



Operation & Maintenance

Best Practice Guidelines for
Solar Photovoltaic Power Plants

India edition

SolarPower
Europe

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Foreword

Welcome to the India edition of the Operation and Maintenance (O&M) Best Practice Guidelines. Building on Version 4.0 of SolarPower Europe's O&M Best Practice Guidelines, this edition has been adapted to the Indian context in a joint effort between the National Solar Energy Federation of India (NSEFI) and SolarPower Europe. It has been revised thoroughly in a joint European-Indian Task Force. NSEFI and SolarPower Europe would like to thank the Indo-German Energy Forum for their continued support that made these Guidelines possible.

O&M is a segment of great importance for the solar industry in India, which is home to one of the largest fleets of solar PV plants worldwide. As power plants age, the industry has realised that proper "health care" is indispensable for power plants to meet performance expectations. Today, O&M has become a standalone segment in the solar value chain in India with an increasing number of companies specialising exclusively in solar O&M. Yet there are still significant quality discrepancies between services provided by different O&M providers.

To address these challenges, NSEFI and SolarPower Europe, supported by IGEF, joined forces to develop the India edition of the O&M Best Practice Guidelines. Our joint O&M Task Force was launched in March 2020 in New Delhi, assembling more than 40 leading solar experts from India and Europe. The kick-off meeting was followed by a series of online working meetings, in which we fine-tuned Version 4.0 of SolarPower Europe's O&M Best Practice Guidelines in order to reflect Indian market conditions and regulatory requirements. The result is a guidance that we hope will help Indian solar stakeholders to increase quality in the O&M segment. This document is aimed at O&M service providers, as well as other parties involved in the operation of solar power plants, such as owners and investors, lenders, technical advisors and data-related service providers. It will help to establish common standards and increase transparency in the sector. It is also worth noting that solar O&M is a particularly value intensive segment that supports a lot of local jobs, and drives important solar innovations notably in the field of digitalisation.

In the India edition, all chapters of the original document have been thoroughly reviewed and revised with an attention to Indian specificities. To highlight some of the adjustments: to adapt the terminology to the Indian context, for example, we introduced the concepts of "Operation Planning", performed by the Central Control Room, and "Operation Execution", performed by the Local Control Room. The fact that utility-scale solar power plants in India usually have on-site staff as part of the Local Control Room, had implications for many requirements and best practices from monitoring to maintenance. Indian requirements related to topics such as grid code compliance, power generation forecasting, energy meter accuracy have been covered. India-specific best practices have been provided on aspects such as trainings, data and forecasting accuracy, water use for module cleaning, Performance Ratio (PR) and Capacity Utilisation Factor (CUF) guarantees.

The publication of these Guidelines is an important milestone in the successful cooperation between NSEFI and SolarPower Europe. It follows the publication of our joint report on *Solar investment opportunities in India* in March 2020 and the publication of our report on *PV waste management in India*, supported by the EU-India Technical Cooperation Programme (PV Rooftop Cell), in September 2020. We will continue working together on topics of mutual interest in the future, such as solar manufacturing, green hydrogen and EPC best practices. If you want to be part of this cooperation, contact NSEFI or SolarPower Europe.



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List of abbreviations

AC	Alternating Current	IPP	Independent Power Producer
AMP	Annual Maintenance Plan	IR	Infrared
AMR	Automatic Meter Reading	IRENA	International Renewable Energy Agency
AMS	Annual Maintenance Schedule	JMR	Joint Meter Reading
API	Application Programming Interface	KPI	Key Performance Indicator
ARC	Anti-Reflective Coating	kW	Kilowatt
BIS	Bureau of Indian Standards	kWh	Kilowatt-Hour
CCTV	Closed Circuit Television	kWp	Kilowatt-Peak
CERC	Central Electricity Regulatory Commission	LAN	Local Area Network
CMMS	Computerised Maintenance Management System	LCOE	Levelised Cost Of Electricity
COD	Commercial Operation Date	LTE-M	Long-Power Wide-Area Network
CSMS	Cybersecurity Management System	LPWAN	Long Term Evolution, Category M1
CUF	Capacity Utilisation Factor	LV	Low Voltage
CT	Current Transformer	MAE	Mean Absolute Error
DC	Direct Current	MCB	Miniature Circuit Breaker
DMS	Document Management System	MIT	Minimum Irradiance Threshold
DOR	Division Of Responsibility	MNRE	Ministry of New And Renewable Energy (India)
DSCR	Debt Service Coverage Ratio	MPPT	Maximum Power Point Tracking
DSL	Digital Subscriber Line	MTBF	Mean Time Between Failure
DSM	Deviation Settlement Mechanism	MTTR	Mean Time To Repair
EH&S	Environment, Health and Safety	MV	Medium Voltage
EMS	Energy Management System	MW	Megawatt
EPC	Engineering, Procurement, Construction	O&M	Operation and Maintenance
EPI	Energy Performance Index	OEM	Original Equipment Manufacturer
ERP	Enterprise Resource Planning System	OS	Operating System
ESIA	Environmental Social Impact Assessment	PAC	Provisional Acceptance Certificate
ESMP	Environmental, Social Management Plan	POA	Plane Of Array
ESS	Energy Storage System	PPA	Power Purchase Agreement
FAC	Final Acceptance Certificate	PPE	Personal Protective Equipment
FIT	Feed-In Tariff	PR	Performance Ratio
FTP	File Transfer Protocol	PV	Photovoltaic
GPRS	General Packet Radio Service	RMSE	Root Mean Square Error
H&S	Health and Safety	ROI	Return On Investment
HV	High Voltage	RPAS	Remotely Piloted Aircraft System (Drone)
ICT	Information and Communication Technologies	SCADA	Supervisory Control And Data Acquisition
IEC	International Electrotechnical Commission	SLA	Service-Level Agreement
IEGC	Indian Electricity Grid Code	SPV	Special Purpose Vehicle
IGBT	Insulated-Gate Bipolar Transistors	STC	Standard Test Conditions (1000 W/M ² , 25°C)
IS	Indian Standard	TF	Task Force
		UPS	Uninterruptible Power Supply

Executive summary

India's target to achieve 220GW of renewable energy by 2022 is an ambitious target, this large quantity of renewable so installed needs to maintain high quality as, it is crucial to maintain the power quality and grid security. As of 2020, India's solar capacity stands at 35GW and with target being 100GW by 2022, it is crucial to understand the importance of quality. This quality in power output could be affected by many factors, Operation and Maintenance (O&M) being a major one.

O&M has become a standalone segment within the solar industry and it is widely acknowledged by all stakeholders that high-quality O&M services mitigate potential risks, improve the Levelised Cost of Electricity (LCOE) and Power Purchase Agreement (PPA) prices, and positively impact the return on investment (ROI). Responding to the discrepancies that exist in today's solar O&M market, the SolarPower Europe O&M Best Practice Guidelines make it possible for all to benefit from the experience of leading experts in the sector and increase the level of quality and consistency in O&M. These Guidelines are meant for O&M contractors as well as investors, financiers, asset owners, asset managers, monitoring tool providers, technical consultants and all interested stakeholders in Europe and beyond.

This document begins by contextualising O&M, explaining the roles and responsibilities of various stakeholders such as the Asset Owner, the O&M Contractor, the Central Control Room and the Local Control Room and by presenting an overview of technical and contractual terms to achieve a common understanding of the subject. It then walks the reader through the different components of O&M, classifying requirements into "minimum requirements", "best practices" and "recommendations".

Environment, Health & Safety

Environmental problems are normally avoidable through proper plant design and maintenance, but where issues do occur, the O&M contractor must detect them and respond promptly. Environmental compliance may be triggered by components of the PV system itself, such as components that include hazardous materials and by-products that may be

used by the O&M contractor such as herbicides and insecticides. In many situations, solar plants offer an opportunity to provide for agriculture and are a valuable natural habitat for plants and animals alongside the primary purpose of power production. Solar plants are electricity generating power stations and have significant hazards present which can result in injury or death. Risks should be reduced through proper hazard identification, careful planning of works, briefing of procedures to be followed, documented and regular inspection, and maintenance. Personnel training and certification and personal protective equipment are required for several tasks. Almost all jobs have some safety requirements such as fall protection for work at heights and electrical arc-flash, lock-out tag-out, and general electrical safety for electrical work; eye and ear protection for ground maintenance.

Personnel & training

It is important that all O&M personnel have the relevant experience and qualifications to perform the work in a safe, responsible and accountable manner. These Guidelines contain a skills' matrix template that helps to record skills and identify gaps.

Operation Planning

In the Indian context, "Operation Planning", performed on the Central Control Room level encompasses the activities at the level of the Central Control Room. It corresponds mostly, but not entirely, to what is called "Technical Asset Management" in Europe. On the one hand, it comprises monitoring & analytics at the level of the solar power plant portfolio. On the other hand, it also encompasses high-level services to maximise energy production, minimise downtime and reduce costs, such as performance reporting to the Asset Owner, contracts management, invoicing and warranty management. "Operation Planning" corresponds approximately, but not fully, to what is called "Technical Asset Management" in Europe. Operation Planning also includes ensuring that the operation of the PV plant complies with national and local regulations and contracts, and also advising the asset owner on technical asset optimisation via e.g. repowering investments.

Operation Execution

Operation Execution, performed on the Local Control Room level in India, is about remote monitoring, supervision and control of the PV power plant and it is an increasingly active exercise as grid operators require more and more flexibility from solar power plants. Operation Execution also involves liaising with or coordination of the maintenance personnel (which is part of the Local Control Room team). A proper PV plant documentation management system is crucial for Operations. A list of documents that should be included in the as-built documentation set accompanying the solar PV plant (such as PV modules' datasheets), as well as a list of examples of input records that should be included in the record control (such as alarms descriptions), can be found in the Annex of these Guidelines. Based on the data and analyses gained through monitoring and supervision, the O&M contractor should always strive to improve PV power plant performance. As there are strict legal requirements for security services in most countries, PV power plant security should be ensured by specialised security service providers.

Maintenance

Maintenance is usually carried out on-site by specialised technicians that are part of the Local Control Room team. A core element of maintenance services, Scheduled Maintenance involves regular visual and physical inspections, functional testing and measurements, as well as the verification activities necessary to comply with the operating manuals and warranty requirements. In India, panel cleaning and vegetation control are also considered to be part of the Scheduled Maintenance performed by the O&M Contractor. The Annual Maintenance Plan (see an example in Annex b) includes a list of inspections and actions that should be performed regularly. Corrective Maintenance covers activities aimed at restoring a faulty PV plant, equipment or component to a status where it can perform the required function. Extraordinary Maintenance actions, usually not covered by the O&M fixed fee, can be necessary after major unpredictable events in the plant site that require substantial repair works. Additional maintenance services may include tasks such as special on-site measurements not in the scope of the O&M contract, which could be done by the O&M contractor or outsourced to specialist providers.

Revamping and repowering

Revamping and repowering are usually considered a part of extraordinary maintenance from a contractual point of view – however, due to their increasing significance in the solar O&M market, these Guidelines address them in a standalone chapter. Revamping and repowering are defined as the replacement of old, power production related components within a power plant by new components to enhance the overall performance of the installation. This chapter presents the best practices in module and inverter revamping and repowering and general, commercial considerations to keep in mind before implementation.

Spare Parts Management

Spare Parts Management is an inherent and substantial part of O&M aimed at ensuring that spare parts are available in a timely manner for Scheduled and Corrective Maintenance in order to minimise the downtime of a solar PV plant. As a best practice, the spare parts should be owned by the asset owner while normally maintenance, storage and replenishment should be the responsibility of the O&M contractor. It is considered a best practice not to include the cost of replenishment of spare parts in the O&M fixed fee. However, if the asset owner requires the O&M contractor to bear replenishment costs, the more cost-effective approach is to agree which are "Included Spare Parts" and which are "Excluded Spare Parts". These Guidelines also include a minimum list of spare parts that are considered essential.

Data and monitoring requirements

The purpose of the monitoring system is to allow supervision of the performance of a PV power plant. Requirements for effective monitoring include dataloggers capable of collecting data (such as energy generated, irradiance, module temperature, etc.) of all relevant components (such as inverters, energy meters, pyranometers, temperature sensors) and storing at least one month of data with a recording granularity of up to 15 minutes, as well as a reliable Monitoring Portal (interface) for the visualisation of the collected data and the calculation of KPIs. Monitoring is increasingly employing satellite data as a source of solar resource data to be used as a comparison reference for on-site pyranometers. As a best practice,

the monitoring system should ensure open data accessibility in order to enable an easy transition between monitoring platforms and interoperability of different applications. As remotely monitored and controlled systems, PV plants are exposed to cybersecurity risks. It is therefore vital that installations undertake a cyber security analysis and implement a cybersecurity management system. To evaluate monitoring tools it is recommended to refer to the Monitoring Checklist of the Solar Best Practices Mark, which is available at www.solarbestpractices.com.

Key Performance Indicators

Important KPIs include PV power plant KPIs, directly reflecting the performance of the PV power plant; O&M contractor KPIs, assessing the performance of the O&M service provided, and PV power plant/O&M contractor KPIs, which reflect power plant performance and O&M service quality at the same time. PV power plant KPIs include important indicators such as the Performance Ratio (PR), which is the energy generated divided by the energy obtainable under ideal conditions expressed as a percentage, the Capacity Utilisation Factor (CUF), which is the ratio between the actual energy production of the solar power plant to the potential output at Standard Test Conditions (STC), and Uptime (or Technical Availability) which are parameters that represent, as a percentage, the time during which the plant operates over the total possible time it is able to operate. O&M contractor KPIs include Acknowledgement Time (the time between the alarm and the acknowledgement), Intervention Time (the time between acknowledgement and reaching the plant by a technician) and Resolution Time (the time to resolve the fault starting from the moment of reaching the PV plant). Acknowledgement Time plus Intervention Time are called Response Time.

Contractual framework

In India, it is common for O&M Contractors to provide PR, CUF as well as Contractual Availability guarantees. PR and CUF guarantees should be agreed upon between the Asset Owner and the O&M Contractor after a thorough assessment of the PV plant and systems by the O&M Contractor and certain conditions should apply. For the Contractual Availability guarantee, 98% or 99% over a year is a best practice. Guarantees may be translated into Bonus Schemes and Liquidated Damages. When setting Response Time guarantees, it is recommended to differentiate between hours and periods with high and low irradiance levels as well as fault classes, i.e. the (potential) power loss.

Innovations and trends

O&M contractors are increasingly relying on innovations and more machine and data-driven solutions to keep up with market requirements. The most important trends and innovations shaping today's O&M market are summarised in this chapter, grouped into three "families": (1) Smart PV power plant monitoring and data-driven O&M, (2) Retrofit coatings for PV modules, and (3) O&M for PV power plants with storage.

O&M for distributed solar

All best practices mentioned in these Guidelines could be theoretically applied to even the smallest solar system for its benefit. However, this is not practical in nature due to a different set of stakeholders and financial implications. This chapter assists in the application of the utility-scale best practices to distributed solar projects, which are shaped by three important factors: (1) a different set of stakeholders – owners of distributed systems not being solar professionals but home owners and businesses, (2) different economics – monitoring hardware and site inspections accounting for a larger share of investment and savings, and (3) a higher incidence of uncertainty – greater shade, lower data accuracy and less visual inspection.

1

Introduction

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1.1. Rationale, aim and scope

A professional Operation & Maintenance (O&M) service package ensures that the photovoltaic system will maintain high levels of technical, safety and consequently economic performance over its lifetime.

Currently, it is widely acknowledged by all stakeholders that high quality O&M services mitigate the potential risks, improve the levelised cost of electricity (LCOE) and positively impact the return on investment (ROI). This can be highlighted if one considers the lifecycle of a PV project which can be broken down into the 4 phases below. The O&M phase is by far the longest:

- Development (typically 1-3 years)
- Construction (a few months)
- Operation & Maintenance (typically 30+ years)
- Decommissioning and disposal (a few months)

Therefore, increasing the quality of O&M services is important and, in contrast, neglecting O&M is risky. The PV industry – a “young” industry that evolves also in the services segment – offers a wide range of practices and approaches. Although this is partly logical, reflecting the specificities of each system, topologies, installation sites and national/state requirements, there is a confusion or lack of clarity and knowledge of many Asset Owners and funding authorities (investors or/and banks) of what the minimum requirements (scope) should be. A few years ago, when feed-in tariffs were very high and

favourable, there was an obvious lack of risk perception in combination with an underestimated performance metrics definition which hindered the proof of value of a professional and high-quality service provision.

As prevention is better than cure, and hence to prevent our solar power plants from encountering major issues, best practices for O&M need to be followed. Energy losses, sudden plant shutdowns, inoperable controls, safety hazards, are often considerable, and results in huge losses to developers and system operators. Following the O&M Best Practice Guidelines will not only conserve the loss of electricity generated, it also improve efficiency and could be considered as a resource addition.

Although for Maintenance there are a number of technical international standards that can be followed and which also cover tasks related to planning, scheduling and administrative, but when it comes to the practical Power Plant Operation, there are many shortcomings. Therefore, it is crucial to develop and disseminate best practices to optimise Power Plant Operation and thus energy production, power plant management and resulting benefits. Best practices that set the quality bar high will enhance investors' understanding and confidence. For this version 4.0, a list of international standards has been added to support these best practises and to avoid misunderstandings in wording and doing. For more detailed information, please refer to Annex a.

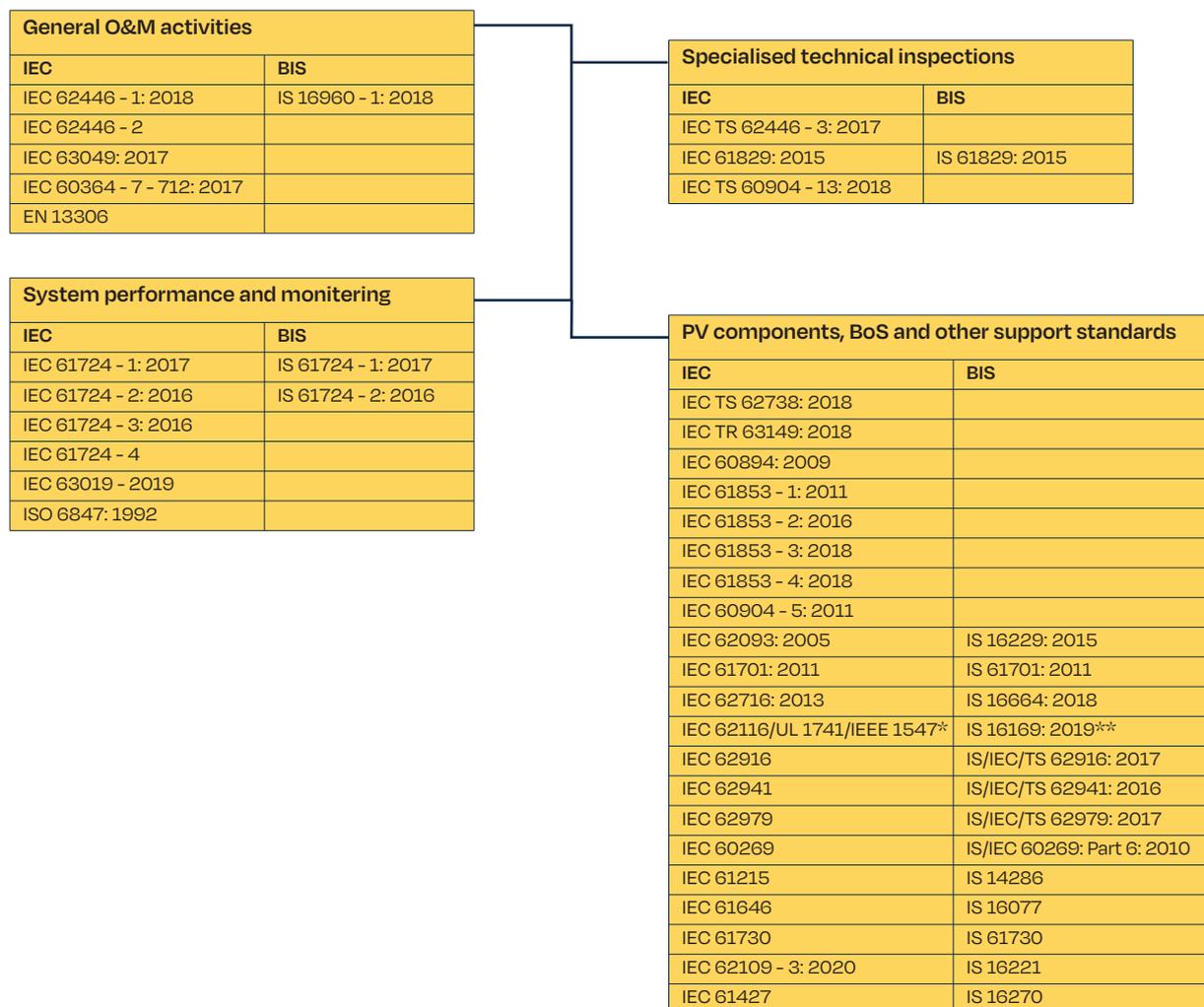
1 Introduction / continued

The Bureau of Indian Standards (BIS) has adopted many IEC standards for implementation in India. Generally speaking, these BIS standards are priced differently for Indian customers so even individuals can afford to buy these in a joint effort to move towards an enhanced quality in the sector.

SolarPower Europe's O&M Best Practice Guidelines are a key tool to set quality standards for O&M service

providers and enhance investors' understanding and confidence. It is to be noted that the present Guidelines focus on the technical O&M services aimed at maintaining and improving the performance and reliability of solar power plants in the operational phase. In contrast to this, improving the commercial and financial profitability of the solar investment is treated in detail in the *Asset Management Best Practice*

FIGURE 1 OVERVIEW OF A SELECTION OF APPLICABLE STANDARDS FOR O&M (STATUS: 2019)



*As applicable.
** First revision.

NOTE: This list is not exhaustive and new standards are under development For more details see Annex a.

Guidelines.¹ The value proposition of these Guidelines is that its industry-led, containing the knowledge and the experience of well-established and leading companies in the field of O&M service provision, project development and construction (EPC), asset management, utilities, manufacturers and monitoring tool providers.

The scope of the current work includes the utility scale segment and more specifically, systems above 1 MW. Specificities related to O&M for distributed solar installations are explained in Chapter 14 on *O&M for Distributed Solar*. These Guidelines are based on the experience of companies operating globally (with a concentration in Europe), therefore, it provides high-level requirements that can be applied worldwide. Specific national considerations such as legal requirements are not included and should therefore be considered separately if these Guidelines are to be used in specific countries.

The content covers technical and non-technical requirements, classifying them when possible into:

- 1. Minimum requirements**, below which the O&M service is considered as poor or insufficient, and which form a minimum quality threshold for a professional and bankable service provider.
- 2. Best practices**, which are methods considered state-of-the-art, producing optimal results by balancing the technical as well as the financial side.
- 3. Recommendations**, which can add to the quality of the service, but whose implementation depends on the considerations of the Asset Owner, such as the available budget.

As for the terminology used in this document to differentiate between these three categories, verbs such as *"should"* indicate minimum requirements, unless specified explicitly otherwise, like in: *"should, as a best practice"*.

1.2. How to benefit from this document

This report includes the main considerations for a successful and professional O&M service provision. Although it has not been tailored for each stakeholder, its use is similar for all: understanding the mandatory requirements and the necessity of professional O&M and incorporating the recommendations accordingly into the service package. Any of the directly relevant

stakeholders (see the following section) can benefit from this work, tailor it to their needs without lowering the bar and know what to ask for, offer or expect.

Although the focus is European, most of the content can be used in other regions around the world. The requirements described in the maintenance part apply without changes in regions with conditions similar to Europe and a moderate climate and additional requirements or modifications can easily be made for other regions with unique characteristics. With regards to the Operations Planning and Execution parts, the requirements apply to PV assets regardless of their location.

1.3. Stakeholders and roles

Usually multiple stakeholders interact in the O&M phase and therefore it is important to clarify as much as possible the different roles and responsibilities. These can be abstracted to the following basic roles:

Asset Owner

The stakeholder that contributes to the financing of construction and operation of the PV power plant is normally the investor (or a group of investors), who can be classified as private individuals, financing investors or investment funds and Independent Power Producers (IPPs) or Utilities. Assets are generally owned by "Special Purpose Vehicles" (SPV), i.e. limited liability companies, specifically incorporated for building, owning and operating one or more PV plants.

Lender

The lender or debt provider (financing bank) is not considered as an "Asset Owner" even if the loans are backed up by securities (collateral). In principal, the interests and performance expectations are different between the investor (equity provider) and the lender who normally measures the risk based on the debt service coverage ratio (DSCR). The role of the lender is becoming increasingly "smart" and less passive, with enhanced considerations and involvement

¹ In addition to the O&M Best Practice Guidelines we recommend SolarPower Europe's Asset Management Best Practice Guidelines and Engineering, Procurement and Construction (EPC) Best Practice Guidelines, two other useful documents to enhance investors' confidence and improve solar service quality. These reports can also be downloaded from www.solarpowereurope.org.

1 Introduction / continued

regarding the requirements for the debt provision. Some projects also have a “Mezzanine Lender” lending Junior debt, where another layer of debt is provided at a higher risk than the original lender case.

EPC Contractor

The entity in charge of the engineering, procurement and construction of the solar power plant. The EPC contractor is in charge of delivering the full solar power plant to the asset owner from authorisation to commissioning and grid connection. Their role is very important in ensuring the procurement of quality components and quality installation, which have a large impact on the long-term performance of the solar power plant. Many EPC contractors offer O&M services for the solar power plants that they have developed. EPC Contractors often provide a 2-year performance warranty period after the Commercial Operation Date (COD) lasting until the Final Acceptance Certificate (FAC). In many cases it is after FAC that a third-party O&M Contractor is contracted to take over the O&M of the solar power plant. In certain mature markets the EPC role is increasingly split between different entities. For more information, see SolarPower Europe’s EPC Best Practice Guidelines (2020).

Asset Manager

The service provider responsible for the overall commercial, financial and administrative management of the project company (Special Purpose Vehicle, SPV). The Asset Manager ensures that SPV and service providers fulfil their contractual obligations, and manages the site with the aim of ensuring optimal profitability of the PV power plant (or a portfolio of plants) by supervising energy sales, energy production, and O&M activities. Asset Managers also ensure the fulfilment of all administrative, fiscal, insurance and financial obligations of the SPVs. Asset Managers review the performance of the sites regularly and report to asset owners, and seeks to balance cost, risk and performance to maximise value for stakeholders. Note that specialised Asset Management service providers are a relatively new trend in Europe. In India, Asset Management is not yet a standalone segment, and commercial, financial and administrative management tasks are usually assumed by the O&M provider on the one hand and the Asset Owner on the

other hand. For detailed information on the Asset Manager’s roles and activities (as observed in Europe), please refer to SolarPower Europe’s Asset Management Best Practice Guidelines.

O&M Contractor (in India often labelled “O&M Manager”)

The entity that is in charge of O&M activities as defined in the O&M contract. In India, this entity usually consists of three levels in the case of utility-scale solar power plants:

- 1. Operation Planning:** activities at the level of the Central Control Room, in charge of monitoring & analytics at the portfolio level, high-level services such as performance reporting to the Asset Owner, contracts management, invoicing and warranty management (corresponds approximately, but not fully, to what is called “Technical Asset Management” in Europe);
- 2. Operation Execution:** activities at the level of the Local Control Room, in charge of monitoring, supervision and control, as well as coordination of the maintenance activities at the single power point level (corresponds approximately, but not fully, to what is called “Power Plant Operations” in Europe);
- 3. Maintenance:** carrying out maintenance activities. Together with the “Operations Execution” team, the “Maintenance team” is part of the Local Control Room team.

The three roles are often assumed by a single entity through a full-service O&M contract. A comprehensive set of O&M activities (technical and non-technical) is presented in this report.

Technical Advisors and Engineers

Individuals or teams of experts that provide specialised services (e.g. detailed information, advice, technical consulting). Their role is important since they ensure that procedures and practices are robust and of high quality – according to standards and best practices – to maintain high performance levels of the PV plant. Technical advisors can represent different stakeholders (e.g. investors and lenders), but often an Independent Engineer is employed, whose opinions on the technical aspects of the project are not biased in favour of any stakeholder.

Specialised suppliers

Providers of specialised services (e.g. technical or operational systems consulting) or hardware (e.g. electricity generating components or security system).

Authorities

Local (e.g. the municipality), regional (e.g. state authorities in India supervising environmental constraints), national (e.g. the national grid operator, government departments), or international (e.g. the authors of a European grid code).

Off-taker

The entity that pays for the produced electricity. This role is still evolving and is often subdivided according to national renewable power support schemes:

- The state or national grid operator / electricity seller(s), or specific authorities for renewable energy (such as GSE in Italy) in a feed-in tariff (FIT) scheme.
- Energy traders or direct sellers in a direct marketing scheme.
- End customers in schemes that underline autonomy in energy supply.

Data-related service providers

Providers of hardware and software solutions such as Monitoring Systems, Asset Management Platforms, Computerised Maintenance Management Systems (CMMS) or Enterprise Resource Planning Systems (ERP) that acquire data from the site and also analyse the data to calculate KPIs (analytical tools) and/or provide data repository for key site information whilst facilitating some administrative workflows. Site data is crucial to ensure owners, and AM and O&M providers are aware of what is occurring on site and how the equipment is behaving throughout its lifetime. It is crucial to ensure that prompt action is taken once a fault is identified and provide vital information on potential areas of underperformance. There is tendency in the industry to opt for solutions that integrate the functionalities of all above mentioned systems and platforms in one software, which has several advantages and can be considered a recommendation.

The aforementioned stakeholders and roles should support the provision of the necessary services and transfer the guidelines of this report to real life situations. For example, in cases where either one stakeholder/party may take over several roles and responsibilities or one role might be represented by several parties:

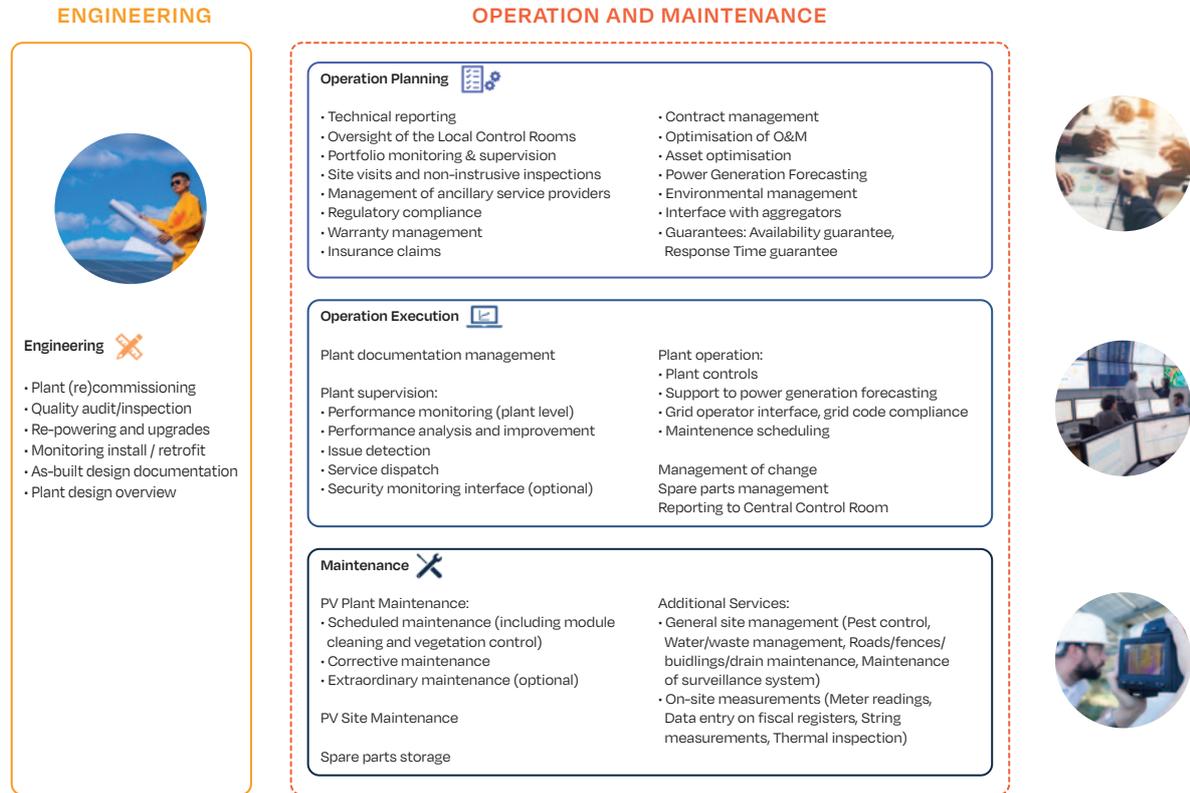
- An investor may take asset management responsibilities.
- An Asset Manager may take over a more active role and intervene in operations.
- An Asset Manager may even take over full O&M.
- An O&M Contractor's role may be subdivided or may also include some asset management activities such as specified below (e.g. reporting, electricity sale, insurance, fiscal registrations, etc).
- The end customer (or electricity buyer) may at the same time be the Asset Owner, Asset Manager, and O&M Contractor (e.g. a PV power plant on an industrial site to cover its own energy needs).

Figure 2 on the following page provides an overview of the different activities assumed by the O&M contractor. Note that some Operation Planning activities may be done in-house by the Asset Owner. This figure is redesigned and based on a figure of GTM (2013).

This grey zone of responsibilities makes it difficult to standardise properly the responsibilities of each stakeholder. With this perspective, it is important that contracts define as precisely as possible scope, rights and obligations of each party and the general work order management.

However, all stakeholders should have a good understanding of both technical and financial aspects in order to ensure a successful and impactful implementation of services. That will require Asset Managers to have technical skills in-house or by hiring an independent technical advisor (engineer) for a meaningful supervision and proper assessment of the technical solutions, and O&M Contractors to have the ability to cost-assess and prioritise their operational decisions and maintenance services.

FIGURE 2 ROLES AND RESPONSIBILITIES BY DIFFERENT STAKEHOLDERS IN THE FIELD OF O&M



NOTE: The responsibilities of the Asset Manager and the O&M Contractor sometimes overlap, and Technical Asset Management and even some aspects of Procurement can be assumed by either the O&M Contractor or the Asset Manager.

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2

Definitions

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This section introduces a basic set of definitions of important terms that are widely used in the O&M field (contracts) and is necessary for all different stakeholders to have a common understanding. In general, there are standards in place that explain some of these terms, however, it is still difficult in practice to agree on the boundaries of those terms and what exactly is expected under these terms or services (e.g. the different types of maintenances or operational tasks).

Indeed, it is more challenging for terms in the Operational field since those are less technical and not standardised as in the case for Maintenance. The chapter provides a short list (alphabetically ordered) which is not exhaustive but reflects the different sections of this document. For the definitions relating to Maintenance the standard EN 13306 ("Maintenance terminology") was used as a basis.

Additional services	Actions and/or works performed, managed or overseen by the O&M Contractor, which are not (but can be if agreed) part of the regular services and normally charged "as-you-go", e.g. ground maintenance, security services etc.
Asset management	Asset Managers are responsible for the commercial and financial management of a solar investment and the supervision and control of technical activities. They manage a company or a portfolio rather than a power plant, often across different geographies, dealing with a variety of regulatory frameworks and business models. Asset management is also defined as the coordinated activities of an organisation to generate value from its assets (ISO 55000). Note that specialised Asset Management service providers are a relatively new trend in Europe. In India, Asset Management is not yet a standalone segment, and technical, commercial, financial and administrative asset management tasks are usually assumed by the O&M provider or the Asset Owner.
Asset management platform	A software package or suite of tools that is used by the Asset Manager to store and manage technical and non-technical data and information collected from and relating to the solar asset, portfolio or SPV. It combines the abilities of a Computerised Maintenance Management System (CMMS) and an Enterprise Resource Planning System (ERP).
Computerised Maintenance Management System (CMMS)	A software designed to measure and record various O&M KPIs (e.g. Acknowledgement Time, Intervention Time, Reaction Time, Resolution Time) and equipment performance (e.g. Mean Time Between Failures) and thus optimise maintenance activities.

2 Definitions / continued

Contract management	Activities related to the proper fulfilment of O&M contract obligations such as reporting, billing, contract amendments, regulator interaction etc.
Contractual framework	An agreement with specific terms between the Asset Owner and the O&M Contractor. This agreement defines in detail the O&M services, both operations and maintenance activities, the management and interfaces of those services, as well as the responsibilities of each party. Liquidated damages and bonus schemes are also part of the contractual commitments.
Control room services (Central control room and local control room)	Local Control Room: Local control room performs actions like monitoring, supervision interaction with grid operators, regulators, Asset Managers and Asset Owners at the site of installation. With the Maintenance team being a part of the Local Control Room team, Local Control Rooms are also responsible for all aspects of plant maintenance. Central Control Room (also known as Remote Operations Center, ROC): Comprehensive actions like PV portfolio monitoring, performance analysis, supervision, remote controls, , and the preparation and provision of regular reporting. These are done remotely at the headquarters of the entity instead of the site unlike in the case of the Local Control Room.
Corrective maintenance	Actions and/or techniques (immediate or deferred) taken to correct failures, breakdowns, malfunctions, anomalies or damages detected during inspections, or through monitoring, alarming, or reporting or any other source. The actions are desired to restore the PV system back into regular and required operation mode.
Data and monitoring requirements	Hardware and software, technical and functional specifications to collect, transmit and store production, performance and environmental data for plant management.
Digital twin	Virtual representation of a physical object or system across its lifecycle. It uses real-time data and other sources to enable learning, reasoning, and dynamically recalibrating for improved decision making.
Documentation management system	A management system that records, manages and stores documents required for O&M and AM, such as technical plant and equipment documentation and drawings, maintenance manuals, photos and reports, including the various versions that are being created by different users, reviews and approvals. Documentation management system also defines a proper format and use (information exchange). Due to the increasing complexity of documents and in order to enable advanced analytics, electronic DMS with the ability to handle meta-tags and searchable, editable documentation is becoming a best practice.
Environment, Health & Safety (EH&S)	Environment, Health and Safety indicates the activities performed to ensure environmental protection, occupational health and safety at work and on site, applicable to staff and visitors according to the national applicable laws and regulations.
Enterprise Resource Planning System (ERP)	A business management software that a company (such as an O&M contractor or an asset manager) can use to gather, store, manage and analyse all types of data relevant for their operations.
Extraordinary Maintenance	Actions and/or works performed in case of major unpredictable faults, such as serial defects, force majeure events etc, that are generally considered outside of the ordinary course of business.
Feed-in tariff (FiT)	A policy mechanism (designed to accelerate investment in renewable energy technologies) which remunerates, through a long term contract, a fixed electricity prices to renewable energy producers for each unit of energy produced and injected into the electricity grid.

