Figure 389: Cable layout.

- Several modules are shaded by a taller room, tower, water tank, parapet walls, and PVC pipes.
- The contacts in the earthing strips between tables are rusted.
- The inverter fans and filters are soiled.
- The Surge Protection Device (SPD) and fans in some inverters have also failed in operation.
- The inverter room is poorly ventilated.
- Modules are heavily soiled.
- Modules are installed beyond roof boundary in high wind zone.
- During inspection, many modules with bent frames were seen due to installation over pipelines.

Figure 390: Module frame bent from installation over pipeline.

Impact on Performance

- The system performance was affected by soiling loss of 28%, estimated from IV curve measurements.
- IR analysis indicates presence of PID in the modules.

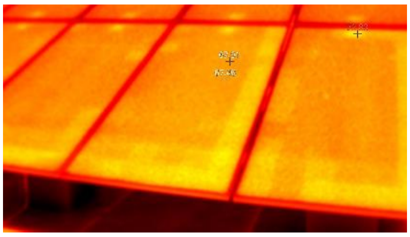


Figure 391: IR analysis indicating PID.

- The EL image also reveals that the modules are severely affected by PID. EL findings also show presence of cracks, isolated cell parts, and finger interruptions.

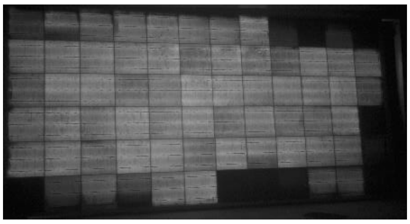


Figure 392: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 35% for the measured modules.

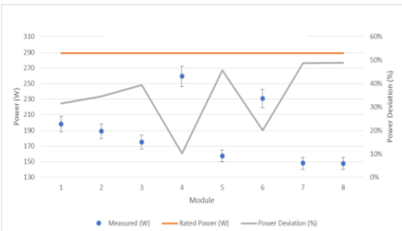


Figure 393: IV curve measurement results.

Proposed Solutions

- Strings, tables, and inverters should have suitable labelling (UV-resistant if applicable). Appropriate protection of cables from animals shall be provided.
- The cleaning cycles shall be increased based on the results of a soiling study.
- The inverter filters and fans shall be cleaned. Faulty components in the inverters shall be replaced.
- Inverter room shall be properly ventilated.
- A re-sorting shall be conducted to have the lower performing modules in the same string at least same MPPT.
- A re-stringing shall be conducted to have shaded modules in the same string or at least same MPPT.
- An anti-PID installation shall be done to reduce performance loss and further module damages from PID.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Installation over pipelines shall be moved, or the pipeline shall be rerouted, and the modules with bent frames shall be replaced to prevent any safety threats.
- Rusted joints and components should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

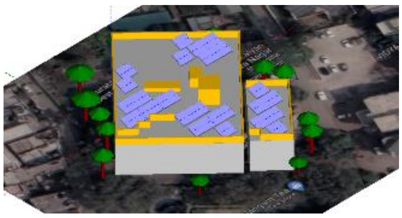


Figure 394: 3D model constructed in PVsyst.

Picture Gallery

Estimated energy boost after conducting the suggested retrofitting actions: 35% to 40%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.19 ₹/Wp, 0.48₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.5 ₹/kWh to 2.2 ₹/kWh


Figure 395: Cables with bite marks.


Figure 396: Soiling condition of modules.


Figure 397: Overview showing pipeline through installation and tower causing shading.


Figure 398: Taller building causing shading in the evening.

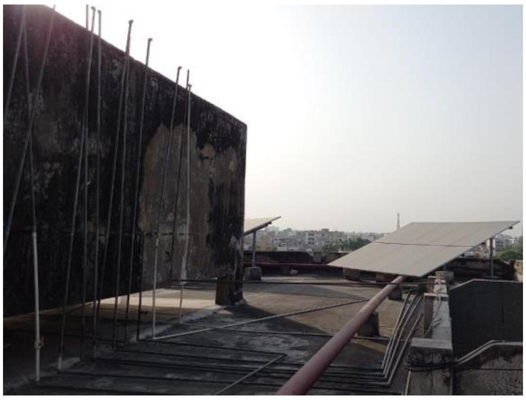


Figure 399: Shading by water tank.


Figure 400: Soiled inverter filters.


Figure 401: No ventilation in inverter room.


Figure 402: Soiled inverter fans.

28

PV plant: ***II.28***
Nominal capacity: ***80 kWp***
Average specific yield since COD (08.03.2017): ***909 kWh/kWp*** *(PVsyst estimation 1312 kWh/kWp)*

***Abstract**: Several modules with open j-boxes and corroded contacts were found, posing severe threat to people. Loosely hanging cables with low bending radius were found. Modules are significantly soiled. It is recommended to (i) replace modules with corroded contacts, (ii) increase the cleaning cycles, (iii) reestablish the earthing connection between structures, (iv) retrofit the mounting structure, and (v) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **20%** and **25%**.*

PV Plant's health

Main Findings

- Poor cable management: Cable layout with low bending radius. In addition, table and string labelling are missing.

Figure 403: Loosely hanging cables and low bending radius.

- The conduit housing the cables are broken, exposing the cables and connectors to ambient conditions without any UV protection.
- Inverters filters and fans are soiled and are noisy in operation.
- Bolts used in mounting structures showed signs of rusting.
- The modules are heavily soiled.

Figure 404: Modules with heavy soiling.

- Earthing between tables is disconnected.
- Modules are misaligned due to improper bolt fixation.
- Modules with open J-boxes and corroded contacts were found, posing a severe risk to people and equipment.
- No weather station identified on site.
- Modules with different year of manufacture were used in same string.

Impact on Performance

- The system performance was affected significantly by soiling loss of 20%, estimated from IV curve measurements.
- IR analysis shows presence of hotspots from soiling.

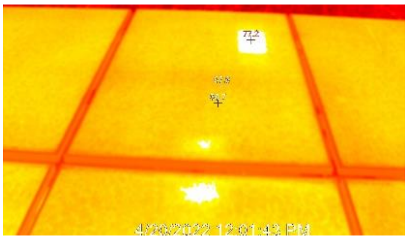


Figure 405: Hotspot from soiling.

- The EL image reveals presence of long cracks, which arises due to issues in transportation or handling. These cracks are not expected to impact performance in their given state.

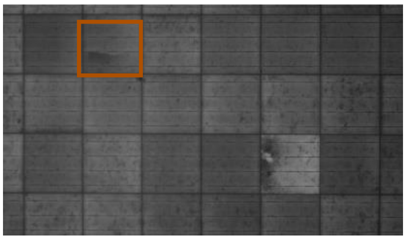


Figure 406: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 4% for the measured modules.

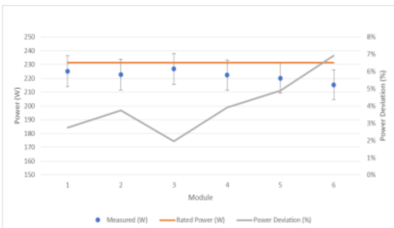


Figure 407: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.13%.

Proposed Solutions

- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Modules with open J-boxes and corroded contacts shall be replaced.
- A re-sorting of modules shall be conducted to have modules with same year of manufacture in the same string or at least same MPPT.
- A re-stringing of modules shall be conducted to have shaded modules in the same string or at least same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Earthing strips between structures shall be properly connected.
- Bolts and nuts shall be properly fixed to reduce module misalignment and improve safety. Polymer end clamps shall be replaced since they are unsuitable.
- Rusted joints should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

Figure 408: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 20% to 25%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.5 ₹/Wp, 0.5 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.2 ₹/kWh to 1.8 ₹/kWh

Picture Gallery

Figure 409: Module misalignment.

Figure 410: Improper bolting.

Figure 411: Broken J-box with corroded contacts.

Figure 412: Shading from tree.

Figure 413: Broken polymer clamps casting shadow.

Figure 414: Cables with low bending radius.

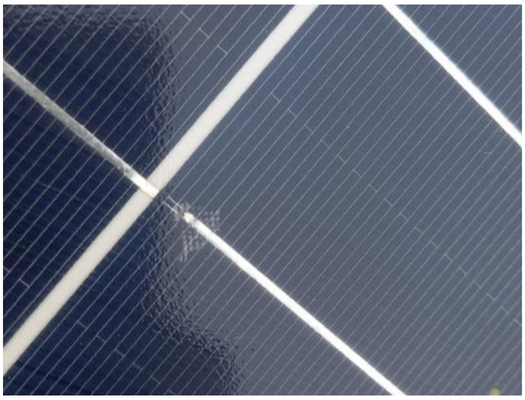


Figure 415: Air bubbles from improper lamination.

Figure 416: Inverter soiled due to ambient exposure.

29

PV plant: ***II.29***

Nominal capacity: ***5 kWp***

Average specific yield since COD (25.10.2016): ***870.6 kWh/kWp*** *(PVsyst estimation 1431 kWh/kWp)*

Abstract: *Cables layout with loosely hanging cables and low bending radius were found. Joints and structures are rusted. Modules were observed to be heavily soiled. It is recommended to (i) optimize cable layout to have optimal bending radius, (ii) increase the cleaning frequency to reduce performance loss and further module damage, (iii) provide safety railings for easier access for the O&M team, and (iv) install a weather station or at least an irradiation sensor on the module plane to monitor the performance ratio. The estimated production n boost expected by the retrofitting actions lies between* ***18%*** *and* ***20%***.

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables from the structure due to broken tags. The minimum cable bending radius is not respected.

Figure 417: Loosely hanging cables and low bending radius.

- The joints and bolts used for structural connections are significantly rusted.
- Access to the tables is unsafe and uneasy.
- Module frames shows signs of corrosion and rusting.
- Inverter room was without proper ventilation.
- Modules are heavily soiled, due to which the module output is shaded from soiling.

Figure 418: Severely soiled modules.

Impact on Performance

- The system performance was affected by soiling loss of 21%, estimated from IV curve measurements.
- IR analysis shows presence of hotspots from soiling. Such hotspots may indicate irreversible cell damage due to shading from soiling.

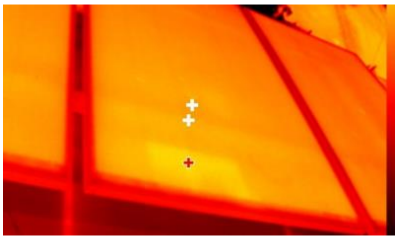


Figure 419: Hotspot from soiling.

- The modules are shaded by stray objects, causing hotspots that may cause irreversible cell damage.

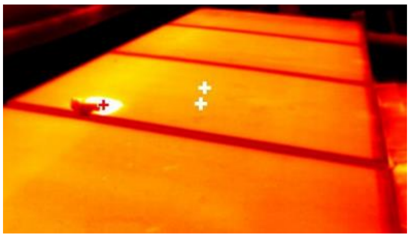


Figure 420: Hotspot from stray object on module.

- Based on the IV curve measurements, the estimated underperformance is 20% for the measured modules.

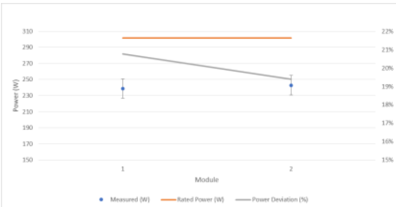


Figure 421: IV curve measurement results.

Proposed Solutions

- The cable layout shall be optimized; the minimum bending radius is 10x times the cable diameter. UV protection measurements shall be taken by using suitable rack with roof or cable coating.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Ideally, the modules permanently damaged from irreversible cell damage shall be replaced.
- Safety railings shall be provided for safer access for cleaning and the O&M operations in general.
- Rusted clamps, joints, and structure shall be replaced.
- A weather station, or at least an irradiation sensor on the module plane shall be installed so that the performance of the system can be properly determined.

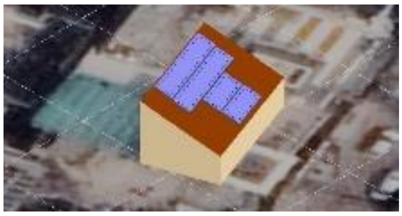


Figure 422: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 18% and 20%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 5.48 ₹/Wp, 0.43 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 4.6 ₹/kWh to 4.1 ₹/kWh

Picture Gallery

Figure 423: System overview.

Figure 424: Corroded module frame.

Figure 425: Stray object on module.

Figure 426: Severely rusted joints.

Figure 427: Cable layout with low bending radius.

Figure 428: Risky access without safety railings.

Figure 429: LA found on site.

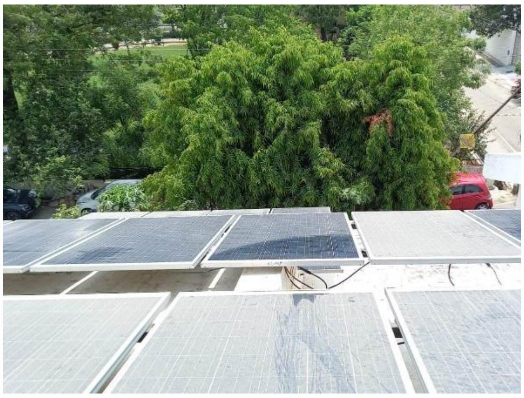


Figure 430: Soiled modules.

30 *PV plant: **II.30***
Nominal capacity: 2kWp

***Abstract**: The purpose was the evaluation of crack evolution from manufaturing until instalation. Although from the pictures* after installation, *it can be established that this activity did not worsen the modules, from the industry standard point of view, the modules under test do not pass a typical EL evaluation for construction (post-installation inspection). The number and type of cracks will likely increase the probability of underperformance. Furthermore, if the cracks develo further, they could degrade into hotspots an become a safety issue. Infrared thermography is recommended for the latter.*

PV Plant's health

According to different logistic providers for PV modules[3], 15M+ solar modules are broken every year prior installation. PV Module damages are often due to shipping on fragile wood pallets and boxes with partial loads. Module handling, transport and installation require minimal understanding of the PV technology.

Even though these issues are known within the industry, mechanical effects in the modules, i.e., cracks, scratches, broken glass, are still a nuisance in project development, especially during transportation (Factory - distribution center - project site - mounting structure). New technologies have also brought new sources of cracking, (interconnect ribbons for 9+ Busbars (CEA), manual solar cell soldering, lamination for certain EVA films with weak moisture impermeability). Furthermore, environmental aspects such as as snow loads, strong winds and hailstorms could induce major cracks on the modules' surface.

The majority of micro-cracks occurred in the range of low resonance frequency during road transportation (L. Chang, et al): diagonal cracks, parallel to busbars crack, perpendicular to busbars crack and branched cracks. Branched cracks are more likely to produce underperformance in the mid term when the cracked areas become isolated.

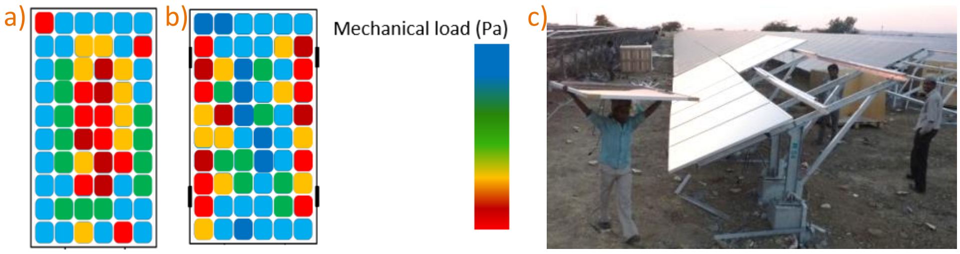


Figure 431: statistical distribution of cracks, a) transportation, b) installation, c) example of both

According to multiples studies in the matter, vertical module is safer than horizontal from vibration commonly experienced from road transport due to that the stiffness of glass is more incline to induce large vibration. Packaging type may lead to different distribution of cracks on PV-module. Moreover a market with low margins pushes manufactures and retailers to save in packaging and logistics.

Figure 432: Modules inspected at warehouse. Left, packaging solution; right, mechanical damages discovered (scratches on glass, cell dents)

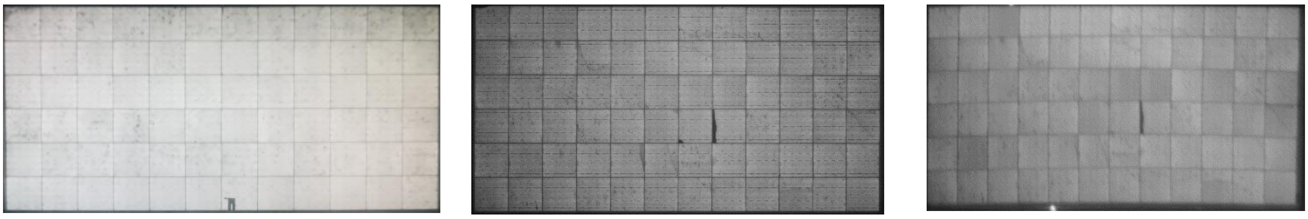
The assessment mainly describes anomalies liekly as result of mechanical stress due to transporation and handling malpractices. Anomalies such as delamination, improper sealing or yellowing are not part of the scope and can be considered as a manufcturing quality issue rather than a logistic malpractice.

[3] Estimates based on 19.2 GW of solar installed in the United States in 2020.

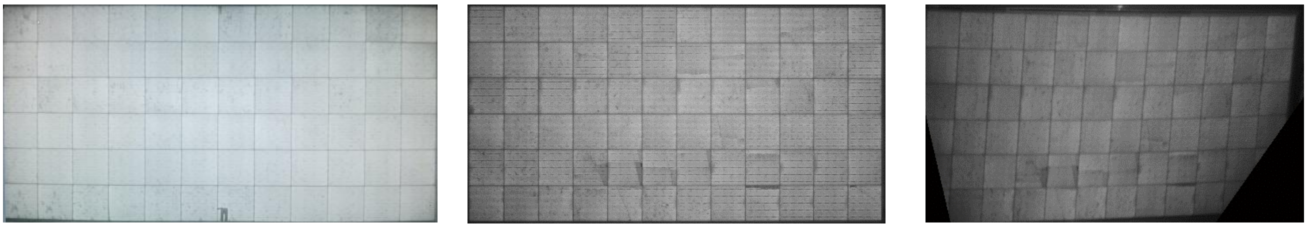
Picture Gallery – Electroluminiscence imaging (Silver Oak)

Manufacturing* | **Warehouse** | **After installation**

SSGS023350252200540:



SSGS023350252200423:



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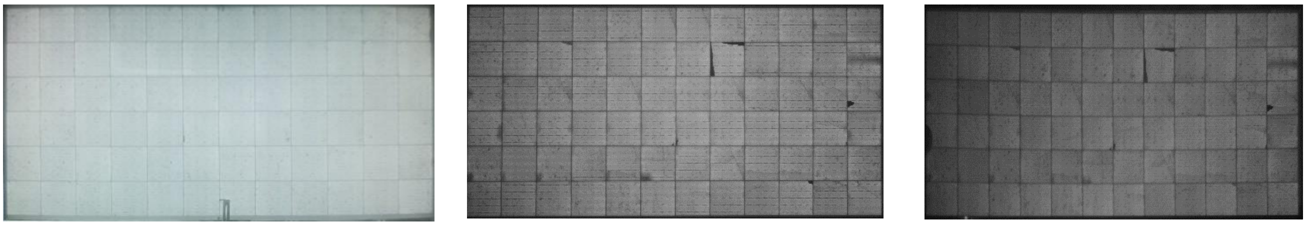

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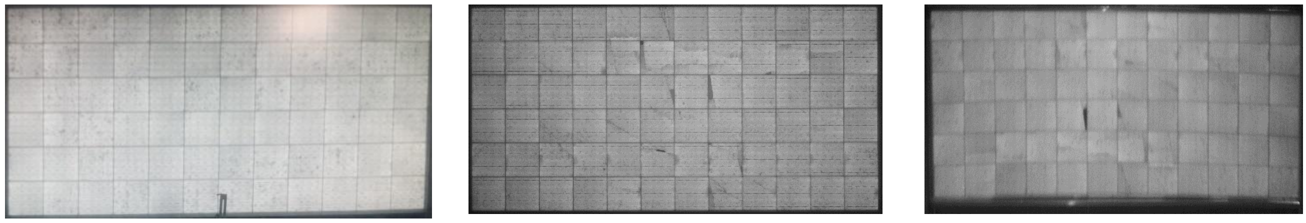

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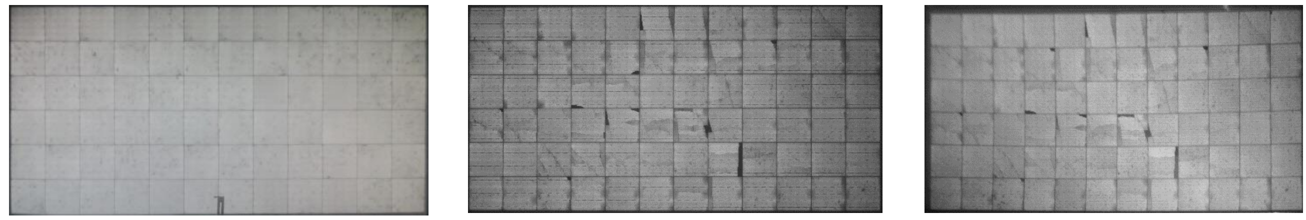
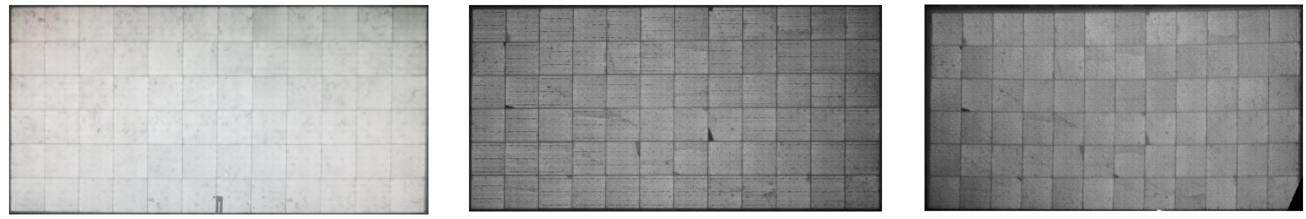


SSGS023350252200535:



***Pictures Pictures submitted by module manufacturer. After multiple reviews, because of the low image quality and the lack of response from the manufacturer, it is highly likely that these EL pictures taken during production don't actually belong to the modules under scope. Similarly to lack of documentation available by plant owners (and in several cases, EPCs), the absence of after sales support from domestic module manufacturers limits development and confidence in local industry, creating a vicious circle.**

Figure 433: Crack evolution from manufating until instalation. Although from the pictures after installation, it can be established that this activity did not worsen the modules, from the industry standard point of view, the modules above do not pass a typical EL evaluation for construction (post-installation inspection). The number and type of cracks (Broken small, crack 45°, branched, broken multiple) will likely increase the probability of underperformance. Furthermore, if the cracks develop, they could degrade into hotspots an become a safety issue. Infrared thermography is recommended for the latter.

31

PV plant: ***II.31***
Nominal capacity: ***10.16 kWp***
Average specific yield since COD (11.10.2016): ***1039.6 kWh/kWp*** *(PVsyst estimation 1392.9 kWh/kWp)*

Abstract*: Loosely hanging cables with low bending radius were found. Several modules show delamination, corrosion of busbars, and degrading sealant around the junction box. It is recommended to (i) optimize the cable layout, (ii) re-sort the modules with different power rating and year of manufacture, (iii) retrofit the mounting structure, (iv) monitor manufacturing issues for further degradation and a possible warranty claim, and (v) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***3%*** *and* ***25%****.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. In addition, the cables and connectors are exposed to ambient.

Figure 434: Cable layout.

- The labelling used in cables to the inverter are in poor condition.
- Several modules show signs of delamination.
- Modules with different power rating and year of manufacture in the same string.
- Corroded busbars were observed in many modules.
- Modules directly bolted onto the table structure which does not provide proper support to top part of the module. Some diagonal straps used in structure damaged. Structure components rusted at joints.
- The sealant used around junction box is degrading.

Figure 435: Degrading sealant around junction box.

- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 1.4%.
- IR analysis shows presence of hot cells.

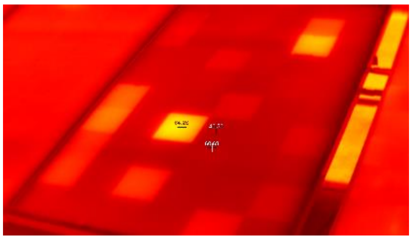


Figure 436: Hot cells from IR imaging.

- The EL image reveals presence of branched cracks, which arises due to issues in transportation or handling. These cracks are not expected to impact performance in their given state.

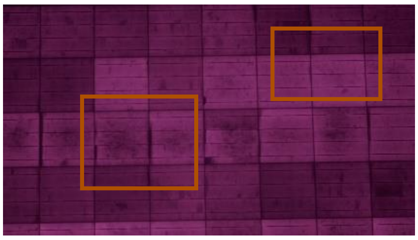


Figure 437: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 5.1% for the measured modules.

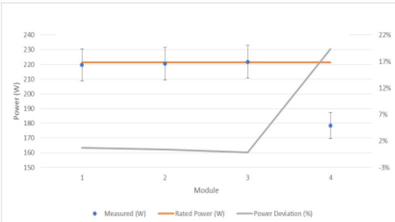


Figure 438: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.48%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Modules with degrading sealant around the junction box pose a safety risk and shall be replaced.
- A re-sorting of modules shall be conducted to have modules with same year of manufacture in the same string or at least same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Defects corresponding to manufacturing issues like delamination and corrosion of busbars shall be monitored for further degradation for a possibly warranty claim in the future.

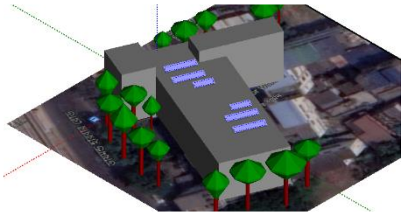


Figure 439: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 2% to 3%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 4.22 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 8.6 ₹/kWh to 5.7 ₹/kWh

Picture Gallery

Figure 440: Degraded labelling used in cables.

Figure 441: Connector exposed to ambient.

Figure 442: Broken J-box with corroded contacts.

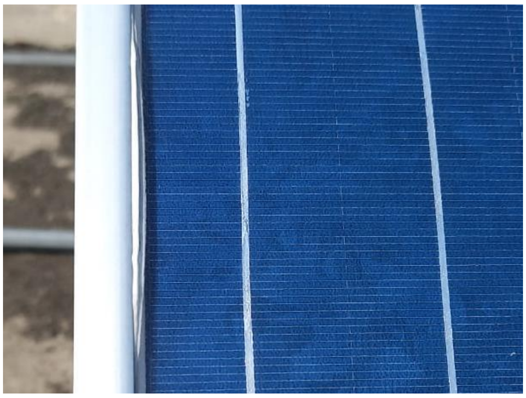


Figure 443: Sealant over cell.

Figure 444: System overview and inter-row spacing.

Figure 445: Structural earthing.

Figure 446: Structure purlin rusted at joint.

Figure 447: Module with different power rating and manufacture year used.

32

PV plant: ***II.32***
Nominal capacity: ***5 kWp***
Average specific yield COD (01.08.2019): ***526.8 kWh/kWp*** *(PVsyst estimation 1252 kWh/kWp)*

Abstract: *Cables with low bending radius were found. Modules observed to be significantly shaded. It is recommended to (i) optimize the cable layout, (ii) trim surrounding trees and clear tree debris, (iii) retrofit the mounting structure, (iv) add module to module equipotential bonding, and (v) increase inter-row spacing, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***9.2%*** *and* ***20%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables with low bending radius. Cables and connectors are degraded. Missing string labelling at the module end.

Figure 448: Cable layout.

- Module to module equipotential bonding missing.
- Improper access to the plant through a window.
- Tables with varying tilt of 24° and 26°.
- Screws and nuts used in the structure and earthing strips are rusted.
- Gap between module and purlin edge is not sufficient (around 50 mm) to hold the modules in the event of high wind loads.
- The modules are significantly shaded by the very less inter-row spacing used, and by the presence of trees in immediate vicinity. The modules are also very slightly shaded by a taller room.

Figure 449: Shading by used inter-row spacing, trees, and taller room.

- No LA found on site.
- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 3.2%. Some show presence of cementing.
- IR analysis reveals hot cells, mostly due to shading by minimal inter-row spacing. This may cause irreversible cell damage.

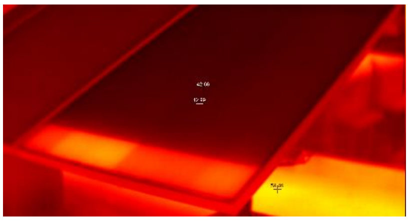


Figure 450: Hot cells from IR imaging.

- The EL image reveals presence of few micro-cracks and manufacturing related defects. These cracks are not expected to impact performance in their given state.

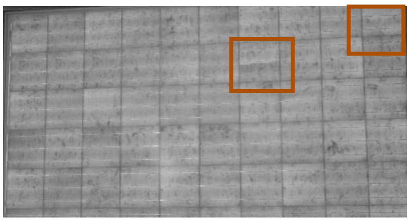


Figure 451: Micro-cracks from EL imaging.

