



Operation & Maintenance

Best Practice Guidelines

Version 5.0

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Foreword

Welcome to the fifth edition of SolarPower Europe's Operation & Maintenance (O&M) Best Practice Guidelines. O&M is a hugely important sector for the solar PV industry and for the EU. Based on its 100% Renewable Europe study, SolarPower Europe calculates that an additional 870 GW of solar PV installations will be required for the EU to meet its 2030 emissions commitments. This rapid growth makes it even more important to ensure that industry best practices are harmonised, allowing O&M service providers to scale up their operations while maintaining quality standards.

These guidelines take a more integrated approach to occupational health & safety by combining them with security and environmental protection in a revamped Health, Safety, Security, and Environment chapter. The Innovations and trends chapter has been updated to include innovative new field inspection techniques, such as drone-based UV Fluorescence imaging. Furthermore, the increasing popularity of commercial & industrial, and residential rooftop PV installations has led to an overhaul of the O&M for rooftop solar chapter to separate these two segments and provide more specialised recommendations. Finally, this fifth edition has seen the Definitions chapter move to the new Lifecycle Quality Guidelines, reflecting the overall importance of a shared language between the stakeholders of a solar PV project.

This document is the first O&M Best Practice Guidelines produced by the newly rebranded Lifecycle Quality Workstream. It builds on 2019's fourth edition and is the result of a year of intensive work by 29 leading solar experts, from 20 companies. The contributors work across the solar PV industry and include O&M service providers, Asset Managers, Asset Owners, renewable energy consultants, legal experts, digital solutions providers, and technical advisors.

The Workstream has been busy in 2021, updating the EPC and O&M Best Practice Guidelines and writing the new Lifecycle Quality Guidelines. Members have also been involved in several international projects, including cooperating with the South African PV Industry Association (SAPVIA) to produce the South African edition of the O&M Best Practice Guidelines (launched in October 2021). The Workstream has also launched projects to create the Indian and Sub-Saharan African editions of the EPC Best Practice Guidelines and will be working to complete these and a new Jordanian edition of the O&M Best Practice Guidelines.

We thank our members for their extraordinary level of engagement, which reflects the importance of lifecycle quality for our sector. We will continue the work in 2022 and invite interested stakeholders to join our Workstream activities and help us further improve our contribution to the solar PV industry.



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Supported by: Intersolar Europe.

Acknowledgements: SolarPower Europe would like to extend special thanks to all the Workstream members that contributed to this report with their knowledge and experience. This work would never have been realised without their continuous support.

Project Information: The SolarPower Europe Lifecycle Quality Workstream officially started its work in April 2015 and continues with frequent exchanges and meetings. The first version of the O&M Best Practices Guidelines was published in June 2016 and since then, the Workstream has regularly updated the Guidelines and produced new ones on EPC and Asset Management. In 2021, the first edition of the Lifecycle Quality Guidelines will be published - the latest addition to the suite. The SolarPower Europe O&M Best Practices Guidelines reflect the experience and views of a considerable share of the European solar PV service provision industry today. There has been no external funding or sponsoring for this project.

Disclaimer: Adherence to the SolarPower Europe O&M Best Practice Guidelines report and its by-products is voluntary. Any stakeholders that wish to adhere to the O&M Best Practice Guidelines are responsible for self-certifying that they have fulfilled the guide requirements through completing the self-certification procedure offered by the "Solar Best Practices Mark" (www.solarbestpractices.com). This report has been prepared by SolarPower Europe. It is being provided to the recipients for general information purposes only. Nothing in it should be interpreted as an offer or recommendation of any products, services or financial products. This report does not constitute technical, investment, legal, tax or any other advice. Recipients should consult with their own technical, financial, legal, tax or other advisors as needed. This report is based on sources believed to be accurate. However, SolarPower Europe does not warrant the accuracy or completeness of any information contained in this report. SolarPower Europe assumes no obligation to update any information contained herein. SolarPower Europe will not be held liable for any direct or indirect damage incurred by the use of the information provided and will not provide any indemnities.

Please note that this Version 5.0 may be subject to future changes, updates and improvements.

Design: Onehemisphere, Sweden. Email: contact@onehemisphere.se.

ISBN: 9789464444247.

Published: December 2021.

SolarPower Europe would like to thank the members of its Lifecycle Quality Workstream that contributed to this report including:



Sponsor members of SolarPower Europe:



Table of contents

Foreword	3	4.8. Asset optimisation (technical)	29	
Table of contents	6	4.9. Environmental management	29	
List of tables and figures	9	4.10. Health & safety management	30	
List of abbreviations	10	4.11. Technical risk management	30	
Executive summary	11	5 Power Plant Operation		
1 Introduction	14	5.1. Documentation Management System (DMS)	31	
1.1. Rationale, aim and scope	14	5.1.1. Information type and depth of detail/as-built documentation	34	
1.2. How to benefit from this document	16	5.1.2. Management and control	34	
5.1.3. Record control		5.1.4. Plant performance monitoring and supervision	34	
2 Health, Safety, Security, and Environment	17	5.3. Optimisation of O&M	35	
2.1. Health, Safety & Security	17	5.4. Power plant controls	36	
2.2. Environment	19	5.5. Power Generation Forecasting	36	
2.2.1. End-of-life (EoL) management optimisation – solar PV O&M for circularity	20	5.6. Grid code compliance	37	
5.7. Management of change		5.8. Power plant security	38	
5.9. Reporting and Technical Asset Management		5.9.1. Asset Management	38	
3 Personnel & training	22			
4 Technical Asset Management	23	6 Power Plant Maintenance		
4.1. Technical reporting	23	6.1. Preventive Maintenance	40	
4.2. Site visits and non-intrusive inspections	25	6.2. Corrective Maintenance	42	
4.3. Management of ancillary service providers	25	6.3. Predictive Maintenance	43	
4.4. Interface with local energy authorities & regulatory compliance	25	6.4. Extraordinary Maintenance	44	
4.5. Warranty management	26	6.5. Additional services	45	
4.5.1. Warranty of good execution of works and equipment warranties	26	6.5.1. Module cleaning	45	
4.5.2. Anomalies Handling	27	6.5.2. Advanced aerial thermography	45	
4.5.3. Pending Works, Insufficiencies and Defects	27	6.5.3. Vegetation Management	48	
4.5.4. Resolution of failures in the case of anomalies of the type "Failures"	27	6.7.1. Damage Reduction	50	
4.5.5. Endemic Failures	27	7 Revamping and Repowering		
4.5.6. Performance Warranty	27	7.1. Definition and rationale of revamping and Repowering	50	
4.5.7. Warranty Enforcement	27	7.2. Module Repowering	50	
4.6. Insurance claims	28	7.2.1. Mechanical installation	50	
4.7. Contract management (operational contracts)	28	7.2.2. Electrical installation	51	
		7.2.3. Further considerations	51	
		7.3. Inverter Repowering	52	
		7.4. General Repowering considerations	53	

Table of contents

8 Spare parts management	55	10.3.8. Technical tracker availability or tracker uptime	76
9 Data and monitoring requirements	58	10.3.9. Tracking performance availability	76
9.1. Data loggers	59	10.4. O&M service provider KPIs	77
9.2. Data quality & curation	59	10.4.1. Acknowledgement time	77
9.3. Monitoring (web) portal	60	10.4.2. Intervention time	77
9.4. Data format	61	10.4.3. Response time	77
9.5. Configuration	61	10.4.4. Resolution time	77
9.6. Interoperability	61	10.4.5. Reporting	77
9.7. Internet connection and Local Area Network	61	10.4.6. O&M service provider experience	78
9.8. Data ownership and privacy	63	10.4.7. Schedule attainment	78
9.9. Cybersecurity	64	10.4.8. Preventive vs corrective maintenance ratio	78
9.10. Types of data collected through the monitoring system	65	10.5. Solar PV power plant/O&M service provider KPIs	78
9.10.1. Irradiance measurements	65	10.5.1. Contractual availability	78
9.10.2. Module temperature measurements	65	10.5.2. Contractual tracker availability	80
9.10.3. Local meteorological data	66	10.5.3. Energy-based availability	80
9.10.4. String measurements	66		
9.10.5. Inverter measurements	66		
9.10.6. Energy meter	67		
9.10.7. Control settings	68		
9.10.8. Alarms	68		
9.10.9. AC circuit/protection relay	68		
9.11. Data collected by specialised PV module field inspections	68	11.1. Contractual Risk Allocation	83
9.11.1. Infrared thermography (IR)	69	11.2. Scope of the O&M contract	84
9.11.2. I-V curve tracing on-site	69	11.3. O&M contract fee	86
9.11.3. Electroluminescence (EL) imaging on-site	69	11.4. Contractual guarantees and price adjustments	86
9.11.4. Magnetic Field Imaging (MFI)	70	11.5. Availability guarantee	86
9.11.5. Soiling measurements	70	11.6. Response time price adjustment	87
10 Key Performance Indicators	71	11.7. Bonus schemes and liquidated damages	87
10.1. PV power plant data	72	11.8. Service standards	88
10.2. Raw data measurements for performance calculation	72	11.9. O&M service providers' qualification	88
10.3. PV power plant KPIs	72	11.10. Responsibility and accountability	88
10.3.1. Reference yield	72	11.11. Spare parts management	89
10.3.2. Specific yield	72	11.12. Power plant remote monitoring	89
10.3.3. Performance ratio	73	11.13. Reporting	89
10.3.4. Temperature-corrected performance ratio	73		
10.3.5. Expected yield	75		
10.3.6. Energy Performance Index	75		
10.3.7. Technical availability or uptime	75		
12 Innovations and trends	90		
12.1. Aerial Electroluminescence	90		
12.2. UV Fluorescence imaging	91		
12.3. Automated plant performance diagnosis	92		
12.4. Predictive Maintenance for optimised hardware replacement	93		
12.5. Augmented Reality, Smart Glasses	94		
12.6. Internet of Things (IoT) and auto-configuration	95		
12.7. PV Monitoring-Imagery Data fusion	95		

Table of contents

13 O&M for Rooftop Solar	97	References	103
13.1. C&I Rooftop Solar	97	Annexes	104
13.1.1. Operations	98		
13.1.2. Maintenance	99	A. Applicable international standards for solar O&M	104
13.1.3. Spare Parts Management	100	B. Proposed skill matrix for O&M personnel	105
13.2. Distributed Residential Solar Portfolios	100	C. Documentation set accompanying the solar PV power plant	106
13.2.1. Operations	100	D. Important examples of input records in the record control	108
13.2.2. Maintenance	101	E. Annual Maintenance Plan	110

List of tables

Table 1:	Proposed indicators/values required for the reporting	24
Table 2:	Three levels of corrective maintenance	42
Table 2:	Examples for additional maintenance services	46
Table 4:	Post-processing activities	47
Table 5:	Options for vegetation management	49
Table 6:	Examples for a minimum list of spare parts	58
Table 7:	Examples of data integration options	62
Table 8:	Pros and cons of different types of monitoring connections	63
Table 9:	Overview of different types of Key Performance Indicators and their purposes	81
Table 10:	Examples for additional maintenance services and general market trends	85
Table 11:	Examples for fault classes and corresponding minimum response times	87
Table 12:	Methods suggested for the collection of reference yield	98
Table 13:	Incidents covered by O&M service agreements for standalone solar systems	99

List of figures

Figure 1:	Overview of a selection of applicable standards for O&M	15
Figure 2:	Overview of the most important tasks in power plant operation	32
Figure 3:	Support levels in fault management	35
Figure 4:	Overview of the different types of power plant maintenance	41
Figure 5:	Differences between revamping and repowering and their main drivers	51
Figure 6:	Energy flow in a grid-connected photovoltaic system with parameters, yields and losses	58
Figure 7:	Examples of magnetic field imaging (MFI)	70
Figure 8:	Overview of different types of KPIs	71
Figure 9:	Various periods of time for the calculation of the Technical Availability	76
Figure 10:	Acknowledgement Time, Intervention Time, Response Time, Resolution Time	77
Figure 11:	Various periods of time for the calculation of the Contractual Availability	79
Figure 12:	Example UV-Fluorescence images after a severe hailstorm	91
Figure 13:	Automated plant performance diagnosis	93
Figure 14:	Predictive maintenance for optimised hardware replacement	94

List of boxes

Box 1:	Preserving and enhancing the Natural Capital values of large-scale solar plants	21
Box 2:	Interpreting Performance Ratio	74

List of abbreviations

AC	Alternating Current	IPP	Independent Power Producer
AM	Asset Management	IR	Infrared
AMP	Annual Maintenance Plan	IRENA	International Renewable Energy Agency
AMR	Automatic Meter Reading	KPI	Key Performance Indicator
AMS	Annual Maintenance Schedule	kW	kilowatt
API	Application Programming Interface	kWh	kilowatt-hour
C&I	Commercial & Industrial	kWp	kilowatt-peak
CCD	Charge-coupled device	LAN	Local Area Network
CCTV	Closed Circuit Television	LCOE	Levelised Cost of Electricity
CMMS	Computerised Maintenance Management System	LTE-M	Long-Term Evolution Machine Type Communication
COD	Commercial Operation Date	LPWAN	Low-power wide-area network
CPN	Cost Priority Number	LV	Low voltage
CSMS	Cybersecurity Management System	MAE	Mean Absolute Error
CSR	Corporate Social Responsibility	MFI	Magnetic Field Imaging
DC	Direct Current	MIT	Minimum Irradiance Threshold
DMS	Document Management System	MPPT	Maximum Power Point Tracking
DOR	Division of Responsibility	MTBF	Mean Time Between Failures
DSCR	Debt Service Coverage Ratio	MV	Medium Voltage
DSL	Digital Subscriber Line	MW	Megawatt
EL	Electroluminescence	O&M	Operation and Maintenance
EMS	Energy Management System	OEM	Original Equipment Manufacturer
EoL	End of life	OS	Operating System
EPC	Engineering, Procurement, Construction	PAC	Provisional Acceptance Certificate
EPI	Energy Performance Index	POA	Plane of Array
ERP	Enterprise Resource Planning System	PPA	Power Purchase Agreement
ESG	Environmental, Social and Governance	PPE	Personal Protective Equipment
ESS	Energy Storage System	PR	Performance Ratio
FAC	Final Acceptance Certificate	PV	Photovoltaic
FIT	Feed-in tariff	RFID	Radio-frequency identification
FMEA	Failure Mode and Effect Analysis	RMSE	Root Mean Square Error
FMECA	Failure Mode, Effects & Criticality Analysis	ROI	Return on Investment
FTP	File Transfer Protocol	RPAS	Remotely Piloted Aircraft System (drone)
GPRS	General Packet Radio Service	SCADA	Supervisory Control and Data Acquisition
H&S	Health and Safety	SLA	Service-level Agreement
HSSE	Health, safety, security, and environment	SPV	Special Purpose Vehicle
HV	High Voltage	STC	Standard Test Conditions (1000 W/M ² , 25°C)
IEC	International Electrotechnical Commission	TAM	Technical Asset Management
IGBT	Insulated-Gate Bipolar Transistors	UPS	Uninterruptible Power Supply
IoT	Internet of Things	VPN	Virtual Private Network

Executive summary

Operation and Maintenance (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 service providers, investors, financiers, Asset Owners, Asset Managers, monitoring tool providers, technical consultants, and all interested stakeholders in Europe and beyond.

In this edition of the O&M Best practice Guidelines, the Definitions and Stakeholders sections have been moved to the new Lifecycle Quality Guidelines. This has been done to reflect the importance of having a common understanding of the roles and responsibilities, and core workloads of each stakeholder in a solar PV project. This document then walks the reader through the different components of O&M, classifying requirements into "minimum requirements", "best practices" and "recommendations".

Health, Safety, Security, and Environment (HSSE)

Solar PV power 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, regular documented inspection, and maintenance. Specific training, 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. Power plant security systems should form an integrated part of health & safety (H&S) by ensuring that trespassers or members of the public do not gain access to the plant or its hazardous areas.

Environmental problems are normally avoidable through proper plant design and maintenance, but where issues do occur, the O&M service provider must detect them and respond promptly. Environmental

compliance obligations may be triggered by components of the solar PV system itself, such as those that include hazardous materials, and by-products that may be used by the O&M service provider such as herbicides and insecticides. In many situations, solar power plants offer an opportunity to support agriculture and are a valuable natural habitat for plants and animals alongside the primary purpose of power production.

Personnel & training

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

Technical asset management

Technical Asset Management (TAM) encompasses support activities to ensure the best operation of a solar power plant or a portfolio, i.e., to maximise energy production, minimise downtime and reduce costs. In many cases, the O&M service provider assumes some TAM tasks such as planning and reporting on Key Performance Indicators (KPIs) to the Asset Owner. However, in cases where the Technical Asset Manager and the O&M service provider are separate entities, close coordination and information sharing between the two entities is indispensable. TAM also includes ensuring that the operation of the solar PV power plant complies with national and local regulations and contracts, and advising the Asset Owner on technical asset optimisation via repowering investments, for example. For more information about AM, please refer to SolarPower Europe's Asset Management Best Practice Guidelines, which can be downloaded from www.solarpowereurope.org.

Power plant operation

Operation is about remote monitoring, supervision, and control of the solar PV power plant and it is an increasingly active exercise as grid operators require increasing flexibility from solar power plants. Power plant operation also involves liaising with or coordination of the maintenance team. A proper solar PV power plant documentation management system is crucial for Operations. A list of documents that should be included in the as-built documentation set

Executive summary / continued

accompanying the solar PV power plant (such as solar PV modules' datasheets), and 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 service provider should always strive to improve solar PV power plant performance. As there are strict legal requirements for security services in most countries, solar PV power plant security should be ensured by specialised security service providers.

Power plant maintenance

Maintenance is usually carried out on-site by specialised technicians or subcontractors, according to the Operations team's analyses. A core element of maintenance services, Preventive 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. The Annual Maintenance Plan (see an example in Annex e) includes a list of inspections and actions that should be performed regularly. Corrective Maintenance covers activities aimed at restoring a faulty solar PV power 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 module cleaning and vegetation control, which could be done by the O&M service provider 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 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 Preventive and Corrective Maintenance to minimise the downtime of a solar PV power plant. As 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 service provider. 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 service provider 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 solar 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 for on-site pyranometers. As best practice, the monitoring system should ensure open data accessibility to enable an easy transition between monitoring platforms and interoperability of different applications. As remotely monitored and controlled systems, solar PV power plants are exposed to cybersecurity risks. It is therefore vital that installations undertake a cybersecurity 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 solar PV power plant KPIs, directly reflecting the performance of the solar PV power plant; O&M service provider KPIs, assessing the performance of the O&M service provided, and solar PV power plant/O&M service provider KPIs, which reflect power plant performance and O&M service quality at the same time. Solar 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, 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 service provider 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 solar PV power plant). Acknowledgement Time plus Intervention Time are called Response Time, an indicator used for contractual guarantees. The most important KPI which reflects solar PV power plant performance and O&M service quality at the same time is the Contractual Availability. While Uptime (or Technical Availability) reflects all downtimes regardless of the cause, Contractual Availability involves certain exclusion factors to account for downtimes not attributable to the O&M service provider (such as force majeure), a difference important for contractual purposes.

Contractual framework

Although some O&M service providers still provide Performance Ratio guarantees, it is best practice to only use Availability and Response Time guarantees, which has several advantages. A best practice is a

minimum guaranteed Availability of 98% over a year, with Contractual Availability guarantees 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. As a best practice, we recommend using the O&M template contract developed as part of the Open Solar Contracts, a joint initiative of the Terrawatt Initiative and the International Renewable Energy Agency (IRENA). The Open Solar Contracts are available at www.opensolarcontracts.org.

Innovations and trends

O&M service providers 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 and include the latest aerial monitoring techniques, and AI, and data-driven decision making.

O&M for rooftop 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 commercial & industrial, and residential rooftop projects. These 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

Quality must be present at every stage of an asset's lifecycle to ensure that it operates smoothly. A professional Operation & Maintenance (O&M) service package ensures that a photovoltaic system will maintain high levels of technical, safety and consequently economic performance over its operational lifetime. It is widely acknowledged by all stakeholders that high quality O&M services are vital to improving the overall quality management of an asset's lifecycle, mitigating the potential risks, improving the levelised cost of electricity (LCOE) and Power Purchase Agreement (PPA) prices, and positively impacting the return on investment (ROI).

Therefore, increasing the quality of O&M services is important and, in contrast, neglecting O&M is risky. However, O&M does not work in a vacuum and poor practices at any stage of an asset's lifecycle can lead to problems in the future. For a full overview of how quality can be assured throughout a solar PV project, please refer to SolarPower Europe's *Engineering, Procurement, and Construction (EPC), Asset Management, and Lifecycle Quality Guidelines*, available at www.solarpowereurope.org.

According to SolarPower Europe's 100% Renewable Europe study, a further 870 GW of solar will be required by 2030 if the EU is to achieve its ambitious climate targets. The sheer amount of additional solar capacity means that O&M service providers will be under greater scrutiny than ever to provide exceptional "health care" that keeps new solar PV plants running optimally. This makes harmonisation of best practices more vital than ever as Europe transitions to carbon neutrality. For this version 5.0, the Definitions and Stakeholders sections have been moved to the new *Lifecycle Quality Guidelines*, highlighting the importance of a common understanding between all stakeholders through a project's lifecycle. This version also takes a more integrated approach to Health, Safety, Security, and Environment (HSSE), showing how quality processes and systems across all these areas interact with each other. Finally, the growth of the commercial & industrial rooftop segment has led to the redesign of the best practice recommendations in Chapter 13. *O&M for rooftop solar*.

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

General O&M activities		PV components and BoS
EN 13306		EN 50380
IEC 62446 - 1: 2016		IEC 61215 (all parts)
IEC 62446 - 2		IEC 61439
IEC 63049: 2017		IEC 61557 (all parts)
IEC 60364 - 7 - 712: 2017		IEC 61730 (all parts)
IEC 62548		IEC 62093
System performance and monitoring		IEC 62109 (all parts)
IEC 61724 - 1: 2017		IEC TS 62804 (all parts)
IEC 61724 - 2: 2016		IEC TS 62915
IEC 61724 - 3: 2016		IEC TS 63126
IEC 61724 - 4		Specialised technical inspections
IEC 63019: 2019		IEC TS 62446 - 3: 2017
ISO 6847: 1992		IEC 61829: 2015
		IEC TS 60904 - 13: 2018
		Other supporting standards
		IEC TS 61836
		IEC TS 62738: 2018
		IEC TR 63149: 2018
		IEC TS 62548
		IEC 60891: 2009
		IEC 61853 - 1: 2011
		IEC 61853 - 2: 2016
		IEC 61853 - 3: 2018
		IEC 61853 - 4: 2018
		IEC 60904 - 5: 2011
		IEC 60904 - 4

NOTE: This list is not exhaustive and new standards are under development.

SolarPower Europe's O&M Best Practice Guidelines are a key tool to set quality standards for service providers and enhance investors' understanding and confidence.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 13. *O&M for rooftop 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.

¹ In addition to the O&M Best Practice Guidelines we recommend SolarPower Europe's Asset Management Best Practice Guidelines, another useful tool to enhance investors' confidence and improve service quality in the field of solar asset management. This report can also be downloaded from www.solarpowereurope.org.

1 Introduction / continued

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 or Asset Manager, 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 Chapter 3. of *SolarPower Europe's Lifecycle Quality Guidelines*) 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 and technical asset management part, the requirements apply to solar PV assets regardless of their location.

2

Health, Safety, Security, and Environment

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The Asset Owner has ultimate legal and moral responsibility for ensuring the health and safety of people in and around the solar plant, the security of the site, and the protection of the surrounding environment. The practical implementation is normally subcontracted to the O&M service provider. In some cases, the Asset Manager can provide or prescribe the systems, which are then implemented by the O&M service provider. This chapter will investigate specific areas of Health, Safety, Security, and Environmental (HSSE) policy and coordination that relate to O&M service providers. For a general overview of the fundamentals of HSSE coordination, please refer to SolarPower Europe's *Lifecycle Quality Guidelines V 1.0* (available at www.solarpowereurope.org).

