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Operation & Maintenance

Best Practice Guidelines

Jordan edition

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Foreword

Welcome to the Jordanian edition of the Operation & Maintenance (O&M) Best Practice Guidelines. Based on Version 4.0 of SolarPower Europe's O&M Best Practice Guidelines, this edition is adapted to the Jordanian context. It is a joint effort between SolarPower Europe and EDAMA, the Jordanian renewable energy association.

Jordan is a country that has limited conventional energy sources and has traditionally been reliant on energy imports, with imported energy answering 88% of the country's energy demand in 2021. To insulate itself from regional geopolitical upheavals, Jordan is increasingly turning to solar PV as a way of ensuring its energy independence. The solar potential in Jordan is enormous, with over 3110 hours of sunlight per year. Seizing the opportunities that this potential presents will mean ensuring that PV power plants are able to reliably achieve performance targets. The key to doing this is ensuring quality O&M practices and procedures throughout the operational phase of an asset's lifecycle. Yet there are still significant quality discrepancies between services from different providers.

To address these challenges, SolarPower Europe joined forces with EDAMA, supported by the Jordanian-German Energy Partnership, funded by the Federal Ministry for Economic Affairs and Climate Action, and implemented by the Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH, to develop the Jordanian edition of the O&M Best Practice Guidelines; Our joint Jordanian-European O&M working group was launched in November 2021, assembling 24 leading solar experts from Jordan and Europe. The kick-off meeting was followed by a series of online working meetings, in which we updated Version 4.0 of SolarPower Europe's O&M Best Practice Guidelines to reflect the market and business conditions in Jordan. The result is a guide that we hope will help Jordanian solar stakeholders improve the quality of the O&M segment. This document is aimed at O&M service providers, as well as other parties involved in the operation of solar power plants, such as owners and investors, lenders, technical advisors, and data-related service providers. It will help establish common standards and increase transparency in the sector. It is also worth noting the solar O&M is especially value intensive as a segment, supporting many local jobs, and driving important solar innovations, notably in the field of digitalisation.

In the Jordanian edition, all chapters of the original document have been thoroughly reviewed and revised with a focus on the unique aspects of the country. The recommendations have been updated to include key processes and codes related to environmental protection within the country, and the legislative framework governing health and safety. The recommendations also reflect the latest version of the Jordanian grid code. There is also a new section dedicated to repowering combiner boxes. To make this document useful to operators and owners of power plants with storage facilities, we have included a chapter on O&M for these types of installations. This includes a detailed overview of the legislative framework governing the use and safe disposal of Battery Energy Storage Systems (BESS). We have also considered that dust and water scarcity may be an issue in Jordan and operators are encouraged to reduce the amount of water used for module cleaning. These are only some of the examples from the many updates we have implemented to make these guidelines as useful as possible for solar businesses in Jordan.

We encourage all solar operators in Jordan to consider adopting these Guidelines and to reach out to EDAMA with any questions or suggestions.

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Project information

The Jordanian edition of SolarPower Europe's O&M Best Practice Guidelines reflects the experience and views of a considerable share of the Jordanian and European O&M industry today. It is based on Version 4.0 of SolarPower Europe's O&M Best Practice Guidelines and has been adjusted to the Jordanian national context in a joint effort between SolarPower Europe and EDAMA. The development of the Jordanian edition was supported by EDAMA and the Jordanian-German Energy Partnership.

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List of abbreviations

AC	Alternating current
AMP	Annual Maintenance Plan
AMR	Automatic meter reading
AMS	Annual Maintenance Schedule
API	Application Programming Interface
CCTV	Closed Circuit Television
CMMS	Computerised maintenance management system
COD	Commercial operation date
CSMS	Cybersecurity management system
DC	Direct current
DMS	Document management system
DOR	Division of responsibility
DSCR	Debt service coverage ratio
DSL	Digital Subscriber Line
EDCO	Electricity Distribution Company - in Jordan
EH&S	Environment, health and safety
EMRC	Energy and Minerals Regulatory Commission
EMS	Energy Management System
EPC	Engineering, procurement, construction
EPI	Energy Performance Index
ERP	Enterprise Resource Planning System
ESS	Energy Storage System
FAC	Final acceptance certificate
FIT	Feed-in tariff
FTP	File Transfer Protocol
GPRS	General Packet Radio Service
H&S	Health and safety
HV	High voltage
IDECO	Irbid District Electricity Distribution Company – in Jordan
IEC	International Electrotechnical Commission
IGBT	Insulated-Gate Bipolar Transistors
IPP	Independent power producer
IR	Infrared
IRENA	International Renewable Energy Agency
IRR-DCC-MV	Intermittent Renewable Resources (IRR) Wind & PV – Distribution Connection Code (DCC) At Medium Voltage (MV)
IRR-TIC	Intermittent Renewable Resources (IRR) Wind & PV – Transmission Interconnection Code (TIC)
JEPCO	Jordanian Electric Power Company ltd. – in Jordan
KPI	Key performance indicator
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt-peak
LAN	Local area network
LCOE	Levelised cost of electricity
LTE-M	Long-power wide-area network
LPWAN	
	Long Term Evolution, category M1
LV	Low voltage
MAE	Mean absolute error
MIT	Minimum irradiance threshold
MPPT	Maximum Power Point Tracking
MV	Medium voltage
MW	Megawatt
NCC	National Control Centre – in Jordan
NEPCO	National Electric Power Company – in Jordan
O&M	Operation and Maintenance
OEM	Original equipment manufacturer
OS	Operating system
PAC	Provisional acceptance certificate
POA	Plane of array
PoCC	Point of Common Coupling
PPA	Power purchase agreement
PPC	Power Plant Controller
PPE	Personal protective equipment
PR	Performance Ratio
PV	Photovoltaic
RMSE	Root mean square error
ROI	Return on investment
RPAS	Remotely Piloted Aircraft System (drone)
SCADA	Supervisory Control And Data Acquisition
SLA	Service-level agreement
SPV	Special purpose vehicle
STC	Standard Test Conditions (1000 W/m2, 25°C)
TF	Task force
UPS	Uninterruptible Power Supply

Executive summary

The Jordanian solar PV market is unique. It has grown steadily from 291 MW of installed capacity in 2016 to a total of 1.75 GW cumulative installed capacity in 2021. According to SolarPower Europe market data, installed capacity could more than double to around 3.6 GW by 2026 in a business-as-usual scenario, and reaching just over 4 GW in a best case scenario. Traditionally, the country has been largely reliant on energy imports to satisfy its energy demand. However, persistent political and social tensions in the region have exposed the precariousness of Jordan's position. With huge solar potential, the Jordanian government is increasingly looking to exploit this, ensuring energy autonomy, and providing Jordanians with inexpensive, clean electricity. As Jordan looks to hit its ambitious renewable energy targets, ensuring the long-term health of these assets will be indispensable in shoring up public support for solar PV. 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 Jordanian edition of the O&M Best Practice Guidelines make it possible for all to benefit from the experience of leading Jordanian and European experts in the sector, and increase the level of quality and consistency in O&M. These Guidelines are meant for O&M contractors as well as investors, financiers, asset owners, asset managers, monitoring tool providers, technical consultants and all interested stakeholders in Jordan. In this edition, the requirements presented in SolarPower Europe's O&M Best Practice Guidelines version 4.0 have been updated to reflect the Jordanian market context. One such example is the inclusion of O&M best practices for smaller Commercial & Industrial (C&I) installations, in the 100s of kW scale, in these Guidelines.

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

Environment, Health & Safety

Environmental problems are normally avoidable through proper plant design and maintenance, but where issues do occur, the O&M service provider must detect them and respond promptly. Environmental compliance may be triggered by components of the PV system itself, such as components that include hazardous materials and by-products that may be used by the O&M service provider such as herbicides and insecticides. In Jordan, water scarcity should be considered, and it is important to consider whether dry cleaning of modules is a more effective use of capital and natural resources.

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

Personnel & training

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

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 the Jordanian context, O&M service providers assume 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 PV plant complies with national and local regulations and contracts, and also advising the asset owner on technical asset optimisation via repowering investments, for example.

Power plant operation

Operation is about remote monitoring, supervision and control of the PV power plant and it is an increasingly active exercise as grid operators require more and more flexibility from solar power plants. Power plant operation also involves liaising with or coordination of the maintenance team. A proper PV plant documentation management system is crucial for operations. A list of documents that should be included in the as-built documentation set accompanying the solar PV plant (such as PV modules' datasheets), as well as a list of examples of input records that should be included in the record control (such as alarms descriptions), can be found in the Annex of these Guidelines. Based on the data and analyses gained through monitoring and supervision, the O&M service provider should always strive to improve PV power plant performance. As there are strict legal requirements for security services in Jordan, 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 b) includes a list of inspections and actions that should be performed regularly. Corrective Maintenance covers activities aimed at restoring a faulty PV plant, equipment, or component to a status where it can perform the required function. Extraordinary Maintenance actions, usually not covered by the O&M fixed fee, can be necessary after major unpredictable events in the plant site that require substantial repair works. Additional maintenance services may include tasks such as 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, revamping and repowering's significance has increased rapidly in solar O&M markets around the world, and Jordan is no exception to this. It is expected that revamping and repowering will gain traction in Jordan in the years to come as assets age and new technologies arrive on the market. Therefore, these Guidelines address them in a standalone chapter. Revamping and repowering are defined as the replacement of old, power production related components within a power plant by new components to enhance the overall performance of the installation. This chapter presents the best practices in module and inverter revamping and repowering and general, commercial considerations to keep in mind before implementation.

Spare Parts Management

Spare Parts Management is an inherent and substantial part of O&M aimed at ensuring that spare parts are available, in a timely manner, for Preventive and Corrective Maintenance, minimising the downtime of a solar PV plant. As best practice, spare parts should be owned by the asset owner while maintenance, storage and replenishment should be the responsibility of the O&M service provider. It is considered 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, a 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. In the Jordanian context, when setting spare parts' stocking levels, the availability of spare parts needs to be considered as components need to be procured from overseas, leading to extended waiting times.

Data and monitoring requirements

The purpose of the monitoring system is to allow supervision of the performance of a PV power plant. Requirements for effective monitoring include dataloggers capable of collecting data (such as energy generated, irradiance, module temperature, etc.) of all relevant components (such as inverters, energy meters, pyranometers, temperature sensors) and storing at least one month of data with a recording granularity of up to 15 minutes, as well as a reliable Monitoring Portal (interface) for the visualisation of the collected data and the calculation of KPIs. Monitoring is increasingly employing satellite data as a source of solar resource data to be used as a comparison reference for on-site pyranometers. As a best practice, the monitoring system should ensure open data accessibility to enable an easy transition between monitoring platforms and interoperability of different applications. As remotely monitored and controlled systems, PV plants are exposed to cybersecurity risks. It is therefore vital that installations undertake a cyber security analysis and implement a cybersecurity management system.

Key Performance Indicators

Important KPIs include PV power plant KPIs, directly reflecting the performance of the PV power plant; O&M service provider KPIs, assessing the performance of the O&M service provided, and PV power plant/O&M service provider KPIs, which reflect power plant performance and O&M service quality at the same time. PV power plant KPIs include important indicators such as the Performance Ratio (PR), which is the energy generated divided by the energy obtainable under ideal conditions expressed as a percentage, 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 can 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 PV plant). Acknowledgement Time plus Intervention Time are called Response Time, an indicator used for contractual guarantees. The most important KPI which reflects 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), an important difference for contractual purposes.

Contractual framework

In Jordan, whilst there is no requirement, O&M service providers will give Performance Ratio guarantees in some cases. PR guarantees can be useful when installation an O&M are performed by the same entity. If this is not the case, then it is best practice to use Availability and Response Time guarantees instead. A best practice is a minimum Availability of 98% over a year should be guaranteed, with Contractual Availability guarantees translated into Bonus Schemes and Liquidated Damages. When setting Response Time guarantees, differentiating between periods with high and low irradiance levels is recommended. The same applies for fault classes, i.e. the (potential) power loss.

Innovations and trends

O&M contractors are increasingly relying on innovations and more machine and data-driven solutions to keep up with market requirements. The most important trends and innovations shaping today's O&M market are summarised in this chapter, and include the use of technology to perform increasingly accurate and targeted data-driven O&M, and coatings for PV modules to improve their performance.

O&M for PV power plants with storage

This chapter assists in the application of the best practices, detailed in the previous chapters of the document, to PV installations with storage. All best practices mentioned in these Guidelines could be theoretically applied to the smallest systems. However, Battery Energy Storage Systems (BESS) require different O&M services to ensure the effective management of energy supply and demand. The chapter discusses the various types of BESS that are in use in Jordan and details best practice recommendations for quality management of these systems.

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 distributed solar projects, which are shaped by three important factors: (1) a different set of stakeholders – owners of rooftop 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

1.1. Rationale, aim and scope

According to SolarPower Europe's market data, Jordan had a cumulative installed solar PV capacity of around 1.75 GW in 2021. This is the result of solid growth since 2016. As the country seeks to achieve energy independence, this number is expected to more than double by 2026 under a business-as-usual scenario. As more capacity comes online in the ensuing years, ensuring that PV installations run efficiently over the course of their lifetime will be vital to ensuring that solar becomes the backbone of Jordan's new electricity system. Today, O&M has become a standalone segment within the solar industry, with an increasing number of companies in Jordan providing specialised services. Yet there are still significant quality discrepancies between services from different providers.

A professional Operation & Maintenance (O&M) service package ensures that the photovoltaic system will maintain high levels of technical, safety and consequently economic performance over its lifetime. Currently, it is widely acknowledged by all stakeholders that high quality O&M services mitigate the potential risks, improve the levelised cost of electricity (LCOE) and Power Purchase Agreement (PPA) prices and positively impact the return on investment (ROI). This can be highlighted if one considers the lifecycle of a PV project which can be broken down into the 4 phases below. The O&M phase is by far the longest:

» Development (typically 1-3 years)

» Construction (a few months)

» Operation & Maintenance (typically 30+ years)

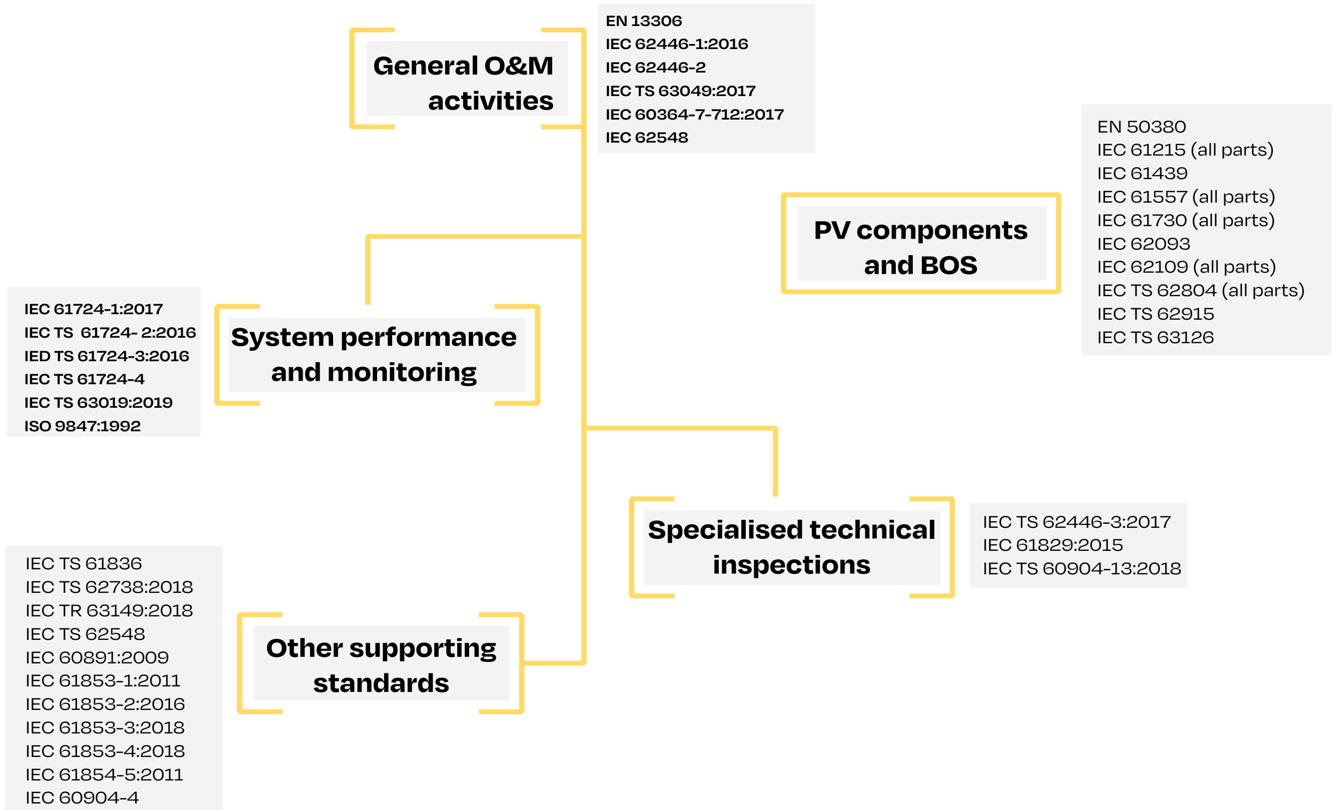
» Decommissioning and disposal (a few months)

Since the operational phase covers by far the longest period during the lifetime of the of a PV power plant project, increasing the quality of O&M services is important and, in contrast, neglecting O&M is risky. According to several studies, yield can be reduced by up to 70% if a PV power plant is not well monitored or maintained. In exceptional cases, temporary yield losses of up to 100% have been reported. Inoperative situations or performance issues need to be detected instantly to avoid serious yield losses. By way of example, just the effect of soiling resulting from regular, wind induced, dust carry-over can result in a performance loss of 10%+ within two weeks, and of 30%+ within a matter of six weeks.