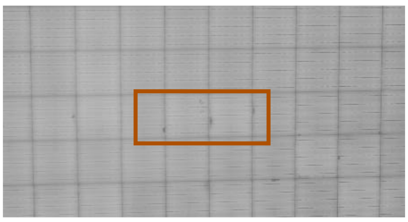


Figure 452: Defects relating to cell processing from EL imaging.

- According to PVsyst simulation, the near shading losses account to 7.63%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- The trees surrounding the system shall be trimmed if allowed and the objects near the modules shall be removed.
- Earthing connections between modules shall be added.
- A better plant access to facilitate better O&M access shall be provided.
- Modules shall be adjusted to have the same module tilt for all tables.
- LA shall be installed on site.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Rusted components and structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- Retrofitting actions on the structure shall be done so that the purlin edges have more gap from the modules.
- If possible, the inter-row spacing shall be increased to reduce self-shading losses and further damage from hot cells due to the same.

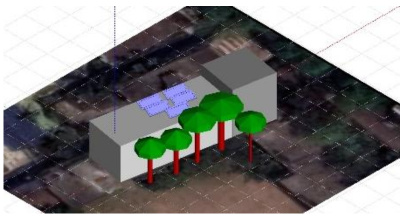


Figure 453: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 9.2% to 20%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 5.13 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 4.8 ₹/kWh to 2.2 ₹/kWh

Picture Gallery

Figure 454: Degraded cables and connectors.

Figure 455: Module cementing.

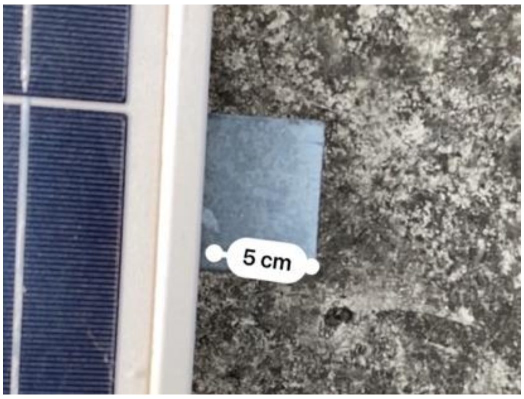


Figure 456: Insufficient gap between module edge and purlin.

Figure 457: Missing module to module equipotential bonding.

Figure 458: Tree and tree debris in plant vicinity.

Figure 459: Current roof access.

Figure 460: Rusted bolt in earthing strip.

Figure 461: Inverter overview.

33

PV plant: ***II.33***
Nominal capacity: ***10.07 kWp***
Average specific yield for: ***1203.6 kWh/kWp*** *(PVsyst estimation 1338 kWh/kWp)*

Abstract*: Cables with low bending radius found. Modules with damaged backsheet found on site. It is recommended to (i) optimize the cable layout, (ii) conduct cleaning more effectively, (iii) replace backsheet damaged modules, (iv) add module to module equipotential bonding, (v) retrofit mounting structure, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***6%*** *and* ***10%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables with low bending radius. Cables and connectors are degraded, and string labelling is missing.

Figure 462: Cable layout.

- Module to module equipotential bonding missing.
- Module back-sheets indicate presence of chalking. Cuts and backsheet burns were observed.
- Cell delamination observed in several modules.
- Rubber washers used for module fixation on purlins.
- Surface cracking observed in installation area due to excess structure weight.
- L channel purlins deformed from handling or transportation.
- Uneven spacing between ballast blocks cause sagging, and modules are fixed improperly on the purlins, both causing module misalignment.

Figure 463: Module misalignment.

- No LA found on site.
- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 2.7%. Modules show presence of cementing.
- IR analysis reveal hot cells, mostly due to module cementing.

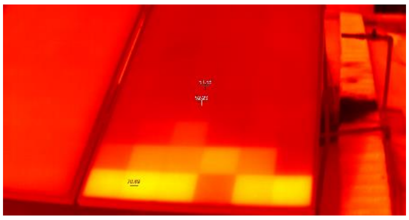


Figure 464: Hot cells from IR imaging.

- The EL image reveals presence of back sheet scratches and long cracks. Back sheet scratches may pose performance and safety threat.

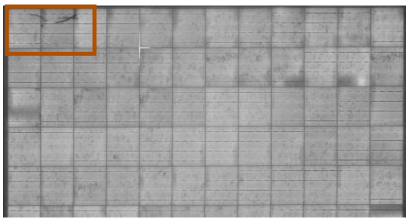


Figure 465: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 5.1% for the measured modules.

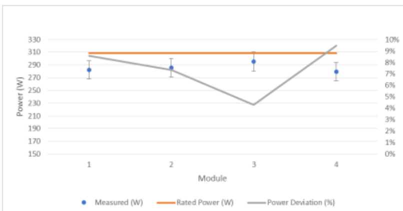


Figure 466: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.54%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Cleaning shall be carried out more effectively to address cementing.
- Modules with backsheet scratches shall be replaced since they pose a severe performance and safety threat.
- Earthing connections between modules shall be added.
- Rubber washers used for module fixation shall be replaced with suitable weather resistant EPDM washers.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least same MPPT.
- Surface levelling shall be re-done to address surface cracking.
- If possible, the ballast blocks shall be redone to have even spacing and reduce losses from module misalignment.
- Retrofitting actions on the structure shall be done be to have deformed purlins replaced.

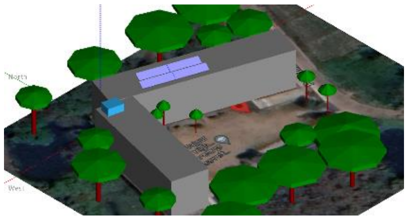


Figure 467: 3D model constructed in PVsyst.

- LA shall be installed on site.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

Estimated energy boost after conducting the suggested retrofitting actions: 6% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 5.87 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 3.7 ₹/kWh to 2.2 ₹/kWh

Picture Gallery


Figure 468: Module to module bonding missing.

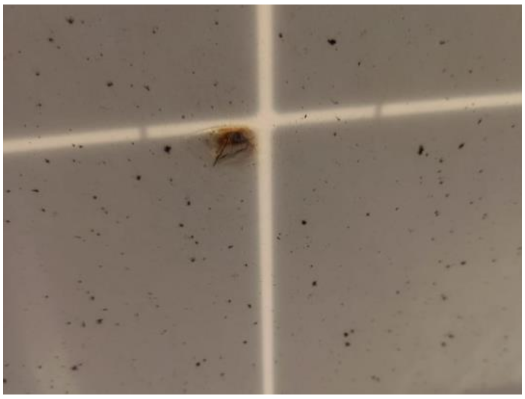


Figure 469: Back sheet burn and chalking.

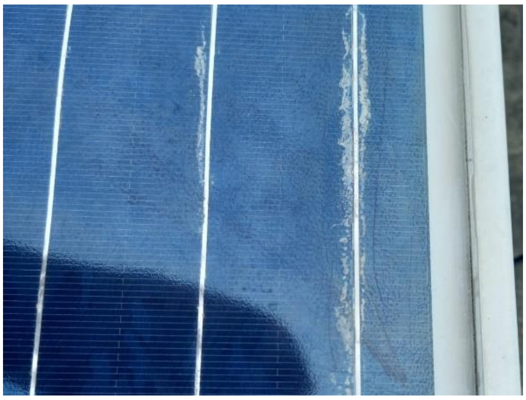


Figure 470: Cell delamination.


Figure 471: Low quality rubber washers used.


Figure 472: Module cementing and surface cracking.


Figure 473: Deformed L channel purlins.


Figure 474: Uneven spacing between ballast blocks.


Figure 475: Irregular module fixation.

34

PV plant: ***II.34***
Nominal capacity: ***10.16 kWp***
Average specific yield since COD (14.10.2018) ***1044.3 kWh/kWp*** *(PVsyst estimation 1295 kWh/kWp)*

Abstract: *Loosely hanging cables with low bending radius were found. Some modules with manufacturing issues found on site. It is recommended to (i) optimize the cable layout, (ii) increase cleaning cycles, (iii) replace damaged modules and re-sort lower performing modules, (iv) retrofit the mounting structure, (v) add module to module equipotential bonding, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***6%*** *and* ***19%***.

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling at the module end.

Figure 476: Cable layout.

- Some cable conduits are broken.
- Manufacturing issues of busbar misalignment and improper sealant observed on modules.
- Cement remains stuck on module glass.
- Screws, nuts, and purlins used in the structure are rusted.
- Structure purlins slightly sagging due to larger spacing between ballast blocks used.
- Module misalignment observed due to vertical post not fixed at the center of ballast block.
- Module to module equipotential bonding missing.
- Staircase room gives uneasy access and causes module shading.

Figure 477: Module shading by staircase room.

- No weather station and LA found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 1.3%. Modules are soiled from cementing.
- IR analysis reveals hot cells from cementing and the stuck cement remains, which can cause permanent cell damage.

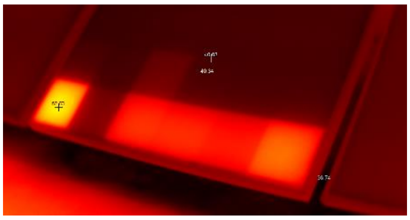


Figure 478: Hot cells from IR imaging.

- The EL image reveals presence of cracks, scratches, and isolated parts, indicating issues from transportation or handling. These may contribute to power loss and hotspots formation during operation.

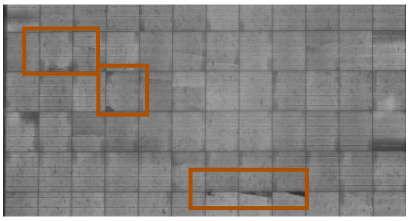


Figure 479: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 10% for the measured modules.

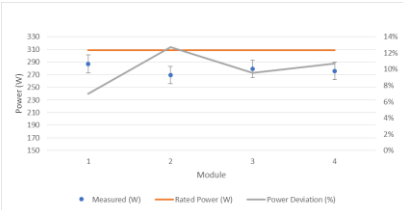


Figure 480: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.31%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Daily effective cleaning is recommended to address cementing and due to presence of school playground in plant's vicinity.
- Severely damaged modules and module with stuck cement remains shall be replaced to reduce further performance loss.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least assigned to individual MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Earthing connections between modules shall be added.
- If possible, tables shall be moved to the left to reduce shading by the staircase room at the expense of increased cable length.
- Rusted component and structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc. Ballast blocks shall be replaced to reduce purlin sagging and vertical posts properly fixed.

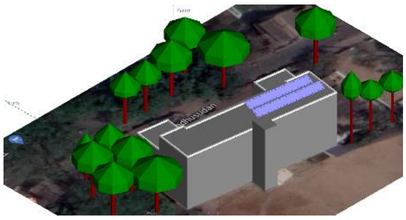


Figure 481: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 6% to 19%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 5.9 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 4.4 ₹/kWh to 1.4 ₹/kWh

Picture Gallery


Figure 482: Module misalignment.


Figure 483: Rusted bolts.


Figure 484: Cement stuck on module glass and module cementing.


Figure 485: Vertical posts fixed away from center.


Figure 486: Missing module-to-module bonding.

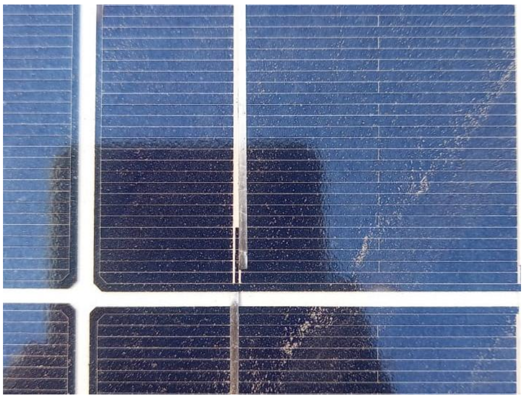


Figure 487: Busbar misalignment.


Figure 488: Improper sealant.


Figure 489: Cementing of module.

35

PV plant: ***II.35***
Nominal capacity: ***20 kWp***
Average specific yield for: ***1331.83 kWh/kWp*** *(PVsyst estimation 1304 kWh/kWp)*

Abstract*: Loosely hanging cables with low bending radius were found. Modules with burn marks on cell fingers and damaged frame were found. It is recommended to (i) optimize the cable layout, (ii) replace damaged modules and re-sort lower performing modules, (iii) relocate the corner tables, (iv) retrofit the mounting structure, (v) add module to module equipotential bonding, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***6%*** *and* ***12.7%****.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables. Missing string labelling at the module end. Connectors are degraded.

Figure 490: Cable layout.

- Modules with burn marks on cell fingers, damaged frame, and cell delamination found.
- Module to module equipotential bonding missing.
- Improper roof access. No safety railings on the installation area.
- Module misalignment due to posts in structure not parallel to each other.
- Structure purlins not parallel to each other due to factory or handling damage.
- Screws used in structure are rusted.
- Front row modules are installed on roof edge without a parapet wall to reduce the wind flow.
- Modules shaded poles placed next to modules on site.

Figure 491: Module shading by poles.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 9.7%.
- IR analysis reveals presence of hot cells and hotspots, due to soiling and presence of isolated cell parts.

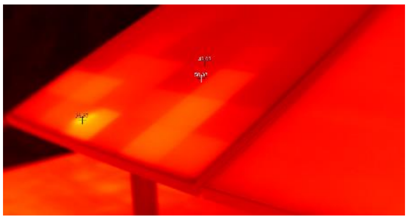


Figure 492: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts indicating issues from transportation or handling. These defects generate hotspots and pose both performance and safety threat.

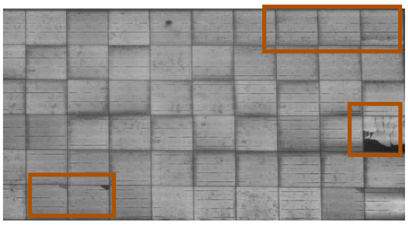


Figure 493: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 2.3% for the measured modules.

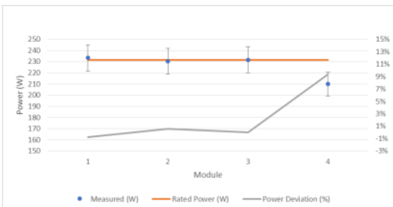


Figure 494: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.48%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cleaning cycles shall be increased based on the results of a soiling study.
- Damaged modules shall be replaced to reduce further performance loss.
- Module to module earthing connections shall be added.
- Safety railings and a better roof access shall be provided if possible for safer and easier O&M activity.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least assigned to individual MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Tables shall be moved away from the roof edge to prevent damage from higher wind loads.
- Rusted components of the structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc. The vertical posts and purlins used in the structure shall be replaced to restore structure functionality and reduce module misalignment.
- Poles causing shading shall be relocated to reduce shading impact.

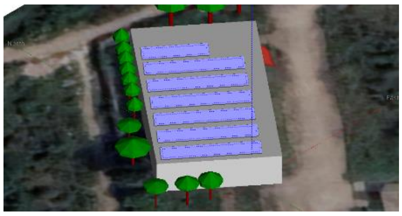


Figure 495: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 6% to 12.7%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 5.24 ₹/Wp, 1.30 ₹/Wp/a
Estimated retrofit cost per additional generation: 19.7 ₹/kWh to 9.3 ₹/kWh

Picture Gallery

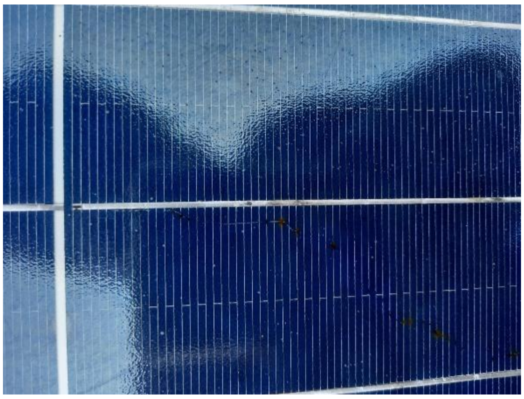


Figure 496: Burn marks on fingers.


Figure 497: Degraded connectors.

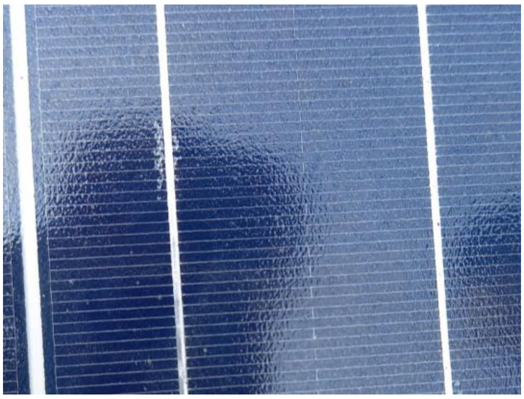


Figure 498: Cell delamination.


Figure 499: Missing module to module bonding.


Figure 500: Site overview.


Figure 501: Missing safety railings.


Figure 502: Module misalignment.


Figure 503: Rusted screw and purlin not parallel.

36

PV plant: ***II.36***
Nominal capacity: ***5 kWp***
Average specific yield since COD (22.03.2018): ***1100.8 kWh/kWp*** *(PVsyst estimation 1249 kWh/kWp)*

Abstract: *Loosely hanging cables with low bending radius were found. Modules with manufacturing issues found on site. It is recommended to (i) optimize the cable layout, (ii) relocate the tables, (iii) replace damaged modules and re-sort lower performing modules, (iv) retrofit the mounting structure, (v) add module to module equipotential bonding, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***6.6%*** *and* ***11.9%****.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables. Missing string labelling at the module end. Water presence observed in cable connectors.

Figure 504: Cable layout.

- Some cable conduits are broken.
- Manufacturing issues of busbar misalignment, delamination, and soldering paste on cell observed on modules.
- Improper access to the site.
- Angle beam disconnected from structure rafter and post.
- Module misalignment observed due to improper fixation of L brackets.
- Modules installed in the west side are very close to the parapet wall, making accessibility challenging.
- Screws and nuts used in the structure are rusted.
- Some modules are shaded by the water storage tank and the parapet wall.

Figure 505: Module shading by water storage tank.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 2.2%.
- IR analysis reveals presence of warm and hot cells. This may be correlated with the defects revealed in EL imaging.

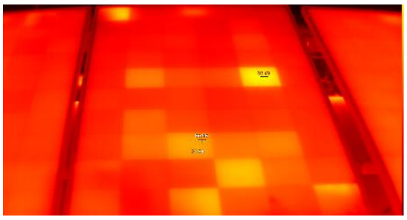


Figure 506: Hot cells from IR imaging.

- The EL image reveals presence of cracks, isolated parts, and dark cells indicating issues from transportation or handling. These defects generate hotspots and pose both performance and safety threat.

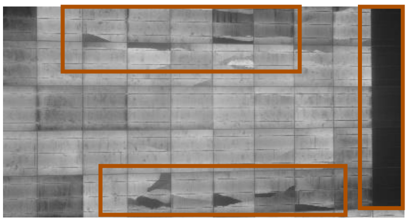


Figure 507: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 26.9% for the measured modules.

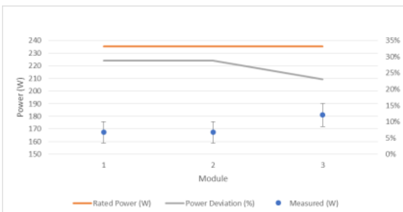


Figure 508: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.02%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized using cable racks to prevent cables from loosely hanging and also avoid water contact.
- Modules severely damaged with isolated parts shall be replaced to reduce further performance loss.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least assigned to individual MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- If possible, tables shall be moved away from the parapet wall and the water storage tank to address the problem of challenging accessibility and shading, since there is sufficient area on the roof.
- Angle beam connection to the rafter shall be redone.
- L brackets shall be properly fixed so that the module misalignment is reduced.
- Rusted components of the structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

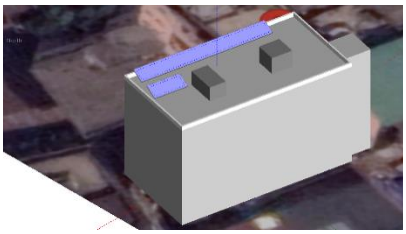


Figure 509: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 6.6% to 11.9%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 8.17 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 4.9 ₹/kWh to 2.7 ₹/kWh

Picture Gallery

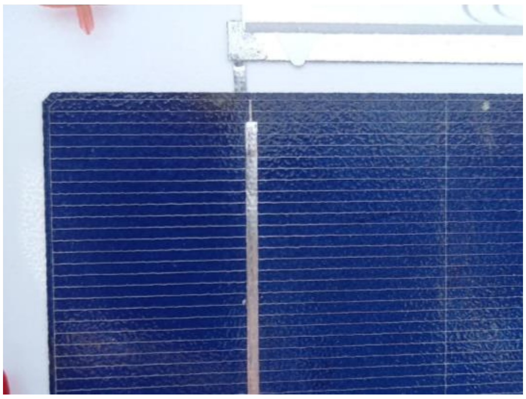


Figure 510: Busbar misalignment.

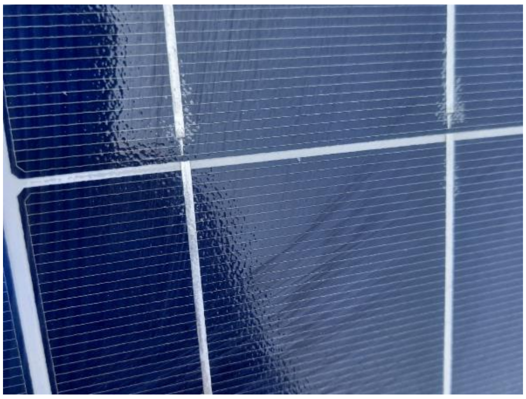


Figure 511: Cell delamination.

Figure 512: Shadow by parapet wall.

Figure 513: Uneasy access.

Figure 514: Disconnected angle beam.

Figure 515: Module misalignment from improper L bracket fixation.

Figure 516: Uneasy access to table rear-side.

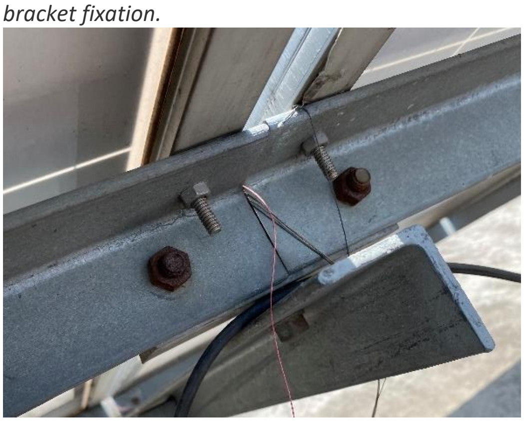


Figure 517: Rusted screws and nuts.

37

PV plant: ***II.37***
Nominal capacity: ***10.075 kWp***
Average specific yield since COD (09.05.2018): ***1172 kWh/kWp*** *(PVsyst estimation 1265 kWh/kWp)*

Abstract: *Cables with low bending radius were found. Several issues concerning mounting structure and components were observed. It is recommended to (i) optimize the cable layout, (ii) relocate the modules from roof boundary, (iii) re-string shaded modules, (iv) retrofit the mounting structure, (v) trim the surrounding trees, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***5.1%*** *and* ***7.3%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables with low bending radius. String labelling missing.

Figure 518: Cable layout.

- Paint remains stuck on module.
- Module installed at roof boundary with no protection against wind loads.
- Vertical post fixed at different angle and depth on each ballast block.
- Support strap connecting rafter and post fixed at varying angle and depth on each ballast block.
- Improper fixation of purlin on rafter.
- Screws and nuts used in the structure are rusted.
- L channel rafter used on one table deformed due to improper handling.
- The PV plant is partly surrounded by buildings, trees and a shed roof that cast shadows on the modules.

Figure 519: Module shading by tree.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 2.2%.
- IR analysis reveals presence of hot cells.

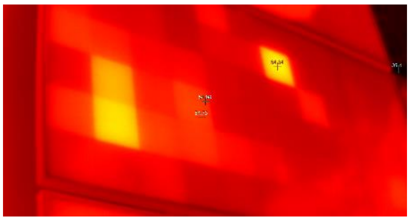


Figure 520: Hot cells from IR imaging.

- The EL image reveals presence of few cracks and soldering defects. These defects are not expected to impact performance at their given state.

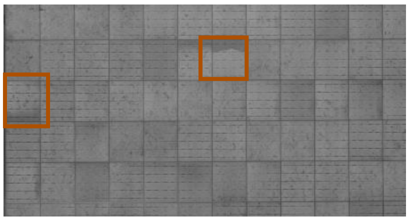


Figure 521: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 5.1% for the measured modules.

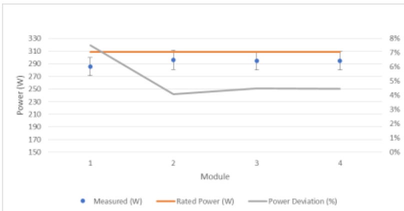


Figure 522: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 5.2%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Modules with foreign material stuck on glass shall be replaced since they can generate permanent hot cells that may pose performance and safety threat in the long run.
- Modules installed at the module boundary shall be moved away from it to prevent damage from wind loads.
- Retrofitting actions shall be done on the structure to have the vertical posts, support straps, and structure purlins properly fixed on the structure. This reduces the module misalignment observed on site.
- Deformed L channel rafters shall be replaced since their functionality may be reduced or compromised.
- Rusted components of the structure shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- The trees surrounding the system shall be trimmed if allowed.
- A re-stringing of modules shall be conducted to have shaded modules in the same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

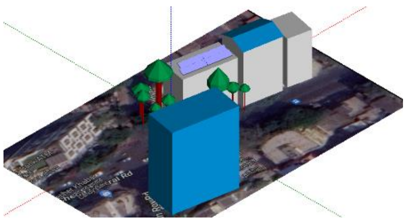


Figure 523: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 5.1% to 7.3%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.54 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.2 ₹/kWh to 0.9 ₹/kWh

Picture Gallery

Figure 524: Module misalignment.

Figure 525: Paint remains stuck on module.

Figure 526: Rusted screws.

Figure 527: Shading by shed roof.

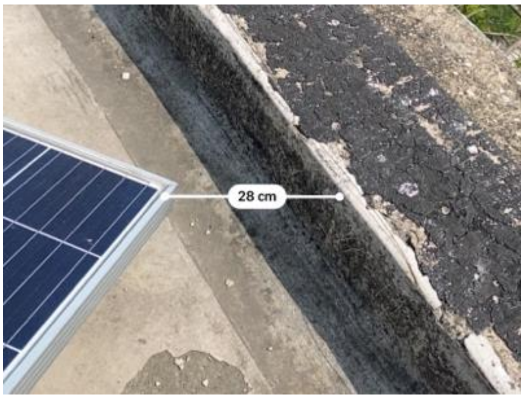


Figure 528: Module installed at roof boundary.

Figure 529: Support straps at varying angle and depth.

Figure 530: Deformed L channel.

Figure 531: Improperly fixed purlin.

38

PV plant: ***II.38***
Nominal capacity: ***10.07 kWp***
Average specific yield since COD (27.11.2018): ***1099.7 kWh/kWp*** *(PVsyst estimation 1186 kWh/kWp)*

Abstract: *Cables with low bending radius were found. Several issues concerning mounting structure and components were observed. It is recommended to (i) optimize the cable layout, (ii) increase cleaning cycles, (iii) retrofit the mounting structure, (iv) add module to module equipotential bonding, and (v) relocate shaded module tables, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***7.7%*** *and* ***10%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables with low bending radius. Missing string labelling at the module end.

Figure 532: Cable layout.

- Connectors are mildly degrading due to exposure to ambient.
- Screws, nuts, and earthing strips used in the structure are rusted.
- Module to module equipotential bonding missing.
- Some vertical posts used in the mounting structure are not perpendicular, causing module misalignment.
- L mounting plates used to fix structure purlins are improperly mounted.
- The longer table with 12 modules are shaded by a room very close to it. The smaller tables are significantly shaded by both room and parapet wall.

Figure 533: Shading by a taller room and parapet wall.

- No LA found on site.
- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 5.6%. Some modules are soiled from bird dropping, and cementing.
- IR analysis reveals hot cells due to cementing.

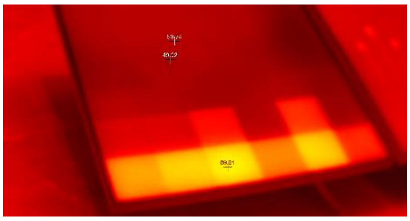


Figure 534: Hot cells from IR imaging.

- The EL image reveals presence of few micro-cracks and soldering issues from manufacturing. These cracks are not expected to impact performance in their given state.

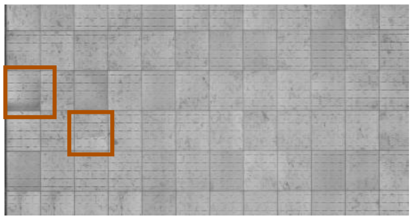


Figure 535: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 6.7% for the measured modules.