Force Majeure	"Force Majeure", as defined by MNRE, are the act that prevents the plants from performing its obligations, due to reasons beyond the control of affected party and: (1) natural phenomena, such as storms, hurricanes, floods, lightning, volcanic eruptions and earthquakes; (2) explosions or fires arising from lighting or other causes unrelated to the acts or omissions of the Party seeking to be excused from performance; (3) acts of war or public disorders, civil disturbances, riots, insurrection, sabotage, epidemic, terrorist acts, or rebellion.
Good industry practice	Good Industry Practice means those practices, methods, techniques, standards, codes, specifications, acts, skills and equipment generally applicable in the international solar power industry (including construction and installation of solar power facilities) and followed or used by good contractors that, in the exercise of prudent, proper and good judgment, in light of the facts known or that reasonably should have been known at the time a decision was made or an action taken or omitted, would have been expected to accomplish the desired result in a manner consistent with applicable laws and permits, are reliable and safe, protect the environment, are economically efficient and are done with the degree of skill, diligence and prudence that would ordinarily be expected. Whereas "good industry practice" is a legal term often used in contracts, "best practice" is a term used in these Guidelines as defined in subchapter 1.1. on the <i>Rationale, aim and scope</i> .
Grid code compliance requirements	Equipment, procedures, actions and activities required by the respective grid operator(s) in order to comply with grid safety, power quality and operating specifications.
Insurance claims	Customer's activities required to claim a reimbursement based on specific insurance policy terms.
Key Performance Indicator (KPI)	A technical parameter that helps the stakeholders to evaluate the successful operation of a PV plant and/or the success of the O&M Contractor's activities.
Load Dispatch Centre (LDC)	Coordinating agency between generation, transmission and distribution of electricity. These load dispatch centres are at state regional and national levels known as State Load Dispatch centre, Regional Load Dispatch Centre and National Load Dispatch centre respectively.
Management of change	Management of change defines the way to handle necessary adjustments of the design of a PV power plant after the Commercial Operation Date. Changes require a close cooperation between the plant owner and the O&M Contractor.
Monitoring system	The digital platform used for the overall management of the PV plants or PV plant portfolio. It allows a centralised monitoring of the functioning, energy generation and reference data of the PV plant and its components. This is ideally performed through near-real-time monitoring module that retrieves data from the local SCADA systems. It also typically includes operational modules such as ticket dispatching, analytics and reporting. The monitoring operates 24 hours a day, all year, and is fed by in-plant data logging systems (or SCADA) as well as by irradiation and temperature measurements from particular sensors and other sources such as meteorological information.

2 Definitions / continued

Operation and Maintenance (O&M)	O&M includes all the services that ensure maximum efficiency and maintenance for a PV plant. The services include monitoring and supervision; scheduled maintenance (including module cleaning) and corrective maintenance; performance analysis and improvement; power generation forecasting and site security management. In India, O&M for utility-scale solar power plants is usually structured into three levels: Operation Planning (assumed by the Central Control Room team), Operation Execution (assumed by the Local Control Room team) and Maintenance (assumed by the Local Control Room team also).
Performance analysis & improvement	Measurements, calculations, trending, comparisons, inspections etc performed in order to evaluate the PV plant, segments and/or single component performance, site conditions, equipment behaviour etc, and to provide reports and assessment studies to interested parties (customer, public authority, etc).
Personnel & training	Operators, technicians, engineers and managers employed for the execution of the O&M activities and training plans/programmes to train them on relevant PV plant related aspects and to keep them continuously updated on their respective roles.
Power plant controls	Actions required by the grid operator, for controlling active and/or reactive power being fed into the grid, other power quality factors that are subject to adjustments and/or (emergency) shut down (if applicable).
Power plant supervision	The activity to supervise and analyse data provided by the monitoring system which is performed by experienced human resources during daylight hours and managed by one or more control rooms (365 days/year). The reception and qualification of the alarms from the monitoring tool is also considered to be part of the supervision.
Predictive maintenance	Actions and/or techniques that are performed to help assess the condition of a PV system and its components, predict/forecast and recommend when maintenance actions should be performed. The prediction is derived from the analysis and evaluation of significant parameters of the component (e.g. parameters related to degradation). Monitoring systems and expert knowledge are used to identify the appropriate actions based on a cost benefit analysis.
Power Generation Forecasting	Adoption of forecasting tools calculating expected power production for a certain timeframe from weather forecasts in order to supply the expected power production to owner, grid operator, energy traders or others. This is normally country/state and plant dependent.
Regulatory compliance	Compliance to any law, statute, directive, bylaw, regulation, rule, order, delegated legislation or subordinate legislation directly applicable in the state where the service is provided, as well as to any mandatory guidelines and measures issued by a utility and any other competent public authority.
Reporting and other deliverables	Deliverables produced periodically, according to requirements detailed in the O&M agreement or following best market practices, including PV plant performance, Key Performance Indicators, maintenance activities and work orders performed, alarm handling, equipment status, warranty handling activities and spare parts tracking and any other analysis performed in compliance with the O&M contract requirements.
Scheduled Maintenance	Actions and/or testing and/or measurements to ensure optimal operating conditions of equipment and of the entire PV plant and to prevent defects and failures. Those take place periodically and according to a specific maintenance-plan and maintenance schedules.

Security	Actions, procedures, equipment and/or techniques that are adopted on site and remotely in order to protect the plant from theft, vandalism, fire and unauthorised entry. Security services are to be provided by specialised security service providers.
Spare Parts Management	Activities that ensure availability of the right amount and type of components, equipment, parts etc, either on site or in warehouses or in manufacturers' consignment stocks, for prompt replacement in case of failure and/or to meet guarantees under O&M contracts.
Supervisory Control and Data Acquisition (SCADA)	Supervisory Control and Data Acquisition (SCADA) is a data acquisition system that connects various hardware and software components in a given site and is used to monitor and control the solar power plant remotely. SCADA systems are typically employed to send data to a centralised Monitoring System for monitoring and analytical purposes (see definition for "Monitoring System").
Warranty management	Warranty management usually aggregates activities of a diverse nature which are linked to areas such as supply of equipment and services, and project construction. All these responsibilities (warranties) are usually materialised with the issue of the Provisional Acceptance Certificate (PAC) by the EPC. Warranty Management is the activity that manages these warranties with the objective of reducing the costs and response times after warranty claims for repair or replacement of certain PV system components (under the warranty of the EPC and/or the components manufacturer).





The Asset Owner has the ultimate legal and moral responsibility to ensure the health and safety of people in and around the solar plant and for the protection of the environment around it. The practical implementation is normally subcontracted to the O&M Contractor. In some cases, the Asset Manager can provide or prescribe the systems, which is then also implemented by the O&M Contractor.

Everyone who enters a solar plant needs to be trained on the EH&S dangers present in addition to their individual skills and experience required for the tasks that they normally perform. The information map with exit routes and first-aid maps should be made available to every personnel working on the same. The Asset Owner shall appoint qualified safety officials. To ensure safety provisions are followed, a periodic monitoring and review could be implemented. Adequate human, physical and financial resources to implement the emergency safety management system and regular mock drills on the same being conducted shall prove to be very helpful. The plant should also ensure the arrangement of adequate medical facilities to provide immediate relief to accident victims and with transportation availability.

Environment

Renewable energies are popular because of their low environmental impact and it is important that solar plants are operated and maintained to minimise any adverse effects. Environmental problems can normally be avoided through proper plant design and

maintenance – for example, bunds and regular inspection of HV transformers will reduce the chances of significant oil leaks – but where issues do occur the O&M Contractor must detect them and respond promptly. Beyond the environmental damage there may be financial or legal penalties for the owner of the plant.

Legal obligations to be fulfilled by the O&M Contractor may include long-term environmental requirements to be implemented either onsite or off-site. Typical requirements can be amongst others water tank installation, tree clearing, drainage systems installation, amphibian follow-up, edge plantation, reptile rock shelters installation. Such requirements should be implemented and managed by the O&M Contractor in order to comply with the authorisation. As a best practice, the O&M Contractor's environmental preservation activities can go beyond legal obligations.

Further the use of water needs to be considered. Water is used in many installations of solar plants in India. Primarily the water is used for cleaning of the solar modules, further water is used in sanitary installations of the solar plants. The amount of water required depends mostly upon the cleaning requirements of the solar modules. It is estimated that the yearly amount of water needed is at least 100 t/MWp for a solar plant where the solar modules are regularly cleaned during the dry season. In many instances the water is taken from nearby sources through contractors that also conduct the cleaning of the solar modules. The contractors for cleaning the solar modules are often local farmers that conduct the cleaning of the solar modules to complement their income.

The water demand from a solar plant can play a significant role in the water balance of a region. This is of particular importance when considering that water scarcity and dwindling groundwater resources are a wide-spread and increasingly alarming phenomenon in India. In many incidences, the operators of the solar plant or their sub-contractors are in a stronger position to source the scarce water and therefore they may endanger the livelihoods of the local population. This situation is to be avoided by all means. Solar plants are typically installed in regions that have abundant sunshine and consequently are rather arid. Thus, the probability for a conflict over water particularly for solar plants is rather high and it will increase with the expected fast expansion of installed solar capacity.

In order to avoid a conflict over water the question of the water requirement from the solar plant as well as the local availability of water also in stressed situations is to be analysed as part of the Environmental Social Impact Assessment (ESIA) prior to implementing the project. An outcome of the ESIA might be on the one hand potential optimisation of the design of the solar plant. On the other hand, any measures required to minimize or mitigate impacts and risks, such as water conflicts, are determined and to be documented in an Environmental, Social Management Plan (ESMP) which is monitored during the construction and the operation of the solar plant.

So far in cases where a potential conflict over water has been determined to be an important risk a rainwater harvesting system has been identified as a possible remedy. In practice these rainwater harvesting systems have shown to be rather simple to install and effective in saving water. Further dry-cleaning - in particular robotic dry-cleaning - has been tried in various installations and has also shown to be very effective. Both rainwater harvesting and robotic dry-cleaning approaches however require to be planned before installation of the solar plant in order to allow for reasonable cost.

During O&M all aspects determined in the ESMP concerning the use of water are to be monitored. In case no ESMP has been developed prior to the installation of the solar plant, then the question of water use and potential conflict over water is to be analysed by a suitable expert and the measures determined through this analysis are to be implemented.

Other aspects that need to be taken into account, as best practice, are recycling of broken panels and electric waste so that glass, aluminium and semiconductor materials can be recovered and reused and hazardous materials disposed of in a safe manner complying with legal requirements. In areas with water scarcity, water use for module cleaning should be minimised.

In many situations, solar plants offer an opportunity, where managed sympathetically, to provide opportunities for agriculture and a valuable natural habitat for plants and animals alongside the primary purpose of generation of electricity. A well thought out environmental management plan can help promote the development of natural habitat, as well as reduce the overall maintenance costs of managing the grounds of the plant. It can also ensure the satisfaction of any legal requirements to protect or maintain the habitat of the site. In any case, environmental requirements from building permits should be complied with. Maintenance services should comply with things such as the proper application of herbicides, pesticides, and poisons used to control rodents. The use of solvents and heat-transfer fluids should also need to be controlled. Cleaning agents (soap) should be specified to be environmentally friendly (no chlorine bleach) and applied sparingly to avoid over-spray and run-off.

Health and Safety

Managing the risks posed by the solar plant to the health and safety of people, both in and around the plant, is a primary concern of all stakeholders. Solar plants are electricity generating power stations and pose significant hazards present which can result in permanent injury or death. Risks can be mitigated through proper hazard identification, careful planning of works, briefing of procedures to be followed regular and well documented inspection and maintenance (see also 6.10. *Power plant security*).

The dangers of electricity are well known and can be effectively managed through properly controlled access and supervision by the O&M Contractor. Any person accessing a PV plant should expect some form of introduction to ensure they are briefed on any hazards and risks. Staff working on electrical equipment must be appropriately trained, experienced and supervised, but it is also key that others working

BOX 1

Agricultural photovoltaics in India

For vegetation and insects control, it is common practice in India, like in Europe, to use pesticides. An alternative that is used in some parts of Europe is the use of sheep to graze under the solar panels. A prerequisite is of course that the cabling is foreseen in cable trays, or high enough mounting structures so it cannot be touched by the grazers. Also, growing

certain crops in the shadow of the solar panels could be an alternative source of income for people that maintain the Indian solar parks. An upcoming report prepared by the National Solar Energy Federation of India and Fraunhofer ISE, with the support of the Indo-German Energy Forum will explore the potential of Agricultural Photovoltaics in India.



Agricultural solar PV installation in India. © GIPCL

around the equipment - for example panel cleaners - are equally aware of the potential risks and have safe methods of working around HV and LV electricity.

Hazardous areas and equipment should carry appropriate markings to warn personnel of possible hazards and wiring sequence. Such markings should be clear and evident to all personnel and third parties (and intruders) entering the plant premises.

As well as the inherent dangers of a typical solar plant, every site will have its own set of individual hazards which must be considered when working on the plant. An up-to-date plan of hazards is important for the O&M Contractor to use to manage his own staff and

to provide third party contractors with adequate information. It is usually the case that the O&M Contractor holds the authority and responsibility to review and, where necessary, reject works taking place in the plant. Failure to carry this out properly has important consequences to general safety.

Besides workers on the solar plant, it is not unusual for other parties to require access to it. This may be the Asset Owner, or their representative, the landlord of the land, or in some situations members of the public. It is important that the plant access control and security system keeps people away from areas of danger and that they are appropriately supervised and inducted as necessary.

The Asset Owner is ultimately responsible for the compliance of H&S regulations within the site/plant. The Asset Owner must make sure that, at all times, the installation and all equipment meet the relevant legislations of the state and also, that all contractors, workers and visitors respect the H&S Legislation by strictly following the established procedures, including the use of established personal protective equipment (PPE).

At the same time, the O&M Contractor should prepare and operate its own safety management systems to be agreed with the Asset Owner taking into account site rules and the Works in relation to health and safety and perceived hazards. The O&M Contractor should ensure that it complies, and that all subcontractors comply with the H&S legislation.

The Asset Owner will have to require from the O&M Contractor to represent, warrant and undertake to the Owner that it has the competence and that it will allocate adequate resources to perform the duties of the principal contractor pursuant to specific national regulations for health and safety.

Before starting any activity on-site, the Asset Owner will deliver risk assessment and method statements to the O&M Contractor who will provide a complete list of personnel Training Certifications and appoint a H&S coordinator. During the whole duration of the contract the O&M Contractor will keep the H&S file of each site updated.

The O&M Contractor must have his personnel trained in full accordance with respective national legal and professional requirements, that generally result in specific certification to be obtained, for example in order to be allowed to work in MV and/or HV electrical plants.

In order to achieve a safe working environment, all work must be planned in advance, normally written plans are required.

Risk assessments need to be produced which detail all of the hazards present and the steps to be taken to mitigate them.

The following dangers are likely to exist on most solar plants and must be considered when listing hazards in order to identify risks. The severity of any injuries caused are commonly exacerbated by the terrain and remoteness often found on solar plants.

- 1. Medical problems.** It is critical that all personnel engaged in work on solar farms have considered and communicated any pre-existing medical problems and any additional measures that may be required to deal with them.
- 2. Slips, trips and falls.** The terrain, obstacles and equipment installed on a solar farm provide plenty of opportunities for slips, trips and falls both at ground level and whilst on structures or ladders; and for roof-top or carport systems, fall-protection and additional equipment is required when working at heights.
- 3. Collisions.** Collisions can occur between personnel, machinery/vehicles and structures. The large areas covered by solar farms often necessitate the use of vehicles and machinery which when combined with the generally quiet nature of an operational solar farm can lead to a lack of attention. General risks such as difficult terrain, reversing without a banksman and walking into the structure supporting the solar panels require special attention.
- 4. Strains and sprains.** Lifting heavy equipment, often in awkward spaces or from uneven ground, presents increased risk of simple strains or longer-term skeletal injuries.
- 5. Electrocutation.** Operational solar farms whether energised or not present a significant risk of electrocution to personnel. This risk is exacerbated by the nature and voltage of the electricity on site and the impossibility of total isolation. Staff engaged in electrical work obviously suffer the greatest risk but everybody on site is at risk from step potential and other forms of electrocution in the event of a fault. Specific training needs to be given to all those entering a solar farm as to how to safely deal with the effects of electrocution. In addition to general electrical safety, common issues for PV plants include: arc-flash protection when working on energized circuits; and lock-out-tag-out to ensure circuits are not unintendedly energised. Electrocutation becomes particularly important for cleaning personnel, since they often consider cleaning activities as non-electrical tasks.
- 6. Fire.** Several sources of combustion exist on a solar farm, the most common being electrical fire others including combustible materials,

3 Environment, health & safety / continued

flammable liquids, and grass fires. Safe exit routes need to be identified and procedures fully communicated. All personnel need to be fully aware of what to do to both avoid the risk of fire and what to do in the event of a fire.

7. **Mud and water.** Many solar farms have water travelling through them such as streams and rivers, some have standing water, and some are floating arrays. Mud is a very common risk particularly in the monsoon season in India. Mud and water present problems for access as well as electrical danger.
8. **Mechanical injury.** Hand-tools, power tools, machinery as well as such mechanisms as unsecured doors can present a risk of mechanical injury on site.
9. **Weather.** The weather presents a variety of hazards, the most significant of which is the risk of lightning strike during an electrical storm. Due to the metal structures installed on a solar farm an electrical storm is more likely to strike the solar array than surrounding countryside. A solar farm **MUST** be vacated for the duration of any electrical storm. Working in cold and rainy weather can cause fatigue and injury just as working in hot sunny weather presents the risk of dehydration, sunburn, and sun stroke. Working during sunny days for undertaking maintenance and/or test in site lead to sunstroke. To avoid this, drinking sufficient water and staying in the shade is recommended.
10. **Wildlife and livestock.** Although there are no animals allowed inside the plant, as most of the solar power plants are fenced, animals such as rodents, snakes, insects such as wasps and others can present a significant risks. The nature of these risks will vary from place to place and personnel need to be aware of what to do in the event of bites

or stings. Snakes, spiders, ticks, bees and bugs are common and pose a number of hazards where snake bites could be lethal, spider bites can cause pain and inflammation, ticks bites could result in tick bite fever, bees can cause allergic reactions and bugs could fly into people's eyes. Monkeys are also an issue for DC cabling. If proper cabling management is not performed in the DC side, Monkeys are likely to bite and even hang from the cables. It is therefore important that all precautions are taken to prevent or manage these incidents. Storage and application of pesticides, herbicides, and rodent poisons also introduce health and safety hazards. For example, Glyphosate was very common in controlling vegetation at PV plants and has been found to be carcinogenic. Mowing has several hazards including flying objects. Every job at a PV site should have safety precautions identified and implemented.

Everyone entering a solar farm, for whatever reason, should have been trained in the dangers present on solar farms and be trained for the individual task that they will be performed. They should have all of the PPE and tools necessary to carry out the work in the safest way possible. The work should be planned in advance and everyone concerned should have a common understanding of all aspects related to the safe execution of their task. Different countries will mandate written and hard copy paperwork to meet legislation, but best practice is to exceed the minimum requirements and to embrace the spirit of all relevant legislation.

Best practice in H&S sees the ongoing delivery of training and sharing of lessons learned and work methods. By increasing the skills of persons involved in the industry, we can make the industry both safer and more productive.



Personnel & training

It is of critical importance that all O&M Personnel have the relevant qualifications to perform the works in a safe, responsible and accountable manner. Training of personnel at a large scale creates skilled jobs and is also crucial to meet India's increasing demand for solar power.

A solar power plant has multiple operating parts with each having its own significance. At the time of occurrence of fault or at instance of instruction from the grid operator, the personnel at the power plant must be able to execute the instructions properly. A properly trained work force forms a crucial part of the sustainable operations of the power plant. A plant no matter how efficient and sustainable it is, it will only remain so if it is operated responsibly. Inadequate O&M services can decrease the plant efficiency, incur damages to system, and affect health, safety, comfort, and productivity. Grid stability is another issue the O&M provider is responsible for by complying with the grid codes at the local and national levels.

The minimum qualifications required for working in a solar power plant, include a well identified and skilled force with knowledge of the plant scenarios. Typical qualifications for working in a solar power plant may include a degree in electrical engineering or related field of work, with some industry experience in a related field considered advantage.

It is difficult to define exactly the suitable employee profile to carry out the work but in general, it is not advisable to be rigid in the necessary requirements. The necessary knowledge and experience can be gained through different career developments and by different engagements.

The solar industry benefits from a wide range of skills and experience. Team members with a range of electrical, mechanical, financial, business and communications skills are required to handle different tasks and all of them strengthen the positive impact of the service provision.

Everyone who enters a solar plant needs to be trained in the dangers present in addition to their individual skills and experience required for the tasks that they normally perform. Awareness of the necessary health and safety regulations is a must. Additionally, the effect of stepping and/or walking on the modules is still disregarded, and sometimes, unknown. The O&M personal shall always be aware of the big impact of this malpractices while cleaning and performing maintenance works, i.e., reaching *less accessible* PV tables.

After the completion of the EPC phase, it is essential that the EPC provider trains the O&M personnel, and also the Asset Owner about the operation of the solar power plant. For more information on this, see Chapter 12 of the *EPC Best Practice Guidelines on Handover to O&M*.

As the solar industry globally is a growth industry, it follows that skills will need to be taught in order to create a suitable workforce. It is therefore incumbent on all employers in the industry to create a training scheme both internally and externally which creates opportunities for qualifications and development. Whilst it is inevitable that some staff will choose to leave, it is unrealistic to imagine that any company can always employ already skilled and qualified staff.

4 Personnel & training / continued

The creation of a training matrix such as shown the proposed skills matrix in Annex b enables a company to record skills, both formal and informal, to identify gaps and to provide training to fill the gaps.

As the industry grows, there is a rapid rate of technological change as well as emergent best practices, which require a programme of continuous personal development to which both individuals and companies need to be committed.

The matrix goes beyond any educational background and focuses on the skills required by the O&M company in a specific country. Therefore, many of the

skills/requirements are adjustable due to different practices and regulations across India.

For the Indian context, it is important to note the Surya Mitra Skill Development Program (SSDP) under the Skill Council for Green Jobs. The Skill Council for Green Jobs is an initiative of the Government of India, promoted by the Ministry of New and Renewable Energy (MNRE) and the Confederation of Indian Industry (CII). The Skill Council designed the SSDP training programme, which encompasses training modules on solar O&M, among other topics relevant for the solar industry.



In the Indian context, “Operation Planning”, performed by the “Operation Manager” encompasses the activities at the level of the Central Control Room. On the one hand, it comprises monitoring & analytics at the level of the solar power plant portfolio and the oversight of the Local Control Rooms. On the other hand, it also encompasses high-level services to maximise energy production, minimise downtime and reduce costs, such as performance reporting to the Asset Owner, contracts management, invoicing and warranty management. “Operation Planning” corresponds approximately, but not fully, to what is called “Technical Asset Management” in Europe.

In many cases, the O&M Contractor assumes some or most tasks related to Operation Planning in India, such as KPI reporting. The tasks presented in this chapter may be performed by the O&M Contractor or the Asset Owner in-house. In cases where multiple entities are involved in the tasks presented in this chapter, a close coordination and information sharing is indispensable. This involves an integral knowledge about how much a project should be producing for any given time, considering factors such as weather, seasons, or degradation of assets, etc, ensuring long-term energy infrastructure reliability. It represents the entire value chain from investors to Asset Managers and service providers.

For more information about the commercial and financial management of solar investments, please refer to SolarPower Europe’s *Asset Management Best Practice Guidelines (2020)*.

5.1. Technical reporting

The Operation Manager is responsible for preparing and providing regular reporting to the Asset Owner and other stakeholders defined in the agreement between the Asset Owner and the Operation Manager.

The frequency of the reporting can be set daily, weekly, monthly, quarterly or annually (with monthly being the most common and considered a best practice), with specifically defined content for each of these reports. Generating a report for any specific time range in the past can also be possible. Detailed time-series data should also be reported or at least archived in the reporting system in order to improve the correct availability calculations. The spatial resolution of reports should be on the level of each inverter to better detect under-performing sections of the plants managed.

Table 1 includes some proposed quantitative and qualitative indicators which should be in reports as a minimum requirement, a best practice or a recommendation. For more details on the individual indicators, see chapter 11. *Key Performance Indicators*.

A new trend in the industry is to extend the reporting beyond the pure PV plant indicators and to incorporate reporting on the actual activities. This means that both the Asset Manager and the O&M Contractor can operate with an Asset Management Platform, ERP CMMS (Computerised Maintenance Management Systems) in order to measure various O&M KPIs (e.g. Acknowledgement Time, Intervention Time, Reaction Time, Resolution Time) and equipment performance (e.g. Mean Time Between Failures). The Operation Manager should also report on Spare Parts

5 Operation Planning (Central Control Room) / continued

Management and in particular on spare parts stock levels, spare parts consumption, in particular PV modules on hand, spare parts under repair. With the emergence of Predictive Maintenance, the Operation Manager can also report on the state of each individual equipment. Furthermore, the periodic reporting can include information on the status of the security and surveillance system. In this case, the security service provider is responsible for providing the relevant input to the Operation Manager.

On top of the periodical standard reports (monthly, quarterly or yearly) where operations activities are reported by the Operation Manager to the Asset Owner, it is a best practice for the Operation Manager to provide an intermediate operation report when a fault is generating a major loss. A loss due to a fault is considered major when PR and availability are affected by more than a certain threshold throughout the ongoing monitoring (or reporting) period. A best practice is to set this threshold to 1% of Availability or 1% PR within a reporting period of one month. The

TABLE 1 PROPOSED INDICATORS/VALUES REQUIRED FOR THE REPORTING

TYPE OF DATA	PROPOSED INDICATOR	TYPE OF REQUIREMENT
Raw data measurements	Irradiance	Minimum Requirement
	Active Energy Produced	Minimum Requirement
	Active Energy Consumed	Best Practice
PV Power Plant KPIs	Reference Yield	Recommendation
	Specific Yield	Recommendation
	Performance Ratio	Minimum Requirement
	Temperature-corrected Performance Ratio	Best Practice
	Energy Performance Index	Best Practice
	Uptime	Best Practice
	Availability	Minimum Requirement
O&M Contractor KPIs	Energy-based Availability	Recommendation
	Acknowledgement time	Minimum Requirement
	Intervention time	Minimum Requirement
	Response time	Minimum Requirement
Equipment KPIs	Resolution time	Minimum Requirement
	Mean Time Between Failures (MTBF)	Recommendation
	Inverter Specific Energy Losses	Recommendation
	Inverter Specific Efficiency	Recommendation
Environmental KPIs	Module Soiling Losses	Recommendation
	Environmental and Biodiversity KPIs may vary depending on the geography, the micro-climate and the conditions of each site	Best Practice
Incident Reporting	Environmental and Biodiversity KPIs may vary depending on the geography, the micro-climate and the conditions of each site	Best Practice
	Main incidents and impact on production	Minimum Requirement
	Warranty issues	Best Practice
	EH&S issues	Best Practice
	Spare parts stock levels and status	Best Practice
	Physical and Cyber Security Issues	Minimum Requirement
Preventive Maintenance tasks performed	Best Practice	

report should be sent as soon as the fault is acknowledged or solved and should contain all the relevant details related to the fault together with recommendations for Extraordinary Maintenance when the necessary operations are not included in the maintenance contract.

- Typically, this maintenance report should contain: Relevant activity tracks (alarm timestamp, acknowledge time, comments, intervention time, operations on site description, pictures etc) .
- The estimated production losses at the moment of writing the report.
- The estimated production losses for the total duration of the period, counting on the estimated resolution time if the issue is not solved yet.
- The device model, type and Serial Number when the fault is affecting a device.
- The peak power of the strings connected to the device(s).
- The alarm and status log as provided by the device.
- The resolution planning and suggestions. Eventual replacement needed.
- Spare parts available.
- Estimated cost for the extra-ordinary maintenance.

5.2. Oversight of the Local Control Rooms

The oversight of and coordination with the Local Control Room teams is one of the key responsibilities of the Operation Manager. Thus, the Operation Manager is responsible for performance supervision, too: proper oversight of O&M, detecting when systems are underproducing and can quickly and accurately diagnosing an under-performing plant.

5.3. Site visits and non-intrusive inspections

It is recommended as a best practise that Operation Managers undertake a bi-annual site visit in coordination with the O&M provider to perform a non-intrusive visual inspection, address current maintenance issues and plan out in cooperation with the O&M contractor and the ancillary service providers (if different) a maintenance improvement plan.

5.4. Management of ancillary service providers

The O&M Contractor is responsible for managing providers of ancillary (additional) services related general site maintenance such as road management, site security; or on-site measurement such as meter readings and thermal inspections. For more information see section 7.5. on *Additional services*.

This requires managing a process which spans from tendering for those services all the way to assessing the deliverables and reassuring in coordination with the O&M compliance with environmental, health and safety policies.

5.5. Interface with local energy authorities & regulatory compliance

The Operation Manager is responsible for ensuring that the operation of the PV plant is in compliance with the regulations. Several levels of regulation have to be considered:

- Many countries, including India, have a governing law for the operation of energy generating assets or renewable energy and PV plants in particular. This is something the O&M Contractor should be aware of in any case.
- Power Purchase Agreements (PPA) and Interconnection Agreements must also to be known and respected by the Operation Manager.
- Power generation license agreements need to be made available by the Asset Owner to the Operation Manager so that the Operation Manager can ensure compliance with the regulations of these licenses.
- Further to the regulatory compliance, the Operation Manager will be responsible to ensure corporate compliance especially on the new post-subsidy environment which is dictated by corporate PPAs and stricter contractual obligations by the owner.
- Specific regulation for the site such as building permits, environmental permits and regulations can involve certain requirements and the need to cooperate with the local administration. Examples include restrictions to the vegetation management and the disposal of green waste imposed by the environmental administration body, or building permits restricting working time on site or storage of utilities.

5 Operation Planning (Central Control Room) / continued

- It is the O&M Contractor's responsibility to ensure grid code compliance. See 6.7. Grid code compliance especially in a country like India where there are varying compliance requirements depending on the state the plant is situated in. It is the responsibility of the Operation Manager to engage the respective Load Dispatch Center (LDC) on discussions which will minimise outages and identify measures to safe-guard export capabilities.
- Other issues requiring formal compliance include reporting of safety plans and incidents, historic/cultural resource protection, noise ordinances that may limit work at night, and any other regulations imposed by an authority having jurisdiction.

As a minimum requirement the agreement between the Operation Manager and the Asset Owner should list all the relevant permits and regulations and specify that the Asset Owner makes relevant documents available to the Operation Manager.

As a best practice, all regulations, permits and stipulations should be managed within the electronic document management system. This allows the Operation Manager to track reporting and maintenance requirements automatically and report back to the Asset Owner or the administration bodies.

5.6. Warranty management

The Operation Manager can act as the Asset Owner's representative for any warranty claims vis-à-vis the OEM manufacturers of PV plant components. The agreement between the Asset Owner and the Operation Manager should specify warranty management responsibilities of the Operation Manager and the Asset Owner and set thresholds under which the Operation Manager can act directly or seek the Asset Owner's consent. The Operation Manager or the Local Control Room team will then inform the Maintenance team to perform warranty related works on site. Usually the warranty management scope is limited by Endemic Failures (see definition below in this section). Execution of warranty is often separately billable.

For any warranty claims the formal procedure provided by the warranty provider should be followed. All communications and reports should be archived for compliance and traceability reasons.

Objectives of Warranty Management:

- improve the efficiency in complaining processes
- Help to reduce the warranty period costs
- Receive and collect all the warranty complaints
- Support the complaint process
- Negotiate with manufacturers more efficient complaint procedures
- Study the behaviour of the installed equipment
- Analyse the costs incurred during the warranty period

Types of warranties on a PV Plant:

- Warranty of Good Execution of Works
- Warranty of Equipment (Product Warranty)
- Performance Warranty

Warranty of good execution of works and equipment warranties

During the warranty period, anomalies can occur in the facility, which the EPC provider is liable for. The anomalies must be resolved according to their nature and classification, in accordance to what is described in the following sections.

The anomalies or malfunctions that might occur within the facility warranty period might be classified in the following way:

- **Pending Works**, in accordance to the List of Pending Works (or Punch List) agreed with the client during EPC phase.
- **Insufficiencies**, these being understood as any pathology in the facility resulting from supplies or construction, that although done according to the project execution approved by the client, has proven to be inadequate, unsatisfactory or insufficient.
- **Defects**, these being understood as any pathology resulting from supplies or construction executed in a different way from the one foreseen and specified in the project execution approved by the client.
- **Failure or malfunction of equipment**, being understood as any malfunction or pathology

found in the equipment of the photovoltaic facility – Modules, Inverters, Power transformers or other equipment.

Anomalies Handling

During the Warranty Period, all the Anomaly processing should, as a best practice, be centralised by the O&M Contractor, who is responsible for the first acknowledgment of the problem and its framework according to its type and is the main point of contact between the internal organisational structure and the client in accordance to the criteria defined below.

Pending Works, Insufficiencies and Defects

In the case of anomalies of the type "Pending Works", "Insufficiencies" or "Defects", the Operation Manager must communicate the occurrence to the EPC provider, who shall be responsible to assess the framework of the complaint in the scope of the EPC contract, determining the action to be taken.

Resolution of failures in the case of anomalies of the type "Failures"

The Operation Manager should present the claim to the equipment supplier and follow the claims process.

Endemic Failures

Endemic failures are product failures at or above the expected failure rates resulting from defects in material, workmanship, manufacturing process and/or design deficiencies attributable to the manufacturer. Endemic failure is limited to product failures attributable to the same root cause.

Performance Warranty

EPC Contractors usually provide a 2-year performance warranty period after the Commercial Operation Date (COD). During the warranty period, it is the responsibility of the Operation Manager to monitor, calculate, report and follow-up the values of Performance Ratio and other KPIs guaranteed by the EPC Contractor.

Within this scope, it is the responsibility of the Operation Manager to:

- Manage the interventions done within the scope of the warranty in order to safeguard the performance commitments undertaken under the contract.
- Periodically inform the Asset Owner about the condition of the contracted performance indicators.

Immediately alert the Asset Owner whenever the levels of the indicators have values or tendencies that could indicate a risk of failure.

Warranty Enforcement

A warranty may be voided by mishandling or not observing instructions or conditions of the warranty. For example, storing modules improperly onsite, such that the packaging is destroyed by rain, may void a warranty. In another case, partial shading of a thin-film module voids the warranty. Failure to provide adequate ventilation may void an inverter warranty. The manufacturer's warranty might cover replacement but not labour to remove, ship, and re-install an underperforming module. A warranty often gives the manufacturer the option to "repair, replace, or supplement," with "supplement" meaning to provide modules to make up the difference in lost power. For example, if a system has 10,000 modules that are underperforming by 5%, the guarantor could satisfy the performance warranty by providing 500 additional modules to make up for the lost power, rather than replacing the 10,000 modules. However, increasing the plant size by 500 modules to restore guaranteed power might not be possible due to lack of rack space or electrical infrastructure. Also, expanding the system "nameplate" capacity would generally trigger a new interconnect agreement and permitting. Manufacturers also often have the option of paying a cash-value equivalent to the lost capacity of under-performing modules, but as the price of modules declines, this might be less than originally paid for the modules. Given the complications described above, this option is often preferred by system owners unless there is a required level of performance that must be maintained.

5 Operation Planning (Central Control Room) / continued

5.7. Insurance claims

The agreement between the Operation Manager and the Asset Owner should specify insurance management responsibilities of the Asset Owner and the Operation Manager. The Operation Manager will at least be responsible for the coordination of site visits by an insurance provider's representative or technical or financial advisors in connection with the information collection and damage qualification, as well as for the drafting of technical notes to support the reimbursement procedure. The Operation Manager may also be in charge of the coordination of the insurance claim and the liaison with the insurers, brokers and loss adjusters, as well as finding the best insurance providers.

Various risks associated with the life cycle of the plant including liabilities of module manufacturers arising out of the performance and warranty. These include underperformance of solar modules on account of performance degradation, faulty manufacturing, material defects, ageing beyond normal wear and tear degradation, energy shortfalls etc.

Delays in project, drop in power demand, labour shortage may be counted towards insurance claims in case of force majeure conditions as well. Normally in insurance programme loss of revenue due to insufficient labour or suppliers' shutdown, and the alternative risk transfer solutions may be taken up in addition to conventional insurances or such alternative risk transfers could be a component of the already prevailing insurance claims, unlike traditional insurance it shall also pay claims based on severity of an epidemic outbreak. For any insurance claims the formal procedure presented by the insurance provider should be followed. All communications and reports should be archived for compliance and traceability reasons.

Types of insurance related to PV plant O&M include:

- Property insurance, hazard insurance: coverage commensurate with the value of equipment and other improvements to a property; may also cover against other risks if included or unless excluded.
- Commercial general liability insurance: in a form covering all actions by owner or contractors, written on an occurrence basis, including coverage for products and completed operations, independent contractors, premises and

operations, personal injury, broad form property damage, and blanket contractual liability. Liability of a fire started by the PV system has increased required liability coverage levels for PV systems. A liability policy should cover negligence claims, settlements, and legal costs too.

- Inland insurance or marine insurance: insures against loss of equipment in shipping or not on the property premises. Inland insurance is often covered under property insurance policy.
- Workmen's compensation: covers costs for employee accidents.
- Professional liability insurance: insures against errors and omissions often required by board of directors
- Commercial vehicle insurance: insurance for owned and rented vehicles or personal vehicles used on company business
- Warranty insurance: equipment warranty issued by manufacturer but backed up by an insurance company in the event that the manufacturing company goes out of business. Many insurance companies do not offer warranty insurance but rather cover such risk under property insurance.
- Business interruption insurance covers lost revenue due to downtime caused by covered event—this can be important in PPAs where revenue is essential for debt service and O&M expenditures.
- Energy production insurance covers cases when energy production is less than previously specified, which can improve access to debt financing and reduce debt interest rate.

The procedure for making claims described in the insurance policy should be followed to the letter, keeping copies of all submittals and correspondence with the insurance company. The insurance company (claims adjuster) will need to have access to the site provided to them in order to assess damage and to collect the information needed to process the claim.

5.8. Contract management (operational contracts)

The Operation Manager is in charge of ensuring compliance with the operational contracts in place,

such as contracts related land lease, insurance, site security, communications and in some cases component procurement.

The Operation Manager oversees various contractual parameters, responsibilities and obligations of the Asset Owner and the contractual partners linked to the respective solar power plant. Contract management responsibilities depend largely on factors such as geographic location, project size, construction and off-taker arrangements.

As a minimum requirement, the initial step in this process is a comprehensive analysis of the contracts followed by a well-defined Division of Responsibility (DOR) matrix that clearly delineates which entity is responsible for which action on both the short and long term. Upon mutual agreement between the parties, the DOR can serve as the driving and tracking tool for term of life contractual oversight.

As a form of best practice, the Contract Manager's responsibilities often also extend to functioning as the initial contact for all external questions. This allows the Asset Owner optimal access to all areas of the service provider's organisation, and adherence to the contractual responsibilities. The Contract Manager also assumes the responsibility for invoicing of the O&M fees to the Asset Owner.

For quality purposes, the Operation Manager should also track their own compliance with the respective contract, either O&M contract or Asset Management contract, and report to the Asset Owner in full transparency.

5.9. Optimisation of O&M

An essential part of Operation Planning is the analysis of all the information generated across the portfolio throughout O&M, such as Response Time, and how this correlates to the various classification of events and root causes. Another vital aspect of this is the analysis of costs incurred for various interventions, categorised into materials and labour. Having such information helps to further optimise the asset by reducing production losses and the cost of O&M itself.

5.10. Asset optimisation (technical)

Operation Managers also start being responsible for providing data and information analysis on assets they

manage as well as to provide asset optimisation solutions. Primarily based on the following key areas:

- Plant performance
- Operation cost reduction
- Technology adaptation and upgrades (e.g. Revamping and repowering²)
- Technical People management and training

It is the role of the Operation Manager to initiate and coordinate discussions with both the Owners and the O&M Contractors to future-proof the assets and come up with a financial proposal based on data analysis which can assist the owners in making informed decisions.

Note that asset optimisation has commercial and financial aspects too, such as contract optimisation, presented in the Asset Management Best Practice Guidelines.

5.11. Power Generation Forecasting

The Asset Owner or the O&M contractor of the power plant is responsible for the power generation forecasts. Power Generation Forecasting in India is an activity done on the level of the Central Control Room, with support from the Local Control Rooms. As per Indian regulations, generation forecasting is mandatory for utility-scale solar power plants. The requirements for such forecasts may differ from state to state. As solar energy being variable in nature, forecasting is an important aid to effective and efficient planning. In India, scheduling power is a mandatory aspect from year 2012, although the forecasting and scheduling for solar was started sooner. From 2015 onwards, penalty is being levied on any deviations in power injection with respect to scheduled power beyond the permissible limits (both overinjection and underinjection). Although these settlements of deviations vary from state to state, they are in line with the deviation's settlement mechanism notified by the Central Electricity Regulatory Commission (CERC). The solar generators in most of the states are allowed revise their schedules up to 16 times a day and penalty are being levied on them is around injection deviations ranging between

² For detailed information about revamping and repowering, please refer to chapter 8 on *Revamping and Repowering*.