The O&M services segment of the solar PV industry is relatively young and serious harmonisation of best practices is yet to take place. Although this is partly logical, reflecting the specificities of each system, topologies, installation sites, and legislative requirements, there is some confusion and a lack of clarity on the part of asset owners and finance providers (investors and/or banks) as to what the minimum requirements (scope) should be.

Today, existing standardisation still does not fill in all the gaps or clarify all the requirements and their implementation. Although in Maintenance, there are a number of technical international standards that can be followed and which also cover tasks related to planning, scheduling and administrative, but when it comes to the practical Power Plant Operation, there are many shortcomings. Therefore, it is crucial to develop and disseminate best practices to optimise Power Plant Operation and thus energy production, power plant management and resulting benefits. Best practices that set the quality bar high will enhance investors' understanding and confidence.

FIGURE 1. OVERVIEW OF A SELECTION OF APPLICABLE STANDARDS FOR O&M (STATUS: 2019). NOTE: THIS LIST IS NOT EXHAUSTIVE AND NEW STANDARDS ARE UNDER DEVELOPMENT.



This report also features best practices and to avoid misunderstandings in wording and doing. For more detailed information, please refer to Annex a.

The Jordan edition of the O&M Best Practice Guidelines is a key tool to set quality standards for service providers and enhance investors' understanding and confidence. Their design has been industry-led and is based on the knowledge and experience of leading O&M service provision, project development and construction (EPC), and asset management firms, alongside utilities, manufacturers, and monitoring tool providers. In this edition, the requirements presented in SolarPower Europe's O&M Best practice Guidelines version 4.0 have been adapted to match the Jordanian market context.

Thus, the scope of the current work also includes smaller scale solar PV installations in the 100s of kW scale such as C&I and residential rooftop installations that are prevalent in the Jordanian market. Recommendations related to O&M for distributed solar installations are explained in Chapter 15. O&M for rooftop solar. New to this edition of the O&M Best Practice Guidelines is a chapter on Battery Energy Storage Systems (BESS). Given the need for grid reinforcement in the Jordanian market to integrate larger amounts of renewable energy generation capacity, BESS are becoming increasingly popular when coupled with rooftop systems. Their growing importance and the specifics of BESS technology means that stakeholders from asset owners to O&M service providers will be required to understand how to best take care of these installations and the cost of doing so.

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 to be 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, as per this example: "should, as a best practice".

1.2. How to benefit from this document

This document includes the main considerations for successful and professional O&M service provision. It can be used by all stakeholders to help improve understanding of the mandatory requirements and importance of O&M, whilst providing key recommendations for inclusion in service packages. Any stakeholders in the following section can benefit from the quality advice and recommendations that this work has to offer, and it serves as a baseline for assuring the maximum efficiency of .solar PV plants

Although the focus is Jordanian, most of the content can be used in other regions around the world. The requirements described in the maintenance part can be useful for regions with similar conditions 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 PV assets regardless of their location. Stakeholders and roles

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

Asset Owner

Asset Owners are the stakeholders that finance the EPC phase, and the overall operation of a PV power plant. They can be a single investor or part of a group and can be classified as either private individuals, investment funds, IPPs, or utilities. The preferred model for asset ownership is an SPV, i.e., limited liability companies, specifically incorporated for building, owning, and operating one or more PV plants. In some cases, when the SPV belongs to large Asset Owners, such as utilities or IPPs, some, or all, of the roles of Asset Owners, Asset Managers, project developers, O&M and EPC service providers may be done in-.house

Lender

The lender or debt provider (financing bank) is not considered as an Asset Owner even if the loans are backed up by securities (collateral). The lender normally measures the risk of providing debt service based on the debt service coverage ratio (DSCR) of an Asset Owner. The role of the lender is evolving, with enhanced considerations and involvement regarding the requirements for the debt provision. Some projects also have a mezzanine lender providing junior debt services, where another layer of debt is provided at a higher risk than in the original lender's case.

EPC service provider

The entity in charge of the engineering, procurement, and construction of a solar power plant. An EPC service provider is responsible for delivering a complete PV power plant to the Asset Owner, handling all aspects from seeking authorisation for the construction to commissioning and securing a grid connection. Their role is very important in procuring quality components and ensuring quality installation, which have a large impact on the long-term performance of solar power plants. Many EPC service providers also offer O&M services to the solar power plants they develop. They often provide a 2-year performance warranty period lasting from the COD until the delivery of an FAC. In certain mature markets the role of the EPC service provider is increasingly split between different entities. For more information, see SolarPower Europe's EPC Best Practice Guidelines.

Asset Manager

The service provider responsible for the overall management of the SPV, from a technical, financial, and administrative point of view. The Asset Manager ensures that SPV and service providers fulfil their contractual obligations. Asset Managers also manages the site to ensure optimal profitability of the PV power plant (or portfolio of plants) by supervising energy sales, energy production, and O&M activities. Asset Managers furthermore ensure the fulfilment of all administrative, fiscal, insurance and financial obligations of the SPVs. Asset Managers review the performance of the sites regularly and report to Asset Owners and seek to balance cost, risk, and performance to maximise value for stakeholders. In some cases, when the SPV belongs to large Asset Owners, such as utilities or Independent Power Producers (IPPs), the AM activity is done in-house. For more information, see SolarPower Europe's Asset Management Best Practice Guidelines (available at www.solarpowereurope.org).

O&M service provider

The entity that responsible for the O&M activities as defined in the O&M contract. In some cases, this role can be subdivided into:

- **Technical Asset Manager,** serving as an interface between some of the technical O&M activities and the Asset Owner. This person is responsible for providing high-level services such as performance reporting to the Asset Owner, managing contracts, and managing invoicing and the warranty agreement
- **Operations service provider** is responsible for the monitoring, supervision, and control of a PV power plant alongside maintenance coordination
- **Maintenance service provider** carries out maintenance

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

Technical AdvisorsTechnical Advisors and Engineers

Individuals or teams of experts that provide specialised services (e.g., detailed information, advice, technical consulting). Their role is important as they ensure that procedures and practices are robust enough – according to standards and best practices – to maintain high performance levels from a PV plant. Technical advisors can represent different stakeholders (e.g., investors and lenders) but often an independent engineer is employed in an attempt to minimise the risk of bias towards any party.

Specialised suppliers

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

Authorities

Local (e.g., the municipality), regional (e.g., the provincial or regional authorities supervising environmental constraints), national (e.g., the national grid operator) or international (e.g., the authors of a European grid code) bodies with competence in areas that relate to stages of a project's lifecycle.

Off-taker

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

» The state or national grid operator / electricity seller(s), or specific authorities for renewable energy in an FiT scheme

» Energy traders or direct sellers in a direct marketing scheme

» End customers in schemes that support autonomy in energy supply

Aggregator

An entity that combines multiple customer loads or generated electricity for sale, purchase, or auction in any electricity market. This is useful for Asset Managers and O&M service providers as aggregators can provide them access to electricity markets, balancing markets, and other future flexibility markets, helping them to sell power produced by distributed assets or stockpiled in storage assets and unlock new revenue streams from providing flexibility services.

Data-related service providers

Companies that provide hardware and software solutions such as monitoring systems, asset management platforms, CMMS, or ERP. Other players in this segment provide advanced data analysis by using site data to calculate KPIs (analytical tools) or provide a repository for key site information whilst facilitating some administrative workflows. Data is crucial to ensuring that Owners, Asset Managers and O&M service providers are aware of on-site conditions, including equipment behaviour. It is vital for ensuring that prompt action is taken once a fault has been identified and providing important information on potential areas of underperformance. There is a tendency in the industry to opt for solutions that integrate all the above-mentioned systems and platforms into one software. There are several advantages to this approach, and it can be considered a recommendation.

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

» an investor may take asset management responsibilities

» an Asset Manager may take over a more active role and intervene in operations

» an Asset Manager may even take over full O&M

» an O&M service provider's role may be subdivided or may also include some asset management activities such as specified below (e.g. reporting, electricity sale, insurance, fiscal registrations, etc)

» the end customer (or electricity buyer) may at the same time be the Asset Owner, Asset Manager, and O&M service provider (e.g., a PV power plant on an industrial site to cover its own energy needs).

Figure 2 on the following page shows the classification and distribution of the responsibilities among the different stakeholders and, in particular the Asset Manager (Asset Management), the O&M service provider (Operation & Maintenance) and the Engineers (Technical Advisors). This figure is redesigned and based on a figure of GTM (2013).

In general, the O&M service provider will have a more technical role (energy output optimisation) and the Asset Manager will undertake more commercial and administrative responsibilities (financial optimisation). The technical aspects of Asset Management are called Technical Asset Management, a role that is often assumed by the O&M service provider. The O&M service provider sometimes even assumes some tasks related to procurement. These Guidelines handle Technical Asset Management as part of the core roles that can be provided by the O&M service provider and thus dedicates a standalone chapter to Technical Asset Management.

FIGURE 2. ROLES AND RESPONSIBILITIES OF DIFFERENT STAKEHOLDERS IN THE FIELD OF O&M. ASSET MANAGER AND O&M SERVICE PROVIDER RESPONSIBILITIES CAN OVERLAP, AND TECHNICAL ASSET MANAGEMENT CAN BE ASSUMED BY EITHER PARTY.

Lifecycle project management.

Support to the owner throughout the project phases:

- » Development
- » Construction
- » Operation
- » Decommissioning
- » Contract scoping
- » Risk identification & tracking
- » Cost management
- » Execution of obligations

Commercial and Financial Asset Management.

- » Strategy management
- » Corporate administrative services
- » Financial reporting
- » Accounting
- » Customer relationship
- » Accounting assistance
- » Invoicing/ billing and payments
- » Revenue control
- » Cash flow managment
- » Working capital reconciliation
- » Financial control
- » Contract management
- » Suppliers account management
- » Suppliers penalties invoicing
- » Interface with banks and investors
- » Equity/debt financing management
- » Tax preparation, filing and administration

Engineering

Engineering

- » Plant (re)commissioning
- » Quality audit/inspection
- » Re-powering and upgrades
- » Monitoring install/ retrofit
- » As-built design documentation
- » Plant design overview

Procurement

- » Supplier selection and evaluation
- » Supply account control
- » Supply chain control

Technical Asset Management

- » Reporting to asset owner
- » Site visits and non-intrusive inspections
- » Management of ancillary service providers
- » Interface with local energy authorities
- » Regulatory compliance
- » Warranty management
- » Insurance claims
- » Contract management
- » Asset optimisation
- » Environmental management
- » Health & safety management

Power Plant Operation

- » Documentation Management System
- » Plant performance monitoring and supervision
- » Performance analysis and improvement
- » Optimisation of O&M
- » Power plant controls
- » Power generation forecasting
- » Grid code compliance
- » Reporting to Technical Asset Manager
- » Management of change
- » Power plant security
- » Maintenance scheduling
- » Spare parts management
- » Decommissioning

Power Plant Maintenance

- » Preventive maintenance
- » Corrective maintenance
- » Predictive maintenance
- » Extraordinary maintenance
- » Additional services:
  - PV site maintenance (panel cleaning, vegetation control, PV waste disposal & recycling, etc.)
  - General site management (pest control, waste management, buildings maintenance, etc.)
  - On-site measurements (meter readings, thermal inspections, etc.)
  - Spare parts storage

Operation & Maintenance

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

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

2 Definitions

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

Indeed, it is more challenging for terms in the Operational field since those are less technical and not standardised as in the case for Maintenance. The chapter provides a short list which is not exhaustive but reflects the different sections of this document. Below are definitions and Jordan Specific terms.

Additional Services	Actions and/or works performed, managed, or overseen by an O&M service provider, which are not (but can be if agreed) part of the regular services and normally charged "as-you-go" (e.g., ground maintenance, module cleaning, security services etc.). Some of the additional services can be part of Preventive Maintenance, depending on the contractual agreement.
Asset Management Platform	A software package or suite of tools that is used by the Asset Manager to store and manage technical, and non-technical data and information collected from and relating to the solar asset, portfolio or Special Purpose Vehicle (SPV). It combines the abilities of a Computerised Maintenance Management System (CMMS) and an Enterprise Resource Planning System (ERP).
Computerised Maintenance Management System (CMMS)	Software designed to measure and record various O&M Key Performance Indicators (KPIs), such as Acknowledgement Time, Intervention Time, Reaction Time, Resolution Time, and equipment performance, including Mean Time Between Failures, to optimise maintenance activities.
Contract management	Managing the rights and obligations of contracts to ensure they are fulfilled. For Asset Managers this involves building, developing, and maintaining business relationships with counterparties of different contracts. This includes selecting service providers, negotiating with banks, landowners, and operations providers, managing insurance and warranty claims, as well as ensuring compliance of the contractual obligations, such as notifying, filing, and reporting. For service providers this involves fulfilling their agreed contractual obligations.
Contractual Framework	An agreement with specific terms between an Asset Owner and a service provider. This agreement defines the scope of the services to be provided, the management and interfaces of those services, and the responsibilities of each party. Liquidated damages and bonus schemes are also part of the contractual commitments.
Control Room Services (also known as Operations Centre Services or Remote Operations Centre)	Comprehensive actions like PV plant monitoring, performance analysis, supervision, remote controls, management of maintenance activities, interaction with grid operators, regulators, Asset Managers and Asset Owners, and the preparation and provision of regular reporting, performed by experienced and qualified staff in a control room, during operational hours for 365 days/year.
Corrective maintenance	Measures (immediate or deferred) taken to correct failures, breakdowns, malfunctions, anomalies, or damages detected during inspections, or through monitoring, alarming, or reporting or any other source. These measures are designed to restore a PV system to regular operating status.

Data and monitoring requirements	Technical and functional specifications for both software and hardware systems used to collect, transmit and store production, performance, and environmental data for power plant management.
Defects Liability Period (DLP) (or Defects Notification Period (DNP))	A period post-construction (usually from the COD) where the EPC service provider is liable for any defects reported by the customer. This can, in principle, last for several years and terminates with the issuance of a Final Acceptance Certificate (FAC) to the EPC service provider.
Document Management System (DMS)	A management system that records, manages, and stores documents required for O&M and AM. These include previous and current versions of technical plant and equipment documentation and drawings, maintenance manuals, photos, reports, reviews, and approvals. DMS also define proper document formats and the processes for information exchange. Due to the increasing complexity of documents and to enable advanced analytics, electronic DMS with the ability to handle meta-tags and searchable, editable documentation are becoming best practice.
Environment, Health & Safety (EH&S)	Environment, Health and Safety indicates the activities performed to ensure environmental protection, occupational health and safety at work and on site. These activities cover staff and visitors and are determined by national regulations and legislation.
Enterprise Resource Planning System (ERP)	Business management software that allows a company (such as an O&M service provider or an Asset Manager) to gather, store, manage and analyse all types of data relevant to their operations.
Extraordinary Maintenance	Actions and/or works performed in case of major unpredictable faults, such as serial defects, force majeure events etc, that are generally considered outside of the ordinary course of business.
Good industry practice	A legal term, often used in contracts, good industry practice is synonymous with best practice throughout SolarPower Europe's guidelines. The term refers to practices, methods, techniques, standards, codes, specifications, acts, skills, and equipment that go beyond the established minimum acceptable baseline in the international solar power industry (including in the construction and installation of solar power facilities). They are adhered to by high-quality service providers and are designed to help accomplish the desired result of a decision or action (or lack thereof), in line with applicable laws and permits. Good industry practices are reliable and safe, economically efficient, protect the environment and are done with the degree of skill, diligence and prudence that would ordinarily be expected.
Grid code compliance requirements	Equipment, procedures, and actions required by a grid operator to comply with grid safety, power quality and operating specifications.
Grid Code Compliance Test	The test which is applied to confirm the compliance of a plant with the Grid Code requirements.
Grid Operator	The entity or entities responsible for operating distribution and transition networks. In Jordan, JEPCO, EDECO, or IDECO operate different distribution networks. The transmission system operator (TSO) is called NEPCO.
Insurance claims	An application to an insurer, from a customer, for reimbursement based on their insurance policy terms.
Key Performance Indicator (KPI)	SMART (specific, measurable, achievable, relevant, time-bound) parameters used to evaluate relative performance against a set of fixed objectives.
Management of change	Management of change defines the way to handle necessary adjustments of the design of a PV power plant after the Commercial Operation Date (COD). Changes require a close cooperation between the Asset Owner and the O&M service provider.