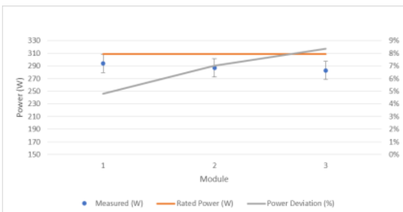


Figure 536: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 3.6%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Cleaning shall be conducted more effectively since module soiling is present despite weekly cleaning frequency reported by the on-site team.
- Inverter shall be cleaned frequently.
- If possible, the smaller tables shall be relocated to the top of a taller room, and the longer table with 12 modules shall be moved slightly away from the room that causes shading.
- LA shall be installed on site.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Earthing connections between modules shall be added.
- Rusted components and structure shall be replaced if possible. Vertical posts shall be realigned to reduce module misalignment. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

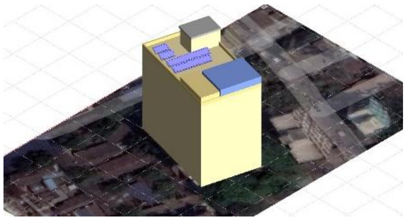


Figure 537: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 7.7% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.61 ₹/Wp, 0.20 ₹/Wp/a
Estimated retrofit cost per additional generation: 3.3 ₹/kWh to 2.5 ₹/kWh

Picture Gallery


Figure 538: Site overview.


Figure 539: Degraded connectors.


Figure 540: Bird dropping.


Figure 541: Improperly mounted L plate.


Figure 542: Rusted bolts and earthing strips.


Figure 543: Module misalignment.


Figure 544: Module to module bonding absent.

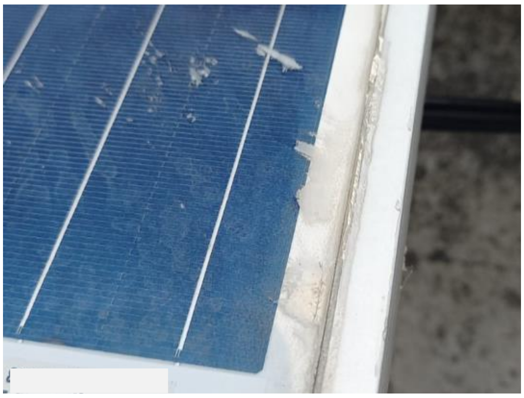


Figure 545: Cement remains on module.

39

PV plant: ***II.39***

Nominal capacity: ***10.16 kWp***

Average specific yield since COD (31.03.2017): ***1039.6 kWh/kWp*** *(PVsyst estimation 1212 kWh/kWp)*

Abstract: *Loosely hanging cables with low bending radius were found. Junction boxes on several modules are detached and left hanging. It is recommended to (i) optimize the cable layout, (ii) replace modules with detached junction boxes, (iii) retrofit the mounting structure, (iv) add module to module equipotential bonding, and (v) clean inverter fans more frequently, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***1.3%*** *and* ***6%****.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling at the module end. In addition, the cables and connectors are exposed to ambient.

Figure 546: Cable layout.

- Junction boxes on several modules are detached from one side and left hanging.
- Structure purlins cut asymmetrically and through the galvanization, causing end to rust.
- Irregular spacing between ballast blocks causes sagging of purlins.
- Screws, nuts, and earthing strips used in the structure are rusted.
- Inverter fans are soiled and noisy.
- Module to module equipotential bonding missing.
- A row of modules are significantly shaded by a parapet wall.

Figure 547: Modules installed close to the parapet wall.

- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 3%. Some modules are soiled from bird dropping, and cementing.
- IR analysis reveals hot cells due to cementing and shading from the parapet wall.

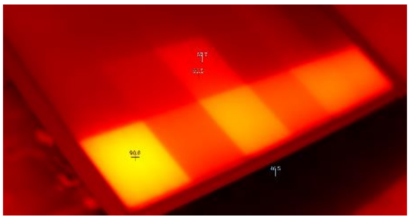


Figure 548: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts, which arises due to issues in transportation or handling. These cracks are not expected to impact performance in their given state.

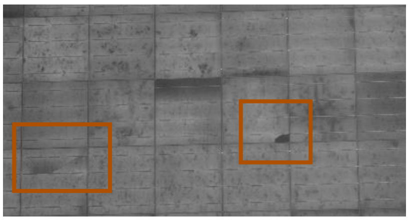


Figure 549: Defects from EL imaging.

- Based on the IV curve measurements, the modules are not underperforming.

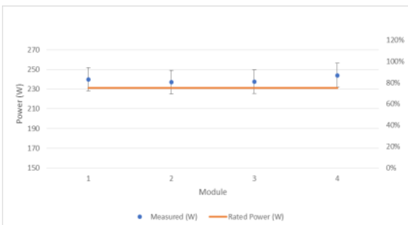


Figure 550: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.66%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Cleaning shall be conducted more effectively due to presence of bird droppings despite the weekly cleaning frequency reported by the on-site team.
- Inverter shall be cleaned frequently.
- Modules with detached junction box pose a safety risk and shall be replaced.
- Modules significantly shaded by the parapet wall shall be moved away to reduce shading losses at the expense of inter-row spacing.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Earthing connections between modules shall be added.
- Rusted component and structure shall be replaced if possible. Purlins causing gaps due to improper cutting shall ideally be replaced so that the modules rest on the structure properly, and the module misalignment is reduced. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.

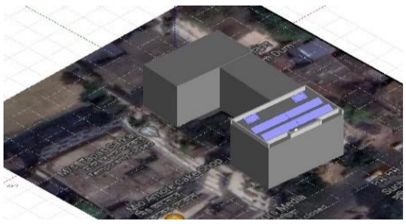


Figure 551: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 1.3% to 6%

Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 4.15 ₹/Wp, 0 ₹/Wp/a

Estimated retrofit cost per additional generation: 15.4 ₹/kWh to 3.3 ₹/kWh

Picture Gallery


Figure 552: Noisy and soiled inverter fans.


Figure 553: Purlin ends rusted from saw cutting.


Figure 554: Detached J-box.


Figure 555: Missing module to module bonding.


Figure 556: Gap between purlins.

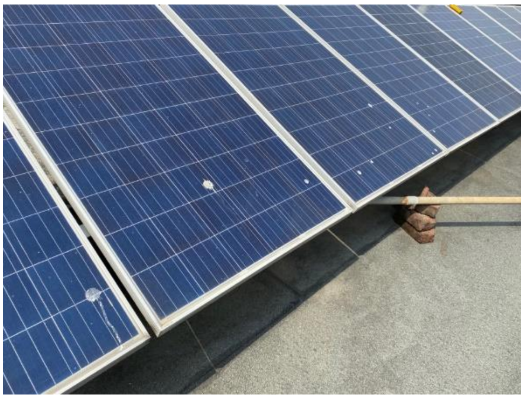


Figure 557: Soiling from bird dropping.


Figure 558: Module misalignment due to improper purlin fixation.


Figure 559: Cementing of module.

40

PV plant: ***II.40***
Nominal capacity: ***348.7 kWp***
Average specific yield since COD (28.3.2017): ***943 kWh/kWp*** *(PVsyst estimation 1304 kWh/kWp)*

Abstract: *The system shows design failures such as self-shading, near shading, and inadequate interrow distance and clearance to the floor. Some elements of the structural earthing are corroded. Poor cable management was found. The plant is modestly affected by soiling. It is recommended to (i) retrofit earthing system and cabling management, (ii) restring the shaded and damaged modules, (iii) retrofit the mounting structure, and (iv) increase the cleaning cycles. The estimated production boost expected by the retrofitting actions lies between 8 and 12%.*

PV Plant's health

Main Findings

- Poor cable management: no string labelling was found at module level, some cables were found exposed to ambient and degraded, and some cables run through sharp edges.

Figure 560: PV cable exposed to ambient and sharp edge

- Inverters are only covered by a small shed and their filters were found soiled.

Figure 561: Inverters exposed to ambient

- A module was found with paint, which caused a hot cell.
- Some elements of the earthing system were found corroded.
- The structure of the modules causes misalignment of the modules, presents short inter-row distance, and leaves a reduced space between modules and roof.
- The design of the system disregards the height of the parapet, water tanks, communication towers, and rebars protruding from the roof, resulting in shaded modules.
- A module was found with a degraded junction box.

Impact on Performance

- According to the simulation of the system, the self-shading and near shading losses account for up to 4.6% and 3.0%, respectively.
- The on-site measured soiling losses were estimated in 5.4% from IV curve measurements.
- IR analysis showed evidence of hot spots possibly caused by near shading objects. EL analysis indicated no sign of PID.

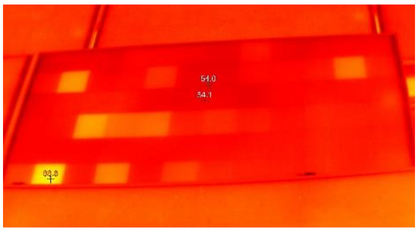


Figure 562: Hot cells on shaded module

- According to the number of cracks and isolated areas discovered via EL imaging; the system is expected to have power losses around 6% due to inactive areas.

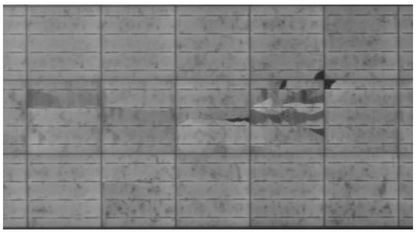


Figure 563: Broken cells from EL imaging

- The underperformance of the measured modules is around 12.2%.

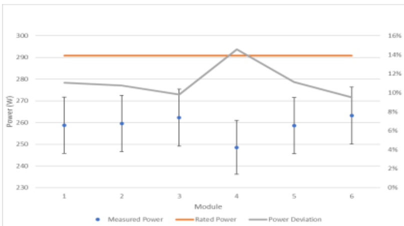


Figure 564: IV curve measurement results

Proposed Solutions

- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Shading objects should be removed if possible. Additionally, restringing of the modules in the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or MPPT.
- The whole structure must be retrofitted and, if possible, increased interrow distance.
- Include in the O&M practices the cleaning of the ventilation system of the inverters.
- The whole grounding system shall be retrofitted.
- All cables should have a suitable labelling and the UV protection against the weather renewed.
- A re-sorting shall be conducted to have modules with isolated parts in the same string or at least same MPPT.

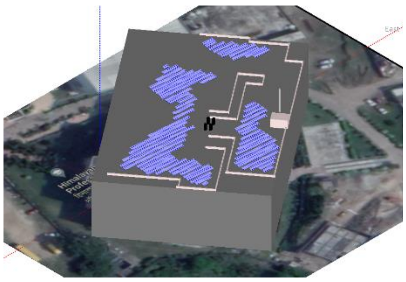


Figure 565: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 8% to 12%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.88 ₹/Wp, 0.13 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.5 ₹/kWh to 2.3 ₹/kWh

Picture Gallery


Figure 566: Soiled filters of inverter


Figure 567: Modules shaded by towers


Figure 568: Paint traces over PV module

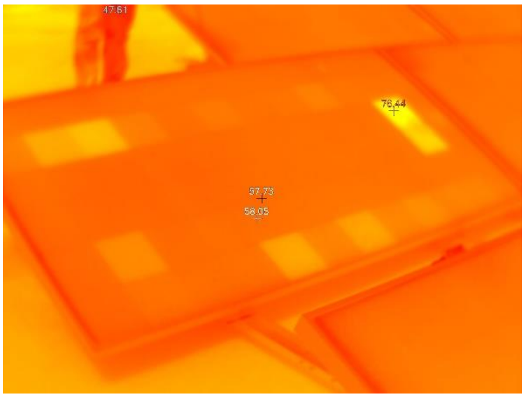


Figure 569: Hot cell caused by paint traces


Figure 570: Rusted contacts of earthing system


Figure 571: Misaligned modules


Figure 572: System design disregards nearby objects


Figure 573: Reduced interrow distance and module shaded by a rebar

41

PV plant: ***II.41***
Nominal capacity: ***29.76 kWp***
Average specific yield since COD (27.07.2017): ***740.77 kWh/kWp*** *(PVsyst estimation 1312 kWh/kWp)*

Abstract*: Cable management on site observed in poor condition. Modules clamps and bolts damaged. It is recommended to (i) optimize the cable layout, (ii) replace broken system components, (iii) relocate installations on roof edge, (iv) relocate shading objects, (v) retrofit the mounting structure, (vi) add module to module equipotential bonding, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***8%*** *and* ***46.9****%.*

PV Plant's health

Main Findings

- Poor cable management: Cables in poor condition. Cables exposed to ambient. Missing string labelling. Cables and connectors degraded and broken from poor crimping.

Figure 574: Cable layout.

- Cable conduits broken and molten.
- Disconnected string due to broken cable.
- Cement remains stuck on modules, and cell delamination found.
- Improper roof access and no walkway found on site.
- Modules installed beyond roof edge in high wind zones.
- Multiple module orientations found on site.
- Poor module racking due to damaged and faulty clamps and bolts, and improper rail placement.
- Module to module equipotential bonding missing.
- Modules shaded by water pipes, water heater and water tanks in the installation area.

Figure 575: Shading water heater and tanks.

- No LA and weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 4.8%. Modules are also soiled from cementing.
- IR analysis reveals presence of hot cells from water pipes running over modules.

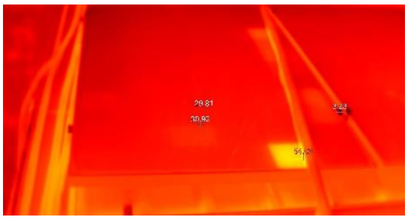


Figure 576: Hot cells from IR imaging.

- Modules shaded by the water tanks cause hotspots and hot cells from shading. This may indicate irreversible cell damage.

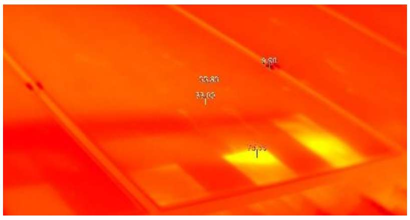


Figure 577: Defects from IR imaging.

- Based on the IV curve measurements, the estimated underperformance is 0.6% for the measured modules.

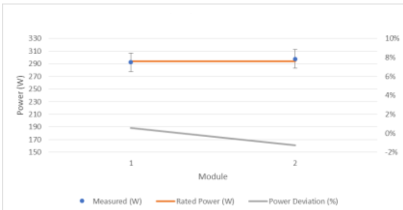


Figure 578: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.85%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Broken cables, connectors and conduits shall be immediately replaced to restore production from disconnected string and safety.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Modules with stuck cement remains shall be replaced since they generate permanent hotspots.
- Module to module earthing connections shall be added.
- If possible, a better roof access and walkway shall be provided for safer and easier O&M activity.
- Installations shall be moved away from the roof edge to prevent damage from higher wind loads.
- If the site layout allows, variation in orientations shall be reduced to reduce mismatch losses.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Damaged clamps and bolts shall be replaced. The rails shall be properly placed for an even load distribution at the clamping points.
- Water pipes, water heater and tanks causing shading shall be relocated to reduce shading impact and hotspot damage.

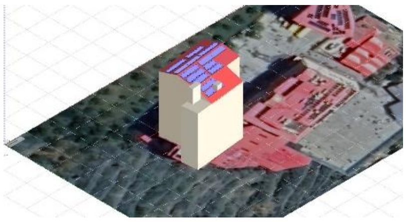


Figure 579: 3D model.

Estimated energy boost after conducting the suggested retrofitting actions: 8% to 46.9%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.18 ₹/Wp, 0.22 ₹/Wp/a
Estimated retrofit cost per additional generation: 5.5 ₹/kWh to 0.9 ₹/kWh

Picture Gallery


Figure 580: Cement remains on modules.


Figure 581: Poor cable management.

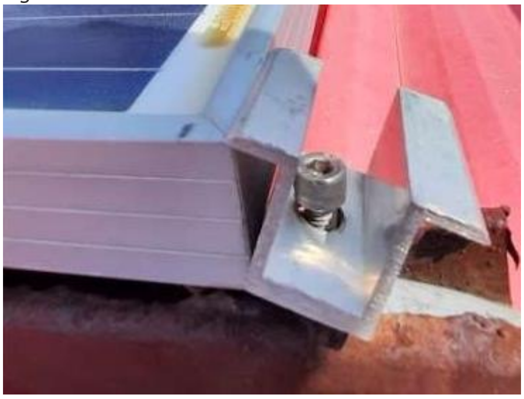


Figure 582: Damaged clamps.


Figure 583: Multiple orientations on site.


Figure 584: Shading by water tank and water pipes.


Figure 585: Molten cable conduit.


Figure 586: Missing module to module bonding.


Figure 587: Disconnected connector due to poor crimping.

42

PV plant: ***II.42***
Nominal capacity: ***300 kWp***
Average specific yield since COD (30.10.2017): ***1190.1 kWh/kWp*** *(PVsyst estimation 1267 kWh/kWp)*

***Abstract**: Cable management on site observed in poor condition. String with cut and burn marks found. It is recommended to (i) optimize the cable layout, (ii) replace modules with defects, (iii) increase cleaning cycles, (iv) relocate shading objects, (v) relocate installations on roof edge(vi) add module to module equipotential bonding, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **6.1%** and **11.6%**.*

PV Plant's health

Main Findings

- Poor cable management: String cables on the floor. String cable with cut and burn found. Missing labelling at string and module end.

Figure 588: Cable layout.

- Cable conduits broken.
- Modules with burned cells, moisture ingress, backsheet burn and damaged frame found on site.
- Modules with broken glass connected to the system.
- Foreign objects placed on and under PV tables.
- Improper roof access to some sections.
- Modules installed beyond roof edge in high wind zones.
- Multiple module orientations and tilts found on site.
- Module to module equipotential bonding missing.
- Modules severely shaded by water tanks, parapet walls, AC ducts, cables running over modules, causing permanent cell damage from hotspots.

Figure 589: Permanent cell damage from shading.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 7.1%. Modules with stuck cement remains, and animal droppings found.
- IR analysis reveals presence of hot cells due to shading by water tank. This may indicate irreversible cell damage.

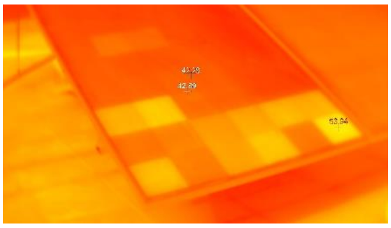


Figure 590: Hot cells from IR imaging.

- The EL image reveals presence of branched cracks and isolated parts indicating issues from transportation or handling. These defects generate hotspots, and pose both performance and safety threat.

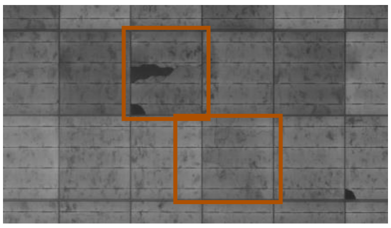


Figure 591: Defects from IR imaging.

- Based on the IV curve measurements, the estimated underperformance is 6.8% for the measured modules.

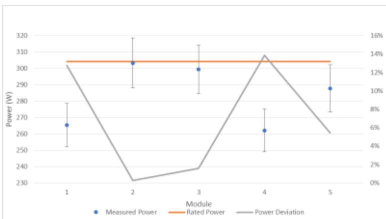


Figure 592: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 4.36%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Broken conduits shall be replaced to restore system safety.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Modules with stuck cement remains, permanent damage like burned cells, backsheet burns, broken glass, and damaged frame shall be immediately replaced as they pose severe performance and safety threat.
- Module to module earthing connections shall be added.
- If possible, a better roof access and walkway shall be provided for safer and easier O&M activity.
- Installations shall be moved away from the roof edge to prevent damage from higher wind loads. Variations in orientation shall be minimized.
- Foreign objects placed on and under modules shall be removed.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Shading objects, or module tables shall be relocated wherever appropriate to prevent further performance loss and module damage.

Figure 593: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 6.1% to 11.6%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.31 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation: 2.5 ₹/kWh to 1.3 ₹/kWh

Picture Gallery

Figure 594: Cut and burn mark on string cable.

Figure 595: Broken cable conduits.

Figure 596: Foreign objects under module.

Figure 597: Missing module to module bonding.

Figure 598: Modules installed in high wind zones.

Figure 599: Improper roof access.

Figure 600: Shading by adjacent table.

Figure 601: Backsheet burn.

43

PV plant: ***II.43***
Nominal capacity: ***160 kWp***
Average specific yield since COD (22.03.2018): ***759.3 kWh/kWp*** *(PVsyst estimation 1258 kWh/kWp)*

***Abstract**: Cable management on site observed in poor condition. A module with glass breakage was connected to the system. It is recommended to (i) optimize the cable layout, (ii) replace modules with defects, (iii) increase cleaning cycles, (iv) relocate shading objects, (v) re-sort lower performing modules, (vi) re-string modules with same orientation, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **13.6%** and **39.6%**.*

PV Plant's health

Main Findings

- Poor cable management: Degraded cables. Cables exposed to ambient. Missing labelling at string and module end.

Figure 602: Cable layout.

- Some cables are routed through the walkway, increasing the chances of causing cuts and abrasions.
- Modules with broken glass connected to the system.
- Foreign objects placed on PV tables.
- Missing walkways on some sections of the system.
- Some modules installed over walkways.
- Multiple module orientations connected to the same string.
- Module structure and installation roof found to be rusted and in poor condition.
- Modules shaded by vegetation and nearby pipes.

Figure 603: Shading by vegetation.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 5.1%. Modules are affected by cementing.
- IR analysis reveals presence of hot cells due to module cementing.

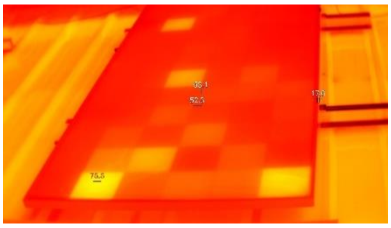


Figure 604: Hot cells from IR imaging.

- The EL image reveals presence of branched cracks and isolated parts indicating issues from transportation or handling. These defects generate hotspots, and pose both performance and safety threat.

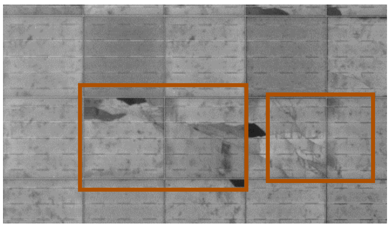


Figure 605: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 5.9% for the measured modules.

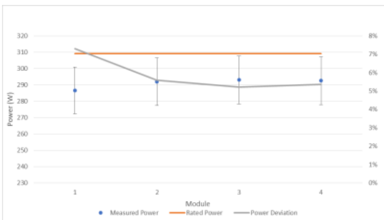


Figure 606: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.04%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- A proper cable rack layout shall be used to prevent further cable degradation from ambient conditions.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Module with broken glass shall be immediately replaced as it poses severe performance and safety threat.
- Foreign objects found on modules shall be removed.
- A properly anchored walkway shall be provided for safer and easier O&M activity.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- A re-stringing shall be conducted to have modules from one orientation in the same string, or at least the same MPPT.
- Rusted structure and roof parts shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Shading objects like pipe and vent shall be moved from module vicinity. If possible, vegetation causing shading shall be trimmed or removed.

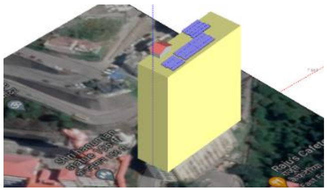


Figure 607: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 13.6% to 39.6%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.2 ₹/Wp, 0.11 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.6 ₹/kWh to 0.6 ₹/kWh

Picture Gallery

Figure 608: Cable driven through walkway.

Figure 609: Module with broken glass.

Figure 610: North and south module orientations connected to the same string.

Figure 611: Rusted structure components.

Figure 612: Module cementing.

Figure 613: Shading by exhaust vent.

Figure 614: Degraded cable from ambient conditions.

Figure 615: Walkways not properly anchored.

44

PV plant: ***II.44***
Nominal capacity: ***300.3 kWp***
Average specific yield since COD (26.02.2018): ***1245.89 kWh/kWp*** *(PVsyst estimation 1429 kWh/kWp)*

***Abstract**: Loosely hanging cables with low bending radius were found. Damaged modules that pose performance and safety threat found on-site. It is recommended to (i) optimize the cable layout, (ii) replace damaged modules, (iii) increase cleaning cycles, (iv) relocate shading objects, (v) re-sort lower performing modules, (vi) retrofit the mounting structure, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **10.7%** and **12.8%**.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling.

Figure 616: Cable layout.

- Phase wire contact exposed to ambient.
- Inverter fans and filters are soiled.
- Modules with broken glass, cell corrosion, damaged backsheet, and burn marks on cell fingers found on site.
- Improper roof access.
- Multiple module orientations and tilts found on site.
- Module misalignment due to improper bolting between structure purlins.
- Excess structure length observed for a PV table.
- Modules shaded by tables with different tilts, water tanks, and taller rooms and buildings in vicinity of the installation area.

Figure 617: Shading by table with different tilt.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 5.5%.
- IR analysis reveals presence of hotspots and hot cells from shading by water tank. This may indicate irreversible cell damage.

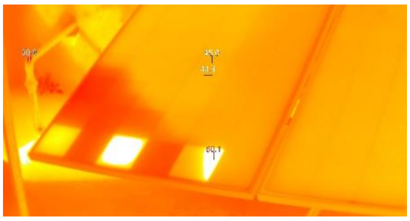


Figure 618: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts. These defects are expected to impact performance and generate hotspots.

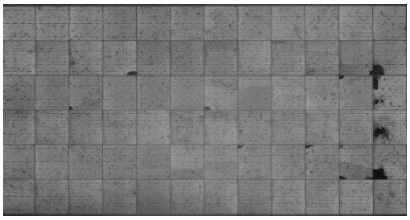


Figure 619: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 0.6% for the measured modules.

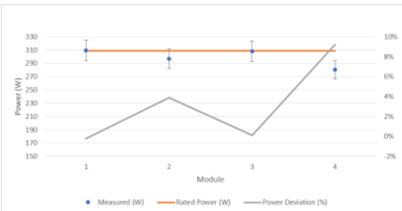


Figure 620: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.86%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Cables and wires with exposed contacts shall be immediately replaced since they pose severe safety threat.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Damaged modules shall be replaced to reduce further performance loss.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- A better roof access shall be provided for safer and easier O&M activity.
- If the site layout allows, variation in orientations shall be reduced to reduce mismatch losses.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Structure purlins shall be properly bolted to reduce module misalignment and improve structure functionality. Retrofitting actions shall be done to have structure length align with the table length.
- Modules and tables shall be adequately spaced away from shading objects wherever possible to reduce shading losses.

Figure 621: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 10.7% to 12.8%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.14 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.3 ₹/kWh to 1.1 ₹/kWh

Picture Gallery

Figure 622: Inverter fans and filters soiled.

Figure 623: Exposed phase wire contact.

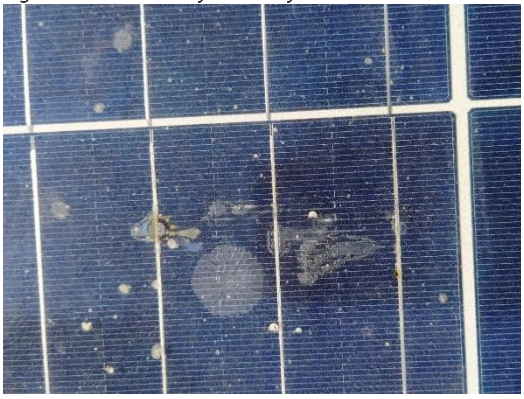


Figure 624: Cell corrosion.

Figure 625: Broken module connected to the system.

Figure 626: Improper bolting in structure.

Figure 627: Excess length in table structure.

Figure 628: Several orientations and shading by taller room.

Figure 629: Cell burn marks due to hotspots from shading.

45

PV plant: ***II.45***
Nominal capacity: ***6.5 kWp***
Average specific yield since COD (02.02.2017): ***1052.1 kWh/kWp*** *(PVsyst estimation 1457 kWh/kWp)*

***Abstract**: Cable management on site observed in poor condition. A module with glass breakage was connected to the system. It is recommended to (i) optimize the cable layout, (ii) replace modules with defects, (iii) increase cleaning cycles, (iv) add equipotential ponding and re-do earthing connections, (v) re-sort lower performing modules, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **8.8%** and **27.8%**.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling at the module end.

Figure 630: Cable layout.

- Detached cable connectors due to poor crimping.
- Damaged connectors found on site.
- Modules with damaged frame and backsheet chipping were observed.
- Wrong string cable and size used.
- Module damage observed due to foreign objects stored under PV tables.
- Module to module equipotential bonding missing.
- Earthing strips between structures are disconnected or detached.
- Module misalignment due to improper structure supports, and misaligned structure posts.

Figure 631: Module misalignment due to improper structure support.

- No weather station found on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 6.8%.
- IR analysis reveals presence of warm cells.

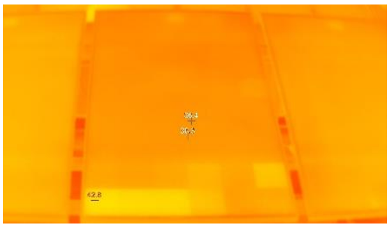


Figure 632: warm cells from IR imaging.

- The EL image reveals presence of several cracks and isolated parts indicating issues from transportation or handling. These defects pose severe performance and safety threat.