2.1. Health, Safety, and Security

Managing the risks that solar plants pose to the health and safety (H&S) 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 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, and regular and well documented inspection and maintenance (see also 5.8. 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 service provider. Any person accessing a solar PV power 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, have sufficient experience, and be supervised. It is also



key that others working 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 service provider to manage their own staff and provide third party contractors with adequate information. It is usually the case that the O&M service provider holds the authority and responsibility for reviewing and, where necessary, rejecting works taking place in the plant. Failure to carry this out properly has important consequences for 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 landowner, 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 compliance with H&S regulations within the site/plant. The Asset Owner must make sure that the installation and all equipment meet the relevant legislations of the country and, 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).

2 Health, Safety, Security, and Environment / continued

At the same time, the O&M service provider should prepare and operate their own safety management systems, previously agreed with the Asset Owner, that take into account site rules relating to H&S and the potential hazards involved in the works. The O&M service provider should ensure that they, and all subcontractors, comply with H&S legislation.

The Asset Owner will expect the O&M service provider to assume the role and duties of the principal contractor under the relevant national regulations governing H&S. This involves the O&M service provider proving that they are competent and are able to allocate enough resources to fulfil these duties.

Before starting any activity on-site, the Asset Owner will deliver a risk assessment and method statements to the O&M service provider 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 service provider will keep the H&S file of each site up to date.

The O&M service provider must have their personnel trained in full compliance with respective national legal and professional requirements. This generally includes obtaining certification necessary for working in a variety of environments, such as MV and/or HV electrical plants. Within Europe, referral to European Standards is not sufficient (examples of standards used today are ISO 14001, OHSAS 18001 etc.).

To achieve a safe working environment, all work must be planned in advance. Normally written plans are required.

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

The following dangers are likely to exist on most solar plants and must be considered when listing hazards and identifying risks. The severity of any injuries caused are exacerbated by the terrain on which solar plants are built and their remoteness.

1. **Medical problems.** It is critical that all personnel engaged in work on solar plants 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 plant, 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. **Electrocution.** Operational solar plants, 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 on how to safely deal with the effects of electrocution. In addition to general electrical safety, common issues for solar PV power plants include arc-flash protection when working on energized circuits; and lock-out-tag-out to ensure circuits are not unintendedly energised.
6. **Fire.** Several sources of combustion exist on a solar farm, the most common being electrical fire. Others include combustible materials, 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 avoid the risk of fire and how to act 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 winter as low-grade farmland is often used for solar farms. Mud and water present problems for access as well as electrical danger.
8. **Mechanical injury.** Hand-tools, power tools, machinery, and mechanisms such 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 testing on site can lead to sunstroke. To avoid this, drinking sufficient water and staying in the shade is recommended.

10. Wildlife and livestock. The renewable energy industry is proud to provide habitats for wildlife and livestock alongside the generation of electricity. Some wildlife, however, presents dangers. There are plants in different regions which can present significant risk, some only when cut during vegetation management. Animals such as rodents and snakes, insects such as wasps, and other wildlife and livestock can present 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. 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 solar PV power plants and has been found to be carcinogenic. Mowing has several hazards including flying objects. Every job at a solar 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 the PPE and tools necessary to carry out the work in the safest way possible. The work should be planned, 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. By increasing the skills of persons involved in the industry, we can make the industry safer and more productive.

2.2. 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 service provider 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 service provider (or the Technical Asset Manager) 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 system installation, amphibian follow-up, edge plantation, and reptile rock shelter installation. Such requirements should be implemented and managed by the O&M service provider to comply with the relevant regulations. As a best practice, the O&M service provider's environmental preservation activities can go beyond legal obligations.

Other aspects that need to be considered 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 habitats, as well as reduce the overall maintenance costs of managing the plant's grounds. 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 be controlled. Cleaning agents (soap) should be environmentally friendly (no chlorine bleach) and applied sparingly to avoid over-spray and run-off.

The SolarPower Europe Solar Sustainability Best Practice Benchmark discusses how to make sure that biodiversity is increased on a solar PV power plant:

- Local best practices should be considered
- Decision frameworks and decision support tools should be used
- Local experts should be consulted

By doing this and after discussion of various management methods, a management plan should be decided, which defines certain objectives concerning biodiversity and describes the activities by which to achieve them. Some typical measures are:

- Categorically forbidding the use of herbicides
- Reducing the frequency of vegetation cutting to the necessary minimum (not all areas need the same frequency)
- Cut vegetation in different phases to make sure that there are always untouched parts
- Limit the number of sheep per hectare to avoid overgrazing (if sheep are part of the management plan)
- Planting hedges with local species at the borders of the plant
- Creating piles of stones as microbiotopes for reptiles
- Arranging heaps of dead wood
- Keeping specific surfaces vegetation-free
- Removing cut grass in specific areas

These activities should be accompanied by regular surveys by local experts, to control evolution of biodiversity. They shall propose changes to the management plan if this is necessary for achieving the objectives.

2.2.1. End-of-life (EoL) management optimisation – solar PV O&M for circularity

Based on the latest available (2019) figures reported on the growth of solar PV installations, we can estimate that about 1-1.2 million solar PV modules are installed every day around the world. With this in mind and with an estimated average annual failure rate of 0.2% in the field, we may anticipate today ~8 million solar PV modules to fail every year, corresponding to a weight of 144 kt of potential annual solar PV waste from solar PV failures only. Adding also other solar PV waste sources and streams, such as the decommissioning of solar PV modules due to end of service lifetime, repowering, insurance claims, etc., the cumulative solar PV waste is expected to reach up to 8 Mt by 2030.

Reported field experiences show that, most solar PV modules with diagnosed/classified failures that are decommissioned, follow a linear EoL management approach: they enter the waste stream and are either disposed as waste (the majority of the time) or recycled. Currently less than 10% of decommissioned modules are recycled. However, experts from the IEA PVPS Task 13 and the CIRCUSOL project estimate that 45%-65% of them, can be diverted from the disposal/recycling path, towards repair and second life solar PV (re-use) or, as aforementioned, revamping.

To ensure the technical-economical bankability of solar PV re-use and second life solar PV, within the O&M framework and the overall solar PV value chain, it is important to:

- Identify the addressable "target volume", i.e., the failed solar PV modules (or strings), the repair of which is technically feasible, and the occurrence or distribution of such failures.
- Determine the post-repair efficiency and/or post-revamping reliability of these modules.
- Integrate optimal sorting-repair-reuse and logistics procedures in the current solar PV O&M value chain, embracing circular economy business models.

On this basis, we identify certain future R&D pathways and challenges to be addressed, to support the development, growth, and bankability of second life solar PV and circular solar PV O&M business:

- Industrialisation and qualification of new solar PV module designs-for-circularity: including "repair-friendly" solar PV components, modular designs, and deployment of repair technology solutions in upscaled re-manufacturing lines.

BOX 1

Preserving and enhancing the Natural Capital values of large-scale solar plants

The growth in ground-mounted solar parks is occurring at a time when there is increasing recognition of the benefits the natural environment provides to society, and how these are under threat from ongoing environmental degradation. When well-managed and in suitable locations, solar parks offer an opportunity to improve the state of the natural environment alongside their primary purpose of generating electricity. This potential is becoming increasingly pertinent with the development of national policies that prioritise the environment, such as the UK Government's 25-Year Environment Plan which stipulates the need for 'net environmental gain', EU directives such as the Habitats Directive (92/43/EEC), and global frameworks such as the Sustainable Development Goals. Further, promoting good environmental stewardship will enhance the solar industry's profile, contribute to corporate Environmental, Social and Governance (ESG) objectives, help to meet planning policy goals, and improve community and landowner relations.

'Ecosystem Services' and 'Natural Capital' are two related frameworks that are being used to characterise and quantify the benefits that the environment provides for us. Natural Capital is the stocks of environmental assets (e.g., water, air, soil, and living material), from which ecosystem goods (e.g., crops and drinking water) and ecosystem services (e.g., climate regulation and pollination) that society rely on are derived.

Solar parks offer an excellent and relatively untapped opportunity to enhance natural capital and ecosystem services as they occupy a notable amount of land for 25–40 years, which is predominantly used solely to

produce low carbon energy. The land remains relatively undisturbed, apart from by maintenance activities. Moreover, because the parks are commonly located in agricultural landscapes, the land they occupy and its immediate surroundings, stand to benefit significantly from enhancement. For example, introducing pollinator habitats on solar parks could improve pollination of surrounding crops leading to higher yields, and changes to the intensity of mowing and grazing can be used to enhance biodiversity.

Within the UK, collaborative research between solar park stakeholders, nature conservation bodies and researchers has produced the Solar Park Impacts on Ecosystem Services (SPIES) decision support tool¹. The SPIES tool provides an accessible, transparent, and evidence-based means of informing management actions on and around solar parks. It is free to use (see www.lancaster.ac.uk/spies) and enables users to explore the impacts of different management scenarios, which can be outputted as pdf documents suitable to support planning applications.

Whilst currently deployed in a UK context, alternative versions of SPIES could be readily developed for other European ecosystems. By engaging more actively in the natural capital and ecosystem services agendas, the European solar industry would boost its environmental credentials, enabling it to continue to produce urgently needed low-carbon electricity while also improving the state of the natural environment upon which society relies.

The SPIES tool is a collaboration between Lancaster University and the University of York funded by the Natural Environment Research Council (NE/N016955/1 & NE/R009449/1). The web-based version of the SPIES tool was developed by Simomics Ltd.³

- Identification and tracking solutions (e.g., RFID) at solar PV components/modules/system level, to facilitate reverse logistics, sorting/inventory of solar PV and warehouse operations.
- (Automated) detection, diagnostics, and classification (incl. recommendation) of repair or re-use operations in solar PV asset management tools for solar PV plants.
- Standardisation/technical specifications for on-site quality control and sorting, as well as off-site design qualification and type approval protocols, towards solar PV reuse-repurposing-recycling
- Synergies of solar PV Asset Owners and O&M service providers, with innovators in supply chain / reverse logistics technologies, also leveraging AI/machine learning aided logistics, sorting, warehouse operations, inventory management for circular solar PV economy.

³ For more information, see: www.lancaster.ac.uk/spies and www.energyenvironment.co.uk.

3

Personnel & training



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It is of critical importance that all O&M personnel have the relevant qualifications to perform works in a safe, responsible, and accountable manner. 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 paths 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 being provided.

As the solar industry scales up globally, it follows that skills training will also need to be scaled up to meet the demand for qualified labour. 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 readily skilled and qualified staff.

The creation of a training matrix as 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 universally by O&M service providers. Therefore, many of the skills/requirements may need to be adjustable to fit different practices and regulations across Europe.

4

Technical Asset Management

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Technical Asset Management (TAM) encompasses support activities to ensure the best operation of a solar power plant or a portfolio, i.e., to maximise energy production, minimise downtime and reduce costs. It comprises the activities presented in this chapter. It is worth noting that TAM can be done by either the O&M service provider or the Asset Manager. The choice over whether to give TAM responsibilities to the Asset Manager or the O&M service provider is ultimately down to the Asset Owner. For more information on the role of the AM, please refer to SolarPower Europe's *Asset Management Best Practice Guidelines V 2.0*.

It is not easy to draw a sharp line between the high-level tasks of the Operations team and the more technical responsibilities of the Asset Manager. A simple way to provide some clarity would be that TAM focusses on the administrative environment of the solar PV power plant and Operations Management focusses on performance and data analysis. In many cases, the O&M service provider assumes some tasks related to TAM, such as KPI reporting. The following tasks can be regarded as TAM and can be performed by the O&M service provider or the AM. In cases where the Technical Asset Manager and the O&M service provider are separate entities, close coordination and information sharing between the two entities is necessary. This involves an integral knowledge about how much power a solar PV power plant 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.

4.1. Technical reporting

The Technical Asset 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 Technical Asset Manager.

The frequency of the reporting should be relative to the level of TAM activity. Standard reporting can be set for monthly, quarterly, or annually. Where specific TAM actions are underway, for example insurance claims or warranty claims, reporting could be more frequent. Report content should be specifically defined. 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 to improve the correct availability calculations. The spatial resolution of reports should be on the level of each inverter to better detect underperforming 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 [10. Key Performance Indicators](#).

A new trend in the industry is to extend the reporting beyond the pure solar PV power plant indicators and to incorporate reporting on the actual activities. This means that both the Asset Manager and the O&M service provider can operate with an Asset Management Platform, ERP (Enterprise Resource Planner), or CMMS (Computerised Maintenance Management Systems) in order to measure various O&M service provider KPIs (e.g., Acknowledgement

4 Technical Asset Management / continued

TABLE 1 PROPOSED INDICATORS/VALUES REQUIRED FOR THE REPORTING

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

Time, Intervention Time, Reaction Time, Resolution Time) and equipment performance (e.g., Mean Time Between Failures).

The Technical Asset Manager should report on:

- Spare Parts Management and, in particular on, spare parts stock levels, spare parts consumption, in particular solar PV modules on hand, spare parts under repair. With the emergence of Predictive Maintenance, the Technical Asset Manager can also report on the state of each individual equipment (see Chapter [8. Spare Parts Management](#)).

- Compliance with regulatory requirements, including from grid operators, regional and national authorities for conditions of operation (refer to section [4.4 Interface with local energy authorities & regulatory compliance](#)).
- Warranty management, warranty claims performance with various component suppliers (refer to section [4.5 Warranty management](#)).
- Insurance claims management, providing lifecycle reporting on new claims raised, claims in progress and claims settled (refer to section [4.6 Insurance claims](#)).

- Contract management, reporting on the performance of the O&M service provider and issues relevant to the O&M contract (refer to section [4.7 Contract management \(operational contracts\)](#)).
- Risk management, updating and reporting on the risk register for the solar PV power plant, highlighting significant changes to the risk register (refer to section [4.11 Technical risk management](#)).
- Status of the security and surveillance system. In this case, the security service provider is responsible for providing the relevant input.

On top of the periodic standard reports (monthly, quarterly or yearly), where the Technical Asset Manager reports on operations activities to the Asset Owner, it is a best practice for the Technical Asset 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 report should be sent as soon as the fault is acknowledged or solved and should contain all the relevant details related to it, 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, acknowledgement time, comments, intervention time, description of on-site operations, pictures, etc.)
- The estimated production losses at the moment of the report was written
- 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
- Recommendations on whether a replacement is needed

- Spare parts available
- Estimated cost for the extraordinary maintenance

4.2. Site visits and non-intrusive inspections

It is recommended as a best practise that a bi-annual site visit is undertaken from a Technical Asset Manager perspective (in coordination with the O&M service provider if they are separate) to perform a non-intrusive visual inspection, address current maintenance issues and plan out, in cooperation with the O&M service provider, and the ancillary service providers (if different), a maintenance improvement plan.

4.3. Management of ancillary service providers

Technical Asset Managers or the O&M service provider are responsible for managing providers of ancillary (additional) services related to solar PV site maintenance such as panel cleaning and vegetation management; general site maintenance such as road management; site security; or on-site measurements such as meter readings and thermal inspections. For more information see section [6.5. 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 service provider, compliance with HSSE policies.

4.4. Interface with local energy authorities & regulatory compliance

The Technical Asset Manager is responsible for ensuring that the operation of the solar PV power plant complies with the relevant regulations. Several levels of regulatory and contractual compliance have to be considered:

- Many countries have a governing law for the operation of energy generating assets and transmission and/or distribution network organisations will likely have specific requirements to be met. This is something the O&M service provider should be aware of in any case, even if the O&M service provider and the Technical Asset Manager are separate entities.
- Requirements of Power Purchase Agreements (PPA) and Interconnection Agreements.

4 Technical Asset Management / continued

- Power generation license agreements.
- Terms and conditions of corporate PPAs and stricter contractual obligations by the Owner.
- Specific regulation for the site such as building permits, environmental permits, and regulations, which can involve certain requirements and the need to cooperate with the local (or regional or national) authorities. 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.
- It is the O&M service provider's responsibility to ensure grid code compliance. See 5.6. Grid code compliance. It is the responsibility of the AM to engage the District Network Operator in 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 O&M agreement should list all the relevant permits, regulations and contracts that are the responsibility of Technical Asset Manager and specify that the Asset Owner makes relevant documents available to the Technical Asset Manager.

As a best practice, all regulations, permits and stipulations should be managed within a regulatory and contractual compliance system that is consistent with the size and complexity of the solar PV power plant. This system should set out: the requirements to be met; the parameters for meeting them; and the frequency of data gathering and assessment against the requirements. This allows the Technical Asset Manager to track compliance requirements and report back to the Asset Owner or the administration bodies, demonstrating a systematic approach to ensuring compliance.

4.5. Warranty management

The Technical Asset Manager can act as the Asset Owner's representative for any warranty claims made on manufacturers of solar PV power plant components.

The agreement between the Asset Owner and the Technical Asset Manager should specify their respective warranty management responsibilities and set thresholds under which the Technical Asset Manager can act directly or seek the Asset Owner's consent. The Technical Asset Manager or the Operations 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 of claims processes
- Help to reduce the warranty period costs
- Receive and collect all the warranty claims
- Support the claims process
- Negotiate more efficient claims procedures with manufacturers
- Study the behaviour of the installed equipment
- Analyse the costs incurred during the warranty period

Types of warranties on a solar PV power plant:

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

4.5.1. Warranty of good execution of works and equipment warranties

During the warranty period, anomalies can occur in the facility, which the EPC service provider is liable for. The anomalies must be resolved according to their nature and classification, in accordance with 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 with the List of Pending Works (or Punch List) agreed with the client during the EPC phase and handover from EPC to O&M service provider.
- **Insufficiencies**, these being understood as any issue 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 issue 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 issue found in the equipment of the solar PV power plant – Modules, Inverters, Power transformers or other equipment.

4.5.2. Anomalies handling

During the warranty period, all the Anomaly processing should, as a best practice, be centralised by the Technical Asset Manager/O&M service provider. The person or people in these roles are responsible for acknowledging and handling issues. They also act as the main point of contact between the internal organisational structure and the client in accordance with the criteria defined below.

4.5.3. Pending works, insufficiencies and defects

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

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

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

4.5.5. 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.

4.5.6. Performance warranty

EPC service providers usually provide a 2-year performance warranty period after the Commercial Operation Date (COD). During the warranty period, it is the responsibility of the Technical Asset Manager to monitor, calculate, report and follow-up the PR and other KPI values guaranteed by the EPC service provider.

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

- Manage the interventions done within the scope of the warranty to safeguard the performance commitments undertaken in 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.

4.5.7. Warranty enforcement

A warranty may be voided by mishandling or not observing instructions or conditions therein. For example, storing modules improperly on-site, 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 a replacement but not the labour costs of removing, shipping, and re-installing 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

4 Technical Asset Management / continued

replacing the 10,000 modules. However, increasing the power 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 interconnection 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 the original cost. 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.

4.6. Insurance claims

The agreement between the Technical Asset Manager and the Asset Owner should specify their insurance management responsibilities. At the very least, the Technical Asset Manager will be expected to organise and coordinate site visits for insurance provider representatives, or technical and financial advisors in connection with information collection and damage qualification. They will also be responsible for drafting technical notes to support reimbursement claims. The responsibility for coordinating insurance claims, liaising with insurers, brokers, and loss adjusters, and finding the most suitable insurance providers usually lies with the Commercial/Financial Asset Manager (for more information on this, see section 7.14. *Suppliers account management* of the Asset Management Best Practice Guidelines).

Types of insurance related to solar PV power 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:** coverage for 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 solar PV system has increased required liability coverage levels for solar PV systems. A liability policy should cover negligence claims, settlements, and legal costs too.

- **Inland insurance or marine insurance:** coverage against loss of equipment in shipping or outside the property premises. Inland insurance is often covered under property insurance policy.
- **Worker compensation:** coverage of costs for employee accidents.
- **Professional liability insurance:** coverage against errors and omissions often required by board of directors.
- **Commercial vehicle insurance:** coverage for owned, rented vehicles, and 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:** coverage for lost revenue due to downtime caused by a covered event. This can be important in PPAs where revenue is essential for debt service and O&M expenditures.
- **Energy production insurance:** coverage for when energy production is less than previously specified, which can improve access to debt financing and reduce debt interest rate.

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. The insurance company (claims adjuster) will need to have access to the site to assess damage and to collect the information needed to process the claim.

4.7. Contract management (operational contracts)

Contract management encompasses both technical and commercial/financial aspects. This section looks at contract management from a Technical Asset Management point of view. For details on the perspective of the Commercial/Financial Asset Manager, see section 7.13. *Contract management (financial contracts)* of the Asset Management Best Practice Guidelines.

The Technical Asset Manager is responsible for ensuring compliance with the operational contracts in place, such as contracts related to O&M services, land lease, insurance, site security, communications and in some cases ancillary (additional) services such as panel cleaning and vegetation control or component procurement. (For more information on procurement, please refer to the Asset Management Best Practice Guideline's Chapter 8. *Procurement*.)

Where the Technical Asset Manager and the O&M service provider roles are separate, the Technical Asset Manager is responsible for coordination with the O&M service provider and for overall performance supervision. They need to detect where systems are underperforming and be able to accurately diagnose an underperforming plant.

The Technical Asset 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.

Effective contract management requires a comprehensive analysis of the contracts to understand the requirements of the parties to the contracts. This is followed by a well-defined Division of Responsibility (DOR) matrix that clearly delineates which entity (on the Asset Owner's side of the contract) 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 Technical Asset Manager's responsibilities often also extend to functioning as the point of contact for all external questions. This allows the Asset Owner optimal access to all areas of the service provider's organisation and helps ensure adherence to the contractual responsibilities. The Technical Asset Manager also assumes the responsibility for invoicing of the O&M fees to the Asset Owner.

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

4.8. Asset optimisation (technical)

To the extent that O&M service providers perform TAM functions, they will have to provide data and information analysis on the assets they manage, and provide asset optimisation solutions based on the following key areas:

- Plant performance
- Operation cost reduction
- Technology adaptation and upgrades (e.g., Revamping and repowering³)
- Technical People management and training

It is the role of the Technical Asset Manager to initiate and coordinate discussions with the O&M service provider (where the roles are separate) and the Owner 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.

4.9. 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. For more information on effective environmental and biodiversity management, please refer to Chapter 2. *Health, Safety, Security, and Environment*.

A part of the Technical Asset Management role is to assess the impact or limitations of environmental legislation on the supplier's existing contracts and to develop an action plan to address existing problems and minimise their impact.

As an example, the Technical Asset Manager oversees the 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 wildlife existing around the

³ For detailed information about revamping and repowering, please refer to Chapter 7. *Revamping and Repowering of the O&M Best Practice Guidelines*.

4 Technical Asset Management / continued

solar PV power plant and the appropriate security equipment, such as loudspeakers, spotlights and fences, must also be adapted. As a best practice, the Technical Asset Manager's (or the O&M service provider's) environmental preservation activities should go beyond legal obligations.

4.10. Health & safety management

The Technical Asset Manager should ensure that the solar PV power plant and the relevant suppliers comply with health & safety (H&S) requirements. If necessary, the Technical Asset Manager should hire an H&S expert to ensure compliance. For more information, see Chapter [2. Health, Safety, Security, and Environment](#).

4.11. Technical Risk management

For an effective technical risk management, the Technical Asset Manager should accurately quantify appearing degradation modes and other performance impairing effects in operating solar PV power plants. Typical methods used in risk management are: Failure Mode and Effect Analysis (FMEA), Failure Mode, Effects & Criticality Analysis (FMECA), Fault Tree Analysis, Reliability Block Diagrams. Reliability practices for technical risk management for the operation of photovoltaic power systems are included in emerging standardisation activities, such

as IEC TR 63292:2020 (active) and the IEC TS 63265 (undergoing the approval phase). One of the methods that allows this type of assessment is the Cost Priority Number (CPN) methodology first developed in the H2020 project Solar Bankability. This methodology assesses the economic impact based on factors such as performance reduction and downtime, in the form of the metric CPN (Cost Priority Number), expressed in €/kWp/year. The methodology helps to identify and classify technical risks and their economic impact by assigning a cost metric that, based on collected statistics, supports preventive and corrective measures, which would then lower the impact of failures on the availability and performance of a solar PV power plant.