Mobilisation period	The time granted to an EPC, or O&M service provider to mobilise the equipment and personnel required to commence work.
Monitoring System	The digital platform used for the overall management of PV plants or a PV plant portfolio. It allows for centralised monitoring of the functioning, energy generation and reference data of a PV plant and its components. Ideally, this would be performed through a real-time monitoring module that retrieved data from local Supervisory Control & Data Acquisition (SCADA) systems. It also includes operational modules such as ticket dispatching, analytics, and reporting. The centralised monitoring module receives data for 24 hours a day, all year from in-plant SCADA systems, purpose-built sensors for measuring irradiation and temperature and other sources such as meteorological information.
Net – Metering Scheme	An electricity billing mechanism that allows consumers who generate some, or all their own electricity through an on-grid PV system to use that electricity anytime, instead of when it is generated. Under such schemes, commercial electricity meters measure PV systems' generation and beneficiaries load consumption at the same electrical point.
Performance analysis & improvement	Measurements, calculations, trends, comparisons, inspections, etc. performed to evaluate a PV plant, segments and/or single component performance, site conditions, equipment behaviour, etc., and to provide reports and assessment studies to interested parties (customer, public authority, etc).
Personnel & training	Operators, technicians, engineers, and managers employed for the execution of the O&M activities and training plans/programmes to train them on relevant PV plant related aspects and to keep them continuously updated on their respective roles.
Point of Common Coupling	The electrical connection point between a PV plant and the utility grid, where the official commercial meter is installed and at where the plant should comply with the Grid Code requirements.
Power Generation Forecasting	Adoption of forecasting tools calculating expected power production for a certain timeframe from weather forecasts to supply the expected power production to Owner, grid operator, energy traders or others. This is normally country and plant dependent.
Power plant controls	Actions required by the grid operator, for controlling active and/or reactive power being fed into the grid, other power quality factors that are subject to adjustments and/or (emergency) shut down (if applicable).
Power plant supervision	The supervision and analysis of data from a monitoring system, by experienced personnel. This takes place during daylight hours and managed by one or more control rooms (365 days/year). The reception and qualification of the alarms from the monitoring tool is also considered to be part of the supervision.
Predictive Maintenance	Actions and/or techniques that are performed to help assess the condition of a PV system and its components, predict/forecast and recommend when maintenance actions should be performed. The prediction is derived from the analysis and evaluation of significant parameters of the component (e.g., parameters related to degradation). Monitoring systems and expert knowledge are used to identify the appropriate actions, based on a cost benefit analysis.
Preventive Maintenance	Actions, testing, or measurements to ensure optimal operating conditions of equipment and the entire PV plant, preventing defects and failures before they arise. Preventive maintenance takes place periodically, and according to a specific maintenance plan and schedule.
Regulatory & statutory compliance	Compliance with any law, statute, directive, bylaw, regulation, rule, order, delegated legislation, or subordinate legislation directly applicable in the country where a service is provided or an SPV and PV power plant are located. This also includes respecting any mandatory guidelines and measures issued by a utility or any other competent public authority.

Reporting and other deliverables	Obligations to provide updates, or deliver results and products, to the relevant stakeholders, issuing from a contract or as best practice.
Security	Actions, procedures, equipment and/or techniques that are adopted on site and remotely to protect the plant from theft, vandalism, fire, and unauthorised entry. Security services are to be provided be specialised security service providers.
Spare Parts Management	Ensuring that the right amounts and types of components and equipment are available to carry out prompt maintenance and minimise the downtime of a PV plant. They can be stored in warehouses or in the O&M service provider's stocks.
Warranty management	Warranty management usually aggregates activities of a diverse nature which are linked to areas such as supply of equipment and services, and project construction. All these responsibilities (warranties) are usually materialised when a PAC is issued by the EPC service provider. Warranty Management is the activity that manages these warranties with the objective of reducing the costs and response times after warranty claims for repair or replacement of certain PV system components (under the warranty of the EPC service provider and/or the components manufacturer).
Wheeling Scheme	An electricity billing mechanism that allows consumers who generate some or all their own electricity through an on-grid PV system far away from their loads, to use that electricity anytime, instead of when it is generated. Under such schemes, commercial electricity meters, which measure PV systems' generation, and meters that measure the beneficiaries' consumption are separate. Additional wheeling fees and losses should be applied as per regulations from the Energy & Minerals Regulatory Commission (EMRC).

3 Environment, Health & Safety

3.1. Environment

Renewables 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. The Ministry of Environment in Jordan is the main regulatory body in this regard.

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 from the relevant authorised body in Jordan. In areas with water scarcity, water use for module cleaning should be minimised, or proper dry cleaning could be considered.

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.

3.2. Health and Safety

The Jordanian Ministry of Labour has issued laws on occupational health and safety, such as Law No. 8 of 1996 (Labour Law of 1996) and its modifications, and the table of occupational injuries and the estimation of the percentages of disability that arise from them (annexe to Labour Law No. 2 of 1996).

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 6.10. Power plant security) .

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

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

As well as the inherent dangers of a typical solar plant, every site will have its own set of individual hazards which must be considered when working on the plant. An up-to-date plan of hazards is important for the O&M Contractor to use to manage his own staff and to provide third party contractors with adequate information. It is usually the case that the O&M Contractor holds the authority and responsibility to review and, where necessary, reject works taking place in the plant. Failure to carry this out properly has important consequences to general safety.

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

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

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

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

Before starting any activity on-site the Asset Owner will deliver risk assessment and method statements to the O&M Contractor who will provide a complete list of personnel Training Certifications and appoint a H&S coordinator. During the whole duration of the contract the O&M Contractor will keep the H&S file of each site updated.
The O&M Contractor must have his personnel trained in full accordance with respective national legal and professional requirements, that generally result in specific certification to be obtained, for example in order to be allowed to work in MV and/or HV electrical plants. Within Europe, referral to European Standards is not sufficient (examples of standards used today are ISO 14001, OHSAS 18001 etc).

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

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

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

1. Medical problems

It is critical that all personnel engaged in work on solar farms have considered and communicated any pre-existing medical problems and any additional measures that may be required to deal with them.

2. Slips, trips and falls

The terrain, obstacles and equipment installed on a solar farm provide plenty of opportunities for slips, trips and falls both at ground level and whilst on structures or ladders; and for roof-top or carport systems, fall-protection and additional equipment is required when working at heights.

3. Collisions

Collisions can occur between personnel, machinery/ vehicles and structures. The large areas covered by solar farms often necessitate the use of vehicles and machinery which when combined with the generally quiet nature of an operational solar farm can lead to a lack of attention. General risks such as difficult terrain, reversing without a banksman and walking into the structure supporting the solar panels require special attention.

4. Strains and sprains

Lifting heavy equipment, often in awkward spaces or from uneven ground, presents increased risk of simple strains or longer term skeletal injuries.

5. Electrocution

Operational solar farms whether energised or not present a significant risk of electrocution to personnel. This risk is exacerbated by the nature and voltage of the electricity on site and the impossibility of total isolation. Staff engaged in electrical work obviously suffer the greatest risk but everybody on site is at risk from step potential and other forms of electrocution in the event of a fault. Specific training needs to be given to all those entering a solar farm as to how to safely deal with the effects of electrocution. In addition to general electrical safety, common issues for PV plants include: arc-flash protection when working on energized circuits; and lock-out-tag-out to ensure circuits are not unintendedly energised.

6. Fire

Several sources of combustion exist on a solar farm, the most common being electrical fire others including 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 both avoid the risk of fire and what to do in the event of a fire.

7. Mud and water

Many solar farms have water travelling through them such as streams and rivers, some have standing water, and some are floating arrays. Mud is a very common risk particularly in 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 as well as such mechanisms as unsecured doors can present a risk of mechanical injury on site.

9. Weather

The weather presents a variety of hazards, the most significant of which is the risk of lightning strike during an electrical storm. Due to the metal structures installed on a solar farm an electrical storm is more likely to strike the solar array than surrounding countryside. A solar farm MUST be vacated for the duration of any electrical storm. Working in cold and rainy weather can cause fatigue and injury just as working in hot sunny weather presents the risk of dehydration, sunburn, and sun stroke. Working during sunny days for undertaking maintenance and/or test in site lead to sunstroke. To avoid this, drinking sufficient water and staying in the shade is recommended.

10. Wildlife and livestock

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, snakes, insects such as wasps and other wildlife as well as 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, tics 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 PV plants and has been found to be carcinogenic. Mowing has several hazards including flying objects. Every job at a PV site should have safety precautions identified and implemented.

Everyone entering a solar farm, for whatever reason, should have been trained in the dangers present on solar farms and be trained for the individual task that they will be performed. They should have all of the PPE and tools necessary to carry out the work in the safest way possible. The work should be planned in advance and everyone concerned should have a common understanding of all aspects related to the safe execution of their task. Different countries will mandate written and hard copy paperwork to meet legislation, but best practice is to exceed the minimum requirements and to embrace the spirit of all relevant legislation.
Best practice in H&S sees the ongoing delivery of training and sharing of lessons learned and work methods. By increasing the skills of persons involved in the industry, we can make the industry both safer and more productive.

4 Personnel & Training

It is of critical importance that all Operations and Maintenance Personnel have the relevant qualifications to perform the 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 developments and by different engagements.

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

Everyone who enters a solar plant needs to be trained in the dangers present in addition to their individual skills and experience required for the tasks that they normally perform. Awareness of the necessary health, safety, and security regulations is a must.

As the solar industry continues to grow, it follows those certain skills need to be taught, developed, and strengthened to create a suitable workforce. Furthermore, as the technology evolves new skills will emerge in the market which will require new training programs. It is therefore essential for all employers in the industry to create a training scheme, internally and externally, to create opportunities for skills improvement and development.

The creation of a training matrix as shown in the proposed skills matrix in Annex b enables a company to record skills, both formal and informal, to identify gaps and to provide training to fill the gaps and full fill its needs and the industry's needs. Furthermore, it is important to continuously update the training matrix to meet the market requirements.

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

The matrix goes beyond any educational background and focuses on the skills required by the O&M operators.

It is advisable to create a certification program for both service providers and individuals. Service providers need to be classified and licensed based on their experience, track record, financial capability, and available resources. The instructions of licensing persons engaged in the design, supply, installation, operation, maintenance and inspection of renewable energy systems, as indicated in "Law No. 13 Of 2012 - Renewable Energy and Energy Efficiency Law" and the EMRC regulations, should be used as a reference point. However, these instructions need to be revised and updated every two to three years to ensure they remain relevant to the rapid changes in the solar industry. Furthermore, a special license should be issued for entities working in the O&M field because operation and maintenance requires different skills and qualifications that several EPC contractors might not possess.

On the other hand, individuals, particularly technicians, should be classified based on their level of experience, skills, and the number of working hours. For example, electricians can be classified as electrician under training, semi-skilled, and skilled electricians and in order to be promoted from one level to another, a certain number of working hours and skill sets need to be achieved and/or maintained. Also, training should be divided into two categories, on the job training and technical school training. Training should also cover theoretical and practical aspects of plant operation and maintenance.

5 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. 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.

It is not always easy to make a clear distinction between the roles and responsibilities of a Technical Asset Manager, and those of an O&M service provider. Ideally, the Technical Asset Manager should act as a liaison between the Asset Owner and the O&M service provider, ensuring that the latter is fulfilling their obligations under the O&M contract. However, elements of these roles are often combined in Jordan. For example, in the case of Design-Build-Own-Transfer, or wheeling projects, Owners may rely on the O&M service provider to fulfil most of the roles and responsibilities of the Technical Asset Manager, including managing the asset, spare parts, EH&S compliance, insurance claims, security, and the interactions with the grid operator and regulatory authorities. Where the Owner handles aspects of these services, the Technical Asset Manager must still monitor the O&M service provider's performance to ensure that the power plant is properly maintained, and any risks are properly identified and mitigated.

5.1. 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 under-performing sections of the plants managed.
Table 1 includes some proposed quantitative and qualitative indicators which should be in reports as a minimum requirement, a best practice, or a recommendation. For more details on the individual indicators, see Chapter 11. Key Performance Indicators.

A new trend in the industry is to extend the reporting beyond the pure 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 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 9. Spare Parts Management)
- Compliance with regulatory requirements, including from grid operators, regional and national authorities for conditions of operation (refer to section 5.4 Interface with local energy authorities & regulatory compliance)
- Warranty management, warranty claims performance with various component suppliers (refer to section 5.5 Warranty management)
- Insurance claims management, providing lifecycle reporting on new claims raised, claims in progress and claims settled (refer to section 5.6 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 5.7 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 5.11 Technical risk management)
- Status of the security and surveillance system. In this case, the security service provider is responsible for providing the relevant input.

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
	EH&S issues	Best Practice
	Spare parts stock levels and status	Best Practice
	Physical and Cyber Security Issues	Minimum Requirements
	Preventive Maintenance tasks performed	Best Practice

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

5.2. Site Visits and non-intrusive inspections

It is recommended as a best practice 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.

5.3. 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 7.5. 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 environmental, health and safety policies.

5.4. 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.
- 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.

5.5. 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

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

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.

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.

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.

Endemic Failures

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

Performance Warranty

EPC 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

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 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.

5.6. 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.

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.

5.7. 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.

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.

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.

5.8. 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 repowering[1])

» 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.

5.9. 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 3. Environment, Health & Safety.

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

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 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 solar PV power plant and the appropriate

1 For detailed information about revamping and repowering, please refer to chapter 8. Revamping and Repowering of the O&M Best Practice Guidelines

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.

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

5.10. 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 3. Environmental, Health & Safety.

5.11. 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 cost/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 [2].

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.

2 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

6 Power Plant Operation

Operations concerns remote monitoring, supervision, control of the solar PV power plant, and technical performance optimisation (refer to Chapter 5. 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.

FIGURE 3. OVERVIEW OF THE MOST IMPORTANT TASKS IN POWER PLANT OPERATION

Documentation Management System (DMS)*

The DMS is an important requirement which allows changes to be traced during the lifetime of a plant's operation. The important aspects to trace the PV plant management information are:

Information	▪ Components And Manuals ▪ Plant Location Overview ▪ Pv Plant Layout ▪ Electrical Diagrams ▪ Eh&S Rules
Management Control	▪ Storage Of Documents ▪ Logbook Of Modification ▪ Access Management
Record Control	▪ Alarms Linked With Maintenance Tasks ▪ O&M Automatic Logbook ▪ Unavailability Documentation and Recording

Plant performance monitoring and supervision

The O&M service provider is responsible for monitoring and supervision of PV plant performance. In the Fault Management there are different roles and interaction levels:

1st Level Support	CONTROL ROOM ▪ Fault Detection ▪ Ticketing ▪ Coordination Of Actions SITE TECHNICIAN ▪ Analysis And Fault Resolution On Site
2nd Level Support	PV ENGINEERS ACCOUNT MANAGERS PROJECT MANAGERS
3rd Level Support	VENDOR'S EXPERTS PROJECT MANAGERS ACCOUNT MANAGERS

Optimisation of O&M

To optimize O&M activities, reducing production losses and costs, the following information must be analyzed:

- Response Time correlated to classification of events and root causes.
- Analysis of costs incurred for various interventions.

Power plant controls

The Power Plant Controller is a control system that can manage several parameters, such as:

- Absolute Active Power Control.
- Power Factor Control.
- Ramp Control.
- Frequency Control.
- Reactive Power Control.
- Voltage Control.

Power Generation Forecasting

The O&M service provider may provide forecasting services, if required by the Asset Owner. Forecast requirements are characterized by:

MINIMUM REQUIREMENT

- Forecast horizon (typically below 48 hours)
- Time resolution (typically 15 minutes to one hour)
- Update frequency:
  - Day-ahead forecasts
  - Intraday forecasts
  - Combined forecasts

The most common KPIs for forecast quality are:

- Root Mean Square Error (RMSE)
- Mean Absolute Error (MAE

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 specialized security service provider will be responsible for:

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

An intrusion system may be formed by:

- Simple fencing or barriers
- 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

Reporting and Technical Asset Mangment

The Operation team provides periodical report. For more I details see 5. Technical Asset Management

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 analyzed at the following level:

MINIMUM REQUIREMENT

- Portfolio level under control of the O&M service provider
- Plant level
- Inverter level

RECOMMENDED

- String level

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 depend on the voltage level of the grid.

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

6.1. Document 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 (See annex A for relevant standards), 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).

6.1.1. 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, EH&S 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.

6.1.2. 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 documents. 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

6.1.3. 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, workflows 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.

6.2. 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.