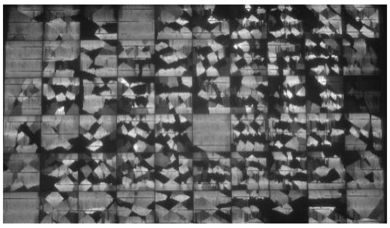


Figure 633: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 65.7% for the measured modules.

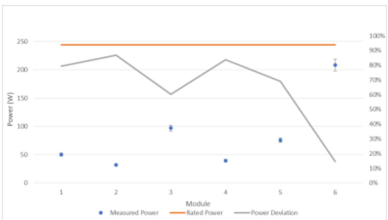


Figure 634: IV curve measurement results.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Damaged and detached cable connectors shall be replaced to restore production and safety.
- Modules affected by isolated parts shall be ideally replaced since they are significantly underperforming.
- Modules with damaged frame shall be replaced.
- Foreign objects stored under PV tables shall be removed to prevent further module damage and facilitate easier O&M access.
- Module to module equipotential bonding shall be added.
- Earthing connections between PV tables shall be re-done.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- Structure posts and vertical posts shall be realigned or replaced to reduce module misalignment and improve structure functionality.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

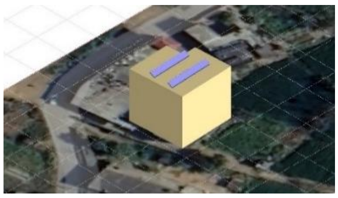


Figure 635: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 8.8% to 27.8%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 9.32 ₹/Wp, 0.92 ₹/Wp/a
Estimated retrofit cost per additional generation: 15 ₹/kWh to 4.7 ₹/kWh

Picture Gallery


Figure 636: Damaged connector.


Figure 637: Disconnected earthing strip.


Figure 638: Damaged frame.


Figure 639: Misaligned vertical posts.


Figure 640: Wrong string cable size used.


Figure 641: Objects stored under PV table.


Figure 642: Backsheet chipping.


Figure 643: Wrong string size.

46

PV plant: ***II.46***
Nominal capacity: ***120 kWp***
Average specific yield for last year: ***907 kWh/kWp*** *(1266 kWh/kWp)*

Abstract*: The PV plant shows varied tilt angles and improper fixation method that prevents proper air flow, some damaged modules were found, the cleaning method is inefficient and casts shadows on the system, some cables are exposed to the weather, and the catwalks are inadequate. It is recommended to (i) retrofit the mounting structure and catwalks, (ii) remove old cleaning system and increase the cleaning cycles, (iii) replace damaged modules, (iv) re-sort the modules according to their mechanical damage, and (v) re-arrange the strings based on the varied tilts. The estimated production boost expected by the retrofitting actions lies between 15 -17%.*

PV Plant's health

Main Findings

- Poor cable management: A cable tray is open, and some cables and connector are exposed to weather conditions and corroded.
- Two damaged modules are connected to the system, resulting in low generation.
- Installed walkways are inadequate in size and material for O&M activities.
- Mid clamping of some modules is absent and improper clamps were selected for end clamping, causing clamps damages.

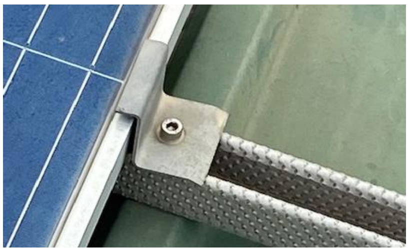


Figure 644: Improper clamping method of the modules

- The curved rooftop causes a variation of tilt angles on both sides of the roof.
- Bus bar corrosion were observed on some modules.
- The system is insufficiently ventilated, which leads to an underperformance of the modules.

Figure 645: Insufficient ventilation.

- A pyranometer was found on site but not data is logged, and the temperature probe shows signs of rust.

Impact on Performance

- Water sprinklers for cleaning and light poles cast shadows on the system, accounting for 0.6% of near shading losses.
- The on-site measured soiling losses were estimated in 13.4% from IV curve measurements.

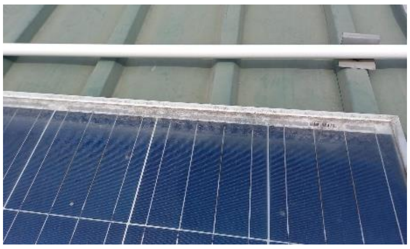


Figure 646: Soiling on the modules

- Severe damaged modules were found with micro-cracks and isolated parts by Electroluminescence analysis.

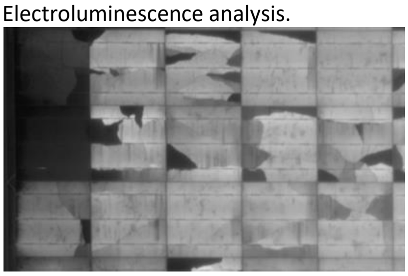


Figure 647: Isolated parts and micro-cracks

- The underperformance of the measured modules is around 34.9%.

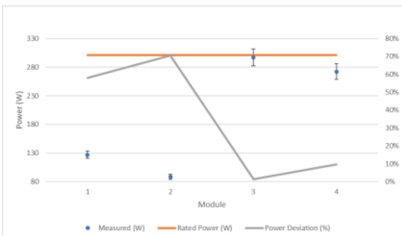


Figure 648: IV curve measurement results

Proposed Solutions

- A data logger shall be installed to properly determine the performance of the system.
- The cleaning cycles shall be increased based on the results of the soiling study that adjusts the cleaning needs to each season.
- Proper walkways shall be installed in order to carry O&M activities safely
- Broken modules should be replaced.
- A restringing of the modules shall be conducted in the following way: modules with the same tilt angle shall be installed in the same string or MPPT.
- Modules with heavy cracks shall be grouped in the same string or at least assigned to one MPPT. The grouping will be conducted based on infrared inspection.
- The shading objects on the roof shall be removed.
- All cables shall be protected against weather with UV protection

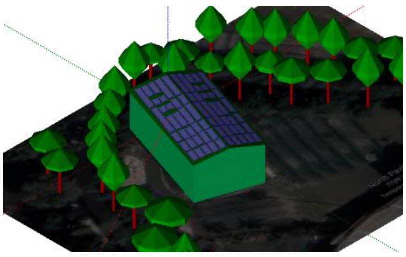


Figure 649: 3D model constructed in PVsyst

- The module fixation method shall be improved as manufacturer specification to allow proper air flow under the system, including missing clamps.

Estimated energy boost after conducting the suggested retrofitting actions: 15% to 17%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.78 ₹/Wp, 0.22 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 2.0 ₹/kWh to 2.2 ₹/kWh

Picture Gallery


Figure 650: Shading due to stadium lights


Figure 651: Busbar corrosion on some modules

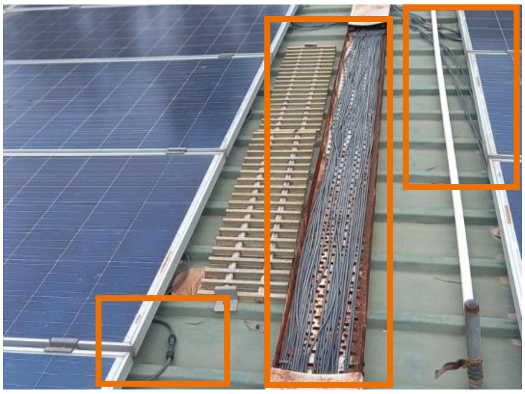


Figure 652: Cables and connectors exposed to weather


Figure 653: Sprinklers cast a shadow on the modules


Figure 654: Bamboo walkway

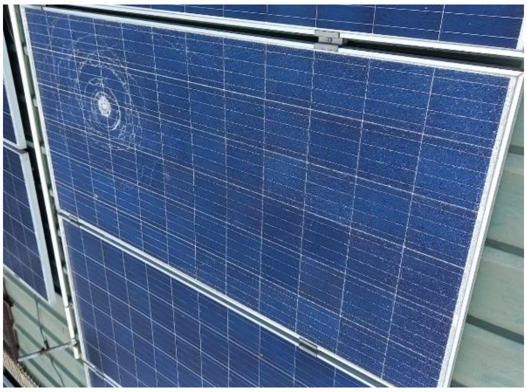


Figure 655: Connected damaged module


Figure 656: Modules with different tilt due to curved rooftop


Figure 657: Pyranometer data is not logged

47

PV plant: ***II.47***
Nominal capacity: ***65.28 kWp***
Average specific yield for last year: ***825 kWh/kWp*** *(1140 kWh/kWp)*

Abstract*: The PV plant consists of a 46 kWp and a 19.2 kWp system. The latter is shaded by the building of the former. The bigger plant shows design failures such as self-shading, near shading, and inadequate tilt angle. The building services vent directly to a module. Cable management and structure are in poor conditions. It is recommended to (i) retrofit the mounting structure including a tilt angle change, (ii) repair inverter room, (iii) replace damaged modules, and (iv) re-arrange the strings based on the shading. The estimated production boost expected by the retrofitting actions lies between 7 and 10%.*

PV Plant's health

Main Findings

- Poor cable management: Labelling of strings is missing, cable conduits are degraded, and the bending radius of the cables was not regarded.
- A damaged module is connected to the system, resulting in low generation.
- Exhaust ventilation system directly towards a module. This has caused hot cells in the module.

Figure 658: Exhaust ventilation towards a module

- The foundation bolt was missing or fixed incorrectly to the ballast in some tables. The purlins of the structure are deformed. Some elements show rust.
- The pyranometer found on site was not properly aligned to the plane of the array, and the ambient probe was not right attached.

- Figure 659: Irradiance sensor not aligned to array.
- An inverter presents evidence of water leakage inside of the room.

Impact on Performance

- According to the simulation of the system, the self-shading, and the deviation of optimal angle (10°) losses of both subsystems account for up to 4.7% and 3.7%, respectively.
- Objects near the modules, such as, water tanks, HVAC units, chimneys, etc. cast shadows over the system, accounting for losses around 5.1%

Figure 660: System shaded by several objects

- Based on the number of cracks and isolated parts discovered during Electroluminescence analysis, the power loss is expected to be around 4%.

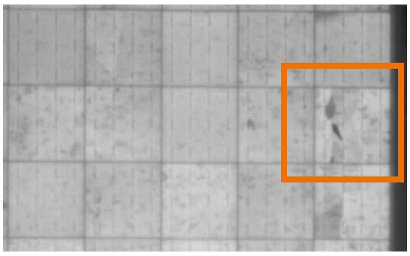
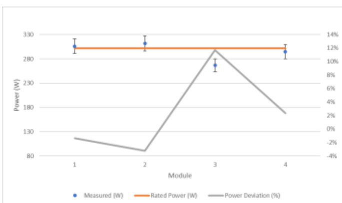


Figure 661: Isolated parts and micro-cracks

- The underperformance of the measured modules is around 4.2%.



Proposed Solutions

- The irradiance sensor shall be installed on the module plane so that the performance of the system can be properly determined.
- Broken module should be replaced.
- The exhaust ventilation system should be redirected to avoid higher temperature and shading of the module.
- A restringing of the modules in the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or MPPT.
- The foundation and fixing method of the mounting structure must be improved.
- Rusted elements of the structure should be replaced. To prevent such problems, metal elements can be painted with zinc.
- All cables should have a suitable labelling and the UV protection against the weather substituted.

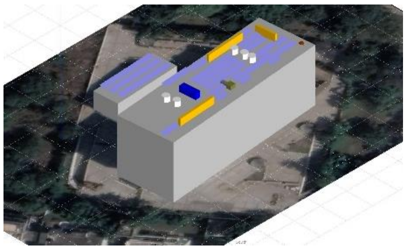


Figure 663: 3D model constructed in PVsyst

- The inverter room should be repaired to avoid water leakage.

Estimated energy boost after conducting the suggested retrofitting actions: 7% to 10%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.1 ₹/Wp, 0.00 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.0 ₹/kWh to 0.7 ₹/kWh

Picture Gallery


Figure 664: Damaged module


Figure 665: The 20 kWp system is shaded by a building

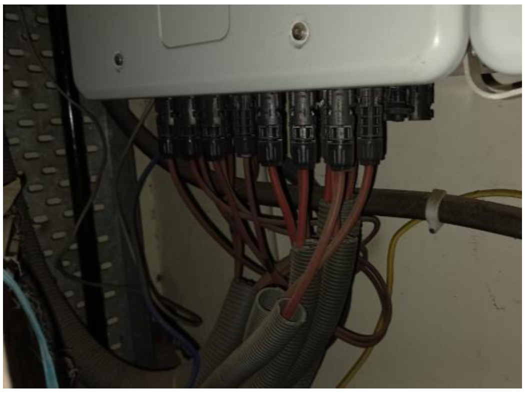


Figure 666: No string labeling at inverter


Figure 667: Rusted elements of the foundation


Figure 668: PV cable conduit degraded


Figure 669: Inverter with evidence of water leakage


Figure 670: Minimum bending radius not considered

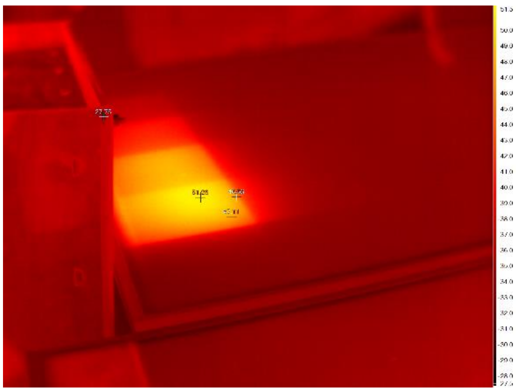


Figure 671: Hot cell developed by exhausting duct

48

PV plant: ***II.48***
Nominal capacity: ***5.02 kWp***
Average specific yield since COD (24/7/2017): ***646 kWh/kWp*** *(PVsyst estimation 1467 kWh/kWp)*

Abstract*: The plant presents underperformance due to near shading. A string is disconnected due to a burnt connector. The structure disregards the optimal tilt angle. It is recommended to (i) substitute the damaged connector, (ii) restring the shaded and damaged modules, (iii) retrofit the mounting structure, and (iv) install an irradiation sensor on the tilted plane to compute and check the Performance Ratio. The estimated production boost expected by the retrofitting actions lies between 50 and 55%.*

PV Plant's health

Main Findings

- Poor cable management: no string labelling was found.

Figure 672: No string labelling

- Non-standard cable selection for earth wire.
- A string is disconnected due to a burnt string connector that has not been repaired.
- Cement deposition was found on a module, which developed a hot cell.
- Modules' structure is bent causing different tilt angle on the same string.

Figure 673: Different tilted modules due to bent structure

- The system disregards the height of the parapet, side rails, and nearby buildings, resulting in shaded modules.
- No weather station was found on site.
- The system is not facing true South.

Impact on Performance

- According to the simulation of the system, the self-shading and near shading losses account for up to 2.1% and 3.3%, respectively.
- The on-site measured soiling losses were estimated in 3% from IV curve measurements.
- IR analysis showed evidence of hot spots possibly caused by near shading objects. EL analysis indicated no sign of PID.

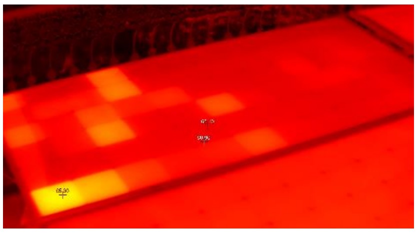


Figure 674: Hot cells on shaded module

- According to the number of cracks discovered via EL imaging; the system is expected to have power losses around 6% due to inactive areas.

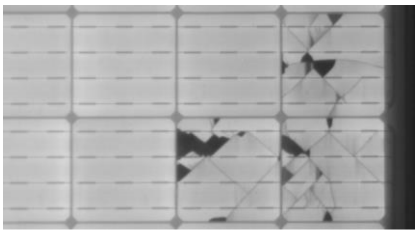


Figure 675: Broken cells from EL imaging

The underperformance of the measured modules is around 3.9%.

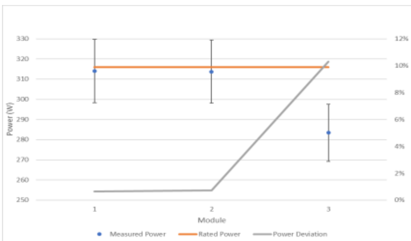


Figure 676: IV curve measurement results

Proposed Solutions

- Damaged or burnt connectors must be replaced to increase energy production.
- Restringing of the modules in the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or MPPT.
- The whole structure must be retrofitted including the modification of the tilt angle to the optimal (30°), change of the azimuth angle, and, if possible, increased inter row distance.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so to determine the performance of the system.
- The whole grounding system shall be retrofitted.
- Cables should be tied up among the substructure and have a suitable labelling and UV protection.
- A re-sorting shall be conducted to have modules with isolated parts in the same string or at least same MPPT.

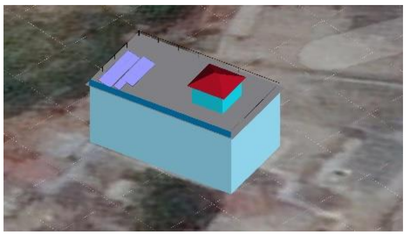


Figure 677: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 50% to 55%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 8.47 ₹/Wp, 0.00 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.3 ₹/kWh to 1.2 ₹/kWh

Picture Gallery

Figure 678: Cement deposition over module

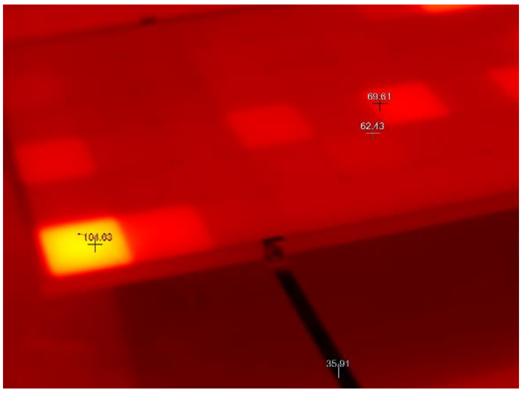


Figure 679: Hot cell developed due to cement deposition

Figure 680: Burnt cable connector

Figure 681: Shaded module by side rail

Figure 682: Non-conventional earthing wire.

Figure 683: Building on the rooftop near the system

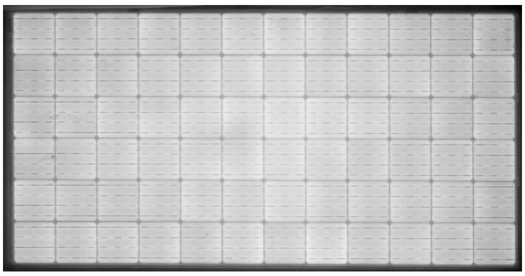


Figure 684: EL imaging showed no evidence of PID

Figure 685: System shaded by nearby building

49

PV plant: ***II.49***
Nominal capacity: ***500.5 kWp***
Average specific yield since COD (12.11.2017): ***839.97 kWh/kWp*** *(PVsyst estimation 1310 kWh/kWp)*

***Abstract**: Cables and connectors observed to be degraded. One inverter found to be non-operational. It is recommended to (i) improve cleaning activity, (ii) replace faulty components and restore inverter functionality (iii) add earthing connections, (iv) replace damaged modules, (v) retrofit the mounting structure, (vi) re-sort modules, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **10.5%** and **35%**.*

PV Plant's health

Main Findings

- Cable management: Cables with low bending radius. Cables with cuts and abrasions found. Degraded connectors and cables.

Figure 686: Cable layout.

- Inverter fans and filters soiled.
- Some inverters are not grounded.
- One inverter non-functional due to burnt wire in mains.
- Improper roof access to some roofs and missing safety rails in the installation area.
- Some earthing strips between structures are disconnected or loose.
- Module misalignment due to bent and damaged purlins and posts in the structure. Sharp structure edges not secured. Clamps improperly installed on sheet roof installations.
- Modules of different power classes connected to the same string.
- Modules shaded by iron rods in front. Some modules are shaded by adjacent tables with different heights.

Figure 687: Shading by iron rods.

- No weather station found on site.

Impact on Performance

- The system performance was affected by soiling loss of 7.8%, estimated from IV curve measurements. Modules on Block B are severely soiled due to nearby industries.
- IR analysis reveals hot cells from soiling on modules from Block B.

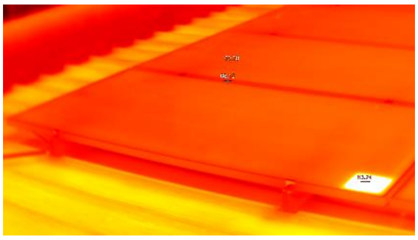


Figure 688: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts. These defects are expected to impact performance and generate hotspots.

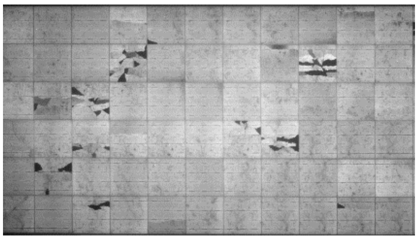


Figure 689: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 28% for the measured modules.

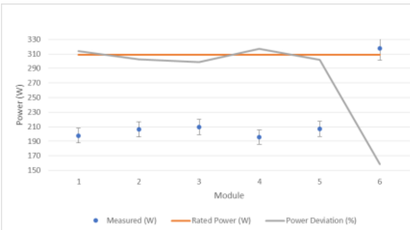


Figure 690: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.67%.

Proposed Solutions

- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter. Cables with cuts shall be replaced due to safety concerns.
- The cleaning cycles shall be increased based on the results of the soiling study.
- Inverter fans and filters shall be cleaned more frequently.
- Inverters shall be grounded. Faulty components in mains shall be replaced to restore inverter generation.
- A better roof access and safety railings shall be provided for safer O&M activity.
- Earthing connections between mounting structures shall be redone.
- Improperly installed clamps on sheet roof and damaged structure components shall be replaced to restore structure functionality and reduce module misalignment.
- A re-sorting shall be conducted to have modules with same power class, and lower performing modules in the same string, or at least the same MPPT dedicated for each case.
- Iron rods shall be relocated and tables shall have same heights.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

Figure 691: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 10.5% to 35%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.72 ₹/Wp, 0.19 ₹/Wp/a
Estimated retrofit cost per additional generation: 2.6 ₹/kWh to 0.8 ₹/kWh

Picture Gallery


Figure 692: Cable cuts.


Figure 693: Burnt wire in mains.


Figure 694: Loose earthing strips and misaligned structure purlins.


Figure 695: Missing safety railings.


Figure 696: Bent and damaged structure.


Figure 697: Module and structure misalignment.


Figure 698: Inverter not grounded.


Figure 699: Severely soiled module.

50

PV plant: ***II.50***
Nominal capacity: ***150.72 kWp***
Average specific yield for last year: ***1081 kWh/kWp*** *(PVsyst estimation 1361 kWh/kWp)*

Abstract*: The PV plant consists of a 50.24 kWp and a 100.48 kWp system. Structural earthing is corroded and bonding between modules is absent. The system design disregarded near shading. Poor cable was management was found. The plant is modestly affected by soiling and bird droppings. It is recommended to (i) improve O&M activities, (ii) retrofit earthing system and cabling management, (iii) replace a damaged connector, and (iv) re-arrange the strings based on the shading. The estimated production boost expected by the retrofitting actions lies between 8 and 12%.*

PV Plant's health

Main Findings

- Poor cable management: Labelling of strings is missing; cable conduits are degraded and missing filling foam.

Figure 700: Cable conduit without foam

- Filters of the inverters were found soiled.
- The pyranometers found on site were not properly aligned to the plane of the array.

Figure 701: Irradiance sensor not aligned to plane of array

- A broken connector was found on-site.
- Bird droppings and traces of paint were found on some modules
- Poor management of grounding: No earthing connection was found between modules and some elements are rusted.

Figure 702: No EPB between modules

Impact on Performance

- According to the simulation of the system, the self-shading, and the deviation of optimal angle (14°) losses of both subsystems account for up to 7.9% and 3.6%, respectively.
- Objects near the system, such as, buildings and trees, cast shadows over the system, accounting for losses around 7.82%

Figure 703: System shaded by trees

- Based on the number of cracks and isolated parts discovered during Electroluminescence analysis, the power loss is expected to be around 2%.

Figure 704: Isolated parts and micro-crack

- The underperformance of the measured modules is around 3.1%.

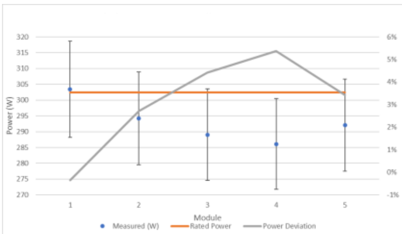


Figure 705: IV curve measurement results

Proposed Solutions

- The irradiance sensor shall be installed on the module plane so that the performance of the system can be properly determined.
- Broken MC4 connector should be replaced.
- The trees surrounding the system shall be trimmed if allowed. Additionally, restringing of the modules in the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or MPPT.
- Include in the O&M practices the cleaning of the ventilation system of the inverters.
- If there is sufficient space, modules tilt shall be changed to optimal tilt of 30°.
- Earthing connections between modules shall be added and rusted elements substituted.
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- All cables should have a suitable labelling and the UV protection against the weather renewed.

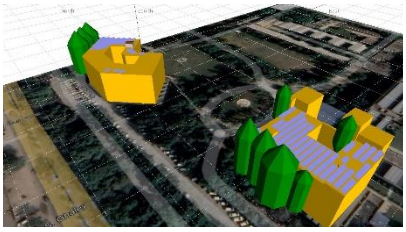


Figure 706: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 8% to 12%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.63 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 1.8 ₹/kWh to 1.1 ₹/kWh

Picture Gallery


Figure 707: Rusted elements of the earth stripe


Figure 708: Broken MC4 connector


Figure 709: Cleanliness of modules


Figure 710: String labelling at inverter level


Figure 711: PV cable conduit degraded


Figure 712: Soiled filters of inverter


Figure 713: Bird droppings on the modules

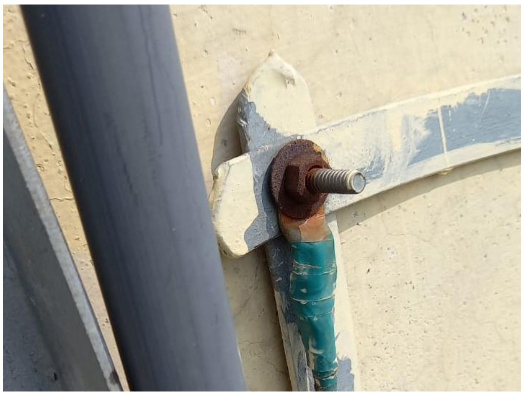


Figure 714: Earthing contacts corroded

51

PV plant: ***II.51***
Nominal capacity: ***100.48 kWp***
Average specific yield since COD (20.12.2017): ***604.31 kWh/kWp*** *(PVsyst estimation 1330 kWh/kWp)*

***Abstract**: Broken cables, exposed wires, and faulty system components were observed. Several damaged modules found on site. It is recommended to (i) improve cleaning activity, (ii) replace broken cables (iii) replace faulty components and inverter, (iv) replace damaged modules, (v) retrofit the mounting structure, (vi) re-sort the lower performing modules, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **13.2%** and **63.2%**.*

PV Plant's health

Main Findings

- Poor cable management: Cables in extremely poor condition. Insulation tapes used to fix broken cable and exposed wires. Wrong cable type used in strings.

Figure 715: Cable layout.

- 3 modules removed from string which were not replaced.
- Modules with broken glass, and damaged and burned backsheet connected to system.
- One of the two inverters non-functional since two years with burnt cable and fuse.
- Mains Air Circuit Breaker (ACB) not secured.
- Insufficient gap between modules.
- Clamps used in structure rusted. Structure purlin edges are sharp and not secured.
- Modules shaded by iron rods in front of modules.

Figure 716: Shading by iron rods.

- No weather station found on site.

Impact on Performance

- The system performance was affected by soiling loss of 3.5%, estimated from IV curve measurements.
- IR analysis reveals hot cells from soiling.

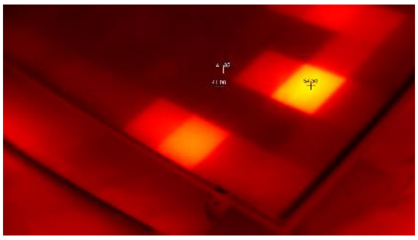


Figure 717: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts. These defects are expected to impact performance and generate hotspots.

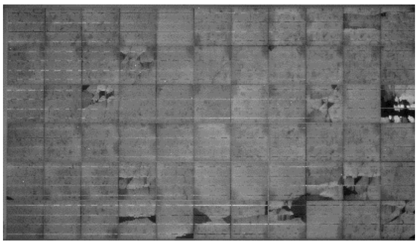


Figure 718: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 10.2% for the measured modules.