5 Operation Planning (Central Control Room) / continued

±7% to ±15% for a specific time block. Most of the renewable energy rich states have notified their RE specific Deviation Settlement Mechanism (DSM) regulations. While many states levy DSM penalties at fixed rate while other charge them as a percentage of the PPA value. All the solar generators connected to the grid including those connected via pooling station, either selling power via open access or captive consumption fall under these mechanisms.

To predict the exact forecast, O&M providers in India usually use historic data and climate forecasting data to predict the output of their power plants. As a best practice, O&M contractors should use on specialised forecasting services. Forecasting services for PV power generation are generally offered by operators of PV monitoring services, and external services can also provide this function. When the Asset Owner requires Power Generation Forecasting from the O&M Contractor, they could choose a service level agreement with the forecast provider. For long-term planning of unit commitment and maintenance decisions, forecasts with longer time horizons are used, typically one week or more.

PV Power Generation Forecasts rely on numerical weather predictions, satellite data and/or statistical forecasting and filtering methods. Most products combine several of these techniques. Good practice requires numerical weather predictions for day-ahead forecasting and a combination with satellite data for intra-day forecasts. In all cases, good practice requires statistical filtering which in turn requires a near-real-time data feed from the monitoring system to the forecast provider. For best practice, the forecast provider should also be informed about scheduled outages and the expected duration of forced outages.

The most common KPIs for forecast quality are the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). They are normalised to peak power and not to energy yield.

5.12. Environmental management

Depending on local and international environmental regulations, as well as on the Asset Owner's Corporate Social Responsibility (CSR) and Environmental internal policies, the Asset Owner may have incentives to reduce or control negative environmental impacts.

An increasing body of scientific evidence indicates that well-designed and well-managed solar energy can support wildlife habitats and contribute significantly to national biodiversity targets. In fact, solar parks can have several additional advantages over other agricultural landscapes, in that they are secure sites with minimal human and technical disturbance from construction, require little or no use of chemical pesticides, herbicides or fertilizers, and typically incorporate ecological features such as drainage ponds and hedgerows, which can be designed to maximize the value of their habitat.

The approach to managing biodiversity will be different for every solar park, and it is recommended that a site-specific plan be devised in each case.

Therefore, the Asset Manager is obliged to assess the impact or limitations of environmental legislation on the supplier's existing contracts. Furthermore, the Asset Manager is required to develop an action plan to address existing problems and minimise their impact.

As an example, the Asset Manager must oversee the O&M provider's operational field work to ensure compliance with local environmental regulation (use of chemicals to control vegetation, use of diesel cutting machines, etc.); the security contract must be adapted, if possible, according to the wild life existing around the photovoltaic plant and the appropriate security equipment, such as loudspeakers, spotlights and fences, must also be adapted.

Long-term environmental requirements can also include water tank installation, tree clearing, installation of drainage systems, amphibian follow-up, edge plantation, and installation of reptile rock shelters. As a best practice, the O&M Contractor's environmental preservation activities should go beyond legal obligations.

5.13. Health & safety management

The Operation Manager should oversee that the solar asset and the relevant suppliers comply with health & safety (H&S) requirements. If necessary, the Operation Manager should hire an H&S expert to ensure compliance. For more information, see Chapter 3. Environment, Health & Safety.

6

Operation Execution (Local Control Room)

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In the Indian context, “Operation Execution” encompasses the activities at the level of the **Local Control Rooms**, i.e. the control rooms located on-site at the majority of utility-scale solar power plants in India.

Local Control Rooms are in charge of monitoring, supervision and control, as well as coordination of the maintenance activities at the single power point level. “Operation Execution” corresponds approximately, but not fully, to what is called “Power Plant Operation” in Europe. Operation Execution used to be a more

passive exercise in the past, but with increasing grid integration efforts, more active and flexible operation will be required by grid operators. Examples include ordered shutdowns, power curtailment, frequent adjustment of settings such as power factor (source reactive power), frequency tolerances, and voltage tolerances. This section gives an overview of the Operation Execution tasks and requirements.

The following figure provides an overview of the most important tasks associated with Operation Execution.

6 Operation Execution (Local Control Room) / continued

FIGURE 3 OVERVIEW OF THE MOST IMPORTANT TASKS IN OPERATION EXECUTION



PERFORMANCE ANALYSIS AND IMPROVEMENT

The O&M contractor is responsible for the performance monitoring quality. The data, collected for different time aggregation, should be analyzed at the following level:

Minimum requirement

- Portfolio level (Central Control Room)
- Plant level (Local Control Room)
- Inverter level (Local Control Room)

Recommended • String level (Local Control Room)

GRID CODE COMPLIANCE

The O&M provider is responsible to operate the PV plant in accordance with the respective state grid code. The requirements provided by the grid operator are usually:

- Power quality
- Voltage regulation
- Management of active power
- Management of reactive power

The specificities and quality requirements depends on the voltage level of the grid.

REPORTING AND TECHNICAL ASSET MANAGEMENT

The Local Control Room team is responsible for providing periodic reporting to the Central Control Room. For more details see Chapter 5. Operation Planning.

MANAGEMENT OF CHANGE

In the event that the design of a PV power plant needs to be adjusted, the O&M contractor should be involved from the beginning in the following phases:

- Concept
- Design works
- Execution

Implementation of the plant SCADA and monitoring system is required being able to trace all changes, including:

- Documentation of inverter replacement date
- Inverter manufacturer and type
- Inverter serial number

In order to optimize the activities, the adjustments needs to be applied to the following:

- Site Operating Plan
- Annual Maintenance Plan
- Annual Maintenance Schedule

POWER PLANT SECURITY

It is necessary that, together with the O&M Contractor, the Asset Owner put in place a Security protocol in case of intrusion on the PV plant. A specialized security service provider will be responsible for:

- Intrusion systems
- Surveillance systems
- Processing alarms
- Site patrolling

An intrusion system may be formed by:

- Simple fencing or barriers
- Alarm detection
- Alerting system
- Remote closed-circuit television (CCTV) video monitoring
- Backup communication line (recommended)

Process for liaison with local emergency services, e.g. police should be considered

6 Operation Execution (Local Control Room) / continued

6.1. Documentation Management System (DMS)

Solar PV plant documentation is crucial for an in-depth understanding of the design, configuration and technical details thereof. It is the Asset Owner's responsibility to provide those documents and if not available, they should, as best practice, be recreated at the Asset Owner's cost.

Before assuming any maintenance and/or operational activities, it is important to understand in-depth the technical characteristics of the asset. There are two important aspects related to the management of this information:

- Information type and depth of detail / as-built documentation
- Management and control

Moreover, for quality / risk management and effective operations management a good and clear documentation of contract information, plant information, maintenance activities and asset management are needed over the lifetime of the plant. This is what is called here:

- Record control (or records management)

Nowadays, there are different DMSs available and described by a series of standards (ISO) that can be implemented. This is an important requirement that would allow any relevant party to trace any changes during the lifetime of the plant's operation and follow up accordingly (e.g. when the O&M Contractor changes, or the teams change, or the plant is sold etc).

Information type and depth of detail / as-built documentation

The documentation set accompanying the solar PV plant should, as a best practice, contain the documents described in Annex c. The IEC 62446 standard can also be considered to cover the minimum requirements for as-built documentation.

In general, for optimum service provision and as a best practice, the O&M Contractor should have access to all possible documents (from the EPC phase). The Site Operating Plan is the comprehensive document prepared and provided by the plant EPC, which lays out a complete overview of the plant location, layout, electrical diagrams, components in use and reference

to their operating manuals, EH&S rules for the site and certain further topics. All detailed drawings from the EPC need to be handed over to the O&M Contractor and being stored safely for immediate access in case of PV plant issues or questions and clarifications with regards to permits and regulation.

Management and control

Regarding the document control, the following guidelines should be followed:

- Documents should be stored either electronically or physically (depending on permits/regulations) in a location with controlled access. An electronic copy of all documents should be available for all documents.
- Only authorised people should be able to view or modify the documentation. A logbook of all the modifications should be kept. As a best practice, such a logbook should contain minimally the following information:
 - Name of person, who modified the document.
 - Date of modification.
 - Reason of modification and further information, e.g. link to the work orders and service activities.
- Versioning control should be implemented as a best practice. Involved people should be able to review past versions and be able to follow through the whole history of the document.

Record control

A key point is that necessary data and documentation are available for all parties in a shared environment and that alarms and maintenance can be documented in a seamless way. Critical to the Local Control Room team is that the maintenance tasks are documented back to and linked with the alarms which might have triggered the respective maintenance activity (work order management system log). Photographs from on-site should complement the documentation (when applicable) – photo documentation. Tickets (ticket interventions) should be stored electronically and made available to all partners. The Asset Owner should also maintain ownership of those records for future references.

To learn from the past and ongoing O&M and to then be able to improve performance via for example Predictive Maintenance in the following years, it is crucial that all data is stored and that all workflows and alarms are stored to create automatic logbooks of operation and maintenance and alarms. Such data collection together with those acquired by the monitoring tool can be used for further analysis and future recommendations to the client. Such analysis and the respective outcomes should also be recorded.

Last but not least, there should be a proper documentation for the curtailment periods as well as the repairing periods when the plant is fully or partly unavailable. This will all be recorded by the monitoring system to be able to measure lost energy during maintenance activities. For this, having the correct reference values at hand is crucial. For important examples of input records that should be included in the record control, see Annex d.

As in the case of the as-built documentation, all records, data and configuration of the monitoring tool and any sort of documentation and log that might be useful for a proper service provision must be backed up and available when required. This is also important when the O&M Contractor changes.

6.2. Plant performance monitoring and supervision

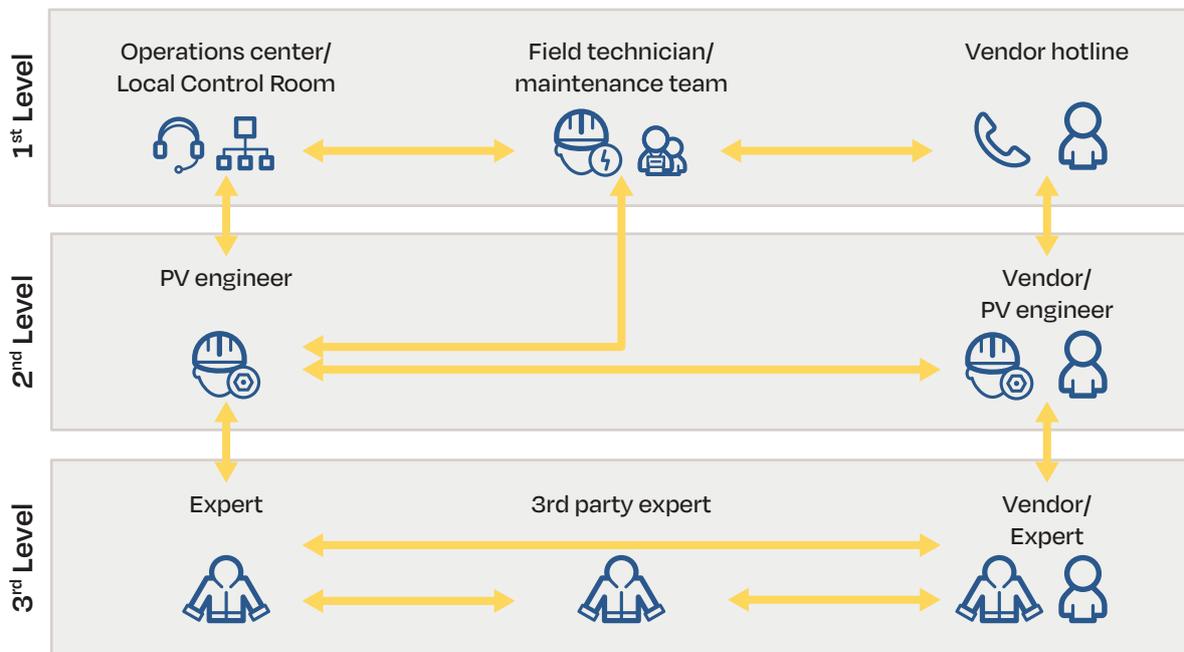
The Local Control Room is responsible for continuous monitoring and supervision of the PV power plant conditions and its performance. In India, this service is done locally by the Local Control Room through the use of monitoring software. The Central Control Room is also able to monitor the solar portfolio. The O&M Contractor should have full access to all data collected from the site in order to perform data analysis and provide direction to the Maintenance service provider/team. Alternatively, if the hierarchy allows it, the Central Control Room will directly manage alarm monitoring and tickets, generating a Work Order that the local control room or O&M team will carry out.

Normally, in **Fault Management (Incident Management)** several roles and support levels interact:

- With the help of monitoring and its alarms the **Local Control Room** detects a fault. It is responsible for opening a “ticket” and coordinates the various actions of troubleshooting. It collects as much information and diagnostics as possible in order to establish an initial documentation, tries to categorise the issue and even to resolve it on the spot. For example by rebooting the communication systems from distance. So, it becomes part of **1st Level Support**. Then it tracks the incidents until their resolution.
- If this does not help or the fault cannot be sufficiently categorised, the Local Control Room may dispatch a field technician, who is a member of the Local Control Room team. They try to analyse and solve the fault on-site (**1st Level Support**). Their knowledge and access rights could be not sufficient for some specific situations, but thanks to their experience they can fix most of the faults or at least create a workaround. They may also contact the **Vendor’s Hotline** to help them with the diagnosis.
- If **1st Level Support** is not able to resolve the incident right away (loss of communication, plant under UPS operation, intrusion detection, among others), it will escalate it to **2nd Level Support**. It consists of **PV engineers** or **Project/Account Managers** who have greater technical skills, higher access permissions, and enough time to analyse the fault in depth. They may be internal or of the Vendor’s staff.
- If the resolution of an incident requires special expertise or access, **2nd Level** engineers might need to contact **experts** (inhouse, Vendor’s or third party’s experts; = **3rd Level Support**). In some organisations the Project/Account Managers can cover both the **2nd** and **3rd** Level Support, based on their seniority and experience.
- When the fault is solved, the Local Control Room closes the ticket.

6 Operation Execution (Local Control Room) / continued

FIGURE 4 SUPPORT LEVELS IN FAULT MANAGEMENT



Besides the data from the site, if a CCTV system is available on site, the O&M Contractor should, as a best practice, be able to access it for visual supervision and also have access to local weather information.

The O&M Contractor is responsible for being the main interface between the plant owner, the grid operator and the regulator (if applicable) over the lifetime of the O&M contract regarding production data. The Local Control Room team should be reachable by the Asset Owner and the Central Control Room via a hotline during daytime, when the system is expected to generate electricity. The Local Control Room team is also responsible to coordinate accordingly with the Maintenance technician team.

For more information on monitoring requirements, see Chapter 10. *Data and monitoring requirements.*

6.3. Performance analysis and improvement

The O&M Contractor (Local Control Room and Central Control Room jointly) makes sure that the performance monitoring is correct.

In general, the data should be analysed down to the following levels:

1. Portfolio level (group of plants) under control of the O&M Contractor (minimum requirement) – responsibility of the Central Control Room
2. Plant level (minimum requirement) – responsibility of the Local Control Room
3. Inverter level (minimum requirement) – responsibility of the Local Control Room
4. String level (as a recommendation) – responsibility of the Local Control Room

The analysis should furthermore show the required data on the specific levels listed above and for different time aggregation periods from the actual recording interval up to monthly and quarterly levels.

The analysis should also include the option for having custom alarms based on client specific thresholds such as for example business plan data or real-time deviations between inverters on-site.

In particular, the agreed KPIs should be computed and reported (see Chapter 11. *Key Performance Indicators*). Special attention should be paid to the fact that such KPI calculations should take into consideration the contractual parameters between O&M Contractor and Asset Owner, in order to provide an accurate and useful calculation for evaluation and eventually liquidated damages or bonuses.

6.4. Power plant controls

If applicable, the Local Control Room team is the responsible contact for the grid operator for plant controls. The Local Control Room team will control the plant (if applicable) or instruct the qualified maintenance personnel to operate breakers/controls on site. The O&M Contractor is responsible for the remote plant controls or emergency shutdown of the plant, if applicable and in accordance with the respective grid operator requirements (see also 6.8. Grid code compliance) and regulations (see 5.2. *Regulatory compliance*). The plant control function varies from state to state. The respective document refers to details in PV plant control regulation which are issued by the respective grid operator and (energy market) regulator.

The Power Plant Controller itself is a control system that can manage several parameters such as active and reactive power and ramp control of PV plants. The set points can normally be commanded either remotely or locally from the SCADA. Moreover, the system should be password protected and log all the executed commands. Any executed commands should release real-time notifications to the Local Control Room team.

The following list shows typically controlled parameters in a PV plant:

- Absolute Active Power Control
- Power Factor Control
- Ramp Control (Active and Reactive Power if needed)
- Frequency Control
- Reactive Power Control
- Voltage Control

6.5. Grid code compliance

The O&M Contractor, and in particular the Local Control Room team with direction from the Central Control Room and the grid operator, is responsible to operate the PV plant in accordance with the respective state and national grid code. The operator of the grid, to which the PV plant is connected (either low voltage grid or medium voltage grid or high voltage grid) provides the requirements for power quality, voltage regulation and management of active and reactive power. In some state (and/or regions) specific grid codes for renewable energy generators and consequently solar PV plants have been issued.

Depending on the voltage level of the grid the plant is connected to, the specificities and quality requirements for the PV plant change. A higher level of the grid usually has more specific and higher quality requirements.

Most of the large solar PV plants in India are required to be controlled and comply with the grid code. The State grid code regulations are for the monitoring grid operations at state level and for supervision over intrastate transmission and distribution networks, hence the grid code and distribution code varies from state to state. Although the grid code vary from state to state, they however move around the framework of IEGC (Indian Electricity Grid Code) which lays out mandatory rules, standards, guidelines by all the power system participants. IEGC provides a regulation which are not just complimentary but mandatory to be followed. The IEGC also considers the variable nature of sources such as solar, hence appropriate mechanism for dealing with deviations are integrated into it. Solar plants are accorded with 'must-run' status and hence they are not subjected to 'merit order despatch' principles. The IEGC provides roles of various organisations and their linkages. In India, the State Load Despatch Centre (SLDC) is the apex body that integrates operation of the power system in a state and works in accordance to the local grid code compliances. The Regional Load Dispatch Centre (RLDC) is apex body for integrated operation in concerned region and the National Load Dispatch Centre (NLDC) are for the supervision of the RLDC. As solar plants have been granted "must run" status, all solar plants above 1MW capacity need to be monitored and should be in direct contact with the respective SLDC, to adjust the power output, to maintain grid security and stability.

6 Operation Execution (Local Control Room) / continued

The O&M Contractor should be familiar with all the details of the grid code and grid operator requirements. Depending on the regulations, the Local Control Room team must manage the plant controller per direction of the grid operator.

6.6. Management of change

In the event that the design of a PV power plant needs to be adjusted after the Commercial Operation Date, the O&M Contractor should, as a best practice, be involved by the Asset Owner and the EPC Contractor and can be a main contributor if not the leader of this change process. Reasons for such changes can be motivated by non-compliance of the PV power plant with the capacity predicted by the EPC, by regulation (introduction of new PV power plant controls regulations), by the unavailability of spare parts or components, or by an interest to upgrade the PV power plant. These events would cause some new design works for the PV power plant, procurement and installation of equipment and will lead to adjustment of operation and maintenance procedures and/or documentation. It may also impact certain performance commitments or warranties provided by the O&M Contractor, which need to be adjusted.

In any such case, the O&M Contractor should be involved in such changes to the PV power plant from the beginning. Concepts, design works and execution need to be coordinated with ongoing O&M activities. Implementation to the plant SCADA and monitoring system is required. For data continuity and long-term analysis, the monitoring system should be able to trace all changes of electrical devices. This should include documentation of inverter replacement date, manufacturer and type, and serial number in a structured way for further analysis (e. g. spare part management, Predictive Maintenance analysis). The monitoring of replaced devices will also facilitate the O&M Contractor to verify that the new component is correctly configured and is sending data of good quality. Adjustments to the Site Operating Plan, the Annual Maintenance Plan and the Annual Maintenance Schedule need to be applied and the O&M Contractor needs to familiarise the O&M staff with the operating manuals of the new equipment. Such change will have a definite impact on Spare Parts Management and inventory (replacement). Depending on the significance of such changes, the O&M annual fee might need to be adjusted.

It is advisable that the O&M Contractor takes the lead in the process of such change. The O&M Contractor is the trusted partner of the Asset Owner and should advise the owner in the decision making of such change processes. In the case of major changes the owner should also consider to inform lenders in the decision process and provide concepts, proposals and calculations.

The fixed O&M fee does not usually cover such services. The Asset Owner and the O&M Contractor should manage changes in a rather formalistic way. This procedure might include the following steps: description of proposed change (including time plan, costs, consequences, and alternatives), authorisation of the change by the Asset Owner, realisation of the change, documentation by the O&M Contractor and acceptance.

6.7. Power plant security

It is important that the solar PV plant, or key areas of it, are protected from unauthorised access. This serves the dual purpose of protecting the equipment of the plant and also keeping members of the public safe. Unauthorised access may be accidental, people wandering into the plant without realising the dangers, or it may be deliberate for the purposes of theft or vandalism.

Together with the O&M Contractor and the security service provider, the Asset Owner will put in place a Security Protocol in case an intrusion is detected.

In most countries there are strict legal requirements for security service providers. Therefore, PV power plant security should be ensured by specialised security service providers subcontracted by the O&M Contractor. The security service provider will be responsible for the correct functioning of all the security equipment including intrusion and surveillance systems as well as processing alarms arriving from the security system by following the Security Protocol and the use of the surveillance systems installed on site. The security system provider will be also responsible for any site patrolling or other relevant services. The security service provider should also assume liability for the security services provided. The O&M Contractor will coordinate with the security service provider and can optionally act as an interface between the Asset Owner and the security service provider.

A security system may be formed of simple fencing or barriers but may also include alarm detection and alerting systems and remote closed-circuit television (CCTV) video monitoring. An access protocol would be required if solar plants have CCTV when reactive and planned works are carried out. This will ensure that authorised access is always maintained. This can be done by way of phone with passwords or security pass codes, both of which should be changed periodically.

For additional security and in high-risk areas it is advised that there is a backup communication line installed (the first thing that gets damaged in case of vandalism is the communication with the surveillance station) as well as an infrastructure for monitoring connectivity and communication with the security system. As well as any remote monitoring, it is likely that provision for onsite attendance is required when significant events occur. Processes for liaison with local emergency services, e.g. police, should be considered.

Within the solar plant, there may also be additional areas with restricted access, for example locations containing High Voltage equipment. When authorising access to the parks it is important that all workers or visitors are appropriately informed of the specific

access and security arrangements and where they should or should not be. Warning signs and notices can form an important part of this and may be mandated depending on local regulations.

As well as the general security of the site over the lifetime of the park, particular attention should be made to periods of construction or maintenance when usual access arrangements may be different. It is important that security is maintained at all times particularly when there are activities that may be of more interest to members of the public, children or thieves.

The Asset Owner will likely have insurance policies in place directly or indirectly and these will be dependent on certain levels of security and response being maintained. Failure to meet these may have important consequences in the case of an accident or crime.

6.8. Support on reporting

The Local Control Room team is responsible for providing periodic reporting to the Central Control Room. For more details on reporting, see subchapter 5.1. on *Technical reporting*.



This chapter is about the various responsibilities and tasks related to the Maintenance of solar power plants.

Maintenance in India is usually carried out on-site by specialised technicians that are part of the Local Control Room team. The Maintenance activities are based on the analyses of the Central and Local Control Rooms.

Figure 5 on the following page provides an overview of the four main types of power plant maintenance.

7.1. Scheduled Maintenance

Scheduled Maintenance (also called Preventive Maintenance) activities are the core element of the maintenance services to a PV plant. It comprises regular visual and physical inspections, as well as verification activities conducted with specific frequencies of all key components which are necessary to comply with the operating manuals and recommendations issued by the Original Equipment Manufacturers (OEMs). It must also maintain the equipment and component warranties in place and reduce the probability of failure or degradation. In India, module cleaning and vegetation control is also considered to be part of Scheduled Maintenance performed by the O&M Contractor itself. (In Europe, module cleaning is often subcontracted by the O&M

Contractor.) The activities should also comply with respective legal issues e.g. national standards for periodic inspection of certain electrical components or environmental requirements when using pesticides. Technical experience and relevant track records will optimise the activities further. The O&M contract should include this scope of services and each task frequency.

This maintenance is carried out at predetermined intervals or according to prescribed OEM and O&M manuals. These are included in a detailed Annual Maintenance Plan which provides an established time schedule with a specific number of iterations for carrying out the maintenance.

It is under the responsibility of the O&M Contractor to prepare the task plan until the end of the contract, following the periodicities or frequencies contracted. These activities should be reported to the Asset Owner. The reporting of this activity is important to follow up the plan.

The "Annual Maintenance Plan" (see Annex e or download it from www.solarpowereurope.org) developed as an attachment of this report includes a list of regular inspections per equipment (e.g. module, inverter etc) and per unit of equipment (e.g. sensors, fuses etc).

FIGURE 5 OVERVIEW OF THE DIFFERENT TYPES OF POWER PLANT MAINTENANCE



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7 Maintenance / continued

An example of Scheduled Maintenance is regular module cleaning as an important part of solar maintenance. The problems associated with soiled modules is often underestimated. Prolonged periods of time between cleans can result in bird droppings etching modules and lichen growth, both of which can be extremely difficult to remove. Module cleaning methods vary from manual, robotic and mechanical. Each have their own advantages and disadvantages. Cleaning frequencies vary greatly on ground, rooftop and floating solar arrays. The frequency of cleaning should be decided on a site-by-site basis and it may be that certain parts of a site will need cleaning more often than other parts of the same site.

When choosing a module cleaning method, the following considerations should be made:

- The suggested method of cleaning is fully in-line with the module manufacturer's warranty and specifications. Pressure washing modules is not an acceptable cleaning method.
- The modules should be cleaned with high quality, ultra-pure water, not tap, mains or borehole water. The water used for cleaning should be low in minerals through a demineralization process. However, this might not be a possibility for every plant size or location. Rainwater is suitable for module cleaning, hence, rain water harvesting could be an economical option in the long run.
- When higher mounting structures are being used with solar panels difficult to be reached, as for example usually the case with co-located Agricultural Photovoltaics, robotic dry cleaning systems may be considered. Special robotic solutions have been developed for trackers also.
- Health and safety considerations should be made in regard to keeping their staff safe on site. This should include some form of health and safety accreditation and specific training for solar module cleaning, including working at height, if cleaning roof mounted modules.
- Cleaning cycles are based on the results of a soiling study that adjusts the cleaning needs to each season.
- Module manufacturer shall approve cleaning methodology (brush, waterless, etc.) in combination with 3rd party laboratory regarding the effect of the cleaning strategy on the anti-reflective coating (ARC) or glass.

Another example of Scheduled Maintenance is thermographic inspection aiming to identify defective panels on a PV plant. Indeed, several categories of anomalies (hot spots, hot strips, moisture ingress, soiling, etc.) can occur, significantly reducing the whole plant productivity. Relevant inspection procedures are performed either by operators with handheld cameras or using remotely piloted drones or piloted aircraft equipped with dedicated thermal and optical payloads. It is noteworthy that aerial thermography as an innovative technology (see subchapter 13.1.1. *Advanced aerial thermography*), can significantly benefit power plant maintenance procedures as it can lead to time and cost savings as well as safety improvements.

Scheduled Maintenance also includes ad-hoc replacement of parts of inverters or sensors (Predictive Maintenance). In general, outside of the equipment warranty terms or after its expiration it is important to follow detailed Scheduled Maintenance procedures, which are agreed upon in the Annual Maintenance Plan.

In cases where downtime is necessary to perform Scheduled Maintenance, its execution during the night would be considered best practice as the overall power generation is not affected.

7.2. Corrective Maintenance

Corrective Maintenance covers the activities performed by the Local Control Room team's site technicians in order to restore a PV plant system, equipment or component to a status where it can perform the required function. The Corrective Maintenance takes place after a failure detection either by monitoring and supervision through the Local Control Room or during regular inspections and specific measurement activities (see *Annex e*).

Corrective Maintenance includes three activities:

1. **Fault Diagnosis** also called troubleshooting to identify fault cause and localisation.
2. **Temporary Repair**, to restore the required function of a faulty item for a limited time, until a Repair is carried out.
3. **Repair**, to restore the required function permanently.

In cases where the PV plant or segments need to be taken offline, the execution of scheduled Corrective Maintenance during night or low irradiation hours would be considered best practice as the overall power generation is not affected.

Corrective Maintenance can be divided into three levels of intervention:

- **1st level:** Intervention to restore the functionality of a device without the need for substituting a component. In general, this kind of Corrective Maintenance includes only labour activity carried out by a specialised technician. This activity could be included in the O&M agreement or billed separately on hourly rates on top of the O&M contract, depending on the specific scope of work agreed between the parties. For example, it could consist of repairing a device that stopped due to a failure.
- **2nd level:** Intervention to restore the functionality of a device that requires substitution of a component. In general, this kind of Corrective Maintenance involves labour activity carried out by a specialised technician (that could belong to the O&M maintenance team or be subcontracted) plus the physical intervention on the device in order to substitute a part of it. An example would be an inverter fan failure where the maintenance team intervenes to substitute the fan in order to restore inverter functionality.
- **3rd level:** Intervention to restore device functionality with a necessity to intervene on the software of the device. In general, this kind of Corrective Maintenance includes both labour activity carried out by specialised technician (that could belong to the O&M maintenance team or be subcontracted) and, often, also an intervention on behalf of the device manufacturer's maintenance team or of other external companies that have been licensed by the device manufacturer to intervene and restore device functionality. This activity could be included in the O&M agreement or billed separately to it, depending on the specific scope of work agreed between the parties. Generally however, this intervention is excluded by the contractual scope of work especially when the device manufacturers' maintenance team or third party licensed company needs to intervene. By way

of an example a 3rd level Corrective Maintenance could involve a device fault without apparent reason or specific broken component that could be restored only through reconfiguration or software update by the manufacturer.

The scope of Corrective Maintenance activities and its "border" or definition with respect to Scheduled Maintenance requires specific attention and it should be properly defined in the Maintenance contract. For an easier comprehension, an example is presented below:

- A cable termination tightening activity using a torque device for the correct fixation should be under the Scheduled Maintenance scope of works, but depending on the quantity and/or frequency, it could be considered a Corrective Maintenance activity.

Usually the Corrective Maintenance is contractually obliged to comply with contractually agreed minimum Response Times (see 11.2.3. *Response Time* and 12.3.2. *Response Time guarantee*).

Contractual agreements can foresee that the included Corrective Maintenance will be capped on a per year basis. Depending on the type of the Asset Owner being a pure financial investor or an energy producer (e.g. utility or IPP) the requirements for coverage under the Corrective Maintenance will vary.

Interventions for reconditioning, renewal and technical updating, save for the cases where those actions are directly included in the scope of the contract, should be excluded from Corrective Maintenance and included in the Extraordinary Maintenance (see 7.3. *Extraordinary Maintenance*).

A key aspect of corrective maintenance is to be able to track failures to their root cause, which is most often a problematic manufacturer/model/serial number but may also be linked to installation errors or environmental conditions such as temperature inside enclosures; also track the efficacy of responses to problems (what fixes the problem reliably?).

7.3. Predictive Maintenance

Predictive Maintenance is a special service provided by O&M Contractors who follow best practices principles. It is defined as a condition-based maintenance carried out following a forecast derived

from the analysis and evaluation of the significant parameters of the degradation of the item (according to IS 12834). A prerequisite for a good Predictive Maintenance is that the devices on-site can provide information about their state, in such a way that the O&M contractor can evaluate trends or events that signal deteriorations of the device. As a best practice, the device manufacturer should provide the complete list of status and error codes produced by the device together with the detailed description of their meaning and possible impact on the function of the device. Additionally, a standardisation of status and error codes through inverters and dataloggers within a same brand should be followed and, in the future, this standardisation should be common to all manufacturers.

The Asset Owner or interested party that wants to benefit from Predictive Maintenance should, as a best practice, select "intelligent" equipment set with sufficient sensors, and opt for an appropriate monitoring software system which should be able to provide basic trending and comparison (timewise or between components and even between PV sites) functionality (minimum requirement).

The Central Control Room, supported by the Local Control Room performs Predictive Maintenance thorough continuous or regular monitoring, supervision, forecast and performance data analysis (e.g. historical performance and anomalies) of the PV plant (at the DC array, transformer, inverter, combiner box or/and string level). This can identify subtle trends that would otherwise go unnoticed until the next circuit testing or thermal imaging inspection and that indicate upcoming component or system failures or underperformance (e.g. at PV modules, inverters, combiner boxes, trackers etc level).

Before deciding which Predictive Maintenance actions to recommend, the O&M provider should implement and develop procedures to effectively analyse historical data and faster identify behaviour changes that might jeopardise systems performance. These changes of behaviour are usually related to the pre-determined or unpredicted equipment degradation process. For this reason, it is important to define and to monitor all significant parameters of wear-out status, based on the sensors installed, algorithms implemented into the supervision system and other techniques.

Following such analysis, the Maintenance team can implement Predictive Maintenance activities to prevent any possible failures which can cause safety issues and energy generation loss.

For an efficient Predictive Maintenance, a certain level of maturity and experience is required, which is at best a combination of knowledge of the respective system's performance, related equipment design, operation behaviour and relevant accumulated experience and track record from the service provider. Normally it is a process that starts after the implementation of an appropriate monitoring system and the recreation of a baseline. Such baseline will then represent the entire PV system operation as well as how equipment interacts with each other and how this system reacts to "environmental" changes.

Predictive Maintenance has several advantages, including:

- Optimising the safety management of equipment and systems during their entire lifetime;
- Anticipate maintenance activities (both corrective and scheduled);
- Delay, eliminate and optimise some maintenance activities;
- Reduce time to repair and optimise maintenance and Spare Parts Management costs;
- Reduce spare parts replacement costs and;
- Increase availability, energy production and performance of equipment and systems;
- Reduce emergency and non-planned work;
- Improve predictability.

The following four specific examples show how Predictive Maintenance might be implemented.

Example 1

An O&M Contractor signs a new contract for a PV plant equipped with central inverters. Analysing its back-log of maintenance, the O&M Contractor knows that these inverters showed several times in the past signs of power loss due to overheating. This might be related to problems in the air flow, filter obstructions, fans or

environmental changes (high temperature during summer). It was decided to monitor the temperature of IGBTs (Insulated-Gate Bipolar Transistors). Before any emergency action might be needed, in case these components have some variations in their behaviour, an "air flow inspection" is performed to detect if this change is related to the air flow. This type of activity is a condition-based inspection performed after the detection of a change in a significant parameter. It is also considered as a type of Predictive Maintenance. The final purpose is to identify if, for example, the ventilation systems will need some upgrade, replacement or if there is any type of air flow obstruction or even if it is required to anticipate replacing or cleaning the filters.

Example 2

The O&M provider detects a possible underperformance of one of the sections inside the PV plant. This could be the power transformer, the inverter or some particular PV generator area that presents a lower performance when compared with others in the same conditions (or past behaviours evidence of loss of production). After the anomaly detection or recognition, an incident is created and immediately sent to the Maintenance team. Before anything happens that might jeopardise contractual guarantees and might need urgent interventions, the O&M Contractor decides to do a "General Infrared Inspection" in the PV field taking general pictures with drones, also known as drones or manned aircraft. The main purpose of this inspection is to identify possible problems related to PV modules that might justify the loss of performance. This is considered as a type of Predictive Maintenance.

Example 3

The O&M provider or the inverter provider monitors all critical parameters of the inverter and can provide information related to the health and performance of each individual inverter as an absolute value or as a relative comparison of different inverters at one PV site, or compare batch of inverters between different PV sites. This type of information can help O&M Contractors to operate PV sites more cost effectively

without compromising the equipment health. On the other side, Asset Manager (or Owner) can also compare how inverters are aging at various sites managed by different O&M companies and evaluate how well their investment is being managed. For instance, one O&M Contractor perceived as more expensive might be providing more regular care to the inverters compared to another; as a result, the inverters are operating in better condition and are not ageing as fast, resulting in less stress and lower expected failure.

Example 4

Predictive maintenance for optimised hardware replacement cycle relying on big data analytics or artificial intelligence. For more information on this innovation, see section 13.1.3. on *Predictive maintenance for optimised hardware replacement*.

7.4. Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant that require substantial activities and works to restore the previous plant conditions or any maintenance activity generally not covered or excluded from the O&M Contract, such as in the case of "Force Majeure" events (see Chapter 2 *Definitions*). Furthermore, it is recommended that O&M contract include clear definitions for Force Majeure events. Extraordinary Maintenance associated with severe weather include: Safety Shutdown; Inspection; Electrical Testing (integrity of circuits and grounding); Remove/repair/replace decisions; and after repairs are completed a Recommissioning confirming proper operation and documenting changes made in the repair.

Generally, these activities are billed separately in the O&M contract and are managed under a separate order. It is advisable that the O&M contract includes the rules agreed among the parties to prepare the quotation and to execute the works. Both a "lump sum turn-key" or a "cost-plus" method can be used for such purposes.

Extraordinary Maintenance interventions are required for:

- Damages that are a consequence of a Force Majeure event.
- Damages as a consequence of a theft or fire.
- Serial defects or endemic failures³ on equipment, occurring suddenly and after months or years from plant start-up.
- Modifications required by regulatory changes.

In case the O&M Contractor was not the EPC of the plant, it is to be considered that also the following occurrence is an Extraordinary Maintenance:

- Major issues of which O&M Contractor becomes aware during its ordinary activity i.e. defects or other problems that are not a consequence of equipment wear or deterioration and that are not of the O&M Contractor's responsibility because they can be reasonably considered to have been caused by design mistakes, quality concerns, installation issues (e.g. e.g. hidden defects that require re-engineering, restructuring, or machinery changes, such as poor load planning, low ampacity cable selection, lower rated MCB used, communication failures, etc.).

Although not necessarily maintenance interventions, also the following revamping and repowering can also be included in the Extraordinary Maintenance list in the O&M agreement, or at least managed with the same rules. For more information on this, see Chapter 8. Revamping and repowering.

After the approval by the Asset Owner of the O&M Contractor's proposal, activities may commence, subject to availability of the required equipment and special machinery (if required).

The potential loss of energy between the event occurrence and full repair generally cannot be considered in the SPV financial model, but it has to be considered that many of the above events are reimbursed to the Asset Owner by the insurance company under any "All Risk Insurance" coverage that is in place.

Best Practices of O&M agreements regarding Extraordinary Maintenance activities include:

- General rules to quantify price and to elaborate a schedule to perform repair activities, and the right of the Asset Owner to ask for third party quotations to compare to the quotation of the O&M Contractor; in this case a "right-to-match" option should be granted to the O&M Contractor.
- The obligation for the Asset Owner to have in place a consistent "All Risk Property" Insurance including loss of profit.

7.5. Additional services

The O&M agreement can foresee services other than those pertaining to electrical and mechanical plant maintenance as per the above sections. Some of these additional services are generally included in the scope of work and the O&M annual fixed fee and some are not.

Additional services not included in the O&M contract scope of work can be requested on demand and can either be priced per service action or based on hourly rates applicable to the level of qualification of staff required to perform the works. These hourly rates usually escalate at the same rate as the O&M Service fee. In some cases, a binding price list for the delivery of some of these additional services can be included in the O&M contract as well.

Table 2 presents a non-exhaustive list of Additional services. For more information on general market trends as regards to whether these additional services are generally included in the O&M agreement or not, see 12.1. *Scope of the O&M contract*.

Note that some of these items can be considered as a part of the Scheduled Maintenance (seasonal module tilting, for instance). This depends on the agreement between the Asset Owner and the O&M Contractor.