Monitoring data should be used in combination with the information contained in maintenance tickets in order to calculate the parameters needed for the determination of the CPN.⁴

For the correct and cost-effective determination of the CPN, the information flow from monitored data, ticketing platform and solar PV power plant metadata needs to be fully automated (key parameters must be extracted from digital documents or databases)

Once the CPN metric is calculated for each event, it is possible to use the metric to benchmark assets within a portfolio, to determine effective O&M strategies and to further optimise them.

⁴ For details please refer to "Identification of technical risks in the photovoltaic value chain and quantification of the economic impact" <https://doi.org/10.1002/pip.2857> and www.solarbankability.eu

5

Power Plant Operation

Central control room. © BayWa r.e.

Operations concerns remote monitoring, supervision, control of the solar PV power plant, and technical performance optimisation (refer to Chapter 4. *Technical Asset Management*). It also involves subcontracting and coordination of maintenance activities. Power plant operation 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 tasks and requirements.

The following figure provides an overview of the most important tasks associated with power plant operation.

5.1. Documentation Management System (DMS)

Solar PV power plant documentation is crucial for an in-depth understanding of the design, configuration, and technical details of an asset. 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 its lifetime. This is what is called here:

- Record control (or records management)

Currently, there are different types of DMS available, along with 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 service provider changes, or the teams change, or the plant is sold etc).

5 Power Plant Operation / continued

FIGURE 2 OVERVIEW OF THE MOST IMPORTANT TASKS IN POWER PLANT OPERATION



PERFORMANCE ANALYSIS AND IMPROVEMENT

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

- | | |
|----------------------------|---|
| Minimum requirement | <ul style="list-style-type: none">• Portfolio level under control of the O&M• Plant level• Inverter level |
|----------------------------|---|

- | | |
|--------------------|--|
| Recommended | <ul style="list-style-type: none">• String level |
|--------------------|--|

MANAGEMENT OF CHANGE

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

- Concept
- Design works
- Execution

SCADA/monitoring system needs to be updated after every change.

- 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

GRID CODE COMPLIANCE

The O&M service provider is responsible for operating the PV plant in accordance with the respective national 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 Operation team provides periodical report. For more details see Chapter 4. *Technical Asset Management*.

POWER PLANT SECURITY

It is necessary that, together with the O&M service provider, the Asset Owner puts in place a Security protocol in case of trespassing on the PV plant. A specialised 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
- Intrusion 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.

5 Power Plant Operation / continued

5.1.1. Information type and depth of detail / as-built documentation

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

In general, for optimum service provision and as a best practice, the O&M service provider 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 service provider, which lays out a complete overview of its location, layout, electrical diagrams, components in use and reference to their operating manuals, HSSE rules for the site and certain further topics. All detailed drawings from the EPC service provider need to be handed over to the O&M service provider and being stored safely for immediate access in case of solar PV power plant issues or questions and clarifications with regards to permits and regulation.

When storing documents, thought must be given to accessibility. As a minimum, project documentation should be available in a searchable PDF format to facilitate the identification of key information. Moreover, project drawings, such as the as-built design, should be editable in case they need correcting, or change management processes mean they need to be updated.

5.1.2. 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. Electronic copies should be made of all documents, and these should be searchable and editable
- 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, logbooks should at a minimum contain the following information:
 - Name of person, who modified the document
 - Date of modification

- Reason for modification and further information, e.g., link to the work orders and service activities
- Versioning control should be implemented as a best practice. People involved should be able to review past versions and be able to follow through the whole history of the document. The easiest way to ensure this is through using an electronic document management system, which should be considered a best practice.

5.1.3. 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 Operations 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 the site should complement the documentation (when applicable). Tickets (ticket interventions) should be stored electronically and made available to all partners. The Asset Owner should also maintain ownership of these records for future references.

To improve future performance and predictive maintenance, it is crucial to keep a record of past and ongoing O&M data, work flows and alarms. This record should seek to link these elements in a cost-effective way, following an agreed naming convention. This will improve accessibility and allow for easier tracing, facilitating comprehensive lessons learned exercises, and resulting in concrete future recommendations for the client. These analyses should also be recorded.

There should be proper documentation for curtailment periods as well as repair periods when the plant is fully or partly unavailable. This will all be recorded by the monitoring system to measure the energy lost 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 proper service provision must be backed up and available when required. This is also important when the O&M service provider changes.

5.2. Plant performance monitoring and supervision

The Operations team of the O&M service provider is responsible for continuously monitoring and supervising of the solar PV power plant conditions and its performance. This service is done remotely using monitoring software systems and/or plant operations centres. The O&M service provider should have full access to all data collected from the site to perform data analysis and provide direction to the Maintenance service provider/team. For more information on monitoring tools please refer to Chapter 9.3. *Monitoring (web) portal* and SolarPower Europe's *Monitoring Best Practice Checklist* (available at www.solarbestpractices.com).

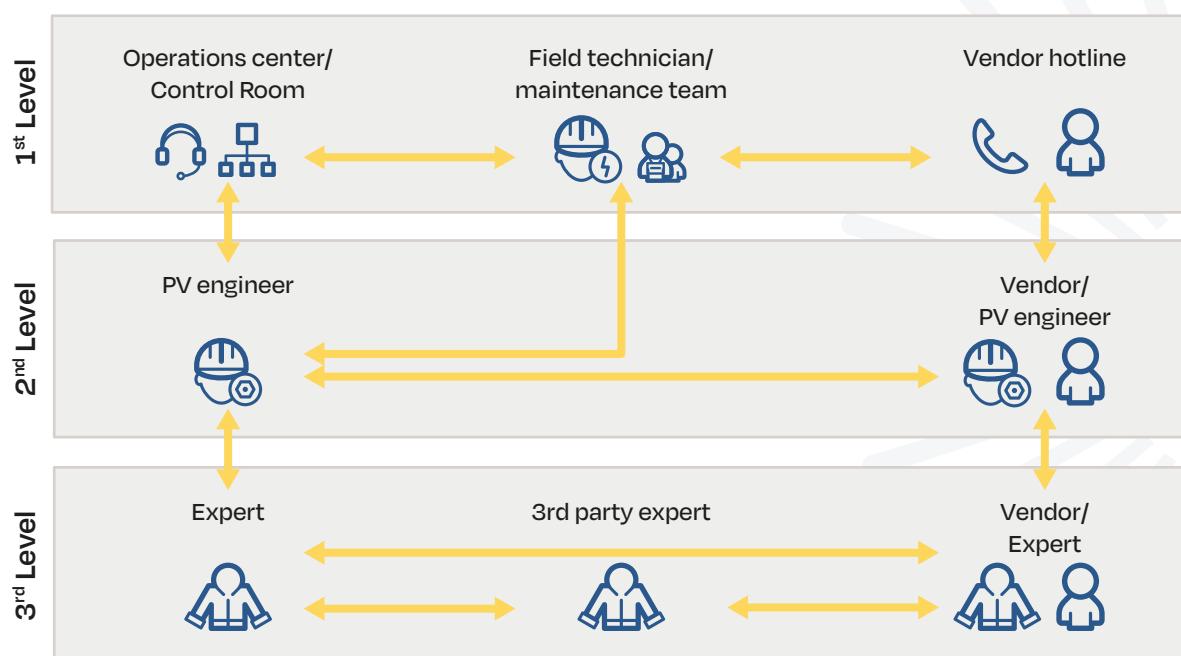
Normally, in Fault Management (Incident Management) several roles and support levels interact:

- With the help of monitoring and its alarms the Operations Center (Control Room) detects a fault. It is responsible for opening a "ticket" and coordinating troubleshooting actions. It collects as

much information and diagnostics as possible to establish initial documentation, tries to categorise the issue and, where possible, to resolve it instantly. This is known as 1st Level Support. Then it tracks the incidents until their resolution.

- If the fault cannot be sufficiently categorised, the Operations Center may call out a field technician who can be a local electrician or member of the maintenance team. This person will analyse and try to resolve the fault on-site (1st Level Support). Their knowledge and access rights may be not sufficient in some situations, but they can fix most faults to an adequate level. 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, it will escalate it to 2nd Level Support. This consists of solar 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.

FIGURE 3 SUPPORT LEVELS IN FAULT MANAGEMENT



- If an incident requires special expertise or access, 2nd Level engineers might need to contact experts (in-house or from the vendor or a third party). This is known as 3rd level support. In some organisations the Project/Account Managers can cover both 2nd and 3rd Level Support, based on their seniority and experience.
- When the fault is solved, the Operations Center closes the ticket.

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

The O&M service provider 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 Asset Owner should be able to contact the Operations team via a hotline during daytime, when the system is expected to generate electricity. The Operations team is also responsible for coordinating accordingly with the Maintenance service provider/team.

For more information on monitoring requirements, see Chapter [9. Data and monitoring requirements](#).

5.2.1. Performance analysis and improvement

The O&M service provider ensures that the performance monitoring is done correctly.

In general, the data should be analysed at the following levels:

1. Portfolio level (group of plants) under control of the O&M service provider (minimum requirement)
2. Plant level (minimum requirement)
3. Inverter level (minimum requirement)
4. String level (as a recommendation)

The analysis should show the required data on the 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 business plan data or real-time deviations between inverters on-site.

In particular, the agreed KPIs should be calculated and reported (see Chapter [10. Key Performance Indicators](#)). Special attention should be paid to the fact that KPI calculations should take into consideration the contractual parameters between O&M service provider and Asset Owner, to provide an accurate and useful calculation for evaluation and eventually liquidated damages or bonuses.

5.3. Optimisation of O&M

An essential part of Operations is the analysis of all the information generated throughout O&M, such as Response Time, and how this correlates to the various classifications of events and root causes. Another vital part of Operations 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. For more information on optimisation of O&M please refer to Chapter [6. Power Plant Maintenance](#) and Chapter [8. Spare Parts Management](#).

5.4. Power plant controls

If applicable, the Operations team can be the point of contact for the grid operator for plant controls. The Operations team will control the plant remotely (if possible) or instruct the qualified maintenance personnel to operate breakers/controls on site. The O&M service provider is responsible for the remote plant controls or emergency shutdown of the plant (if possible) and in accordance with the respective grid operator requirements (see also [5.6. Grid code compliance](#)), regulations (see [4.4. Interface with local energy authorities & regulatory compliance](#)) and the aggregator's requirements. The plant control function varies from country to country and in some cases from region to region. The respective solar PV power plant control document for the area details regulations issued by the 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 solar PV power plants. The set points can normally be

commanded either remotely or locally from the Supervisory Control And Data Acquisition system (SCADA). Moreover, the system should be password protected and log all the executed commands. Any executed commands should release real-time notifications to the Operations team.

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

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

5.5. Power Generation Forecasting

Forecasting services for solar PV power generation are generally offered by operators of solar PV monitoring services. However, external services can also provide this function. When the Asset Owner requires Power Generation Forecasting from the O&M service provider, they could opt for a service level agreement with the forecast provider. Forecasting may have an influence on the contract agreement for electricity dispatching between the Asset Owner and a trading service provider.

The requirements for forecasts may differ from country to country and also depend on the contract agreement for electricity dispatching between the Asset Owner and a trading service provider. Forecast requirements are characterised by the forecast horizon, the time resolution, and the update frequency, all depending on the purpose. For power system or power market related purposes, forecast horizons are typically below 48 hours and the time resolution is 15 minutes to one hour, in line with the programme time unit of the power system or the market. Common products are day-ahead forecasts, intra-day forecasts and combined forecasts. Day-ahead forecasts are typically delivered in the morning for the next day from 0 to 24 and updated once or twice during that day. Intraday forecasts are delivered and updated several times per day for the rest of the day and should be delivered automatically by 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.

Solar 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.

5.6. Grid code compliance

The O&M service provider, and in particular the Operations team is responsible for operating the solar PV power plant in accordance with the respective national grid code. The operator of the grid to which it 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 countries (and/or regions) specific grid codes for renewable energy generators have been issued.

Depending on the voltage level of the grid the plant is connected to, the specificities and quality requirements for the solar PV power plant change. Grids with a higher voltage level usually have more specific and demanding requirements.

Most of the grid-connected utility scale solar PV power plants in Europe must undergo an external test to meet the grid operator requirements. These plant tests allow the grid operator to adjust the power output from the solar PV power plant according to the grid capacity and power frequency requirements.

The O&M service provider is expected to be familiar with all the details of the grid code and grid operator requirements. Depending on the regulations, either the

5 Power Plant Operation / continued

grid operator themselves is steering the solar PV power plant controller (with remote signals) or the Operations team is managing the plant controller under the direction of the grid operator.

5.7. Management of change

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

The O&M service provider should be involved in changes to the solar PV power plant from the beginning. Concepts, design works, and execution need to be coordinated with ongoing O&M activities. Any changes should also be reflected in the plant SCADA and monitoring systems. 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 help the O&M service provider verify that the new component is correctly configured and is sending high quality data. Adjustments to the Site Operating Plan, the Annual Maintenance Plan and the Annual Maintenance Schedule need to be applied and the O&M service provider needs to familiarise the O&M staff with the operating manuals of the new equipment. These types of changes will have an impact on Spare Parts Management and inventory (replacement). Depending on the significance of the change, the O&M annual fee might need to be adjusted.

It is advisable that the O&M service provider lead these sorts of change processes. The O&M service provider is the trusted partner of the Asset Owner and should advise the Owner when they are making decisions on changes to the plant. In the case of major changes, the Owner should also consider informing lenders about the decision process and provide concepts, proposals, calculations and updates.

The fixed O&M fee does not usually cover change services. The Asset Owner and the O&M service provider should manage changes in a formalised way. This procedure should 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 service provider and acceptance.

5.8. Power plant security

It is important that the solar PV power plant, or key areas of it, are protected from unauthorised access. This serves the dual purpose of protecting the plant's equipment and keeping members of the public safe. Unauthorised access may be accidental with 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 service provider and the security service provider, the Asset Owner must 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, solar PV power plant security should be ensured by specialised security service providers subcontracted by the O&M service provider. The security service provider will be responsible for the proper functioning of all the security equipment including intrusion and surveillance systems. They are also responsible for processing alarms 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 service provider will coordinate with the security service provider and may choose to act as an intermediary with the Asset Owner.

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. If solar PV power plants have CCTV systems in place, an access protocol would be required 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 advisable to have a backup communication line installed (often, the first thing that gets damaged in case of vandalism is 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 liaising with local emergency services 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 and 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 compulsory 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 always maintained particularly when there are activities that may be of more interest to members of the public 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.

5.9. Reporting and Technical Asset Management

The Operations team is responsible for providing periodic reporting to the AM or directly to the Asset Owner. In many cases, the Operations team also assumes further TAM responsibilities. For more details on reporting and other TAM tasks, see Chapter 4. *Technical Asset Management*.

6

Power Plant Maintenance



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This chapter is about the various responsibilities and tasks related to Maintenance.

Maintenance is usually carried out on-site by specialised technicians or subcontractors, in close coordination with the Operations team's analyses. In modern solar PV power plants, automation of maintenance tasks is becoming more prevalent. However, this practice is still developing and is not widespread currently. The following figure provides an overview of the four main types of power plant maintenance.

6.1. Preventive maintenance

Preventive Maintenance activities are the core element of the maintenance services to a solar PV power plant. It comprises regular visual and physical inspections, as well as verification activities.

The maintenance of all key components is carried out at predetermined intervals or at least 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 must also maintain the equipment and component warranties in place and reduce the probability of failure or degradation. The activities must also be consistent with respective legal issues such as national standards for periodic inspection of certain electrical components. It should be noted that the various maintenance activities that an O&M service provider is expected to carry out require personnel qualified to carry them out. The O&M service provider must ensure that they have the appropriate range of skills available to fulfil their

contractual obligations (for more information on maintenance activities and the skills they require, see Annex b of these Guidelines and Annex a of the *Lifecycle Quality Guidelines*). The O&M contract should include this scope of services and each task frequency.

It is the responsibility of the O&M service provider to prepare the task plan, according to the time intervals in the contract.

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).

An example of Preventive Maintenance is thermographic inspection which aims to identify defective panels on a solar PV power 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.

Preventive Maintenance also includes ad-hoc replacement of parts of inverters or sensors. In general, it is important to follow detailed Preventive Maintenance procedures, which are agreed upon in the Annual Maintenance Plan.

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

FIGURE 4 OVERVIEW OF THE DIFFERENT TYPES OF POWER PLANT MAINTENANCE

INCLUDED IN ALL O&M CONTRACTS

Preventive Maintenance

Preventive Maintenance are the core elements of the maintenance services to a PV plant. It comprises regular visual and physical inspections, as well as verification that all the key components of the solar plant are in good working order. This maintenance is carried out at predetermined regular intervals according to prescribed OEM & O&M manuals and are included in the "Annual Maintenance Plan".

Corrective Maintenance

Corrective Maintenance corresponds to any activity performed to restore a PV plant system, equipment or component to a functioning state, and occurs after a failure detection by remote monitoring or during an on-site inspection. Corrective Maintenance includes Fault Diagnosis, Temporary Repair & Repair and can be divided into 3 levels of intervention: Intervention without the need of substitution, with the need of substitution and with the need to intervene on the software of a device.

Predictive Maintenance

Predictive Maintenance is a condition-based intervention carried out following a forecast derived from the analysis and evaluation of the significant parameters of the degradation of an item. The site must have "intelligent" equipment and an appropriate monitoring software system, allowing the Operations team to perform regular monitoring, supervision, forecast and performance data analysis of the main equipment of the PV plant (transformer, inverter, combiner box and/or DC array).

Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events require substantial activities to restore the previous plant conditions. These interventions are required for damages due to Force Majeure, damages due to a theft or fire, endemic failures of the equipment, modifications required by regulatory changes and equipment wear or deterioration due to design faults.

Additional Services

The O&M agreement can foresee services other than electrical and mechanical plant maintenance. 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 include PV site maintenance activities such as panel cleaning and vegetation control, general site maintenance tasks like waste disposal and maintenance of buildings and on-site measurements such as I-V curve measurement on modules or thermal inspections.

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6 Power Plant Maintenance / continued

6.2. Corrective maintenance

Corrective Maintenance covers the activities performed by the Maintenance team to restore a solar PV power plant system, equipment or component to a status where it can perform the required function. Corrective Maintenance takes place after a failure detection either by remote monitoring and supervision or during regular inspections and specific measurement activities (see Annex e).

Corrective Maintenance includes three activities:

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

In cases where the solar PV power plant or segments thereof need to be taken offline, Corrective Maintenance should be performed at night or during periods of low irradiation as the overall power generation is not affected.

A key aspect of corrective maintenance is to be able to track failures to their root cause. This 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. Corrective Maintenance processes should also track the efficacy of responses to problems (what fixes the problem reliably?).

Corrective Maintenance can be divided into three levels of intervention (See Table 2) to restore the functionality of a device, that could be included in the O&M agreement or billed separately on hourly rates.

3rd level activities 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.

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 6.4. Extraordinary Maintenance).

The scope of Corrective Maintenance activities and its "border" or definition with respect to Preventive 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 correct fixation should be under the Preventive Maintenance scope of works, but depending on the quantity and/or frequency, it could be considered a Corrective Maintenance activity. The Annual Maintenance plan therefore states the extent of each planned activity.

Usually, Corrective Maintenance work must be accomplished within the contractually agreed minimum Response Times (see 10.4.3. Response Time and 11.6. Response Time price adjustment).

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

TABLE 2 THREE LEVELS OF CORRECTIVE MAINTENANCE

LEVEL OF INTERVENTION	CHARACTERISTICS	REQUIRED LABOUR SKILL	EXAMPLE ACTIVITY
1st level	No need for substitution	Maintenance team	Restart of an inverter
2nd level	Substitution of a component	Maintenance team/solar PV Engineer	Substitute a fan to restore inverter functionality
3rd level*	Intervention on the software	Solar PV Engineer/3 rd party expert	Reconfiguration or Parameterisation of an inverter

6.3. Predictive maintenance

Predictive Maintenance is a special service provided by O&M service providers 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 EN 13306). 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 service providers can evaluate trends or events that signal deterioration in a device. As a best practice, the device manufacturer should provide a complete list of status and error codes produced by the device, together with the detailed description of their meaning and their impact on the functioning of the device. Additionally, a standardisation of status and error codes through inverters and dataloggers from the same brand should be followed and, in the future, this standardisation should be common to all manufacturers.

Stakeholders that wants to benefit from Predictive Maintenance should, as a best practice, select "intelligent" equipment set with sufficient sensors, and opt for a monitoring software system that provides basic trending and comparison (timewise or between components and even between solar PV sites) functionalities (minimum requirement).

The Operations team of the O&M service provider enables Predictive Maintenance thorough continuous or regular monitoring, supervision, forecast and performance data analysis (e.g., historical performance and anomalies) of the solar PV power 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 round of circuit testing or thermal imaging inspection and that indicate upcoming component or system failures or underperformance (e.g., at solar PV modules, inverters, combiner boxes, trackers, etc. level).

Before deciding which Predictive Maintenance actions to recommend, the Operations team 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 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 the service provider's track record. Normally it is a process that starts after the implementation of an appropriate monitoring system and the recreation of a baseline. This baseline will then represent the entire solar PV system operation, how different pieces of equipment interact with each other, and how the system reacts to "environmental" changes.

Predictive Maintenance has several advantages, including:

- Optimising the safety management of equipment and systems during their entire lifetime
- Helping to anticipate maintenance activities (both corrective and preventive)
- Delaying, eliminating and optimising some maintenance activities
- Reducing time for repairs and optimising maintenance and Spare Parts Management costs
- Reducing spare parts replacement costs
- Increasing availability, energy production and performance of equipment and systems
- Reducing emergency and non-planned work
- Improving predictability

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

Example 1

An O&M service provider signs a new contract for a solar PV power plant equipped with central inverters. Analysing its backlog of maintenance, the O&M service provider knows that these inverters showed signs of power loss due to overheating at several

points in the past. This might be related to problems in the air flow, filter obstructions, fans, or environmental changes (high temperature during summer). A decision was taken to monitor the temperature of IGBTs (Insulated-Gate Bipolar Transistors). An "air flow inspection" was performed, prior to any emergency action being required, to determine whether power loss was related to 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 a filter replacement or cleaning is required.

Example 2

Predictive Maintenance for optimised hardware replacement cycle relying on big data analytics or artificial intelligence. For more information on this innovation, see section [12.4. Predictive maintenance for optimised hardware replacement](#).

6.4. 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).

"Force Majeure" events affecting solar PV power plants include high winds, flooding, hurricanes, tornados, hail, lightning, and any number of other severe weather events. Extraordinary Maintenance associated with severe weather include safety shutdown, inspection to document damage, electrical testing (integrity of circuits and grounding), remove/repair/replace decisions, and recommissioning confirming proper operation and documenting changes made during repairs.

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 resulting from theft or fire.
- Serial defects or endemic failures on equipment, occurring suddenly and after months or years from plant start-up.
- Modifications required by regulatory changes.

In cases where the O&M service provider and the EPC service provider are different entities, the following occurrence should also be considered as Extraordinary Maintenance:

- Major issues that the O&M service provider becomes aware of during its ordinary activity. These could be defects or other problems that are not a consequence of equipment wear or deterioration and can be reasonably considered to have been caused by design mistakes (e.g., "hidden" defects that require re-engineering).

Although not necessarily maintenance interventions, 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 [7. Revamping and repowering](#).

After the approval by the Asset Owner of the O&M service provider'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 is very difficult to determine in the SPV financial model. However, many of the above events can be reimbursed to the Asset Owner by the insurance company under any "All Risk Insurance" coverage that is in place. Relevant conditions and requirements according to the insurance policies of the Asset Owner need to be shared with the O&M service provider.

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

⁵ For a definition of endemic failures and its repercussions in terms of warranty, see section [4.5. Warranty management](#).

of the Asset Owner to ask for third party quotations to compare to the quotation of the O&M service provider. In this case a "right-to-match" option should be granted to the O&M service provider.

- The obligation for the Asset Owner to have in place a consistent "All Risk Property" Insurance including loss of profit.

6.5. 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.

6.5.1. Module cleaning

Regular module cleaning is an important part of solar maintenance and the problems associated with soiled modules are 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. The intensity and type of soiling depend heavily on the location of the solar PV system (e.g., its proximity to industrial areas, agricultural land, or railway lines).