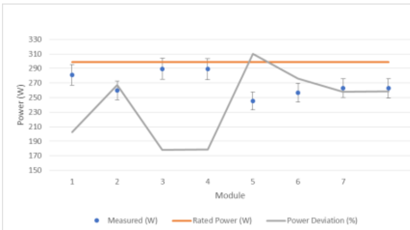


Figure 719: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.59%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Broken cables and exposed wires shall be immediately replaced due to serious safety concerns.
- The 3 modules removed from the string shall be replaced.
- Damaged modules shall be replaced since they pose both performance and safety threat.
- Non-functional inverter shall be investigated further for root-cause and get replaced to fully utilize the generation. Observed faulty safety components such as the ACB, and fuses shall also be replaced.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- The iron rods in front of the modules shall be relocated to avoid hotspot from permanent shading.
- Rusted clamps used in the structure shall be replaced. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc. Sharp edges on purlins must be secured to improve safety of O&M personnel.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

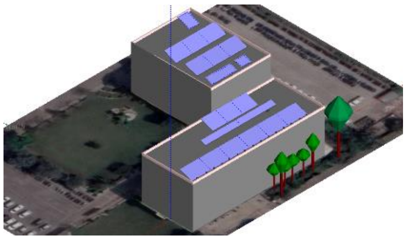


Figure 720: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 13.2% to 63.2%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.45 ₹/Wp, 0.12 ₹/Wp/a
Estimated retrofit cost per additional generation: 3 ₹/kWh to 0.6 ₹/kWh

Picture Gallery

Figure 721: Disconnected modules.

Figure 722: Module with glass breakage connected.

Figure 723: Insufficient gap between modules.

Figure 724: Sharp and rusted purlin edge.

Figure 725: Rusted clamps.

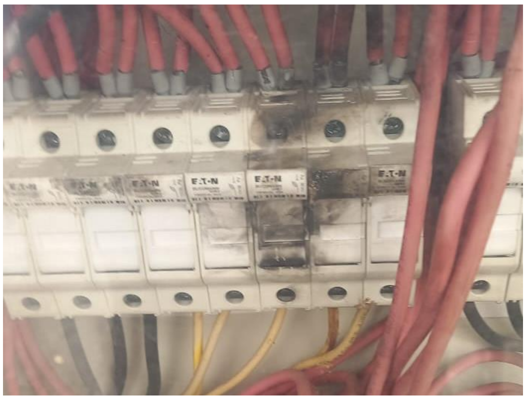


Figure 726: Burned fuse.

Figure 727: Broken cables and exposed wires.

Figure 728: Orientations overview.

52

PV plant: ***II.52***
Nominal capacity: ***90.09 kWp***
Average specific yield since COD (02.11.2017): ***1294.84 kWh/kWp*** *(PVsyst estimation 1321 kWh/kWp)*

***Abstract**: Installations in high wind zones observed to be bolted through asbestos. Modules with damaged backsheet found on site. It is recommended to (i) assign string labelling, (ii) provide better roof access for easier O&M activities, (iii) replace damaged modules, (iv) retrofit the mounting structure, (v) remove name board from the installation area, and (vi) clean inverter fans and filters more frequently. The estimated production boost expected by the retrofitting actions lies between **5.3%** and **6%**.*

PV Plant's health

Main Findings

- Cable management: Cable layout with cable racking. Missing string labelling.

Figure 729: Cable layout.

Figure 730: Missing string labelling at inverter end.

- Foreign object stuck on module glass.
- Modules with damaged backsheet found on site.
- Inverter fans and filters are soiled.
- PV table structures in high wind zones bolted through asbestos.
- Multiple table orientations found on site.
- Improper roof access.
- Modules shaded by a name board and LA.

Figure 731: Shading by name board.

- Irradiance sensor and LA found on site.

Impact on Performance

- Modules were not soiled due to frequent rains.
- IR analysis reveals hot cells from shading.

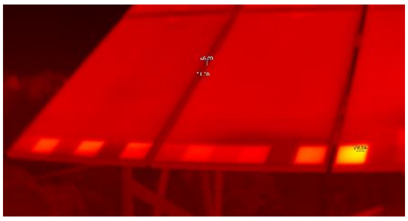


Figure 732: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated parts. These defects are expected to impact performance and generate hotspots.

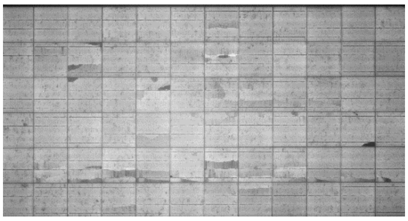


Figure 733: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 36% for the measured modules.

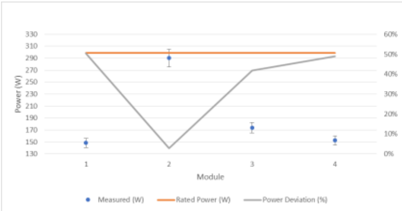


Figure 734: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.88%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Modules with stuck foreign objects, isolated parts, and damaged backsheet shall be replaced as they pose performance and safety threat.
- Inverter fans and filters shall be cleaned more frequently.
- The condition of asbestos shall be closely inspected to evaluate its suitability to support tables in high wind zones.
- A better roof access shall be provided to facilitate O&M activities.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- A re-stringing shall be done to have modules with same orientation in one string, or at least the same MPPT.
- If possible, name board and LA shall be relocated so that they do not cause module shading.

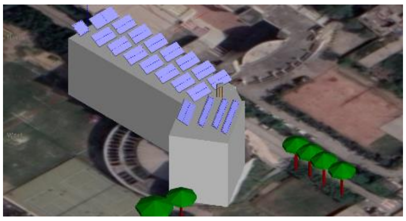


Figure 735: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 1.9% to 5.3%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.28 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 4.4 ₹/kWh to 1.6 ₹/kWh

Picture Gallery


Figure 736: Foreign object on module glass.


Figure 737: Module with backsheet damage.

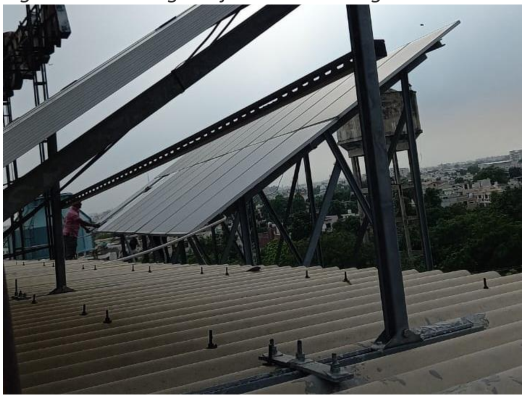


Figure 738: Table structure bolted through asbestos.


Figure 739: Soiled inverter fans.


Figure 740: Multiple orientations found on site.


Figure 741: Improper roof access.


Figure 742: Irradiance sensor.


Figure 743: LA on site.

53

*PV plant: **II.53***
*Nominal capacity: **80.01 kWp***
*Average specific yield since COD (20.03.2018): **1275.81 kWh/kWp** (PVsyst estimation 1362 kWh/kWp)*

Abstract**: Loosely hanging cables with low bending radius were found. Modules with detached J-boxes found on site. It is recommended to (i) assign string labelling, (ii) improve cleaning activity, (iii) clean inverter fans and filters more frequently, (iv) establish inverter grounding, and (v) sharp objects shall be immediately removed from the installation area. The estimated production boost expected by the retrofitting actions lies between **4%** and **6.3%.

PV Plant's health

Main Findings

- Cable management: Cable layout with cable racking. Missing string labelling.

Figure 744: Missing string labelling.

- Conduits are secured with filling foam.

Figure 745: Cable conduit with foam.

- Inverter fans and filters are noisy from soiling.

Figure 746: Inverter filters soiled.

- Inverter is not grounded.
- Sharp blade placed between modules

Figure 747: Sharp blade between modules.

- Irradiance sensor and LA found on site.

Impact on Performance

- The system performance was affected by soiling loss of 2.9%, estimated from IV curve measurements. Modules are soiled from cementing.
- IR analysis reveals hot cells from soiling.

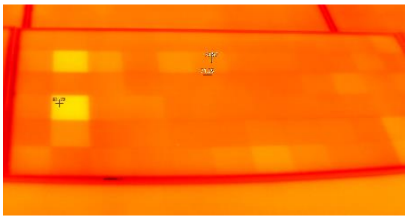


Figure 748: Hot cells from IR imaging.

- The EL image reveals presence of few long cracks. These defects are not expected to impact performance or safety in their present state.

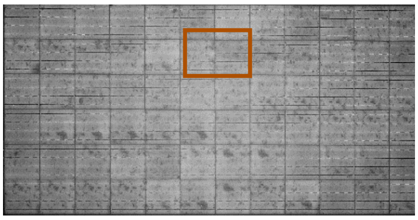


Figure 749: Defects from EL imaging.

- Based on the IV curve measurements, no underperformance was observed in the tested modules.

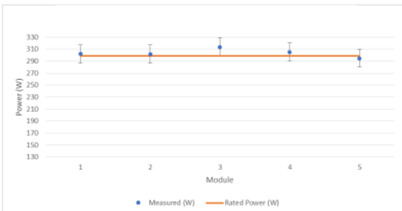


Figure 750: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.16%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- Inverter fans and filters shall be cleaned more frequently.
- Grounding shall be established in inverter to ensure system and personnel safety.
- Modules are shaded from the inter-row spacing used. Tables shall be rearranged to have a higher pitch.
- Sharp blades and objects found on site shall be immediately removed since they pose a safety threat.

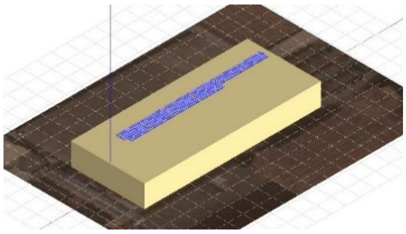


Figure 751: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 4% to 6.3%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.2 ₹/Wp, 0.07 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.7 ₹/kWh to 1.1 ₹/kWh

Picture Gallery


Figure 752: Site overview.


Figure 753: Inverter fans soiled.


Figure 754: Inverter not grounded.


Figure 755: Bird dropping.


Figure 756: Irradiance sensor found on site.


Figure 757: LA found on site.


Figure 758: Module placed on parapet wall.


Figure 759: Orientations overview.

54

PV plant: ***II.54***
Nominal capacity: ***70.56 kWp***
Average specific yield since COD (01.03.2018): ***1262.8 kWh/kWp*** *(PVsyst estimation 1321 kWh/kWp)*

Abstract: *Modules with damaged backsheet found on site. Table structures observed to be bent at corners.It is recommended to (i) assign module labelling, (ii) clean inverter fans and filters more frequently, (iii) replace damaged modules, (iv) establish necessary grounding connections, (v) identify and rectify the inverter issues, (vi) retrofit the mounting structure, and (vii) re-sort and re-string modules. The estimated production boost expected by the retrofitting actions lies between* ***4.4%*** *and* ***5.1%****.*

PV Plant's health

Main Findings

- Cable management: Cable layout with cable racking. Missing string labelling at module end.

Figure 760: Cable layout.

- Inverter fans and filters are soiled.
- Inverter not grounded.
- One of the inverters run in derating state, which may limit the system from maximum generation.

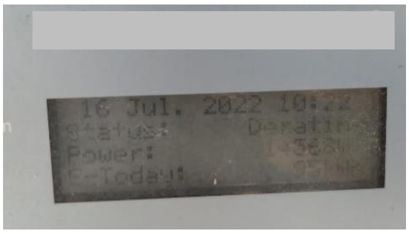


Figure 761: Inverter running in derating mode.

- Module with isolated cell parts, damaged backsheet, and J-box cover found on site.
- Module to module equipotential bonding missing.
- Table structure bent at corners.
- Modules shaded by LA.

Figure 762: Shading by LA.

- Irradiance sensor and LA found on site.

Impact on Performance

- Modules were not soiled due to frequent rains.
- IR analysis reveals hot cells from cracks and isolated cell parts. This may indicate irreversible cell damage.

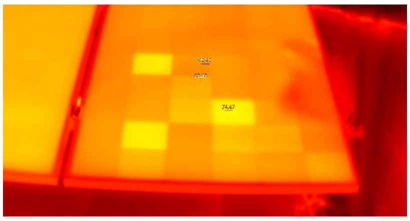


Figure 763: Hot cells from IR imaging.

- The EL image reveals presence of cracks and isolated part. These defects are expected to impact performance and generate hotspots.

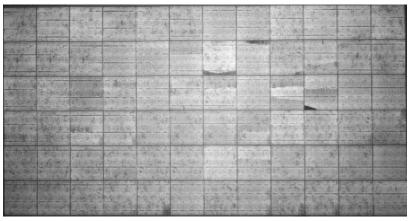


Figure 764: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 14% for the measured module.

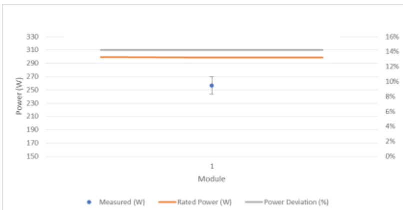


Figure 765: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.49%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- Inverter fans and filters shall be cleaned more frequently.
- Grounding shall be established in inverter to ensure system and personnel safety.
- A root-cause-analysis shall be conducted on the inverter running in derating mode to identify the problem and restore the inverter generation.
- Modules with isolated parts, damaged backsheet, and J-box cover shall be replaced as they pose performance and safety threat.
- Earthing connections between modules shall be added.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- Retrofitting actions shall be done on the structure to fix bent structure corners.
- A re-stringing shall be conducted to have shaded modules in one string, or at least the same MPPT.

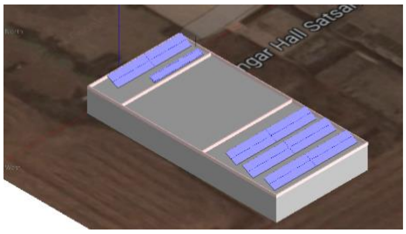


Figure 766: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 4.4% to 5.1%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.23 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.9 ₹/kWh to 1.7 ₹/kWh


Figure 767: Inverter fans soiled.


Figure 768: Inverter not grounded.


Figure 769: Backsheet damage.


Figure 770: Damaged J-box cover.


Figure 771: Missing module to module bonding.


Figure 772: Bent structure.


Figure 773: Site overview.


Figure 774: Cable conduit used.

55

PV plant: ***II.55***
Nominal capacity: ***399.42 kWp***
Average specific yield since COD (31.03.2018): ***1040.58 kWh/kWp*** *(PVsyst estimation 1376 kWh/kWp)*

***Abstract**: Loosely hanging cables with low bending radius were found. Modules with detached J-boxes found on site. It is recommended to (i) optimize the cable layout, (ii) improve cleaning activity, (iii) replace damaged modules, (iv) retrofit the mounting structure, (v) relocate tables away from parapet wall and high wind zones, (vi) clean inverter fans and filters more frequently, and (vii) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **8.5%** and **18.8%**.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling.

Figure 775: Cable layout.

- Layer of spray paint on module glass.
- Modules found with J-box detached and hanging.
- PV tables installed beyond roof boundaries in high wind zones.
- Inverter fans and filters are noisy from soiling.
- Poor quality clamps that are not suitable for high wind zones. Clamps were also observed to be easily displaced from grooves.
- Tables observed to have varying orientation and tilts.
- Modules placed on parapet walls have permanent cell damage from reduced heat dissipation.
- Modules are shaded by parapet walls, leading to permanent cell damage from hotspots.

Figure 776: Shading by parapet wall.

- No weather station found on site.

Impact on Performance

- The system performance was affected by soiling loss of 2.5%, estimated from IV curve measurements.
- IR analysis reveals hot cells from shading by parapet wall, which may indicate irreversible cell damage.

Figure 777: Hot cells from IR imaging.

- The EL image reveals presence of cracks, isolated parts, and dark cells. These defects are expected to impact performance and generate hotspots.

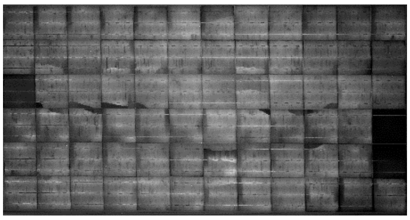


Figure 778: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 18.8% for the measured modules.

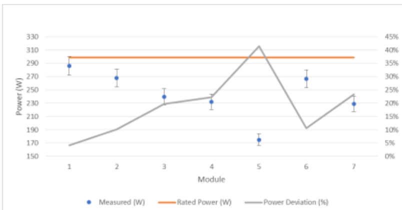


Figure 779: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.34%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- Modules with detached J-boxes, irreversible cell damage, and modules with spray paint layers shall be replaced as they pose performance and safety threat.
- Tables installed beyond roof boundaries to prevent damage from high wind loads.
- Inverter fans and filters shall be cleaned more frequently.
- Poor quality clamps used shall be replaced with better quality ones suitable for local wind loads.
- PV tables shall be rearranged to have uniform orientation and tilt. The module tilt shall be changed to optimal tilt of 30°.
- Modules placed on parapet walls shall be moved away to prevent mechanical damage and improve air flow.
- A re-sorting shall be conducted to have lower performing modules in the same string, or at least the same MPPT.
- Module tilt shall be changed to optimal tilt of 30°.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

Figure 780: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 8.5% to 18.8%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 0.5 ₹/kWh to 0.2 ₹/kWh

Picture Gallery

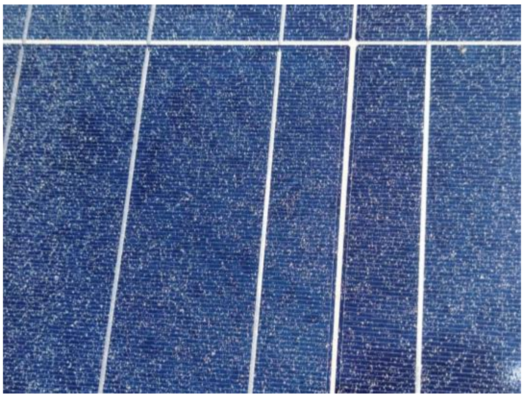


Figure 781: Spray paint layer over glass.

Figure 782: Detached J-box.

Figure 783: Installation beyond roof boundary.

Figure 784: Soiled inverter fans.

Figure 785: Quality of the clamps used.

Figure 786: Cell damage from reduced heat dissipation.

Figure 787: Module placed on parapet wall.

Figure 788: Orientations overview.

56

PV plant: ***II.56***
Nominal capacity: ***71.68 kWp***
Average specific yield since COD (27.10.2017): ***664 kWh/kWp*** *(PVsyst estimation 1277 kWh/kWp)*

Abstract: *Loosely hanging cables with low bending radius were found. Damaged modules that pose performance and safety threat found on-site. It is recommended to (i) optimize the cable layout, (ii) improve cleaning activity, (iii) replace damaged modules and re-string shaded modules (iv) retrofit the mounting structure, (v) clean inverter fans and filters more frequently, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between* ***10.2%*** *and* ***20%****.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling. Additionally, the cables are degrading and conduits are broken.

Figure 789: Cable layout.

- Several cable conduits are broken.
- Cement remains and scratches found on module glass.
- Modules with broken glass, broken backsheet, burned backsheet, and open J-box found on-site.
- Inverter fans and filters are severely soiled.
- Screws and bolts used in the structure are rusted.
- Modules are shaded by taller rooms, chiller structures, and exhaust ducts running above the system.

Figure 790: Module shading by exhaust duct.

- No weather station found on site.

Impact on Performance

- Modules were not soiled due to frequent rains, however module cementing was observed.
- IR analysis reveals hot cells from cementing.

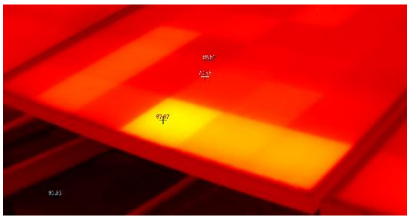


Figure 791: Hot cells from IR imaging.

- The EL image reveals presence of cracks, and soldering issues from manufacturing. These defects are not expected to impact performance in their given state.

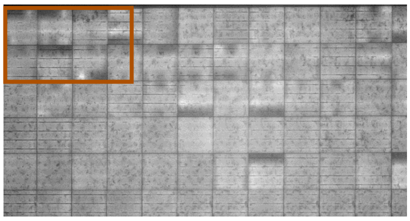


Figure 792: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 4.7% for the measured modules.

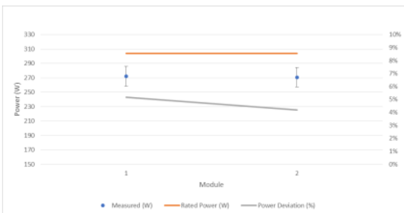


Figure 793: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 3.49%, and tilt loss of 3.9% relative to the optimal tilt.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- A more effective cleaning is recommended to address module cementing.
- Damaged modules and modules with cement remains shall be replaced as they pose performance and safety threat.
- Inverter fans and filters shall be cleaned more frequently.
- Rusted components shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- A re-stringing shall be conducted to have shaded modules in the same string.
- Module tilt shall be changed to optimal tilt of 30°.
- Ideally, the exhaust duct system shall be re-routed since they cause permanent module shading.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

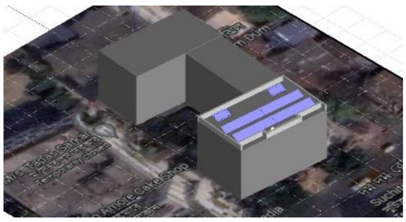


Figure 794: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 10.2% to 20%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.68 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.2 ₹/kWh to 0.6 ₹/kWh

Picture Gallery


Figure 795: Module with glass breakage.


Figure 796: Damaged backsheet.


Figure 797: Burned backsheet.


Figure 798: Module cementing.


Figure 799: Shading by taller rooms.


Figure 800: Inverter fans and filters soiled.


Figure 801: Scratch on module glass.


Figure 802: Open J-box.

57

PV plant: ***II.57***
Nominal capacity: ***100.68 kWp***
Average specific yield since COD (23.08.2017): ***1194.6 kWh/kWp*** *(PVsyst estimation 1341kWh/kWp)*

***Abstract**: Loosely hanging cables with low bending radius were found. Damaged modules that pose performance and safety threat found on-site. It is recommended to (i) optimize the cable layout, (ii) increase cleaning activity, (iii) replace damaged modules (iv) retrofit the mounting structure, (v) re-sort and re-string the modules, and (vi) install a weather station or at least an irradiation sensor on the module plane. The estimated production boost expected by the retrofitting actions lies between **7.5%** and **10.9%**.*

PV Plant's health

Main Findings

- Poor cable management: Loosely hanging cables with low bending radius. Missing string labelling.

Figure 803: Cable layout.

- Foreign material remains and scratches found on module glass.
- Modules with damaged frame and backsheet found on site.
- Inverters fans are running noisy from soiling.
- Module misalignment found on several tables.
- Screws, bolts and purlins used in the structure are rusted.
- Vertical post used in structure bent, contributing to module misalignment.
- Multiple table orientations found on site.
- Modules in the corner are installed too close to the parapet wall.
- Modules with different power class installed in same string.
- Structures from the same row are not aligned between tables.

Figure 804: Structures not aligned.

- No weather station found on site.

Impact on Performance

- Modules were not soiled due to frequent rains, however module cementing was observed.
- IR analysis reveals hot cells from cementing.

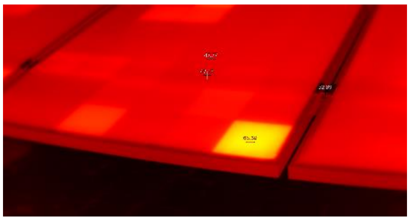


Figure 805: Hot cells from IR imaging.

- The EL image reveals presence of several cracks, isolated cell parts and dark cells. These defects severely impact system performance and safety.

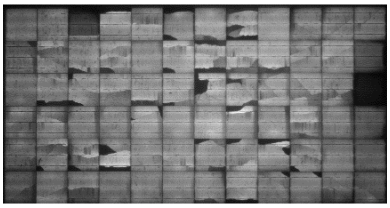


Figure 806: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 10.2% for the measured modules.

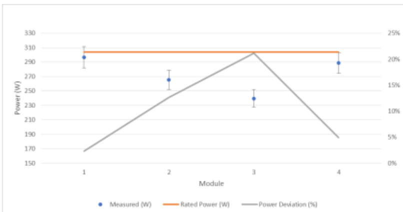


Figure 807: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 1.53%.

Proposed Solutions

- Strings, tables, and inverters should have a suitable labelling (UV-resistant).
- The cable layout can be optimized; the minimum cable bending radius is 10x the cable diameter.
- A more effective cleaning is recommended to address module cementing.
- Damaged modules shall be replaced as they pose performance and safety threat.
- Inverter fans shall be cleaned more frequently.
- A re-sorting shall be conducted to have lower performing modules and modules with same power class in the same string for each case, or at least the same MPPT.
- Damaged structure vertical posts shall be replaced to restore the structure functionality. Rusted components shall be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- If possible, modules in the corner shall be moved away from the parapet wall to facilitate easier O&M access.
- If possible, table with higher tilt angle shall be spaced adequately to reduce the effects of shading.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.

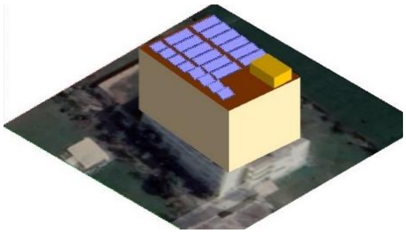


Figure 808: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 7.5% to 10.9%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 2.06 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.2 ₹/kWh to 0.8 ₹/kWh

Picture Gallery


Figure 809: Module with damaged frame.


Figure 810: Rusted purlin.


Figure 811: Module glass scratch.


Figure 812: Modules installed close to parapet wall.


Figure 813: Backsheet scratch.


Figure 814: Module misalignment and cementing.


Figure 815: Damaged frame.


Figure 816: Soiled inverter fans.

58

PV plant: ***II.58***
Nominal capacity: ***670 kWp***
Average specific yield (since COD: 26.03.2018): ***746.7 kWh/kWp*** *(PVsyst estimation 1292.5 kWh/kWp)*

Abstract*: The PV plant is heavily soiled. Some modules with mechanical damages were detected (broken modules and damaged frames). Cables hang under the modules and damaged cable conduits and MC4 connector were found. Interrow distance is insufficient. Structural earthing is incomplete and corroded. It is recommended to (i) increase the cleaning cycles, (ii) replace damaged modules and cables, (iii) retrofit the mounting structure, (iv) install a new earthing system, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the Performance Ratio. The estimated production boost expected by the retrofitting actions lies between* ***12%*** *and* ***17%****.*

PV Plant's health

Main Findings

- Poor cable management: Broken, burnt, and open cable conduits, cables hanging loose, and no string labelling.

Figure 817: Cables hanging under the tables.

- Six broken modules were found on site and other five showed a damaged frame.

Figure 818: Broken module

- A plant section was uninstalled due to a new construction, reducing its nominal capacity.
- Broken, open, burnt, and weather exposed MC4 connectors are found on site.
- No LA was found close to the system.
- No weather station, and hence no PR monitoring.
- An inverter shows heavy degrees of soiling in the fan and the labelling of some others are degraded.
- Few tables have structural earthing and those with it present rusted contacts.
- Walkways for maintenance are missing and the ones existing are rusty.

Impact on Performance

- The system presents heavy degrees of soiling. The on-site measured soiling losses were estimated in 13.1%.
- IR analysis showed that interrow shading developed hot cells in the bottom part of the modules. According to the PVsyst simulation, self-shading losses account for up to 6.3%.

Figure 819: Hot cells due to reduced inter-row distance.

- According to the number of cracks discovered via EL imaging; the system is not expected to have large power losses due to inactive areas.

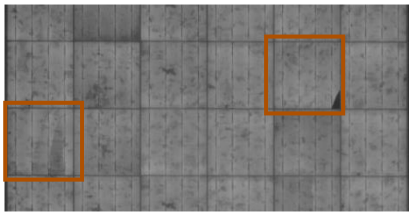


Figure 820: Microcracks and isolated area discovered during EL imaging

- Several objects were found casting shadows over the modules, such as, small trees, a cable conduit, and a plastic sheet.

Figure 821: Conduit over PV system

Proposed Solutions

- The cleaning cycles of modules and inverters shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- All broken and damaged modules shall be replaced.
- The cables shall be fixed to the mounting structure and the cable conduit renovated with UV protection.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so that the performance of the system can be properly determined.
- Foreign objects casting shadows over the modules shall be removed.
- The whole site should have safe walkways installed to carry out O&M tasks.
- Earthing of the complete mounting structure shall be renovated and bonding between modules included.
- LA shall be relocated closer to the PV system.
- Include in the O&M practices the cleaning of the ventilation system of the inverters.
- If possible, the interrow distance and tilt angle should be improved to reduce self-shading.