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

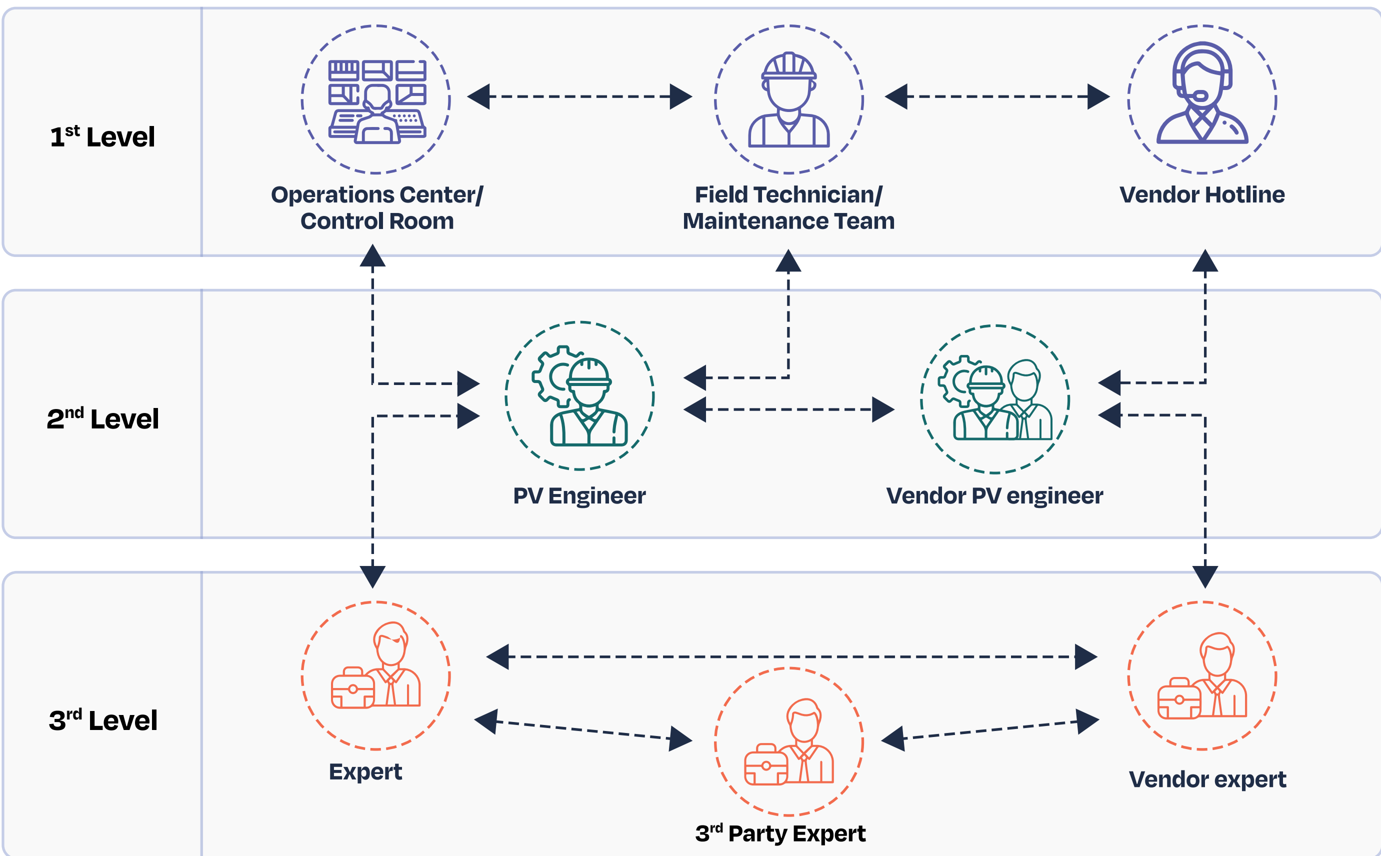
» If the fault cannot be sufficiently categorised, the Operations Center may call out a field technician who can be a local electrician or member of the maintenance team. This person will analyse and try to resolve the fault on-site (1st Level Support). Their knowledge and access rights may be not sufficient 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

» 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 Centre closes the ticket

FIGURE 4. SUPPORT LEVELS IN FAULT MANAGEMENT



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 10. Data and monitoring requirements.

6.3. 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 11. 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.

6.4. 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 7. Power Plant Maintenance and Chapter 9. Spare Parts Management.

6.5. 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

6.6. 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.

6.7. 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 s (IRR-DCC-MV and IRR-TIC) and EMRC regulations (ENA Standard). The operator of the grid , to which the PV plant is connected (either low voltage grid or medium voltage grid or high voltage grid) provides the requirements (mentioned in the national grid code and EMRC regulations) for power quality, voltage regulation and management of active and reactive power .

Depending on the voltage level of the grid the plant is connected to, the specificities and quality requirements for the PV plant change. A higher level of the grid usually has more specific and higher quality requirements.
Most of the grid-connected utility scale solar PV power plants in Jordan must be controllable 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.

It is expected that the O&M service provider is familiar with all the details of the grid code and grid operator requirements. Depending on the regulations, either the grid operator himself is steering the PV plant controller (with remote signals) or the Operations team is managing the plant controller per direction of the grid operator .

6.8. 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.

In case of any change in the technical specifications of the solar power plant after the Commercial Operation Date, the grid operator must be informed especially if the change will result in an overall modification on the plant's generation capacity, or if main components of the generation facility, such as transformers and inverters, are to be replaced.
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.

6.9. 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/or the security service provider, the Asset Owner must put in place a Security Protocol in case an intrusion is detected.

In Jordan there are strict legal requirements for security service providers. Therefore, PV power plant security may be ensured by specialised security service providers, subcontracted by the O&M service provider. The O&M service provider is responsible for the correct functioning of all the security equipment, including the intrusion and surveillance systems. The security service provider is responsible for processing the alarms arriving from the security system, following agreed security protocols and, using the surveillance system 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 can optionally act as an interface between the Asset Owner and the security service provider.

A security system may be formed of simple fencing or barriers but may also include alarm detection and alerting systems and remote closed-circuit television (CCTV) video monitoring. 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.

6.10. 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 5. Technical Asset Management.

7 Power Plant Maintenance

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.

FIGURE 5. OVERVIEW OF THE DIFFERENT TYPES OF POWER PLANT MAINTENANCE

Included all O&M contracts

Preventive Maintenance

Preventive Maintenance are the **core elements** of the maintenance services to a PV plant. It comprises of regular visual and physical inspections, as well as verification activities on all the key components of the solar park. 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 the 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 (DC array, transformer, inverter, combiner box and/or string level).

Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when **major unpredictable event**s 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 incladed 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 meter readings or thermal inspections.

7.1. 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. All preventive maintenance activities should follow manufacturer recommendations. 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. These tasks should be reported to the Client (Asset Owner or Asset Manager). This is particularly important for demonstrating that the task plan is being followed.

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).

There are several examples of Predictive Maintenance tasks including, cleaning inverter filters and fans, and ensuring that a site's draining systems and civil works are in good working order. A further crucial aspect of Predictive Maintenance is using thermographic inspection techniques to identify defective panels on a PV plant. Indeed, several categories of anomalies (hot spots, hot strips, moisture ingress, soling, etc.) can occur, significantly reducing the productivity of the whole plant. Relevant inspection procedures are performed either by operators with handheld cameras, or using remotely piloted drones, or piloted aircraft equipped with dedicated thermal and optical payloads. It is noteworthy that aerial thermography as an innovative technology (see section 13.2. Advanced aerial thermography), can significantly benefit power plant maintenance procedures as it can lead to time and cost savings as well as safety improvements.

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.

7.2. 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 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 to restore the functionality of a device, that could be included in the O&M agreement or billed separately on hourly rates:

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 / 3rd party expert	Reconfiguration or Parameterisation of an inverter

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.

7.3. 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.

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 want 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 can 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 – The Operations team detects an underperforming section of the PV system. This could be the power transformer, the inverter, or any other area that has a lower performance level in comparison to other versions of the same piece of equipment in the same conditions (or past behaviours evidence of a loss of production). After the anomaly detection or recognition, an incident is created and immediately sent to the Maintenance team. Before anything happens that might jeopardise contractual guarantees and require urgent interventions, the O&M service provider can decide to do a "General Infrared Inspection" in the PV field taking pictures with drones. The main purpose of this inspection is to identify possible problems related to PV modules that might justify the loss of performance. This is considered as a type of Predictive Maintenance.

Example 3 – The Operations team or the inverter provider monitors all critical parameters of the inverter and can provide information related to the health and performance of each individual inverter as an absolute value, or as a relative comparison of different inverters at one PV site or compare a batch of inverters between different PV sites. This type of information can help O&M service providers to operate PV sites more cost effectively without compromising equipment health. This also allows the Asset Manager (or Owner) to compare how inverters are aging at various sites managed by different O&M service providers and evaluate how well their investment is being managed. For instance, one O&M service provider perceived as more expensive might be providing more regular care to the inverters compared to another. As a result, the inverters are operating more efficiently and are not ageing as fast, resulting in less stress and lower expected failure.

Example 4 – Predictive Maintenance for optimised hardware replacement cycle relying on big data analytics or artificial intelligence. *For more information on this innovation, see section 13.4. Predictive maintenance for optimised hardware replacement.*

7.4. Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant that require substantial activities and works to restore the previous plant conditions (or any maintenance activity generally not covered or excluded from the O&M Contract).

"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[3] on equipment, occurring suddenly and after months or years from plant start-up

3 For a definition of endemic failures and its repercussions in terms of warranty, see section 5.5. Warranty management.

» Modifications required by regulatory changes

In cases where the EPC and O&M service providers 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 8. 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 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

7.5. Additional services

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

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

For example, regular cleaning is an important part of solar maintenance and the problems associated with soiled modules are often underestimated. Module cleaning methods vary from manual, to robotic and mechanical. Each have their own advantages and disadvantages. Cleaning frequencies vary greatly on ground, rooftop, and floating solar arrays. The frequency of cleaning should be decided on a site-by-site basis, and it may be that certain parts of a site will need cleaning more often than other parts of the same site.
When choosing a module cleaning company, asset owners and O&M providers should check the following:

» The suggested method of cleaning is fully in-line with the module manufacturer's warranty. Pressure washing modules is not an acceptable cleaning method

» In Jordan water scarcity is an issue that needs to be considered. As there is currently no regulation governing the use of water for PV module cleaning, it is incumbent that the O&M service provider find the most cost-effective way of cleaning modules. This can either be through dry or wet cleaning methods, but wet cleaning methods should use high-quality, ultra-pure water only

» Health and safety considerations should be made to keep their staff safe on site. This should include some form of health and safety accreditation and specific training for solar module cleaning, including working at height, if cleaning roof mounted modules.Table 2 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.

TABLE 2. EXAMPLES FOR ADDITIONAL MAINTENANCE SERVICES

	Additional services
Solar PV site maintenance	Module cleaning
	Vegetation management
	Snow or sand 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 10.11. Data collected by specialised solar PV module field inspections) – to the extent exceeding the agreed level of Preventive Maintenance

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).

8 Revamping and Repowering

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.

8.1. Definition and rationale of revamping and repowering

Revamping and repowering are defined as the replacement of old, power production related components of a power plant 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.

When an Asset Owner decides to repower a solar PV power plant, they must inform the grid operator about the changes to the plant's original design and grant their approval before the work can go ahead

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.

FIGURE 6. DIFFERENCES BETWEEN REVAMPING AND REPOWERING AND THEIR MAIN DRIVERS

Revamping	Repowering
involves replacement of components (mainly inverters and modules) without substantially changing the plant's nominal power.	involves replacement of components (mainly inverters and modules) which causes a substantial change to the plant's nominal power

Main drivers for Revamping or Repowering

- » Aging solar assets: In early 2022, there was over 1 TW of PV capacity installed worldwide. The fleet of modules and inverters is getting older which leads to an increased failure rate, higher degradation and expiring warranties.
- » Unavailability of spare parts and support: Many manufacturers of modules and inverters have left the market. This complicates the supply of spare parts or repair solutions and may leave an exchange of components as the only alternative.
- » Technological Improvements: The technological advancement of modules and inverters has been significant. Thus, exchanging components can lead to an improved performance and availability. As further benefits, new components offer higher design flexibility and advanced features at reduced maintenance costs. Another example is installing battery storage system on an existing plant.
- » Decreasing prices: The prices for PV components have decreased substantially. This trend helps to create an economically feasible re-investment case.
- » Environment, Health & Safety: Old components may not be compliant with new EH&S legislation and revamping may be required to maintain compliance.
- » Additional benefits: A repowering project usually includes additional benefits, such as new warranty terms and compliance with the latest regulations. Furthermore, it provides an opportunity to correct potential planning mistakes from the initial construction

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

8.2. 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:

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

» 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

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

» 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

Further considerations

» A module repowering might underlie regulatory aspects and will vary depending on the interconnection agreement between the asset owner and the grid operator. 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

» 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

8.3. 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 underlie regulatory aspects, which will vary depending on the interconnection agreement entered between the asset owner and the grid operator. The responsible regulatory institution should be consulted well in advance to clarify aspects such as
  o Maximum power to be installed
  o 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.

8.3.1. Combiner Boxes Repowering

Repowering central inverters may necessitate the replacement of other key components to meet design requirements, such as DC combiner boxes.
Replacing DC combiner boxes is a challenging matter with several things to consider:

» Condition of DC cables and insulation

» Current capacity ratings for DC cables, as the DC side capacity is often modified while repowering inverters

» If the existing main DC cables are to be replaced, the asset owner, in consultation with all stakeholders, must determine whether to leave the old cables underground and unused or to extract them

- If new trenches and cables are to be excavated, the location must be carefully chosen to avoid damaging any other underground components
- If existing cables and cable accessories are replaced, it is critical that they be disposed of in a safe and environmentally responsible manner. In many instances, such components are recycled in exchange for a monetary incentive that may benefit the asset owner

8.4. 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

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.

9 Spare Parts Management

It is important to differentiate between Consumables and Spare Parts.

Consumables are items which are intended to be depleted or worn out relatively quickly and then replaced. They are necessary for the regular operation of the 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. 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.

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 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 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 PV system there are certain spare parts that could be considered as essential to have – no matter the cost.

Table 3 below 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.

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

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)

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.

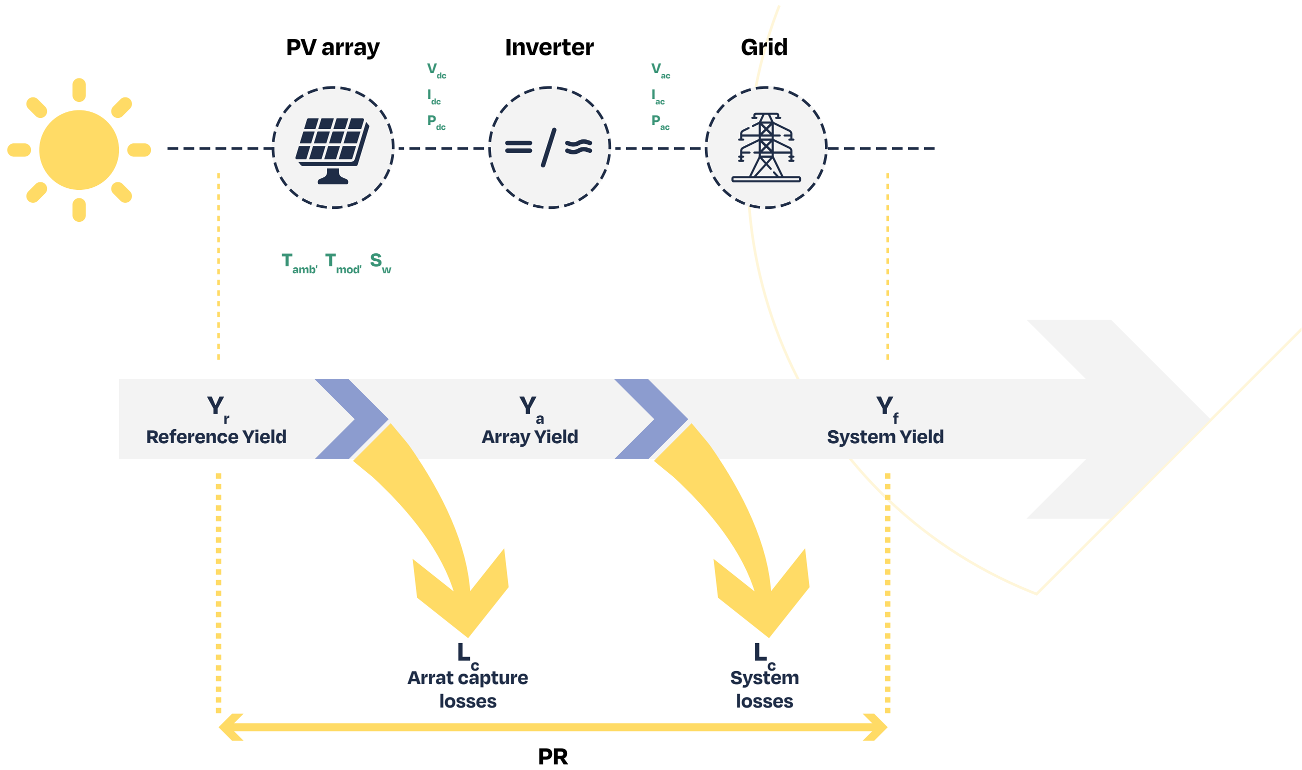
The decision to have either an on-site or an off-site warehouse facility or just an agreement with the suppliers to provide the spare parts, depends on many factors, including the kind of part, the commercial agreement, and the facilitation of the service provision. If the spare parts owned by the Asset 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.

10 Data and monitoring requirements

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 7. These yields and losses are always normalised to installed solar PV power at standard test conditions in kilowatt-peak (kWp) 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[4].

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



10.1. 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)

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

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 secured 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.

10.2. 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, fibre, wireless, etc.). 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.

10.3. Monitoring (web) portal

Monitoring portals add value by helping to identify opportunities to improve a PV power plant's operation. These include:

» Providing a better understanding and optimising the amount of time clients are paying for power and adjusting the energy consumption during peak daylight hours
» Protecting the system against power outages. If something goes wrong with the system, an alert will direct a maintenance team to the issue straight away
» Pinpointing repair solutions for the system
» Keeping track of historical weather data. This data is valuable and can help with forecasting how weather patterns might affect the overall energy production of the system
» Levelling the energy costs

The minimum set of requirements for operating a monitoring portal are:

» Internet cable
» Internet subscription

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 11. Key Performance Indicators, 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

10.4. 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.

10.5. 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 of equipment monitored should be checked to make sure it is properly labelled in the Monitoring System. This can be done by temporarily covering insolation sensors or switching off others such as string boxes or inverters.

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 it is done by automatically capturing device IDs and configuration information. This also allows for automatic detection of inverter or sensor replacement.

10.6. 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 4 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.