³ For a definition of endemic failures and its repercussions in terms of warranty, see → 5.3. *Warranty management*.

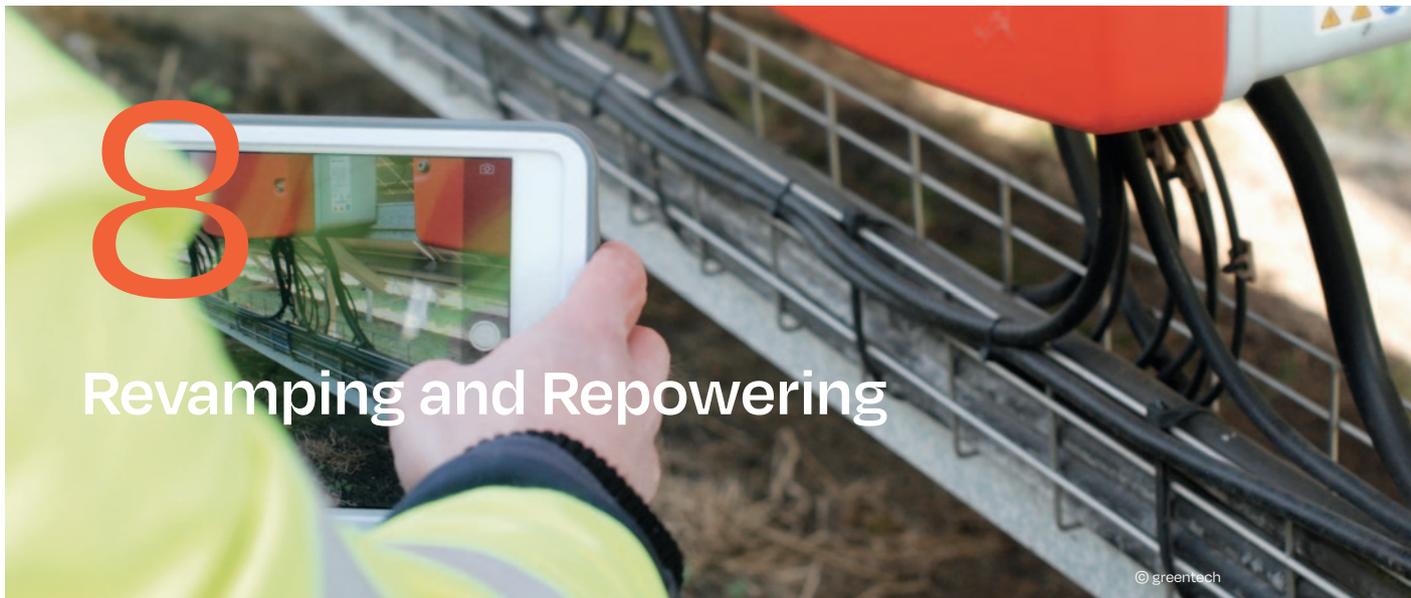
TABLE 2 EXAMPLES FOR ADDITIONAL MAINTENANCE SERVICES

	ADDITIONAL SERVICES
General site maintenance	Pest control
	Waste disposal
	Road management
	Perimeter fencing repair
	Maintenance of buildings
	Maintenance of Security Equipment
On-site measurement	Weekly/monthly meter readings
	Data entry on fiscal registers or in authority web portals for FIT tariff or other support scheme assessment (where applicable)
	String measurements – to the extent exceeding the agreed level of Scheduled Maintenance
	Thermal inspections, I-V curve tracing, electroluminescence imaging (for more information, see the section 10.10. <i>Data collected by specialised PV module field inspections</i>) – to the extent exceeding the agreed level of Scheduled Maintenance

From a technological point of view, the usage of aerial inspections is beneficial to efficiently (time and costs) obtain a context awareness needed to perform better

planning of site maintenance activities as well as execution of on-site measurements (specifically thermal inspections).





Revamping and Repowering

Revamping and repowering are usually considered to be part of extraordinary maintenance from a contractual point of view. Even though revamping and repowering are not a common practice in India yet, due to their increasing significance in the global solar O&M market, these Guidelines are addressing them in a standalone chapter. It is expected that revamping and repowering will become more common in India in the next 2 to 3 years.

8.1. Definition and rationale of revamping and repowering

Revamping and repowering are defined as the replacement of old, power production related components of a power plant by new components to enhance its overall performance. Revamping involves component replacement, but without substantially changing the plant's nominal power, whereas repowering involves increasing it. The differentiation to ordinary replacement lies in the aim to increase the performance by exchanging all components within a functional area or a significant ratio of them. The aspects and consideration in the following sections focus on repowering but apply in most cases also for revamping and even repair and extraordinary maintenance.

There are several reasons, why repowering of solar PV plants can be a necessary and/or beneficial investment. For an overview, see the following figure.

There are numerous ways of repowering a PV plant. In the following we will concentrate on the two most important opportunities of module and inverter repowering.

8.2. Module Repowering

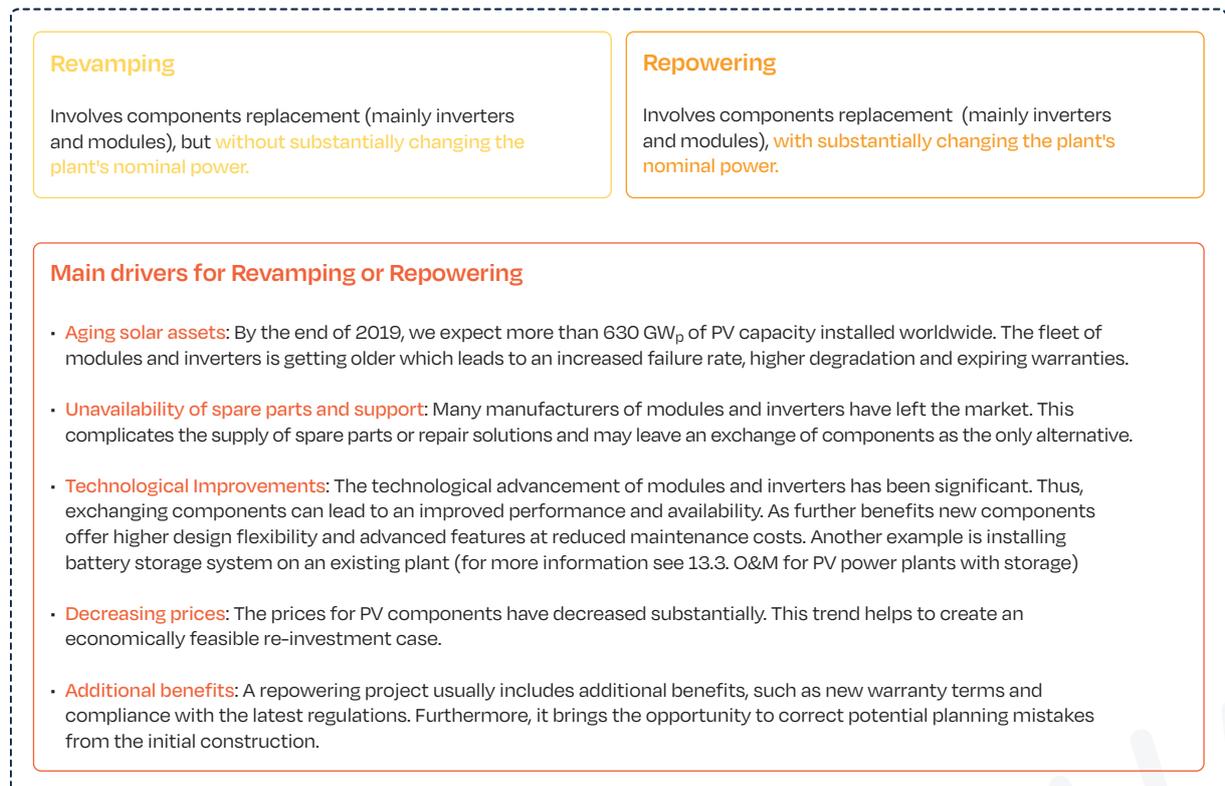
Natural or increased degradation, underperformance or simple defects of modules which are not repairable or available for direct replacement on the market may force the investor to consider a module repowering. This can be carried out for the entire PV plant or for specific parts. When the repowering is focused on a partial module replacement, it is recommended to exchange some more modules than technically required, to keep some intact old modules as spare parts for the future.

Due to the fast development of PV technology it is not very likely that the same components are still available on the market in the required quantity or at a competitive price. Certainly, exchanging the identical modules would make a repowering very simple, but this would also reduce the utilisation of the repowering opportunities in lower price and higher efficiency. In case different modules are to be used for the repowering project, the following aspects need to be considered during planning and executing:

Mechanical installation

- If the modules have different dimensions in height, length and width, the compatibility with the mounting system needs to be considered. Often adaptive challenges can be solved by applying new module clamps but in extreme cases (e.g. changing from thin film to crystalline modules) a new mounting structure needs to be installed.
- In case of higher weight and larger surface of the new module area the structural impacts on the mounting system or the building need to be checked and aligned.

FIGURE 6 DIFFERENCES BETWEEN REVAMPING AND REPOWERING AND THEIR MAIN DRIVERS



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- The new modules need to be integrated into the grounding system as before.

Electrical installation

- Depending on the rated power and the electrical characteristics of the new module type a new string design can be inevitable. The maximum DC power, voltage and current need to be in-line with the inverter requirements.
- A mix of different electrical characteristics at one inverter or at least one MPP tracker should be avoided. Alternatively, bypass diodes can be integrated as protection in case of failures such as reverse current.
- Most likely, the new module type will have different connectors. Therefore, the string cable connector needs to be replaced accordingly.

- The dimensioning of existing cables and fuses needs to be checked and verified to be suitable for the new DC-layout.

Further considerations

- A module repowering might underlie regulatory aspects, which will vary from state to state. The regulatory body should be contacted well in advance in order to clarify aspects such as:
 - Maximum power to be installed
 - Requirements for proving the faults of modules
 - Registration of new modules
 - Disposal of old modules

8 Revamping and Repowering / continued

- Module repowering should be considered as a relevant interference into the electrical system. All affected strings should be tested and documented according to IEC 60364-7-712:2017, IEC 60364-6:2016 and IEC 62446-1:2016 after the repowering project.
- The new string layout could be optimised about shading or DC / AC ratio. Furthermore, an in-depth check of the mounting structures, cables and connectors could be performed.
- If not all modules are being exchanged and power measurements of these modules are being performed, it is recommended to install the old modules according to their remaining power. This means all modules in one string or connected to one MPP tracker should have similar power in order to reduce mismatching losses.
- Depending on the status of the old modules (and the regulatory requirements), they can be either sold to the secondary market or should be disposed or recycled by a professional provider.
- PPA contracts in India generally allow module repowering after commissioning. This is to give developer flexibility for optimal use of AC systems as DC capacity is degraded year-on-year due to module degradation. However as contracted capacity and grid connectivity is limited by AC output, repowering of AC systems (inverter) above contracted capacity is not allowed.
- **Partial or complete exchange:** If not all inverters are affected a partial exchange of the inverter fleet of the PV system can be an option. This potentially reduces the overall costs but it can also increase the complexity regarding the electrical design or the implementation of two different inverter types into one communication concept on-site. If the repowering does not affect all inverters on-site, it is advisable to store the old devices as potential spare parts. Additionally, it can be practical to exchange more inverters than technically required to store those as potential exchange devices for future defects of the old inverter type.
- **Exchange of same or different power class:** Exchanging inverters with the same power class is easier for the DC and AC integration. However, replacing multiple devices through one with a larger power class can increase the system efficiency and reduce the component costs as well as future maintenance costs.

When an inverter repowering is planned, several factors need to be considered:

Mechanical installation

- If the new inverters have different dimensions or weight, a suitable solution for the installation or mounting of the inverter needs to be prepared. The same accounts for a proper cabling if DC or AC connections are changed.
- The manufacturer of the new device might have different requirements for the mounting with regards to fixings, distance to other components or to the roof, ventilation, etc. All requirements need to be checked and implemented.
- The new inverters need to be integrated into the grounding system according to the standards and the manufacturers specifications.

Electrical installation

- The integration of the DC side to the new inverters needs to follow the DC input requirements of the new inverter. Eventually, the string length and the number of connected strings need to be adjusted to suit the technical parameters of maximum current and voltage as well as ideal operational conditions. In case larger inverters will be installed, additional DC combiner boxes might be required and different or additional fuses are to be integrated.

8.3. Inverter Repowering

As all electronic devices, inverters have a limited lifetime. With increasing age and wear, the likelihood of failures and breakdowns increases. If the warranty of the device has expired, a technically and economically suitable solution needs to be identified. Some manufacturers or service providers offer repair and spare parts services. With new components it might even be possible to increase the efficiency of an older inverter, e.g. with a replacement of an old control board with a new device with better performance characteristics, such as MPP tracking. If an identical replacement inverter, repair services or spare parts are not available, the exchange with a new component is inevitable. There are different strategies for inverter repowering which should be evaluated on a case by case basis:

- If different inverter sizes are installed, the integration to the AC side needs to be re-engineered. This includes the cable diameters, protection devices (fuses) and connectors.
- In any case the applicable electrotechnical rules and regulations need to be followed.

Communication system

- Before choosing an adequate inverter, the compatibility with the physical communication cables should be checked.
- The installed data logger needs to support the new inverter's data protocol. Otherwise, an update or the exchange of the data logger will be required.
- If different inverter types are installed, it can be an option to integrate the different component types on different phases of one communication cable or integrate them into one network. The compatibility of the datalogger and the monitoring platform to work with different inverter types at one PV system needs to be validated.

Further considerations

- An inverter repowering might underlie regulatory aspects, which will vary from state to state. The responsible regulatory institution should be consulted well in advance to clarify aspects such as:
 - Maximum power to be installed
 - Compatibility to grid code and plant certificate
- Inverter repowering should be considered as a relevant interference into the electrical system. All affected cables and connectors should be tested and documented according to IEC 60364-7-712:2017, IEC 60364-6:2016 and IEC 62446-1:2016 during the repowering project
- Additional benefits may be utilised during the project. The new inverters could be optimised regarding shading or DC / AC ratio. When the new inverter has advanced features in comparison with the old inverter, e.g. multiple MPP tracker, this could be an additional advantage for the repowering project.
- The noise levels of the inverters may vary, and it should be adequately checked against the permitting and the neighbouring activities.

- Depending on the status of the old inverters, they can be either kept as potential spare parts, sold to the secondary market. If both options are not practical, the devices should be disposed or recycled by a professional service provider.
- New or different maintenance scope and intervals need to be included into the preventative maintenance schedule.
- All involved people should be informed about the changes and accordingly trained regarding preventative and reactive maintenance.

In some cases, inverter repowering is even profitable if the old inverter still operates with full availability, but a new inverter produces more energy due to higher efficiency or better operating conditions.

8.4. General Repowering Considerations

Although, a repowering project is mainly technically driven, for the owner of the PV system it is a commercial re-investment case. Therefore, it is of great importance to calculate a detailed and solid business case before the project and review it during the project stages. All technical and commercial data, such as historical performance, future performance, revenues, costs, extended life span and changed maintenance requirements need to be considered to come up with a prognosis of the future income streams. With this, a classical return on investment or break-even calculation can be performed and presented to the investor as a decision basis.

As an additional analysis, it is recommended to calculate the sensitivities of the most important factors. This will provide a better understanding of the influence of changing conditions, e.g. if the costs for the project will change or the projected performance will be different to the assumptions.

Each repowering activity should be approached as an individual project, which can be structured as follows:

Performance analysis

- Historical yield assessment & identification of performance issues.
- Verification of issues on site with additional inspections or testing.
- Determination of root causes and areas for improvement.

8 Revamping and Repowering / continued

Potential assessment

- Technical feasibility study of different options.
- Commercial analysis, taking investment costs and additional revenues or reduced losses into account.
- Analysis of the regulatory requirements and their implications.
- Risk assessment for the case if the solution does not meet expectations.

Solution Design

- Detailed technical engineering.
- Determination of all costs for time and material.
- Setting up project plan.
- Update commercial analysis with more precise information.

Implementation

- Execution of repowering measures.
- Project management.
- Constant quality control.
- Commissioning and documentation.
- Update of maintenance guidelines.

Review

- Technical evaluation regarding reliability and performance.
- Commercial evaluation regarding costs and return on investment.

A rigorous project management and quality control across all project stages will ensure a realisation of the project in time, budget and quality.



Spare Parts Management

It is important to differentiate between Consumables and Spare Parts.

“Consumables” are items which are intended to be depleted or worn out relatively quickly and then replaced. they are necessary for the regular operation of the PV plant and O&M contractors should always have consumables on stock and maintenance crews should carry consumables with them, together with the relevant tools.

“Spare Parts” are all the items (materials and equipment such as modules or inverters) listed on the “Spare Parts List”, not in use or incorporated in the PV plant, intended to replace similar items in the PV plant.

Spare Parts Management is an inherent and substantial part of O&M that should ensure that spare parts are available in a timely manner for Corrective Maintenance in order to minimise the downtime of (a part of) a solar PV plant. As regards to Spare Parts Management, the following considerations have to be made:

- Ownership and responsibility of insurance
- Stocking level
- Location of storage
 - a. Proximity to the plant
 - b. Security
 - c. Environmental conditions

Although it is best practice for the O&M Contractor to be responsible for replenishing the spare parts stock, it is not necessarily responsible for the full cost of doing so. Some Asset Owners require O&M Contractors to be

fully responsible for the cost of all spare parts within the O&M fee, however, the more cost-effective approach is to agree which are “Included Spare Parts” and which are “Excluded Spare Parts”.

Included Spare Parts are those which the O&M Contractor is to be responsible for within the O&M fee. Excluded Spare Parts are those which the Asset Owner is responsible for the cost of replenishing and do not fall within the O&M Contractor's O&M fee. This is a flexible approach allowing the Asset Owner and O&M Contractor to agree which spare parts fall into which category. It enables both parties to have a level of cost certainty whilst balancing this with the Asset Owner's appetite for risk.

Ownership of spares is often with the Asset Owner from delivery to site or placement in the spares stock. In the case of excluded spare parts, ownership transfers to the Asset Owner from the date that the O&M Contractor receives payment for the same.

Maintenance, storage and replenishment are the responsibility of the O&M Contractor. Besides ownership matters, it is very important to make sure, upon mutual agreement, that one of the parties undertakes the responsibility of insuring the spares: as a recommendation spare parts stored on-site should be insured by the Asset Owner and spare parts stored off-site should be insured by the O&M Contractor.

Note that in India, where the O&M Contractor operates on two levels (the Central Control Room and the Local Control Room), the Spare Part Management should be assumed on the central level for efficiency reasons.

9 Spare Parts Management / continued

For a new PV plant, the initial spare parts for two years from COD are procured by the Asset Owner or the EPC on behalf of the Asset Owner. However, it is best practice for the EPC and O&M Contractor to have agreed upon the list. The O&M Contractor should, as a best practice, recommend additional spares that they deem necessary to meet the contractual obligations (e.g. availability guarantees).

Generally, it is not economically feasible to stock spare parts for every possible failure in the plant. Therefore, the O&M Contractor together with the Asset Owner should define the stocking level of specific spare parts that make economic sense (Cost-Benefit Analysis). For example, if a specific part in a solar PV plant has a frequency of failure at least of once every year or more and the loss of revenues due to such failure is greater than the spare part cost, it is important to have such a spare part kept available. Some very large O&M contractors now propose to own the spare parts in their different warehouses in replacement or addition of the asset owner spares stock. Since they operate a large number of sites, they limit the shortage of unusual spare part by maintaining a small stock.

Regarding the stocking level, due to the very different configurations and sizes of solar PV plants, it is very difficult to define a hard number for stocking specific spare parts, however 0.2% of total module quantity is often found in commercial contracts. Furthermore, the regional portfolio of the O&M Contractor might also influence this and as it was mentioned above, the determination of spare items and quantity is also driven by the O&M Contractor's contractual commitments and guarantees. In an attempt to define the stocking levels of Spare Parts and Consumables, the following parameters should be taken into consideration:

- Frequency of failure
- Impact of failure
- Cost of Spare Part
- Degradation over time
- Possibility of consignment stock with the manufacturer
- Equipment reliability

However, for any given utility scale solar PV system there are certain spare parts that could be considered as essential to have – no matter the cost.

Table 3 on the following page summarises a minimum list. This list is not exhaustive and system requirements and technology developments can lead to this list being updated following discussion with manufacturers, amongst others.

Regarding the storage and warehousing, this should be done in locations where the spare parts cannot be damaged (e.g. by humidity or high temperature variations) and are easily identifiable as being owned by the Asset Owner. Additionally, the storage sites should have appropriate security measures.

The decision of having either on-site or an off-site warehouse facility or just an agreement with the suppliers to provide the spare parts, depends on many factors, including the kind of part, the commercial agreement, and the facilitation of the service provision. If the spare parts owned by the Asset Owner are stored off-site, such spares should be stored separately and be clearly identified as the property of the Asset Owner.

While proximity to the plant is a parameter that needs to be evaluated on a case by case basis, security and environmental conditions are very important as they could lead to a loss of property either through thefts or damage.

TABLE 3 MINIMUM LIST OF SPARE PARTS (NON-EXHAUSTIVE)

NO.	SPARE PART
1	Fuses for all equipment (e.g. inverters, combiner boxes etc) and fuse kits
2	Modules
3	Inverter spares (e.g. power stacks, circuit breakers, contactor, switches, controller board etc)
4	Uninterruptible Power Supply (UPS)
5	Voltage terminations (MV)
6	Power Plant controller spares
7	SCADA and data communication spares
8	Transformer and switchgear spares
9	Weather station sensors
10	Motors and gearboxes for trackers
11	Harnesses and cables
12	Screws and other supplies and tools
13	Specified module connectors (male and female should be from the same manufacturer)
14	Structures components
15	Security equipment (e.g. cameras)





As pointed out in the previous chapters, utility-scale solar power plants have on-site personnel, which are part of the Local Control Room team. In Europe, large-scale plants are usually monitored only remotely. Onsite teams in India do have a value, however an increasing amount of stakeholders realise the value of digitalisation and consequently more automated O&M of the solar parks. When monitoring data are directly pushed to the cloud (when internet allows it in remote areas) the quality of the data is less person dependent and can assure higher reliability. On top an improvement in data quality can show in trend analysis hidden issues over a large period of time that cannot be observed by the human eyes or ears.

In general, the Monitoring System should allow follow-up on the energy flows within a photovoltaic system. In principle, it reports on the parameters that determine the energy conversion chain. These parameters, along with the most important energy measures in terms of yields and losses, are illustrated in the following figure. These yields and losses are always normalised to installed PV power at standard test conditions in kilowatt-peak (kWp) for ease of performance comparison.

Utility-scale solar power plants should have a Monitoring System. The absence of a Monitoring System makes it difficult to trace the performance of the solar system in real-time, let alone get immediate notifications of fault or system downtime. Without a Monitoring System, it is almost impossible to proactively maintain your solar assets. Fixed maintenance schedules and manual checking of the system's condition restricts the optimum care that a solar system need.

Solar PV Monitoring Systems helps you visualise plant's performance data captured through the data loggers. Through these remote monitoring systems, one could see the overall performance of the system as well as the performance of the individual components. Typically, a solar PV plan does not require a control mechanism; however, control features can add values in grid interaction by controlling the operations of various equipment used in the solar PV plant. A Supervisory Control & Data Acquisition (SCADA) system, which is well known in the power industry can play a vital role in further strengthening the O&M of the plant.

All components and different aspects of technical data management and monitoring platforms are described in the following paragraphs. It is also recommended to refer to the Monitoring Checklist of the Solar Best Practices Mark for a synthesis of the most important best practices and recommendation with respect to these points.⁴

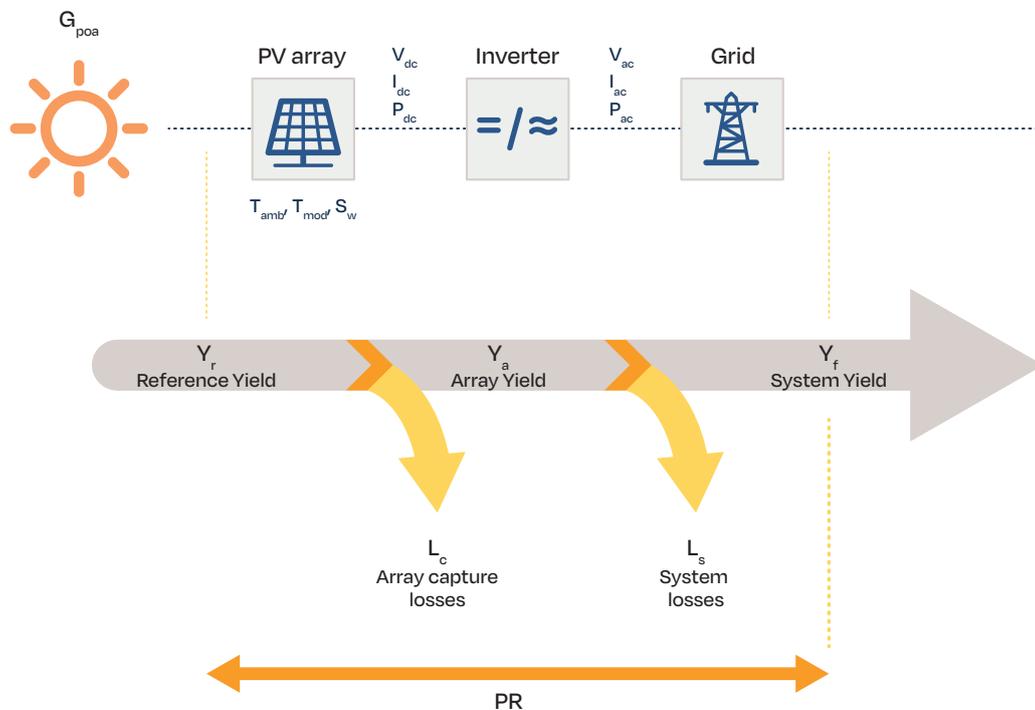
10.1. Data loggers

The main purposes of a datalogger are:

- Collecting data of relevant components (inverters, meteo data, energy meter, string combiners, status signals) with every device registered separately.
- Basic alarm functionality (e.g. Field Communication issues, time critical events like AC Off).
- Provide a temporary data backup (in case of missing internet connection).

⁴ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com

FIGURE 7 ENERGY FLOW IN A GRID-CONNECTED PHOTOVOLTAIC SYSTEM WITH PARAMETERS, YIELDS AND LOSSES⁵



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- Support the technicians during commissioning (e.g. checking whether all inverters work and feed-in).

In addition to this, some dataloggers can also provide the following functions:

- Power Plant Controller (Monitoring & Control should be managed by one instance to avoid communication issues regarding concurrent access). The Power Plant Controller can be integrated in the datalogger or can be a separate device using the communication channel of the datalogger or even a separate specific one with preferential bandwidth.
- Solar Energy Trading Interface (control the active power by a third-party instance like energy trader).

As a best practice, dataloggers installed should be selected following a selection process list of criterion by the operating party as listed below. For example, an EPC Contractor will choose and install the data logger used to monitor the site. This datalogger should be selected:

- For its compatibility with the inverters and auxiliary equipment present on site. Preference for inverter-agnostic dataloggers.
- For any command functionality that may be needed (this is site type and state specific).
- For its connectivity strength to the internet
- For its robustness (longevity of life and durability for the environmental conditions it will be kept in).
- For its, and the cloud server it is connected to, cyber security measures, namely the possibility to set up a VPN tunnel at least.
- For its capability to store data during internet communication outages.

The recording interval (also called granularity) of the datalogging should range from 1 minute to 15 minutes. Within one monitoring environment granularity should be uniform for all the different data collected.

⁵ The figure is redesigned and based on a figure produced by 3E and published in (Woyte et al. 2014).

10 Data and monitoring requirements / continued

As a minimum requirement, data loggers should store at least one month of data. Historical data should be backed up constantly by sending it to external servers and, after every communication failure, the data logger should automatically send all pending information. Moreover, data transmission should be secure and encrypted (see 10.8. Cybersecurity). There should also be a logbook to track configuration changes (especially relevant when acting as Power Plant Controller).

As a best practice, the data logger should store a minimum of three months of data locally and a full data backup in the cloud. Moreover, the operation of the data logger itself should be monitored. Such monitoring should be done out of an independent server remotely and should ideally deliver information on the status of operation of the data loggers on Operating System (OS) and hardware level and also provide alerts to the control room in case of failures and communication loss.

Best practice is to have dataloggers and routers constantly monitored by a watchdog device on site. In case of no response to the control unit, the power supply will be interrupted by the watchdog unit performing a hard reset on the stopped equipment. In cases where it is not possible to have an external watchdog it can be useful to have an automatic reboot function.

The entire monitoring installation should be protected by an uninterruptible power supply (UPS). This includes data loggers, network switches, internet modems/routers, measurement devices and signal converters.

For more information, see also IEC 61724-1 Photovoltaic system performance – Part 1: Monitoring.

For the O&M Contractor it is important that the solar power plant's SCADA is deployed in a standardised way. This means that the taglist from the solar plants is defined in the same way on one plant and in between different plants that use the same SCADA. This way the deployment of the Monitoring System will go much quicker and comparative analysis between parks will be easier.

10.2. Monitoring Portal

The main purposes of the Monitoring Portal are:

- Reading any type of raw data coming from any type of datalogger or other PV platforms with no preference on brands and models.

- Long-term (at least 12 months) archive for all raw data provided by the asset, and ability to compare performance with past data.
- Modelling each PV asset using all available information regarding the actual set up and devices (type of devices, installation/replacement date, modules-string-inverter system layout, modules inclination, orientation, type of installation etc).
- Visualisation of aggregated data in the highest possible granularity (1 to 15 min is a best practice for most of the indicators).
- Visualisation of data in standard and specific diagrams.
- Computation and visualisation on dashboards and views of Key Performance Indicators. For the list of indicators to be computed, see Chapter 11 on KPIs. Indicators computational inputs might be selectable by the user.
- Validation of data quality (e.g. through calculation of data availability).
- Detection of malfunctions, performance deviation as well as long-term degradations with customisable alarms to cater for different plan configurations.
- Handling of alerts about "events" from field devices like SCADA, dataloggers or inverters.
- Calculate typical Key Performance Indicators (such as Performance Ratio and Availability) with the possibility to adapt parameters.
- Provision of consistent and easy to use aggregated KPI for the set up of customizable reports for single plants as well as for portfolios.
- Making data available via a standardised interface for use in other systems.

The monitoring portal should fulfil the following minimum requirements:

- Accessibility level of at least 99% across the year.
- Interface and/or apps dedicated to use cases (on-site service, investor etc).
- Customisable user Access Level.
- Graphs of irradiation, energy production, performance and yield.

- Downloadable tables with all the registered figures
- Alarms register.

As best practice, the following features will also be included in the Monitoring Portal:

- Configurable User Interface to adjust the views depending on the target group (e.g. O&M Manager, EPC, Investor, Asset Manager).
- User configurable alarms.
- User configurable reports.
- Ticket system to handle alarm messages.
- Plant specific KPIs.
- Integrate Third Party Data (e.g. Solar power forecast, Weather data, Satellite data for irradiance).
- Granularity of data should be adaptable for downloads of figures and tables.

The above lists are not exhaustive. For a comprehensive overview of recommended functionalities, refer to the Monitoring Checklist of the Solar Best Practices Mark.⁵

10.3. Data format

The data format of the recorded data files must respect standards such as IEC 61724 and has to be clearly documented. Data loggers should collect all inverter alarms in accordance with original manufacturers format so that all available information is obtained.

10.4. Configuration

The configuration of the monitoring systems and data loggers needs to reflect the actual layout of plant details (hardware brand, model, installation details such as orientation, wiring losses, set up date, ..) in order to perform the better expected performances simulation and obtain consistent insight about plant actual status. Whenever this is not done during the plant construction phase, it should be done at commissioning phase or at plant takeover by a new O&M Contractor (recommissioning of the monitoring system).

During commissioning, each single equipment monitored should be checked to make sure it is properly labelled in the Monitoring System, this can be

done by temporarily covering insolation sensors or switching off others such as string boxes or inverters.

The best practice is to have a Monitoring System capable to read and record all IDs from all sensors and equipment monitored, which will reduce the possibility of mislabelling elements and to trace equipment and sensor replacement along the life of the facility. Some Monitoring Systems have even an auto-configuration feature (plug-and-play) that reduces start-up time and potential mistakes. This is done by capturing automatically the device ID and configuration information. This also allows for automatic inverter or sensor replacement detection.

It is a best practice to have a monitoring system capable or adapting to each user personae, role and scope of responsibility. Based on the custom requirement of the user the platform must be configurable to display relevant KPIs and provide advanced access right user management to ensure that each member of the team has access to his scope of responsibility. Each plant has its own configuration (trackers, string monitoring, irradiance sensors etc.). It is a best practice that the monitoring system offers the ability to customize KPIs to cater for each plant configuration.

10.5. Interoperability

As best practice, the system should ensure open data accessibility (bilateral possibility to receive and send data), in order to enable easy transition and communication between monitoring platforms. Table 4 shows some examples of data integration options. Because of the lack of unifying standards, this is normally not the case and every Monitoring System provider has its own method to store and retrieve data. Best practice systems have the possibility to retrieve data by using open interfaces such as RESTful, providing interoperability between different systems.

Another important aspect of interoperability is the possibility to aggregate data from different platforms that normally serve different scopes of the PV business, such as administration, accountancy, planning & on site intervention, stock management specific applications. This way, the information can be

⁵ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

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exploited by the central monitoring platform without affecting the more specific external applications. For example, an O&M Contractor works with several types of ticketing system for different clients. The monitoring platform should be able to collect data from all of them. On the other side, information of tickets managed from the central monitoring system should be automatically transferred to the dedicated ticketing application.

10.6. Internet connection and Local Area Network

Solar parks in India are mostly installed in remote areas. Having a decent ICT infrastructure in place as a prerequisite for data monitoring is then also not so obvious. Good internet connection from remote solar sites is not always available and grid infrastructure (electricity) is not always reliable. Therefore, good data storage (proportional to the flow and possible downtime duration) on each datalogger/SCADA is key to ensure data integrity.

TABLE 4 EXAMPLES OF DATA INTEGRATION OPTIONS

METHOD	ADVANTAGES	DISADVANTAGES
FTP Push or FTP Pull	Easy to implement No need for additional hardware	Not secure unless: <ul style="list-style-type: none"> • Proper VPN is set up. • Using sFTP or FTPs encryption method. • FTP access control methods implemented. Limited control of data flow to the FTP server
Modbus/TCP (with additional logger on site)	Reliable and secure Best control of data flow	Additional cost for additional hardware More time-consuming implementation Relies on the existing monitoring system hardware, hence, two hardware vendors involved
API (or similar) in the cloud	Fast and easy to implement No need for additional hardware Reliable depending on providers' conditions and communication conditions	Small time lag from data collection to final destination (data pull technology requires automated back-filling technology in case of data gaps or communications issues) Relies on the existing monitoring system vendor, double fees for monitoring (No control over data) API may face data quality issues and limits – data granularity, data depth, availability, correctness, currentness, completeness – depending on the provider's terms conditions (SLAs) and technical abilities
OPC Data Access (DA)/ Unified Architecture (UA)	Whenever a SCADA is installed, OPC method is a reliable method for data acquisition The data acquisition can thus be standardised across the portfolio using this method Data accuracy and reliability is often better	Initial setup costs may apply.

The O&M Contractor should make sure to provide the best possible network connectivity. As a minimum requirement, the bandwidth need to be sufficient to transfer the data in a regular way.

Whenever a fiber connection is available within the PV-site area, this should be the preferred way to connect to the internet, with industrial routers considered as standard. In case a fiber connection is not available, 4G or wifi communication is preferred. Satellite connection is the least preferred communication type. An additional back-up system can be seen as best practice. Any subscription should allow for the data quantity required and should foresee the amount

of data (e.g. Closed-Circuit Television (CCTV) or not) and the granularity of data.

For PV plants larger than 1MW it is advised to have a WAN connection and as an alternative an industrial router that allows for mobile or satellite communication back-up in case the WAN connection fails. A system with an reset capability in case of loss of internet connection is recommended. A direct connection to a monitoring server with a service-level agreement (SLA) guarantees continuous data access. If data passes via alternative monitoring servers without SLA, (e.g. monitoring portal of the inverter manufacturer), this SLA can no longer be guaranteed. The automatic

TABLE 5 PROS AND CONS OF DIFFERENT TYPES OF MONITORING CONNECTIONS

MONITORING CONNECTION	PRO	CON	COMMENT
WIFI	<ul style="list-style-type: none"> • Broadband • Real time monitoring • Easy to set up 	<ul style="list-style-type: none"> • Modem/provider dependent • Requires skilled personnel • Can be intermittent • Possible issues when router is replaced 	In residential installations (e.g. social housing) often no Internet available. In some countries there are regional WIFI providers, which provide a connection better than DSL
LAN	<ul style="list-style-type: none"> • Free • Broadband • Real time monitoring • Reliable 	<ul style="list-style-type: none"> • Modem/provider dependent • Requires skilled personnel • Additional cabling needed 	In residential installations (e.g. social housing) often no internet available LAN is the preferred option in terms of reliability
Cellular 2G/4G	<ul style="list-style-type: none"> • Large geographical coverage • Independent from local internet connection • Remote management • Bi-directional • Plug&play installation • High level of security using VPN • Reliable (depending on the geographical location) 	<ul style="list-style-type: none"> • Subscription based • Real time monitoring requires higher data volume • Easy to implement 	
LPWAN (NB-IoT, LTE-M etc.)	<ul style="list-style-type: none"> • Independent from local internet connection • Remote management • Bi-directional • Good network penetration inside buildings 	<ul style="list-style-type: none"> • Subscription based. • Limited bandwidth, in some case insufficient for real time monitoring 	Not (yet) all cellular providers offer each of these communication technologies Monthly fee to be predicted low
Bluetooth	<ul style="list-style-type: none"> • Free 	<ul style="list-style-type: none"> • Only local monitoring possible • Requires simple pairing protocol 	
LPWAN (LoRa, Sigfox etc)	<ul style="list-style-type: none"> • Independent from local Internet connection • Remote management • Good network penetration inside buildings 	<ul style="list-style-type: none"> • Subscription based with in some case proprietary communication protocols • Limited bandwidth in some case insufficient for real time monitoring • Limited bi-directional communication 	

firmware updates of the data logger should be disabled. Firmware updates are subject to change management procedure with the monitoring service.

All communication cables must be shielded. Physical distances between (DC or AC) power cables and communication cables should be ensured, as well as the protection of communication cables from direct sunlight. Furthermore, cables with different polarities must be clearly distinguishable (label or colour) for avoiding polarity connection errors.

Pros and cons of different types of monitoring connections can be seen in Table 5 on the previous page.

10.7. Data ownership and privacy

The data from the monitoring system and data loggers, even if hosted in the cloud, should always be owned by and accessible to the Asset Owner (or SPV). Stakeholders such as the O&M Contractor, the Asset Manager or auditors during due diligence phases that need the data to perform their duties should be granted access. It is also important to have at least two access levels (read-only, full access).

The monitoring system hardware can be provided by the O&M Contractor or a third-party monitoring service provider (but the monitoring system hardware remains the property of the Asset Owner as part of the installation):

- If the O&M Contractor is the monitoring service provider, the O&M Contractor has full responsibility for protecting and maintaining the data and the proper functioning of the monitoring system.
- In case of a third-party monitoring service provider, the responsibility for protecting and maintaining the data resides with the third-party monitoring service provider. The O&M Contractor should use his best endeavours to make sure the performance monitoring is correct, to the extent possible, considering best practices as mentioned in previous paragraphs. The O&M Contractor's ability to properly maintain and use the monitoring system should be evaluated. If necessary, the O&M Contractor should be appropriately trained to use the monitoring system. Data use by third party monitoring providers should be extremely limited, i.e. for the sole purpose of correcting bugs and developing additional functions to their systems.