Figure 822: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 12% to 17%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 0.5 ₹/Wp, 0.15 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.6 ₹/kWh to 1.1 ₹/kWh


Figure 823: Uninstalled section of the site

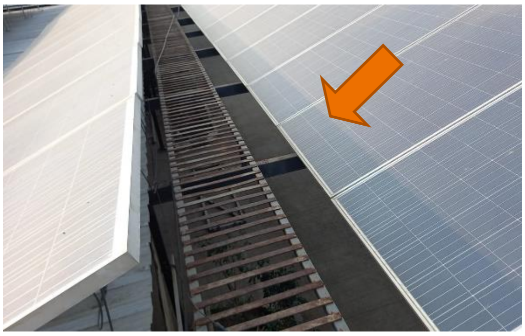


Figure 824: Interrow shading and corroded walkway

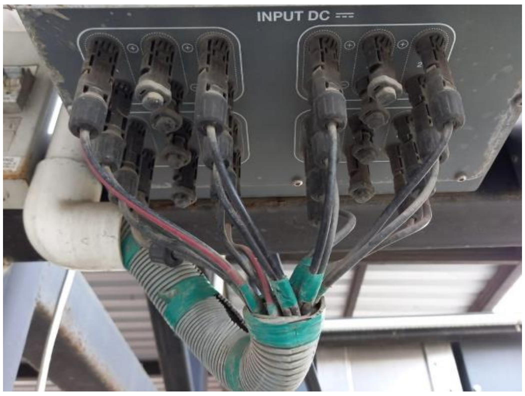


Figure 825: No string labelling at inverter end


Figure 826: Burnt connector


Figure 827: Mechanical damage of the frame


Figure 828: Rusted contact of structural earthing.


Figure 829: Edge module shaded by nearby tree.


Figure 830: Degraded cable conduit.

59

PV plant: ***II.59***
Nominal capacity: ***40.3 kWp***
Average specific yield: ***1439.9 kWh/kWp*** *(PVsyst estimation 1458 kWh/kWp)*

Abstract*: Some modules with backsheet scratches were detected. Cables loosely hanging from the modules were found. Module-to-module earthing is absent. It is recommended to (i) add earthing connections between modules, (ii) optimize the cable layout, (iii) replace modules with back-sheet damage, (iv) replace rusted components of the mounting structure, and (v) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions lies between* ***1.2%*** *and* ***3.7%****.*

PV Plant's health

Main Findings

- Poor cable management: Cables loosely hanging from the structure, and exposed to ambient. The minimum cable bending radius is not respected. Connectors are soiled.

Figure 831: Poor cable management.

- Cable conduits degraded.
- Improper access to the site.
- The joints and bolts in the mounting structures are rusted.
- Modules shaded by tree and the LA on site, causing module hotspots.
- Module-to-module equipotential bonding is absent.

Figure 832: Shading by tree.

- No weather station identified on site.

Impact on Performance

- Based on the IV curve measurements, the soiling loss is estimated to be 7.4%. Modules are affected by cementing.
- IR analysis shows presence of hotspots, from shading and cementing. This may indicate irreversible cell damage.

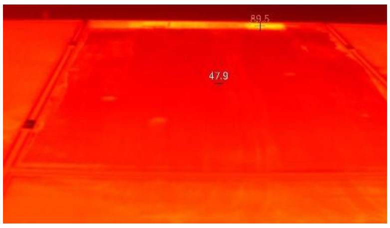


Figure 833: Hotspots from IR imaging.

- The EL image reveals presence of branched cracks, isolated parts, and back-sheet scratches, which are expected to impact performance and safety.

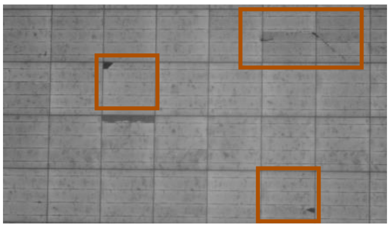


Figure 834: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 15.7% for the measured modules.

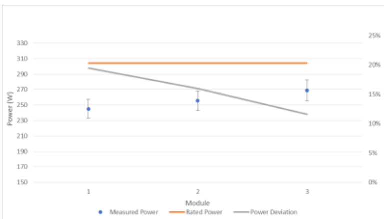


Figure 835: IV curve measurement results.

- According to the PVsyst simulations, the near shading losses account to 0.91%.

Proposed Solutions

- Strings, tables, and inverters shall have suitable labelling (UV-resistant if applicable).
- A proper cable rack layout shall be used to prevent cable degradation from ambient conditions.
- Degraded cable conduits shall be replaced with suitable ones.
- The cleaning cycles shall be increased based on the results of a soiling study.
- Modules with back-sheet scratches shall be replaced to avoid safety threats.
- A re-sorting shall be conducted to have lower performing modules in the same string or at least assigned to individual MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Earthing connections between modules shall be added.
- Rusted joints and bolts in the structure shall be replaced. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc.
- If possible, LA that causes shading shall be moved from module vicinity and the tree causing shading shall be trimmed.

Figure 836: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 1.2% to 3.7%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 3.7 ₹/Wp, 0.32₹/Wp/a
Estimated retrofit cost per additional generation: 28.9 ₹/kWh to 9.4 ₹/kWh

Picture Gallery

Figure 837: Rusted structure bolts.

Figure 838: Rusted bolts and joints.

Figure 839: Soiling condition of modules.

Figure 840: Module misalignment.

Figure 841: Missing module-to-module bonding.

Figure 842: Module cementing.

Figure 843: Improper roof access.

Figure 844: Shading by LA.

60

PV plant: ***II.60***
Nominal capacity: ***10 kWp***
Average specific yield since COD (24.07.2017): ***1131 kWh/kWp*** *(PVsyst estimation 1237 kWh/kWp)*

Abstract*: The plant is heavily affected by soiling. Some modules are shaded causing hotspots. Structural earthing is incomplete and corroded. The PV cables loosely hanging, poorly inter-connected, and with low bending radius were found. It is recommended to (i) optimize cable layout, (ii) remove shading objects, (iii) retrofit the mounting structure, and (iv) install an irradiation sensor on the tilted plane to compute and check the Performance Ratio. The estimated production boost expected by the retrofitting actions lies between* ***14%*** *and* ***16%****.*

PV Plant's health

Main Findings

- Poor cable management: The minimum cable bending radius is not considered, no string labelling was found; and a non-standard way of connection string cable to module.

Figure 845: Bending radius not considered

- Non-standard cable selection for string wire.
- Non-conventional iron wire (corroded) used for earthing
- Modules within the same string have a different orientation.
- Modules' structure disregards the height of the parapet and nearby objects resulting in shading of the modules.

Figure 846: Design disregards building's parapet

- Bus bar corrosion/burn marks observed on some modules.
- No weather station was found on site.
- Filters of the inverters were found soiled.

Impact on Performance

- According to the simulation of the system, the self-shading and near shading losses account for up to 7.8% and 4.8%, respectively.
- The on-site measured soiling losses were estimated in 15.3% from IV curve measurements.
- IR analysis showed evidence of hot spots caused by near shading objects.

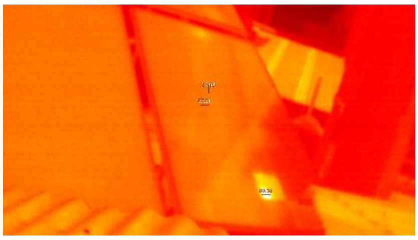


Figure 847: Hot spot in shaded module

- According to the number of cracks discovered via EL imaging; the system is not expected to have large power losses due to inactive areas.

Figure 848: Scratch and microcrack on cell

The underperformance of the measured modules is around 12.9%.

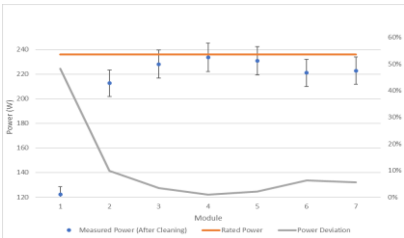


Figure 849: IV curve measurement results

Proposed Solutions

- The cleaning cycles shall be increased based on the results of a soiling study that adjusts the cleaning needs to each season.
- If possible, shading objects should be removed. Additionally, restringing of the modules in the shaded areas shall be conducted in the following way: modules with similar shading conditions shall be installed in the same string or MPPT.
- Include in the O&M practices the cleaning of the ventilation system of the inverters.
- A weather station, or at least an irradiation sensor on the module plane, shall be installed so to determine the performance of the system.
- The rusted elements of the grounding shall be substituted, and all the connections have to be done to the grounding hole of the module frame.
- Cables should be tied up among the substructure, have a minimum bending radius to avoid early damages, and have a suitable labelling.
- The tables with different orientation shall be aligned with the rest of the tables towards true south.

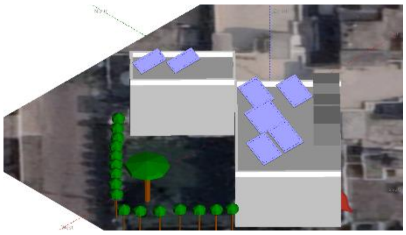


Figure 850: 3D model constructed in PVsyst

Estimated energy boost after conducting the suggested retrofitting actions: 14% to 16%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 3.88 ₹/Wp, 0.30 ₹/Wp/a
Estimated retrofit cost per additional generation for remaining lifetime: 3.1 ₹/kWh to 2.7 ₹/kWh

Picture Gallery

Figure 851: Shaded module with hot spot

Figure 852: Evidence of self-shading

Figure 853: High degree of soiling

Figure 854: Burnt busbar

Figure 855: Non-conventional structural earthing

Figure 856: Inverter filters soiled

Figure 857: Different azimuth orientation

Figure 858: Poor cable management

61

PV plant: ***II.61***
Nominal capacity: ***120.01 kWp***
Average specific yield: ***1215.5 kWh/kWp*** *(PVsyst estimation 1389 kWh/kWp)*

Abstract**: Cable connectors severely soiled and deformed. Damaged modules were found on site. Several modules are shaded. It is recommended to (i) investigate isolation issues in the system, (ii) replace damaged modules, (iii) retrofit the mounting structure, (iv) re-sort different power class and lower performing modules, (v) re-string shaded modules, and (vi) install a weather station or at least an irradiation sensor on the module plane to quantify and monitor the performance ratio. The estimated production boost expected by the retrofitting actions is expected to be around* ***5.4% to 12.5%.

PV Plant's health

Main Findings

- Cable management: Connectors deformed and soiled.

Figure 859: Cable layout.

- One of the inverters found to have faulty fan and isolation issues.
- Modules with paint remains stuck on module, solder flux over cell, and damaged frame observed on site.
- Module-to-module bonding missing.
- Module tables installed in roof edges without parapet walls in high wind zones.
- Modules of different power class and manufacture year found in the same string.
- Purlin and module sagging observed due to uneven ballast block placement. The vertical posts are not parallel to each other.
- Nuts and bolts used in the structure are rusted.
- Modules are shaded due to varying table configurations, trees, safety railings, and shed roofs.

Figure 860: Module shading by taller roof.

Impact on Performance

- The system performance was affected by soiling loss of 2.4%, estimated from IV curve measurements. Some modules were severely soiled from cementing.
- IR analysis indicates hot cells from cementing which may cause permanent cell damage.

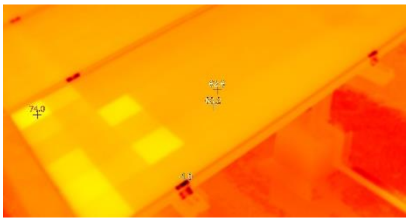


Figure 861: Defects from IR imaging.

- The EL image reveals presence of cracks, isolated cell parts and dark cells. These defects are expected to impact performance and generate hotspots.

Figure 862: Defects from EL imaging.

- Based on the IV curve measurements, the estimated underperformance is 6.1% for the measured modules.

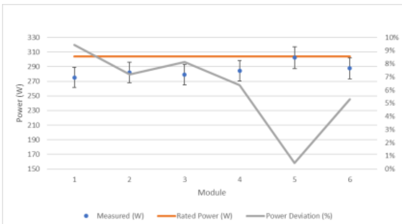


Figure 863: IV curve measurement results.

- According to PVsyst simulation, the near shading losses account to 2.11%.

Proposed Solutions

- Deformed and degraded connectors shall be replaced.
- Faulty components in the inverters shall be replaced. A root-cause-analysis shall be conducted to investigate and rectify isolation problem.
- Modules with stuck paint remains, solder flux remains, isolated cell parts, and damaged frame shall be replaced as they pose performance and safety threat.
- Module tables installed in roof edges shall either be relocated to reduce wind loads.
- A re-sorting shall be conducted to have the modules with same power class and lower performing modules in the same string at least same MPPT, dedicated for each case.
- A re-stringing shall be conducted to have shaded modules in the same string or at least same MPPT.
- A weather station, or at least an irradiation sensor on the module plane shall be installed.
- Rusted components should be replaced if possible. To prevent such problems, metal objects vulnerable to corrosion can be painted with zinc. Ballast blocks shall be replaced to reduce purlin sagging and vertical posts shall be realigned and fixed.

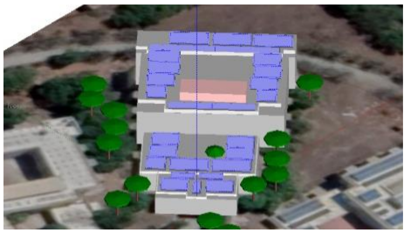


Figure 864: 3D model constructed in PVsyst.

Estimated energy boost after conducting the suggested retrofitting actions: 5.4% to 12.5%
Estimated costs of proposed retrofitting actions (CAPEX, OPEX): 1.94 ₹/Wp, 0 ₹/Wp/a
Estimated retrofit cost per additional generation: 1.4 ₹/kWh to 0.6 ₹/kWh

Picture Gallery

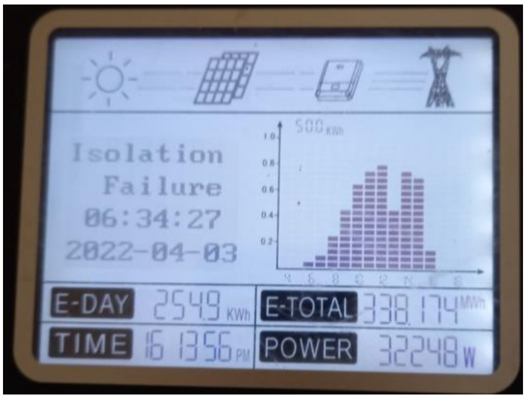


Figure 865: Isolation failure in an inverter.

Figure 866: Paint remains stuck on glass.

Figure 867: Missing module to module bonding.

Figure 868: Tables in high wind zones.

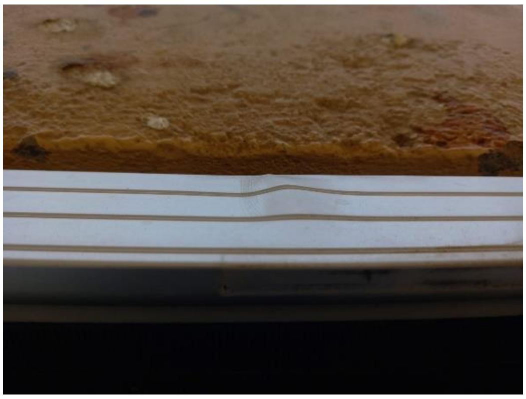


Figure 869: Bent frame.

Figure 870: Shading by safety railings.

Figure 871: Shading by tree.

Figure 872: Varying table orientations in same area.

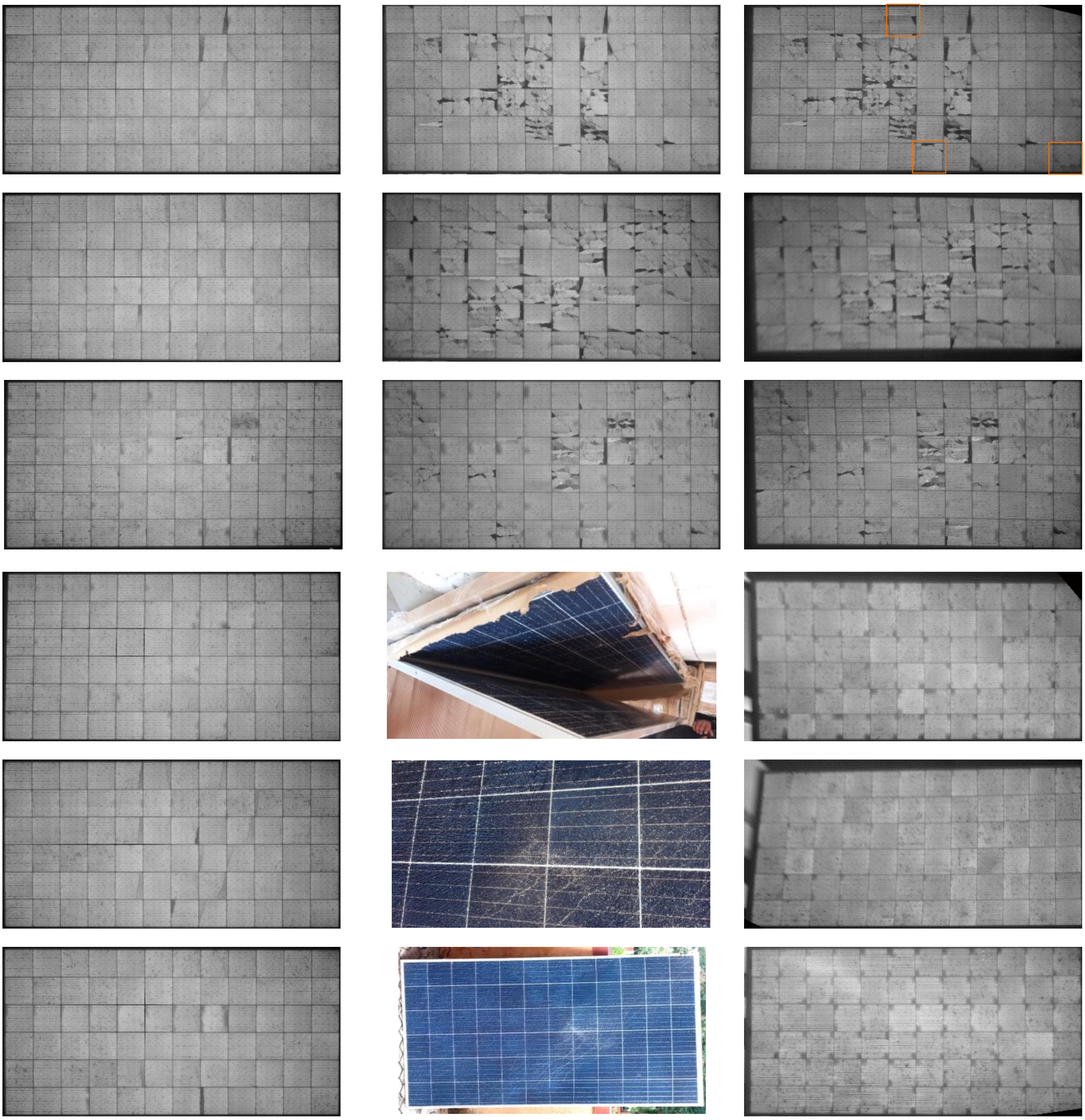
62

*PV plant: **II.62***
Nominal capacity: 2kWp

PV Plant's health

***Abstract**: The purpose was the evaluation of crack evolution from warehouse (pre-dispatch) until instalation. The number and type of cracks will likely increase the probability of underperformance. Furthermore, if the cracks develop further, they could degrade into hotspots an become a safety issue. Yearly infrared thermography is recommended for the latter.*

PV port pre-dispatch inspection | **Before Installation** | **After installation**



The assessment mainly describes anomalies likely as result of mechanical stress due to transportation and handling malpractices. Although from the pictures after installation (compared against pre-installation) it can be established that the installation did not worsen the modules, from the industry standard point of view, the modules under test do not pass a typical EL evaluation for construction (post-installation inspection). Furthermore, from the 2kWp planned (6 modules) the number of broken modules (3 units) represents a major issue in the quality control of the PV plant components.

63

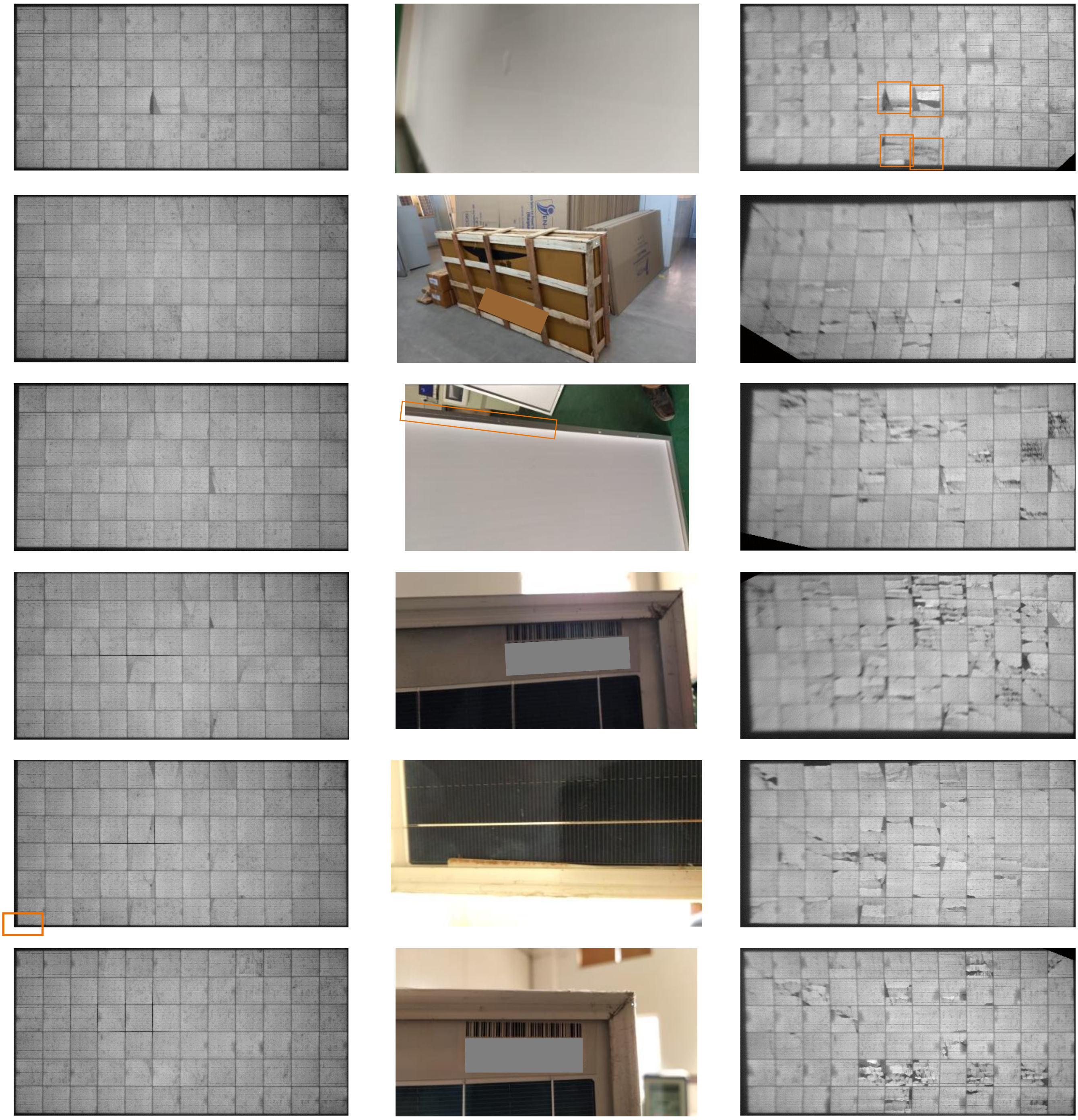
PV plant: ***II.63***

Nominal capacity: 2kWp

PV Plant's health

***Abstract**: The assessment mainly describes anomalies likely as result of mechanical stress due to transporation and handling malpractices. Micro-cracks could be produced by low resonance frequency during road transportation: diagonal cracks, parallel to busbars crack, perpendicular to busbars crack and branched cracks. Branched cracks are more likely to produce underperformance in the mid-term when the cracked areas become*

PV port pre-dispatch inspection (EL) | **Before Installation (Visual inspection)** | **After installation (EL)**



For this site, about 50% of the modules at the warehouse would already fail the PV port pre-dispatch inspection due to the type and distribution of the cracks. During the project, the consortium approached and requested the support of the Module manufacturer several times. The idea was the evaluation of the module quality throughout the entire supply chain (Manufacturing to installation). Unfortunately, the absence of after sales support from manufacturers limits development and confidence in local industry, creating a vicious circle.

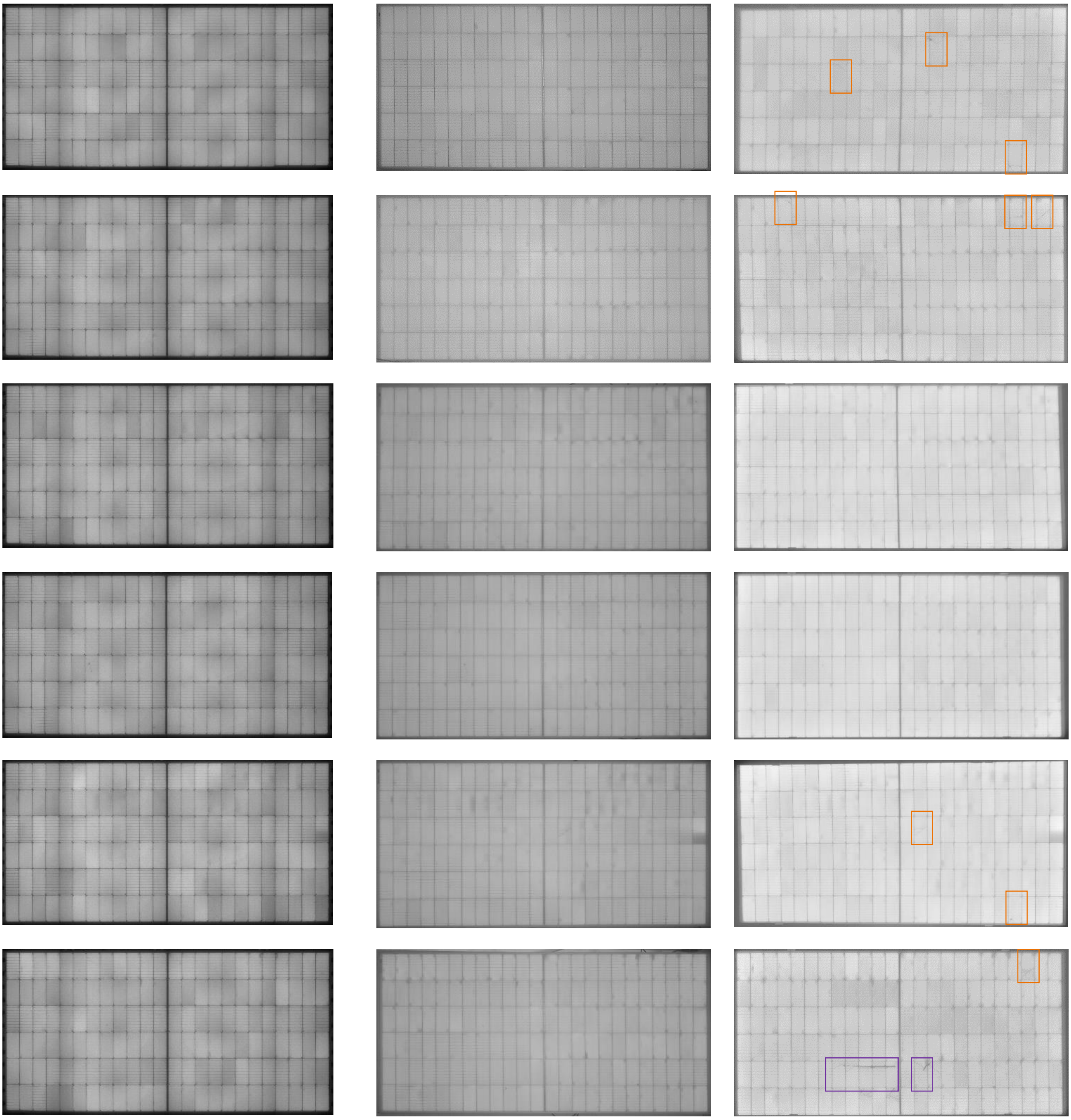
64

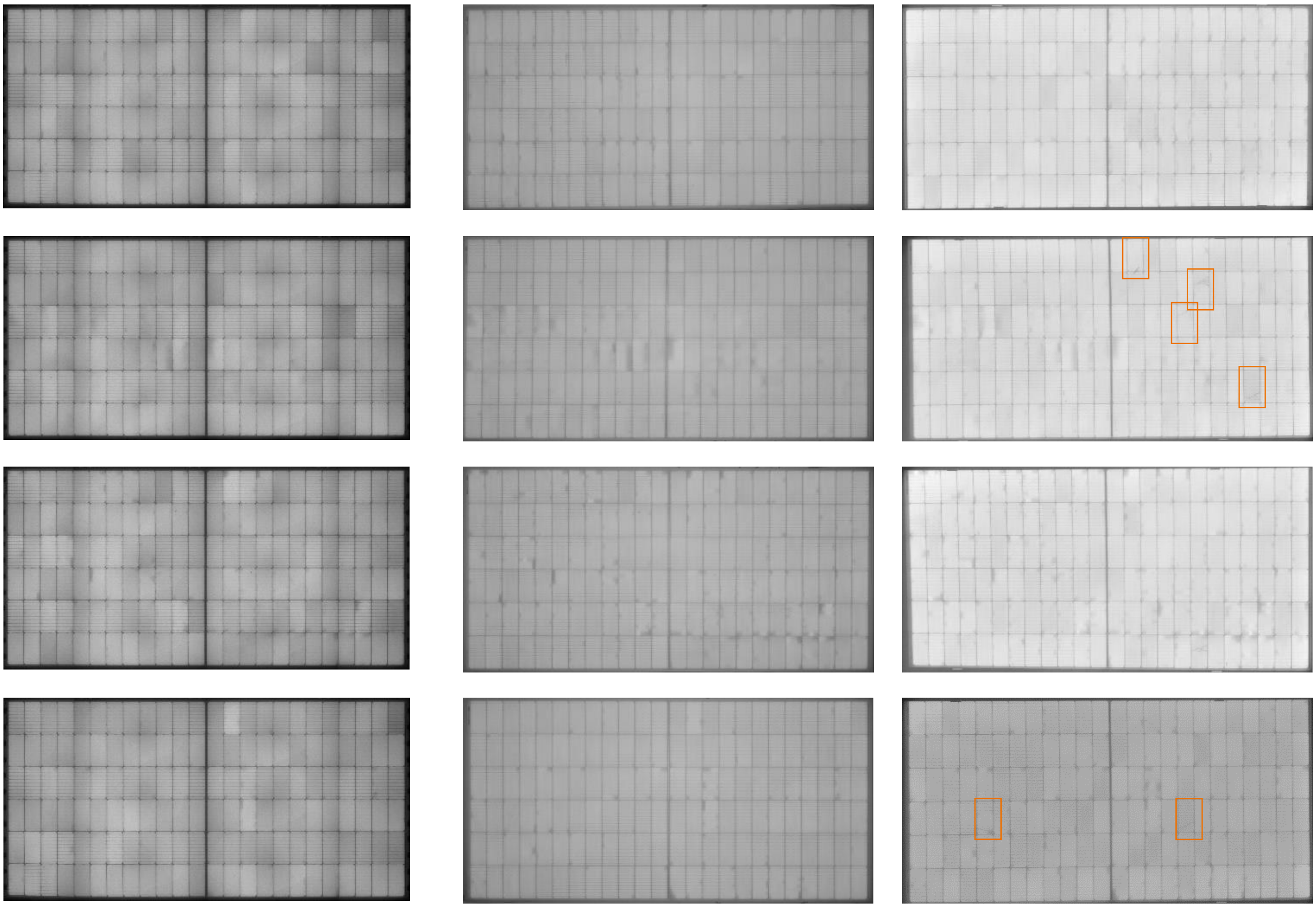
PV plant: ***II.64***
Nominal capacity: 33kWp

Abstract*: The purpose was the evaluation of crack evolution from manufaturing until instalation. PV Module damages are often a result of shipping on fragile wood pallets and boxes with partial loads. Similarly, module handling, transport and installation are important sources of module damages. Futhermore, new technologies (i.e., Half-cut cells, Tiling Ribbon Technology, M10, M12 cell sizes, etc.) have also brought new sources of cracking.*

PV Plant's health

Manufacturing EL	Before Installation EL	After installation EL





PV Module damages are often due to shipping on fragile wood pallets and boxes with partial loads. Similarly, module handling, transport and installation are important sources of module damages. Hence, the purpose was the evaluation of crack evolution from manufaturing until instalation. As common practice, the installers/EPC should always follow PV Module manfuacturing guidelines for transportation, installation and handling, as well as PV industry best practices.