TABLE 4. EXAMPLES OF DATA INTEGRATION OPTIONS

Method	Advantages	Disadvantages
FTP Push or FTP Pull	» Easy to implement » No need for additional hardware	Not secure unless: - 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

10.7. 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 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 a WAN connection is advisable with an industrial router as a back-up, 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:

TABLE 5. THE ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF INTERNET CONNECTIONS.

Monitoring connection	Pro	Con	Comment
Wi-Fi	» Broadband » Real time monitoring » Easy to set up	» Modem/Provider dependent » Requires skilled personnel » Can be intermittent » Possible issues when router is replaced	
LAN	» Free » Broadband » Real time monitoring » Reliable	» Modem/Provider dependent » Requires skilled personnel » Additional cabling needed	
Cellular 2G/4G	» 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)	» Subscription based » Real time monitoring requires higher data volume	
LPWAN (NB-IoT, LTE-M etc.)	» Independent from local Internet connection » Remote management » Bi-directional » Good network penetration inside buildings	» 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	» Free	» Only local monitoring possible » Requires simple pairing protocol	
LPWAN (LoRa, Sigfox etc)	» Independent from local Internet connection » Remote management » Good network penetration inside buildings	» Subscription based with proprietary communication protocols in some cases » Limited bandwidth (in some cases) and insufficient for real time monitoring » Limited bi-directional communication	

10.8. 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 endeavours to make sure performance monitoring is correct and takes the best practices mentioned in the previous 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

10.9. 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[5].

Cybersecurity is a vast area and multiple measures are possible. The following suggestions 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)

5 Definition: https://www.itgovernance.co.uk/what-is-cybersecurity.

and implement a cybersecurity management system (CSMS) that incorporates a plan-do-check-act cycle. The CSMS should start from a cybersecurity policy, and definition of formal cybersecurity roles and responsibilities, and proceed to map this onto the system architecture in terms of detailed countermeasures applied at identified points (e.g., via analysis of the system in terms of zones and conduits). These 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 see ISO 27001 Information Security Management.

10.10. Types of data collected through the monitoring system

10.10.1. Irradiance measurements

10.10.1.1. 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.

Irradiance sensors must be placed in an unshaded location (or in the least shaded one). They must be mounted and wired in accordance with manufacturers' guidelines. Preventive Maintenance and calibration of the sensors must follow the manufacturers' guidelines.

In Jordan, the calibration reference for irradiance sensors is the Royal Scientific Society (RSS). The irradiance should be recorded with a granularity of up to 15 minutes (minimum requirement). IEC recommends either to do the calibration with a 1-year interval or to follow the manufacturer's recommendation. The consensus is that a calibration interval of more than 2 years involves a significant risk.
Further information on the categorisation of plant sizes and the use of appropriate measuring technology is provided in IEC 61724-1.

10.10.1.2. 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. 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.

10.10.2. 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 < 1± °C.

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.

10.10.2.1. 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 than10 MWp, 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 Chapter 11. Key Performance Indicators). Solar resource data derived from satellite image processing is available from several services at a nominal per-site and per time-segment (such as one week) 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.

10.10.2.2. String measurements

Individual string current measurements may be deployed when not supported by the inverters. String level monitoring allows for more precise trouble-shooting 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.

10.10.2.3. 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.

10.10.3. 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 ± 0.5%, especially for plants > 100 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.

10.10.4. 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.

10.10.5. 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, and any alarms and security measures need to be agreed between the Asset Owner and the O&M service provider, reflecting the requirements of insurance providers, lenders, and any other relevant stakeholders.

10.10.6. 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.

10.11. 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.

10.11.1. 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.

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. Wind speed shall equal a maximum of 28 km/h, cloud coverage shall equal a maximum of 2 Okta, and the soiling shall be low. Infrared cameras need to possess a thermal resolution of at least 320 x 240 pixels and a thermal sensitivity of at least 0.1 K. Best practice is to use a thermal camera with a resolution of 640 x 512, and a thermal sensitivity of 0.04 K. Measurements shall be taken at a distance which ensures that the resolution of the infrared image equals 5 x 5 pixels per 6" solar PV cell. IEC recommends conducting the aerial infrared thermography at a Ground Sample Distance (GSD) of 3 cm/pixel. Further requirements are to be found in IEC TS 62446-3 Part 3: Photovoltaic modules and plants – outdoor infrared thermography.

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

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.

10.11.2. 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.

10.11.3. 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.

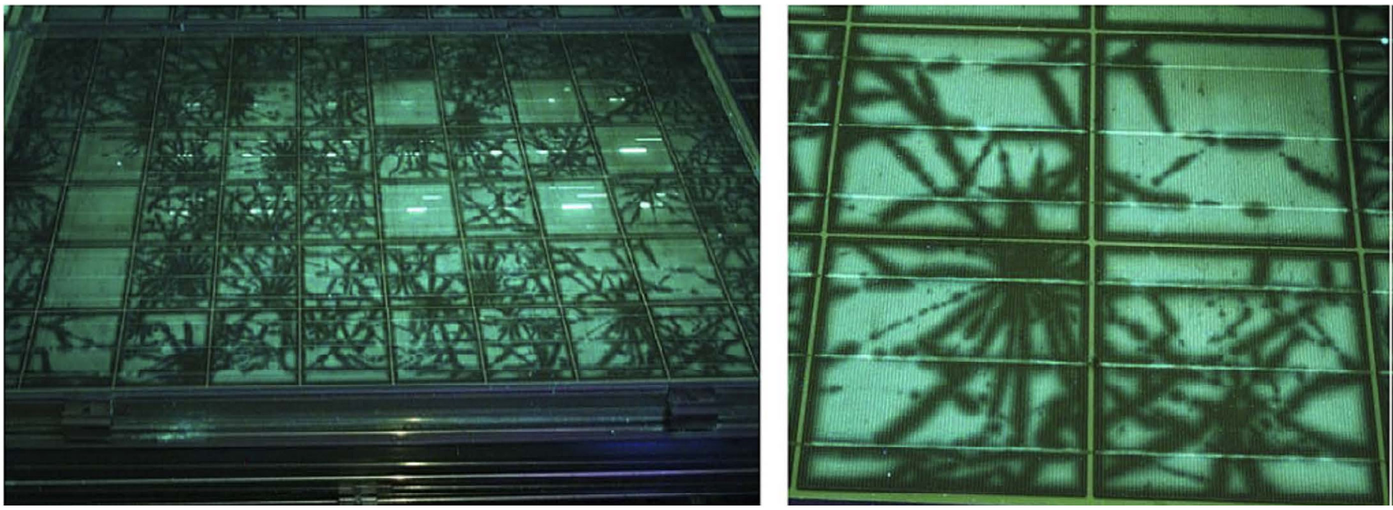
EL is usually done in a dark environment because the amount of NIR emitted by the solar PV modules is low compared to the radiation emitted by the background light and from the sun. This requires that EL imaging conducted on-site has to be done during the night, while covering the solar PV modules with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

10.11.4. Fluorescence imaging

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 back sheet 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 8. 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 8. EXAMPLE UV-FLOURESCENCE IMAGES AFTER A SEVERE HAILSTORM, TAKEN FROM W. MUEHLEISEN (2018)



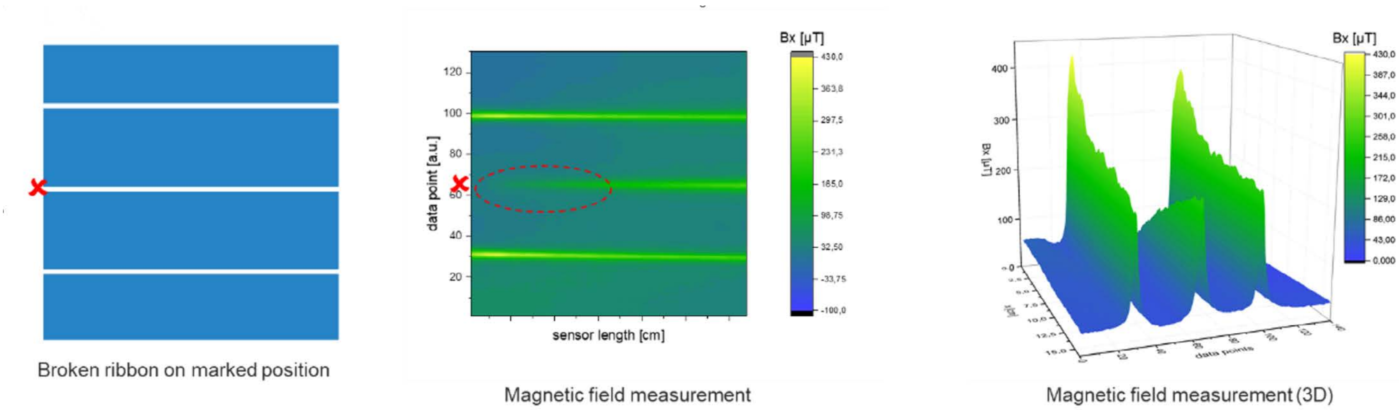
10.11.5. Magnetic Field Imaging (MFI)

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 9), missing solder joints or defective bypass diodes in the junction boxes of the modules.

FIGURE 9. LEFT: SCHEMATIC OF 3 BB SOLAR CELL, „X“ INDICATES THE POSITION OF BROKEN RIBBON; CENTER: BX MAGNETIC FIELD IN 2D REPRESENTATION AND MORE VISUAL 3D ON THE RIGHT SIDE (LAUCH ET AL, 2018; PATZOLD ET AL, 2019).



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 μm), yet.

10.11.6. 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.

11 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

FIGURE 10. OVERVIEW OF DIFFERENT TYPES OF KPIS

PV plant KPIs

directly reflect the performance of the PV power plant. PV plant KPIs are quantitative indicators:

- Reference Yield
- Expected Yield
- Specific Yield
- Performance Ratio
- Temperature-corrected Performance Ratio
- Energy Performance Index
- Technical Availability (Uptime)
- Tracker Availability

O&M Service Provider KPIs

reflect the performance of the service provided by the O&M service provider. O&M service provider KPIs are both quantitative and qualitative indicators:

- Acknowledgement Time
- Intervention Time
- Response Timew
- Resolution Time
- Reporting
- O&M Service Provider experience
- Schedule attainment
- Preventive vs Corrective Maintenance ratio

Being both PV plant KPIs and O&M service provider KPIs

reflect both plant and O&M service provider KPIs measuring at the same time plant performances and ability of the O&M service provider to keep the PV power plant ready to produce:

- Contractual Availability
- Energy-Based Availability

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 5.1. 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 section 12.4.* Contractual guarantees. 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.

11.1. PV power plant data

Solar 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

11.1.1. Raw data measurements for performance calculation

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

» AC Apparent Power produced (kVA)

» AC Active Power (kW)

» AC Energy produced (kWh)

» AC Energy metered (kWh)

» Reactive power (kVAR)

» Irradiance [6] (reference for the plant or the sub-plants) (W/m2)

» Air and module temperature (Celsius degrees)

» Alarm, status code and duration

» Outages, unavailability events

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

11.2. PV power plant KPIs

Calculated KPIs give a more balanced view of the operation of a 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 period used in computation.

11.2.1. 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 11.2.3. 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 solar PV array (POA) for the period i (kWh/m2)

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

11.2.2. 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:

$$Y_i = \frac{E_i}{P_0}$$

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_0 = 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 MWp ground mounted solar PV power plant can be compared directly to that of a 1 MWp 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 Specific Yield within a plant, it is possible to detect whether an inverter is performing worse than others.

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6 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/m^2).
- 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/m^2)

11.2.3. 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 11.4.1. Contractual Availability) at the inverter or plant level. Note that special attention is needed when assessing the PR of overrated plants, where the output of the plant is limited by the inverter'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. Stakeholders should be careful assessing PR values for overrated plants, although the amount of overrating is normally statistically constant or with negligible differences on a yearly basis.

11.2.4. 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 period i should be calculated by weighting the mean temperatures of the time periods j according to Specific Yield of this time period[7].

Temperature-corrected PR can be defined as follows:

$$PR_{T0(i)} = \frac{Y_i}{Y_{r(i)} \times \left[(1 - \frac{\beta}{100} \times \left(T_{MOD(i)} - Tsim\ C\right)\right]} \times 100$$

Where:

$PR_{T0}(i)$ = 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/kWp) or peak sun hours (h)

β =Temperature coefficient for P0 that corresponds to the installed modules (%/°C).

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

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

T_{sim} = Average module temperature from the simulation for the period i, weighted according to the Yield of the same period from the reference simulation.

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

Where:

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

$T_{MOD\ (MEAS(j))}$ = Average measured module temperature for the period j (°C)

$$T_{sim} = \frac{\sum_{s=1}^{i} Y_s \times T_{MOD_{sim(s)}}}{\sum_{s=1}^{i} (Y_s)}$$

Where:

$T_{MODsim(s)}$: Module temperature for the period (s) extracted from the reference simulation (usually the minimum interval can be got from the simulation tool is 1-hour bases)

Y(s): plant expected yield for the period (s) as extracted from the reference simulation in (kWh/m2) (usually the minimum interval can be got from the simulation tool is 1 hour basis)

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

- In the time-weighted method, PR is weighted over a period by the time interval. An example would be if the SCADA system provides data in 1 min / 5min / 10 min average values. PR is then calculated for that 1 min / 5min / 10 min period and the resulting PR values are then averaged. This method will generally yield higher PR values in the morning, while production is low and lower PR values mid-day, but with high energy production. Therefore, low PR value are given the same with as the high PR

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 (considering the temperature coefficient of the modules, given as % of power loss per °C).

Interpretation of PR for overrated plants (lower PR as designed)

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.

11.2.5. Expected Yield

Expected Yield Yexp(i) is the Reference Yield Yr(i) multiplied by the expected PR and thus expresses the Specific Yield that has been expected for a certain period i.

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/kW_p) or peak sun hours (h)

$PR_{exp}(i)$ = Average Expected Performance Ratio of the plant over the period i, based on simulation with given actual temperature and irradiation and plant characteristics. (PRexp simulation is beyond the scope of the present document but for more information on this, see Brabandere et al (2014), Klise and Stein (2009), NREL (2017), PVsyst (2017) and SANDIA (2017).)

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

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.

11.2.6. Energy Performance Index

The Energy Performance Index (EPI) is defined as the ratio between the observed Specific Yield Yf(i) and the Expected Yield Yexp(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.

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

Where:

EPI(i) = Energy Performance Index for the period i (%)

$Y_f(i)$ = Specific Yield for the period i (kWh/kW_p) or (h)

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

The advantage of using the EPI is that its expected value is 100% at project start-up and is independent of climate or weather. This indicator relies on the accuracy of the model. Unfortunately, there 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.

11.2.7. 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 11.4. 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:

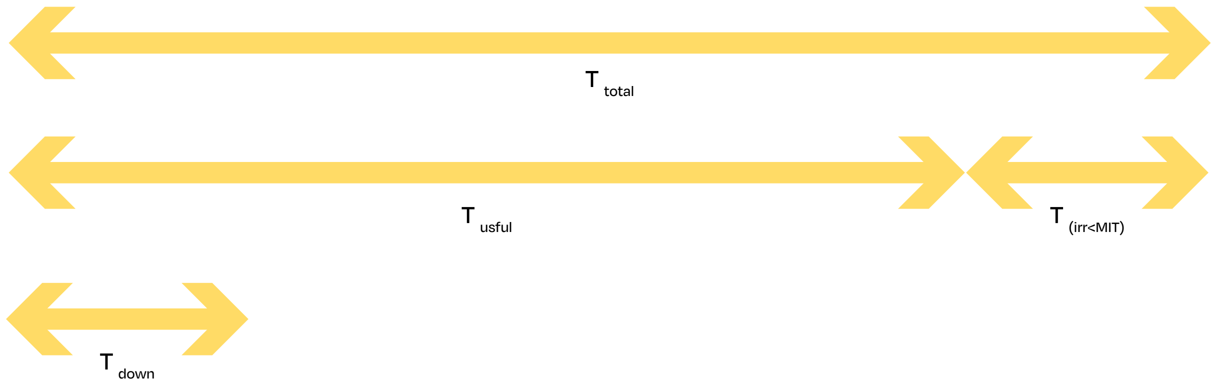
A_t = Technical Availability (Uptime) (%)

T_{useful} = period of time with in-plane irradiation above MIT (h)

T_{down} = period of Tuseful when the system is down (no production) (h)

The figure below illustrates the various periods in time mentioned above.

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



Normally, only the time where irradiance is above the MIT is considered and this is noted above as Tuseful,, 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).

Technical Availability should be measured also at inverter level. Individual inverters' Technical Availability At_k should be weighted according to their respective installed DC power Pk. In this case, the Technical Availability of the total solar PV power plant A_{t_total} with a total installed DC power of P0 can be defined as follows:

$$A_{t\_total} = 100 \times \sum (AT_k \times \frac{P_k}{P_0})$$

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)

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.