Module cleaning methods therefore vary from manual, to robotic and mechanical and each have their own advantages and disadvantages. 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 company, Asset Owners and O&M service providers should check the following:

- The suggested method of cleaning is fully in-line with the module manufacturer's warranty and

according to specifications from IEC 61215 (e.g., maximum pressure load).

- The modules should be cleaned with high quality, ultra-pure water, not tap, mains or borehole water. Detergents must be biodegradable and comply with local environmental regulations.
- H&S considerations should be made with regard to keeping staff safe on site. This should include some form of H&S accreditation and specific training for solar module cleaning, including working at height, if cleaning roof mounted modules.

Table 3 on the following page presents a non-exhaustive list of Additional services. For more information on whether these additional services are generally included in the O&M agreement or not, see [11.2. Scope of the O&M contract](#).

Some of these items can be considered as a part of Preventive Maintenance. This depends on the agreement between the Asset Owner and the O&M service provider.

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 thermographic inspections).

6.5.2. Advanced aerial thermography

The general functionality of thermographic data is further outlined in Chapter [9.11.1. Infrared thermography](#). While thermographic inspections have become well established as a tool in preventive 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 solar 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 of Preventive and Corrective Maintenance tasks. If deployed properly, aerial thermography can provide several operational and financial advantages. It also

6 Power Plant Maintenance / continued

TABLE 3 EXAMPLES FOR ADDITIONAL MAINTENANCE SERVICES

	ADDITIONAL SERVICES
Solar PV site maintenance	Module cleaning
	Vegetation management
	Snow, sand or dust removal
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 Preventive Maintenance
	Thermal inspections, I-V curve tracing, electroluminescence imaging (for more information, see the section 9.11. Data collected by specialised solar PV module field inspections) – to the extent exceeding the agreed level of Preventive Maintenance.

reduces H&S risks involved in manual inspections, such as prolonged field exposure in dangerous working environments, and the hazards involved in moving around the site, particularly on rooftop installations. Aerial inspections can also pinpoint anomalies to precise locations, thus focusing and reducing the time required for repair work.

Please 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.⁶

Data acquisition

In this stage a flyover is performed where raw infrared (IR) thermographic 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. The drone is typically pre-programmed with a flight path designed to cover the entirety of the solar PV asset being inspected. The pre-programmed flight

path allows for precise and repeatable flights to be performed, increases the accuracy of results, and ensures that the same parameters are used during each subsequent aerial inspection.

With the advent of aerial inspections, resources required for data collection can be significantly reduced. For instance, a 12MWp solar PV power plant can be inspected in a single day. Aerial IR thermography must always be conducted following a set of minimum technical requirements (described in IEC TS 62446-3:2017). Otherwise, it is of little value 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 solar PV module failure analysis that could trigger conclusive maintenance decisions. Furthermore, field interventions can be optimised, and solar PV power plant underperformance can 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

⁶ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

claims or in correlation with solar PV monitoring data). Additionally, since images are taken from the air, the data yields a helpful overview for checking whether plant layout, its electrical/physical configuration and other documents are correct.

As with any form of thermography, the inspection method and its diagnostic efficiency are significantly limited by and dependent on meteorological conditions. For the inspection data to be of value, a minimum radiation of 600 W/m² is required. For drone inspections, to control the RPA safely wind speeds should not exceed 28 km/h (this is dependent on the type of RPA used).

Post-processing

The post-processing activities consist of all the data processing and analysis techniques used to produce the final report and all the related deliverables. These activities can be done manually or automatically with specialised software.

The activities comprised in this stage are described as a series of subtasks in the Table 4 below.

There are many companies offering high-quality industrial aerial flights in the market. These are typically referred to as Drone Service Providers (DSPs). While there are companies using drones in a variety of

TABLE 4 POST-PROCESSING ACTIVITIES

POST-PROCESSING SUBTASK	DESCRIPTION
Geolocation of PV modules	Manual or automated location of the solar 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 solar PV module is identified on the plant's layout. Minimum requirements for this analysis can be found in IEC TS 62446-3:2017.
Solar PV module failure analysis	Diagnosis and root-cause analysis of solar PV module failures. This is where the link between thermal anomaly and solar 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 solar PV power plant. These can include degradation trends, failure distribution by harm degree and by module manufacturer, etc. Some specialised data analytics platforms can generate power loss assessments and financial impact statements by inputting PPA figures to help estimate the financial impact of power loss from thermal anomalies.
Maintenance implementation plan	Actions needed to minimise yield losses, based on the seriousness of the defect. It can be seen as a list of recommendations that can be directly translated into preventive or corrective field operations.
Reporting	<p>Report created manually or automatically. In ideal circumstances the report should be tailored to the customer's needs and requirements. It contains a summary of the findings and additionally, depending on the provider, it could contain some calculations of estimated power losses and the resulting financial implications. These reports can be used for a variety of cases from insurance/warranty claims, preventative and corrective maintenance/repair of the solar PV asset, to reporting for various stakeholders throughout the value chain.</p> <p>While reports can still come in the form of pdf or other documents, increasingly the best practice is for reports to be housed within a cloud-based platform, where the information can be accessed from a variety of portals, devices and formats (e.g. on client side as well as O&M and AM), and the data can be easily manipulated into various report formats.</p> <p>These cloud-based platforms also allow for the results of previous inspections to be easily compared with new ones to note measurements such as year-to-year power degradation. Some platforms now offer benchmarking of the inspected site's performance, not only against its historical performance, but also against other solar PV sites in the same portfolio, and against a global data set.</p>

6 Power Plant Maintenance / continued

situations (IR inspections of solar PV power plants, wind turbines, oil ducts, offshore oil extraction platforms, and infrastructure etc.), DSPs are emerging that focus solely on the solar solar PV segment. Therefore, this data acquisition stage is an activity that could be easily outsourced by O&M service providers, mitigating the risks related to technology obsolescence and avoiding the costs and complexities of regular drone maintenance. This is particularly beneficial given the rapid rate of development and innovation in the drone technology space. Selecting a DSP with specialisation in solar solar PV inspections gives O&M service providers the additional advantage of relevant expertise and experience, which can equip them with superior insights from the data captured.

There are some companies which utilise specially modified piloted aircraft, flying at a higher altitude, in lieu of drones for inspections of large sites and portfolios. These aircraft are able to cover ground quicker than drones (up to 150MW/hr) while maintaining high resolution due to the higher quality of cameras which can be used. However, these systems are prohibitively expensive for individual sites due to the large mobilisation costs.

Most companies today still rely on manual data processing, which represents a major drawback for large portfolios as human-error (and user-dependence) drives down the accuracy and "consistency" of thermal imaging assessments. This means that companies with automated solutions have a huge advantage in this regard. The advent of AI and machine learning algorithms built into automated data processing solutions also provides customers with significantly greater processing speed and inspection accuracy, and analyses that improve over time.

Aerial inspections and their associated post-processing activities are evolving very rapidly, and the adoption of such new technologies is of significant strategic importance in today's highly competitive O&M market. As the playing field moves towards a post-subsidy era, such additional services as advanced aerial thermography that can save O&M service providers time and money, seeing them become a standard practice out of necessity.

Pilots

Any aerial thermography or other solar PV module and plant monitoring application involving drones or piloted aircrafts must be carried out by a licensed and insured operator and in accordance with all local and EU-level civil aviation regulations. 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.

6.5.3. Vegetation Management

Vegetation management can represent a significant portion of the operations costs of a solar PV system. Some key items to consider in vegetation management:

- **Damage Reduction:** Vegetation management can reduce direct mechanical damage caused by vegetation - especially woody vegetation - growing into modules and structures. Damage can also be caused by direct shading causing hot-spot formation on modules, potentially leading to long-term module damage.
- **Performance Enhancement:** Vegetation can cause module shading, which leads to degraded module performance. This effect is disproportionate to the amount of shading, so a small amount of shading can cause a significant amount of power loss.
- **Erosion Control:** Vegetation is critical for soil stabilisation and avoidance of erosion damage on sites. Uncontrolled erosion can cause significant structural damage on a project over time.
- **Carbon Sequestration:** Continuous vegetation management can assist in increasing soil carbon sequestration, especially with the use of grazing animals, who are able to fertilize the soil while enhancing soil carbon capture.
- **Biodiversity Enhancement:** The use of natural pollinators and native vegetation can enhance local biodiversity. This can improve community engagement, lead to reduced vegetation management costs, and in some cases add revenue streams to a project.

- **Community engagement and social license to operate:** Vegetation management can be one of the most visible maintenance activities for local communities and can affect aesthetics, noise pollution, erosion, runoff, and chemical contamination concerns. Vegetation management done well can enhance relations with the

community and local councils and improve the social license to operate. Done poorly, vegetation management can cause conflict with local communities and planning councils and can lead to potential legal concerns.

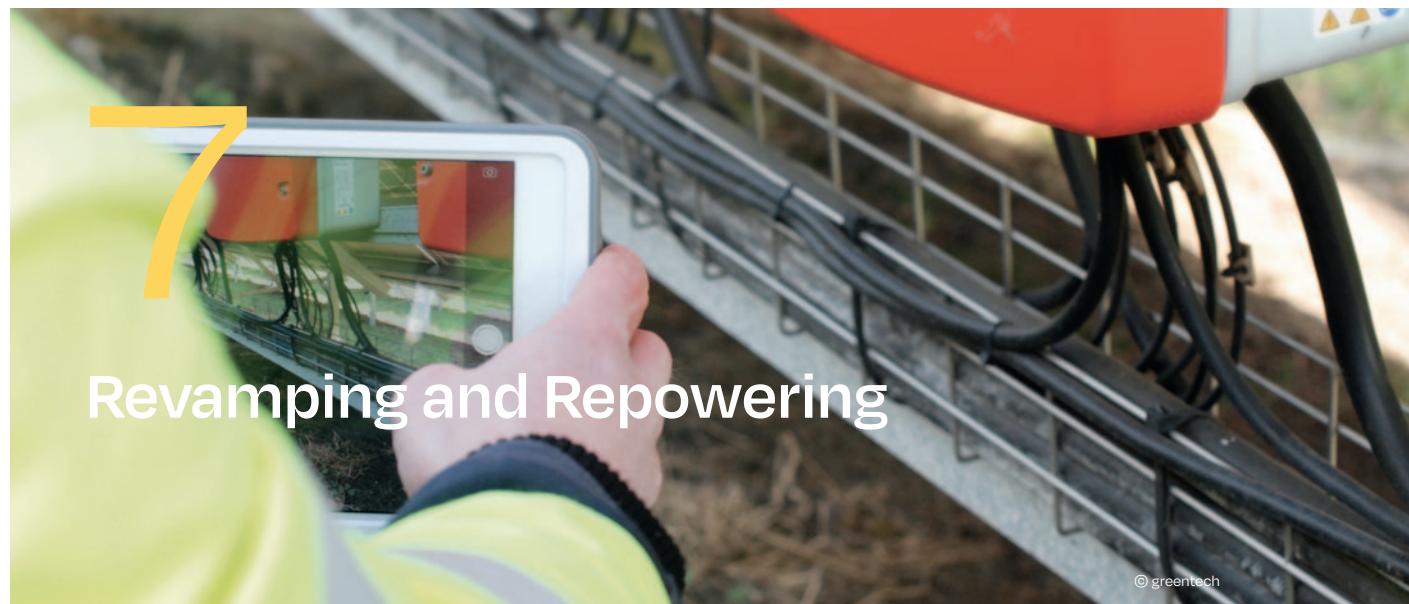
Some options for vegetation management are outlined in Table 5 below.

TABLE 5 OPTIONS FOR VEGETATION MANAGEMENT

OPTION	ADVANTAGES	DISADVANTAGES
Manual Mechanical Removal <i>Human operated mowers and trimmers used periodically throughout the year</i>	<ul style="list-style-type: none"> ▪ Adaptive to different vegetation sizes (e.g manual removal of woody growth) ▪ Flexible access to different parts of the site 	<ul style="list-style-type: none"> ▪ Costs ▪ Potential for module damage ▪ Quality is dependent on contractors ▪ On site safety variance due to differences in contractor quality
Automated / Robotic Mechanical Removal <i>Use of autonomous robots which can mow defined patterns in an array while actively avoiding obstacles</i>	<ul style="list-style-type: none"> ▪ Costs ▪ Ability for increased mowing cadence ▪ Ability to integrate into predictive models of vegetation growth 	<ul style="list-style-type: none"> ▪ Difficulty adapting to different site conditions. E.g water pooling, obstructions ▪ Difficulty removing some types of vegetation (e.g., woody vegetation)
Grazing <i>Use of Grazers (typically sheep) managed by an on-site shepherd for vegetation control. Grazers are typically transported to site periodically for vegetation management</i>	<ul style="list-style-type: none"> ▪ Costs (dependent on grazer availability) ▪ Good local community engagement and can enhance social license to operate ▪ Erosion control through ground fertilization ▪ Soil carbon sequestration 	<ul style="list-style-type: none"> ▪ They will not eat everything e.g., thistle and woody plants ▪ Quality dependent on farming partners ▪ Costs can be high if supply of grazers is low
Chemical <i>Herbicide use for large area vegetation control</i>	<ul style="list-style-type: none"> ▪ Costs ▪ Speed ▪ Coverage - it is easy to get large and consistent coverage on site 	<ul style="list-style-type: none"> ▪ Can cause significant erosion ▪ Runoff concerns can cause environmental damage ▪ Permitting required and not legally allowed in some locations ▪ Can hurt community relations and reduce social license to operate
Passive vegetation control through system design <i>Designing systems with high ground clearance and seeding with low growth natural vegetation or natural pollinators</i>	<ul style="list-style-type: none"> ▪ Low operating costs ▪ Potential for enhanced community engagement ▪ Potential for additional project revenue streams 	<ul style="list-style-type: none"> ▪ Higher project capital costs ▪ Increased system design costs for specifying appropriate local vegetation

7

Revamping and Repowering



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Revamping and repowering are usually considered as part of Extraordinary Maintenance from a contractual point of view – however due to their increasing significance in the solar O&M market, these Guidelines are addressing them in a standalone chapter.

7.1. 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 with 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 difference between revamping and repowering, and ordinary replacement is that the former aims to increase performance by exchanging all components within a functional area or a significant ratio of them. The following sections focus principally on repowering but also broadly apply to revamping and even repairs and Extraordinary Maintenance.

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

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

7.2. Module repowering

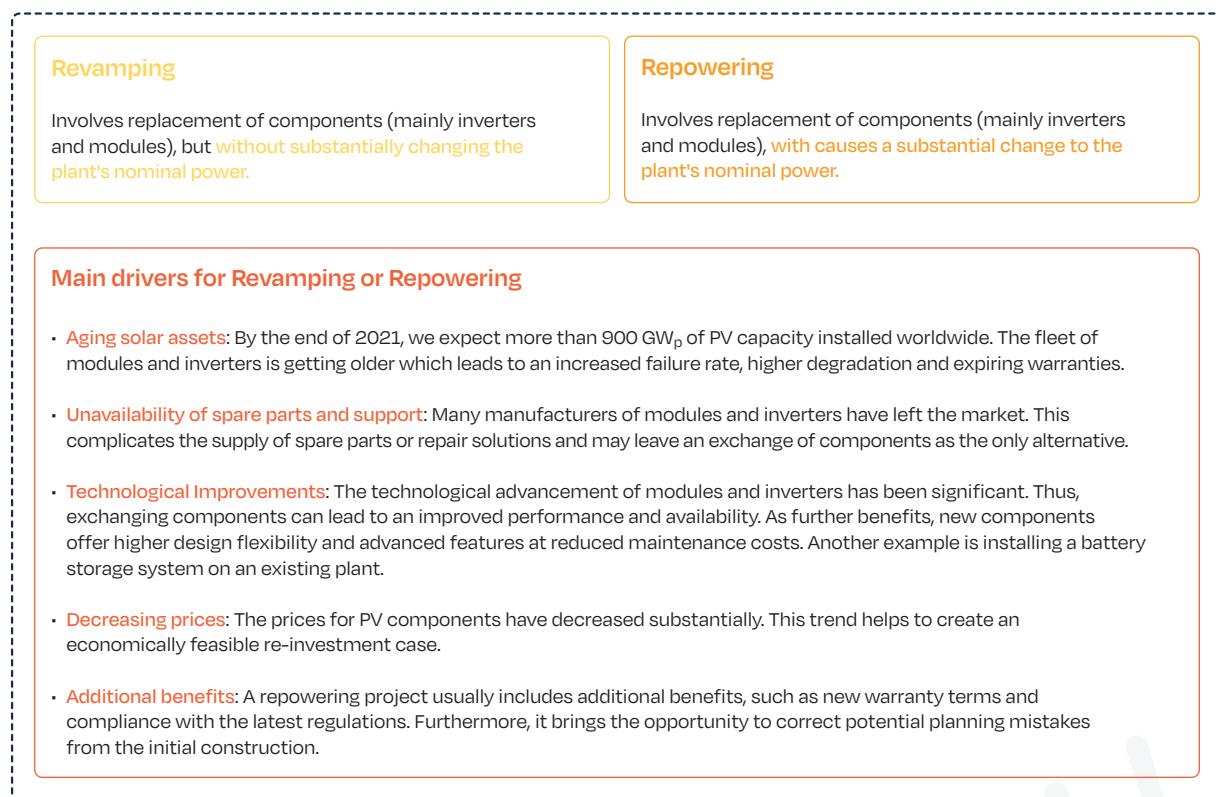
Modules with irreparable defects that cannot be directly replaced in a like-for-like swap may force the investor to consider a module repowering. This can be carried out for the entire solar PV power plant or for specific parts. When repowering is focused on partial module replacement, exchanging more modules than is technically required is advised as this keeps old modules intact as spare parts for the future.

Due to the rapid development of solar 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 identical modules would make repowering very simple. However, this would mean spending money to maintain performance, instead of taking advantage of opportunities to raise efficiency at a lower proportional cost. Where different modules are used for the repowering project, the following aspects need to be considered during planning and execution:

7.2.1. Mechanical installation

- If the modules have different dimensions in height, length and width, 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. To save widespread changes to the plant's infrastructure, agile repowering strategies such as changing from central to string inverters, replacing transformers etc. should be considered.

FIGURE 5 DIFFERENCES BETWEEN REVAMPING AND REPOWERING AND THEIR MAIN DRIVERS



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- If the new module is heavier and has a larger surface area the structural impacts on the mounting system or the building need to be checked and aligned.
- The new modules need to be integrated into the grounding system as before.
- It is likely that 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 ensure it is suitable for the new DC-layout.

7.2.2. 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.

7.2.3. Further considerations

- A module repowering might contain various regulatory aspects, which will vary from country to country. The regulatory body should be contacted well in advance 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

7 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 should be optimised towards shading or DC / AC ratio. Furthermore, an in-depth check of the mounting structures, cables and connectors should be performed.
- If only some of the modules are being exchanged and power measurements of the old type of 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 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.

7.3. Inverter repowering

As with all electronic devices, inverters have a limited lifetime. With increasing age and wear, the likelihood of failures and breakdowns increases. If the warranty of a 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., by replacing an old control board with a new device with better performance characteristics, such as Maximum Power Point (MPP) tracking). If an identical replacement inverter, repair services or spare parts are not available, using a new component becomes inevitable. There are different strategies for inverter repowering which should be evaluated on a case-by-case basis:

- Partial or complete exchange:** If only some of the inverters are affected, a partial exchange of the inverter fleet of the solar 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 applies for 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. The string length and the number of connected strings may need to be adjusted to suit the technical parameters of maximum current and voltage as well as ideal operational conditions. In case larger inverters are installed, additional DC combiner boxes might be required, and different, or additional fuses may need to be integrated.
- 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 all cases the applicable electrotechnical rules and regulations need to be followed.

Communication system

- Before choosing an adequate inverter, 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 also 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 solar PV system needs to be validated.

Further considerations

- An inverter repowering might contain various regulatory aspects, which will vary from country to country. 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 should be optimised towards shading or DC / AC ratio. When the new inverter has more advanced features than the old one (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 restrictions 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 these options are not practical, the devices should be disposed of or recycled by a professional service provider.

- New or different maintenance scope and intervals need to be included into the Preventive Maintenance schedule.
- All involved people should be informed about the changes and accordingly trained regarding Preventive and Corrective 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.

7.4. General repowering considerations

Although, a repowering project is mainly technically driven, for the Owner of the solar PV system it is a commercial re-investment case. Therefore, it is of great importance to calculate a detailed and solid business case before starting 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 the basis for a decision.

As an additional analysis, calculating the sensitivities of the most important factors is recommended. 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.

7 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 where 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. Similarly, reporting to the AM and Asset Owner should be provided throughout all stages of a repowering project.

Spare Parts Management

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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 solar PV power plant and O&M service providers 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 solar PV power plant, intended to replace similar items in the solar PV power 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 to minimise the downtime of (part of) a solar PV power plant. to the following considerations have to be made in Spare Parts Management:

- 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 service provider 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 service providers 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 a set of Included Spare Parts and Excluded Spare Parts. Similarly, a financial limit for Included Spare Parts can be negotiated.

Included Spare Parts are those which the O&M service provider 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 service provider's O&M fee. This is a flexible approach allowing the Asset Owner and O&M service provider 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. The contract should contain provisions on who is liable in the event that a spare part is unavailable. The various parties are responsible for their replenishment and bear the associated production loss.

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 service provider receives payment for the same.

Maintenance, storage, and replenishment are the responsibility of the O&M service provider. 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 service provider.

8 Spare Parts Management / continued

For a new solar PV power plant, the initial spare parts for two years from COD are procured by the Asset Owner, or the EPC service provider on behalf of the Asset Owner. However, it is best practice for the EPC and O&M service providers to have agreed upon the list. The O&M service provider should, as a best practice, recommend additional spares that they deem them 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 service provider 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 solar PV power 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. This can also apply for parts with a long replenishment period. Similarly, one must consider the management risk that a fault can cause. For example, if a component of a SCADA system stops working, there is no resultant power loss. However, there is a risk of not being able to detect future power loss if this part is not replaced. Some very large O&M service providers now propose using the spare parts in their different warehouses in place of, or in addition to the Asset Owner's spares stock. Since they operate many sites, they limit the shortage of unusual spare parts by maintaining a small stock.

Regarding the stocking level, due to the very different configurations and sizes of solar solar PV power 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 service provider might also influence this and, as mentioned above, the determination of spare items and quantity is also driven by the O&M service provider's contractual commitments and guarantees. 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
- Replenishment time
- Management risk

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

Table 6 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 to have either an 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. If the O&M service provider exchanges spare parts, an agreement should be drawn up with the supplier that ensures the warranty is not voided.

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 6 EXAMPLES FOR A MINIMUM LIST OF SPARE PARTS

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 and tracker control board
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)

9

Data & monitoring requirements

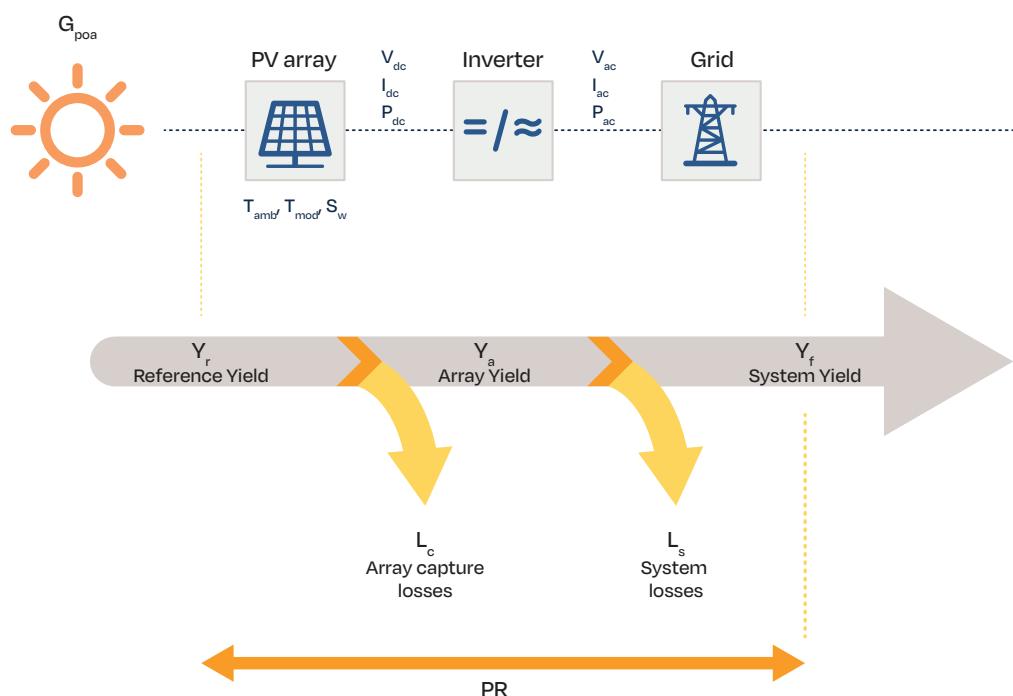


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In general, monitoring systems should allow follow-up on the energy flows within a solar PV system. In principle, it reports on the parameters that determine the energy conversion chain. These parameters, along with the most important energy measures in terms of yields and losses, are illustrated in Figure 6. These yields and losses are always normalised to installed solar PV power at standard test conditions in kilowatt-peak (kW_p) for ease of performance comparison.