10.8. Cybersecurity

Since PV plants will at least include inverters and power plant controllers (and monitoring systems) and these are expected to be accessible from (i.e. connected to) the internet to enable surveillance and remote instructions by operators, they have significant exposure to cybersecurity risks.

Cybersecurity comprises technologies, processes and controls that are designed to protect systems, networks and data from cyber-attacks. Effective cyber security reduces the risk of cyber-attacks and protects organisations and individuals from the unauthorised exploitation of systems, networks and technologies.⁷

Cybersecurity is a vast area and multiple measures are imaginable. The following hints may help as a starting point:

- Keep it simple: If possible, reduce the type of network devices to a minimum.
- As a recommendation, traffic of the network devices may be monitored in order to detect abnormally high use of bandwidth.
- Secure physical access to the network devices and implement a secure password policy. Avoid the use of standard passwords especially, and change all factory setting passwords.
- Control access from Internet via strict firewall rules:
 - Port forwarding should not be used because this is a big security gap. Only router ports that are necessary should be opened.
 - Reduce remote access to the necessary use cases.
 - The use of VPNs (Virtual Private Networks – a secure connection built up from the inside of the private network) is necessary.
 - VPN access to the site from outside is a minimum requirement.
 - A VPN server or VPN service which works without requiring a public IP on-site should be preferred.
 - Each PV plant should have different passwords.
 - Keep your documentation up to date to be sure that no device was forgotten.

⁷ Definition: <https://www.itgovernance.co.uk/what-is-cybersecurity>.

- Use different roles to the extent possible (e.g. read only user, administration access).
- Use professional (industrial grade) hardware; only this hardware provides the security and administration functions your plant needs to be secure.
- Implement vulnerability management (i.e. identifying and remediating or mitigating vulnerabilities, especially in software and firmware):
 - Improve insecure software configurations.
 - The firmware and software of devices should be kept up-to-date.
 - Use anti-virus software if possible and keep it up to date.
 - Avoid wireless access if it is not necessary.
 - Audit your network with the help of external experts (penetration tests).
- Keep your company safe:
 - Do not store passwords in plain text format, use password manager (e.g. 1Password, Keeppass etc.)
 - Train your employees on IT security awareness.
 - Do not share access from all plants to all employees. Give access only to those who need it. This way damage can be prevented in case one employee is hacked.
 - Management of leaving and moving employees; change passwords of plants which are overseen by an employee who have left the company or moved to another department.

It is therefore best practice that installations undertake a cyber security analysis, starting from a risk assessment (including analysis at the level of the system architecture) and implement a cybersecurity management system (CSMS) that incorporates a plan-do-check-act cycle. The CSMS should start from a cybersecurity policy, and definition of formal cybersecurity roles and responsibilities, and proceed to map this onto the system architecture in terms of detailed countermeasures applied at identified points (e.g. via analysis of the system in terms of zones and conduits). These detailed countermeasures will include the use of technical countermeasures such as firewalls, encrypted interfaces, authorisation and access controls, and audit/detection tools. But they

will also include physical and procedural controls, for example, to restrict access to system components and to maintain awareness of new vulnerabilities affecting the system components.

As minimum requirements, loggers should not be accessible directly from the internet or should at least be protected via a firewall. Secure and restrictive connection to the data server is also important.

The manufacturer of the datalogger and the monitoring platform should provide information on penetration tests for their servers, any command protocol activation channels and security audits for their products. Command functions should be sent using a secure VPN connection to the control device (best practice). Double authentication would be an even more secure option.

10.9. Types of data collected through the monitoring system

10.9.1 Irradiance measurements

Irradiance Sensors

Solar irradiance in the plane of the PV array (POA) is measured on-site by means of at least one irradiance measurement device according to Class A quality classification and ISO 9060:2018 (ISO 9060 2018). The calibration of this devices shall be performed by an ISO/IEC 17025 accredited laboratory. The higher the quality of the pyranometer, the lower the uncertainty will be. Best practice is to apply at least two pyranometers in the plane of the PV array. In case of different array orientations within the plant, at least one pyranometer is required for each orientation. It should be ensured that the pyranometers are properly assigned to the different arrays for the calculation of the Performance Ratio (PR) and Expected Yield.

Pyranometers class A are preferred over silicon reference cells because they allow a direct comparison of the measured performance of the PV plant with the performance figures estimated in the energy yield assessment. For plants in Central and Western Europe, measuring irradiance with silicon cells yields approximately 2 to 4% higher long-term PR than with a thermopile pyranometer (N. Reich et al. 2012).

Irradiance sensors must be placed at the least shaded location. They must be mounted and wired in accordance with manufacturers' guidelines.

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Scheduled Maintenance and calibration of the sensors must follow the manufacturers' guidelines.

The irradiance should be recorded with a granularity of up to 15 minutes (minimum requirement).

Further information on the categorisation of plant sizes and the use of appropriate measuring technology is provided in IEC 61724-1.

Satellite-based Irradiance Measurements

In addition to the irradiance sensors, irradiance data from a high-quality satellite-based data service as a complement can be acquired after certain period to perform comparisons with data from ground-based sensors. This is especially useful in case of data loss or when there is low confidence on the data measured onsite by the Monitoring System and it can be considered as best practice. In particular, high quality satellite-based should be used for irradiation sensor data quality assessment. The longer the period considered the lower the error will be for satellite-based irradiation data. For daily irradiation values, the error is relatively high, with root-mean-square error (RMSE) values of 8 to 14% in Western Europe. For monthly and annual values it decreased below 5 and 3%, respectively, which is in line with an on-site sensor (Richter et al. 2015).

When satellite-based irradiance data is used, hourly granularity or less (15 minutes if possible) is recommended. The data must be retrieved once per day at least.

1.0.9.2. Module temperature measurements

Module temperature can be measured for performance analysis in KPIs such as the temperature-corrected PR (see 11.1.2.4. *Temperature-corrected Performance Ratio*).

The accuracy of the temperature sensor, including signal conditioning and acquisition done by the monitoring system hardware, should be better than ± 1 °C.

The temperature sensor should be stuck with appropriate and stable thermally conductive glue to the middle of the backside of the module in the middle of the array table, positioned in the centre of a cell, away from the junction box of the module (Woyte et al. 2013). The installation should be in accordance

with manufacturer guidelines (e.g. respecting cabling instructions towards the datalogger).

PV module temperature is not supposed to be identical for all modules in a plant mainly due to different wind exposure. Therefore, in large plants more sensors will be required across the site because module temperature should be measured at different representative positions, e.g. for modules in the centre of the plant and for modules at edge locations where temperature variation is expected.

The granularity of module temperature data should be at least 15 minutes to perform a correct PR calculation.

1.0.9.3. Local meteorological data

It is best practice to measure ambient temperature, wind speed, rain fall and other site relevant meteorological measurement with the installation of a local meteorological station in accordance with the manufacturers' guidelines. Ambient temperature is measured with a shielded thermometer, e.g. of the PT100 type. The shield protects the sensor from radiative heat transfer. Wind speed is measured with an anemometer, at 10 m height above ground level.

Wind and ambient temperature data are normally not required for calculating PR unless this is a contractual requirement/agreement (e.g. according to specific recommendations such as from NREL). However, they are required when the PV plant is to be modelled in operation or in retrospect.

Additionally, whenever the module temperature measurements are not available or not suitable, wind speed and ambient temperature coupled with installation specifications can be used to retrieve a good estimation of module temperature. In this case, 15 minutes granularity of measurement is still the best practice.

For plants larger than 10 MWp, it is recommended to have automated data collection of independent hourly meteo data (ambient temperature, wind speed, snow coverage, rainfall) from an independent meteo source. The reason for this is that on-site meteorological stations are subject to local phenomena and installation-specific results. Data from an independent meteo-station is less subject to this while being also more stable and robust with respect to long-term drift. They can therefore be used to evaluate the quality, and eventually replace, the on-site measurement.

Therefore, for both performance assessment and detailed analysis purposes, it is recommended to enable automated data collection from a nearby independent meteo reference. However, for performance assessment the most important measurement remains the in-plane irradiation (see 11. *Key Performance Indicators*).

Solar resource data derived from satellite image processing is available from several services at a nominal per-site and per time-segment (such as one week). The measurement error in satellite data might be greater than that of an on-site instrument, but is often more reliable than a mis-aligned, low class or dirty on-site pyranometer and less susceptible to soiling or tampering.

1.0.9.4. String measurements

Individual string current measurements may be deployed when not supported by the inverters. String level monitoring, as compared with inverter level, allows for more precise trouble-shooting procedures. Depending on module technology used in the plant, strings can be combined (in harnesses) which can help reducing operation costs.

In order to detect problems quickly and to increase the plant uptime, it is good to install string monitoring equipment (as a recommendation). Even though some inverter models are not capable to perform this task, there are multiple combiner box solutions in the market that can supply this functionality.

This will constantly measure the current of every string and register those measurements every up to 15 minutes. To reduce costs, the current sensor can potentially measure more than one string, but it is not recommended to parallel more than two of them.

1.0.9.5. Inverter measurements

Inverters have a big amount of values that are constantly measured by its hardware that can be interrogated from the monitoring system and registered. The data sent from the inverter to the monitoring system should, as a recommendation, be cumulative values to allow the monitoring of the overall electricity generation of the inverter even in case of outages of the monitoring system.

Recommended variables to be monitored are:

- Cumulative Energy generated (kWh)
- Instant Active Power injected (kW)
- Instant Reactive Power injected (kVAr)
- Instant Apparent Power injected (kVA)
- AC Voltage per each phase (V)
- AC Current per each phase (A)
- Power Factor / Cos Phi
- Frequency for each phase (Hz)
- Instant DC Power for each MPPT (kW)
- Instant DC Current for each MPPT (A)
- Instant DC Voltage for each MPPT (V)
- Total instant DC Power for all MPPTs (kW)
- Total instant DC Current for all MPPTs (A)
- Average instant DC Voltage for all MPPTs (V)
- Internal temperature (°C)
- Conversion components temperature (°C)
- Inverter failure signals

It should be noted that the precision of inverter-integrated measurements is not always documented by the manufacturers and can be imprecise. For example, energy or AC power measurements taken by inverters may differ substantially from the values recorded by the energy meter. Monitoring systems and reporting should specify and be transparent about the devices used to acquire each measurement.

It is also very useful to have the Monitoring System collecting all inverter alarms as they are a valuable source of information for fault detection. Also, low importance alarms or warnings can be used for the organisation of maintenance activities and even setting up Scheduled Maintenance actions.

In certain cases, the grid connection has limits that must be always respected, such as the maximum AC power that can be injected. For these cases there are two possibilities, one is to set limits using inverter parameters, the second one is to install Power Plant Controller that will change inverter parameters dynamically. In both cases it could be useful to monitor inverter parameters and to program alarms

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so that the O&M Contractor is notified when there is a parameter that has been changed wrongly and does not respect certain limit.

Best practice for the measurement of inverter-based variables is a 15-minute sampling and a granularity of up to 1 minute. For ad-hoc performance analysis purposes e.g. to allow the analysis of PV array performance, root cause analysis or possible MPP-tracking problems, the input DC voltage and current need to be measured and stored separately.

In general, and as best practice, all common inverter parameters should be logged by the data loggers, since there are a lot of additional important parameters such as internal temperature, isolation level etc that could be useful for O&M services.

Inverters should detect overheating of its conversion components to protect themselves under extreme or abnormal operating conditions. Therefore, it is advisable to record the temperature as provided by the inverter so that ventilation performance can be assessed.

1.0.9.6. Energy meter

One of the most important features of a Monitoring System is the automated collection of energy meter data with a granularity of up to 15 minutes. Gathering energy meter data is required for invoicing purposes but it is also the best reference for measuring energy and calculating plant PR and Yield and is much more accurate than using inverter data.

To allow data acquisition via the Monitoring System, it is recommended to have a meter with two communication bus ports as well as Automatic Meter Reading (AMR) service from the Utility or Meter Operator.

Electrical energy exported by the plant is regularly monitored with the use of Joint Meter Readings (JMR). At the end of billing period the JMR data report is used to bill the consumer. A typical JMR, consists of Current and previous readings of both main and check meters, so installed along with their CT and PT ratio from which multiplication factor (M.F.) is calculated. It is essential to follow a prescribed format for JMR, and should reflect data such as, billing date, and meter number. The difference between the readings of check and main meter shall not differ by a factor of 0.5%.

Meter shall have one port for downloading facilities of metered data through Common Meter Reading Instrument (CMRI) and another port/system for remote communication.

Accuracy class of the meters shall be as per the Indian requirements, and meters shall meet the required conditions.

The location of meter to be installed should be:

- At the inverter AC output terminals.
- On each incoming feeder of 3.3 kV and above.
- On the low voltage side of each incoming transformer feeder of low voltage (415 V) buses.

TABLE 6 REQUIRED ACCURACY OF ENERGY METERS IN INDIA

ENERGY ACCOUNTING METERS (UTILITY SCALE)	METER ACCURACY
At Inverter AC output meters Above 132 kV	Not inferior to 0.2s accuracy class addition to other meters with 1.0s accuracy class or better
ENERGY ACCOUNTING METER (DISTRIBUTED SOLAR)	METER ACCURACY
Up to 650V Direct connected	1.0s
Up to 650 volts CT connected	Class 0.5s as per relevant IS where separate CTs are used, or Class 1.0s as per relevant IS for terminal current range meters
Above 650 Volts and up to 33KV	0.5s
Above 33KV	0.2s

1.0.9.7. Control settings

It is important to monitor all control settings of the plant at inverter level as well as grid injection level if available. Many plants apply control settings for local grid regulation (injection management) or optimisation of the market value of the PV generation portfolio (remote control). These settings need to be monitored for reasons of contractual reporting or performance assessment.

1.0.9.8. Alarms

As a minimum requirement, the monitoring system will have the possibility of generating the following alarms and, at the user's discretion, to have them sent by email:

- Loss of communication
- Plant stops
- Inverter stops
- Plant with Low Performance
- Inverter with Low Performance (e.g. due to overheating)

As best practice, the following alarms will also be sent by the monitoring system:

- String without current
- Plant under operation
- Discretion Alarm
- Alarm Aggregation

As a best practice, the following alarms should also be followed by the O&M Contractor, but these alarms are sent by separate systems other than the monitoring system:

- Intrusion detection
- Fire alarm detection

The above lists are not exhaustive. For a comprehensive overview of recommended functionalities, refer to the Monitoring Checklist of the Solar Best Practices Mark.⁸

1.0.9.9. AC circuit / Protection relay

It is recommended to monitor the status of MV switch gear and important LV switches through digital inputs. Whenever possible, it can also be useful to read and register the alarms generated by the protection relay control unit via communication bus.

10.10. Data collected by specialised PV module field inspections

Not all types of data are collected automatically through the monitoring system. Certain data are collected via on-site measurements and field inspections manually or with aerial inspections.

PV modules are engineered to produce electricity for 25-30 years and nowadays are being deployed in ever more and ever bigger large-scale PV plants. Quality assurance is the cornerstone for long-term reliability in order to maximise financial and energy returns and therefore, the need for tracking down the source of failures once the modules are installed becomes vital. For that reason, field technical inspections, such as infrared (IR) thermography, electroluminescence (EL) imaging and I-V curve tracing, are being put into practice in order to assess the quality and performance of PV modules on-site.

Such field inspections can be part of contractual Scheduled maintenance tasks or could be offered as additional services triggered by the O&M contractor in cases where, for example, plant underperformance is not clearly understood just by looking at the monitoring data.

10.10.1. Infrared thermography (IR)

Infrared (IR) thermographic data provides clear and concise indications about the status of PV modules and arrays and are used in both predictive and corrective maintenance.

Depending on its temperature, every object (e.g. a PV module) emits varying intensities of thermal radiation. As explained by Max Planck's theories, this radiation measurement can be exploited for the determination of the actual temperature of objects. Thermal radiation

⁸ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

– invisible to the human eye – can be measured using an infrared camera and is presented in the form of a thermal image. If abnormalities in PV modules occur, this typically leads to higher electrical resistance and thus a change in temperature of the affected module or cell. Based on the visual form and quantifiable temperature differences over the thermal image of a PV module, abnormalities such as hotspots, inactive substrings or inactive modules can be identified.

In order for the thermographic data to be usable, a number of minimum requirements have to be met. Irradiance shall equal a minimum of 600 W/m² and shall be continuously measured on-site, ideally orthogonally to the module surface. Infrared cameras need to possess a thermal resolution of at least 320 x 240 pixels and a thermal sensitivity of at least 0.1 K. Measurements shall be taken at a distance which ensures that the resolution of the infrared image equals 5 x 5 pixels per 6" PV cell. Further requirements are to be found in IEC TS 62446-3 Part 3: Photovoltaic modules and plants – outdoor infrared thermography.

Besides PV modules, IR thermography can also be used to inspect other important electrical components of a PV plant, such as cables, contacts, fuses, switches, inverters and batteries. For more information, see IEC TS 62446-3 Part 3: Photovoltaic modules and plants – outdoor infrared thermography and IEA-PVPS T13-10:2018 report: review on infrared and Electroluminescence imaging for PV Field applications.

IR thermography is the first step to identify anomalies within modules. The frequency of thermography should be dependent on the age of the plant. Manual thermography takes a long time, is highly costly, and data collected is in unstructured format. Advancements in technology has enabled to do IR thermography of site with drones. A detailed write-up on the same can be found in Chapter 13 on *Innovations and trends*. One of the best practice is to conduct a drone-based thermography across the plant twice a year.

The utilisation of IR thermography alone is sometimes not enough to reach a conclusive diagnosis on the cause and the impact of certain PV module failures. Therefore, it is usually combined with the following complementary field tests.

10.10.2. I-V curve tracing on-site

Measurements of the I-V curve characteristic determine the power, short-circuit current, open-circuit voltage and other relevant electric parameters (shunt and series resistance, fill factor) of single PV modules or strings. The shape of the curve provides valuable information to identify failures and it also provides with a quantitative calculation of power losses. A typical outdoors I-V curve measurement setup consists of a portable I-V curve tracer, which in combination with an irradiance sensor (a reference cell usually) and a thermometer is used to measure the PV modules electrical behaviour. Because on-site ambient conditions differ greatly from standardised lab values, the measured results should be translated into STC.

10.10.3. Electroluminescence (EL) imaging on-site

Another technology being deployed on-site for PV module quality control is EL imaging, which allows the identification with great detail of failures such as cell cracks and microcracks, which are invisible to the human eye and usually not conclusively identified by IR.

During the electroluminescence (EL) phenomenon a material emits light in response to the passage of an electric current. This is applied in order to check integrity of PV modules: here a current flows through the PV-active material, and as a result, electrons and holes in the semiconductor recombine. In this process the excited electrons release their energy as light. EL imaging detects the near infrared radiation (NIR), i.e. wavelengths between 0,75 and 1,4 µm. The EL is induced by stimulating single PV modules or strings with a DC current supplied by an external portable power source. The NIR emissions then are detected by a silicon charged-coupled device (CCD) camera. This is usually done in a dark environment because the amount of NIR emitted by the PV modules is low compared to the radiation emitted by the background light and from the sun. This means that EL imaging on-site has to be done usually during the night or while covering the PV modules with a tent. A typical setup consists of a modified single-lens reflex (SLR) camera, a tripod, a portable DC power supply and extension cables. Additionally, a high pass edge filter at 0.85 µm may be used to reduce interfering light from other sources. The resolution of the camera should be at least high enough so that the fingers of the solar cells

in the module can be clearly identified. The noise of the camera output has to be as low as possible (lowest ISO number possible) and the camera should be as steady as possible in order to avoid blurry images. Exposure times of 15 seconds are common.

10.10.4. Fluorescence imaging

UV-Fluorescence imaging is a non-destructive imaging technique for failure analysis of PV-modules. The development of the technique started around 2010 with first publications in 2012 (Köngtes et al, 2012; Schlothauer et al, 2012; Eder et al, 2017; Muehleisen et al, 2018). UV-Fluorescence measurements are performed in dark environment (typically at night) by illumination of the PV-modules with UV-light (<400nm). Most encapsulants show fluorescence in the visible region and thus the material's response can be captured with a photographic camera. No disconnecting nor powering of modules is required.

The observed fluorescence of the encapsulation above the cells with respect to (i) spatial distribution, (ii) intensity and (iii) spectral shift of the fluorescent light is dependent on operation time in the field, climatic conditions as well as type of encapsulant and backsheet used. The fluorescence signal furthermore depends on type of defect like micro cracks in c-Si cells, hotspots or glass breakage

Imaging of PV modules typically takes less than 60 seconds. An example of UV-fluorescence is given in the following figure. The advantages of the technique are that no modifications are necessary to the PV systems and in combination with Electro-Luminescence (EL) also there is potentially an evaluation of timelines possible as the fluorescence signal is a function of time. New cracks for instance are only visible in EL because there was no time to "bleach" the fluorescence signal.

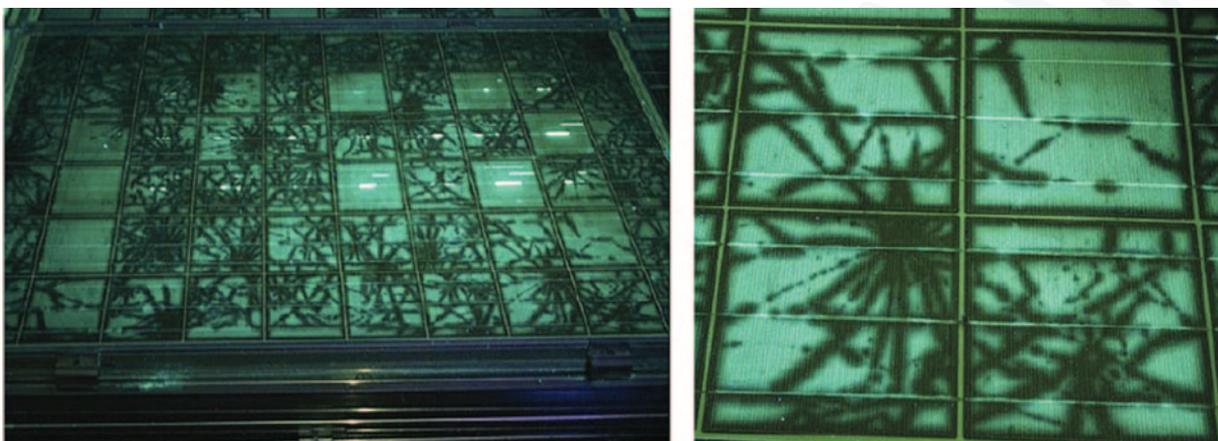
10.10.5. Magnetic Field Imaging (MFI)

Magnetic field imaging (MFI) is a new and innovative method that allows to analyze flowing electric currents non-destructively, contactless and quantitatively.

The underlying physics are very simple: every electric current generates a magnetic field. A magnetic field sensor images this by simply being moved over the current-carrying component. Strength and direction of the electric current can be inferred.

Current-carrying components such as solar cells, modules or batteries have a characteristic current distribution. If components have defects that influence the electrical current distribution significantly, the resulting magnetic field also changes in specific ways. These changes can be detected by MFI and thus traced back to the defects.

FIGURE 8 EXAMPLE UV-FLOURESCENCE IMAGES AFTER A SEVERE HAIL-STORM



SOURCE: Taken from W. Muehleisen (2018).

10 Data and monitoring requirements / continued

The fields of application are manifold. In PV, defects relevant for the operation of solar modules can be detected reliably (Lauch et al, 2018; Patzold et al, 2019). These are, for example, broken connectors or ribbons (see the figure), missing solder joints or defective bypass diodes in the junction boxes of the modules.

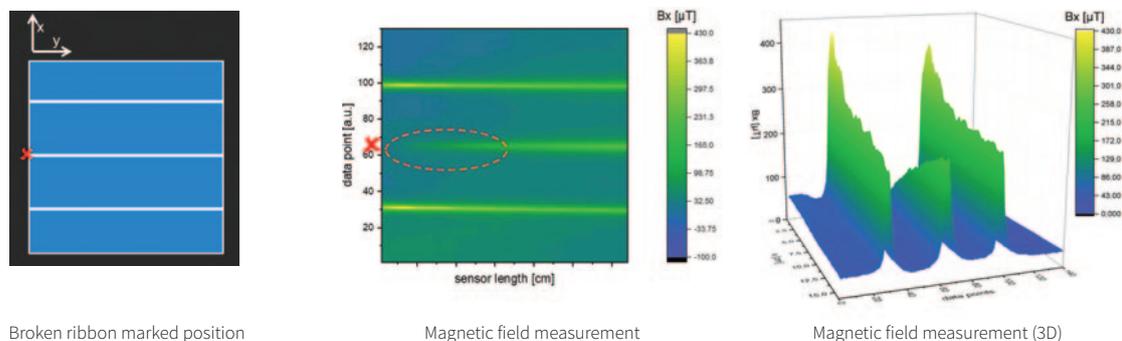
The advantages of the measurement technique that it is non-destructive, fast and quantitative (the measurement signal is proportional to the underlying electric current). A disadvantage of using magnetic fields is that the distance to the sample must be low, in the millimeter range, to result in high quality imaging results. The measurement cannot resolve microscopic structures ($< 100 \mu\text{m}$), yet.

10.10.6. Soiling measurements

The operational efficiency of modules is affected by soiling accumulation. Soiling limits the effective

irradiance and, therefore, the output of the PV module. It is recommended to measure soiling in order to optimise cleaning schedules and thus revenues. Several methodologies exist for soiling monitoring, the most basic being human inspections. A widely used soiling measurement method is using ground-based soiling reference modules consisting of a module that remains soiled, a cleaned reference cell, an automatic washing station and measurement electronics. There are several variations employing different principles to measure the effect of soiling. Upcoming digital solutions for soiling monitoring include the analysis of satellite imagery with remote sensing techniques, machine intelligence algorithms and statistical methods. Possible soiling analyses include taking a swab of the soil to an independent analytical laboratory to determine its nature (diesel soot; pollen; organic soil; inorganic dust), the appropriate cleaning solution and the effect on the latter on the glass and ARC coating.

FIGURE 9 EXAMPLES OF MAGNETIC FIELD IMAGING (MFI)



SOURCE: Lauch et al, 2018; Patzold et al, 2019.

NOTE: Schematic of 3 BB solar cell, „x“ indicates the position of broken ribbon; center: Bx magnetic field in 2D representation and more visual 3D on the right side.

11

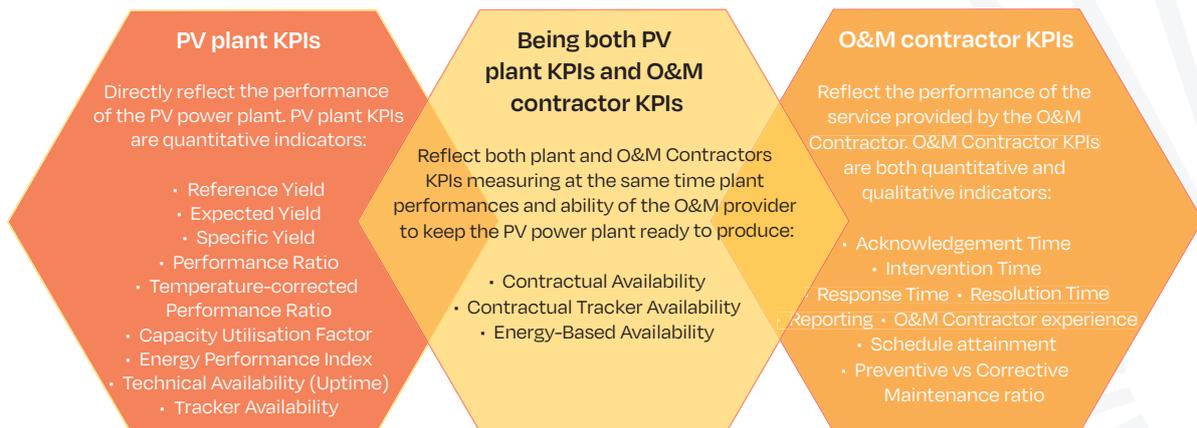
Key Performance Indicators

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This section deals with Key Performance Indicators (KPIs), which provide the Asset Owner with a quick reference on the performance of the PV power plant. The KPIs are divided into the following categories:

- PV plant KPIs, which directly reflect the performance of the PV power plant. PV plant KPIs are quantitative indicators.
- O&M Contractor KPIs, which reflect the performance of the service provided by the O&M Contractor. O&M Contractor KPIs are both quantitative and qualitative indicators.
- PV plant/O&M Contractor KPIs, which reflect PV power plant performance and O&M service quality at the same time.

FIGURE 10 OVERVIEW OF DIFFERENT TYPES OF KPIs



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11 Key Performance Indicators / continued

Note that KPIs related to revenue generation are treated in the *Asset Management Best Practice Guidelines*.

The O&M Contractor is generally responsible for the calculation of the KPIs and reporting to the Asset Owner, see 5.1. *Reporting*.

It is important to underline that the O&M Contractor cannot and is thus not responsible for providing contractual guarantees for all the KPIs listed in this chapter. For more information on suggested contractually guaranteed KPIs, see 12.3. *Contractual guarantees*. When they are warranties in place it is strongly advised that the party liable for the warranties is not the only one to calculate the KPIs.

Another important note is related to data quality. Solar power plants, particularly in India, are often situated in remote areas, and sometimes even in harsh places. Therefore, equipment and systems are subject to difficult conditions and are often subject to data quality issues, such as false negative values, outliers, spikes, data gaps and junk values. The nature of these data quality issues are very diverse, depending on the plant, type of measurement or systems in place. It is therefore difficult to implement an overall and systematic data quality strategy. These data quality issues are obvious and may impact many KPIs which are calculated on this basis. Biased KPIs leads to unnecessary operations costs (unrequired onsite intervention) and performance losses, since defects may remain undetected. What is more challenging to identify, are slight and progressive data deviations overtime. As a best practice, the monitoring solution and system should be capable of filtering these values in the most automated but also personalised way to cater for each specific case.

11.1. PV power plant data

PV power plant data can be split into two groups:

1. Raw data measurements: data obtained directly from the PV plant and used for performance calculation.
2. PV power plant KPIs using the raw data from the PV plant to give a more balanced overview of the operation of the PV plant.

11.1.1. Raw data measurements for performance calculation

The following is a list of raw data measurements that can be used to calculate KPIs:

- AC Apparent Power produced (kVA)
- AC Active Power (kW)
- AC Energy produced (kWh)
- AC Energy metered (kWh)
- Reactive power (kVAR)
- Irradiance⁹ (reference for the plant or the sub-plants) (W/m²)
- Air and module temperature (Celsius degrees)
- Alarm, status code and duration
- Outages, unavailability events

This is a basic list and it is non-exhaustive.

11.2. PV power plant KPIs

Calculated KPIs give a more balanced view of the operation of a PV plant as they take into account the different operating conditions for each plant. Suggestions for calculated KPIs along with relevant formula can be found below. These KPIs can be calculated over different time periods, but often they are computed on an annual basis. When comparing different KPIs or different PV power plants' KPIs, it is important to keep consistency in the time period used in computation.

11.2.1. Reference Yield

The Reference Yield represents the energy obtainable under standard conditions, with no losses, over a certain period of time. It is useful to compare the Reference Yield with the final system yield (see 11.1.2.3. *Performance Ratio*).

⁹ Although irradiance and irradiation are often used as synonyms, they do not express the same physical quantities and should not be used interchangeably (see IEC 61724-1:2017):

- Irradiance is the power of the sunlight at a specific moment per unit of area, usually expressed in Watt per square meter (W/m²).
- Irradiation is the power of the sunlight integrated over a period of time, e.g. an hour, a day or a year. In other words, irradiation is the energy per unit of area calculated as the sum of irradiances over a period of time. It is commonly expressed in kilowatt-hour per square meter (kWh/m²).

The Reference Yield is defined as:

$$Y_{r(i)} = \frac{H_{POA}}{G_{STC}}$$

Where:

$Y_{r(i)}$ = Reference Yield for the time period i expressed in peak sun hours (h) or (kWh/kW)

$H_{POA(i)}$ = Is the measured irradiation on modules' plane for the time period i (kWh/m²)

G_{STC} = The reference irradiance at standard test conditions (STC) (1,000 W/m²).

11.2.2. Specific Yield

Specific Yield is the measure of the total energy generated per kW_p installed over a certain period of time.

This measure is generally calculated at plant AC energy metered. In both cases it indicates the number of full equivalent hours a plant produced during a specific time frame.

Specific Yield is calculated as follows:

$$Y_i = \frac{E_i}{P_o}$$

Where:

Y_i = Plant Specific Yield for the time period i , expressed in (kWh/kW_p) or peak sun hours (h)

E = Plant energy production or Plant energy metered for the time period i (kWh)

P_o = Plant Peak DC power (nominal power) (kW_p)

This measurement normalises plant output over a chosen time frame and thus allows the comparison of the production of plants with different nominal power or even different technologies (e.g. PV, wind, biomass etc). For example, the Specific Yield of a PV Plant can be compared against the Specific Yield of a wind plant for investment decision taking or the Specific Yield of a 5 MW_p ground mounted PV plant can be compared directly to a 1 MW_p double tracker PV plant's Specific Yield.

Calculating Specific Yield on the inverter level also allows a direct comparison between inverters that may have different AC/DC conversion rates or different nominal powers. Moreover, by checking inverter level Specific Yield within a plant, it is possible to detect whether an inverter is performing worse than others.

11.2.3. Performance Ratio

The Performance Ratio (PR) is a quality indicator of the PV plant. As the ratio between the actual Specific Yield and the theoretically possible Reference Yield, PR captures the overall effect of losses of the PV system when converting from nameplate DC rating to AC output. Typically, losses result from factors such as module degradation, temperature, soiling, inverter losses, transformer losses, and system and network downtime. The higher the PR is, the more energy efficient the plant is.

PR, as defined in this section, is usually used to report on longer periods of time according to the O&M contract, such as day, month or year. Based on PR, the O&M Contractor can provide recommendations to the plant owners on possible investments or interventions.

Performance Ratio is defined as:

$$PR = \frac{Y_f}{Y_r} \times 100$$

Where:

PR = Performance Ratio over a year (%)

Y_f = Specific Yield over a year (also called final yield) expressed in (kWh/kW_p) or peak sun hours (h)

Y_r = Reference Yield over a year expressed in (kWh/kW_p) or peak sun hours (h)

These definitions are based on (Woyte et al. 2014) in line with the IEC 61724-1:2017 and are common practice.

PR is measured for available times (see 11.4.1. *Contractual Availability*) at the inverter or plant level.

Note that special attention is needed when assessing the PR of overrated plants, where the output of the plant is limited by the inverter maximum AC output. In such situations and for the period that overrating takes place, PR will calculate lower than normal although there is no technical problem with the plant. Stakeholders should be careful assessing PR values for overrated plants, although the amount of overrating is normally statistically constant or with negligible differences on a yearly basis.

11 Key Performance Indicators / continued

11.2.4. Temperature-corrected Performance Ratio

In some situations, such as a commissioning test or PV power plant handover from one O&M Contractor to another, PR needs to be measured over a shorter time period, such as two weeks or a month. In such situations, it is recommended to use a PR formula corrected with temperature factor in order to neutralise short-term PR fluctuation due to temperature variations from STC (25°C). As a best practice, temperature should be registered with a granularity of up to 15 minutes (referred to as time period j below) and the average temperature for the time period i should be calculated by weighting the mean temperatures of the time periods j according to Specific Yield of this time period.¹⁰

Temperature-corrected PR can be defined as follows:

$$PR_{TO(i)} = \frac{Y_i}{Y_{r(i)} \times \left[\left(1 - \frac{\beta}{100} \times (T_{MOD(i)} - 25^\circ\text{C}) \right) \right]} \times 100$$

Where:

$PR_{TO(i)}$ = Temperature-corrected Performance Ratio for the time period i (%)

Y_i = Plant Specific Yield for the time period i , expressed in (kWh/kW_p) or peak sun hours (h)

$Y_{r(i)}$ = Reference Yield for the time period i , expressed in (kWh/kW_p) or peak sun hours (h)

β = Temperature coefficient for P_o that corresponds to the installed modules (%/°C).

P_o = Plant Peak DC power (nominal power) (kW_p)

$T_{MOD(i)}$ = Average module temperature for the period i , weighted according to Specific Yield Y_j (°C)

$$T_{MOD(i)} = \frac{\sum_{j=1}^i Y_j \times T_{MODMEAS(j)}}{\sum_{j=1}^i (Y_j)}$$

Where:

Y_j = Plant Specific Yield for the time period j ($j \leq 15$ minutes), expressed in (kWh/kW_p) or peak sun hours (h)

$T_{MODMEAS(j)}$ = Average measured module temperature for the time period j ($j \leq 1$ hour) (°C)

11.2.5. Capacity Utilisation Factor

The Capacity Utilisation Factor (CUF) is the ratio between the actual energy production of the solar power plant to the potential output at Standard Test Conditions (STC). The CUF is an KPI often used in India for solar power plants. It is expressed as a percentage and usually measured over a year. In India, CUF for solar ranges between 17%-25%, mainly influenced by the solar irradiation across the country. The CUF does not consider on-site environmental, de-rating and degradation factors, grid availability, etc, hence, a separate degradation factor is multiplied to get the expected CUF in that year. In India, the CUF is often used alongside the Performance Ratio for contractual purposes (see also subchapter 12.3. on *Contractual guarantees and price adjustments*).

The Capacity Utilisation Factor is defined as:

$$CUF_{(i)} = \frac{E_i}{P_o \times 24h \times 365} \times 100$$

Where:

CUF = Capacity Utilisation Factor over a year (%)

E_i = Plant energy production or Plant energy metered for the time period i , usually a year (kWh)

P_o = Plant Peak AC power (kW)

10 The temperature-corrected PR calculation is not consistently applied. Therefore, this note clarifies in brief the best practice for calculating PR using the formulas provided above. There are 2 methods to apply the formula:

- In the *time-weighted* method, PR is weighted over a period by the time interval. An example would be if the SCADA system provides data in 1 min / 5min / 10 min average values. PR is then calculated for that 1 min / 5min / 10 min period and the resulting PR values are then averaged. This method will generally yield higher PR values in the morning, while production is low and lower PR values mid-day, but with high energy production. Therefore, low PR value are given the same with as the high PR values and the use of an average value of the PR does not take into account the different weight that PR may have over the day. This can artificially increase the PR by up to a couple of percentage points.
- In the *irradiance-weighted* method, irradiance as a sum counts higher irradiance values as more impactful on the total PR for any given period. This eliminates the weighting effect and provides a more accurate PR. Therefore, all relevant measured parameters should be summed above and below the line over the calculation period before any division and calculation of PR is performed.

BOX 2

Interpreting Performance Ratio

Careful attention needs to be paid when interpreting PR, because there are several cases where it can provide misleading information about the status of the PV plant:

Seasonal variation of PR (*lower PR in the hot months, higher in colder months*)

The calculation of PR presented in this section neglects the effect of PV module temperature, using the fixed value for the plant's power rating, P_0 . Therefore, the performance ratio usually decreases with increasing irradiation during a reporting period, even though energy production increases. This is due to an increasing PV module temperature that results in lower efficiency. This gives a seasonal variation, with higher PR values in the cold months and lower values in the hot months. It may also give geographic variations between systems installed in different climates.

This seasonal variation of PR can be significantly reduced by calculating a *temperature-corrected PR to STC*, which adjusts the power rating of the plant at each recording interval to compensate for differences between the actual PV module temperature and the STC reference temperature of 25 °C (taking into account the temperature coefficient of the modules, given as % of power loss per °C).

Interpretation of PR for overrated plants (*misleading lower PR*)

Special attention is needed when assessing the PR of

overrated plants (DC/AC ratio higher than 1) where the output of the plant is limited by the inverter maximum AC output ($P_0 > P_0, AC$). In such situations, when derating takes place, PR will be lower than normal although there is no technical problem with the plant. Stakeholders should be careful assessing PR values for overrated plants, although the amount of derating is normally statistically constant or with negligible differences on a yearly basis.