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

$$A_{t\_tracker} = \frac{T_{t\_useful} - T_{t\_down}}{T_{t\_useful}} \times 100$$

Where:

$A_{t\_tracker}$ = Technical Tracker Availability (%)

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

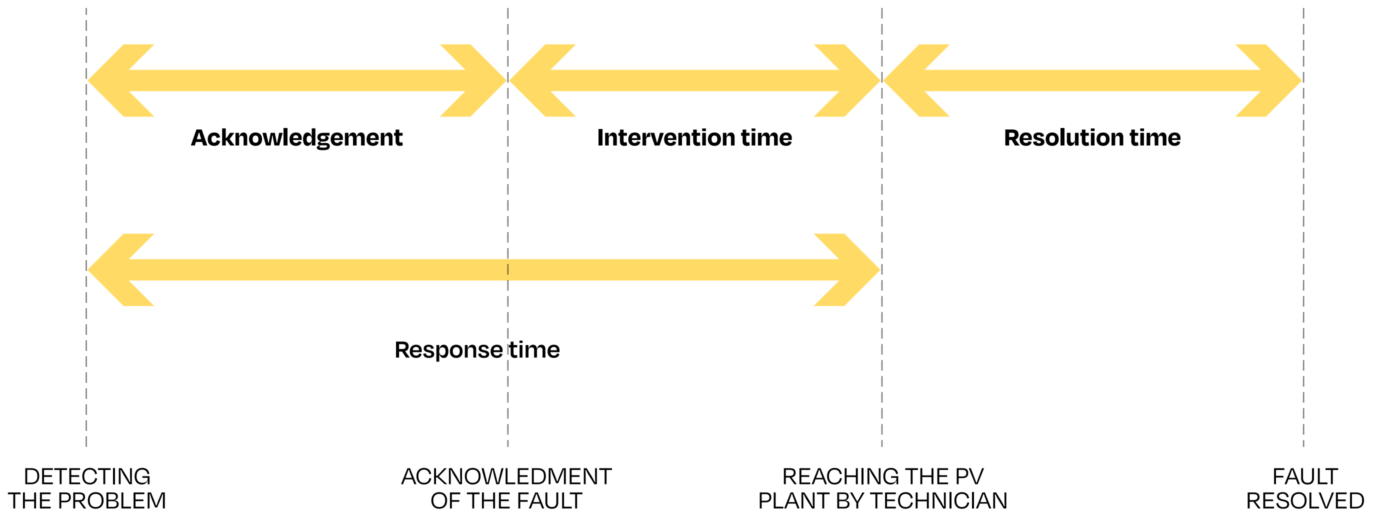
T_{t_useful} = Period when the tracker is functional (h)

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.

11.3. 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

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



The following time KPIs are illustrated in Figure 10.

11.3.1. Acknowledgement Time

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

11.3.2. 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.

11.3.3. Response Time

The Response Time is the Acknowledgement Time plus the Intervention time. Used for contractual purposes, minimum Response Times are guaranteed 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 12.6. Response Time price adjustment.*

11.3.4. 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 cannot be fully controlled by the O&M service provider.

11.3.5. 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 timeline is an important indicator for reliability and process adherence within the O&M service provider's organisation. See also section 5.1. Technical reporting.

11.3.6. O&M service provider experience

An O&M service provider's experience of working on solar power plants in Jordan can play an important role. The EMRC categorises companies based on their compliance with EMRC licences and the quality and efficiency of the services they provide. However, in general there is no universal ratings system that is applied. It is important that any O&M service provider has the appropriate experience and resources to perform their tasks effectively on the size of project they are being considered for.

11.3.7. 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:

- hat preventive maintenance is not done which will lead to equipment failures over time
- he O&M service provider might not have sufficient numbers of qualified technical staff to performance maintenance
- he O&M service provider systems such as the management of stores and spares, procurement processes are not effective
- here 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:

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

11.3.8. 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.

11.4. PV power plant/O&M service provider KPIs

11.4.1. 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 12.5. 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:

Ac = Contractual Availability (%)

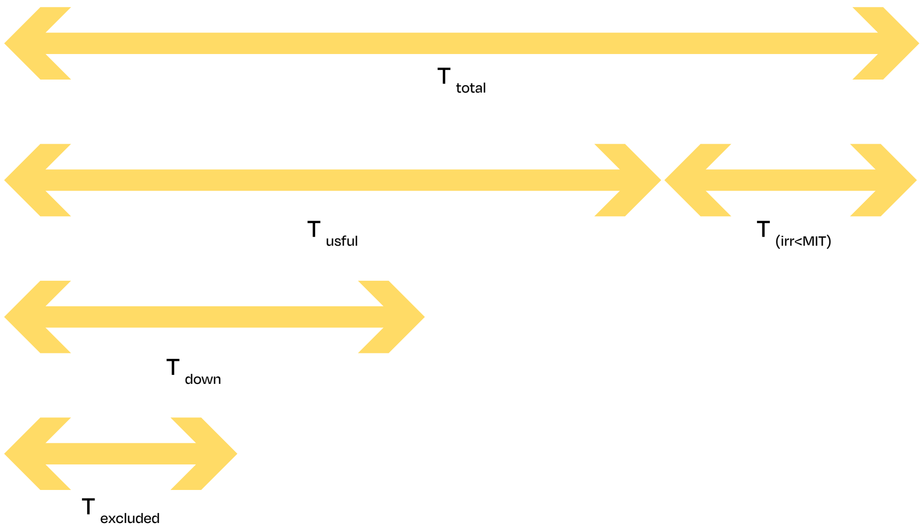
Tuseful = period of time with in-plane irradiation above MIT (h)

Tdown = period of Tuseful when the system is down (no production) (h)

Texcluded = part of Tdown to be excluded because of presence of an excl

The figure below illustrates the various periods in time mentioned above.

FIGURE 13. VARIOUS PERIODS OF TIME FOR THE CALCULATION OF CONTRACTUAL AVAILABILITY [8]



Like Technical Availability, Contractual Availability is also calculated for irradiance levels above the MIT and measured at inverter level. Individual inverters' Contractual Availabilities ACk should be weighted according to their respective installed DC power Pk. In this case the Contractual Availability of the total solar PV power plant AcAc total with an installed total DC power of P0 can be defined as follows:

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

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)

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.

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

8 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.

» 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.

11.4.2. 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.

$$A_{c\_tracker} = \frac{T_{t\_useful} - T_{t\_down} + T_{t\_excluded}}{T_{t\_useful}} \times 100$$

where:

$A_{t\_tracker}$ = Technical Tracker Availability (%)

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

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

$T_{t\_excluded}$ = part of T_{t_down} to be excluded because of presence of an exclusion factor (see above) (h)

11.4.3. Energy-based Availability

Energy-based Availability takes into consideration that an hour in a period 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:

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

where:

Ae(i) = Energy-based Availability for the period i (%)

Eloss(i) = Calculated lost energy in the period i (kWh)

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

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 6. OVERVIEW OF DIFFERENT TYPES OF KEY PERFORMANCE INDICATORS AND THEIR PURPOSES

	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
Reference Yield	O	O	✓	O	✓	O	Useful during plant designing and economic valuation
Expected Yield	✓	O	✓	O	✓	O	Useful during plant designing and economic valuation
Specific Yield	✓	O	✓	O	✓	O	Useful during plant designing and economic valuation
Performance Ratio	✓	O	✓	O	✓	o	Useful during plant life for assessing plant performance over time
Temperature-corrected Performance Ratio	✓	O	✓	O	✓	O	Useful FAC and PAC or in other specific moment in plant life to assess plant PR starting point
Energy Performance Index	✓	O	✓	O	✓	O	Useful during plant life for assessing plant performance over time, against plant expected performance at plant designing

Technical Availability (Uptime)	✓	O	✓	O	✓	O	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)	✓	O	✓	O	✓	O	Useful during plant life for assessing how much time, during the time frame under analysis, the trackers are functioning properly
Acknowledgement Time	O	✓	✓	O	✓	✓	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	O	✓	✓	O	✓	✓	Useful during plant operation for assessing readiness of the O&M service provider to reach the plant once a failure is "realised"
Response Time	O	✓	✓	O	✓	✓	Useful during plant operation for assessing readiness of the O&M service provider from acknowledging a failure and subsequently reaching the site
Resolution Time	O	✓	✓	O	O	✓	Useful during plant operation for assessing the time used to solve a fault from when the plant is reached
Contractual Availability	✓	✓	✓	O	✓	✓	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	✓	✓	✓	O	✓	✓	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	✓	✓	✓	O	✓	✓	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	O	✓	✓	✓	✓	✓	Useful during plant operation for assessing reliability of reporting services
O&M service provider experience	O	✓	O	✓	✓	O	Useful during O&M service provider awarding/tendering for assessing O&M service provider reliability from a purely document-based analysis
Schedule Attainment	O	✓	✓	O	✓	O	Useful during O&M Contract awarding/tendering for assessing O&M service provider reliability
Preventive vs Corrective Maintenance ratio	O	✓	✓	O	✓	O	Useful during O&M Contract awarding/tendering to assess O&M service provider reliability and effectiveness

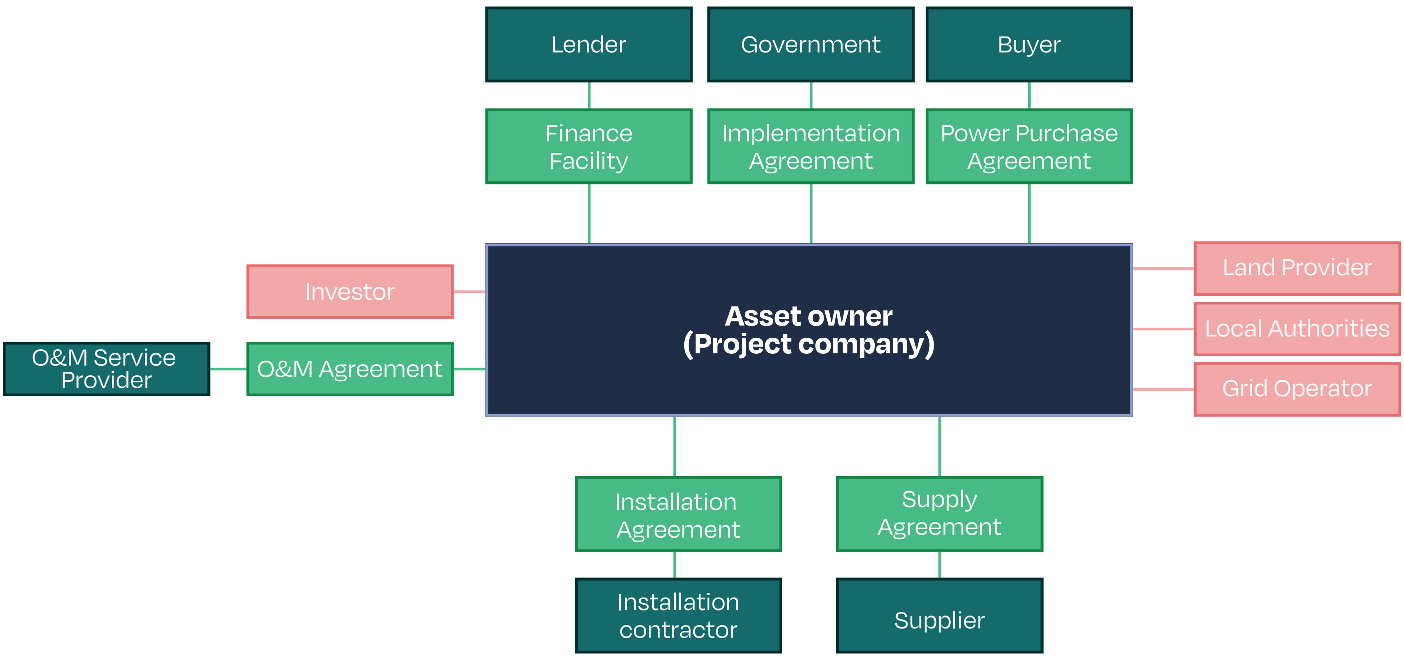
12 Contractual Framework

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

Using the O&M template contract developed as part of the Open Solar Contracts suite of template contracts is recommended. 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

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



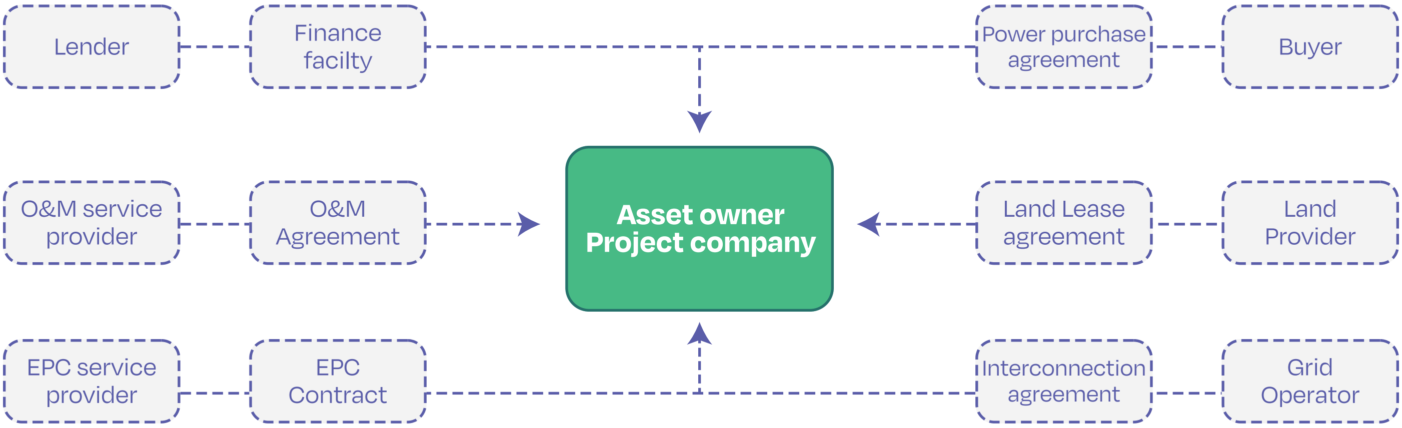
Copies of each contract and explanatory guidance can be found at the Open Solar Contracts website: www.opensolarcontracts.org.

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.

Aside from the O&M contract, the other templates can include:

- » Power Purchase Agreement, Wheeling, or Net Metering Agreements
- » Finance Facility Agreement term sheet
- » EPC Agreement and warranties
- » Asset Management Agreement
- » Interconnection Agreement
- » Insurance Agreements
- » Land Lease Agreement

FIGURE 15. OVERVIEW OF THE TEMPLATE CONTRACTS NEEDED DURING OPERATION AND MAINTENANCE OF PV PLANTS



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.

12.1. 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

12.2. 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 7.2. Corrective Maintenance)*
- Extraordinary Maintenance (generally not included in the O&M fixed fee but it is advisable that the O&M contract includes the rules to prepare the quotation and to execute Extraordinary Maintenance works, for more information, *see section 7.4. Extraordinary maintenance)*. In the Open Solar Contracts O&M template, this would fall within "Additional Services".

Additional maintenance services (optional, *see section 7.5. Additional services*). In the Open Solar Contracts O&M template, this would fall within "Additional Services"

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.

TABLE 7. 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
	Snow or sand 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 6.9. 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

All the services not included in the scope and in the fixed fee such as Extraordinary Maintenance (*see section 7.4. Extraordinary Maintenance*) and Additional services (*see section 7.5. 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 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 9. Spare Parts Management)

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

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

12.3. O&M contract fee

As a best practice, O&M services should be provided on a fixed fee plus escalation basis. *See section 12.11* in this chapter which discusses how spare parts management may impact on the contract fee.

12.4. Contractual guarantees

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 affect 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 of quality of services. Availability guarantees and Response Time price adjustments avoid burdensome change management processes resulting from the need to recalculate the guaranteed PRon 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.

12.5. Availability guarantee

A best practice is a Minimum Guaranteed Contractual Availability of 98% over a year at least at inverter level. For contractual KPI reasons, Availability should be calculated at inverter level, on an annual basis. For more information on this, *see section 11.4.1. 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 12.7. Bonus Schemes and Liquidated Damages*.

12.6. 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 11.3.3. 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 8.

TABLE 8. EXAMPLES FOR FAULT CLASSES AND CORRESPONDING MINIMUM RESPONSE TIMES. 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.

Fault class	Fault class definition	Response time guarantee
Fault class 1	The entire plant is off, 100% power loss.	4 daytime hours
Fault class 2	More than 30% power loss or more than 300kWp down	24 hours
Fault class 3	0%-30% power loss	36 hours

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 12.11. 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.

12.7. Bonus Schemes and Liquidated Damages (LDs)

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".
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 11.4.1. 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

12.8. 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.

12.9. 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.

12.10. 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 12.4. Contractual Guarantees of the present chapter also represent a level of accountability for the O&M service provider.

12.11. Spare Parts Management

Generally, the O&M service provider is responsible for the management and storage of the Initial Spare Parts supplied by the EPC service provider and shall promptly replenish the Initial Spare Parts when used. The O&M service provider shall be responsible for the procurement, subject to the agreed upon cost plus rates, management and storage of all spare parts required for the performance of the O&M services. The O&M service provider should enforce all assigned warranties to ensure that spare parts, covered in the Assigned warranties, are promptly replenished in a timely manner.

It is recommended that the O&M service provider regularly reviews the required quantities and inventory of spare parts and ensures that it is supplemented and promptly replenished, subject to the agreed upon cost plus rates, to comply with prudent O&M Practices.

In normal circumstances, the cost of replenishing spare parts will be borne by the Asset Owner. However, if spare parts are used to remedy a situation in which the O&M service provider has been negligent, they shall bear the cost of replenishing the inventory.

There should be a components, materials, and spare parts defects warranty for 12 months from the date of installation, which should continue to apply even after expiry or termination of the O&M contract.
For more information on Spare Parts Management, see the Chapter 9. Spare Parts Management.

Power plant remote monitoring

The O&M service provider should operate and maintain the monitoring system according to the grid operator requirements .

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 Chapter 10. 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.