Onsite site conditions for access and module handling

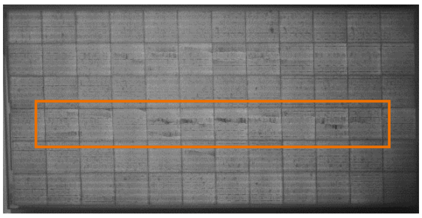
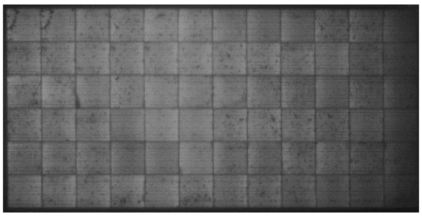
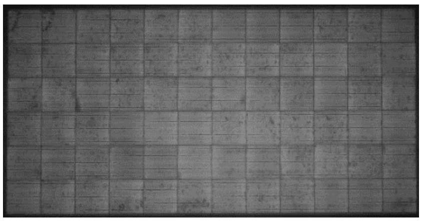
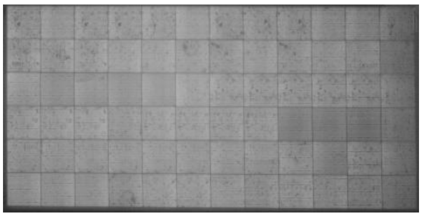
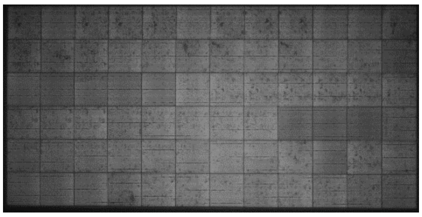
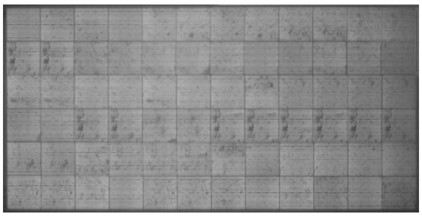
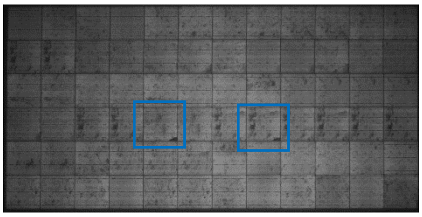
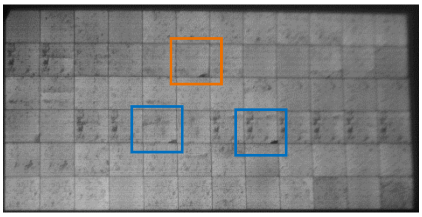
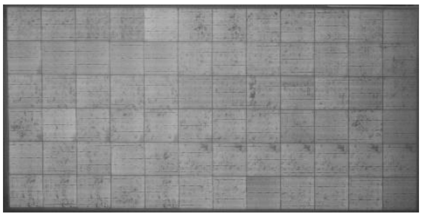
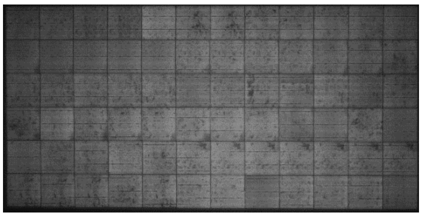
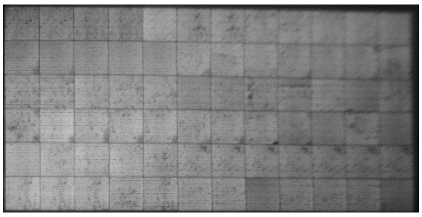
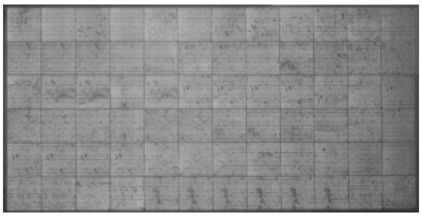
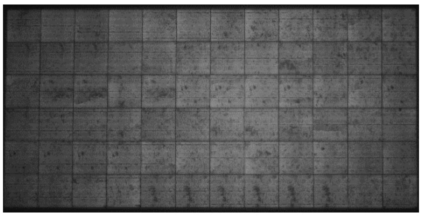
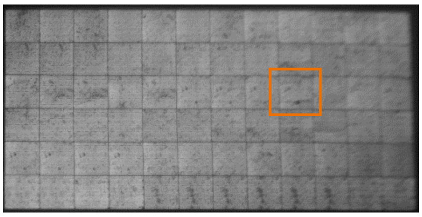
New technologies (i.e., Half-cut cells, Tiling Ribbon Technology, M10, M12 cell sizes, etc.) have also brought new sources of cracking, (interconnect ribbons for 9+ Busbars, manual solar cell soldering, lamination for certain EVA films with weak moisture impermeability). Although EL criteria varies throughout the industry, the number of cracks allowed during manufacturing (pre-shipment) is very often limited to 1 and even to zero, when the crack length ≤1/2 of full cell length; and or the crack size M10 ≤ 5% of cell area.
Based on the findings above, an initial retrofitting action could be to monitor the cracks via yearly infrared inspection. In case of an accelerated cracking degradation rate, an option could be the redistribution of the modules in strings with similar level of cracking. This could potentially reduce the impact of mismatch losses in the system.

65

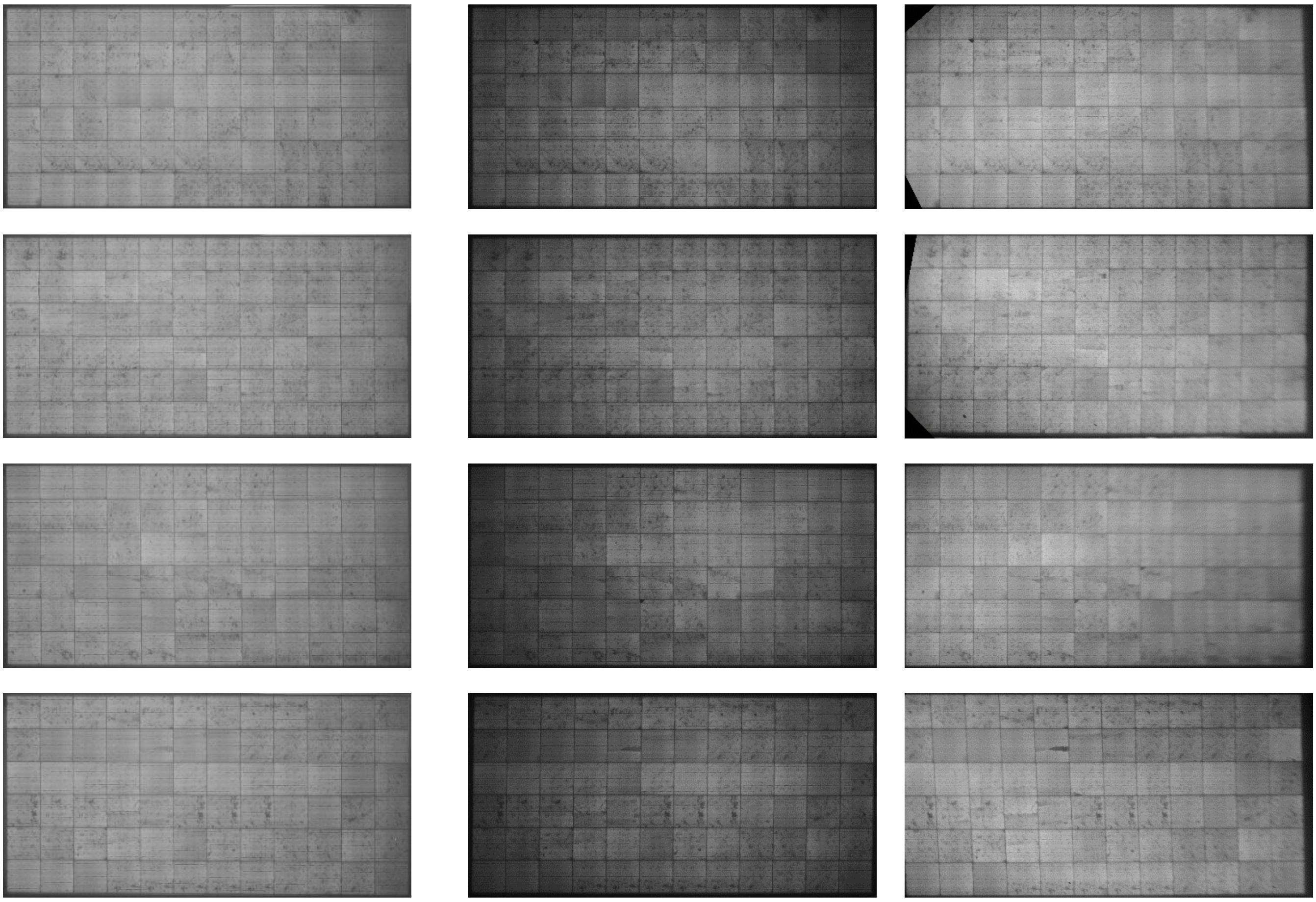
PV plant: ***II.65***
Nominal capacity: 5kWp

PV Plant's health

Abstract*: The scope of this assessment was the evaluation of module transportation, handling and delivery practices, from warehouse until installation. Although from the pictures after installation it could appear that the logistics did not worsen the modules, from the industry standard point of view, the modules already show significant cracks which could hindern the long-term performance and likely void module warranties.*

Warehouse	Before Installation	After installation
	N/A Module failed at warehouse (pre-dispatch inspection)	N/A
		N/A
		N/A
		
		
		

According to multiples studies in the matter, vertical module is safer than horizontal from vibration commonly experienced from road transport due to that the stiffness of glass is more incline to induce large vibration. Packaging type may lead to different distribution of cracks on PV-module. Moreover, a market with low margins pushes manufactures and retailers to save in additional packaging and logistics.



Even though transportation issues are known within the industry (cracks, scratches, broken glass), they are still a nuisance in project development, particularly during transportation

Onsite site conditions for access and module handling. Furthermore, PPE and H&S practices disregarded.

For this site, MCIND team had to come up with additional safety measures to perform the after-installation inspection on the modules, as the installer did not consider and/or enable a safe access to the rooftop, i.e., temporary metal staircase, crane, walkaway, etc.

During installation, the technical advisor would normally provide oversight of the installation of the modules and testing on a quantity of installed modules (VI and EL) and mounting structure (VI) to verify the quality of the installation work, including but not limited to: PV Module Handling & Storage and PV Module Mounting (EPC, different crews). Quality criteria defined in the supply agreement is normally used, unless specified otherwise. PV Modules with critical defects are to be replaced after inspection by the owner/constructor, according to contractual criteria (with replacement modules being inspected under the same criteria).

8. Lessons Learned and Outlook for the Next Generation Projects

The results of the evaluation of each of the 30 PV plants exposed in the previous section, will be used in this chapter to shed some light on three fundamental questions.

8. 1. Which findings arise more often, and which have the highest impact on the performance?

The following chart shows the top findings detected on-site having a negative impact on the performance of the analyzed PV plants. The number at each bar shows in how many PV plants each finding was present.

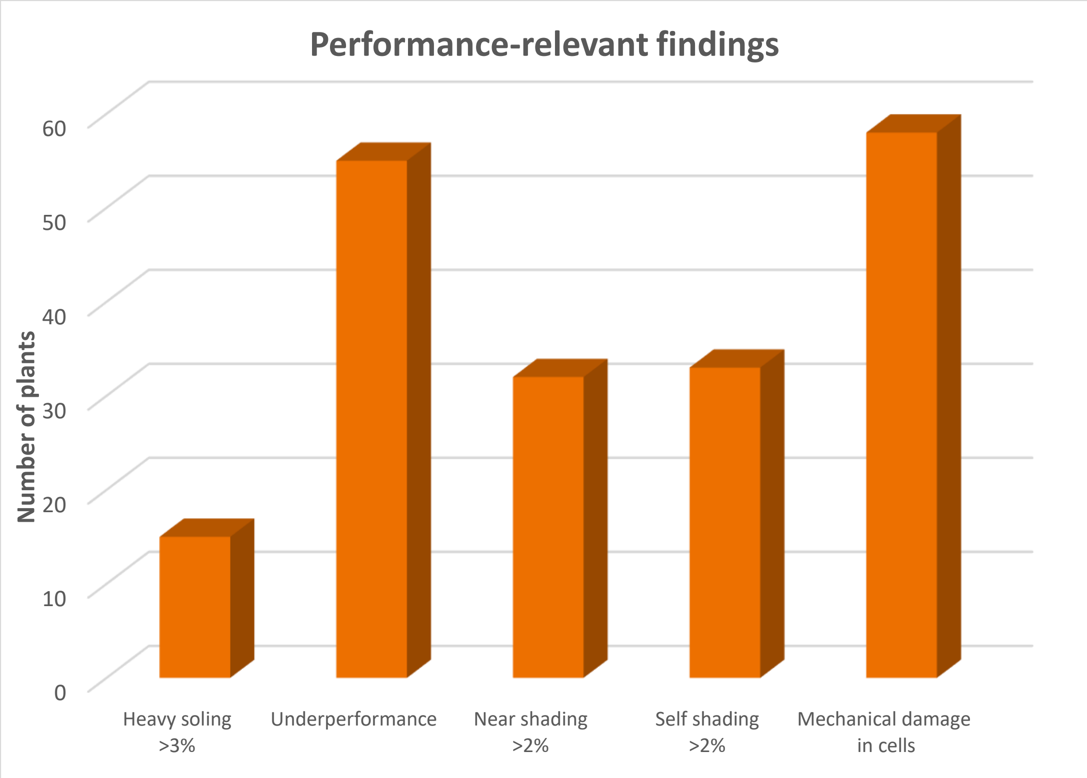


Figure 873: Chart showing occurrence of relevant findings across inspected plants.

It can be seen that *underperformance* appears in around 93% of the inspected in-service plants. *Mechanical damages in cells,* which is related to the electromechanical integrity of the modules, is a defect that also appears in virtually all the sites, and it is highly likely caused by improper module handling, during the installation and operation phase[4].

[4] *Walking and stepping on the modules also contribute to the appearance of cell damages*

In regard to underperforming systems, modules with power performance considerably under the expected values[5] were discovered in every PV plant. This issue shall be further addressed in cooperation with the developer, installer (EPC) and/or module manufacturer, and, when applicable (according to the specific installation contracts and the guarantees included), initiate the adequate claim.

The low performance of the inspected PV plants is caused by a mix of (i) heavy soiling, (ii) near shading and (iii) high module degradation rates.

As described in chapter 7, the access to many of the sites might have compromised the integrity of the cells within the PV modules. Although some product failures might not be performance-relevant now, i.e., deformed J-boxes, they will likely become relevant when, for example, the diodes breakdown due to environmental exposure, ultimately leading to open-circuit strings.

Most PV plants show certain degree of soiling. Despite some of them have a cleaning program scheduled, poor cleaning tools or the lack of them were found during the site visits. The degree of soiling was estimated by performing IV-curve measurements before and after cleaning of the modules and comparing how the maximum power increases after the cleaning. Heavy soiling is considered when the latter measurement shows a power increase larger than 3% of the first measurement. Additionally, most of the sites with no or minimal soiling also displayed signs of module cementing, were the soil remains on the module edges which are missed during cleaning activities harden and form a layer on the module corners. This causes hotspots (as revealed in the IR findings) due to shading by the soil layer, which in turn causes permanent cell damage in the long run.

Snail trails were found in some of the plants inspected. The degradation is not in an advanced stage, but these in combination with soiling and shading issues could lead to hotspots. It should be periodically monitored and evaluated via infrared inspection whether the snail trails have reached stabilization.

Another aspect that also contributes to the loss of energy production is an operation and maintenance plan below market standards. Specifically, the lack of spare parts on site coupled with relaxed reaction times are two aspects that directly result in loss of performance and availability, and therefore, underperformance. None of the PV plants had properly installed weather stations, spare parts on-site, and moreover, no written agreement setting the contractual reaction times.

[5] The power is corrected taking into account the light induced degradation and yearly natural degradation, according to the number of years in operation, flash-lists (when available) and label values.

The absence of O&M contracts stating clear procedures for the corrective maintenance plan, the reaction times, the Performance Ratio monitoring, and the contractual availability values, is a key factor that contributes decisively to lowering the PV plant's output.

The following graph shows highest impacts on the performance from the aforementioned findings of the inspected PV plants. The graph also indicates the maximum energy loss values associated to each of these findings[6].

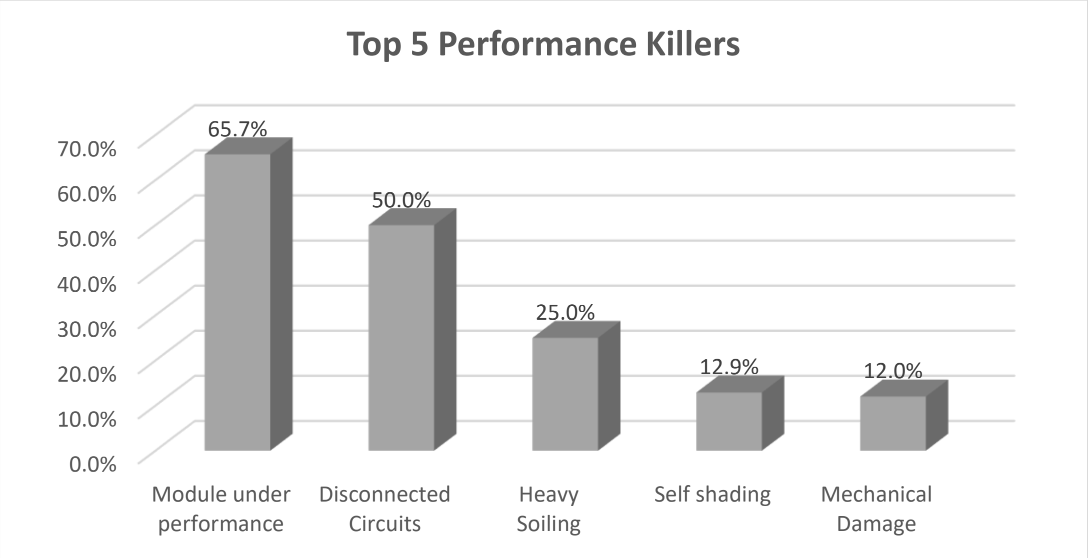


Figure 874: Top 5 findings with the highest performance impact on the inspected PV plants

As shown in the graph, underperforming modules (due to higher degradation rates and possibly early stage of Potential Induced Degradation) could lead to a yield loss of 15% at the system level. This rapid degradation could be explained by a PID sensitivity of the PV cells in the installed modules, in combination to the typical hot and humidity conditions. The presence of bird droppings, debris, or pollution, result in soiling losses as high as 25% for some of the systems. In this regard, it is important to understand that some PV plants visited by PI Berlin underwent cleaning activities a few days before the inspection. Hence, the values measured on-site by PI Berlin can be greatly exceeded if cleaning activities are disregarded, particularly during the dry season.

[6] *These values have been calculated by PI Berlin through (i) estimates based on PI Berlin's long-term experience, (ii) 3D simulation, (ii) processing of data obtained directly on site by means of special equipment.*

According to PI Berlin's calculations, the global losses at the system level caused by underperformance could exceed 15%, while the losses associated with soiling can widely exceed 20% during the dry season.

One of the plants was found with a malfunctioning inverter, which led to a loss of an entire section of the system, accounting to roughly 50%. The repair of said inverter, if possible, or its replacement, offers one of the simplest opportunities to boost the energy production of the affected plants.

During PI Berlin's visits to the power plants, some parts of the plants were found disconnected, generating losses as big as 50% due to a malfunctioning inverter in one of the sites.

The maximum losses caused by near shading are estimated to be close to 8%. Although it may give the impression that these losses are difficult to avoid since they are a consequence of near buildings, rooftop objects and vegetation, a proper site assessment prior installation would have probably reduced these issues. However, self-shading is a finding that was estimated to generate higher losses. One of the plants presented losses around 13% due to self-shading. Both issues should have been properly addressed during the design phase, since after the installation only mitigation actions can be implemented. Furthermore, shading losses caused by trees can only be reduced in case the trimming is allowed by the authorities. Finally, the losses associated with mechanical damage of cells can reduce the production of some PV plants in 9-12% according to PI Berlin's estimations.

According to PI Berlin's estimations, while in some of the inspected PV plants the losses caused by near shading are close to 8%, the self shading losses range up tp 13%. In PV plants with severe mechanical damage at the module level, the nominal power of the PV plant can be reduced by up to 12%.

Worldwide, PV manufacturers have developed advanced production and inspection techniques to ensure that the "dispatched modules" have a limited amount of product failures, such as microcracks. Moreover, PI Berlin' long-term experience in the matter indicates that most of the *mechanical stress induced cracks* occur during handling and module installation, as well as during O&M activities. However, the assessment of cracks in operating PV modules is not an easy task since the crack distribution will not certainly lead to a homogenous power degradation. Additionally, since the warranties[7] offered by the installation company are limited to the product and do not include workmanship, the module damages from mishandling during the installation remain contractually uncovered.

8. 2. Mounting structure

Mounting structures are used to support photovoltaic modules. Since PV modules are built to last for 20-25 years, it is very important to choose an adequate, robust, and technically simple module mounting structure that will be able to support the solar PV module for 25 years. The most representative issues found during the inspection are shown in the list below, as well as the proper retrofitting actions to i) reduce the risk of further development of the issue and/or ii) minimize the impact of the issue.

a) Flat Roof Sites

- **Issues Observed:**
  a. Major structural components like columns, rafters, purlins are corroded.
  b. Fasteners are found to be corroded at many places.
  c. Overhanging of structure beyond the roof limits
  d. Improper design of structure in terms of component sections used
  e. Structure starts to corrode from foundation side due to capillary effect from water saturation on the roof

- **Retrofitting actions:**
  a. Regular inspection of the structure needs to be done.
  b. Fasteners needs to be checked for sufficient torque or tightness on regular basis and should be a part of O&M activities.
  c. Corroded fasteners to be replaced immediately with Stainless Steel Fasteners to avoid any corrosion in future.
  d. Apply of Zinc sprays over the rusted/ corroded part to be done on regular intervals of approx. 1~2years depending on the inspection.
  e. Missing components should be installed immediately.
  f. Foundation should be painted with waterproof material paint to avoid any capillary action resulting in corrosion of structure
  g. Earthing of mounting structure and modules should be done immediately, when not present

b) Metal Sheds

- **Issues Observed:**
  a. Steel GI components are used for mounting of structure

[7] *In some cases, the EPC warranty has also expired without a Final Acceptance Test or proper commissioning.*

b. No proper gap is provided between module and metal sheet roof during selection of mounting structure
c. No Walkways or Safety lines provided for O&M activities
d. Orientation of modules kept same as metal sheet orientation.

- **Retrofitting actions:**

a. Inspection of structure to check the corrosion should be done.
b. Inspection should be done to check the bending of metal sheet due to weight of GI structure should be done.
c. Walkways & Safety lines should be installed.

8. 3. Which retrofitting solutions can be implemented to boost the energy production of the inspected PV plants?

These 15 PV plants exposed some of the most common failure modes, not only in the Indian market, but worldwide. PI Berlin suggests 5 retrofitting actions to partially mitigate the negative consequences of the findings described in the previous section. The most important actions associated to these retrofitting actions are described below:

- **Improvement of module cleaning frequency**. The source of soiling in most of the inspected PV plants is either bird droppings, city pollution, debris, or a combination of all three. In order to figure out what the optimum cleaning interval is, the output of clean[8] and dirty strings shall be compared for at least 3 months. As soon as the difference in the output leads to a loss of revenue that offsets the cleaning costs of the whole plant, a cleaning visit will be needed. This study will be performed separately for the dry and rainy season, as natural cleaning comes into place in the rainy months. Cleaning becomes particularly relevant in those plants where the modules are mounted with very flat angles.

- **Re-sorting of modules and strings**. A re-sorting of the modules shall be conducted in those cases where the present configuration leads to significant mismatch at inverter level or to low output currents of some strings due to the low performance of individual modules. Modules affected by heavy cracks with isolated cell sections that induce hotspots, shall be grouped in the same strings. In those cases where the output voltage of low performing strings significantly affects the string voltage, "good" and "bad" strings shall be assigned to different MPP trackers. The distinction between good and bad strings and between damaged and not damaged modules can be conducted with a multimeter and an infrared camera respectively. The infrared inspection shall be conducted after cleaning and at irradiation values higher than 800W/m².

- **Module replacement**. The replacement of the modules should only be carried out if the cost of the components is borne by the manufacturer. This case will only occur (i) if the manufacturer still exists, (ii) if the reasons why the replacement is required are due to product defects or a loss of performance higher than the guaranteed values, and (iii) if the warranties are still active. The manufacturer's warranties do not cover damages caused by bad handling or improper installation and poor O&M practices.

- **Increase of the albedo factor**. A possible alternative to extra-boosting the yield is to paint the surface with light colors, cover the ground with white gravel and/or stick reflective materials to the walls and shading objects surrounding the PV modules. These measures aim at increasing the overall albedo factor to 0.5 and thus, the amount of kWh/m² reaching the PV module plane of array. Glaring of neighboring buildings shall be avoided.

- **Understanding and follow up** of Module transportation, installation and handling guidelines and industry best practices.

[8] *The clean strings are used as a benchmark and will be cleaned every day.*

Depending on the status of each PV plant, and as long as the future O&M contractor has sufficient personnel and budget, all or only some of the abovementioned measures can be applied. In any case, the measures proposed by PI Berlin do not imply huge investments and can be implemented with a reasonable budget. The measures suggested by PI Berlin must be complemented with a reinforcement of the commercial conditions in the O&M contracts, mainly in regard to (i) the reduction of the reaction times and (ii) the storage of spare parts needed to commit to the said reaction times.

PI Berlin suggests 4 retrofitting actions that depending on the status of each PV plant may lead to a performance boost between 5% and 35%. Furthermore, these actions do not require large investments in the OPEX.