Calculation of PR using GHI instead of POA (*misleading higher PR*)

Calculation of the PR using the Global Horizontal Irradiance (GHI) instead of in-plane (POA) irradiance is an alternative in situations where GHI measurements are available but POA measurements are not. The PR calculated with GHI would typically show higher values which may even exceed unity. These values cannot necessarily be used to compare one system to another but can be useful for tracking performance of a system over time and could also be applied to compare a system's measured, expected, and predicted performance using a performance model that is based only on GHI.

Soiled irradiance sensors (*misleading higher PR*)

Special attention is needed when assessing the PR using data from soiled irradiance sensors. In this case, PR will present higher values and will give the false impression that the PV plant is performing better than expected and even some underperformance issues could remain hidden.

11 Key Performance Indicators / continued

11.2.6. Expected Yield

Expected Yield $Y_{exp(i)}$ is the Reference Yield $Y_{r(i)}$ multiplied by the expected PR and thus expresses what should have been produced over a certain period of time i .

Note that Expected Yield is based on past values of irradiation data. Predicted Yield is based on forecasted data, from day ahead and hour ahead weather reports.

Expected Yield can be defined as:

$$Y_{exp(i)} = PR_{exp(i)} \times Y_{r(i)}$$

Where:

- $Y_{exp(i)}$ = Expected Yield for the time period i , expressed in (kWh/kW_p) or peak sun hours (h)
- $PR_{exp(i)}$ = Average Expected Performance Ratio of the plant over the period i , based on simulation with given actual temperature and irradiation and plant characteristics. (PR_{exp} simulation is beyond the scope of the present document but for more information on this, see Brabandere et al (2014), Klise and Stein (2009), NREL (2017), PVsyst (2017) and SANDIA (2017).)
- $Y_{r(i)}$ = Reference Yield for the time period i (based on past irradiation data) expressed in (kWh/kW_p) or peak sun hours (h)

11.2.7. Energy Performance Index

The Energy Performance Index (EPI) is defined as the ratio between the Specific Yield Y_i and the Expected Yield Y_{exp} as determined by a PV model. The EPI is regularly recalculated for the respective assessment period (typically day/month/year) using the actual weather data as input to the model each time it is calculated. This concept was proposed, e.g. in (Honda et al. 2012).

The Energy Performance Index (EPI) is defined as:

$$EPI_i = \frac{Y_i}{Y_{exp(i)}}$$

Where:

- EPI_i = Energy Performance Index for the time period i (%)
- Y_i = Specific Yield for the time period i (kWh/kW_p) or (h)
- $Y_{exp(i)}$ = Expected Yield for the time period i (kWh/kW_p) or (h)

The advantage of using the EPI is that its expected value is 100% at project start-up and is independent of climate or weather. This indicator relies on the accuracy of the model. Unfortunately, there are more than one established models for the Expected Yield of PV systems in operation and not all of them are transparent. Therefore, the use of EPIs is recommended mainly for the identification of performance flaws and comparison of plants.

11.2.8. Technical Availability or Uptime

Technical Availability (or Uptime), Contractual Availability and Energy-based Availability are three closely related indicators to measure whether or not the PV power plant is generating electricity. The latter two KPIs are explained in section 11.4. *PV power plant/O&M Contractor KPIs*.

Technical Availability is the parameter that represents the time during which the plant is operating over the total possible time it is able to operate, without taking any exclusion factors into account. The total possible time is considered the time when the plant is exposed to irradiation levels above the generator's Minimum Irradiance Threshold (MIT). Technical Availability is covered extensively in IEC TS 63019:2019.

Technical Availability is then defined and calculated as:

$$A_t = \frac{T_{useful} - T_{down}}{T_{useful}} \times 100$$

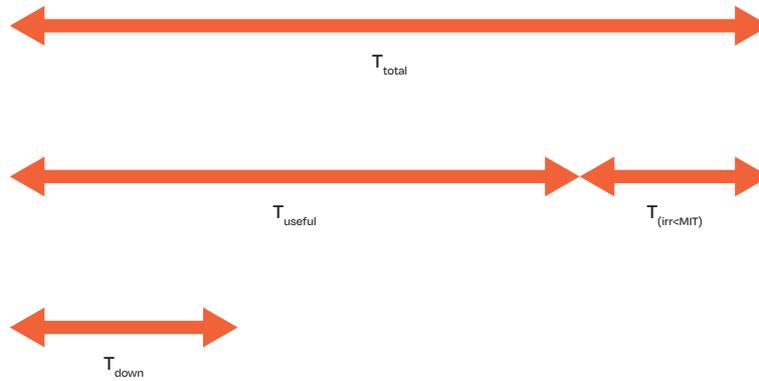
Where:

- A_t = Technical Availability (Uptime) (%)
- T_{useful} = Period of time with in plane irradiance above MIT (h)
- T_{down} = Period of T_{useful} when the system is down (no production) (h)

Figure 11 on the following page illustrates the various periods in time mentioned above.

Normally, only the time where irradiance is above the MIT is considered and this is noted above as T_{useful} where $T_{useful} = T_{total} - T_{irr < MIT}$. Typical MIT values are 50 or 70 W/m². MIT should be defined according to site and plant characteristics (e.g. type of inverter, DC/AC ratio etc).

FIGURE 11 VARIOUS PERIODS OF TIME FOR THE CALCULATION OF THE TECHNICAL AVAILABILITY



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Technical Availability should be measured also at inverter level. Individual inverters' Technical Availability $A_{t,k}$ should be weighted according to their respective installed DC power P_k . In this case, the Technical Availability of the total PV power plant $A_{t,total}$ with an installed total DC power of P_0 can be defined as follows:

Technical Availability weighted by individual inverters' installed DC power:

$$A_{t,total} = 100 \times \sum \left(A_{t,k} \times \frac{P_k}{P_0} \right)$$

Where:

- $A_{t,total}$ = Technical Availability of the plant (%)
- $A_{t,k}$ = Technical Availability of the inverter k
- P_k = Installed DC power of the inverter k
- P_0 = Plant Peak DC power (nominal power) (kW_p)

For the calculation of Technical Availability, typically up to 15 minutes of irradiation and power production data should be taken as basis, if granularity of components remains at the level of inverter or higher. Anything below the level of inverter is then captured with the Performance Ratio calculation presented above.

11.2.9. Technical Tracker Availability or Tracker Uptime

Similar to Technical Availability, Technical Tracker Availability is simply a ratio of the useful time compared to the uptime or downtime of the tracker. This measurement is a pure technical parameter and

would not allow for any agreed exclusions in the availability. To calculate the technical tracker availability, the following formula can be used:

Technical tracker availability is calculated as:

$$A_{t,tracker} = \frac{T_{t,useful} - T_{t,down}}{T_{t,useful}} \times 100$$

Where:

- $A_{t,tracker}$ = Technical Tracker Availability (%)
- $T_{t,down}$ = Period of time when the tracker is down (h)
- $T_{t,useful}$ = Period of time when the tracker is functional (h)

Tracking Performance Availability

Functional failure of a tracker can be an inaccurate tracking or out of sync tracking compared to the set point. This failure can often lead to shading or small performance deviations, based on the deviation from the sun path. The formula for the tracking performance availability is similar to the technical availability, with one small change to the classification of $T_{t,down}$. In this case the downtime is classified to any time the tracker is x (can be defined per site, depending on row spacing but ultimately can be modelled in PVSyst to give you a good general value for all seasons) degrees from the tracker set point. As long as the deviation angle is specified, this metric can be a good indicator to support the maximisation of single-or dual-axis tracking performance.

11 Key Performance Indicators / continued

11.3. O&M Contractor KPIs

As opposed to power plant KPIs, which provide the Asset Owner with information about the performance of their asset, O&M Contractor KPIs assess the performance of the O&M service.

The following time KPIs are illustrated in Figure 12.

11.3.1. Acknowledgement Time

The Acknowledgement Time (also called Reaction Time) is the time between detecting the problem (receipt of the alarm or noticing a fault) and the acknowledgement of the fault by the Local Control Room by dispatching a technician. The Acknowledgement Time reflects the O&M Contractor's operational ability.

11.3.2. Intervention Time

The Intervention Time is the time to reach the point of the fault in the plant by a service technician from the moment of acknowledgement. Note that in India most utility-scale PV plants have on-site personnel, in such cases the Intervention Time may be shorter than in Europe, where there is no on-site staff. Even so, the Intervention Time won't equal zero, because reaching and finding the point of the fault will take some time even for the on-site staff, especially in the case of very large utility-scale power plants. This is not the case for rooftop PV plants, which do not always have on-site

staff in India. Also note that in certain cases the on-site technician is not able to repair the fault and third-party involvement is necessary. Intervention Time assesses the capacity of the O&M Contractor how fast they can mobilise and be on site.

11.3.3. Response Time

The Response Time is the Acknowledgement Time plus the Intervention time. Used for contractual purposes, minimum Response Times are guaranteed on the basis of fault classes classified on the basis of the unavailable power and the consequent potential loss of energy generation and the relevance of the failure in terms of their safety impact. For recommendations on Response Time guarantees, see 12.3.2. *Response Time price adjustment*.

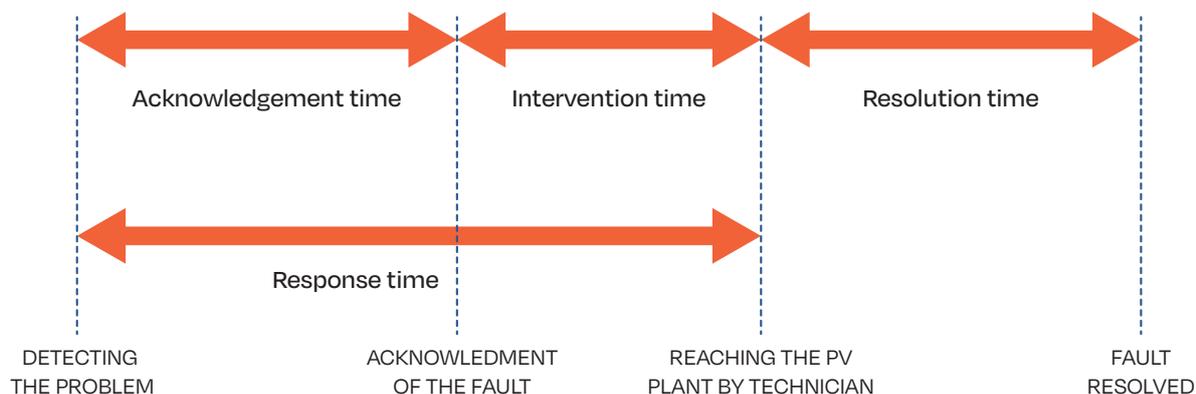
11.3.4. Resolution Time

Resolution Time (or Repair Time) is the time to resolve the fault starting from the moment of reaching the PV plant. Resolution Time is generally not guaranteed, because resolution often does not depend totally on the O&M Contractor.

11.3.5. Reporting

It is very important for the O&M Contractor to comply with reporting requirements and reporting timelines. Content and timing of the reporting is generally agreed

FIGURE 12 ACKNOWLEDGEMENT TIME, INTERVENTION TIME, RESPONSE TIME, RESOLUTION TIME



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by the parties in the Contract agreement. Content of the reporting should be expected to be consistent and any change in content or format needs to be explained by the O&M Contractor. Delivery of reports per the agreed upon timeline is an important indicator for reliability and process adherence within the O&M Contractors organisation. See also 5.1. *Reporting*.

11.3.6. O&M Contractor experience

Experience of the O&M Contractor with PV power plants in the particular region or state in India, grid environment and/or with PV power plants equipped with certain technology or size can play an important role. This is quite relevant for the selection of the O&M Contractor and can be tracked by the owner over time (track record).

11.3.7. Schedule Compliance

Schedule Attainment (or Schedule Compliance) is the ability of the O&M contractor to execute the preventive maintenance schedule within the required timeframes, typically weekly, monthly, quarterly, half-yearly and yearly.

O&M Contractors who adhere to the schedule as much as possible ensure accomplishing as much Scheduled maintenance and other timely corrective work as possible. Schedule compliance provides a measure of accountability.

Low schedule compliance can provide key warning signs to the asset owner regarding the O&M Contractor:

- That Scheduled maintenance is not done which will lead to equipment failures over time.
- O&M Contractor might not have sufficient number of or qualified technical staff to performance maintenance.
- O&M Contractor systems such as the management of stores and spares, procurement processes are not effective.
- There are high levels of corrective maintenance work – which could be due to unsolved technical issues.

Best practice requires > 90%, based on the following formula:

$$\text{Schedule Attainment} = \frac{\text{Number of completed schedules in the period}}{\text{Total number of schedules for the period}} \times 100$$

11.3.8. Scheduled vs Corrective Maintenance ratio

This metric measures the reactive nature of the plant maintenance work. Management desires reactive work to lessen in proportion to proactive work. This indicator is based on the actual hours technicians spend on jobs. The actual hours are measured regardless of the originally estimated hours of the planners.

When the maintenance O&M Contractor has control over the equipment, the O&M Contractor decides when to take certain actions to preserve equipment. When the equipment has control over the O&M Contractor, the equipment drives the efforts of maintenance. A more reactive plant environment has more circumstances of the equipment experiencing problems and causing the O&M Contractor to break the weekly schedule. The proactive maintenance force in control of its equipment experiences few circumstances of a sudden equipment problem that interrupts scheduled work.

Best practice requires that the ratio of scheduled vs corrective maintenance is 80/20.

11.4. PV power plant/O&M Contractor KPIs

11.4.1. Contractual Availability

Contractual Availability is Technical Availability with certain contractually agreed exclusion factors (see below) applied in the calculation used as a basis for the general Contractual Availability guarantees provided by the O&M Contractor to the Asset Owner and included in the O&M Contract. A best practice is a Minimum Guaranteed Contractual Availability of 98% over a year. (For more details on Availability guarantee provided by the O&M Contractor, see 12.3.1. *Availability guarantee*).

11 Key Performance Indicators / continued

Contractual Availability is thus the parameter that represents the time in which the plant is operating over the total possible time it is able to operate, taking into account the number of hours the plant is not operating for reasons contractually not attributable to the O&M Contractor (listed below in the same section).

Contractual Availability is therefore defined and calculated as:

$$A_c = \frac{T_{\text{useful}} - T_{\text{down}} + T_{\text{excluded}}}{T_{\text{useful}}} \times 100$$

Where:

- A_c = Contractual Availability (%)
- T_{useful} = period of time with in plane irradiance above MIT (h)
- T_{down} = period of T_{useful} when the system is down (no production) (h)
- T_{excluded} = part of T_{down} to be excluded because of presence of an exclusion factor (see below) (h)

Contractual Availability weighted by individual inverters' installed DC power:

$$A_{c\text{ total}} = 100 \times \sum (A_{c k} \times \frac{P_k}{P_o})$$

Where:

- $A_{c\text{ total}}$ = Availability of the plant (%)
- $A_{c k}$ = Availability of the inverter k
- P_k = Installed DC power of the inverter k
- P_o = Plant Peak DC power (nominal power) (kW_p)

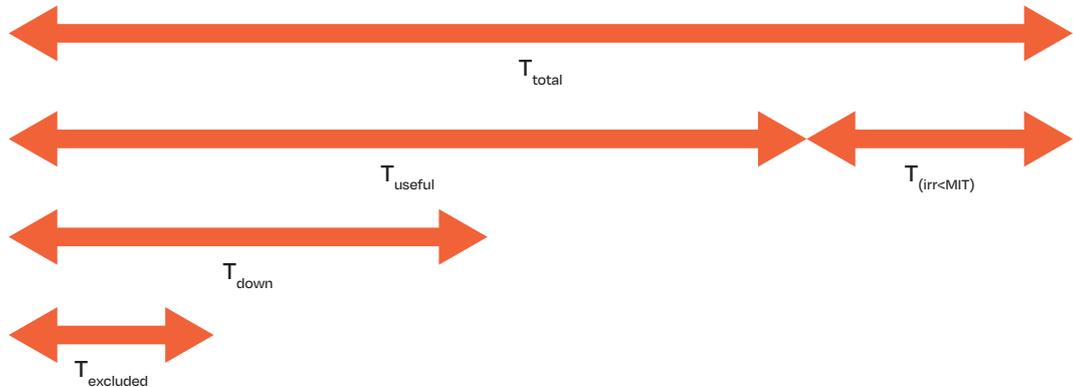
For the calculation of Contractual Availability, typically up to 15 minutes of irradiation and power production data should be taken as basis, if granularity of components remains at the level of inverter or higher. Anything below the level of inverter is then captured with the Performance Ratio calculation presented above.

As Contractual Availability is used for contractual purposes, any failure time should only begin to run when the O&M Contractor receives the error message. If the data connection to the site was not available due to an external issue that is beyond the O&M Contractor's responsibility, failure time should only begin after reestablishment of the link. However, if the data connection was lost due to the unavailability of the monitoring system, the failure time should count. In general, the O&M Contractor should immediately look at the root cause of the communication loss and resolve it.

Figure 13 below illustrates the various periods in time mentioned above.

Like the Technical Availability, the Contractual Availability is also calculated for irradiance levels above the MIT and measured at inverter level. Individual inverters' Contractual Availabilities $A_{c k}$ should be weighted according to their respective installed DC power P_k . In this case the Contractual Availability of the total PV power plant $A_{c\text{ total}}$ with an installed total DC power of P_o can be defined as follows:

FIGURE 13 VARIOUS PERIODS OF TIME FOR THE CALCULATION OF CONTRACTUAL AVAILABILITY¹¹



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11 The T_{down} represents the whole downtime, before the exclusions are applied. Therefore, T_{excluded} is a part of T_{down} in the diagram. In practice you often first see that a plant is down (= measurement of T_{down}) and only in the course of troubleshooting one gets the information whether you can exclude part of the downtime.

The Asset Owner and the O&M Contractor should agree on certain failure situations that are not taken into account (exclusion factors) in the calculation of Contractual Availability. Evidences should be provided by the contractor for any exclusion factor and the reason for excluding the event must not be due to an O&M contractor fault. Some good examples for exclusion factors are:

- Force majeure (see the definition of Force Majeure in India in Chapter 2. *Definitions*).
- Snow and ice on the PV modules.
- Damage to the PV plant (including the cables up to the feed-in point) by the customer or third parties who are not sub-contractors of O&M Contractor, including but not limited to vandalism.
- Disconnection or reduction of energy generation by the customer or as a result of an order issued to the customer by a court or public authority.
- Operational disruption by grid disconnections or disruptions in the grid of the grid operator.
- Disconnections or power regulation by the grid operator or his control devices.
- Downtimes resulting from failures of the inverter or MV voltage components (for example, transformer, switchgear), if this requires:
 - Technical support of the manufacturer and/or
 - Logistical support (for example supply of spare parts) by the manufacturer.
- Outages of the communication system due to an external issue that is beyond the O&M Contractor's responsibility. Any failure time only begins to run when the O&M Contractor receives the error message. If the data connection to the site was not available, failure time shall only begin after reestablishment of the link.
- Delays of approval by the customer to conduct necessary works.
- Downtimes for implementation of measures to improve the PV plant, if this is agreed between the parties.
- Downtimes caused by the fact that the customer has commissioned third parties with the implementation of technical work on the PV plant.

- Downtimes caused by Serial Defects on Plant components.
- Depending on the O&M contract, time spent waiting for some spare parts to arrive can be sometimes excluded from the calculation of Contractual Availability, however this is not considered a best practice.

11.4.2. Contractual Tracker Availability

Like the Contractual Availability, the Contractual Tracker Availability also makes allowance for pre-defined exclusions, like maintenance, panel cleaning, etc. A similar formula is used to the technical availability with provision made for any predefined contractual exclusions (see above). The formula can be seen below.

Contractual tracker availability is calculated as:

$$A_{c_tracker} = \frac{T_{t_useful} - T_{t_down} + T_{t_excluded}}{T_{t_useful}} \times 100$$

Where:

$A_{t_tracker}$ = Technical Tracker Availability (%)

T_{t_down} = Period of time when the tracker is down (h)

T_{t_useful} = Period of time when the tracker is functional (h)

$T_{t_excluded}$ = Part of T_{t_down} to be excluded because of presence of an exclusion factor (see above) (h)

11.4.3. Energy-based Availability

Energy-based Availability takes into consideration that an hour in a period with high irradiance is more valuable than in a period with low irradiance. Therefore, its calculation uses not time but energy (and lost energy) for its basis:

Energy-based Availability is defined as:

$$A_{e\ i} = \frac{E_i}{E_i + E_{loss(i)}} \times 100$$

Where:

$A_{e\ i}$ = Energy-based Availability for the time period i (%)

$E_{loss(i)}$ = Calculated lost energy in the period i (kWh)

E_i = Plant energy production or Plant energy metered in the time period i (kWh)

Generally, the *Energy Based Availability* is used within the O&M contract in the Availability guarantee chapter and then generally the exclusion factors defined for Contractual Availability apply for Energy-based Availability too.

11 Key Performance Indicators / continued

The following table provides an overview of different types of Key Performance Indicators and their main purposes.

TABLE 7 OVERVIEW OF DIFFERENT TYPES OF KEY PERFORMANCE INDICATORS AND THEIR PURPOSES

	PV POWER PLANT KPI	O&M CONTRACTOR KPI	QUANTITATIVE	QUALITATIVE ¹²	TO BE MONITORED WITHIN THE O&M CONTRACT	GUARANTEED IN THE O&M CONTRACT	USAGE MAIN PURPOSE
Reference Yield	✓	X	✓	X	✓	X	Useful during plant designing and economic valuation
Expected Yield	✓	X	✓	X	✓	X	Useful during plant designing and economic valuation
Specific Yield	✓	X	✓	X	✓	X	Useful during plant designing and economic valuation
Performance Ratio	✓	X	✓	X	✓	X	Useful during plant life in order to assess plant performances over time
Temperature-corrected Performance	✓	X	✓	X	✓	X	Useful FAC and PAC or in other specific moment in plant life to assess plant PR starting point
Capacity Utilisation Factor	✓	X	✓	X	✓	✓	Useful during plant life in order to assess plant performances over time, often used in India
Energy Performance Index	✓	X	✓	X	✓	X	Useful during plant life in order to assess plant performances over time, against plant expected performances at plant designing
Technical Availability (Uptime)	✓	X	✓	X	✓	X	Useful during plant life in order to assess the how much time during the time frame under analysis the plant is ready to produce
Technical Tracker Availability (Tracker Uptime)	✓	X	✓	X	✓	X	Useful during plant life in order to assess the how much time during the time frame under analysis the trackers are well-functioning
Acknowledgement Time	X	✓	✓	X	✓	✓	Useful during plant operation in order to assess readiness of the O&M Provider to “realise” (detected by the monitoring system and acknowledge by the O&M provider) plant failures
Intervention Time	X	✓	✓	X	✓	✓	Useful during plant operation in order to assess readiness of the O&M provider to reach the plant upon a failure is “realised”

¹² Qualitative data is concerned with descriptions, i.e. information that can be observed but not computed (e.g. service experience). In contrast, quantitative is measured on a numerical scale (e.g. Performance Ratio).

TABLE 7 OVERVIEW OF DIFFERENT TYPES OF KEY PERFORMANCE INDICATORS AND THEIR PURPOSES -
continued

	PV POWER PLANT KPI	O&M CONTRACTOR KPI	QUANTITATIVE	QUALITATIVE	TO BE MONITORED WITHIN THE O&M CONTRACT	GUARANTEED IN THE O&M CONTRACT	USAGE MAIN PURPOSE
Response Time	X	✓	✓	X	✓	✓	Useful during plant operation in order to assess readiness of the O&M provider from acknowledging a failure and subsequently reaching the site
Resolution Time	X	✓	✓	X	X	X	Useful during plant operation in order to assess the time used to solve a fault from when the plant is reached
Contractual Availability	✓	✓	✓	X	✓	✓	Useful during plant life in order to assess how much time during the time frame under analysis the O&M Provider keeps the plant ready to produce
Contractual Tracker Availability	✓	✓	✓	X	✓	✓	Useful during plant life in order to assess how much time during the time frame under analysis the O&M Provider keeps the trackers well-functioning
Energy Based Availability	✓	✓	✓	X	✓	✓	Useful during plant life in order to assess how much energy has been lost due to causes attributable to the O&M Contractor, during the time frame under analysis
Reporting	X	✓	✓	✓	✓	✓	Useful during plant operation in order to assess reliability of reporting services
O&M Contractor experience	X	✓	X	✓	✓	X	Useful during O&M Contract awarding/tendering in order to assess O&M Contractor reliability on a pure documental analysis
Schedule Attainment	X	✓	✓	X	✓	X	Useful during O&M Contract awarding/tendering to assess O&M Contractor reliability
Preventive vs Corrective Maintenance ratio	X	✓	✓	X	✓	X	Useful during O&M Contract awarding/tendering to assess O&M Contractor reliability and effectiveness



Navigating via the solar power project documentation can be a time consuming and costly process. A large number of contracts are required for the development, construction and operation of a solar power plant. These contracts do not only document the legal structure, but are an essential factor in mitigating the risks for all the parties involved along the project's lifecycle. With a large number of projects being executed and contracts being awarded, it becomes an essential aspect to understand and distribute the specific and detailed scope of work adequately in order to avoid future conflicts. Contracts also play an important role to understand and manage the taxation, legal and commercial challenges prevailing with these projects during the lifetime. Contracts also contain methods of negotiations, contract management and dispute resolution, so as to avoid loss of any finances in future. Most of the times these contracts are non-transferable and it is the responsibility of the parties for authenticity of the data and hence expected to verify, validate and independently access information provided.

This section contains a set of considerations for the contractual framework of O&M services for the utility scale segment, and more specifically, systems above 1 MWp. A complement to the technical specifications detailed in the previous chapters, the contractual framework described in this chapter are considered as a best practice.

As a best practice, we recommend using the O&M template contract developed as part of the Open Solar Contracts by the Terrawatt Initiative and the

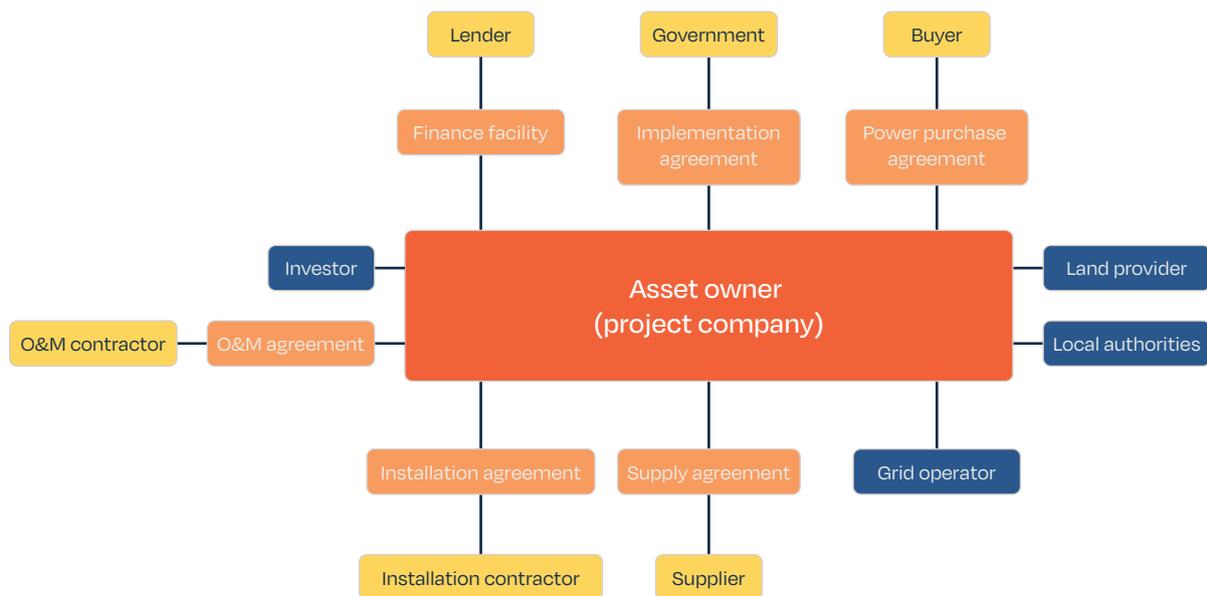
International Renewable Energy Agency (IRENA). SolarPower Europe contributed to the drafting of the template O&M contract, which is one of six templates in a suite of contracts designed to be used as a package to streamline the procurement of solar projects and make it simpler to aggregate projects using standard terms. Aside from the O&M contract, the other templates include:

- Implementation Agreement
- Power Purchase Agreement
- Finance Facility Agreement term sheet
- Supply Agreement
- Installation Agreement
- Asset Management Agreement

The public review stage of the Open Solar Contracts suit of contract templates was launched in the summer of 2019. Copies of each contract and explanatory guidance can be found at the Open Solar Contracts website: www.opensolarcontracts.org.

A common contractual framework for PV O&M is "fixed price" for specified scope of work such as administrative, operations, and scheduled maintenance and then "cost plus" for corrective maintenance or additional services. For the "cost plus" part, labour rates, equipment markup, overhead and profit are negotiated in the contract and added to the actual equipment costs incurred in correcting unexpected problems.

FIGURE 14 OVERVIEW OF THE SIX TEMPLATE CONTRACTS DEVELOPED UNDER THE OPEN SOLAR CONTRACTS INITIATIVE



12.1. Scope of the O&M contract

Services to be provided by the O&M Contractor include:

Operation Planning (Central Control Room level)

- Reporting to Asset Owner
 - Reporting on PV plant performance
 - Reporting on O&M performance
 - Reporting on incidents
- Ensuring regulatory compliance
 - Legal requirements for PV plant operation
 - Power Purchase Agreements and Interconnection Agreements
 - Power generation licence agreements
 - Building permits and environmental permits
 - Power Generation Forecasting (optional)
- Warranty management
- Insurance claims
- Contract management
- Monitoring and supervision on the portfolio level

Operation Execution (Local Control Room Level)

- Plant documentation management
- Plant supervision
 - Performance monitoring and documentation
 - Performance analysis and improvement
 - Issue detection/diagnostics
 - Service dispatch/supervision
 - Security monitoring interface (optional)
- Plant operation
 - Plant controls
 - Grid operator interface, grid code compliance
 - Maintenance scheduling
- Management of change (optional)
- Reporting to the Central Control Room

Power Plant Maintenance

- PV Plant Maintenance
 - Scheduled Maintenance, including module cleaning and vegetation control
 - Corrective Maintenance in accordance with agreed Response Time guarantees (some types of maintenance activities may be beyond the scope of the contract, for more information, see 7.2. *Corrective Maintenance*)
 - Extraordinary Maintenance (generally not included in the O&M fixed fee but it is advisable that the O&M contract includes the rules to prepare the quotation and to execute Extraordinary Maintenance works, for more information, see 7.3. *Extraordinary maintenance*).

- Additional maintenance services (optional, see 7.4. *Additional services*).

Here below is a non-exhaustive list of Additional services and general market trends with regards to whether these Additional services are generally included in the O&M agreement or not.

All the services not included in the scope and in the fixed fee such as 7.4. *Extraordinary Maintenance* and 7.5. *Additional services* should be regulated within the contract. A dedicated clause should indicate the procedure that should include: (i) a proposal by the O&M Contractor within a fixed time frame, (ii) a fixed period for the Asset Owner to accept it or request modification, (iii) a final approval. Pre-agreed tariffs for manpower, machinery renting etc could be agreed and a specific table could be attached as Contract Annex.

TABLE 8 EXAMPLES FOR ADDITIONAL MAINTENANCE SERVICES AND GENERAL MARKET TRENDS

	ADDITIONAL SERVICES	GENERAL BEHAVIOUR
General site maintenance	Pest control	Generally not included
	Waste disposal	Generally included with reference to waste generated during O&M activities
	Road management	Generally not included
	Perimeter fencing repair	Generally not included and often caused by force majeure (i.e.: theft)
	Maintenance of buildings	Generally not included
	Maintenance of Security Equipment	Generally not included, these activities are performed by a separate surveillance and security provider in order to have clearly defined responsibilities (see 6.7. <i>Power plant security</i>)
On-site measurement	Meter weekly/monthly readings	Generally included since it feeds the periodical performance reporting to the Asset Owner
	Data entry on fiscal registers or in authority web portals for FIT tariff assessment (where applicable)	Generally this activity is deemed to the Asset Manager. Can be however included in O&M scope of work
	String measurements – to the extent exceeding the agreed level of Scheduled Maintenance	Generally not included but a price could be agreed in advance in the O&M contract
	Thermal inspections – to the extent exceeding the agreed level of Scheduled Maintenance	Generally not included but a price could be agreed in advance in the O&M contract

Spare Parts Management

(See also Chapter 9 on *Spare Parts Management*)

- Spare parts maintenance
- Spare parts replenishment
- Spare parts storage (optional)

For more information on the specific items in the above list, please view the respective sections and chapters of the present Guidelines.

12.2. O&M contract fee

As a best practice, O&M services should be provided on a fixed fee plus escalation basis. See section 12.8. of this chapter on *Spare Part Management* which discusses how spare parts management may impact on the contract fee.

12.3. Contractual guarantees and price adjustments

It is relatively common in India for O&M Contractors to provide contractual guarantees for *Contractual Availability*, *Performance Ratio (PR)*, *Capacity Utilisation Factor (CUF)*, and even yield. Yield-based guarantees mean a very high level of risk for the O&M Contractor and are rarely accepted, because the factors that determine yield (such as the irradiation) are largely beyond the control of the O&M Contractor, even if the O&M Contractor is the same entity as the EPC Contractor. A PR guarantee, with a bonus scheme based on exceedance, is therefore a better option, especially if the O&M Contractor is the same entity as the EPC Contractor, as PR captures the quality of the installation. However note that in some markets, such as Europe, SolarPower Europe has concluded that PR is not an appropriate KPI for specialised (third-party) O&M Contractors that are not the same entity as the EPC Contractor that built the power plant.¹³ CUF guarantee is an Indian specificity due to the fact that grid operators require a minimum CUF from the Asset Owner.

Availability guarantees and Response Time price adjustments protect the Asset Owner from poor performing O&M Contractors, even with no PR or CUF guarantee in place. Availability is the KPI that best reflects O&M Contractor's service. Thanks to the Response Time price adjustment, in case of events affecting the performance of the plant that are not

covered by the Availability guarantee, the contractor has to intervene in a pre-agreed timeframe depending on the impact of the fault. Moreover, the O&M Contractor is also obliged to intervene in case of incidents not affecting the performance, referring to good industry practices in general. A further upside is that it makes the transition to a new contractor much smoother and hence allows Lenders and Owners to pick a contractor of their choice and with the sole criterium of quality of services. Availability guarantees and Response Time price adjustments avoid heavy change management process due to the necessity of recalculating the guaranteed PR in case of power plant handover, which is an obstacle in the market.

12.3.1. Performance Ratio (PR) Guarantee

In India it is common to have PR guarantees in the O&M contract, as agreed between the parties. It should be agreed upon between the Asset Owner and the O&M Contractor after a thorough assessment of the PV plant and systems by the O&M Contractor. Penalties for not meeting PR is usually levied on the O&M Contractor on annual basis (see subchapter 12.4. on *Bonus schemes and Liquidated Damages*). However, some contracts specify monthly PR calculation also.

If PR guarantees are provided, they should be provided under the following conditions:

- Based on design/PAC/FAC data if the O&M Contractor has been the same entity as the EPC.
- Based on a specific procedure, preliminary to guarantee commencement, designed to objectively assess PR of the plant at take over.
- With a formula that clarifies exceptions to the calculation (same exceptions as with Contractual Availability).

¹³ PR is to a large extent a result of equipment choice, design and construction, over which a (third-party) O&M Contractor has little influence, beyond vegetation control and module cleaning. Moreover, removing PR as an O&M Contractor KPI makes power plant handover from EPC to O&M Contractor or from O&M Contractor to O&M Contractor simpler. Generally the PR warranties are applied on projects where the O&M contractor remain the same company (or a close company) as the EPC contractor, in which case the O&M contractor carry on the risk of the technology made by its sister company. Although a PR guarantee is not anymore standard in the European independent/third-party O&M market, it is possible to set a PR target that can trigger a joint analysis between the Asset Owner and the O&M Contractor, in order to identify causes and agrees on possible corrective actions, including revamping projects.

- By defining whether periods of low irradiation or non-availability have to be taken into consideration (not recommended), and which kind of measurement device is used for irradiance measurement.
- With a procedure that describes how to consider module degradation.

12.3.2. Capacity Utilisation Factor (CUF) Guarantee

In India, the off-taker (the grid operator) requires the Asset Owner to meet the Capacity Utilisation Factor (CUF) delivery guarantee, as agreed in the PPA, and considering the annual de-gradation factor. If the CUF guarantee is not met, the Asset Owner has to pay penalties to the off-taker. CUF guarantee is essential for the off-taker to plan their energy requirements, and plan the finances accordingly. This is the reason why in India, including CUF guarantees in the O&M contract between the Asset Owner and the O&M Contractor has seen an increasing trend with contracted CUF being between 17-24% and a decreasing trend in annual CUF degradation of between 0.75%-1.2% currently.

12.3.3. Availability guarantee

A best practice is a Minimum Guaranteed Contractual Availability of 98% over a year at least at inverter level. In certain jurisdictions, such as in India or in Mexico, where labour legislation and the requirements of the network operator stipulate the presence of full-time technical on-site staff, a Minimum Guaranteed Availability of 99% can be provided – it should, however, be appropriately reflected in the O&M agreement's price.

For contractual KPI reasons, Availability should be calculated at inverter level, on an annual basis. For more information on this, see 11.4.1. *Contractual Availability*.

Tracker availability test shall be carried out (in parallel to inverter availability), with the same duration as the system availability test and the tilt angle of each tracker lied within a $\pm 2^\circ$ range during 98% of the operational time

The Availability achieved by the O&M Contractor is translated into Bonus Schemes and Liquidated Damages. For more information on this, see 12.4. *Bonus Schemes and Liquidated Damages*.

12.3.4. Response Time price adjustment

The O&M Contractor should be obliged to react on alarms received from the plant through the monitoring and supervision system within a certain period of time, 7 days a week. This translates in a minimum guaranteed Response Time with the consequence of an adjustment to the contract price (the O&M fee) payable to the O&M Contractor in the event of failure to meet the Response Times. For a definition of Response Time, see 11.3.3. *Response Time*.

When setting a Response Time price adjustment, it is recommended to differentiate between hours and periods with high and low irradiance levels as well as fault classes, i.e. the (potential) loss of energy generation capacity or relevance in terms of safety impact of the failure.

An example for response times according to fault classes can be seen below in Table 9.

TABLE 9 EXAMPLES FOR FAULT CLASSES AND CORRESPONDING MINIMUM RESPONSE TIMES

FAULT CLASS	FAULT CLASS DEFINITION	RESPONSE TIME GUARANTEE
Fault class 1	The entire plant is off, 100% power loss.	4 daytime hours
Fault class 2	More than 30% power loss or more than 300kWp down.	24 hours
Fault class 3	0%-30% power loss	36 hours

NOTE: Fault classes and the corresponding Response Time guarantees APPLIED even if the duration of the respective power loss is less than the corresponding Response Time guarantee, provided that the power loss may occur again.

In case the replacement of an equipment is needed, the O&M Contractor should commit to make it available to the plant's site and replace it within 8 business hours from the end of the Response Time, if the spare part is included in the portfolio of minimum spare parts list. If the spare part is not included in the minimum spare parts list, the O&M Contractor should commit to order the spare part within 8 business hours from the end of the Response Time and to replace it on the plant area in the fastest possible way, after receiving the related spare part from the equipment supplier.

In case the fault cannot be fixed by the O&M Contractor and the equipment supplier's intervention is required, the following actions are necessary:

- If the intervention requires spare parts up to the limit under the O&M cost responsibility (see 11.8. Spare Parts Management), the O&M Contractor may proceed without separate approval (insurance aspects to be considered).
- If the costs exceed the above budget limit, the Contractor should communicate the issue in writing to the Asset Owner within 8 business hours from the end of the Response Time.