12.12. 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 5.1. Technical reporting*.

13 Innovations and trends

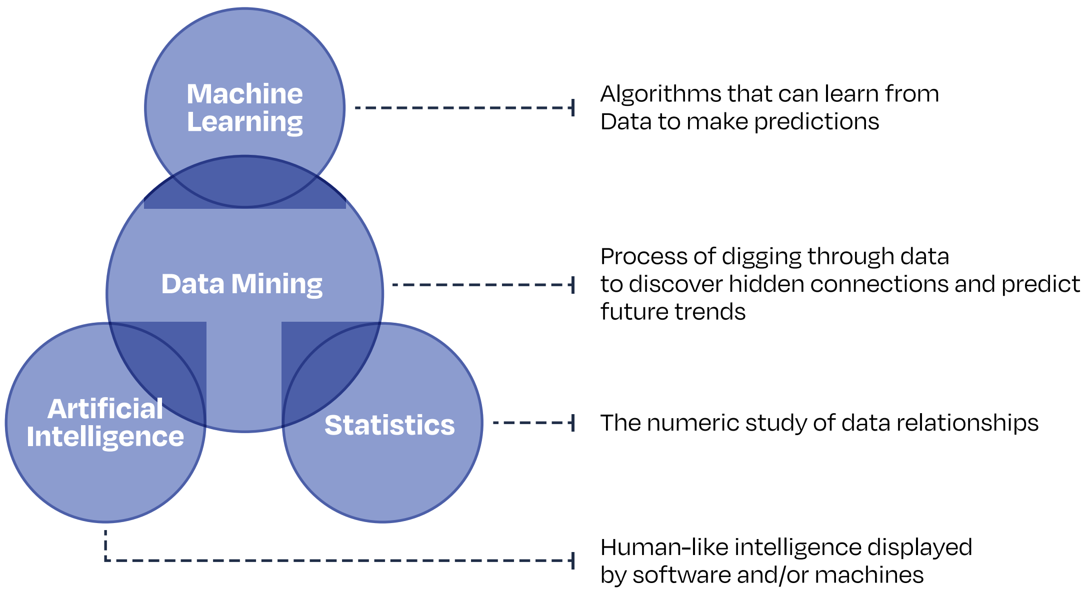
O&M service providers are under increasing pressure to do more with less. Increasing human resource efficiency through the use of data-driven and Industry 4.0 techniques are key themes for O&M as the industry works to reduce the number of human interventions and embraces digitisation.
The following chapter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

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

Purpose and description

Traditional monitoring systems generally consist of on-site data loggers that collect electrical data from devices installed on the PV plant inverters, strings, meters, and weather data from meteorological stations. Management software enables remote performance management, data visualisation, basic KPI calculations, reporting, and alarm and ticket management. These systems, used on their own, commonly fail to detect the root causes of underperformance. The industry is therefore rapidly moving towards the adoption of 'smarter' solutions based on advanced data mining techniques.
Data mining is the process of digging through data to discover hidden connections and predict trends. Sometimes referred to as "knowledge discovery in databases," the term "data mining" was not coined until the 1990s. Its foundation is comprised of three intertwined scientific disciplines:

FIGURE 16. DATA MINING FOUNDATIONS. ADAPTED FROM: WWW.SAS.COM



State of play

Although data mining is not a new discipline, its capabilities are now being unleashed due to the potential of big data and increasingly affordable computing power and storage. Its potential to enable O&M service providers to move beyond manual, time-consuming practices to quick, easy and automated data analysis is now becoming more tangible (source: SAS, 2018).

13.2. Advanced aerial thermography

Purpose and description
The general functionality of thermographic data has already been outlined in section 10.11.1. Infrared thermography. While thermographic inspections have become well established as a tool in preventive and corrective maintenance scheduling, the amount of effort and costs involved in gathering data

from a site are stumbling blocks to wider use.
Using thermographic cameras mounted on drones or purpose-modified piloted aircraft, instead of handheld devices, the operator flies over the PV modules to capture thermographic images or videos. This data is then analysed to create inspection reports which can be used to identify preventive and corrective maintenance tasks. If deployed properly, aerial thermography can bring several operational and financial advantages.

Data acquisition

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

Post-processing

The post-processing activities consists of all the data processing and analysis techniques to produce the final report and all the related deliverables. These activities can be done manually or automatically by means of specialised software.
The activities comprised in this stage can be thought of as serial list of subtasks described in the following table.

TABLE 9. AERIAL IR THERMOGRAPHY – POST-PROCESSING SUBTASKS. SOURCE: BAYWA R.E.

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

The data acquisition stage is now well understood as drone technology matures. There are already many companies that offer high-quality industrial aerial flights. Therefore, the 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 of regular drone maintenance.
There are some companies which utilise specially modified piloted aircraft in lieu of drones for inspections of large sites and portfolios. These systems have advantages of much faster capture times (up to 1.5MW/hr) while maintaining high resolution due to the higher quality of cameras which can be used. The disadvantage of them is that they are more expensive, meaning their use on individual sites makes less sense.

Most companies today still rely on manual data processing, which represents a big drawback for large portfolios as human-error drives down the accuracy of thermal imaging assessments. This means that companies with automated solutions have a huge advantage in this regard.

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

Pilots

Any aerial thermography or other PV module and plant monitoring application involving drones or piloted aircrafts must be carried out by an operator licensed under FAA 107. 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.

Flight Permits

Before taking off on any flight in Jordan, the drone operator must obtain permission from the Civil Aviation Regulatory Commission (CARC). To qualify, the drone operator must be at least 21 years old and possess the relevant training or qualifications set by the authorities. Additionally, the drone operator must have insurance and adhere to basic flight rules to operate drone in Jordan.
The drone operator must always:

- Fly below the maximum altitude of 121 meters and at a maximum range of 500 meters from the take off site
- Keep a safe distance from private property, moving vehicles, people, and large crowds, and respect individuals' privacy
- Ensure a maximum flight duration of three hours
- Fly a drone that weighs less than 25 kg, has electric motors, and is equipped with geofencing and electronic identification
- Stay away from airports (or any other location where aircraft or helicopters take off or land) and make way for all other types of aircraft
- Stay away from areas where drone use could jeopardize the work of law enforcement or first responders
- Avoid areas deemed sensitive, such as government or military facilities

With the advent of aerial inspections, resources required for data collection can be significantly reduced. High-quality IR images captured by an aerial platform and their proper post-processing allow for a detailed PV module failure analysis that could trigger conclusive maintenance decisions. Furthermore, field interventions can be optimised, and PV plant underperformance can also be better understood and addressed (e.g. faulty modules that need to be replaced can be identified with precision and high-quality IR images can be used as proof in warranty claiming processes). Aerial thermography reduces the inspection time and the number of personnel on site. For instance, using this method, a 15 MWp PV plant can be inspected in a single day. Additionally, since images are taken from the air, the data yields a helpful overview to check whether plant layout and other documents are correct.

As with any form of thermography, the inspection method is limited by meteorological conditions: For the inspection data to be of value, a minimum radiation of 600 W/m2 is required. For drone inspections, for the RPA to be controlled safely, and depending on the type of RPA used, wind speeds should not exceed 28 km/h, cloud coverage should not exceed 2 Okta, and soiling should be low. A best practice is to conduct the inspection with an ambient temperature of 24 °C and above.

State of play

The demand for IR inspections is growing fast, as is the range of services offered by new players in the market, who are now pushing aerial inspections beyond basic reporting. Advanced aerial inspections, understood as semi-automated or fully automated solutions are being put into practice for both IR inspection stages, data acquisition and post-processing.
Aerial thermography is becoming a widely accepted and employed tool of inspection in corrective maintenance worldwide. Given the price drop in equipment (of both drones and thermographic cameras), it will become even more widespread. Further innovation is to be expected in autonomously controlled drones as well as data analysis using Artificial Intelligence.
If deployed properly, aerial inspection could become a cornerstone technology for effective O&M.

13.3. Automated plant performance diagnosis

Purpose and description

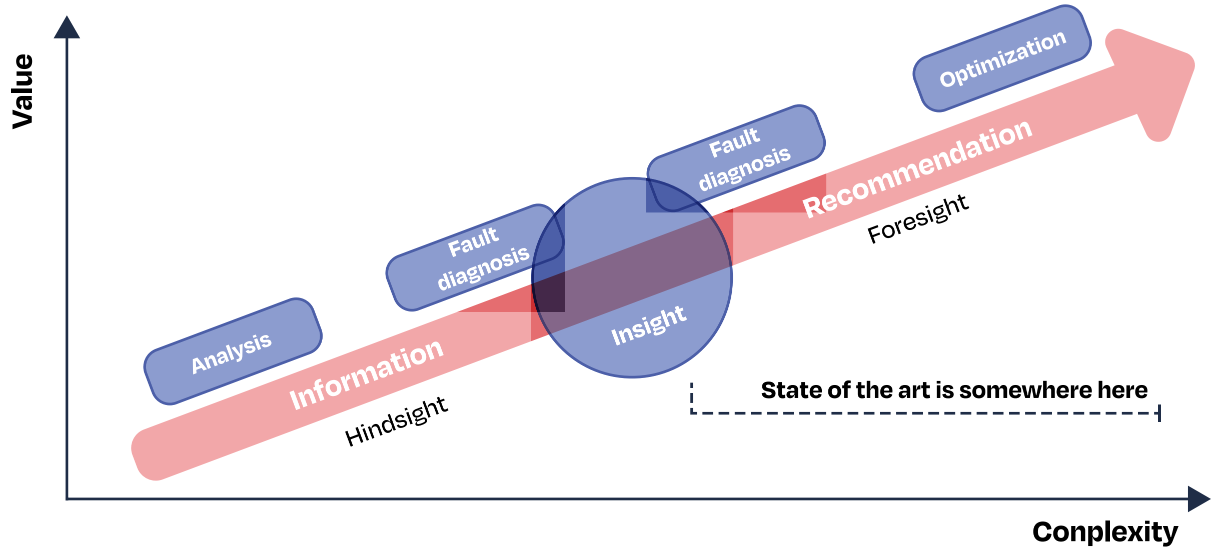
Plant performance assessment is typically executed using a top-down approach, analysing low performing objects by drilling down from substations, and inverters to junction boxes and strings. This process is time consuming and expert dependent. Furthermore, the process does not guarantee revealing all 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 handing 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 17. AUTOMATED PLANT PERFORMANCE DIAGNOSIS BY ACHIM WOYTE, 3E

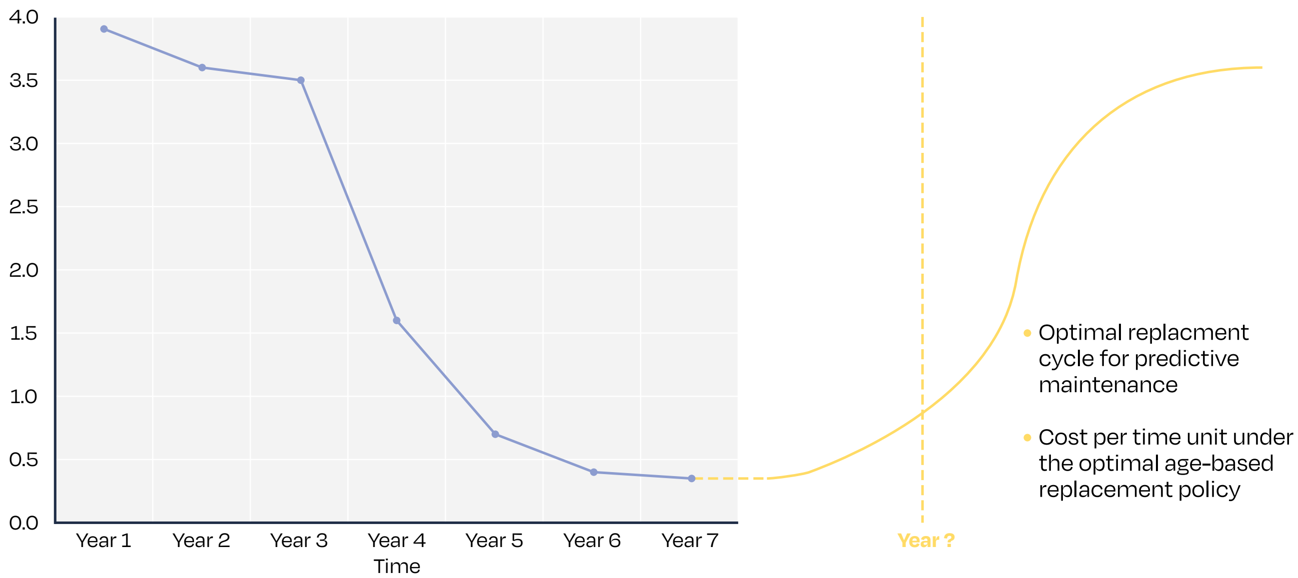


13.4. Predictive maintenance for optimised hardware replacement

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.

FIGURE 18. PREDICTIVE MAINTENANCE FOR OPTIMISED HARDWARE REPLACEMENT



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 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.

13.5. PV plant yield forecasting

Purpose and description

Electricity generation from PV plants is limited by the varying availability of the sun's radiation. The growing penetration of PV may force new regulations to always guarantee grid stability and the correct balancing of electricity supply and consumption, causing unpredictable losses to plant owners (curtailment).

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

State of play

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

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

13.6. 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.

13.7. Future best practices in document management systems

Purpose and description

Asset contractual and technical documentation as described in today's Best Practices can be handled either physically or electronically, as far as the employed Document Management System (DMS) keeps all documents ready consultation by or transfer to relevant stakeholders. The inventory of technical documentation linked to a portfolio of plants can become very complex, especially in an era where the European solar sector is moving towards a secondary market. Considering the number of documents to be stored and exchanged per plant, the increasing number of stakeholders that should have free access to a subset or the totality of the documentation, the physical exchange and storage of files becomes nearly impossible to be maintained without a proper quality process. Electronic document management and storage is thus becoming a best practice within the Solar industry.

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

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

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

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

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

State of play

In terms of technological readiness and market uptake, digital DMS solutions using meta-tags and full-text search are already existing and adopted by some Asset Managers and O&M service providers. This technology could become soon a best practice, though the standardisation of document tagging in the solar industry is not yet implemented.
Document recognition and meta-tag autofilling is already available on most documents including some scanned file types via OCR (Optical Character Recognition). At a next level, image recognition and auto-tagging would save operational time.

13.8. Retrofit coatings for PV modules

13.8.1. Anti-soiling coatings

Purpose and description

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

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

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

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

When it comes to applying coatings to already installed modules in general, the O&M service provider should carefully evaluate possible consequences for PV module warranties and for any incentive or tariff schemes.
Retrofit anti-soiling coatings are a layer applied on the surface of the modules that in principle don't affect the properties of the glass surface and that can be removed if needed for warranty purposes.

State of play

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

13.8.2. Anti-reflective coatings

Purpose and description

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

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

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

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

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

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

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

State of play

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

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

14 O&M for PV power plants with storage

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

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

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

14.1. Types of storage systems

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

The most mature and commonly used ESS for utility scale solar plants are solid-state batteries (e.g., lithium-ion), liquid electrolyte (lead acid) and Flow Batteries (e.g., vanadium redox).

Solid state batteries contain a higher C-rate than batteries with liquid electrolyte, meaning they can discharge quicker and are more effective in situations where a large amount of power is required over a short period (e.g. blackouts). Solid state batteries typically last 15 years, meaning they must be replaced at least once during a project's lifecycle. ESS lifetimes are difficult to predict because it depends on number of cycles; charge/discharge rates; depth of discharge; temperature; and their cumulative effect. O&M of flooded lead acid batteries is extensive, requiring continuous maintenance of the electrolyte, whereas sealed batteries require replacement. There are application specific standards for the percentage of remaining capacity (e.g. 70% of initial capacity) that trigger a replacement.

Power conditioning electronics that push battery maintenance functions down to the unit level have operational advantages (redundancy, fault isolation) over a single string of large-capacity cells, similar to those of micro-inverters on a PV array. Batteries deployed to serve DC load couple well with PV for data centers and telecommunications applications.
Flow batteries are very efficient for meeting a steady, long term energy demand (e.g. night-time application), but will be less efficient in blackout scenarios. Flow batteries provide less harm to the environment and present fewer safety risks (much less flammable) than their solid-state counterparts. However, this is counterbalanced by their higher cost.
As a rule of thumb, to obtain 1 MWh of storage 15m2 of lithium-ion batteries or 80m2 of Flow Batteries are required. Therefore, lithium-ion batteries are more appropriate for more constrained sites.

14.2. Environment, Health & Safety

Most batteries are subject to environmental regulations that require recycling or proper disposal at end of performance period. In Jordan the rules are the same as for appliances.

The ESS mentioned above are electrical appliances and as such are subject to significant health & safety risks. To prevent hazards (e.g. uncontrolled release of energy), an appropriate risk assessment must be performed during the design and planning phases and necessary safety precautions implemented. The hazards must be identified during these stages and appropriate measures taken to mitigate risk and to protect those operating the system. The main risks are impact, excessive heat, crush or water penetration and electrical shock There is also a significant health and safety risk of poisoning or mishandling hazardous materials, especially the sulphuric acid electrolyte added to lead-acid batteries.