All components and different aspects of technical data management and monitoring platforms are described in the following paragraphs. Reference should also be made 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.⁷

FIGURE 6 ENERGY FLOW IN A GRID-CONNECTED PHOTOVOLTAIC SYSTEM WITH PARAMETERS, YIELDS AND LOSSES⁸



⁷ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com

⁸ The figure is redesigned and based on a figure produced by 3E and published in (Woyte et al. 2014).

9.1. Data loggers

The main purposes of a datalogger are:

- Collecting data of relevant components (inverters, meteorological 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).
- Providing a temporary data backup (in case of missing internet connection).
- Supporting 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 one with preferential bandwidth.
- Solar Energy Trading Interface (control the active power by a third-party instance like energy trader).

As best practice, dataloggers should be selected following a list of criterion by the operating party as listed below. For example, an EPC service provider 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 country 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 cyber security measures (and those of the cloud server to which it is connected), 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.

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 [9.9. 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. This should be done remotely and from an independent server, delivering information on the data loggers' operating status at Operating System (OS) and hardware level. It should also provide alerts to the Operations 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 uninterruptable 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.

9.2. Data Quality & Curation

The main purpose of the monitoring system is to collect data from all the relevant components (energy meters, meteorological sensors, inverters, string combiner boxes, etc.) which are typically installed across the field and connected to the plant SCADA through the local network by using various technologies (serial links, cable, fiber, wireless, etc.).

9 Data and monitoring requirements / continued

Moreover, renewable plants, and solar plants, are often situated in remote environments, and sometimes in harsh places. As such, equipment and systems are subject to difficult conditions and are often subject to data quality issues.

The data quality issues that equipment may face may be categorised as follow:

- False negative values
- Outliers
- Spikes
- Data gaps
- Junk values

These data quality issues can provoke situations that vary extremely depending on the plant, type of measurement, or systems in place. As such, it is very difficult to implement an overall and systematic data quality strategy for renewable Asset Owners as each case is unique.

The data quality issues mentioned above are obvious and may impact many KPIs which are calculated on this basis. More challenging to identify, are slight and progressive data deviations overtime.

Biased KPIs lead to unnecessary operations costs (unrequired on-site intervention) and performances losses, as defects may remain undetected.

As a best practice, the monitoring solution and system should be capable of filtering these values in the most automated and personalised way to cater for each specific case.

Most effective techniques for data validation are based on the analysis of data over relatively long timespans (i.e., daily data validation), with a granularity between 1 and 15 minutes.

9.3. Monitoring (web) portal

The main purposes of the monitoring portal are:

- Reading any type of raw data coming from any type of data logger or other solar PV platforms with no preference on brands or models.
- Creating a long-term archive for all raw data provided by the asset.

- Modelling each solar 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.).
- Visualising aggregated data in the highest possible granularity (1 to 15 min is a best practice for most of the indicators).
- Visualising data in standard and specific diagrams.
- Computing and visualising dashboards and views of KPIs. For the list of indicators to be computed, see Chapter [10. Key Performance Indicators](#). Computational inputs might be selectable by the user.
- Validating data quality (e.g., through calculation of data availability).
- Detecting malfunctions as well as long term degradations with customisable alarms.
- Handling alerts from field devices like dataloggers or inverters.
- Calculating typical KPIs (such as PR and Availability) with the possibility to adapt parameters.
- Providing consistent and easy to use aggregated KPIs for customisable reports for single plants and 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 service provider, EPC service provider, 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, meteorological 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.⁹

9.4. Data format

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

9.5. 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, etc.) to better perform expected performances simulations and obtain consistent insight about a plant's actual status. If this has not been done during the plant's construction phase, it should be done at the commissioning phase or when a new O&M service provider takes over (recommissioning of the monitoring system).

During commissioning, each single piece equipment monitored should be checked to make sure it is properly labelled in the Monitoring System. This can be done by temporarily covering isolation sensors or switching off others such as string boxes or inverters.

It is best practice to have a Monitoring System capable of reading and recording all IDs from all sensors and equipment it monitors. This will reduce the possibility of mislabelling elements and improve the tracing of

equipment and sensor replacement during 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 automatically capturing device IDs and configuration information. This also allows for automatic detection of inverter or sensor replacement.

9.6. Interoperability

As a best practice, the system should ensure open data accessibility (both for sending and receiving data bilaterally) to enable easy transition and communication between monitoring platforms. Table 7 shows some examples of data integration options. Due to the lack of unifying standards, every Monitoring System provider has their own method of storing and retrieving data. The best systems can retrieve data by using open interfaces such as RESTful, providing interoperability between different systems.

Another important aspect of interoperability is the ability to aggregate data from different platforms that serve a range of areas in the solar PV business, such as administration, accountancy, planning & on-site intervention, and stock management applications. This way, information can be exploited by the central monitoring platform without affecting the external applications. For example, an O&M service provider works with several types of ticketing systems for different clients. The monitoring platform should be able to collect data from all of them. Likewise, information about tickets managed from the central monitoring system should be automatically transferable to the dedicated ticketing application.

9.7. Internet connection and Local Area Network

The O&M service provider should make sure to provide the best possible network connectivity. As a minimum requirement, the bandwidth needs to be adequate enough to transfer data in a regular way.

Whenever a fibre connection is available within the solar PV-site area, this should be used to connect to the internet, with industrial routers considered as standard. Where a fibre connection is unavailable, 4G

⁹ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

9 Data and monitoring requirements / continued

TABLE 7 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 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, how current it is, completeness – depending on the provider's terms conditions (Service-Level Agreement/SLAs) and technical abilities.

or Wi-Fi communication is preferred. Satellite connection is the least preferred communication type. An additional back-up system is best practice. Any subscription should allow for the data quantity required and should foresee the amount (e.g., Closed-Circuit Television (CCTV) or not) granularity of the data.

For solar PV power plants larger than 1MW it is advised to have a WAN connection and as an alternative to an industrial router, that allows for mobile or satellite communication back-up in case the WAN connection fails. A system with a reset capability in case of loss of internet connection is recommended. A direct connection to a monitoring server with an SLA guarantees continuous data access. If data passes via alternative monitoring servers without an SLA, (e.g.,

monitoring portal of the inverter manufacturer), the SLA can no longer be guaranteed. The automatic firmware updates of the data logger should be disabled. Firmware updates are subject to a 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, and communication cables should be shielded 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 8 on the following page.

TABLE 8 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 	
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 	
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 	
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 ▪ Insufficient for real time monitoring (in some cases) 	Not 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 proprietary communication protocols in some cases ▪ Limited bandwidth (in some cases) and insufficient for real time monitoring ▪ Limited bi-directional communication 	

9.8. 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 service provider and the Asset Manager need the data to perform their duties and should be granted access. In addition to this, auditors working in the due diligence phases of a project should also have access. It is important to have at least two access levels (read-only, full access).

The monitoring system hardware can be provided by the O&M service provider 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 service provider is the monitoring service provider, they have full responsibility for protecting and maintaining the data, and ensuring the proper functioning of the monitoring system
- Where there is a third-party monitoring service provider, responsibility for protecting and maintaining the data resides with them. The O&M service provider should endeavour to make sure performance monitoring is correct and takes the best practices mentioned in the previous

9 Data and monitoring requirements / continued

paragraphs into consideration. The O&M service provider's ability to properly maintain and use the monitoring system should be evaluated. If necessary, the O&M service provider should be appropriately trained to use the monitoring system. Data use by third-party monitoring providers should be extremely limited, i.e., for correcting bugs and developing additional functions to their systems.

9.9. Cybersecurity

As solar PV power plants have inverters and power plant controllers (and monitoring systems) that are connected to the internet to enable surveillance and remote instructions by operators, there are significant 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.¹⁰

Cybersecurity is a vast area and multiple measures are possible. 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 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 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 is preferred.

- Each solar PV power plant should have different passwords.
- Keep your documentation up to date to be sure that no device has been forgotten.
- 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 fixing 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, Keepass 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 limited if an individual employee is hacked.
 - Management of leaving and moving employees; change passwords of plants which are overseen by an employee who has 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

¹⁰ Definition: <https://www.itgovernance.co.uk/what-is-cybersecurity>.

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 will include the use of technical countermeasures such as firewalls, encrypted interfaces, authorisation and access controls, and audit/detection tools. 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 a minimum requirement, data loggers should not be accessible directly from the internet or should at least be protected via a firewall. Secure and restricted connection to data servers 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 the results of 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.

For further information, beyond the scope of this document, please look at the EU Cybersecurity Act (EC, 2019) and the European Parliament's study "Cyber Security Strategy for the Energy Sector" (EP, 2016).

9.10. Types of data collected through the monitoring system

9.10.1 Irradiance measurements

Irradiance Sensors

Solar irradiance in the plane of the solar PV array (POA) is measured on-site by at least one irradiance Class A quality measurement device and ISO 9060:2018 (ISO 9060 2018). 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 solar 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 PR and Expected Yield.

Class A Pyranometers are preferred over silicon reference cells because they allow a direct comparison between the measured performance of the solar PV power plant and 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 in the least shaded location. They must be mounted and wired in accordance with manufacturers' guidelines. Preventive 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 irradiance sensors, complementary irradiance data from a high-quality satellite-based data service can be acquired after a 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 in the data measured onsite by the Monitoring System and it can be considered as best practice. In particular, high-quality satellite-based data should be used for irradiation sensor data quality assessments. 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 decreases 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.

9.10.2. Module temperature measurements

Module temperature can be measured for performance analysis in KPIs such as the temperature-corrected PR (see [10.3.4. Temperature-corrected Performance Ratio](#)).

The accuracy of the temperature sensor, including signal conditioning and acquisition done by the monitoring system hardware, should be $< \pm 1^{\circ}\text{C}$.

9 Data and monitoring requirements / continued

The temperature sensor should be attached to the middle of the backside of the module in the middle of the array table, in the centre of a cell, away from the junction box with appropriate and stable thermally conductive glue (Woyte et al. 2013). The installation should be in accordance with manufacturer guidelines (e.g., respecting cabling instructions towards the data logger).

Varying solar PV module temperature in a plant is 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.

9.10.3. 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, such as a PT100. The shield protects the sensor from radiative heat transfer. Wind speed is measured with an anemometer, at 10m 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 those from the National Renewable Energy Laboratory in the USA). However, they are required when the solar PV power plant is modelled in operation or retrospectively.

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 MW_p, having automated collection of hourly meteorological data (ambient temperature, wind speed, snow coverage, rainfall) from independent sources is recommended. The reason for this is that on-site meteorological stations

are subject to local phenomena and installation-specific results. Data from an independent weather-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, automated, local meteorological data is recommended. However, for performance assessment the most important measurement remains the in-plane irradiation (see [10. 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) fee. 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, inadequate or dirty on-site pyranometer, and less susceptible to soiling or tampering.

9.10.4. String measurements

Individual string current measurements may be deployed when not supported by the inverters. String level monitoring allows for more precise troubleshooting procedures than at inverter level. Depending on the module technology used in a plant, strings can be combined (in harnesses) which can help reduce operation costs.

To detect problems quickly and to increase plant uptime, installing string monitoring equipment is recommended. This will constantly measure the current of every string and register those measurements in intervals of up to at 15 minutes. To reduce costs, the current sensor can be used to measure more than one string. However, no more than two strings should be measured in parallel.

9.10.5. Inverter measurements

Inverters have a large set of variables that are constantly measured by their hardware, and that can be registered and investigated from the monitoring system. The data sent from the inverter to the monitoring system should be in 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 data from all the 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 Preventive Maintenance actions.

In certain cases, grid connections have 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 so that the O&M service provider is notified when there is a parameter that has been changed wrongly and does not respect a given limit.

Best practice dictates that the sample size for the measurement of inverter-based variables is 15 minutes at one minute interval. For ad-hoc performance analysis purposes such as allowing the analysis of solar 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, and isolation level, etc. that could be useful for O&M services.

Inverters should be capable of detecting when their conversion components are overheating, 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.

9.10.6. 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. It is also much more accurate than using inverter data.

Using a high accuracy energy meter to measure energy produced and consumed by the plant is normally required by the Utility. When this is not the case it is a best practice to install a meter with a maximum uncertainty of $\pm 0.5\%$, especially for plants $> 100 \text{ kWp}$.

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.

For meters that can store historical data it is a best practice to have a Monitoring System capable of retrieving historical data to avoid any production data loss in case of Monitoring System outages.

9 Data and monitoring requirements / continued

9.10.7. Control settings

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

9.10.8. Alarms

As a minimum requirement, the Monitoring System shall be able to generate the following alarms and, at the user's discretion, send them 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 tracked by the O&M service provider. However, these alarms are sent by separate systems:

- 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.¹¹

9.10.9. AC circuit / Protection relay

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

9.11. 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.

solar PV modules are engineered to produce electricity for 25-30 years and nowadays are being deployed in ever more and ever larger solar PV power plants. Quality assurance is the cornerstone for long-term reliability and maximising financial and energy returns. This makes tracking down the source of failures once modules have been installed 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 to assess the quality and performance of solar PV modules on-site.

Field inspections like these can be part of contractual Preventive Maintenance tasks or could be offered as additional services, triggered by the O&M service provider in cases where, for example, plant underperformance is not clearly understood just by looking at monitoring data.

9.11.1. Infrared thermography (IR)

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

Depending on its temperature, every object (e.g., a solar 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 – 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 solar 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 solar PV module, abnormalities such as hotspots, inactive substrings or inactive modules can be identified.

¹¹ The best practice checklists of the Solar Best Practices Mark are available at: www.solarbestpractices.com.

For 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 640 × 512 pixels and a thermal sensitivity of at least 0.04 K. Measurements shall be taken at a distance which ensures that the resolution of the infrared image equals 5 × 5 pixels per solar PV cell. Further requirements are to be found in IEC TS 62446-3 Part 3: Photovoltaic modules and plants – outdoor infrared thermography.

IR thermographic data can be captured with specialised IR thermographic cameras mounted either on manual hand-held devices or on drones. There are significant advantages in time and cost savings, speed and accuracy of data analysis and reporting, and worker health and safety that come with drone-enabled IR thermography as opposed to traditional manual inspection methods. The larger-scale the solar PV asset, the greater the advantages become. For more information, please refer to Chapter 6.5.2. *Advanced aerial thermography*.

Besides solar PV modules, IR thermography can also be used to inspect other important electrical components of a solar PV power 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 solar PV Field applications.

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

9.11.2. 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 solar PV modules or strings. The shape of the curve provides valuable information for identifying failures and it also provides a quantitative calculation of power losses. A typical outdoors I-V curve measurement setup consists of a portable I-V curve tracer. In combination with an

irradiance sensor (a reference cell usually) and a thermometer this can be used to measure the solar PV modules electrical behaviour. As on-site ambient conditions differ greatly from those in a standardised lab, the measured results should be translated into STC.

9.11.3. Electroluminescence (EL) imaging on-site

EL images are typically taken of every module when leaving the factory production line and are a very useful baseline for the health of the module before leaving the factory. An EL image will show cell level imperfections and cracks which are invisible to the naked eye. EL imaging can be used on-site to better understand module quality post installation as well as further investigation following the identification of anomalies by thermography.

During the EL testing a material emits light in response to the passage of an electric current. This is applied in order to It is used to check integrity of solar PV modules. Here, a current flows through the solar PV-active material, and as a result, electrons and holes in the semiconductor recombine. In this process the 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 solar PV modules or strings with a DC current supplied by an external portable power source. The NIR emissions then are detected by a silicon charge-coupled device (CCD) camera.

EL is usually done in a dark environment because the amount of NIR emitted by the solar PV modules is low compared to the radiation emitted by the background light and from the sun. This requires that EL imaging conducted on-site has to be done during the night, while covering the solar PV modules with a tent, or in a purpose-built mobile test lab. 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 must 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.

9 Data and monitoring requirements / continued

High volume approaches to EL testing such as using drones are being offered by some niche service providers. See [Chapter 12](#) for further information.

9.11.4. Magnetic Field Imaging (MFI)

Magnetic field imaging (MFI) is a new and innovative method for quantitatively analysing flowing electric currents non-destructively, and without contact.

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

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. These changes can be detected by MFI and thus traced back to the defects.

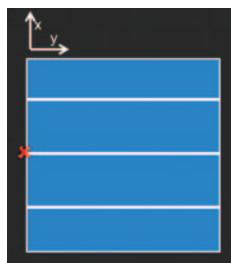
The fields of application are manifold. In solar PV, defects relevant for the operation of solar modules can be detected reliably (Lauch et al, 2018; Patzold et al, 2019). These are, for example, broken connectors or ribbons (see Figure 7), missing solder joints or defective bypass diodes in the junction 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 in the millimeter range to produce high quality imaging results. The measurement cannot resolve microscopic structures ($< 100 \mu\text{m}$), yet.

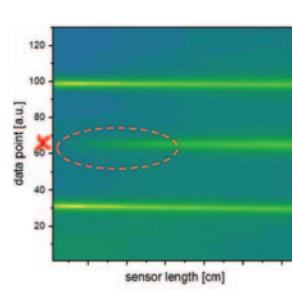
9.11.6. Soiling measurements

The operational efficiency of modules is affected by soiling accumulation. Soiling limits the effective irradiance and, therefore, the output of the solar PV module. Measuring soiling is recommended as it can help 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 using different principles to measure the effect of soiling. Digital solutions for soiling monitoring that are currently under development 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 analytical laboratory to determine its nature (diesel soot; pollen; organic soil; inorganic dust) and the appropriate cleaning solution.

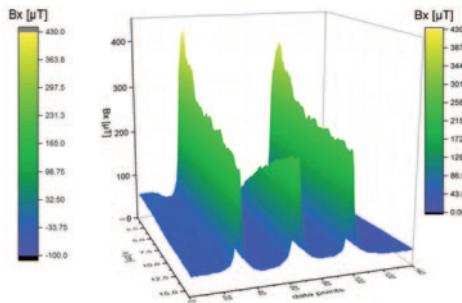
FIGURE 7 EXAMPLES OF MAGNETIC FIELD IMAGING (MFI)



Broken ribbon marked position



Magnetic field measurement



Magnetic field measurement (3D)

SOURCE: Lauch et al, 2018; Patzold et al, 2019.
NOTE: Left: Schematic of 3 BB solar cell, „x“ indicates the position of broken ribbon; centre: Bx magnetic field in 2D representation and more visual 3D on the right side.

10

Key Performance Indicators



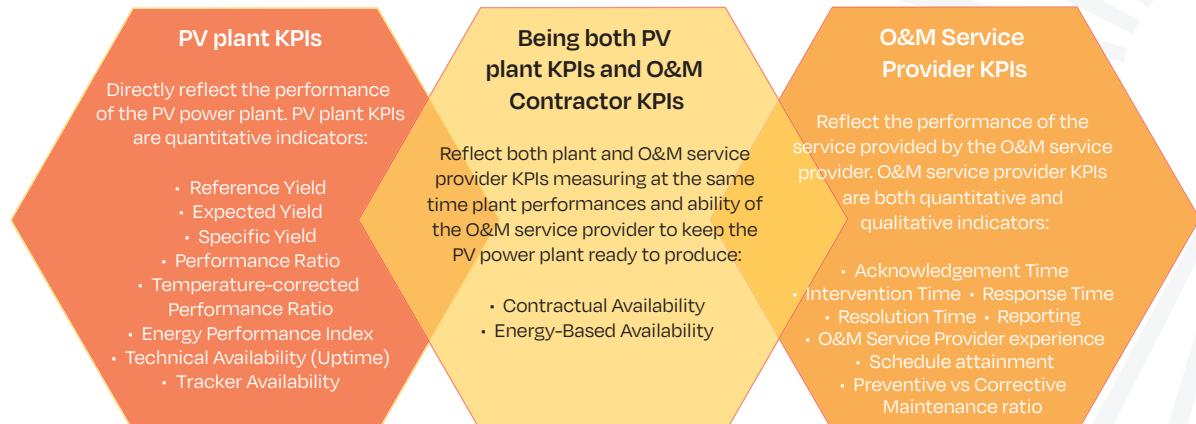
This section deals with Key Performance Indicators (KPIs), which provide the Asset Owner with a quick reference on the performance of the solar PV power plant. The KPIs in this chapter are divided into the following categories:

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

The O&M service provider (or the Technical Asset Manager) is generally responsible for the calculation of the KPIs and reporting to the Asset Owner, see section [4.1. Technical reporting](#).

It is important to underline that the O&M service provider is not responsible for providing contractual guarantees for all the KPIs listed in this chapter. For more information on suggested contractually guaranteed KPIs, see [10.4. O&M service providers KPIs](#) and price adjustments. When there are warranties in place it is strongly advised that the party liable for the warranties is not the only one calculating the KPIs.

FIGURE 8 OVERVIEW OF DIFFERENT TYPES OF KPIs



10 Key Performance Indicators / continued

10.1. PV power plant data

PV power plant data can be split into two groups:

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

10.2. 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)
- Irradiance¹² (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.

10.3. PV power plant KPIs

Calculated KPIs give a more balanced view of the operation of a solar PV power plant as they take into account the different operating conditions for each plant. Suggestions for calculated KPIs, along with relevant formulas, 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 solar PV power plants' KPIs, it is important to be consistent in the time period used in computation.

10.3.1. Reference yield

The Reference Yield Y_r represents the energy obtainable under standard conditions, with no losses, over a certain period i . It is useful to compare the Reference Yield with the final system yield (see section [10.3.3. Performance Ratio](#)).

The Reference Yield is defined as:

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

Where:

$Y_r(i)$ = Reference Yield for the period i expressed in peak sun hours (h) or (kWh/kW_p)

$H_{POA}(i)$ = Is the measured irradiation on plane of the PV array (POA) for the period i (kWh/m²)

G_{STC} = The reference irradiance at standard test conditions (STC) (1000 W/m²)

10.3.2. Specific yield

Specific Yield, also called final yield, Y_f is the measure of the total energy generated, normalised per kW_p installed, over a certain period i .

Specific Yield is calculated as follows:

$$Y_f(i) = \frac{E(i)}{P_o}$$

Where:

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

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

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

This measurement integrates plant output over a chosen time frame, and since it normalises to nominal power, comparison of the production of plants with different nominal power or even different technologies (e.g., solar PV, wind, biomass etc) is possible. For example, the Specific Yield of a solar PV power plant can be compared against the Specific Yield of a wind plant for the purposes of making an investment decision. Moreover, the Specific Yield of a 5 MW_p ground mounted solar PV power plant can be compared directly to that of a 1 MW_p double tracker power plant, for example.

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

¹² 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).

Specific Yield within a plant, it is possible to detect whether an inverter is performing worse than others.

10.3.3. Performance ratio

PR is a quality indicator of the solar PV power plant. As the ratio between the actual Specific Yield and the theoretically possible Reference Yield, PR captures the overall effect of solar PV system losses when converting from a 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 month or year. Based on PR, the O&M service provider 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 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 IEC 61724-1:2017 and are common practice.