Force Majeure events are excluded from Response Time obligations.

In the Open Solar Contracts O&M template, a failure to comply with a Response Time by more than five business days on any one occasion may also entitle an Asset Owner to terminate the O&M contract.

12.4. Bonus Schemes and Liquidated Damages

The Availability, PR or CUF guarantees provided by the O&M Contractor can be translated into Bonus Schemes and Liquidated Damages. These ensure that the Asset Owner is compensated for losses due to lower-than-guaranteed Availability, PR or CUF, and that the O&M Contractor is motivated to improve their service in order to achieve higher Availability. Higher Availability usually leads to higher power generation and an increase of revenues for the benefit of the plant owner. Hence the Bonus Scheme agreements lead to a win-win situation for both parties and ensures that the O&M Contractor is highly motivated.

Since the O&M Contractor's responsibility is focused on the O&M works for the PV asset, other influencing

factors like force majeure events, grid operator activities to reduce the plant output, grid instability or offline periods should be exempted from the O&M Contractor's responsibility and therefore from any Liquidated Damages. (See exclusion factors in 11.4.1. Contractual Availability.)

An example for Availability Bonus Schemes and Liquidated Damages can be found below:

- Bonus Schemes: if the measured availability exceeds the Minimum Guaranteed Availability, the additional revenue based on the base case scenario expected annual revenue will be divided (50/50) between the Asset Owner and the O&M Contractor in percentages previously agreed. There are also often minimum thresholds for bonuses to be due in case the overall plant energy do not meet certain target.
- Liquidated Damages: if the Minimum Guaranteed Availability is less than the measured availability, 100% of the lost revenue due to the Availability shortfall from the Minimum Guaranteed Availability based on the base case scenario expected annual revenue will be compensated by the O&M Contractor. This is usually invoiced by the Asset Owner to the O&M Contractor.
- Bonuses can be offset against Liquidated Damages and vice versa.
- The amount of Liquidated Damages should be capped at 100% of the O&M annual fee on a period of 12 months. Reaching this cap usually results in termination rights for the Asset Owner and the O&M Contractor, although in the Open Solar Contracts O&M template, the right is only given to the Asset Owner.

12.5. Service standards

O&M Contractor is to provide the services in accordance with all laws, authorisations, good industry practice, planning consents, manufacturer's warranties and operating manuals and to the standard of a reasonable and prudent operator.

The Asset Owner should be entitled to instruct a third-party operator to provide the services at the O&M Contractor's cost, where the O&M Contractor fails to provide the services and fails to follow a corrective maintenance programme.

12.6. O&M contractors' qualification

The O&M Contractor has the means, skills and capabilities to operate and maintain the plant in accordance with the contractual obligations. Experience and availability of a professional organisation, skilled teams and access to spare parts are criteria for the selection of the O&M Contractor. As O&M services are a combination of remote operations services and local maintenance activities, the Asset Owner should make sure that both components are well managed and interfaces between operations services and maintenance services are well defined, especially when subcontracted to different entities by the O&M Contractor where each entity is responsible and can be held accountable for the overall O&M performance.

12.7. Responsibility and accountability

The responsibility of the O&M Contractor is usually defined in the Scope of Works, which forms a part of the O&M contract. In the Open Solar Contract O&M template, this is set out in the O&M Services Schedule. A detailed description of the O&M scope items ensure clarity of what the O&M Contractor will do during the term of the contract. In addition to the Scope of Works, the Annual Maintenance Plan (AMP) and Annual Maintenance Schedule (AMS) (please refer to attachment "Annual Maintenance Plan") outline the granularity and frequency of (predominantly) Scheduled Maintenance works. The execution of the activities is being reported to the Asset Owner through the regular reporting – this forms the minimum requirements. Best practices can be seen if the regular reporting compares the executed activities with the AMP and AMS, and outlines deviations and reasoning.

Corrective Maintenance activities, which will be performed in case of any component failure or energy generation shortfall, are controlled by performance commitments signed by the O&M Contractor. In the Open Solar Contracts O&M template, these are set out as "Corrective Maintenance Services".

Moreover, the Availability Guarantee and Response Time price adjustment explained in 12.3. *Contractual guarantees and price adjustments* of the present chapter also represent a level of accountability of the O&M Contractor.

In most countries there are strict legal requirements for security service providers. Therefore, PV power plant security should be ensured by specialised security service providers directly contracted by the Asset Owner or, exceptionally, subcontracted by the O&M Contractor. The security service provider should also assume liability for the security services provided. For more information on this, see 6.7. *Power plant security*.

12.8. Spare Parts Management

The Open Solar Contracts O&M template takes two approaches to Spare Parts management. Either the O&M Contractor takes full responsibility for Spare Parts or there is a distinction between "Included Spare Parts", which are included in the O&M Contractor's fee, and "Excluded Spare Parts", the cost of which would be payable in addition to the fee plus a pre-agreed margin. In either case, replenishing Spare Parts stock will be the O&M Contractor's responsibility, although at the Asset Owner's cost in relation to Excluded Spare Parts. This guidance considers it best practice to take the second approach of clearly identifying Included and Excluded Spare Parts, in order to find an appropriate balance between the amount of risk that the Asset Owner is willing to accept against the cost of the O&M fee.

Although it is best practice for the O&M Contractor to be responsible for replenishing the spare parts stock, it is not necessarily responsible for the full cost of doing so. Some Asset Owners require O&M Contractors to be fully responsible for the cost of all spare parts within the O&M fee, however, the more cost-effective approach is to agree which are "Included Spare Parts" and which are "Excluded Spare Parts".

Included Spare Parts are those which the O&M Contractor is to be responsible for within the O&M fee. Excluded Spare Parts are those which the Asset Owner is responsible for the cost of replenishing and do not fall within the O&M Contractor's O&M fee. This is a flexible approach allowing the Asset Owner and O&M Contractor to agree which spare parts fall into which category. It enables both parties to have a level of cost certainty whilst balancing this with the Asset Owner's appetite for risk.

Ownership of spares is often with the Asset Owner from delivery to site or placement in the spares stock.

In the case of excluded spare parts, ownership transfers to the Asset Owner from the date that the O&M Contractor receives payment for the same.

Besides ownership matters, it is very important to make sure, upon mutual agreement, that one of the parties undertakes the responsibility of insuring the spares: as a recommendation spare parts stored on-site should be insured by the Asset Owner and spare parts stored off-site should be insured by the O&M Contractor.

There should be a components, materials and spare parts defects warranty for 12 months from the date of installation, which should continue to apply even after expiry or termination of the O&M contract.

For more information on Spare Parts Management, see the Chapter 9 on *Spare Parts Management*.

12.9. Power plant monitoring

The O&M Contractor should operate and maintain the metering system according to local regulations or norms. In some countries there are two metering

systems: one that measures power injection in the grid, owned and operated by the grid operator, and one that measures power production, owned by the Asset Owner as part of the installation and operated by the O&M Contractor.

The O&M Contractor will also make sure that performance monitoring and reporting is operated and maintained according to the monitoring specifications and best practices (see Chapter 10 on *Data and monitoring requirements*).

The Asset Owner has the right to carry out the verification of the metering system to evaluate and control the exactitude of the measured data.

12.10. Reporting

Reporting should be done periodically, as contractually agreed between the O&M Contractor and the Asset Owner. The Asset Owner should have the right to debate the report within a certain timeframe.

For more information on industry best practices regarding Reporting, see 5.1. *Technical reporting*.



O&M contractors are increasingly relying on innovations and more machine and data-driven solutions to keep up with market requirements. Innovations in O&M services are anticipated to reduce the levelised cost of electricity (LCOE) by 0.8% to 1.4% between 2015 and 2030. The savings are dominated by improvements in OPEX and power plant availability, and hence net Annual Energy Production (source: KIC InnoEnergy, 2015).

The most important trends and innovations shaping today's O&M market are summarised in this section, grouped into three "families":

1. Smart PV power plant monitoring and data-driven O&M;
2. Retrofit coatings for PV modules;
3. O&M for PV power plants with storage.

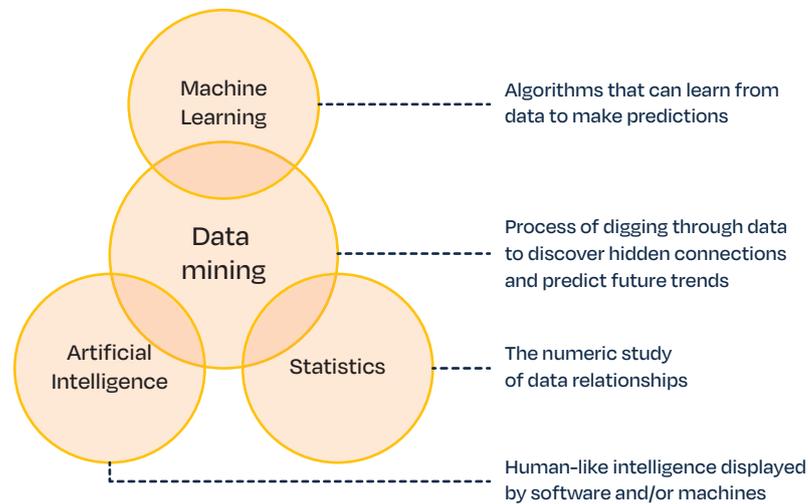
13.1. Smart PV power plant monitoring and data-driven O&M

Traditional monitoring systems generally consist of on-site data loggers that collect electrical data from devices installed on the PV plant inverters, strings, meters and weather data from meteorological stations. A management software then allows remote performance management, data visualisation, basic KPI calculations, reporting and alarm and ticket management.

These systems, used on their own, commonly fail to detect the root causes of underperformance. The industry is therefore rapidly moving towards the adoption of 'smarter' solutions based on advanced data mining techniques.

Data mining is the process of digging through data to discover hidden connections and predict trends. Sometimes referred to as "knowledge discovery in databases," the term "data mining" was not coined until the 1990s. Its foundation is comprised of three intertwined scientific disciplines as shown in 6

FIGURE 15 DATA MINING FOUNDATIONS



Adapted from: WWW.SAS.COM

13.1.1. Advanced aerial thermography

Purpose and description

The general functionality of thermographic data has already been outlined in Chapter 10.10.1. *Infrared thermography*. While thermographic inspections have become well established as a tool in scheduled and corrective maintenance scheduling, the amount of effort and manual labour required for data gathering in the field has posed financial and operational challenges for their widespread use.

Using thermographic cameras mounted on drones (Remotely Piloted Aircrafts, RPAs or Unmanned Aerial Vehicles, UAVs) or purpose-modified piloted aircraft, instead of handheld devices, the operator flies over the PV modules to capture thermographic images or videos. This data is then analysed to create inspection reports which can be used to form the basis for scheduled and corrective maintenance tasks. If deployed properly, aerial thermography can bring a number of operational and financial advantages.

Not all drone IR imaging is created equal. There are a few parameters that make UAV thermal analysis possible for PV inspections. Height, altitude and time at which the drone shall flight are based on site specific conditions. Furthermore, the service is defined according to the desired visible features:

absolute temperature accuracy, modules, diodes, hotspots and/or cells. It is recommended to refer to the Aerial Thermography Checklist of the Solar Best Practices Mark for a synthesis of the most important best practices and recommendation with respect to aerial thermography.¹⁴

Data acquisition

In this stage a flyover is performed where raw thermographic infrared (IR) images and visual photos or videos are recorded. Depending on the solution additional geolocation services and 3D modelling of the entire plant may be offered. Some other solutions provide additional sensors to record weather variables (usually irradiance and ambient temperature) during the flyover.

Post-processing

The post-processing activities consists of all the data processing and analysis techniques to produce the final report and all the related deliverables. These activities can be done manually or automatically by means of specialised software. Automated detection helps in reducing manual errors. There are two methods for

¹⁴ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

processing data: Ortho-mosaic map based, and individual image based. Both methods have their own advantages. In terms of detection and classification accuracy, both approaches are equivalent and work well.

The activities comprised in this stage can be thought as a serial list of subtasks described in the following table.

The data acquisition stage is now well understood as drone technology ripens and becomes a trend. There are already many companies that offer high-quality industrial aerial flights. Usually companies using drones as a daily-work tool do not only conduct IR inspections of PV plants, but also industrial aerial inspections of oil ducts, off-shore oil extraction platforms, roads, bridges and wind turbines, just to name a few. Therefore, the data acquisition stage is an activity that could be easily outsourced by O&M contractors, mitigating the risks related to technology obsolescence and avoiding the costs of drone regular maintenance.

Most companies today still rely on manual data processing, which represents a big drawback for large portfolios as human-error drives down the accuracy of thermal imaging assessment. This means that companies with automated solutions have a huge advantage in this regard. Asset Owners should favour automated software-based detection and classification to reduce errors which are possible in manual detection and classification.

Aerial inspections and their associated post-processing activities are evolving very rapidly and the quick adoption of new technologies is of high strategic importance in today's highly competitive O&M market.

Pilots

Any aerial thermography or other PV module and plant monitoring application involving drones must be

TABLE 10 AERIAL IR THERMOGRAPHY – POST-PROCESSING SUBTASKS

POST-PROCESSING SUBTASK	DESCRIPTION
Geolocation of PV modules	Manual or automated location of the PV modules inspected. Layout recreation with precise geolocation down to individual module ID or even to module's serial number.
Thermal anomalies detection and classification	Manual or automated detection of thermal anomalies, where the exact position of each affected PV module is identified on the plant's layout. Minimum requirements for this analysis can be found in IEC TS 62446-3:2017.
PV module failure analysis	Diagnosis and root-cause analysis of PV module failures. This is where the link between thermal anomaly and PV module failure is done (warning: not all the thermal anomalies may be considered failures). Temperature differences should be projected to nominal irradiance in accordance with IEC TS 62446-3:2017.
Data analytics	Basic or advanced data treatment to describe the impact of failures in the PV plant. e.g. degradation trends, failure distribution by harm degree and by module manufacturer; power losses assessment and impact on revenue, etc.
Maintenance implementation plan	Actions needed to minimise yield losses based on defect criticality. It can be seen as a list of recommendations that can be directly translated into scheduled or corrective field operations.
Inspections follow-up	Usually as a cloud-based platform, it's where the results of previous inspections can be easily compared with new ones, e.g. year-to-year power degradation.
Reporting	Report created manually or automatically. In most cases the report is tailored to the customer's needs and requirements. It contains the summary of the findings and additionally, depending on the provider, it could contain some calculations of estimated power losses. Additional digital tools like ticketing and Mobile App can help field engineers in locating these faults in the plant easily and manage hotspot rectification activities efficiently in the field.

Source: BAWIA R.E.

carried out by a licensed operator and in accordance with all national and state-level civil aviation regulations. Since drone flying and certification rules are evolving, onus is on the companies providing these services to ensure necessary best practices are employed. Before any such operations can take place, each flight must be thoroughly planned from a logistics, regulatory and safety perspective, and a comprehensive on-site risk assessment conducted, with findings recorded in a flight log. In addition to the collected inspection data, each flight should also be fully recorded in terms of date, time, wind speed and direction and battery levels. Pilots should be technically qualified with diploma or engineering degree holders.

Advantages and disadvantages

With the advent of aerial inspections, resources required for data collection can be significantly reduced. Aerial infrared (IR) thermography might seem a trivial activity, but when not conducted following a set of minimum technical requirements (described in IEC TS 62446-3:2017), it is almost of no use for effective plant maintenance. In that context, high-quality IR images captured by an aerial platform and their proper post-processing allow for a detailed PV module failure analysis that could trigger conclusive maintenance decisions. Furthermore, field interventions can be optimised, and PV plant underperformance can also be better understood and addressed (e.g. faulty modules that need to be replaced can be identified with precision and high-quality IR images can be used as proof in warranty claiming processes). Aerial thermography reduces the inspection time and the number of personnel on site. For instance, using this method, a 12 MW_p PV plant can be inspected in a single day. Additionally, since images are taken from the air, the data yields a helpful overview to check whether plant layout and other documents are correct.

As with any form of thermography, the inspection method is limited by meteorological conditions: For the inspection data to be of value, a minimum radiation of 600 W/m² is required. For drone inspections, in order for the RPA to be controlled safely, and depending on the type of RPA used, wind speeds should not exceed 28 km/h.

State of play

The demand for IR inspections is growing fast, and so is the range of services offered by new players in the market, who are now pushing aerial inspections beyond basic reporting. Advanced aerial inspections, understood as semi-automated or fully-automated solutions are being put into practice for both IR inspection stages, data acquisition and post-processing.

Aerial thermography is becoming a widely accepted and employed tool of inspection in corrective maintenance worldwide. Given the price drop in equipment (both RPAs and thermographic cameras), it will become even more available. Further innovation is to be expected in autonomously controlled RPAs as well as data analysis using Artificial Intelligence.

If deployed properly, aerial inspection could become a cornerstone technology for effective O&M and they would not only be an activity performed just to comply with contractual obligations. Developers can invest in hardware and use cloud processing platforms to analyse data quickly and carry out rectification as routine maintenance versus annual maintenance.

13.1.2. Automated plant performance diagnosis

Purpose and description

As described in SolarPower Europe's Global Market Outlook, the PV industry showed in 2017 the highest growth in the energy market, with total capacity installed of nearly 100 GW worldwide. In such a context, PV plant reliability is subject to higher reliability requirements. With special consideration for aging plants in Europe where the secondary market is growing, automating diagnostics of PV assets is crucial.

Until now, plant performance assessment is typically executed in a top-down approach, analysing low performing objects by drilling down from substations, inverters to junction boxes and strings. This process is time consuming and expert dependent. Furthermore, the process does not guarantee revealing all underperformance issues.

Automated bottom-up diagnosis using advanced big data mining techniques can overcome the disadvantages of classic plant performance assessment by experts: time saving of expert data handling, more error prone and better diagnosis performance.

State of play

Big data mining algorithms have been successfully applied to solar plant data and have proven to reveal performance issues beyond top-down expert analysis in a semi-automated way. Further R&D into this subject area serves to make the algorithms more robust for automated application on large portfolio's and bringing them to root-cause failure identification.

13.1.3. Predictive maintenance for optimised hardware replacement

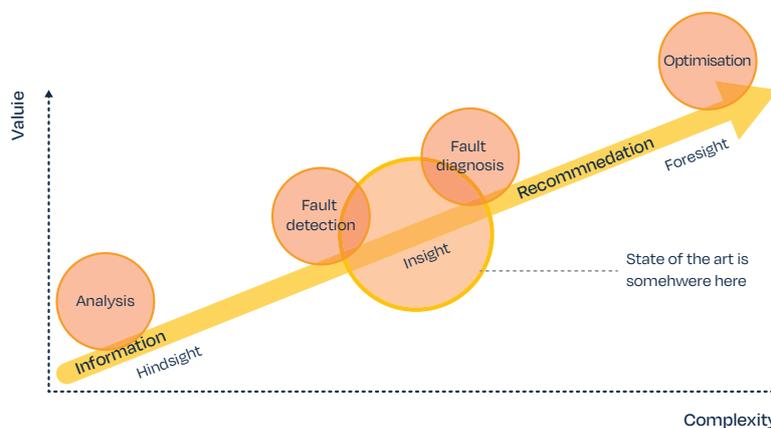
Purpose and description

In India, O&M practices to maintain plant's performance is currently very manual and schedule-driven pre-determined maintained activities are in the mainstream. With technologies like Artificial Intelligence and Machine learning, the solar PV systems could have a dynamic cleaning schedule for different sections of the plant at different intervals to achieve or surpass the target production from the sites. Dynamic cleaning schedules help companies optimise their maintenance staff's allocation as well as water usage. AI and ML have begun to help the industry in detecting shading on panels, detecting early degradation in solar panels and predicting system failures. Prolonged shading on a panel and degradation of one panel affects the whole string and could induce permanent damages to the string/array.

Operational costs of PV plants can have a significant impact on the total LCOE and therefore, on the profitability of a project. Optimisation of operation quality, reducing maintenance costs and maximising plant performances, is the key for a successful project. This process goes through a trade-off between reducing the number of interventions and spare parts replacement during the lifetime of a project while ensuring the plant performs in the best conditions.

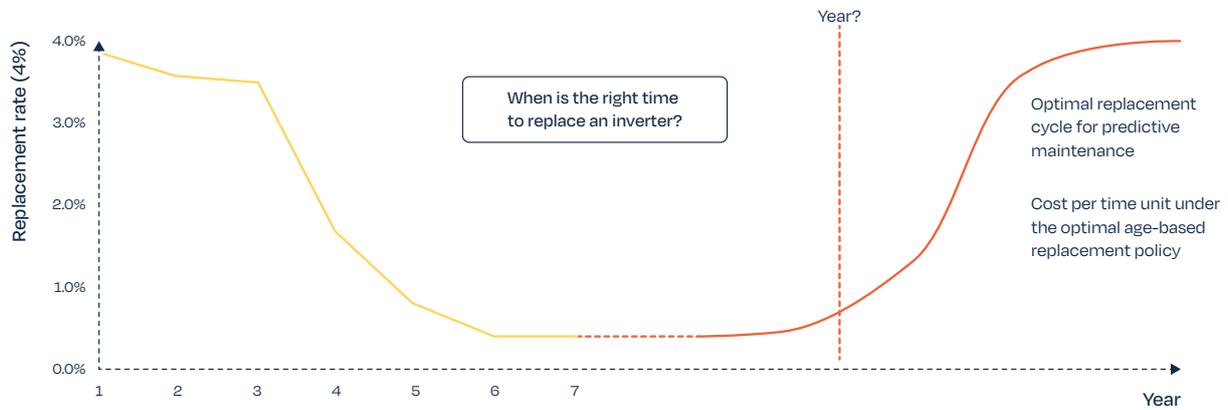
Scheduled maintenance is scheduled periodically according to contractually agreed schedules based on expert knowledge. On top of that, condition-based maintenance may be scheduled when the operator identifies an unexpected deviation in performance through the monitoring system, even before the system would fail. Different maintenance optimisation models are employed to find the optimal balance between the costs and benefits of maintenance interventions. All those models count on the probability of failure of each component of the PV system and the impact of possible single device failure over the entire system. For example, in the case of PV inverters, it is still uncertain what their actual lifetime will be under site specific operating conditions. In practice, inverters will not fail at a precise given moment in time as often modelled in the business plan. Moreover, failure-based maintenance i.e. replacing the inverter(s) when this fails may not be the most efficient solution.

FIGURE 16 AUTOMATED PLANT PERFORMANCE DIAGNOSIS



Source: ACHIM WOYTE, 3E

FIGURE 17 PREDICTIVE MAINTENANCE FOR OPTIMISED HARDWARE REPLACEMENT



Source: ACHIM WOYTE, 3E

A good predictive monitoring system could help on assessing the optimal hardware replacement cycle by modelling the uncertainty in the time-to-failure with a known probability distribution function. Maintenance optimisation models can provide tools relying on the output from root cause analyses, remaining useful life time analyses and alerting and prediction of assets failures in the optimal planning of maintenance and related resource allocation.

Big data analytics can bring added value at any stage of O&M objectives: analysis from observation of collected information to fault detection, fault diagnosis and finally optimisation through recommendations issued from the advanced monitoring system. Today different approaches are proposed. Whereas classic Artificial Intelligence (AI) proposes an advanced diagnostic through knowledge-based models, unsupervised and supervised learnings methods offer different approaches (e.g. neural networks) using statistical approaches.

Advantages and disadvantages

Advantages:

- Lowering the cost of ineffective scheduled maintenance
- Reducing device downtime

Disadvantage:

- Methods are often very sensitive to device models and brands and can thus not be generalised easily.

State of play

Today, no model has been proven to be completely reliable. Big-data analysis allows easy recognition of a fault and, in some cases, provides a clear diagnosis and recommendations on the short-term actions to take to avoid probable upcoming issues. The trend is to model the behaviour of the entire system and to plan optimal maintenance and hardware replacement programs in the medium to long term. This will of course reduce the overall risk of a PV project and hence increase the investing opportunities.

13.1.4. Enhanced power generation forecasting

Purpose and description

Electricity generation from PV plants is limited by the varying availability of the sun's radiation. Even though grid operators are generally obliged to dispatch PV plant production at all times, the growing penetration of PV may force new regulations to guarantee grid stability and the correct balancing of electricity supply and consumption at all times, causing unpredictable losses to plant owners (curtailment). (For more information on *Power Generation Forecasting* requirements in India, see subchapter 5.11.).

Ramp-rate control with and without local storage is currently studied in order to mitigate the impact of fast irradiance fluctuations on power system stability. Approached from the generator side, large PV plants could also contribute to power system stability by providing upward or downward reserves. Technically, this is possible; however, particularly the provision of upward reserves will reduce the overall performance of the plant in question. The business case for such operation modes will depend on the incentives available for deviating from the objective of maximum energy yield.

State of play

The prediction of PV production is becoming an essential tool to capture economies in a market with large penetration of variable renewable energy sources. Expected PV yield output accounting for specific PV plant simulation model and forecasted meteorological resource is a well proven technology. Algorithms that are able to match weather forecasts with PV plant characteristics in order to predict energy production on an hourly basis for few hours ahead and up to the next 48 hours are already playing an important role in the monitoring software market.

The market is rapidly moving towards the need of advanced intra-day correction of the forecasted energy production at sub-hourly resolution and by taking into account actual PV plant conditions like remote curtailment, broken inverters, local losses, etc. Therefore, long and short-term data collection constitute an added value to improve the PV plant yield forecasting. A clear communication protocol between devices in the field (sensors, modules, inverter, loggers, etc.) would help to improve the intra-day forecasting and better exchange with the energy grid. A comprehensive exchange of information between the devices can be used by the simulation model to compute performance expectations. This can be achieved by a trained machine learning system where the operator can set, review and validate specific conditions. In this frame, a proper standardization of terminology and languages used by any communicating device onsite is crucial. The topic of Internet of Things and its application to PV is addressed in the subchapter 13.1.5.

For OPEX model plants, usually the production is estimated before the commissioning of the plant and accordingly production targets are given to the O&M contractor/staff. After a few years, these pre-construction estimates often deviate a lot in comparison with the actual production of the system. But if along with the weather forecast, Air Quality Index (AQI) and increasing temperature are integrated as variables along with the plant's current condition then monthly production estimates could be set accordingly on an ongoing basis and perhaps could lead to tweaking of the O&M contract terms. A related innovation is to constantly increase energy forecast accuracy levels using **machine learning and data exchange between the monitoring solution provider and the energy forecast provider**. This technology help increasing dramatically forecast accuracy levels thereby reducing penalties for Indian asset owners and further help to balance Indian grid.

The monitoring provider exchanges energy production and KPIs data streams with the energy forecast providers. The forecast provider is then able to compare actual production levels with forecasted energy production levels. The forecast provider then improves the accuracy of its forecast machine learning and weather model by learning from the difference between the actual production sent by the monitoring provider and the forecast values provided to the grid. Additional elements that the forecast provider can take into account to increase accuracy level are things such as inverter failures or planned maintenance interventions.

Another way to increase forecast accuracy is utilising **highly accurate satellite-based irradiation data** are available for India and applying Cloud Physical Properties models to further increase the accuracy of the solar resource quantification for solar energy applications. The use of underlying cloud models considering the physical properties of the clouds has improved significantly the accuracy of the satellite-based irradiation data over this region. Moreover, models compensating for satellite sun path and cloud geometry provide the highest accuracy, even at high temporal resolutions (hourly or sub-hourly data).

The resulting data is comparable and sometimes even better than the one of the on-site measurements, particularly in remote regions like, where local sensors are prone to more issues and failures due to severe environment conditions. The improved high temporal resolution accuracy and the availability of real-time 15-minute data is enabling the digitalisation of solar energy in emerging markets. Solar energy forecasting services, for example, are benefiting from this new technology resulting in improved forecast accuracy, thanks to the use of real-time 15 minutes satellite data through implementation of new continuous training algorithms for intra-day corrections. Smart data analytics also benefits from this higher quality satellite-based irradiation data due to its temporal and spatial availability. There are available services in India that rely on this satellite-based irradiation data for quality checks and digital twin models enabling increased accuracy of failure detection routines and root cause identification.

13.1.5. Internet of Things (IoT) and auto-configuration

Purpose and description

Solar monitoring, being a crucial function in the asset operations, is often still a painful and costly process: failing or unstable local hardware, failing communication between the local devices, failing communication with the cloud or data centre infrastructure, configuration issues in loggers or in the portal, high costs for communication, configuration or reporting.

Additionally, requirements with respect to the interaction of the solar power plants with the grid and the electricity markets, increase and put new specifications on the speed, the protocols and the security levels applied.

Internet of Things (IoT) in photovoltaic systems represents an interoperability environment where all devices in the field are connected to each other and spontaneously show themselves as available to be connected to the system. Additionally, each connecting device should provide the following information:

- Device parameters (brand, type, Serial Number, internal datasheet specifications)
- Device status and conditions (operational status, temperature, etc.)

- Connection with other devices & mapping (strings connected, inverter, sensor position, etc.)
- Any other relevant information

Standardisation efforts (e.g. SunSpec Alliance's Orange Button initiative) are taking place throughout the PV market and will help to improve on configuration costs for solar monitoring. However, the solar monitoring industry will also benefit heavily from the emerging Internet-of-things technologies that further improve plug-and-play behaviour of device communication, improve the quality and the security of the communication and reduce the cost of hardware.

Edge Computing and Decentralized Decision Making: The data of the solar plants available for C&I rooftops and utility scale plants is at best at the string level. Panel level IoT sensors are now available with capability to perform edge computing and detect anomalies at the panel level. Such panel level IoT sensors help detect faults faster and when multiple such sensors are strategically installed in the plant, it helps generate a mapping of the degradation, shading and other losses within the plant. This would make the decision making decentralized and O&M contractor/staff would be able to follow a data driven maintenance cycle for the optimal performance of the plant.

Advantages and disadvantages

Advantages

- Reduce the cost of monitoring hardware and infrastructure.
- Reduce the cost of configuration and maintenance of the monitoring infrastructure.
- Improve the quality and the stability of the data.
- Improve the security level and the options for bidirectional communication.

Disadvantages

- Existing hardware and monitoring equipment will not be necessarily compatible with the new Internet-of-Things technologies resulting in hybrid solutions until the former technologies are phased out.

State of play

Many Internet-of-Things (IoT) technologies have passed the prototype phase and are available for massive deployment. However many different technological solutions and approaches are still available in the market and no final best-practice approach has emerged.

Again, this leads to a standardisation issue for industry-wide adoption of Internet-of-Things technology within the solar industry and as such benefits from its advantages will be reduced when considering PV on a larger scale.

13.1.6. Digital Twin

A digital twin is the virtual representation of a physical object or system across its life-cycle. It uses real-time data and other sources to enable learning, reasoning, and dynamically recalibrating for improved decision making. The idea is to create a virtual model of a solar plant using the physical and electrical model of each power plant and organize all plant data around the digital model of the plant. Building a digital twin requires capture of all data (SCADA, drones, sensors, maintenance etc.) related to the asset in a manner that is indexed to the digital model. This should enable seamless multi-variable analysis and creation of a unique performance model of the solar plant. Ideally, there is a need for software tools that allow digital twin to be created automatically as data flows in from various systems and all data sources. Digital twin adoption can be already seen in industries like aviation, factory automation etc.

13.1.7. Future best practices in document management systems

Purpose and description

Asset contractual and technical documentation as described in today's Best Practices can be handled either physically or electronically, as far as the employed Document Management System (DMS) keeps all documents ready consultation by or transfer to relevant stakeholders. The inventory of technical documentation linked to a portfolio of plants can become very complex, especially in an era where the Indian solar sector is moving towards a secondary market. Considering the number of documents to be

stored and exchanged per plant, the increasing number of stakeholders that should have free access to a subset or the totality of the documentation, the physical exchange and storage of files becomes nearly impossible to be maintained without a proper quality process. Electronic document management and storage is thus becoming a best practice within the Solar industry. In addition to storing these documents centrally, it is also important to tag these documents at plant level. Digital Twin and DMS should be in unison to ensure right document is available at right time and is easily accessible from the office as well as on site.

At the same time, the use of meta-tags instead of a classical tree structure is a technique of filing that is becoming more widespread where asset documentation can be considered as relevant to different stakeholders or belonging to different portfolios. The use of meta-information and their standardisation under a common nomenclature is seen as the next best practice, especially to facilitate the contractual management of big portfolios and the maintenance operations.

Next to meta-tagging documents with additional information, making any document (scan, word, xls, mail, etc.) full text searchable adds to the best practices to make sure that all information can be listed and searched for when the need occurs.

Both technical and contractual documentations, including device replacement, scheduled maintenances, operators contacts, calendar of operations, intervention reports, should be tagged and electronically stored using a standardised terminology. This will facilitate their retrieval and updates as well as operation management or transition of a plant to a new O&M contractor.

Additionally, the selected DMS should allow a suitable user management system that will automatise the exchange and security of sensitive documents between stakeholders.

Advantages and disadvantages

The idea of meta-tagging documentation allows any document to be tagged with different criteria. Additionally, capturing location information and tagging to plant components enables easier archiving and retrieval, ensuring information is available on need

to know basis. This way any piece of information can be stored over multiple time areas, assets, records or any relevant criterium. The-meta tagging allows the user or the applications to filter information on relevant criteria only. For example, only pictures from a certain period, or only plans from a defined equipment type. This way of meta tagging also avoids the need for documents to be copied or stored in multiple locations.

State of play

In terms of technological readiness and market uptake, digital DMS solutions using meta-tags and full-text search are already existing and adopted by some Asset Managers and O&M contractors. This technology could become soon a best practice, though the standardisation of document tagging in the solar industry is not yet implemented.

Document recognition and meta-tag autofilling is already available on most documents including some scanned file types via OCR (Optical Character Recognition). At a next level, image recognition and auto-tagging would save operational time.

13.2. Retrofit coatings for PV modules

13.2.1. Anti-soiling coatings

Purpose and description

Solar cells, just like human eyes, need a clean field to function properly. Deposits and particles covering the surface of PV panels, like soiling, staining, dirt and grime, leaves, pollen, bird droppings, lime-scale and other environmental or industrial pollutants, prevent solar radiation from reaching the cells of PV modules and inevitably the efficiency and the optimal function of the solar system is reduced.

Soiling influences the levelised cost of electricity (LCOE) in two ways: by leading to an O&M cost (periodic cleaning), and by reducing the energy produced from 1%-10% in normal cases and up to 80% in extreme situations. In general, the presence of dirt or any other particles on the module surface has an impact on the anti-soiling properties; specific coating products with anti-soiling properties which also provide anti-reflective performances have been developed in the last years.

Advantages and disadvantages

Modules treated with anti-soiling coatings get dirty less quickly and are easier to clean and therefore maintain higher performance levels for longer, reducing the amount of module cleaning necessary and increasing yield by up to 3%.

Some anti-soiling coatings can also be used to restore corroded PV module surfaces. Most anti-soiling coatings are relatively easy to use so that they can be applied by the O&M Contractor.

When it comes to applying coatings to already installed modules in general, the O&M Contractor should carefully evaluate possible consequences for PV module warranties and for any incentive or tariff schemes.

Retrofit anti-soiling coatings are a layer applied on the surface of the modules that in principle don't affect the properties of the glass surface and that can be removed if needed for warranty purposes.

State of play

There are already various commercially available anti-soiling coatings that can be applied on PV modules that have already been installed. New solutions are also being developed – some of which outperform older anti-soiling coatings or even anti-reflective coatings in terms of power gain. The new generation of retrofit anti-soiling coatings are mostly based on spray technologies but some anti-soiling coating suppliers are developing specific solutions for desertic areas that are applied via mechanical systems.

13.2.2. Anti-reflective coatings

Purpose and description

Reflection losses are one of the first loss factors occurring in the energy flow when converting sunlight to electricity via the PV power plant.

New anti-reflective coatings (ARC) that can be applied directly via a 'retrofit' method onto PV modules already installed in the field. Applied to the surface of the panels, these coatings reduce the reflection and thereby the losses due to reflection resulting in a higher energy output.

Innovative new coatings specifically engineered for aftermarket application are based on the same technology platform as the leading anti-reflective technology for new modules. These coatings reduce the amount of light reflected off the glass, allowing more light to travel through to the solar cell and to be converted into electricity.

An ARC works by providing an incoming photon with a very gradual transition from air to glass. It does this by varying the porosity of the material from very high at the coating-air interface to very low at the coating-glass interface. An ARC layer has typically a thickness of 120-150nm and can be applied on the module surface through special equipment, commonly named "applicator", or via spray. Both technologies provide different results in terms of layer uniformity, thickness and performance. The more controllable is the coating process the better will be the final result.

ARC is based on a silica-gel solution that is applied on the module surface. Once applied, the solution becomes a solid layer after a period of curing. Tests executed with mechanical application show power gain in the range of 3%-5%. An additional point to be considered when it comes to ARC retrofit technology is the durability of the coating layer. A good ARC should last for at least 5 years with a physiological yearly degradation that shouldn't reduce the coating properties more than 30% from its original performance.

Advantages and disadvantages

Retrofit anti-reflective coatings can increase module output in the field by up to 3-4%. In some cases, pilot tests have shown energy gains up to 5%.

When it comes to applying coatings to already installed modules in general, the O&M Contractor should carefully evaluate possible consequences for PV module warranties and for any incentive or tariff schemes. An ARC, if applied properly through a mechanical application specifically developed for the purpose, does not damage the module surface. A new generation of modules has an ARC applied during the manufacturing process. A coating supplier that performs ARC properly should be able to provide the client specific warranties (e.g. product liability insurance).

State of play

There are already commercially available anti-reflective coatings that can be applied in a retrofit manner. Other products are currently being developed and tested to substantiate the applicability of the solution on a large scale and data will be collected from different locations.

"Mature" ARC technologies which have been tested for years are already available. They provide reliable results both in terms of durability and overperformance. This coating solution is based on a mechanical application via a controlled process that involves pre-coating measurements, quality control during the coating process and post-coating measurements. For this purpose, sophisticated equipment such as spectrometers, able to measure the variation (%) of reflection before and after the coating process, are needed. The market provides a wide offer of such devices and with prices in the range of 5-9k EUR, but not all spectrometers are good for ARC applications.

13.3. O&M for PV power plants with storage

Energy Storage Systems (ESS) are a set of technologies whose aim is to decouple energy generation from demand. The systems allow for excess electricity to be "stored" and released during periods of high electricity demand, providing cost-saving opportunities to consumers and ensuring a steady and safe electricity supply.

ESS are flexible and can be used in many different ways, from ensuring energy security to blackout relief, all the way to energy arbitrage. By adopting ESS on a commercial scale, the EU can decrease its energy imports, improve the efficiency of the energy system, and keep prices low by better integrating variable renewable energy sources.

Ultimately, energy storage can contribute to better use of renewable energy in the electricity system since it can store energy produced when the conditions for renewable energy are good, but demand may be low. This more variable power generation pattern has significantly increased the need for flexibility in the electricity grid (source: European Commission, 2018).

13.3.1. Types of storage systems

The selection of a storage system can significantly influence a project's overall O&M strategy. Technical parameters such as battery lifetime, efficiency, depth of discharge (DoD) and/or power density, should be taken into consideration at the development stage to select the adequate ESS and avoid unnecessary costs throughout the project's lifecycle.

Despite there being many forms of ESS (flywheels, compressed air, thermal), and with pumped hydro energy storage (PHES) being widely used in conjunction with hydro plants, the most mature and commonly used systems for utility scale solar plants are solid-state batteries (e.g. lithium-ion), liquid electrolyte electrolyte electrolyte electrolyte electrolyte electrolyte electrolyte (lead acid) and Flow Batteries (e.g. vanadium redox). (e.g. lead-acid). There are many different types of Li-ion battery each with its own environmental conditions, efficiency, and lifetime characteristics.