Besides the retrofitting actions suggested to increase the energy generation, any necessary improvements to operate the PV plants in a safe environment shall also be carried out.

These safety improvements shall be conducted regardless how high or small the estimated performance boost is[9].

8. 4. Which mechanisms are needed to avoid underperformance and to ensure the revenues in the next generation projects?

Problems caused by wrong decisions taken during the design phase can only be partially solved during the operational phase. Therefore, preventive measures shall be applied in order to save costs and time at later stages. PI Berlin makes the following suggestions based on the issues and findings detected during the assessment of the 10 PV plants:

1. An energy yield assessment shall be conducted during the development phase. That said, it shall consider all shading objects that might have an impact on the system performance. This will help to avoid overestimations of the yearly output and an inaccurate modelling of the cash flows.
2. Where near shadings seem to pose a significant impact in the energy production, module strings shall be sized with less modules and they shall be grouped accordingly. Near shading losses higher than 5% shall be avoided.
3. Self-shading between rows shall be kept as low as possible. Lower tilt angles help achieving this goal.
4. The PV plants shall not deviate more than 30° from true South. Aligning the PV plant´s layout to the orientation of the building is not always the optimal solution.
5. All PV plants shall be *commissioned* before handover, according to the industrial best practices. These practices shall include, besides all safety tests specified in the IEC 62446, a PR test of at least 5 days and an infrared inspection of 100% of the PV modules,

[9] An example of this is the installation of a safety lifeline (when applicable) or the replacement of damaged cables and modules (from broken Jbox or glass).

inverters, and cables. The reliability of the SCADA system and the weather station shall be evaluated as well.

6. In case of lack of experience, the installation and O&M teams shall be trained to avoid damages on the PV modules, during daily activities regarding
    a. Awareness of the impact of advanced cell cracking.
    b. Awareness of the existence of *Module transportation, installation and handling guidelines and best practices*, often directly created and distributed by Module manufacturers.
    c. Use of Personal Protective Equipment
    d. PV plant design considering adequate site access for the delivery of Modules. When the access cannot be guaranteed, rather early in the project a crane should be budgeted as part of the installation equipment.
    e. In the event of additional transportation, the repacking should comply manufacturer guidelines. This includes the activities by shipping companies.
    f. If possible, plant owners/developers should request to manufacturers the installation of "shockwatch" sensors.
7. The O&M contracts shall include clear indications on the expected reaction times, intervention plan during corrective maintenance, preventive maintenance plan, spare part management, reporting, contractual availability values and SCADA visualization. These topics shall be tailor made to the needs of each individual PV plant.[10]
8. The module cleaning frequency shall be adjusted after the first year based on the methodology described in chapter 8.2.
9. The EPC contract shall include dedicated sections describing the best practices for installation and commissioning activities, as well as the *pass and fail* criteria for handover, with its associated penalties.[11]
10. Each PV plant shall include a weather station with at least (i) one irradiation sensor on the tilted plane (GTI), (ii) one ambient temperature sensor and (iii) one module temperature sensor. All sensors shall be properly installed according to the manufacturer's requirements. The irradiation sensor shall be calibrated, at least, every 2 years. It shall be kept clean and at the right tilt, in order to ensure an accurate and representative PR calculation.

Examples of best practices to improve logistic activities

[10] *This recommendation may be difficult to implement for small rooftop systems*
[11] *This recommendation may be difficult to implement for small rooftop systems*

Literature and References

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[5] "Influence of micro cracks in multi-crystalline silicon solar cells on the reliability of pv modules"; Grunow P. et al.; 20th European Photovoltaic Solar Energy Conference, 6 –10 June 2005, Barcelona, Spain.

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Annex I – Online portal

- Digital Twins

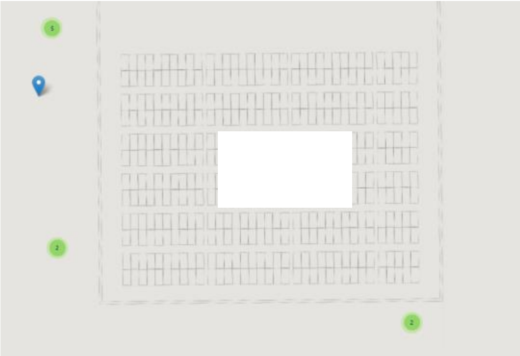


Figure 875: II.8

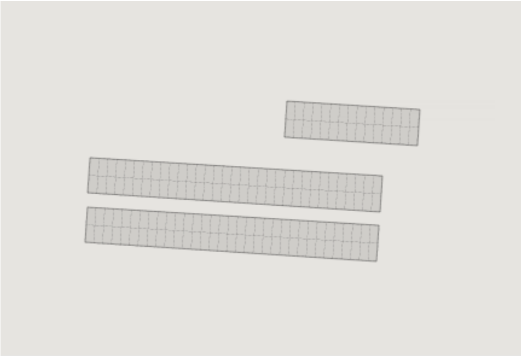


Figure 876: II.13

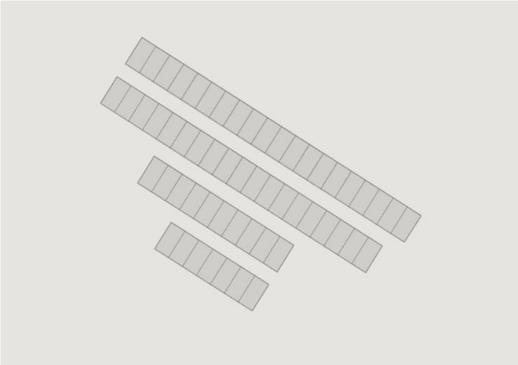


Figure 877: II.15

Figure 878: II.7

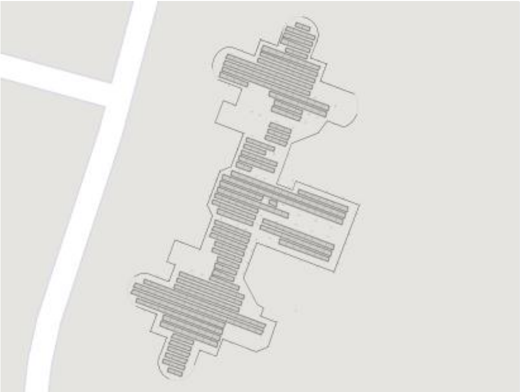
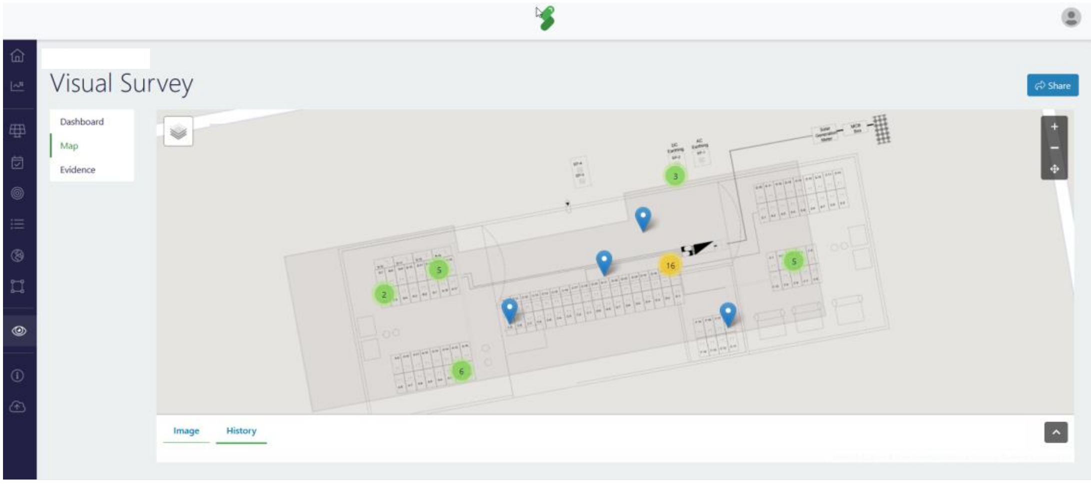


Figure 879: II.14

- Geo-localized inspection

Geolocation is a technique that uses data collected from a computer or mobile device to identify or characterize the user's real physical location. The advantage of this system is the reduction of the fallibility of the human operation, as well as time minimization for data processing and reporting.



- Eyesite App:

A purpose-built smart application that empowers the inspection teams to conduct site inspections using a mobile or tablet. Above's EyeSite Inspections tool accelerates ground-based data collection and processing times by systematically capturing, collating and storing inspection data within the SolarGain platform.

Even though the application of such IT system is focused on large scale system, with a economy of scale the use on C&I system could be considered for asset management companies. The idea is to consolidate all the field data in one platform to track the performance of the plant during the project lifetime, i.e., yearly inspections.

Annex II – Documentation required from the Rooftop Owners

Required Documents		Description	Available		Comments Owner
			yes	no	
1	**GENERAL ASPECTS**				
1.1	Customer name				
2	**RELEVANT DOCUMENTS DURING THE DEVELOPMENT PHASE**				
2.1	Yield assessment				
3	CONTRACTS				
3.1	O&M contract				
3.2	EPC contract				
4	**COMPONENTS**				
4.1	PV Module				
4.1.1	Number of modules				
4.1.2	Datasheet				
4.1.3	Warranty documentation				
4.1.4	Flash-lists				
4.2	Mounting structure				
4.2.1	Technical description				
4.2.2	Sectional drawings of the module-tables/structure				
4.3	Inverter				
4.3.1	Number of inverters				
4.3.2	Warranty documentation				
4.3.3	Datasheet				
4.4	Combiner boxes				
4.4.1	Drawings				
4.4.1	Datasheets				
4.5	Monitoring system (SCADA)				
4.5.1	Remote access to SCADA system				
4.5.2	Datasheets of the weather sensors				
5	**DESIGN**				
5.1	Exact module and inverter location (if possible as CAD drawings as well)				
5.2	Location of combiner boxes in the field				
5.3	Number of strings				
5.4	Single line diagram				
6	**INSTALLATION**				
6.1	Installation date and grid connection date				
6.2	Location of the installed sensors				
6.3	As-built layout				
7	**COMMISSIONING**				
7.1	Commissioning protocols				
8	**PERFORMANCE**				
8.1	Internal or external reports				
8.2	Irradiation and temperature data on hourly basis since COD				
9	**O&M**				
9.1	Monthly operating reports or any other information collected since COD regarding the operational status of the plant				
9.2	Procedures for verifying correct system operation				
9.3	Preventive maintenance checklists				
9.4	Cleaning procedure				

Annex III – TDD Checklist

0	Category / Subcategory	Condition of item
0.1	Name of the PV plant	☆☆☆☆☆
0.2	Location	☆☆☆☆☆
0.3	Contact person	☆☆☆☆☆
0.4	Financing/ Stakeholders	☆☆☆☆☆
0.5	Owner's Engineer	☆☆☆☆☆
0.6	Lender's Technical Advisor	☆☆☆☆☆
0.7	EPC	☆☆☆☆☆
0.8	Site owner	☆☆☆☆☆
0.9	Energy Yield Assessment / P50	☆☆☆☆☆
1	**Contracts**	**Condition of item**
1.1	Warranties of the EPC contract (PAC and FAC)	☆☆☆☆☆
1.2	Warranties of the O&M contract	☆☆☆☆☆
1.3	Completeness of the PAC in the EPC contract	☆☆☆☆☆
2	**Design**	**Condition of item**
2.1	DC size	☆☆☆☆☆
2.2	AC size	☆☆☆☆☆
2.3	Level of injection	☆☆☆☆☆
2.4	Module type	☆☆☆☆☆
2.5	Module technology	☆☆☆☆☆
2.6	Size of each PCU	☆☆☆☆☆
2.7	Inverter type	☆☆☆☆☆
2.8	Inverter size	☆☆☆☆☆
2.9	Pitch	☆☆☆☆☆
2.10	Tilt of the modules	☆☆☆☆☆
2.11	Mounting structure type	☆☆☆☆☆
2.12	Module arrangement	☆☆☆☆☆
2.13	Location of the inverters	☆☆☆☆☆
2.14	Grounding / Equipotential bonding system	☆☆☆☆☆
2.15	Functional grounding (if available)	☆☆☆☆☆
3	**Electromechanical installation**	**Condition of item**
3.1	**Mounting structure**	
3.1.1	Mounted panel orientation	☆☆☆☆☆
3.1.2	Structure configuration	☆☆☆☆☆
3.1.3	Mounting structure assembly	☆☆☆☆☆
3.1.4	Mounting structure material	☆☆☆☆☆
3.1.5	Material Grade	☆☆☆☆☆
3.1.6	Type of Material for HDG structure	☆☆☆☆☆
3.1.7	Galvanization thickness (mm)	☆☆☆☆☆
3.1.8	Fasteners of structure & module	☆☆☆☆☆
3.1.9	Rust on mounting structure or fasteners	☆☆☆☆☆
3.1.10	Labeling of rows	☆☆☆☆☆
3.1.11	Mechanical defects	☆☆☆☆☆
3.1.12	Type of foundation	☆☆☆☆☆
3.1.13	Concrete grade	☆☆☆☆☆

3.1.14	Foundation distance	☆☆☆☆☆
3.1.15	Adhesive	☆☆☆☆☆
3.2	**Combiner box (CB)**	
3.2.1	General view	☆☆☆☆☆
3.2.2	Sealing of glands	☆☆☆☆☆
3.2.3	Cleanliness	☆☆☆☆☆
3.2.4	Overvoltage Protection	☆☆☆☆☆
3.2.5	Labeling of CB	☆☆☆☆☆
3.3	**DC cable management**	
3.3.1	Management and routing	☆☆☆☆☆
3.3.2	Labeling	☆☆☆☆☆
3.3.3	Connectors	☆☆☆☆☆
3.3.4	Fixation	☆☆☆☆☆
3.3.5	Bending radius	☆☆☆☆☆
3.3.6	Protection against UV	☆☆☆☆☆
3.3.7	Sealing of tubes	☆☆☆☆☆
3.3.8	Cable ducts	☆☆☆☆☆
3.4	**Inverter station**	
3.4.1	General view	☆☆☆☆☆
3.4.2	Overvoltage (when applicable)	☆☆☆☆☆
3.4.3	Cleanliness	☆☆☆☆☆
3.4.4	Proper cooling	☆☆☆☆☆
3.4.5	Status of filters	☆☆☆☆☆
3.5	**Civil work**	
3.5.1	Status of the roof	☆☆☆☆☆
3.5.2	Status of the drainage system	☆☆☆☆☆
3.5.3	Walls and foundations	☆☆☆☆☆
3.5.4	Surroundings	☆☆☆☆☆
3.6	**Documentation**	
3.6.1	As-built documentation	☆☆☆☆☆
3.6.2	Progress reports during installation phase	☆☆☆☆☆
4	**Commissioning**	**Condition of item**
4.1	Test conducted (PAC and FAC)	☆☆☆☆☆
4.2	Witness and validation (FAC and PAC)	☆☆☆☆☆
5	**System performance**	**Condition of item**
5.1	Irradiation: accurate sensor readings	☆☆☆☆☆
5.2	Temperature: accurate sensor readings	☆☆☆☆☆
5.3	Date of calibration of the sensors	☆☆☆☆☆
5.4	Weather station status	☆☆☆☆☆
5.5	Anemometer (Wind speed)	
5.6	PV plant "PR" since grid connection	☆☆☆☆☆
5.7	PR calculation	☆☆☆☆☆
5.8	Soiling loss	☆☆☆☆☆
5.9	Shadings	☆☆☆☆☆
5.10	Inverter unavailability	☆☆☆☆☆
5.11	Plant monitoring	☆☆☆☆☆

6	Module quality and performance	Condition of item
6.1	Visual inspection of panels	☆☆☆☆☆
6.2	Flash lists	☆☆☆☆☆
6.3	Scratches (Back-sheet)	☆☆☆☆☆
6.4	Underperforming PV modules	☆☆☆☆☆
6.5	Special certifications requested for the PV panels	☆☆☆☆☆
6.6	Special certifications requested for inverters	☆☆☆☆☆
6.7	Infrared inspection	☆☆☆☆☆
6.8	Electroluminescence	☆☆☆☆☆
6.9	IV Curve measurements	☆☆☆☆☆
7	**O&M**	**Condition of item**
7.1	Problems reported since COD	☆☆☆☆☆
7.2	Site environmental issues	☆☆☆☆☆
7.3	Experience of workers in PV	☆☆☆☆☆
7.4	Experience of workers in O&M	☆☆☆☆☆
7.5	Personnel on-site	☆☆☆☆☆
7.6	Personnel trained for LV/MV devices	☆☆☆☆☆
7.6	Spare parts on-site	☆☆☆☆☆
7.7	Health and safety program	☆☆☆☆☆
7.9	Soiling losses calculation	☆☆☆☆☆
7.1	Vegetation	☆☆☆☆☆
7.11	Tools and devices available	☆☆☆☆☆
7.12	Reporting	☆☆☆☆☆
7.13	Reaction times / Matrix	☆☆☆☆☆
7.14	Preventive maintenance	☆☆☆☆☆
7.15	Predictive maintenance	☆☆☆☆☆
7.16	Corrective maintenance	☆☆☆☆☆
7.17	Availability calculation	☆☆☆☆☆
7.18	SCADA system - responsible	☆☆☆☆☆
7.19	SCADA system - String level visualization	☆☆☆☆☆
7.20	Theft / Vandalism	☆☆☆☆☆
7.21	Curtailments	☆☆☆☆☆
7.22	Reactive power	☆☆☆☆☆
8	**Logistics**	**Condition of item**
8.1	SPV Module	☆☆☆☆☆
8.2	Inverter	☆☆☆☆☆
8.3	Mounting structure	☆☆☆☆☆
8.4	Other Components	☆☆☆☆☆
8.5	Damages during logistics	☆☆☆☆☆
9	**Handling / Construction**	**Condition of item**
9.1	Storage space availability	☆☆☆☆☆
9.2	Components storage	☆☆☆☆☆
9.3	Components stacked properly	☆☆☆☆☆
9.4	Safety strap	☆☆☆☆☆
9.5	Site access	☆☆☆☆☆
9.6	Damages due to handling	☆☆☆☆☆
9.7	Damages due to improper installation	☆☆☆☆☆

Annex IV – Measurement Equipment used on Site

[redacted], calibration date 07.10.2021, tolerance 5%]

[redacted] is a peak power measuring device and IV curve tracer that provides the measurement of the IV curve of photovoltaic modules and strings on site. Measurements of PV array IV characteristics under actual on-site conditions and their extrapolation to Standard Test Conditions (STC) can provide data on power rating, verification of installed array power performance relative to design specification, detection of possible differences between on-site module characteristics and laboratory or factory measurements, and detection of a possible performance degradation of module and arrays with respect to on-site initial data.

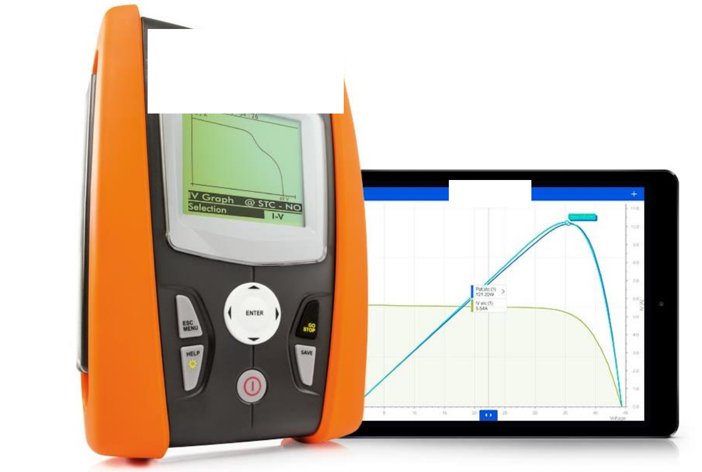


Figure 8806:

Irradiation sensor [redacted], calibration date 07.10.2021, tolerance <3%]

[redacted] is a reference cell for sun irradiation measurements that enables a precise analysis of PV module power or energy yields using measured values from the sensor. It has a double input for connection to mono or multi crystalline modules.

Figure 137: Duo reference cell [source: PI Berlin]

[redacted], calibration date 05.01.2021]

The [redacted] enables non-destructive diagnosis of some thermal and electrical failures in PV modules. It provides fast, real-time, two-dimensional infrared (IR) imaging, revealing characteristic features of PV systems. The measurements can be performed during normal operation for individual PV modules as well as large arrays.

Figure 138: Infrared camera [source: [redacted]

Through the [redacted] camera with a CCD High pass edge filter, electroluminescence pictures are taken in the field to reveal failures such as microcracks, PID, failure of diodes or similar, as a complement to the STC-measurement and infrared inspection. EL imaging is particularly suitable for the detection and tracking of crack-related issues, which can occur for example during module transportation or installation.

Figure 139: [redacted] with CCD high pass edge filter [source: PI Berlin]

Annex V – Normative References Used for the Study

IEC 61557-4:2007	**Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures Part 4: Resistance of earth connection and equipotential bonding**
IEC 60664-1:2007	Insulation coordination for equipment within low-voltage systems Part 1: Principles, requirements and tests
IEC 61215:2021	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 61730-1&2:2021	Photovoltaic (PV) module safety qualification
IEC 61829:2015	Photovoltaic (PV) array - On-site measurement of current-voltage characteristics
IEC 60364-4-41:2005	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock
IEC 60364-4-42:2010	Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects
IEC 60364-4-43:2008	Low-voltage electrical installations - Part 4-43: Protection for safety - Protection against overcurrent
IEC 60364-4-46:1981	Electrical installations of buildings. Part 4: Protection for safety. Chapter 46: Isolation and switching
IEC 60364-5-51:2005	Electrical installations of buildings - Part 5-51: Selection and erection of electrical equipment - Common rules
IEC 60364-5-52:2009	Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems
IEC 60364-5-54:2011	Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors
IEC 60364-6:2006	Low-voltage electrical installations - Part 6: Verification
IEC 60364-7-712:2017	Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
IEC 60529 1989+A1:1999+A2:2013	Degrees of protection provided by enclosures (IP Code)
IEC 60068-2-68:1997	Environmental testing - Part 2: Tests; test L: Dust and sand
IEC 60721 1-2:2013	Classification of environmental conditions
IEC 60721 3-4:2019	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 4: Stationary use at non-weather protected locations (?)
IEC 61084-1:2017	Cable trunking and ducting systems for electrical installations
IEC 61238-1:2003	Foundation earth electrode - Planning, execution and documentation
IEC 62446:2016	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance
IEC 62548:2016	Photovoltaic (PV) arrays - Design requirements
UL 1703:2016	Standard for Flat-Plate Photovoltaic Modules and Panels
VDE-AR-E-2283-4:2010-10	Requirements for cables for PV systems
2 PfG 1169/08.2007*	Requirements for cables for use in photovoltaic systems

Annex VI – Additional Mounting Structure Considerations

a) Flat Roof Sites

Mostly Galvanized steel structures are used for mounting structure.

- **Issues Observed:**

  a. Major structural components like columns, rafters, purlins are corroded
  b. Fasteners are found to be corroded at many places

- **Implication:**

  a. Structure is vulnerable to failures in long term.
  b. Failure may result in damage of modules and the generation might be affected.
  c. With heavy winds the corroded part becomes the weak point of failure and structure gets break and modules may fly. There is a major safety concern of accidents of property or human life.

- **Recommendations:**

  a. Aluminium structures should be used to avoid corrosion of structural components.
  b. Stainless Steel Fasteners should be used for fixing of structure and modules.
  c. Aluminium structure gives best resistance towards corrosion and are light in weight.
  d. Aluminium is easy to handle logistically.
  e. If Steel GI structure needs to be used, then GI should be minimum 80micron and above depending on the corrosive environment of project site.

- **Retrofitting actions:**

  a. Regular inspection of the structure needs to be done.
  b. Fasteners needs to be checked for sufficient torque or tightness on regular basis and should be a part of O&M activities.
  c. Corroded fasteners to be replaced immediately with Stainless Steel Fasteners to avoid any corrosion in future.
  d. Apply of Zinc sprays over the rusted/ corroded part to be done on regular intervals of approx. 1~2years depending on the inspection.
  e. If possible, the structure should be replaced with new ones.

1. Layout & Design of Mounting structure.

- **Issues Observed:**

  a. It has been observed that most of structures are designed with double portrait or landscape orientation
  b. Overhanging of structure beyond the roof limits
  c. Improper design of structure in terms of component sections used

- **Implications:**

  a. Design failures may lead to physical damages like breakage, corrosion, bending, module damages, etc.
  b. Double portrait or landscape orientation develops more surface for wind impact. This leads of higher wind forces on modules and structure. Thus, more structural strength is required.
  c. Overhanging of modules beyond roof limits may lead to physical damages and failures.

d. Any failure will directly impact the surrounding due to overhanging and may lead to fatal accidents.
e. This also compromises the aesthetic looks and elevation of building.
f. O&M activities are difficult to practice due to higher elevations of modules and structures.

- **Recommendations:**

a. Low ballast structures should be used
b. Single portrait or landscape layouts should be adopted. If any failures exists, then the damaged components shall remain within roof limits.
c. Non penetrative structures of aluminium are the best solution to prevent such design failures
d. Standardized structure shall be used

- **Retrofitting actions:**

a. If space permits, then overhang modules should be de-installed and re-installed in some other place
b. Revalidating of the design and additional structural components should be installed to make the structure stable and safe
c. Regular inspection of structure, fasteners, and strength should be done

2. Foundation of Structure

- **Issues Observed:**

a. Foundations designed and installed are not of adequate size
b. Concrete Foundations installed are of different size for same site
c. Structure starts to corrode from foundation side due to capillary effect from water saturation on the roof

- **Implications:**

a. Foundation is one of the major components of the system. It holds the complete structure and keep it intact to the position. Inadequate design and installation may lead to physical failures

- **Recommendations:**

a. Low ballast structure shall be used to avoid criticality of foundation failures
b. Non-penetrative ballast blocks should be used.
c. Proper standardized and designed mounting system should be used to avoid any failures of foundation or relevant components.

- **Retrofitting actions:**

a. Regular inspection of foundation should be done in terms of stability
b. If required additional concreting should be done to avoid any instability and corrosion of structure
c. Foundation should be painted with waterproof material paint to avoid any capillary action resulting in corrosion of structure

3. Miscellaneous Important Failure Points

- **Issued Observed:**

a. Missing structure pieces especially clamps.
b. Wrong Installation & Misalignment of modules.
c. Deviation in Inclination of modules with respect to designed inclination.
d. Non-Earthing of structure and modules.
e. No Spare available on site.
f. No or Improper Access to modules or structure O&M activities.

- **Implications:**

a. Missing components may lead to major failures of structure and modules.
b. Wrong or misalignment of module installation leads to long term failures and generation reduction.
c. Installation with wrong inclination may lead to loss of generation.
d. Non-Earthing of structure & modules may lead to serious physical damages of the system.
e. Non availability of spare may result in delay in rectification and eventually stop the generation of plant.
f. Improper access for O&M leads to prolonging of the rectification activity and thus more prone to failures.

- **Recommendations:**

a. Thorough inspection during commissioning of all components should be done to avoid any missing parts.
b. Mounting structure with provision of Earthing should be used to avoid such failures.
c. Proper handover list should be made with all check points during the commission from projects team to O&M team.

- **Retrofitting actions:**

a. Missing components should be installed immediately.
b. If possible misaligned modules should be installed properly
c. Fasteners should be fixed properly which may reduce or resolve the inclination issue.
d. Earthing of structure and modules should be done immediately
e. If possible, spares should be kept at site and should be used to rectify during O&M.
f. Proper access should be made either by installing new stairs or clearing the existing route.

b) Metal Sheds

- **Issues Observed:**

a. Steel GI components are used for mounting of structure
b. No proper gap is provided between module and metal sheet roof during selection of mounting structure
c. No Walkways or Safety lines provided for O&M activities
d. Orientation of modules kept same as metal sheet orientation.

- **Implications:**

a. Steel GI components are more prone to corrosion. This may lead to structural failures.
b. Steel GI components are heavy. Using Steel GI components results in more load on the metals sheet. This may result in failure of metal sheet and facility structure.
c. If the modules are not placed at sufficient elevation from metal sheet, the temperature losses will be very high, and the generation will reduce drastically.
d. Walkways guides the way over the roof. This avoids any direct damage to the metal sheet or system due to unbalancing problems. Also, the mounting structure do not get affected due to putting of foot wrongly over some adjacent metal sheet developing undue stresses. Safety lines prevents from fatal accidents of the O&M team.

e. If the modules are inclined towards South with properly designed and reputed mounting structure, the generation can be enhanced.

- **Recommendations:**

a. Only aluminium light weight structure should be used over metal sheet.
b. Elevation of 100mm is recommended for installation of modules over the metal sheet to avoid thermal losses. Mounting structure with such provision should be used.
c. Proper walkway & safety line provisions should be done during designing stage and same shall be executed at site.
d. Inclined structures give more generation and reduces the thermal losses.

- **Retrofitting actions:**

a. Inspection of structure to check the corrosion should be done.
b. Inspection should be done to check the bending of metal sheet due to weight of GI structure should be done.
c. If possible, walkways & Safety lines should be installed.