PR is measured for available times (see section [10.5.1. 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's 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.

¹³ 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

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.

10.3.4. Temperature-corrected performance ratio

In some situations, such as a commissioning test or solar PV power plant handover from one O&M service provider to another, PR needs to be measured over a shorter period, such as two weeks or a month. In such situations, using a PR formula corrected with temperature factor is recommended. This can help 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 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.¹³

Temperature-corrected PR can be defined as follows:

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

Where:

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

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

$Y_r(i)$ = Reference Yield for the period i, expressed in (kWh/kW_p) or peak sun hours (h)

β = Temperature coefficient of the installed modules (%/°C)

P_0 = Plant Peak DC power (nominal power) (kW_p)

$T_{MOD(i)}$ = Average module temperature for the period i, weighted according to Specific Yield $Y_r(j)$ (°C) – see formula below.

$$T_{MOD(i)} = \frac{\sum_{j=1}^i Y_{r(j)} \times T_{MOD,MEAS(j)}}{\sum_{j=1}^i (Y_{r(j)})}$$

$T_{MOD(j)}$ = See above

$Y_{r(j)}$ = Plant Specific Yield for the period j, expressed in (kWh/kW_p) or peak sun hours (h)

$T_{MOD(j)}$ = Module temperature for the period j (°C)

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 solar PV power 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 solar PV module temperature on its power. Therefore, the performance ratio usually decreases with increasing irradiation during a reporting period, even though energy production increases. This is due to an increasing solar 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 solar 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. In these plants installed DC power is

higher than inverter AC power (DC/AC ratio higher than 1), as a consequence, during sunny periods the output of the plant may be limited by inverter maximum AC output. In such situations, when derating takes place, PR will be lower than normal although there is no technical problem with the plant – lower PR in high-production periods is in fact the consequence of a design decision. 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 only GHI measurements are available. 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 the 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 solar PV power plant is performing better than expected and even some underperformance issues could remain hidden.

10.3.5. Expected yield

Expected Yield $Y_{exp(i)}$ is the Reference Yield $Y_r(i)$ multiplied by the expected PR and thus expresses the Specific Yield that has been expected for a certain period 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.

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 is more than one established model for calculating the Expected Yield of solar PV systems in operation and not all of them are transparent. Therefore, the use of EPI is recommended mainly for the identification of performance flaws and comparison of plants.

Expected Yield can be defined as:

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

Where:

$Y_{exp(i)}$ = Expected (Specific) Yield for the period i , expressed in (kWh/kWp) 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), Pvyst (2017) and SANDIA (2017).)

$Y_r(i)$ = Reference Yield for the period i (based on past irradiation data) expressed in (kWh/kWp) or peak sun hours (h)

10.3.6. Energy Performance Index

The Energy Performance Index (EPI) is defined as the ratio between the observed Specific Yield $Y_f(i)$ and the Expected Yield $Y_{exp(i)}$ as determined by a solar 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 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 period i (%)

$Y_i(i)$ = Specific Yield for the period i (kWh/kWp) or (h)

$Y_{exp(i)}$ = Expected Yield for the period i (kWh/kWp) or (h)

10.3.7. Technical availability or uptime

Technical Availability (or Uptime), Contractual Availability and Energy-based Availability are three closely related indicators to measure whether the solar PV power plant is generating electricity. The latter two KPIs are explained in section [10.5. Solar PV power plant/O&M service provider KPIs](#).

Technical Availability is the parameter that represents the time during which the plant is operating over the total possible time it can operate, without taking any exclusion factors into account. The total possible time is considered as the period 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 irradiation above MIT (h)

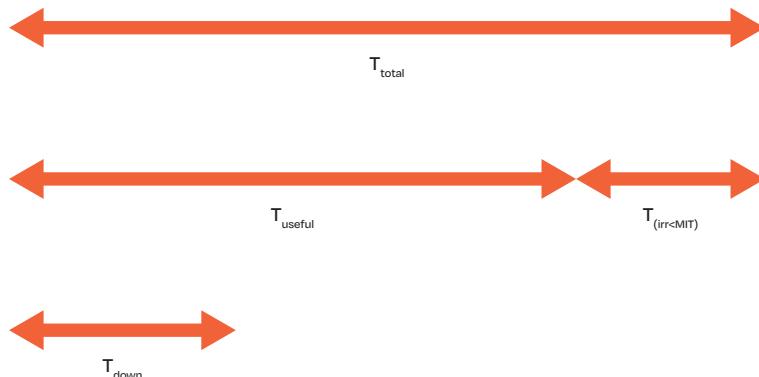
T_{down} = Period of T_{useful} when the system is down (no production) (h)

Figure 9 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).

10 Key Performance Indicators / continued

FIGURE 9 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 solar PV power plant $A_{t,total}$ with a total installed DC power of P_0 can be defined as follows:

Technical Availability weighted by individual inverters' installed DC power:

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

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)

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 when the tracker is down (h)

$T_{t,useful}$ = Period when the tracker is functional (h)

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

10.3.8. 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 purely technical parameter and

10.3.9. Tracking performance availability

Functional failure of a tracker can count as inaccurate, 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 tracker's performance availability is like the technical availability. $T_{t,down}$ is defined as the period during which deviation of the tracker's tilt is higher than the accepted deviation angle. This metric can help to improve single-or dual-axis tracking performance.

10.4. O&M service provider KPIs

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

The following time KPIs are illustrated in Figure 10.

10.4.1. 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 O&M service provider by dispatching a technician. The Acknowledgement Time reflects the O&M service provider's operational ability.

10.4.2. Intervention time

The Intervention Time is the time between the acknowledgment of a fault and the arrival of a service technician or a subcontractor at the plant. Intervention Time assesses the capacity of the O&M service provider, and how fast they can mobilise and be on site. It is worth noting that, in certain cases remote repair is possible, or the O&M service provider is not able to repair the fault and third-party involvement is necessary.

10.4.3. Response time

The Response Time is the Acknowledgement Time plus the Intervention time. Used for contractual purposes, minimum Response Times are guaranteed based on fault classes, classified on the basis of the unavailable power, 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 section [11.6. Response Time price adjustment](#).

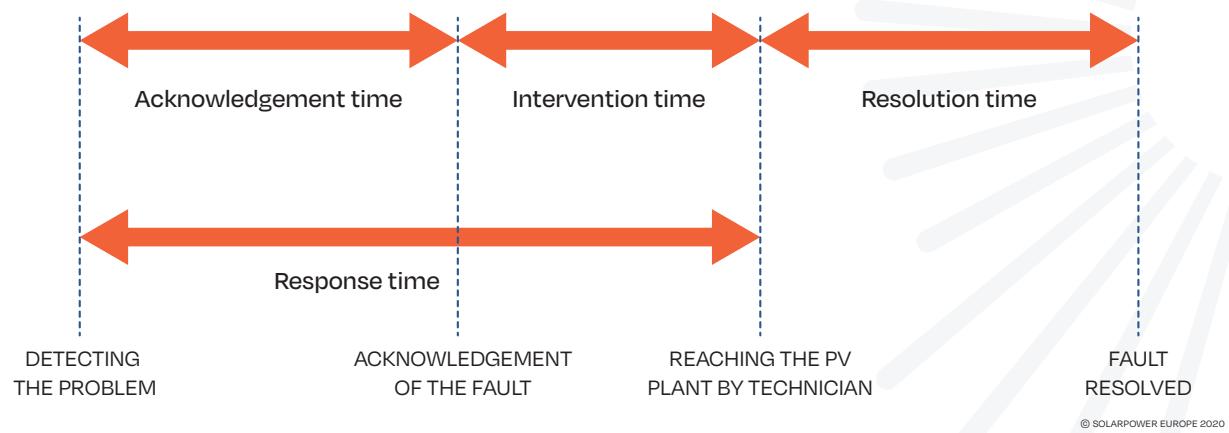
10.4.4. Resolution time

Resolution Time (or Repair Time) is the time taken to resolve a fault, starting from arrival at the solar PV power plant. Resolution Time is generally not guaranteed as resolution often does not fully controlled by the O&M service provider.

10.4.5. Reporting

It is very important for the O&M service provider to comply with reporting requirements and reporting timelines. Content and timing of the reporting is generally agreed by the parties in the Contract agreement. Content of the reporting is expected to be consistent and any change in content or format needs to be explained by the O&M service provider. Delivery of reports per the agreed upon timeline is an important indicator for reliability and process adherence within the O&M service provider's organisation. See also section [4.1. Technical reporting](#).

FIGURE 10 ACKNOWLEDGEMENT TIME, INTERVENTION TIME, RESPONSE TIME, RESOLUTION TIME



10 Key Performance Indicators / continued

10.4.6. O&M service provider experience

Experience of the O&M service provider with solar PV power plants in a particular country, region, grid environment and/or with solar PV power plants equipped with certain technology or size can play an important role. This is relevant for the selection of the O&M service provider and can be tracked by the Owner over time (track record).

10.4.7. Schedule attainment

Schedule Attainment (or Schedule Compliance) is the ability of the O&M service provider to execute the Preventive Maintenance schedule within the required timeframes (typically across a period of a week or month).

O&M service providers who adhere to the schedule ensure accomplishing as much preventive maintenance and other timely corrective work as possible. Schedule Attainment provides a measure of accountability.

Low Schedule Attainment can provide key warning signs to the Asset Owner regarding the O&M service provider:

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

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

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

10.4.8. Preventive vs corrective maintenance ratio

This metric measures the reactive nature of the plant maintenance work. Asset Owners and AMs prefer a higher proportion of Preventive maintenance than Corrective Maintenance. 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 O&M service provider has control over the equipment, the O&M service provider decides when to take certain actions to preserve equipment. When the equipment has control over the O&M service provider, 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 service provider to break the weekly schedule. A more proactive one experiences few circumstances of sudden equipment problems interrupting scheduled work.

Best practice requires that the ratio of Preventive vs Corrective Maintenance is 80/20.

10.5. Solar PV power plant/O&M service provider KPIs

10.5.1. Contractual availability

Contractual Availability is Technical Availability with certain contractually agreed exclusion factors (see below) applied in the calculation; It is used as a basis for evaluating the general Contractual Availability guarantees provided by the O&M service provider 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 service provider, see section [11.5. Availability guarantee](#)).

Contractual Availability is 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 service provider (listed below in the same section).

Contractual Availability is therefore defined and calculated as:

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

Where:

A_c = Contractual Availability (%)

T_{useful} = Period of time with in-plane irradiation 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:

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

Where:

$A_{c\ total}$ = Contractual Availability of the plant (%)

$A_{c\ k}$ = Contractual Availability of the inverter k

P_k = Installed DC power of the inverter k

P_0 = Plant Peak DC power (nominal power) (kW_p)

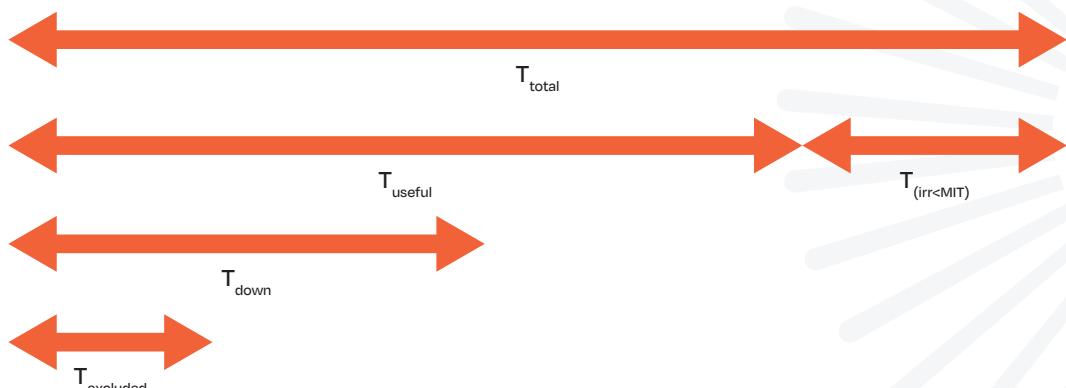
Figure 11 below illustrates the various periods in time mentioned above.

Like Technical Availability, 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 solar PV power plant $A_{c\ total}$ with an installed total DC power of P_0 can be defined as follows:

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

As Contractual Availability is used for contractual purposes, any failure time should only begin to run when the O&M service provider 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 service provider'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 service provider should immediately look at the root cause of the communication loss and resolve it.

FIGURE 11 VARIOUS PERIODS OF TIME FOR THE CALCULATION OF CONTRACTUAL AVAILABILITY¹⁴



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¹⁴ 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.

10 Key Performance Indicators / continued

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

- Force majeure.
- Snow and ice on the solar PV modules.
- Damage to the solar PV power plant (including the cables up to the feed-in point) by the customer or third parties who are not sub-contractors of O&M service provider, 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 caused by the grid operator.
- Disconnections or power regulation by the grid operator or their 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 service provider's responsibility. Any failure time only begins to run when the O&M service provider 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 solar PV power 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 solar PV power 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 excluded from the calculation of Contractual Availability. However, this is not considered a best practice.

10.5.2. Contractual tracker availability

Like Contractual Availability, 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:

$$A_{c\text{ tracker}} = \frac{T_{t\text{ useful}} - T_{t\text{ down}} + T_{t\text{ excluded}}}{T_{t\text{ useful}}} \times 100$$

Where:

$A_{c\text{ tracker}}$ = Technical Tracker Availability (%)

$T_{t\text{ down}}$ = Period when the tracker is down (h)

$T_{t\text{ useful}}$ = Period when the tracker is functional (h)

$T_{t\text{ excluded}}$ = Part of $T_{t\text{ down}}$ to be excluded because of presence of an exclusion factor (see above) (h)

10.5.3. Energy-based availability

Energy-based Availability takes into consideration that an hour in a period of high irradiance is more valuable than in a period of low irradiance. Therefore, its calculation uses energy (and lost energy), instead of time, 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 period i (%)

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

$E(i)$ = Plant energy production or Plant energy metered in the period i (kWh)

Generally, the Energy Based Availability is used within the O&M Contract in the Availability guarantee chapter and the exclusion factors defined for Contractual Availability tend to apply for Energy-based Availability too.

The following table provides an overview of different types of KPIs and their main purposes.

TABLE 9 OVERVIEW OF DIFFERENT TYPES OF KEY PERFORMANCE INDICATORS AND THEIR PURPOSES

	SOLAR PV POWER PLANT KPI	O&M SERVICE PROVIDER KPI	QUANTITATIVE	QUALITATIVE ¹⁵	TO BE MONITORED WITHIN THE O&M CONTRACT	GUARANTEED IN THE O&M CONTRACT	USAGE MAIN PURPOSE
Reference Yield	✓	✗	✓	✗	✓	✗	Useful during plant designing and economic valuation
Expected Yield	✓	✗	✓	✗	✓	✗	Useful during plant designing and economic valuation
Specific Yield	✓	✗	✓	✗	✓	✗	Useful during plant designing and economic valuation
Performance Ratio	✓	✗	✓	✗	✓	✗	Useful during plant life for assessing plant performance over time
Temperature-corrected Performance	✓	✗	✓	✗	✓	✗	Useful FAC and PAC or in other specific moment in plant life to assess plant PR starting point
Energy Performance Index	✓	✗	✓	✗	✓	✗	Useful during plant life for assessing plant performance over time, against plant expected performance at plant designing
Technical Availability (Uptime)	✓	✗	✓	✗	✓	✗	Useful during plant life for assessing how much time, during the time frame under analysis, the plant is ready to produce power
Technical Tracker Availability (Tracker Uptime)	✓	✗	✓	✗	✓	✗	Useful during plant life for assessing how much time, during the time frame under analysis, the trackers are functioning properly
Acknowledgement Time	✗	✓	✓	✗	✓	✓	Useful during plant operation for assessing readiness of the O&M service provider to "realise" (detected by the monitoring system and acknowledge by the O&M service provider) plant failures
Intervention Time	✗	✓	✓	✗	✓	✓	Useful during plant operation for assessing readiness of the O&M service provider to reach the plant once a failure is "realised"

¹⁵ 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).

10 Key Performance Indicators / continued

TABLE 9 OVERVIEW OF DIFFERENT TYPES OF KEY PERFORMANCE INDICATORS AND THEIR PURPOSES - *continued*

	SOLAR PV POWER PLANT KPI	O&M SERVICE PROVIDER 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 for assessing readiness of the O&M service provider from acknowledging a failure and subsequently reaching the site
Resolution Time	X	✓	✓	X	X	✓	Useful during plant operation for assessing the time used to solve a fault from when the plant is reached
Contractual Availability	✓	✓	✓	X	✓	✓	Useful during plant life for assessing how much time during the time frame under analysis, the O&M service provider keeps the plant ready to produce power
Contractual Tracker Availability	✓	✓	✓	X	✓	✓	Useful during plant life for assessing how much time, during the time frame under analysis, the O&M service provider keeps the trackers functioning properly
Energy Based Availability	✓	✓	✓	X	✓	✓	Useful during plant life for assessing how much energy has been lost due to causes attributable to the O&M service provider, during the time frame under analysis
Reporting	X	✓	✓	✓	✓	✓	Useful during plant operation for assessing reliability of reporting services
O&M service provider experience	X	✓	X	✓	✓	X	Useful during O&M Contract awarding/tendering for assessing O&M service provider reliability from a purely document-based analysis
Schedule Attainment	X	✓	✓	X	✓	X	Useful during O&M Contract awarding/tendering for assessing O&M service provider reliability
Preventive vs Corrective Maintenance ratio	X	✓	✓	X	✓	X	Useful during O&M Contract awarding/tendering to assess O&M service provider reliability and effectiveness

11

Contractual framework

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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 MW_p. A complement to the technical specifications detailed in the previous chapters, the contractual framework described in this chapter is considered best practice.

We recommend using the O&M template contract developed as part of the Open Solar Contracts suite of template contracts. Formerly known as the Global Solar Energy Standardisation Initiative (SESI) this is a joint effort of the Terrawatt Initiative and the International Renewable Energy Agency (IRENA). SolarPower Europe contributed to the drafting of the template O&M contract. There are a total 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

Copies of each contract and explanatory guidance can be found at the Open Solar Contracts website: www.opensolarcontracts.org.

A common contractual framework for solar PV O&M is the "fixed price" model for a specified scope of work that

can include administrative, operational, and Preventive Maintenance tasks. A "cost plus" element can then be added for Corrective Maintenance or additional services. The "cost plus" element requires, labour rates, equipment markup, overheads and profits to be negotiated in the contract and added to the actual equipment costs incurred in correcting unexpected problems.

11.1 Contractual Risk Allocation

The O&M contract is a project agreement between the Asset Owner and the O&M service provider for the purpose of managing, operating, and maintaining the solar PV power plant. The O&M contract, together with the EPC contract, is a key document in any project finance transaction. Its provisions should stem financial risks associated with the failure of the O&M service provider to keep the solar PV power plant operating properly. In general, an O&M contract should minimise financial risks through appropriate operational risk allocation. Financial risks posed to the Asset Owner from operational failures include (i) shortage of actual revenues in comparison with expected ones - displayed in the base case, (ii) inability of the Asset Owner to meet their debt service obligations to the lenders, (iii) Asset Owner's liabilities under other agreements with third-parties, including any PPA; and ultimately, (iv) the risk of depreciation of the project assets.

As for the EPC contracts, the Asset Owner may choose between entering into a fully wrapped O&M agreement, which provides the lenders with a single recourse party for fulfilment of all obligations and responsibilities in relation to the O&M of the Plant. Another option is to have several agreements that,

together, cover the O&M of the plant. If some of the O&M services are allocated to third-parties under different agreements, the Asset Owner should clearly define the obligations and responsibilities of each contractual party to ensure the absence of risk allocation "gaps".

A balance between the lenders' demands and the Asset Owner's interests can be struck by aligning key clauses in the contract regarding timing, cost and quality of the works, and market standards. In this regard, the main drivers are:

- A detailed list of Ordinary and Extraordinary services to be performed by the O&M service provider, both before and after commercial operation of the project. To prevent confusion over risk allocation the operator's obligations may be defined as general performance requirements and closely linked to performance results.
- Availability or Performance Guarantees: in a power project, performance requirements typically include availability, output, outages, emissions, and other performance-related standards. Penalties for non-fulfilment of the performance obligations should also be included. At their most severe, this can mean termination of the O&M contract. These performance guarantees are usually supported by Bonus Schemes and backed-up by Liquidated Damages (LDs).
- Spare Parts warranties: management and availability of spare parts is a key aspect of minimising the impact of both scheduled and unscheduled outages on the project's revenue stream.
- O&M service provider's limited liability in respect of consequential loss, loss of revenue, loss of profit and other financial losses.

11.2. Scope of the O&M contract

Services to be provided by the O&M service provider include:

TAM (either O&M service provider or AM)

- Reporting to Asset Owner (referred to in the Open Solar Contracts templates as "Monitoring Services", although the detail is to be determined by the parties)
 - Reporting on solar PV power plant performance
 - Reporting on O&M performance

- Reporting on incidents
- Ensuring regulatory compliance
 - Legal requirements for solar PV power plant operation
 - PPAs and Interconnection Agreements
 - Power generation licence agreements
 - Building permits and environmental permits
- Warranty management
- Insurance claims
- Contract management

Power Plant Operations

- 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
 - Power Generation Forecasting (*optional*)
 - Grid operator interface, grid code compliance
 - Maintenance scheduling
- Management of change (*optional*)
- Reporting to Technical Asset Manager (in case O&M service provider is not the Technical Asset Manager)

Power plant Maintenance

- Solar PV power plant Maintenance
 - Preventive Maintenance (which is referred to in the Open Solar Contracts as "Scheduled Maintenance")
 - 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 section [6.2. 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 section [6.4. Extraordinary maintenance](#)). In the Open Solar Contracts O&M template, this would fall within "Additional Services".

Additional maintenance services (optional, see section [6.5. Additional services](#)). In the Open Solar Contracts O&M template, this would fall within "Additional Services".

In the table 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 Extraordinary Maintenance (see [6.4. Extraordinary Maintenance](#)) and Additional services (see [6.5. Additional services](#)) should be regulated within the contract. A dedicated clause should indicate the procedure and should include: (i) a proposal by the O&M service provider within a fixed time frame, (ii) a fixed period for the Asset Owner to

TABLE 10 EXAMPLES FOR ADDITIONAL MAINTENANCE SERVICES AND GENERAL MARKET TRENDS

	ADDITIONAL SERVICES	GENERAL BEHAVIOUR
Solar PV site maintenance	Module cleaning	Generally included, or as a priced option
	Vegetation management	Generally included, but need to specify perimetral vegetation management and management of possible environmental compensation measures
	Sand and dust removal	Generally, not included and also generally not easy to provide
General site maintenance	Pest control	Generally 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 section 5.8. Power plant security)
On-site measurement	Meter weekly/monthly readings	Generally included since it feeds the periodic performance reporting to the Asset Owner. However, these readings are now generally automated from the site SCADA system
	Data entry on fiscal registers or in authority web portals for FIT tariff assessment (where applicable)	Generally this activity is the responsibility of the AM. However, it can be included in O&M scope of work
	String measurements – to the extent exceeding the agreed level of Preventive 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 Preventive Maintenance	Generally not included but a price could be agreed in advance in the O&M contract

accept it or request modification, (iii) a final approval. Pre-agreed tariffs for personnel, machinery renting etc. could be agreed and a specific table could be attached as Contract Annex. This is provided for in the Open Solar Contract O&M template, with reference to "Standard Rates", which can be pre-agreed for Additional services.

Spare Parts Management

(See also Chapter [8. 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.

11.3. O&M contract fee

As a best practice, O&M services should be provided on a fixed fee plus escalation basis. See section [11.11](#) in this Chapter which discusses how spare parts management may impact on the contract fee.

11.4. Contractual guarantees and price adjustments

Although some O&M service providers still provide PR guarantees, recent developments, including the recommendations of the Open Solar Contracts initiative, show that eliminating PR guarantees and only using Availability guarantees and Response Time price adjustments has several advantages.