Solid state batteries contain a higher C-rate than batteries with liquid electrolyte, meaning they can discharge quicker and are more effective in situations where a large amount of power over a short period of time is required (e.g. blackouts). Solid state batteries typically last 15 years, meaning they must be replaced at least once during a project's lifecycle. Lifetime is difficult to predict because it depends on number of cycles; charge/discharge rates; depth of discharge; temperature; and their cumulative effect. There are standards for the percent of remaining capacity (eg 70% of initial capacity) that triggers a replacement. O&M of flooded lead acid batteries is extensive, requiring continuous maintenance of the electrolyte, whereas sealed batteries don't require frequent maintenance but do require replacement. There are standards for the percent of remaining capacity (e.g. 70% of initial capacity) that triggers a replacement that are specific to the application.

Power conditioning electronics that push battery maintenance functions down to the unit level have operational advantages (redundancy, fault isolation) over a single string of large-capacity cells, similar to those of micro-inverters on a PV array. Batteries deployed to serve DC load couple well with PV for data centers and telecommunications applications.

Flow batteries are very efficient for meeting a steady, long term energy demand (e.g. night-time application), but will be less efficient in blackout scenarios. Flow batteries provide less harm to the environment as well as less safety risks (much less flammable) than their solid-state counterparts; however, this is counterbalanced by their higher cost.

As a rule of thumb, to obtain 1 MWh of storage you need 15m² of lithium-ion batteries or 80m² of Flow Batteries. Therefore, you may want to select Li-ion batteries if your site is constrained.

13.3.2. Environment, Health & Safety

Most batteries are subject to environmental regulations that require recycling or proper disposal at end of performance period.

The ESS mentioned above are electrical appliances and as such are subject to significant health & safety risks. To prevent hazards (e.g. uncontrolled release of energy), an appropriate risk assessment must be performed during the design and planning phases and necessary safety precautions implemented. The hazards must be identified during these stages and appropriate measures taken to mitigate risk and to protect those operating the system. The main risks are: impact, excessive heat, crush or water penetration and electrical shock. There is also a significant health and safety risk of poisoning or mishandling hazardous materials, especially the sulphuric acid electrolyte added to lead-acid batteries.

Both external and internal factors should be considered during the risk assessment since, in some cases, the ESS itself can be the cause of hazardous event. The major hazards for large-scale ESS can be categorised as follows:

- **Electrical**, occurring when there is direct contact between a person and the system.
- **Mechanical**, occurring after a physical collision.
- **Poisoning** or exposure to hazardous materials.
- **Other**, occurring due to an explosion, fire, thermal runaway, or the leaking of chemical components from the system.

To avoid risks, the system should not overheat, come into contact with water, or suffer from either electrical stress or high humidity. The risk of electrical shock can be mitigated - as is common practice in photovoltaic plants - with appropriate electrical insulation: for instance, by wearing appropriate personal protective equipment (PPE). The energy storage system should be maintained by trained technicians since improper handling increases the risk of electrical shock. For personnel qualifications during the installation and maintenance of stationary batteries, reference should be made to IEEE 1657 - 2018.

Safety data sheets should be provided to those operating the system. In case of repair or replacement, addition or alteration of the system, the safety system should be re-evaluated and, if necessary, additional safety systems implemented.

It is good practice to design the system in a way that allows straightforward removal and replacement of modules. The system itself should be easily accessible for inspection without needing to significantly disassemble the ESS system. Disposal of hazardous material should comply with local and national rules and regulations.

13.3.3. Operation & Monitoring

To increase the lifecycle and efficiency of an ESS, the implementation and regular follow-up of an efficient monitoring system is essential. ESS should always be equipped with an Energy Management System (EMS) to track charge/discharge states and make sure that the system does not exceed/go under the prescribed charging limits. The EMS should also gather data coming from energy meters, auxiliary systems and operating parameters, such as temperature, voltage, current, power level, state of charge, state of energy and warning messages, in order to assess the condition of the ESS daily.

When dealing with ESS, communication between the operator and the grid administrator is a key factor. The energy producer should, one day prior, communicate

to the grid administrator an estimation of the hour (battery) charging is expected to stop, as well as an estimation of the hour where discharge is expected to start. The producer should also communicate his expected production at constant power on a daily basis. In some cases, the producer must provide the grid administrator with hourly estimations of charge/discharge periods and peak production capacity. In any case, an understanding of the precise rules of the different national electricity systems are required to determine the obligations relating to forecast usage of the battery storage system.

13.3.4. Maintenance

In order to perform a systematic maintenance, a plan on location showing how component and system must be tested is required. In case of reparation or replacement or of any component within the system, it should be checked whether the change comply with the applicable regulation.

The EES systems should be provided by an operational manual, including at least the following topics:¹⁵

- System overview and site layout.
- System component description.
- Maintenance cycles for all components, including the actions to be taken during the inspection and maintenance activities.
- Safety instructions.

In addition, to avoid reducing the lifetime of your ESS, it is recommended to keep your batteries environment-controlled container (25°C, no humidity). An EMS should be put in place to monitor the charge/discharge conditions of your battery based on market demand. Whilst Flow Batteries are resilient and can undertake full charge/discharge cycles, lithium-ion batteries will slowly deteriorate if they experience such cycles. As a rule of thumb, lithium-ion batteries should not be charged at more than 90% and less than 10% of their energy storage capacity.

¹⁵ Note: this list is intended to be illustrative and not limiting.

14

O&M for distributed solar



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This chapter is to assist in the application of the established utility-scale best practices, detailed in the previous chapters of the document, to distributed solar projects. All best practices mentioned in these Guidelines could be theoretically applied to even the smallest solar system for its benefit, however this is not practical in nature due to a different set of stakeholders and financial implications. This chapter attempts to avoid different best practices between residential and commercial rooftop projects, rather when a higher level of accuracy and care is economically feasible it should be the adopted approach.

As no people are on site here (as is the case for utility scale plants in India), digitalisation in O&M is even more important in the case of distributed solar.

Primary consideration must be made to provide the highest possible care in the most cost-efficient manner to deliver the lowest levelised cost of electricity (LCOE) to distributed Asset Owners – typically home or business owners or public entities.

The key factors that impact changes to application of the utility best practices are:

- Different set of stakeholders: Asset owners are not solar professionals.
- Different economics: Additional monitoring hardware (temperature / irradiance) on top of inverter accounts for a greater percentage of the total investment. Costs of physical site inspections and call-outs are proportionally higher compared to savings.
- Higher incidence of uncertainty: greater shade, lower data accuracy, less visual inspection.

As in utility-scale best practices, jurisdiction-specific national requirement such as administrative and reporting requirements linked to support schemes, environment, health & safety requirements, building codes, etc., must always be complied with in distributed solar O&M, too.

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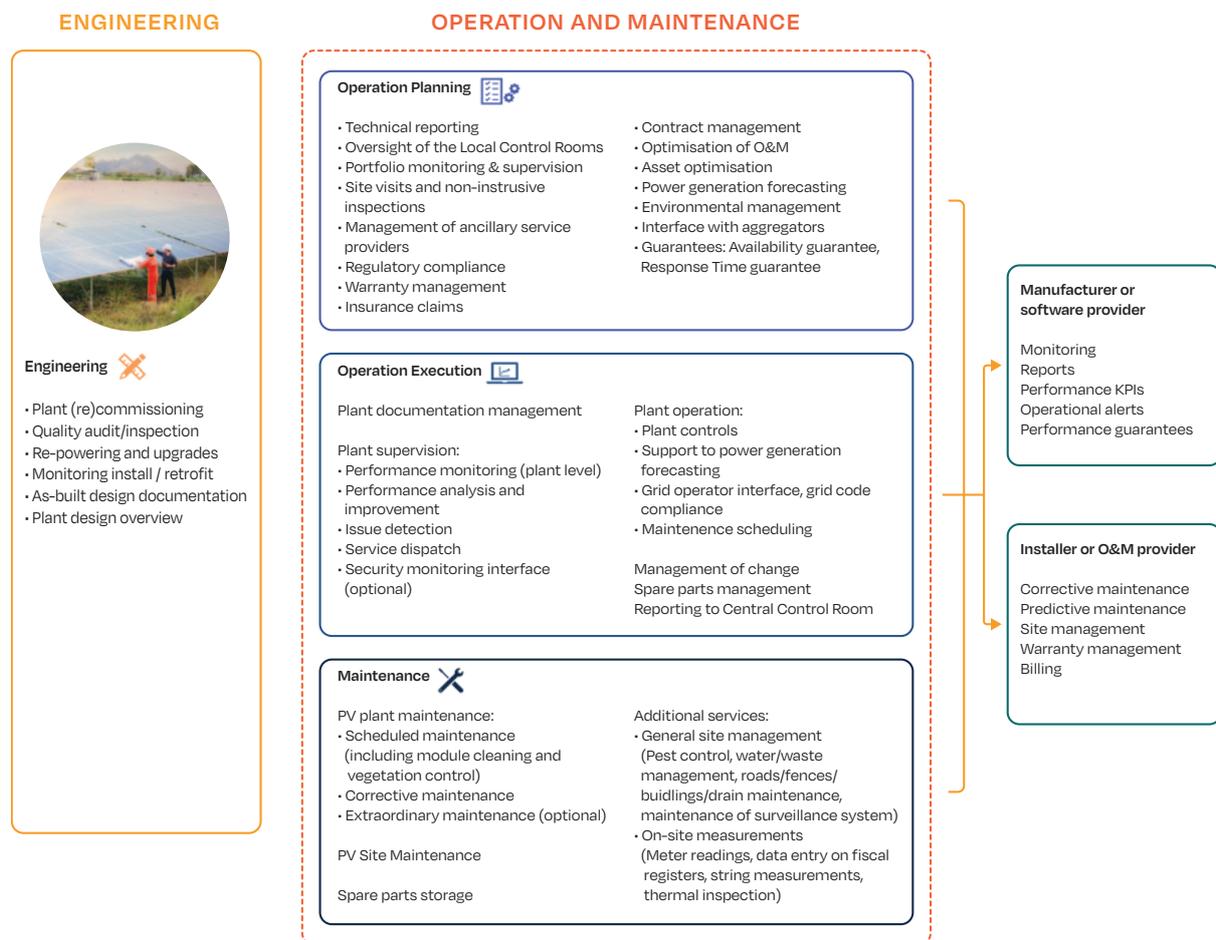
14.1. Stakeholders

The active O&M stakeholders in a distributed solar system have historically been limited to the system owner and the retailer/installer with direct involvement by suppliers, third party engineers/advisors and lenders. The Installer will typically make use of third-party software providers to provide the monitoring and basic alerting services.

The Installer must not take advantage of their position of strength and should honestly and accurately provide all information to system owners. In particular, it must be clear what the impact is if yield predictions are not achieved and the requirements for O&M must include planned electrical inspections and corrective maintenance.

The Installer should not state that solar systems are self-cleaning and do not require any maintenance.

FIGURE 18 ROLES AND RESPONSIBILITIES BY DIFFERENT STAKEHOLDERS IN THE FIELD OF O&M FOR DISTRIBUTED SOLAR



NOTE: The responsibilities of the Asset Manager and the O&M Contractor overlap sometimes, and Technical Asset Management can be assumed by either the O&M Contractor or the Asset Manager. For distributed solar, software providers and installers take over tasks that are historically responsibility of other stakeholders.

14.2. Environment, Health & Safety

Necessary precautions as outlined in Chapter 3. Environment, Health & Safety of the utility best practices should be taken. Further emphasis should be placed on training and skills required for working in heights and on roofs.

It is more likely that access to the system is available to other parties not directly involved in the upkeep of the solar system. Developers and O&M providers should provide "stakeholder training" for people working or living in the proximity of the installation.

Proper signalization of dangers should be displayed beside any hazardous device.

14.3. Personnel and training

When dealing with a non-professional Asset Owner, additional thought must be given to the information provided to them at all stages of project lifecycle.

- Retailers/installers should be clear about the need for ongoing maintenance and make sure this is reflected in any financial analysis provided to customers. Best practice would involve either;
 - the retailer providing maintenance service themselves or,
 - Ensuring a clear and continuous handover to 3rd party O&M.
- Provide a manual to the homeowner with contact information and description of operational indicators and procedures they can do, including clear documentation that states the customer as responsible for maintaining original insolation/shade.

Online Training:

Most of the on-site ground staff in India come from a less educated background. Training of such personnel on understanding a system fault and the remedial steps would help the industry to mature in its maintenance efforts. Some companies are putting in effort by providing mobile applications wherein the solar system's error message or fault prediction alerts are integrated with a lesson to rectify the respective fault. Such online on-site training, in local Indian language, would help the O&M staff to educate themselves about the solar PV system.

14.4. Monitoring & Reporting

The Asset Owner is typically not a solar professional, therefore reporting needs to be easily understood and clear. The purpose of reporting is to verify the asset is performing in accordance to expectations as promised by the retailer/installer in the selling process.

A central question of O&M for distributed solar is to ensure the accuracy of the performance monitoring of a small-scale distributed system, given the likely absence of a pyranometer and module temperature sensors.

Often there are connectivity issues between the monitoring device and the cloud, and data loggers or monitoring service for smaller scale systems are mostly expensive. Based on the location of the site, GSM based communication protocols could be a very cost effective and reliable communication solution. Moreover, the monitoring on the DC side of the solar system is, at best, available at the string level. Using a panel-level IoT sensor (several available in the market) would help monitor up to panel level and the same device (usually plug and play) could be plugged in to panels of different strings as a diagnostic tool to perform a root cause analysis of an underperforming string/panel. The quick localisation of fault enables technicians to quickly resolve the fault. Hence, providing cost saving on maintenance efforts.

Protocols

The use of standard and secure communication protocols should be promoted in order to avoid "supplier lock-in". When standard protocols are used, a free and competitive market is created on level of hardware and software.

Privacy and cybersecurity

Privacy and cybersecurity are very important aspects not only for utility-scale PV plants but also distributed installations. The recommendations in section 10.7. on *Data ownership and privacy* and 10.8. on *Cybersecurity* also apply for distributed installations.

Key Performance Indicators

For reporting to Asset Owners, emphasis shall be placed on the Energy Performance Index (EPI) rather than availability, downtime or PRs. EPI is an easily

14 O&M for distributed solar / continued

explainable metric that does not require an in depth understanding of solar. (See 11.1.2.6. *Energy Performance Index* for more details)

If EPI is greater than 100% the system is performing to expectation based on actual weather conditions experienced.

The expected yield based on actual weather conditions must use the same assumptions (PR, shade, degradation) as was made to invest. The EPI should be reported to Asset Owner at least annually, but O&M Provider should be reviewing and take action more frequently (monthly).

Reference Yield Data Collection

In order to accurately calculate the Energy Performance Index, collection of Reference Yield (Local Irradiation) and temperature data is required.

The following methods can be applied for collection of reference yield as seen in Table 11 below.

Shade

Distributed projects have much greater and more variable shade profiles than utility scale projects, even large commercial projects typically encounter significant roof obstacles. Best practice requires that expected yields used in the EPI are adjusted based on shade expectation for the KPI interval.

As a recommendation, horizon and obstacle plotting should be included in all yield modelling.

14.5. Operation

To ensure production maximisation and hence the lowest levelised cost of electricity (LCOE) of a solar asset, the owner should perform or subcontract a proper O&M activity.

The Asset Owner should have access to a customer support hotline and know who to contact in the event of issue. This information is ideally placed next to the inverter.

O&M services for distributed systems should cover the incidents below as seen in Table 12 on the following page.

TABLE 11 METHODS SUGGESTED FOR THE COLLECTION OF REFERENCE YIELD

REFERENCE YIELD SOURCE	ACCURACY	HARDWARE COST	COMMENT
Onsite Pyranometer	High*	High	For more information, see 10.10.1. <i>Irradiance measurements</i> . Public pyranometers may be used if available.
Module level sensor	High	High	
Satellite Data	Medium-High**	None	For more information, see 10.10.1. <i>Irradiance measurements</i> .
Cell Sensors	Medium	Low	
Local Comparison	Medium-Low	None	The established baseline must be verified.
Historic Data	Low	None	Monthly variation may be +/-20%.

* Pyranometers and cell sensors needs periodical cleaning and recalibration to keep the highest level of accuracy. If this cannot be sustained, a good satellite irradiation data set is preferable.

** Satellite data accuracy depends on type of source. However, the best references have a granularity of 3x3 km² and do not include local shades.

TABLE 12 INCIDENTS COVERED BY O&M SERVICE AGREEMENTS FOR DISTRIBUTES SOLAR SYSTEMS

INCIDENT	CLASSIFICATION	COMMENT
Inverter alarms	Minimum requirement	Alarms generated by the inverter should be acknowledged at least daily. Maintenance responsible should take necessary actions in the shortest delay: <ul style="list-style-type: none"> • Residential: Within 7 days • Commercial: Within 1 day
Monitoring Failure	Minimum requirement	Remote diagnosis of monitoring failure should be completed within 2 days. As monitoring failure is often caused by inverters failure or DC issues, this diagnosis must be done quickly to determine if the failure is limited to monitoring or if yield production is impacted. O&M Provider should have good guidelines and troubleshooting guides that allow system owner to self-diagnose and resolve. Resolution of monitoring failure without yield losses: <ul style="list-style-type: none"> • Residential: Within 7 days • Commercial: Within 2 days
Inverter failure	Minimum requirement	As soon as inverter failure is indicated by inverter alarms or monitoring failure a replacement should be installed: <ul style="list-style-type: none"> • Residential: Within 1 day • Commercial: Within 1 day
System Level Performance Alerts	Best Practice	Duration and frequency of reporting should be according to the expected accuracy and availability of live irradiation data. Best Practice for monthly comparison, minimum annually.
Module- String/ Inverter Level Alerts	Recommended	For commercial projects with more than one inverter, reporting should be at minimum at inverter level. String or MPPT level reporting to alert to string failure is recommended where possible.
Module cleaning (and pyranometers or sensor cells if present)	Minimum requirement	The expectation for module cleaning planning should be based on the site, the installation type and size, the environmental conditions. Actual planning of module cleaning can be adjusted based on the performance (EPI) of system over time.

14.6. Maintenance

The distributed O&M service provider should provide a Maintenance Plan to the Asset Owner during or before system commissioning.

Roofs under warranty require annual scheduled roof maintenance to maintain the roof warranty. It is a best practice for the retailer/installer and O&M provider to meet with the roof maintenance provider to make sure both teams understand their roles and responsibilities and respect the needs of the other.

Most end-customers rely on their inverter's physical display to confirm their system's performance. There is a lack of awareness that monitoring portals could generate alerts for the system owners which could be received either via email or text messages. There is a need to build customer friendly communication channels (for example WhatsApp) to keep customers constantly informed of their system's performance and recommend actions to improve their system's performance (e.g. precise date to clean the panels). The provisioning of such mechanism will keep the

14 O&M for distributed solar / continued

end-users engaged, aware and eventually, it will lead towards a higher acceptance of solar PV systems.

14.7. Spare Parts Management

If economically feasible, the O&M provider should have basic spare parts in stock. Failing this, care should be taken to select component manufacturers which can provide local service and fast replacement of faulty goods to India.

The O&M contractor has a strategy based on warehousing/storage or agreements with the original equipment manufacturers and/or distributors to optimize the activities related to spare parts management.

After completion of the Provisional Acceptance Commissioning of the power plant, all necessary spare parts and consumables shall be defined (cost-benefit analysis) by the contractor together with the owner.

The following parameters should be taken into consideration when selecting the stocking level:

- Frequency of failure (MTBF, MTTR)
- Impact of failure
- Cost of the spare part
- Degradation over time
- Equipment reliability
- Shipping time

The inverter is the most important spare part as most monitoring is reliant on it.

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A Annex

A. Applicable international standards for solar O&M

IEC/other international	Equivalent BIS standards	
Generic for O&M		
IEC 62446-1:2018	IS 16960-1:2018	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
IEC 62446-2		Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 2: Grid connected (PV) systems - Maintenance of PV systems
IEC TS 63049:2017		Terrestrial photovoltaic (PV) systems – Guidelines for effective quality assurance in PV systems installation, operation and maintenance
IEC 60364-7-712:2017		Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
EN 13306		Maintenance terminology
System Performance and Monitoring		
IEC 61724-1:2017	IS 61724-1:2017	Photovoltaic system performance - Part 1: Monitoring
IEC TS 61724-2:2016	IS 61724-2:2016	Photovoltaic system performance - Part 2: Capacity evaluation method
IEC TS 61724-3:2016		Photovoltaic system performance - Part 3: Energy evaluation method
IEC TS 61724-4		Photovoltaic system performance - Part 4: Degradation rate evaluation method (not yet published as of October 2019)
IEC TS 63019:2019		Photovoltaic power systems (PVPS) – Information model for availability
ISO 9847:1992		Calibrating field pyranometers by comparison to a reference pyranometer
Specialised Technical Inspections		
IEC TS 62446-3:2017		Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 3: Photovoltaic modules and plants - Outdoor infrared thermography
IEC 61829:2015	IS 61829:2015	Photovoltaic (PV) array - On-site measurement of current-voltage characteristics
IEC TS 60904-13:2018		Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules

A. Applicable international standards for solar O&M - *continued*

IEC/other international	Equivalent BIS standards	
PV components, BoS and other supporting documents		
IEC TS 62738:2018		Ground-mounted photovoltaic power plants - Design guidelines and recommendations
IEC TR 63149:2018		Land usage of photovoltaic (PV) farms - Mathematical models and calculation examples
IEC 60891:2009		Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics
IEC 61853-1:2011		Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating
IEC 61853-2:2016		Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements
IEC 61853-3:2018		Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules
IEC 61853-4:2018		Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles
IEC 60904-5:2011		Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
IEC 62093:2005	IS 16229:2015	Balance-of-System components for PV systems - Design qualification natural environments
IEC 61701:2011	IS 61701:2011	Salt Mist Corrosion Testing of Photovoltaic (PV) Modules
IEC 62716:2013	IS 16664:2018	Photovoltaic (PV) Modules - Ammonia (NH ₃) Corrosion Testing
IEC 62116/ UL 1741/ IEEE 1547 (as applicable)	IS 16169:2019 (First revision)	Utility-interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures
IEC 62916	IS/IEC/TS 62916:2017	Photovoltaic Modules Bypass Diode Electrostatic Discharge Susceptibility Testing
IEC 62941	IS/IEC 62941:2016	Terrestrial Photovoltaic (PV) Modules Guidelines for Increased Confidence in PV Module Design Qualification and Type Approval
IEC 62979	IS/IEC 62979:2017	Photovoltaic Modules Bypass Diode Thermal Runaway Test
IEC 60269	IS/IEC 60269: Part 6: 2010	Low-Voltage Fuses Part 6 Supplementary Requirements for Fuse-Links for the Protection of Solar Photovoltaic Energy Systems
IEC 61215	IS 14286	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 61646	IS 16077	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 61730	IS 61730	Photovoltaic (PV) module safety qualification
IEC 62109-3:2020	IS 16221	Safety of power converters for use in photovoltaic power systems
IEC 61427	IS 16270	Secondary cells and batteries for solar photovoltaic application - General requirements and methods of test

C Annex

C. Documentation set accompanying the solar PV plant. (Download it from www.solarpowereurope.org)

INFORMATION TYPE AND DEPTH OF DETAIL / AS-BUILT DOCUMENTS			
NO.	MINIMUM REQUIREMENTS	DESCRIPTION	COMMENTS
1	Site Information	<ul style="list-style-type: none"> Location / Map / GPS Coordinates Plant Access / Keys Access Roads O&M Building Spare Parts Storage / Warehouse Site Security Information Stakeholder list and contact information (for example, owner of the site, administration contacts, firefighters, subcontractors / service providers, ...) 	
2	Project Drawings	<ul style="list-style-type: none"> Plant Layout and General Arrangement Cable routing drawings Cable list Cable schedule/ cable interconnection document Single Line Diagram Configuration of strings (string numbers, in order to identify where the strings are in relation to each connection box and inverter) Earthing/Grounding System layout drawing Lightning Protection System layout drawing Lighting System layout drawing (optional) Topographic drawing 	"Lightning Protection System layout drawing" can be considered as optional
3	Project studies	<ul style="list-style-type: none"> Shading study/simulation Energy yield study/simulation Inverter sizing study 	
4	Studies according to national regulation requirements	<ul style="list-style-type: none"> Voltage drop calculations Protection coordination study Short circuit study Grounding study Cable sizing calculations Lightning protection study 	
5	PV Modules	<ul style="list-style-type: none"> Datasheets Flash list with PV modules positioning on the field (reference to string numbers and positioning in the string) Warranties & Certificates 	
6	Inverters	<ul style="list-style-type: none"> O&M Manual Commissioning Report Warranties & Certificates Factory Acceptance Test Inverter settings Dimensional drawings 	
7	Medium Voltage/ Inverter Cabin	<ul style="list-style-type: none"> Medium Voltage/Inverter Cabin layout and general arrangement drawing Medium Voltage/Inverter Cabin foundation drawing Erection procedure Internal Normal/Emergency Lighting Layout Drawing Fire Detection and Fire Fighting System Layout Drawing (if required) HVAC system Layout Drawing HVAC system Installation & O&M Manual HVAC Study (according to national regulations) Earthing system layout drawing Cable list 	
8	MV/LV Transformer	<ul style="list-style-type: none"> O&M Manual Commissioning Report Factory Acceptance Test Report Type Test Reports Routine Test Reports Warranties & Certificates Dimensional drawing with parts list 	

NO.	MINIMUM REQUIREMENT	DESCRIPTION	COMMENTS
9	Cables	<ul style="list-style-type: none"> • Datasheets • Type & Routine test reports 	
10	LV & MV Switchgear	<ul style="list-style-type: none"> • Single Line Diagram • Switchgear wiring diagrams • Equipment datasheets and manuals • Factory Acceptance Test report • Type Test Reports • Routine Test Reports • Dimensional drawings • Warranties & Certificates • Protection relays settings • Switching procedure (according to national regulations) 	“Protection relays settings” and “Switching procedure” are considerations for the MV Switchgear
11	HV Switchgear	<ul style="list-style-type: none"> • Single Line Diagram • Steel structures assembly drawings • HV Switchyard general arrangement drawing • HV Equipment Datasheets and Manuals (CTs, VTs, Circuit Breakers, Disconnectors, Surge Arresters, Post Insulators) • Protection & Metering Single Line Diagram • HV Equipment Type & Routine Test Reports • Interlock study • Switching procedure (according to national regulations) • Warranties & Certificates 	
12	UPS & Batteries	<ul style="list-style-type: none"> • Installation & O&M Manual • Commissioning report • Warranties & Certificates • Datasheets • Dimensional Drawings 	
13	Mounting Structure	<ul style="list-style-type: none"> • Mechanical Assembly Drawings • Warranties & Certificates 	
14	Trackers	<ul style="list-style-type: none"> • Mechanical Assembly Drawings • Electrical Schematic Diagrams • Block diagram • Equipment Certificates, Manuals and Datasheets (Motors, Encoders) • PLC list of inputs and outputs (I/O) by type (Digital, Analog or Bus) • Commissioning reports • Warranties & Certificates 	
15	Security, Anti-intrusion and Alarm System	<ul style="list-style-type: none"> • Security system layout/general arrangement drawing • Security system block diagram • Alarm system schematic diagram • Equipment manuals and datasheets • Access to security credentials (e.g. passwords, instructions, keys etc) • Warranties & Certificates 	
16	Monitoring/ SCADA system	<ul style="list-style-type: none"> • Installation & O&M manual • List of inputs by type (Digital, Analog or Bus) • Electrical Schematic diagram • Block diagram (including network addresses) • Equipment datasheets 	I/O list includes e.g. sensor readings that are collected by data loggers.
17	Plant Controls	<ul style="list-style-type: none"> • Power Plant Control System description • Control Room (if applicable) • Plant Controls instructions • Breaker Control functionality (remote / on-site) and instructions • List of inputs and outputs 	
18	Communication system	<ul style="list-style-type: none"> • Installation and O&M manual • System internal communication • External Communication to monitoring system or Operations Centre • IP network plan • Bus network plans 	

D Annex

D. Important examples of input records in the record control. (Download it from www.solarpowereurope.org)

RECORD CONTROL				
NO.	ACTIVITY TYPE	INFORMATION TYPE	INPUT RECORD	REFERENCES/ COMMENTS
1	Alarms / Operation Incidents	Alarms description	Date and Time, Affected Power, Equipment Code / Name, Error messages / Codes, Severity Classification, Curtailment Period, External Visits/Inspections from third parties	
2	Contract Management	Contract general description	Project Name / Code, Client Name, Peak Power (kWp)	
3	Contract Management	Asset description	Structure Type, Installation Type	
4	Contract Management	Contract period	Contract Start and End Date	
5	Contract Management	Contractual clauses	Contract Value, Availability (%), PR (%), Materials / Spare parts, Corrective Work Labour	
6	Corrective Maintenance	Activity description	Detailed Failure Typification, Failure, Fault Status, Problem Resolution Description, Problem Cause	EN 13306 - Maintenance. Maintenance terminology
7	Corrective Maintenance	Corrective Maintenance event	Associated Alarms (with date), Event Status	EN 13306 - Maintenance. Maintenance terminology
8	Corrective Maintenance	Corrective Maintenance event log	Date and Time of Corrective Maintenance Creation (or Work Order), Date and Time status change (pending, open, recovered, close), End date and time of the intervention, Start date and time of the intervention, Technicians and Responsible Names and Function	EN 13306 - Maintenance. Maintenance terminology
9	Corrective Maintenance	Intervention equipment/ Element name	Affected Power and Affected Production, Equipment Code / Name	
10	Inventory Management	Warehouse management	Inventory Stock Count and Movement, Equipment Code / Name	
11	Monitoring & Supervision	Equipment status	Date, Status log (protection devices, inverters, monitoring systems, surveillance systems)	
12	Monitoring & Supervision	Meteo data	Irradiation, Module temperature, Other meteo variables (ambient temperature, air humidity, wind velocity and direction, ...)	IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
13	Monitoring & Supervision	Production / consumption data	AC active and reactive power at PV Plant Injection Point and other subsystems or equipment, Consumption from auxiliary systems, Other variables (DC/AC voltages and currents, frequency), Power from DC field	IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
14	Monitoring & Supervision	Performance data	PV Plant Energy Production; PR; Expected vs Real	

RECORD CONTROL				
NO.	ACTIVITY TYPE	INFORMATION TYPE	INPUT RECORD	REFERENCES/ COMMENTS
15	Scheduled Maintenance	Intervention equipment/ Element name	Affected Power and Affected Production, Equipment Code / Name, Intervention Start and End Date	
16	Scheduled Maintenance	Maintenance description	Measurements, Scheduled Maintenance Tasks Performed, Problems not solved during activity and its Classification and Typification, Technicians and Responsible Names and Function	
17	PV Plant Documentation	Commissioning	Commissioning Documentation and Tests Results	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
18	PV Plant Documentation	Operation and maintenance	Equipment Manuals, PV Plant O&M Manual	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
19	PV Plant Documentation	System Documentation	As built documentation (Datasheets, wiring diagrams, system data)	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
20	Warranty Management	Claims registration	Affected Equipment, Claim Description, Occurrence Date; Communications between O&M, client and manufacturer/supplier	

E Annex

E. Annual Maintenance Plan. (Download it from www.solarpowereurope.org)

The utility maintenance plan is conceived for a 3-5 MW site (land-locked site far from seashore). The distributed maintenance plan is conceived for a 50 kW to 1 MW fixed mount rooftop installation with secure access. The maintenance plan applies for both utility and distributed solar plants. For distributed, please take into account the following legend.

a: distributed: only if required; b: distributed: recommendation; c: distributed: not applicable; d: distributed: best practice

The abbreviations describe the importance and frequency of the maintenance tasks related to each component of the solar plant:

D: Daily, M: Monthly, Q: Quarterly, SA: semi-annual, Y: yearly, nYr: every n years; T: Total installation; S: Defined subset; R: random subset.

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Modules	Integrity inspection & replacement	Minimum requirement	Y	T
	Thermography inspection	Recommendation if required	Y	T
	Measurements inspection	Minimum requirement	Y	S
	Check tightening of clamps	According to local conditions	Y	R
	Modules cleaning	Recommendation	(Y)	T
	Sample internal inspection of junction boxes (if possible)	Minimum requirement if required	Y	T
	Integrity check & cleaning	Minimum requirement	Y	T
	Documents inspection	Minimum requirement if required	Y	T
	Check labelling and identification	Minimum requirement	Y	R
	Electrical protections visual inspection & functional test	Minimum requirement	Y	T
Electrical cabinets and switchboards - Array/string junction box - Generator junction box - AC switchboards - AUX switchboard - General utilities switchboard - Weather station's cabinet - Monitoring system cabinet - Communication cabinet - Security system board - Other cabinets	Check fuse status	Minimum requirement	Y	T
	Check surge protection status (if applicable)	Minimum requirement	Y	T
	Check integrity of cables & state of terminals	Minimum requirement ^a	Y	T
	Sensor functional verification (if applicable)	Recommendation ^a	Y	T
	Measurements inspection	Best practice ^a	Y	T
	Thermographical inspection	Recommendation ^a	Y	T
	Check tightening	Minimum requirement ^a	Y	T
	Lubrication of locks	Minimum requirement ^a	Y	T
	Monitoring operation test (if applicable)	Recommendation ^a	Y	T
	Integrity inspection	Minimum requirement	Y	R
Cables - DC / AC cables - Cables in switchboards, cabinets, inverters	Check labelling and identification	Minimum requirement	Y	R
	Check cable terminals	Minimum requirement	Y	R
	Measurements inspection	Recommendation	Y	R
	Integrity check & cleaning	Minimum requirement	Y	T
	Documents inspection	Best practice	Y	T
	Check labelling and identification	Minimum requirement	Y	R
	Electrical protections visual inspection, check correct operations	Minimum requirement	Y	T
	Check fuses	Minimum requirement	Y	T
	Check surge protections	Minimum requirement	Y	T
	Thermographical inspection	Best practice ^b	Y	T
Inverters - Central inverters - String inverters	Sensors functional verification	Minimum requirement	Y	R

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Inverters - Central inverters - String inverters	Measurements inspection	Minimum requirement	Y	T
	Check parameters	Minimum requirement	Y	T
	Functional test of ventilation system	Minimum requirement	SA	T
	Check batteries	According to manufacturer's recommendations	(Y)	T
	Replace batteries		(3yr)	T
	Replace fans		(5yr)	T
	Safety equipment inspection	Minimum requirement	Y	T
	Clean filters	Minimum requirement	SA	T
	Replace filters	Minimum requirement	2yr	T
	Integrity check & cleaning	According to local conditions	(Y)	T
Transformer ° - Power transformer - AUX transformer	Check labelling and identification	Minimum requirement	Y	R
	Thermographical inspection	Best practice	Y	T
	Functional verification of sensors & relays	Minimum requirement	Y	T
	Check parameters	Minimum requirement	Y	T
	Check oil level (if applicable) and max. temperature	Minimum requirement	Y	T
	Check of cooling system (fans) if applicable	Minimum requirement	Y	T
	Check of MV surge discharger devices (if applicable)	Minimum requirement	Y	T
	Integrity check & cleaning	According to local conditions	(Y)	T
	Safety equipment inspection	Minimum requirement	Y	T
	Check labelling and identification	Minimum requirement	Y	R
MV switchgear incl. protection devices °	Electrical protections visual inspection	Minimum requirement	Y	T
	Thermographical inspection, if possible	Recommendation	Y	T
	Sensors functional verification	Minimum requirement	Y	T
	Measurements inspection	Minimum requirement	Y	T
	Check correct operation	Minimum requirement	Y	T
	Check fuse status	Minimum requirement	Y	T
	Check cables terminals	Minimum requirement	Y	T
	Battery / UPS check	Minimum requirement	Y	T
	Mechanical lubrication	According to manufacturer's recommendations and necessity	(5yr)	T
	Replace certain mechanical parts		(5yr)	T
	Battery / UPS replacement		(3yr)	T

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
MV switchgear incl. protection devices °	Check protection parameters	According to local grid code	(5yr)	T
	Functional check of protection devices		(5yr)	T
Power analyser °	Integrity check & cleaning	Minimum requirement	Y	T
	Check labelling and identification	Minimum requirement	Y	R
	Measurements inspection	Minimum requirement	Y	T
	Software maintenance	Recommendation	Y	T
	Monitoring operation test	Minimum requirement	Y	T
	Check parameters	Minimum requirement	Y	T
Energy meter	Integrity check & cleaning	Minimum requirement	Y	T
	Check labelling and identification	Minimum requirement	Y	R
	Check values and parameters	Recommendation	Y	T
	Check of communication devices (modem, converters) if applicable	Recommendation	Y	T
Power control unit °	Check batteries	According to manufacturer's recommendations	(Y)	T
	Replace batteries		(3yr)	T
UPS °	Functional verification		Y	T
	Integrity check & cleaning	Minimum requirement	Y	T
	Integrity check & cleaning	Minimum requirement	Y	T
	Check batteries	According to manufacturer's recommendations	(Y)	T
	Replace batteries		(3yr)	T
	Functional test of ventilation system (if applicable)	Best practice	Y	T
Emergency generator (if applicable) °	Integrity check & cleaning	According to manufacturer's recommendations	(Y)	T
	General maintenance		(Y)	T
	Check correct operation		(Y)	T
	Replacement of filters		(5yr)	T
Lights and electric sockets	Integrity check & cleaning	Minimum requirement	Y	T
	Check correct operation	Minimum requirement	Y	T
	Check conformity to local security standards	Minimum requirement	3yr	T
HVAC (if applicable)	Integrity check & cleaning	According to manufacturer's recommendations	(Y)	T
	Functional verification		(Y)	T
	Change of air filters		(Y)	T

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Water supply system (if applicable)	Integrity inspection	If applicable	Y	T
	Integrity check & cleaning	According to manufacturer's recommendations and local requirements	(Y)	T
Fire detection central (if applicable)	Check correct operation		(Y)	T
	Battery inspection		(Y)	T
	Sensors functional verification		(Y)	T
	Cleaning of cameras & sensors		(Y)	T
			(Y)	T
Lightning protection (if applicable)	Integrity inspection	Minimum requirement	Y	R
Fences and gates	Integrity inspection	Minimum requirement	Y	T
	Lubrication of locks	Minimum requirement	SA	T
	Vegetation clearing	According to local conditions	(Q)	T
Paths	Integrity inspection	Best practice	Y	T
	Vegetation clearing	Recommendation	Y	T
Drainage System	General cleaning	Minimum requirement	SA	T
	Integrity inspection	Best practice	Y	T
Buildings	Integrity check & cleaning	According to local requirements	(Y)	T
	Lubrication of locks	Minimum requirement	SA	T
	Documents inspection	According to local requirements	(Y)	T
	Check fire extinguishers		(Y)	T
	Check earthing		(3yr)	T
Safety equipment	Integrity check & cleaning	Minimum requirement	Y	T
	Check correct operation	Minimum requirement	Y	T
PV support structure	Integrity inspection	Minimum requirement	Y	R
	Check tightening	Minimum requirement	Y	R
	Check potential equalization	Minimum requirement	2yr	T
	Integrity check & cleaning	Minimum requirement	Y	T
Tracker system *	Check correct operation	According to manufacturer's recommendations	(Y)	T
	Check tightening		(Y)	R
	General maintenance		(Y)	T
	Mechanical lubrication		SA	T

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Weather station ^d	Integrity check & cleaning	According to manufacturer's recommendations	(Y)	T
	Functional test of sensors		(Y)	T
	Check correct operation		(Y)	T
	Check batteries (if applicable)		(Y)	T
	Monitoring operation test		(Y)	T
Irradiation sensors	Integrity check & cleaning	According to manufacturer's recommendations and local requirements	Q	T
	Calibration		2yr	T
	Monitoring operational test		Y	T
Communication Board	Functional communications check	Minimum requirement	D	T
	Integrity check & cleaning	Minimum requirement	Y	T
Intrusion detection and verification system ^e	Functional verification of intrusion detection	According to manufacturer's recommendations	(Y)	T
	Functional verification of alarming		Y	T
	Functional verification of cameras		M	T
	Specific maintenance		Y	T
	Inventory of stock		Y	T
Stock of spare parts ^d	Visual inspection of stock conditions	Minimum requirement	Y	T
	Stock replenishment	Minimum requirement	M	T





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