PR is to a large extent a result of equipment choice, design and construction, over which a (third-party) O&M service provider has little influence, beyond vegetation control and module cleaning. Moreover, removing PR as an O&M service provider KPI makes power plant handover between EPC and O&M service providers or between O&M service providers simpler. Generally, the PR warranties are applied on projects where the O&M and EPC service providers are the same company (or an affiliate). Here the O&M service provider carries forward the risk of the technology made by its sister company.

Availability guarantees and Response Time price adjustments protects Asset Owners from poor performance on the part of O&M service providers. Availability is the KPI that best reflects an O&M service provider's service. Thanks to the Response Time price adjustment, the O&M service provider has to intervene within a pre-agreed timeframe (dependant on the fault) when events that effect plant performance are not covered by the Availability guarantee. Moreover, the O&M service provider is obliged to intervene during incidents that do not effect performance, referring to good industry practices in general. A further upside is that it makes the transition to a new O&M service provider much smoother and allows Lenders and Owners to pick a service provider based solely on quality of services. Availability guarantees and Response Time price adjustments avoid burdensome change management processes resulting from the need to recalculate the guaranteed PR on the event of a plant handover.

PR warranties are no longer standard in the independent/third-party O&M market. However, it is possible to set a PR target that, if not fulfilled, can trigger a joint analysis between the Asset Owner and the O&M service provider, to identify causes and agree on possible corrective actions, including revamping projects.

11.5. 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 Mexico, where labour legislation and the requirements of the network operator stipulate the presence of full-time technical staff on-site, a Minimum Guaranteed Availability of 99% can be provided. This should be 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 section [10.5.1. Contractual availability](#).

The Availability achieved by the O&M service provider is translated into Bonus Schemes and LDs. For more information on this, see section [11.7. Bonus schemes and liquidated damages](#).

11.6. Response time price adjustment

The O&M service provider should be obliged to react to alarms received from the plant within a certain period, 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 service provider in the event of failure to meet the Response Times. For a definition of Response Time, see section [10.4.3. Response Time](#).

When setting a Response Time price adjustment, periods with high and low irradiance levels, and fault classes should be differentiated. This accounts for 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 11.

In case an equipment replacement is needed, the O&M service provider should commit to doing this 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 service provider should commit to ordering the spare part within 8 business hours from the end of the Response Time and to carrying out the replacement as soon as possible.

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

- If the intervention requires spare parts beneath the O&M cost responsibility (see section [11.11 Spare](#)

Parts Management), the O&M service provider may proceed without separate approval (insurance aspects to be considered).

- If the costs exceed the budget limit mentioned above, the O&M service provider 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, failure to comply with a Response Time guarantee by more than five business days entitles an Asset Owner to terminate the O&M contract.

11.7. Bonus schemes and liquidated damages

The Availability guarantees provided by the O&M service provider can be translated into Bonus Schemes and LDs. The Bonus Scheme concept is referred to in the Open Solar Contract O&M template as the "Availability Bonus". These ensure that the Asset Owner is compensated for losses due to lower-than-guaranteed Availability and that the O&M service provider is motivated to improve their service to achieve higher Availability. Higher Availability usually leads to higher power generation and an increase of revenues for the Owner. Hence, the Bonus Scheme agreements lead to a win-win situation for both parties and ensures that the O&M service provider is highly motivated. The Open Solar Contracts O&M template provides for a list of "Excusable Events".

TABLE 11 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 300 kW _p 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.

Since the O&M service provider's responsibility are the O&M works for the solar PV asset, they should be exempted from other influencing factors like force majeure events, grid operator activities to reduce the plant output, grid instability, or offline periods, and any related LDs. (See exclusion factors in section [10.5.1. Contractual availability](#).)

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

- **Bonus Schemes:** if the measured availability exceeds the Minimum Guaranteed Availability, the additional revenue will be divided between the Asset Owner and the O&M service provider per previously agreed shares. In this case additional revenue should be calculated against the expected annual revenue in the base case scenario. Targets for overall plant production constitute minimum thresholds for bonuses.
- **Liquidated Damages:** if the Minimum Guaranteed Availability is less than the measured availability, all the revenue lost due to the availability shortfall should be reimbursed to the Asset Owner by the O&M service provider. In this case revenue lost should be calculated against the expected annual revenue in the base case scenario. This is usually invoiced by the Asset Owner to the O&M service provider.
- Bonuses can be offset against LDs and vice versa.
- The amount of yearly LDs should be capped at 100% of the O&M annual fee. Reaching this cap usually results in termination rights for the Asset Owner and the O&M service provider. In the Open Solar Contracts O&M template, the right is only given to the Asset Owner.

11.8. Service standards

The O&M service provider must act 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. Compliance with adequate H&S standards, is also a critical requirement and expectation within the standard of the services.

The Asset Owner should be entitled to instruct a third-party to provide any services that the O&M service provider cannot at the O&M service provider's cost. This entitlement should only be triggered if the O&M service provider fails to follow a corrective maintenance programme.

11.9. O&M service providers' qualification

The O&M service provider must have the means, skills and capabilities to operate and maintain the plant in accordance with the contractual obligations. Experience and professionalism, H&S capabilities, skilled teams, and access to spare parts are criteria for the selection of the O&M service provider. 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 the two are well defined. This is especially important should the O&M service provider subcontract any aspect of the work, as each entity will need to be held accountable for the overall O&M performance.

11.10. Responsibility and accountability

The responsibility of the O&M service provider is usually defined in the Scope of work, 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 on what the O&M service provider will do during the term of the contract. In addition to the Scope of work, the Annual Maintenance Plan (AMP) and Annual Maintenance Schedule (AMS) (please refer to attachment "Annual Maintenance Plan") outline the granularity and frequency of (predominantly) Preventive Maintenance works. The execution of the activities should be regularly reported to the Asset Owner- this forms the minimum requirements. Best practice in reporting is to compare the executed activities with the AMP and AMS, and outlines deviations and reasoning.

Corrective Maintenance activities performed in cases of component failure or energy generation shortfall, are controlled by performance commitments signed by the O&M service provider. 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 section [11.4. Contractual Guarantees and price adjustments](#) of the present chapter also represent a level of accountability for the O&M service provider.

In most countries there are strict legal requirements for security service providers. Therefore, solar 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 service provider. The security service provider should also assume liability for the services provided. For more information on this, see section [5.8. Power plant security](#).

11.11. Spare parts management

The Open Solar Contracts O&M template takes two approaches to Spare Parts management. Either the O&M service provider takes full responsibility for Spare Parts or there is a distinction between "Included Spare Parts" (included in the O&M service provider's fee), and "Excluded Spare Parts" (payable in addition to the O&M service provider's fee within a pre-agreed margin). In either case, replenishing Spare Parts stock will be the O&M service provider'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.

There should be a component, 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 [8. Spare Parts Management](#).

11.12. Power plant monitoring

The O&M service provider should operate and maintain the metering system according to local regulations and 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 and operated by the O&M service provider.

The O&M service provider will also make sure that performance monitoring and reporting is operated and maintained according to the monitoring specifications and best practices (see [9. Data and monitoring requirements](#)).

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

11.13. Reporting

Reporting should be done periodically, as contractually agreed between the O&M service provider (the Technical Asset Manager) and the Asset Owner. The Asset Owner should have the right to contest the report within a certain timeframe.

For more information on industry best practices regarding reporting, see section [4.1. Technical reporting](#).

12

Innovations and trends



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O&M service providers are under increasing pressure to do more with less. Increasing human resource efficiency through the use of data-driven and Industry 4.0 techniques are key themes for O&M as the industry works to reduce the number of human interventions and embraces digitisation.

The following chapter lists important technology areas being developed by several innovative industry service providers. Many of these new technologies are becoming close to mainstream adoption, others are in early-stage development.

12.1. Aerial Electroluminescence

Purpose and description

To gain a deeper understanding of the nature and root cause of defects identified through thermography, or to understand the overall health of a large number of modules on a solar plant, EL imaging is often used (see [Chapter 9.11.3.](#)). Typically limited by logistical complexity and cost, the ability to deliver EL imaging at volume and economically is often a barrier to the wider adoption of this type of test. However, in recent years, advances in the technology used to control the required current applied to the module (often referred to as 'back powering'), aerial camera technology and AI for image processing are resulting in early-stage commercialisation of high volume EL testing using drones.

State of play

Aerial EL needs to be conducted at night. Modules must also be back powered to allow them to emit the light required for EL image capture. Key to benefiting from the drone-based approach is being able to back power enough modules at a given time to enable the drone to collect images quickly and at high volume. Back powering is typically provided by the use of generators meaning there will be limitations on the number of modules that can be back powered at the same time. Advances in switching consoles to control the back powering as the drone passes over a given area, and the development of inverters capable of switching to back power mode, are helping address this particular challenge.

The main difficulty with aerial EL image collection is obtaining adequate image quality to enable the useful analysis and identification of subtle defects and cracks. Also, depending on the onward use of the images, if you were to pursue a manufacturer warranty claim, poor quality images would be rejected by the manufacturer. There are several parameters that are key to producing a quality image: a consistent and low flight path over the module table for the drone; camera stability; and consistent back powering levels. Currently, these factors are difficult to fully control with the existing technology. Advanced drone sensors are being developed which will help maintain a safe and consistent low height above a target surface. This technology, when mature, could be used to control a low flight path over a module table, irrespective of the solar plant topographical profile.

Once good images have been collected, the next challenge is processing at high volume. This requires accurate segmentation, localisation, and identification of defects within the module and their consistent classification. Computer vision and AI have been successfully used to process IR images, but there are significant challenges with applying similar techniques to EL images. The defects that need to be identified in EL images are much more subtle and varied in nature. Training a neural network to reliably and accurately process these images requires a significant volume of training data, covering the many permutations of module types.

It is expected that many of the challenges outlined above will be overcome within the next 5 years and that aerial EL will become more common place and cost competitive in the industry. However, at present this technique remains more expensive than aerial thermography, meaning it is used predominantly as a secondary inspection technique for inaccessible roof arrays and targeted follow up testing ahead of a warranty claim.

12.2. UV Fluorescence imaging

Purpose and description

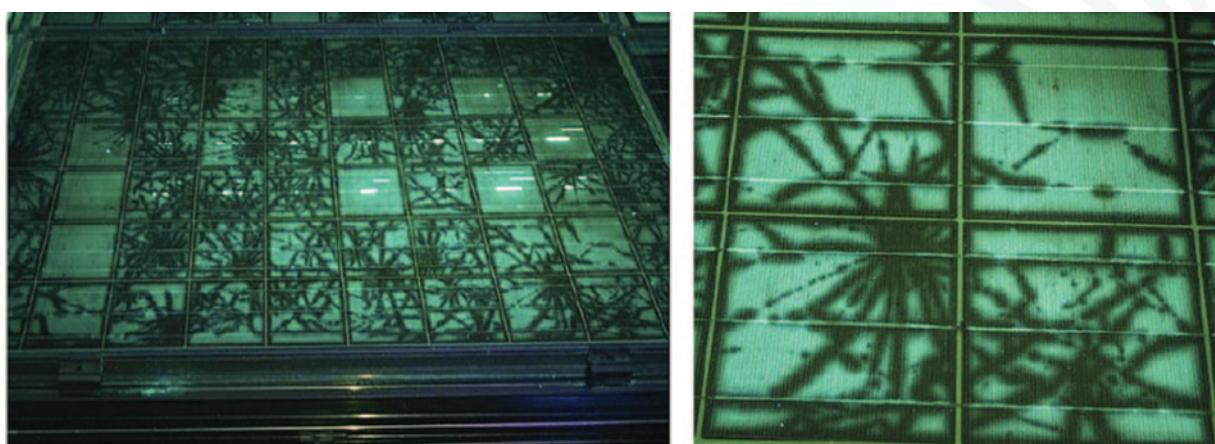
UV-Fluorescence imaging is a non-destructive imaging technique for failure analysis of solar PV-

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 must be performed in a dark environment (typically at night) by illuminating the solar 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. Modules do not need to be disconnected or powered during this procedure.

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, and the type of encapsulant and backsheet used. Furthermore, the fluorescence signal depends on the type of defect (micro cracks in c-Si cells, hotspots, or glass breakage).

Imaging of solar PV modules typically takes less than 60 seconds. An example of UV-fluorescence is given in Figure 12. The advantages of the technique are that no modifications are necessary to the solar PV systems and, when used in combination with EL, an evaluation of timelines for various instances of damage becomes 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.

FIGURE 12 EXAMPLE UV-FLUORESCENCE IMAGES AFTER A SEVERE HAILSTORM



SOURCE: Taken from W. Muehleisen (2018).

State of Play

There are several things to consider when performing drone-based UV Fluorescence (UVF) Imaging inspections. The cost of drones and trained pilots can be a prohibitive factor in using UVF technology. Similarly, conditions must be stable enough to take images in the dark with a 0.1 second exposure time and the drone needs to be powerful enough to support the extra weight of a camera and a UV lamp.

A minimum of two trained people are required for a UVF inspection, one being the pilot and the other being the photographer. The extra weight of the camera and the UV lamp on the drone means that batteries drain quicker and poses limits on inspections. These constraints are increased further by the UV lamp drawing power from the battery as well. This means that a 4.5 Ah battery can provide a flight time of 8-10 minutes. Moreover, the drone's flight path must be relatively low to be able to capture quality images.

Estimates predict that it is possible to inspect 720 modules per hour (including time for six battery changes) if conditions are perfect. However, there are several other factors that can affect inspection time, such as project design and weather conditions. To be most effective UVF inspections must be done in the dark and in calm conditions, both of which are far from guaranteed. Working in the dark risks damage to the drone from increased operating difficulty, secondly finding staff willing to work at night comes with added costs to the project (paying overtime or taking on more staff). Moreover, new modules with UVA transparent EVA technology reduce the effectiveness of drone based UVF inspection. Despite these drawbacks, using drones to perform UVF inspections can save time, particularly when inspecting rooftop installations as staff do not need to get up onto roofs.

As this technology is still emerging, many O&M service providers lack the in-house expertise to interpret the findings of UVF inspections. This adds an extra layer of cost to the process and has prevented the technology being mainstreamed for solar PV power plant inspection.

12.3. Automated plant performance diagnosis

Purpose and description

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

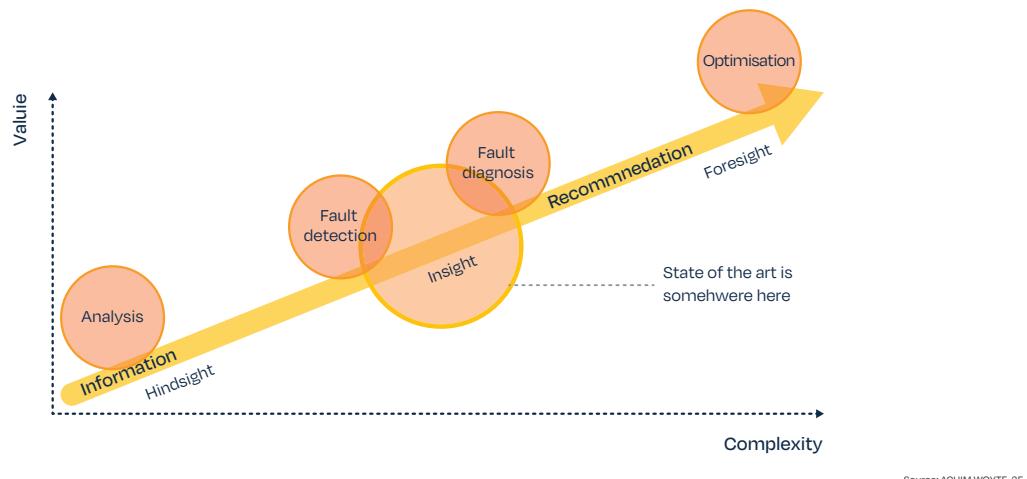
Automated bottom-up diagnosis using advanced big data mining techniques can overcome the disadvantages of classic plant performance assessment by experts, namely, the difficulty of expertly handling data, and the likelihood or error in performance diagnosis.

However, there are some key disadvantages to automated plant performance diagnosis. The principal drawback is around scaling up the use of the technology. Currently it is very expensive to implement. This would not be an issue if the technology could be applied across a portfolio of solar PV power plants. However, there is a lack of uniformity amongst SCADA systems, meaning that information and learning are difficult to transfer between sites. Coupled with this, the current lack of in-house expertise in O&M companies means external service providers would be required to implement the system, driving up costs. Finally, the remoteness of some sites can cause communication issues, impacting the value of fully automated plant performance diagnosis.

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.

FIGURE 13 AUTOMATED PLANT PERFORMANCE DIAGNOSIS



Source: ACHIM WOYTE, SE

12.4. Predictive Maintenance for optimised hardware replacement

Purpose and description

Preventive Maintenance occurs periodically according to contractually agreed schedules and based on expert knowledge. In addition, Preventive Maintenance may be scheduled when the operator identifies an unexpected deviation in performance through the monitoring system. Different maintenance optimisation models are employed to find the optimal cost to benefit balance between maintenance interventions. These models count on the probability of failure of each component of the solar PV system and the impact of that failure on the entire system. For example, the actual lifetime of solar PV inverters under different operating conditions is still uncertain. In practice, inverters will not fail in a predictable way, after a certain period of time, as usually modelled in business plans. Moreover, failure-based maintenance i.e., replacing inverters as they fail may not be the most efficient solution.

A good predictive monitoring system could help with assessing the optimal hardware replacement cycle by modelling the uncertainty in the time-to-failure with a known probability distribution function. Maintenance optimisation models use the output of root cause analyses and remaining useful lifetime

analyses to predict future asset failures. This can be used to optimise planning of maintenance and related resource allocation.

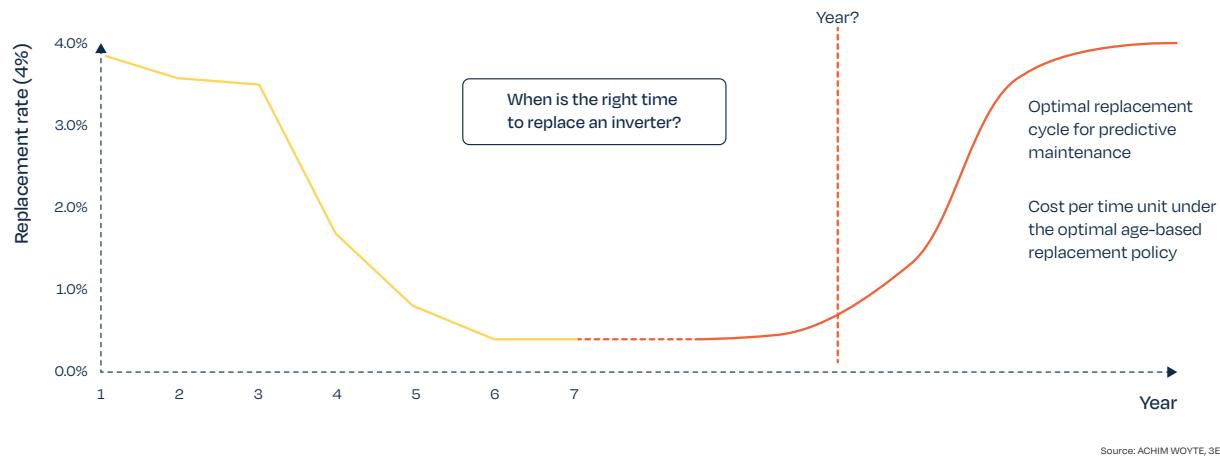
Big data analytics can bring added value at any stage of O&M objectives: analysis from observation of collected information, fault detection, fault diagnosis, and optimisation through recommendations issued from the advanced monitoring system. Today different approaches are proposed. Whereas classic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

The advantages of these Predictive Maintenance optimisation models are that they lower the cost of maintenance by scheduling it more effectively. The diagnostic element of the models also helps to reduce plant downtime. However, the methods are sensitive to device models and brands, making them hard to generalise.

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

FIGURE 14 PREDICTIVE MAINTENANCE FOR OPTIMISED HARDWARE REPLACEMENT



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 solar PV project and hence increase investment attractiveness.

12.5. Augmented Reality, Smart Glasses

Purpose and Description

Virtual or augmented reality refers to digital elements of interactions using cameras on e.g. smartphones, tablets, or special devices such as smart glasses. Specifically, virtual reality is a computer-generated simulation of a three-dimensional environment that can be interacted with by a person using special electronic equipment. Augmented reality refers to an enhanced version of the real world achieved through using digital elements. For the sake of simplification, the term augmented reality is used in the following referring to the use of smart glasses in O&M.

O&M service providers and their operations teams face the recurring challenge of working with a considerable variety of hardware and software from different manufacturers at various sites (at sometimes remote locations). This heterogeneity requires broad knowledge, skill transfer, and good cross-departmental communication. New technologies based on augmented reality can support O&M service providers with these challenges by easing the collaboration between offices and field engineers.

Corresponding software applications combined with smart glasses enable users to interact visually and acoustically to support works on site. The field engineer using the smart glasses is connected to a supervising (desktop) user who will be able to guide them through working steps, using the desktop version of the respective software. The smart glasses user is connected to the supervisory user via an integrated headset. Visually, conditions on site are recorded by an integrated camera. The recordings are then displayed live for the supervisory user who can add explanatory diagrams, screenshots, comments, etc. These additions are then displayed on the lens of the smart glasses. This ensures secure working in line with common H&S requirements (hands free) while the field engineer is guided through working procedures. Furthermore, holograms can be used to enable access to animated maintenance instructions.

State of play

Smart glasses and corresponding software solutions are becoming more popular in the O&M segment. Decreasing price levels for O&M services require improved service/cost efficiency. Augmented reality can support O&M service providers' operations by easing skills and information transfer and ad hoc solutions which can positively affect service efficiency.

There are many advantages to this technology, including: increased efficiency in O&M service provision; more fluid knowledge transfer between senior and junior colleagues; and effective upskilling of O&M personnel, resulting in fewer resourcing challenges and generating savings on internal costs for O&M service providers.

However, there are still limitations on the technology's usefulness. A stable internet connection is required to maintain contact between the field engineer and the supervisor. This can be problematic for solar PV power plants in more remote locations. At present the technology is also expensive. However, as it becomes more mainstreamed, cost competitiveness should improve.

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

Purpose and description

Internet of Things (IoT) in solar PV systems represents an interoperability environment where all devices in the field are connected to each other and show themselves as available to be connected to the system. This can improve integrated, secure communication and efficiency. 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 solar 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.

State of play

There are several advantages to this technology. Principally, it can reduce the costs of monitoring hardware and infrastructure. Similarly, it eases the configuration and maintenance of monitoring systems, whilst improving the quality and stability of data. It also provides for improved secure communications.

However, there is a risk that existing hardware and monitoring equipment will not be compatible with the new technology, resulting in expensive hybrid solutions until it becomes more mainstreamed.

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 solar PV on a larger scale.

12.7. PV Monitoring-Imagery Data fusion

Purpose and description

Current solar PV monitoring solutions track key parameters of solar PV assets (e.g., energy production, irradiance, performance ratios, etc.), with high temporal resolution (e.g., up to 1-10 minutes) and trigger alarms when deviations from expected performance occur. However, there are no specific optimisation objectives linked to detection of underperformance. This method, which relies solely on solar PV monitoring data, presents two significant intrinsic limitations:

- **Expert-dependence:** As such, a misconfiguration of (manually defined) expected performance data often leads to misdetection (or misinterpretation) of deviations from the monitored performance data (i.e., false negatives/positives).
- **Insufficient spatial granularity:** solar PV monitoring data alone is insufficient for identifying the root-causes and locations of energy losses within solar PV systems, as their best spatial resolution is typically down to string

level (i.e., 10–30 solar PV modules combined). As a result, several underperformance issues – especially at solar PV array, module, and submodule level – may remain undetected or unidentified.

Currently, root cause analysis at higher granularity is carried out through various aerial imaging inspection techniques, some of which are described earlier in the chapter). Although these methods have impressive time-efficiency and spatial resolution of aerial imagery data analytics (inspection rates of several MW/hour; detection down to submodule/cell level), there are also considerable drawbacks:

- Practically nonexistent temporal granularity: Aerial imagery inspections/scans of solar PV power plants are carried out per-schedule (e.g., bi-annually), rather than as part of preventive maintenance. This means they can, at best, only offer a qualitative “instant picture” of the condition of a solar PV power plant and its components.
- Decoupled from solar PV monitoring: There is no real-time communication or correlation with crucial solar PV monitoring data (inverter outputs, PR, weather data, etc.), preventing precise determination of the causes of underperformance and power losses with image data (fault) signatures.

From this perspective, enabling fusion (and interoperability) between heterogeneous solar PV monitoring and imagery data/sensors, will be a key functionality and differentiator for next generation “integrated” solar PV monitoring solutions. Indeed, this concept offers key advantages: i) solar PV performance

monitoring data becomes more actionable, leveraging the diagnostic capacity and accuracy of image data with high spatial granularity; ii) the solar PV imagery data gain a temporal and quantitative dimension, being coupled and correlated with real-time monitoring data and power gain/loss analytics.

Other innovation pathways towards solar PV monitoring-image data fusion solutions can include their interfacing with solar PV digital twins, for example, or the integration of BIM and GIS data, and the replacement of (aerial) IR image data by hyperspectral or multispectral image data of solar PV power plants.

State of play

Several commercial solutions of advanced solar PV monitoring exist, offering software-driven quantification and classification of string/inverter-level failures, data analytics for soiling rates and performance degradation, and weather and energy flow analytics. On the other hand, turnkey commercial aerial-IR imagery services offer AI-based data analytics, fault diagnostics and reporting, as well as recommendations for corrective maintenance actions. Yet, in practice, solar PV monitoring platforms are decoupled from IR imagery diagnostics and not optimally aligned in today's solar PV O&M.

Concepts towards aggregation and fusion of solar PV monitoring and inspection/imagery data are under development and being patented, in ongoing international R&D projects. The aim is to gain validation by 2024. Over the last 5 years, there have been efforts and patented methodologies that couple solar PV monitoring and/or IR imaging data with physics-based solar PV yield simulations and loss analytics.

13

O&M for Rooftop Solar

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This chapter is to assist in the application of established utility-scale best practices, detailed in the previous chapters of the document, to rooftop solar projects. It also highlights where rooftop solar projects are distinctively different from utility-scale projects, and where they may require specific O&M best practices that may not be present or applicable for utility-scale projects.

A rooftop solar PV system has its electricity-generating solar panels mounted on the rooftop of a residential or commercial building or structure. On residential buildings they have typically a power of about 5 to 20 kWp, while those mounted on commercial buildings often reach 100 kWp to 1 MWp. Large roofs can house industrial scale solar PV systems in the range of 1-10 MWp. Since O&M organisation depends on size and structure of the asset we distinguish between::

- C&I (commercial and industrial) rooftop solar and,
- Huge portfolios of residential systems (distributed solar portfolios).

13.1. C&I Rooftop Solar

C&I rooftop solar systems are designed and installed for commercial or industrial applications. They are either built, owned, and operated by an IPP who then sells electricity to a company or institution via a PPA, or ownership is transferred to a company or institution by an IPP which continues to operate the installation. In addition, a growing trend observed internationally in energy-intensive built-up urban areas with high-rise residential, commercial, or mixed-use blocks, is for rooftop solar systems that either feed into the grid or are set up as distributed generation.

C&I rooftop solar systems frequently occur in what is known as a "distributed generation" setup. Distributed generation refers to energy-generating technologies, including solar PV, that are sited either on or nearby the premises that are consuming that energy generated. Sometimes distributed generation energy systems are part of a microgrid that offers a degree of crucial power independence from the main grid in cases such as mains electricity outages during extreme climate events. C&I distributed generation is being paired increasingly with on-site energy storage solutions to enhance energy independence and efficiency for the site.

Due to the relatively significant size of C&I rooftop systems (500kWp-10 MWp), the best practices highlighted elsewhere in these Guidelines should be applied to these installations. However, their location on roofs and their situation in commercial/industrial environments require additional guidelines to address these factors.

Regarding H&S considerations for C&I rooftop solar, the necessary precautions outlined in Chapter 2. *Health, Safety, Security, and Environment* should be taken into account, but need to be complemented to address the dangers associated with working at height (see for example [Best practice guidelines for working at height in New Zealand, HSA Guide to the Safety, Health and Welfare at Work or IACS Guidelines for Working at Height](#)). These additional precautions include:

- Presence of permanent guardrails or other forms of edge protection
- Presence of maintenance corridors
- Use of mobile elevating work platforms, forklift platforms, etc.

13 O&M for Rooftop Solar / continued

- Use of safety mesh
- Use of temporary work platforms (also to avoid damage of modules)
- Marking of dangerous areas (for example, fragile roof material)
- Correct use of harness systems and lifelines
- Correct use of ladders

As a best practice, aerial inspections should be conducted with drones as they can safely and accurately capture visual and thermographic data in significantly less time than it takes to manually inspect the entire array. The images and reports generated allow O&M technicians to identify precise locations and even the types of rectifications required. This enables swifter, safer repairs that also save costs in terms of repair time required.

13.1.1. Operations

An asset-centric approach to operations that promotes the free flow of data and transparency between all stakeholders for the entire lifecycle of the asset should be followed. This is made possible by using a monitoring and asset management platform.

Operating a C&I rooftop solar asset is similar in principle to the guidelines mentioned in Chapter 5. *Power plant Operation*. To recap, it should include:

- A Document Management system
- Plant performance monitoring and supervision

- Performance analysis and improvement
- Optimization of O&M
- Maintenance scheduling
- Spare part Management
- Decommissioning

As best practice, drones equipped with visual, thermographic, and other specialised inspection equipment should be used to support the O&M operations of C&I rooftop solar assets. They can provide image data that can identify anomalies missed by ground monitoring equipment. This allows problems to be spotted and rectified in a proactive, time- and cost-efficient manner, reducing the likelihood of more serious issues further down the line.

To accurately calculate the Energy Performance Index, collection of Reference Yield (Local Irradiation) and temperature data is required.

Table 12 shows the different methods that can be applied for collection of reference yield.

The variety of conditions leads to a higher incidence of uncertainty: greater shade, lower data accuracy, lower comparability between assets.

For example, greater and more variable shade profiles, due to significant roof obstacles, require that expected yields used in the EPI are adjusted based on shade expectation for the KPI interval.

As shading and vegetation control tend to be an ongoing problem for smaller-scale C&I given their

TABLE 12 METHODS SUGGESTED FOR THE COLLECTION OF REFERENCE YIELD

REFERENCE YIELD SOURCE	ACCURACY	HARDWARE COST	COMMENT
Onsite Pyranometer	High*	High	For more information, see section 9.10.1. Irradiance measurements . Public pyranometers may be used if available.
Module level sensor	High	High	
Satellite Data	Medium-High**	None	For more information, see section 9.10.1. Irradiance measurements .
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 need 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. It is also worth noting that real-time satellite data provision comes at a cost. Another alternative is comparing the performance of neighbouring systems

relative size, and proximity to trees and gardens, as well as ongoing construction of neighbouring buildings that could affect the shading profile of the solar PV installation site, drones can be considered as a fast, accurate, safe and non-intrusive method of delivering shading analysis and vegetation management inspections at regular intervals appropriate to the site.

As a recommendation, horizon and obstacle plotting should be included in all yield modelling.

13.1.2. Maintenance

C&I O&M service providers should provide a Maintenance Plan to the Asset Owner during or before system commissioning.

Roofs under warranty require annual preventive roof maintenance to maintain the roof warranty. It is best practice for the retailer/installer and O&M service provider to meet with the roof maintenance provider to make sure both teams understand their roles and responsibilities and respect each other's needs.

Maintenance staff need to control the security infrastructure regularly for integrity. The Owner should ideally opt for local maintenance service providers to minimise the cost of maintenance and keep response times low. This means that further emphasis should be placed on training and skills required for working at height.

TABLE 13 INCIDENTS COVERED BY O&M SERVICE AGREEMENTS FOR DISTRIBUTED SOLAR SYSTEMS

INCIDENT	CLASSIFICATION	COMMENT
Inverter alarms	Minimum requirement	Alarms generated by the inverter should be acknowledged at least daily. The personnel responsible for maintenance should take necessary actions within 2 days for smaller C&I installations. Faults in larger installations with central inverters need to be dealt with quicker.
Monitoring Failure	Minimum requirement	Remote diagnosis of monitoring failure should be completed within 2 days for smaller C&I installations. Faults in larger installations with central inverters need to be dealt with quicker. As monitoring failure is often caused by inverter failures 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 service provider should have good guidelines and troubleshooting guides that allow the Owner to self-diagnose and resolve. Resolution of monitoring failure without yield losses: Within 2 days for smaller C&I installations. Faults in larger installations with central inverters need to be dealt with quicker.
Inverter failure	Minimum requirement	As soon as inverter failure is indicated by inverter alarms or monitoring failure a replacement or repair should be done 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 is a monthly comparison, and annually as a minimum.
Module- String/ Inverter Level Alerts	Recommended	For commercial projects with more than one inverter, reporting should be at the inverter level as a minimum. String or MPPT level reporting to enable string failure alerts, 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, installation type, size, and environmental conditions. Actual planning of module cleaning can be adjusted based on the performance (EPI) of the system over time.

Normally C&I solar PV systems are situated next to other third-party activities. This can entail extra considerations that need to be made:

- The risk assessment should analyse dangers arising from proximity to third parties and plan countermeasures.
- O&M service providers should propose a "stakeholder training" for people working next to the installation.
- Dangerous areas should be marked in a way that is also understood by third-party personnel.

Table 13 on the previous page summarizes incident handling for C&I rooftop solar PV systems.

13.1.3. Spare Parts Management

If economically feasible, the O&M service 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 in Europe.

The inverter is the most important spare part as energy production and most monitoring processes rely on it.

13.2. Distributed Residential Solar Portfolios

Distributed solar portfolios refer to portfolios comprising multiple, small assets installed on residential rooftops.

Ownership of assets varies from country to country and is based on the bilateral agreement between the constructor/ operator and the roof owner. Generally, there are three kinds of owners:

1. Homeowners that own the installations on their homes
2. Third-party companies that own the installations and usually lease the rooftop or sell the electricity produced to the owner of the rooftop at a discounted price from the one offered by utilities one
3. Local councils or private and social housing associations that have equipped their properties with solar panels

Homeowners that own the installations on their homes have paid for the installation themselves and usually have a bilateral net- metering agreement with the local utility for the energy produced.

In the case of third parties that have paid for the installation themselves, they usually undertake the maintenance as well. The financial model depends on the bilateral agreement between themselves and the rooftop owners. Common practices include leasing the rooftop area and taking advantage of all the generated power, or selling the power produced at a discounted price to the rooftop owner.

Apart from the general aspects of rooftop solar systems, main challenges of large distributed solar portfolios are:

- The multitude of assets: portfolios of 10,000+ installations are common.
- The variety of conditions (for example, shading, inclination, orientation, etc.).
- The variety of equipment used: multiple inverter brands (including monitoring systems) and panels.
- The common presence of stakeholders who are not solar professionals.
- Getting access to the house for maintenance activities requires making appointments with the tenants.

13.2.1. Operations

Since physical site inspections and callouts at multiple sites mean higher costs, it is economically cheaper to invest into monitoring hardware (temperature / irradiance) on top of inverter monitoring, and implement automatic root cause analyses, where this is possible. Therefore, monitoring equipment accounts for a greater percentage of the total investment.

For large portfolios of small installations extra monitoring hardware might be too expensive. Automated analysis methodologies comparing neighbouring installations can be used in combination with irradiation data coming from meteorological stations and satellites, or theoretical clear-sky irradiation data.

Monitoring of a large portfolio of residential installations requires a different approach to monitoring an individual installation. For the latter, the inverter built-in monitoring system via Wi-Fi might be sufficient, making the tenant responsible for communication with the server.

When performing long-term monitoring of a high number of installations, using a communication channel independent from the house Internet connection, i.e., cellular communication is advised. This largely decreases the number of support calls and local interventions to resolve communications issues. It also decreases the installation cost (cabling, configuration) and the risk of cyber security issues.

For local data acquisition, three approaches can be followed:

- Inverter manufacturer built-in system: This is often free-of-charge including access to a portal for the installer and end-user. The disadvantage is that, when multiple inverter brands are used, different monitoring systems need to be managed which makes it more complex and time consuming.
- Independent data logger: These are compatible with multiple inverter brands decreasing the dependency on a single manufacturer. The disadvantage is the extra investment.
- External energy meter: These are easy to install and often have an integrated communication module. It is the only solution when a calibrated measurement is required following the European Measurement Instrument Directive (MiD). The disadvantage is the extra investment and that only AC parameters are measured.

In case only an energy meter is used in the monitoring systems, the following parameters need to be measured at the minimum:

- AC Energy production: This is the basis for yield calculations. A resolution of minimum 15 minutes is advised for further intra-day performance analysis. In some contractual models a calibrated measurement is required following the European Measurement Instrument Directive (MiD).

- AC voltage: In areas with a lot of local production, AC voltage can rise to a level that sends the inverter into safety mode. The level is dependent on local legislation.

In case more detailed inverter data is acquired, the following parameters provide useful information:

- Inverter alarms.
- Inverter temperature: This can give an indication of an upcoming problem or clogged ventilation holes.

When monitoring large portfolios of solar PV installations, the following challenges can occur:

- High volumes of different installations with very different characteristics.
- Base parameters (W_p , orientation, tilt) are often incorrect or missing in the monitoring database.
- Shading effects (trees, chimneys, etc.) which are season dependent resulting in errors in yield analysis.
- Local irradiation measurement is too expensive
- Errors in yield analysis due to clipping effects

The following best practices should be adopted:

- Apply robust procedures during installation to start from correct parameters. Installer technicians need to provide the correct information as part of the commissioning process.
- Avoid a high variety of data acquisition methods and monitoring systems.
- Apply performance index calculations that are immune from the effects of shading (e.g., part of the day, clear sky index).
- Compare with a pool of nearby installations to neutralise temperature, wind, and pollution effects on performance indexes

13.2.2. Maintenance

The Installer should not state that solar systems are self-cleaning and do not require any maintenance. As best practice, the Installer should educate their clients about the necessity and benefits of a regular, high-quality O&M practice for the lifetime of their solar

13 O&M for Rooftop Solar / continued

assets. This should include a minimum yearly inspection, and cleaning and maintenance based on the environmental conditions. This will ensure the continuous safe operation of the asset and minimise H&S risks to building users. It will also maximise the energy production capability of their asset throughout its lifetime.

Preventive Maintenance of large residential portfolios is often limited to cleaning as part of a maintenance contract. Cleaning should be condition-based, rather than conform to a regular schedule. This can be combined with visual inspection of the cabling and cleaning of inverter ventilators.

It needs to be clarified to homeowners or tenants that they should not clean the panels themselves using high pressure systems. This would void the warranty.

In areas with a high density of residential solar PV installations, collective drone inspection should be considered. In a short period, thermographic data of lots of installations can be collected.

Corrective Maintenance of large residential portfolios relies heavily on a good monitoring system. Besides detecting and communicating alarms it should be able to detect decreasing performance trends.

Once an anomaly is detected, a trade-off will be made between speed of intervention and financial loss. Often it is cheaper to group interventions in a certain geographical area. A limiting factor is also the access to the house. Appointments must be made with the occupants, which can take time.

To avoid the cost of sending an intervention team on-site, tenants are often requested to perform certain actions such as removing dust from ventilators and resetting an installation (switch off/on). O&M service providers should propose training for these tasks.

More advanced residential monitoring systems calculate trends in decreasing performance and increasing inverter temperature. Both parameters predict an upcoming failure.

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A Annex

A. Applicable international standards for solar O&M

Generic for O&M	
IEC 62446-1:2016	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 solar PV systems
IEC TS 63049:2017	Terrestrial photovoltaic (PV) systems – Guidelines for effective quality assurance in solar 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
System Performance and Monitoring	
IEC 61724-1:2017	Photovoltaic system performance - Part 1: Monitoring
IEC TS 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	Photovoltaic (PV) array - On-site measurement of current-voltage characteristics
IEC TS 60904-13:2018	Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules
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 solar 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

B Annex

B. Proposed skill matrix for O&M personnel. (Download it from www.solarpowereurope.org)

Planned	Not required	Required	Update required						
First name	Surname	Function	Health & Safety	Environmental	Monitoring & Metering	PV Modules	Inverter	Electrical	Data & Comms
		Managerial/ Electrical Engineer	Company's Services introduction Health & Safety assessment test Manual Handling Display Screen Equipment Risk Assessment Occupational Health & Safety training course Training to handle Health & Safety in a team Certification of Occupational Health & Safety First Aid at Work HV Substation Access Managing Contractors Other task, company or country relevant requirements (e.g., working at height, asbestos awareness, use of specific equipment, construction/installation)						
		Managerial/ Electrical Engineer	Certificate of Environmental Management and Assessment Other relevant training course and/or certificate of Environmental Management						
		Managerial/ Electrical Engineer	Certain Monitoring tool training Meter accreditation and calibration Other relevant skills (e.g., data handling)						
		Electrician/ supervisor	Basic knowledge about the installed product (e.g., handling, general safety guidelines, installation etc.; see also recommendations by module manufacturer/installation manual) Basic measurement skills (e.g., thermography, power measurements)						
		Electrician/ supervisor	Power Electronics Learning Tools Interoperability (LTI) Other skills (e.g., experience with specific product and type of inverter)						
		Electrician/ supervisor	Certification of Electrical Qualification Other relevant skills (e.g., Specific Inspection & Test training, relevant accredited courses etc.)						
		Trainee Electrician	Termination of specific communication cabling Installation of the monitoring system Installation and connection of meters Installation of satellite broadband system Other skills						
		Trainee Electrician							
		Data & Comms							

C Annex

C. Documentation set accompanying the solar PV power 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	Solar PV Modules	<ul style="list-style-type: none"> • Datasheets • Flash list with solar 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 	

C Annex / continued

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 solar PV power 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	Solar PV power plant Energy Production; PR; Expected vs Real	

D Annex / continued

RECORD CONTROL				
NO.	ACTIVITY TYPE	INFORMATION TYPE	INPUT RECORD	REFERENCES/ COMMENTS
15	Preventive Maintenance	Intervention equipment/ Element name	Affected Power and Affected Production, Equipment Code / Name, Intervention Start and End Date	
16	Preventive Maintenance	Maintenance description	Measurements, Preventive Maintenance Tasks Performed, Problems not solved during activity and its Classification and Typification, Technicians and Responsible Names and Function	
17	Solar PV power 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	Solar PV power plant Documentation	Operation and maintenance	Equipment Manuals, solar PV power 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	Solar PV power 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 service provider, 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	Y	T
	Measurements inspection	if required	Y	S
	Check/tightening of clamps	Minimum requirement	Y	R
	Modules cleaning	According to local conditions (Y)		T
	Sample internal inspection of junction boxes (if possible)	Recommendation	Y	T
	Integrity check & cleaning	Minimum requirement	Y	T
	Documents inspection	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	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
	Lubrification of locks	Minimum requirement ^a	Y	T
	Monitoring operation test (if applicable)	Recommendation ^a	Y	T
	Integrity inspection	Minimum requirement	Y	R
Cables	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	Sensors functional verification	Minimum requirement	Y	R
	- Central inverters - String inverters			

F Annex / continued

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Inverters - Central inverters - String inverters	Measurements inspection Check parameters Functional test of ventilation system Check batteries Replace batteries Replace fans Safety equipment inspection	Minimum requirement Minimum requirement Minimum requirement According to manufacturer's recommendations (3yr) (5yr)	Y Y SA T	T T
Transformer ^c - Power transformer - AUX transformer	Integrity check & cleaning Check labelling and identification Thermographical inspection Functional verification of sensors & relais	According to local conditions Minimum requirement Best practice Minimum requirement	(Y) 2yr T	T T
MV switchgear incl. protection devices ^c	Check parameters Check oillevel (if applicable) and max. temperature Check of cooling system (fans) if applicable Check of MV surge discharger devices (if applicable) Integrity check & cleaning Safety equipment inspection	Minimum requirement Minimum requirement Minimum requirement Minimum requirement According to local conditions Minimum requirement	Y Y Y Y (Y) T	R T T T T T
	Check labelling and identification Electrical protections/visual inspection Thermographical inspection, if possible Sensors functional verification Measurements inspection Check correct operation Check fuse status Check cables terminals Battery / UPS check Mechanical lubrication Replace certain mechanical parts Battery / UPS replacement	Recommendation Minimum requirement Minimum requirement Minimum requirement Minimum requirement Minimum requirement Minimum requirement According to manufacturer's recommendations and necessity (5yr) (5yr) (3yr)	Y Y Y Y Y Y Y T T T	

E Annex / continued

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
MV switchgear incl. protection devices ^c	Check/protection parameters Functional check of protection devices	According to local grid code (5yr)	Y	T
Power analyser ^c	Integrity check & cleaning Check labelling and identification Measurements inspection Software maintenance Monitoring operation test: Check parameters	Minimum requirement Minimum requirement Minimum requirement Recommendation Minimum requirement Minimum requirement	Y Y Y Y Y Y	T R T T T T
Energy meter	Integrity check & cleaning Check labelling and identification Check values and parameters Check of communication devices (modem, converters) if applicable	Minimum requirement Minimum requirement Recommendation Recommendation According to manufacturer's recommendations (3yr)	Y Y Y Y Y Y	T T T T T T
Power control unit ^c	Check batteries Replace batteries Functional verification Integrity check & cleaning	Minimum requirement Minimum requirement According to manufacturer's recommendations (3yr)	Y Y Y Y	T T T T
UPS ^c	Integrity check & cleaning Check batteries Replace batteries	Best practice According to manufacturer's recommendations (3yr)	Y Y Y	T T T
Emergency generator (if applicable) ^c	Functional test of ventilation system (if applicable) Integrity check & cleaning General maintenance Check correct operation Replacement of filters	According to manufacturer's recommendations (3yr)	Y Y Y Y Y	T T T T T
Lights and electric sockets	Integrity check & cleaning Check correct operation Check conformity to local security standards	Minimum requirement Minimum requirement According to manufacturer's recommendations	Y Y Y	T T T
HVAC (if applicable)	Integrity check & cleaning Functional verification Change of air filters	According to manufacturer's recommendations (3yr)	Y Y Y	T T T

F Annex / continued

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Water supply system (if applicable)	Integrity inspection	If applicable	Y	T
Fire detection central (if applicable)	Integrity check & cleaning	According to manufacturer's recommendations and local requirements	(Y)	T
	Check correct operation		(Y)	T
	Battery inspection		(Y)	T
	Sensors functional verification		(Y)	T
	Cleaning of cameras & sensors		(Y)	T
Lightning protection (if applicable)	Integrity inspection	Minimum requirement	Y	R
	Integrity inspection	Minimum requirement	Y	T
Fences and gates	Lubrication of locks	Minimum requirement	SA	T
Vegetation	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
Manholes	Integrity inspection	Best practice	Y	T
Buildings	Integrity check & cleaning	According to local requirements	(Y)	T
	Lubrification 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
Tracker system ^c	Integrity check & cleaning	Minimum requirement	Y	T
	Check correct operation	According to manufacturer's recommendations	(Y)	T
	Check tightening		(Y)	R
	General maintenance		(Y)	T
	Mechanical lubrication		SA	T

E Annex / continued

EQUIPMENT	TASK	IMPORTANCE	FREQUENCY	EXTENT
Weather station ^d	Integrity check & cleaning Functional test of sensors Check correct operation Check batteries (if applicable) Monitoring operation test	According to manufacturer's recommendations	(Y)	T
Irradiation sensors	Integrity check & cleaning Calibration Monitoring operational test	According to manufacturer's recommendations and local requirements	Q 2yr	T
Communication Board	Functional communications check	Minimum requirement	D	T
Intrusion detection and verification system ^c	Integrity check & cleaning Functional verification of intrusion detection Functional verification of alarming Functional verification of cameras Specific maintenance	Minimum requirement According to manufacturer's recommendations	Y Y M Y	T
Stock of spare parts ^d	Inventory of stock Visual inspection of stock conditions Stock replenishment	Minimum requirement Minimum requirement Minimum requirement	Y Y M	T





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ISBN NUMBER 9789464444247