Both external and internal factors should be considered during the risk assessment since, in some cases, the ESS itself can be the cause of hazardous event. The major hazards for large-scale ESS can be categorised as follows:

» electrical, occurring when there is direct contact between a person and the system
» mechanical, occurring after a physical collision
» poisoning or exposure to hazardous materials
» other, occurring due to an explosion, fire, thermal runaway, or the leaking of chemical components from the system

To avoid risks, the system should not overheat, come into contact with water, or suffer from either electrical stress or high humidity. The risk of electrical shock can be mitigated - as is common practice in photovoltaic plants - with appropriate electrical insulation: for instance, by wearing appropriate personal protective equipment (PPE). The energy storage system should be maintained by trained technicians since improper handing increases the risk of electrical shock.
Safety data sheets should be provided to those operating the system. In case of repair or replacement, addition or alteration of the system, the safety system should be re-evaluated and, if necessary, additional safety systems implemented.
It is best practice to design the system in a way that allows straightforward removal and replacement of modules. The system itself should be easily accessible for inspection without needing to significantly disassemble the ESS system. Disposal of hazardous material should comply with local and national rules and regulations "Electrical and Electronic Waste Management Instructions for the year 2021, issued in accordance with the provisions of paragraph (b) of Article 13 of the Hazardous Materials and Waste Management System No. 68 of 2020" issued by the Ministry of Environment.

14.3. Operation & Monitoring

To increase the lifecycle and efficiency of an ESS, the implementation and regular follow-up of an efficient monitoring system is essential. ESS should always be equipped with an Energy Management System (EMS) to track charge/discharge states and make sure that the system does not exceed/go under the prescribed charging limits. The EMS should also gather data coming from energy meters, auxiliary systems and operating parameters, such as temperature, voltage, current, power level, state of charge, state of energy and warning messages, in order to assess the condition of the ESS on a daily basis.

When dealing with ESS, communication between the O&M service provider and the grid administrator is a key factor. The energy producer should, one day prior, communicate to the grid administrator an estimation of the time (battery) charging is expected to stop, as well as an estimation of when discharge is expected to start. The producer should also communicate their expected production at constant power on a daily basis. In some cases, the producer must provide the grid administrator with hourly estimations of charge/ discharge periods and peak production capacity. In any case, an understanding of the precise rules of the different national electricity systems are required to determine the obligations relating to forecast usage of the battery storage system.

14.4. Maintenance

To perform systematic maintenance, a plan on location showing how components and the system must be tested is required. If any component within the system requires repairs or replacement, care should be taken to ensure that changes comply with the applicable regulation by the Jordan Standards and Metrology Organization (JSMO).
The EES systems should be accompanied by an operational manual, including at least the following topics [9]:

» System overview and site layout
» System component description
» Maintenance cycles for all components, including the actions to be taken during the inspection and maintenance activities
» Safety instructions

In addition, to avoid reducing ESS lifetime, keeping batteries in an environment-controlled container (25°c, no humidity) is recommended. An EMS should be put in place to monitor the charge/discharge conditions of batteries, based on market demand. Whilst Flow Batteries are resilient and can undertake full charge/discharge cycles, lithium-ion batteries will slowly deteriorate if they experience such cycles. As a rule of thumb, lithium-ion batteries should not be charged at more than 90% and less than 10% of their energy storage capacity.

9 Note: this list is intended to be illustrative and not limiting.

15 O&M for Rooftop Solar

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 rooves 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)

15.1. 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 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 rooves 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 3. Environment, Health & Safety 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.
- 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.

15.2. 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 6. 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.
The following methods can be applied for collection of reference yield:

TABLE 10. METHODS SUGGESTED FOR THE COLLECTION OF REFERENCE YIELD

Reference yield source	Accuracy	Hardware Cost	Comment
Onsite Pyranometer	High*	High	For more information, *see section 10.10.1. Irradiance measurements*. Public pyranometers may be used if available
Module level sensor	High	High	
Satellite Data	Medium-High**	None	For more information, *see section 10.10.1. 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 km^2 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*

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 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.

15.3. 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.

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 11 summarizes incident handling for C&I rooftop solar PV systems.

TABLE 11. INCIDENTS COVERED BY O&M SERVICE AGREEMENTS FOR ROOFTOP 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.**

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

15.5. 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.

15.6. 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 (Wp, 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

15.7. 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 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 is important to inform 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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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 PV systems
IEC TS 63049:2017	Terrestrial photovoltaic (PV) systems – Guidelines for effective quality assurance in PV systems installation, operation and maintenance
IEC 60364-7-712:2017	Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
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 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) Proposed skill matrix for O&M personnel (Download it from www.solarpowereurope.org)

Employee	First name																
	Surname																
	Function	Managerial	Managerial	Managerial	Managerial	Administration	Administration	Administration	Electrician/ supervisor	Electrician/ supervisor	Electrician/ supervisor	Electrician/ supervisor	Trainee Electrician	Trainee Electrician	Trainee Electrician	Trainee Electrician	Data & Comms
Health & Safety	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 certificate etc.)																
Environmental	Certificate of Environmental Management and Assessment																
	Other relevant training course and/or certificate of Environmental Management																
Monitoring & Metering	Certain Monitoring tool training																
	Meter accreditation and calibration																
	Other relevant skills (e.g. data handling tool)																
PV Modules	Basic knowlege about the installed product (e.g. handling, general sefety guidlines, installation etc.; see also recommendations by module manufacturer / installation manual)																
	Basic measurement skills (e.g. thermography, power measurements)																
Inverter	Power Electronics																
	Learning Tools Interoperability (LTI)																
	Other skills (e.g. experience with specific product and type of inverter)																
Electrical	Certification of Electrical Qualification																
	Other relevant skills (e.g. Specific Inspection & Test training, relevant accredited courses etc.)																
Data & Comms	Termination of specific communication cabling																
	Installation of the monitoring system																
	Installation and connection of meters																
	Installation of satellite broadband system																
	Other skills																

Planned | Not required | Required | Update required

c) Documentation set accompanying the solar PV plant (Download it from www.solarpowereurope.org)

Information type and depth of detail / as-built documents			
No.	**Minimum Requirements**	**Description**	**Comments**
1	Site Information	» 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	» 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	» Shading study/simulation » Energy yield study/simulation » Inverter sizing study	
4	Studies according to national regulation requirements	» Voltage drop calculations » Protection coordination study » Short circuit study » Grounding study » Cable sizing calculations » Lightning protection study	
5	PV Modules	» Datasheets » Flash list with PV modules positioning on the field (reference to string numbers and positioning in the string) » Warranties & Certificates	
	DC Combiner Boxes-PV Array boxes	» Installation and O&M manual » Warranties and certificates » Electrical wiring drawings » Internal communication wiring drawings	
6	Inverters	» O&M Manual » Commissioning Report » Warranties & Certificates » Factory Acceptance Test » Inverter settings » Dimensional drawings	

Annex c) Documentation set accompanying the solar PV plant / continued

7	Medium Voltage/ Inverter Cabin	» 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	» O&M Manual » Commissioning Report » Factory Acceptance Test Report » Type Test Reports » Routine Test Reports » Warranties & Certificates » Dimensional drawing with parts list	
9	Cables	» Datasheets » Type & Routine test reports	
10	LV & MV Switchgear	» 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)	
11	HV Switchgear	» 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 & Auxiliary Generator	» Installation & O&M Manual » Commissioning report » Warranties & Certificates » Datasheets » Dimensional Drawings	
13	Mounting Structure	» Mechanical Assembly Drawings » Warranties & Certificates	

14	Trackers	» 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	» 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	» Installation & O&M manual » List of inputs by type (Digital, Analog or Bus) » Electrical Schematic diagram » Block diagram (including network addresses) » Equipment datasheets	
17	Plant Controls	» 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	» Installation and O&M manual » System internal communication » External Communication to monitoring system or Operations Centre » IP network plan » Bus network plans	
	Metering System	» Installation and O&M manual » Data sheets » Warranties and certificates » Electrical wiring drawings » Communication wiring drawings	
	Weather stations	» Installation and O&M manual » Data sheets » Warranties and certificates » Electrical wiring drawings	

d) Important examples of input records in the record control (Download it from www.solarpowereurope.org)

Record control				
No.	Activity Type	Information Type	Input Record	References/Comments
1	Alarms / Operation Incidents	Alarms description	Date and Time, Affected Power, Equipment Code / Name, Error messages / Codes, Severity Classification, Curtailment Period, External Visits/Inspections from third parties	
2	Contract Management	Contract general description	Project Name / Code, Client Name, Peak Power (kWp)	
3	Contract Management	Asset description	Structure Type, Installation Type	
4	Contract Management	Contract period	Contract Start and End Date	
5	Contract Management	Contractual clauses	Contract Value, Availability (%), PR (%), Materials / Spare parts, Corrective Work Labour	
6	Corrective Maintenance	Activity description	Detailed Failure Typification, Failure, Fault Status, Problem Resolution Description, Problem Cause	EN 13306 - Maintenance. Maintenance terminology
7	Corrective Maintenance	Corrective Maintenance event	Associated Alarms (with date), Event Status	EN 13306 - Maintenance. Maintenance terminology
8	Corrective Maintenance	Corrective Maintenance event log	Date and Time of Corrective Maintenance Creation (or Work Order), Date and Time status change (pending, open, recovered, close), End date and time of the intervention, Start date and time of the intervention, Technicians and Responsible Names and Function	EN 13306 - Maintenance. Maintenance terminology
9	Corrective Maintenance	Intervention equipment/ Element name	Affected Power and Affected Production, Equipment Code / Name	
10	Inventory Management	Warehouse management	Inventory Stock Count and Movement, Equipment Code / Name	
11	Monitoring & Supervision	Equipment status	Date, Status log (protection devices, inverters, monitoring systems, surveillance systems)	
12	Monitoring & Supervision	Meteo data	Irradiation, Module temperature, Other meteo variables (ambient temperature, air humidity, wind velocity and direction, ...)	IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
13	Monitoring & Supervision	Production / consumption data	AC active and reactive power at PV Plant Injection Point and other subsystems or equipment, Consumption from auxiliary systems, Other variables (DC/AC voltages and currents, frequency), Power from DC field	IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
14	Monitoring & Supervision	Performance data	PV Plant Energy Production; PR; Expected vs Real	
15	Preventive Maintenance	Maintenance Plan	Preventive Maintenance Plan	
	Preventive Maintenance	Intervention equipment/ Element name	Affected Power and Affected Production, Equipment Code / Name, Intervention Start and End Date	

Annex d) Important examples of input records in the record control / continued

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	PV Plant Documentation	Commissioning	Commissioning Documentation and Tests Results	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
18	PV Plant Documentation	Operation and maintenance	Equipment Manuals, PV Plant O&M Manual	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
19	PV Plant Documentation	System Documentation	As built documentation (Datasheets, wiring diagrams, system data)	IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
20	Warranty Management	Claims registration	Affected Equipment, Claim Description, Occurrence Date; Communications between O&M, client and manufacturer/supplier	

Annex / continued

e) Annual Maintenance Plan (Download it from www.solarpowereurope.org)

Maintenance plan for 3-5MW site (land-locked site far from seashore)

Equipment	Task	Importance	D	M	Q	SA	Y	nY	Extent
Modules	Integrity inspection & replacement	Minimum requirement					x		T
	Thermography inspection	Recommendation					x		T
	Measurements inspection	if required					x		S
	Check tightening of clamps	Minimum requirement					x		R
	Modules cleaning	According to local conditions					(x)		T
	Sample internal inspection of junction boxes (if possible)	Recommendation					x		T
Electrical cabinets and switchboards - Array/string junction box - Generator junction box - AC switchboards - AUX switchboard - General utilities switchboard - Weather station>s cabinet - Monitoring system cabinet - Communication cabinet - Security system board - Other cabinets	Integrity check & cleaning	Minimum requirement					x		T
	Documents inspection	if required					x		T
	Check labelling and identification	Minimum requirement					x		R
	Electrical protections visual inspection & functional test	Minimum requirement					x		T
	Check fuse status	Minimum requirement					x		T
	Check surge protection status (if applicable)	Minimum requirement					x		T
	Check integrity of cables & state of terminals	Minimum requirement					x		T
	Sensor functional verification (if applicable)	Recommendation					x		T
	Measurements inspection	Best practice					x		T
	Thermographical inspection	Recommendation					x		T
	Check tightening	Minimum requirement					x		T
	Lubrification of locks	Minimum requirement					x		T
	Monitoring operation test (if applicable)	Recommendation					x		T
Cables - DC / AC cables - Cables in switchboards, cabinets, inverters	Integrity inspection	Minimum requirement					x		R
	Check labelling and identification	Minimum requirement					x		R
	Check cable terminals	Minimum requirement					x		R
	Measurements inspection	Recommendation					x		R
Inverters - Central inverters - String inverters	Integrity check & cleaning	Minimum requirement					x		T
	Documents inspection	Best practice					x		T
	Check labelling and identification	Minimum requirement					x		R
	Electrical protections visual inspection, check correct operations	Minimum requirement					x		T
	Check fuses	Minimum requirement					x		T
	Check surge protections	Minimum requirement					x		T
	Thermographical inspection	Best practice					x		T
	Sensors functional verification	Minimum requirement					x		R
	Measurements inspection	Minimum requirement					x		T
	Check parameters	Minimum requirement					x		T
	Functional test of ventilation system	Minimum requirement							T
	Check batteries	According to manufacturer>s recommendations					(x)		T
	Replace batteries							3	T
	Replace fans							5	T
	Safety equipment inspection	Minimum requirement					x		T
	Clean filters	Minimum requirement				x			T
	Replace filters	Minimum requirement						2	T

Annex e) Annual Maintenance Plan / continued

Transformer - Power transformer - AUX transformer	Integrity check & cleaning	Minimum requirement					x		T
	Check labelling and identification	Minimum requirement					x		R
	Thermographical inspection	Best practice					x		T
	Functional verification of sensors & relais	Minimum requirement					x		T
	Check parameters	Minimum requirement					x		T
	Check oil level (if applicable) and max. temperature	Minimum requirement					x		T
	Check of cooling system (fans) if applicable	Minimum requirement					x		T
	Check of MV surge discharger devices (if applicable)	Minimum requirement					x		T
MV switchgear incl. protection devices	Integrity check & cleaning	Minimum requirement					x		T
	Safety equipment inspection	Minimum requirement					x		T
	Check labelling and identification	Minimum requirement					x		R
	Electrical protections visual inspection	Minimum requirement					x		T
	Thermographical inspection, if possible	Recommendation					x		T
	Sensors functional verification	Minimum requirement					x		T
	Measurements inspection	Minimum requirement					x		T
	Check correct operation	Minimum requirement					x		T
	Check fuse status	Minimum requirement					x		T
	Check cables terminals	Minimum requirement					x		T
	Battery / UPS check	Minimum requirement					x		
	Mechanical lubrication	According to manufacturer>s recommendations and necessity						(5)	T
	Replace certain mechanical parts							(5)	T
	Battery / UPS replacement							(3)	T
	Check protection parameters	According to local grid code						(5)	T
	Functional check of protection devices							5	T
Power analyser	Integrity check & cleaning	Minimum requirement					x		T
	Check labelling and identification	Minimum requirement					x		R
	Measurements inspection	Minimum requirement					x		T
	Software maintenance	Recommendation					x		T
	Monitoring operation test	Minimum requirement					x		T
	Check parameters	Minimum requirement					x		T
Energy meter	Integrity check & cleaning	Minimum requirement					x		T
	Check labelling and identification	Minimum requirement					x		R
	Check values and parameters	Recommendation					x		T
	Check of communication devices (modem, converters) if applicable	Recommendation					x		T
Power control unit	Check batteries	According to manufacturer>s recommendations					(x)		T
	Replace batteries							3	T
	Functional verification						x		T
	Integrity check & cleaning	Minimum requirement					x		T

Annex e) Annual Maintenance Plan / continued

UPS	Integrity check & cleaning	Minimum requirement					x		T
	Check batteries	Minimum requirement					x		T
	Replace batteries	Recommendation						3	T
	Functional test of ventilation system (if applicable)	Best practice					x		T
Emergency generator (if applicable)	Integrity check & cleaning	According to manufacturer›s recommendations					(x)		T
	General maintenance						x		T
	Check correct operation						x		T
	Replacement of filters							5	T
Lights and electric sockets	Integrity check & cleaning	Minimum requirement					x		T
	Check correct operation	Minimum requirement					x		
	Check conformity to local security standards	Minimum requirement						3	T
HVAC (if applicable)	Integrity check & cleaning	According to manufacturer›s recommendations					(x)		T
	Functional verification						x		T
	Change of air filters						x		T
Water supply system (if applicable)	Integrity inspection	if applicable					x		T
Fire detection central (if applicable)	Integrity check & cleaning	According to manufacturer›s recommendations and local requirements					(x)		T
	Check correct operation						x		T
	Battery inspection						x		T
	Sensors functional verification						x		T
	Cleaning of cameras & sensors						x		T
Lightning protection (if applicable)	Integrity inspection	Minimum requirement					x		R
Fences and gates	Integrity inspection	Minimum requirement					x		T
	Lubrication of locks	Minimum requirement				x			T
Vegetation	Vegetation clearing	According to local conditions			(x)				T
Paths	Integrity inspection	Best practice					x		T
	Vegetation clearing	Recommendation					x		T
Drainage System	General cleaning	Minimum requirement				x			T
Manholes	Integrity inspection	Best practice					x		T
Buildings	Integrity check & cleaning	Minimum requirement					x		T
	Lubrification of locks	Minimum requirement				x			T
	Documents inspection	According to local requirements					(x)		T
	Check fire extinguishers						x		T
	Check earthing							3	T
Safety equipment	Integrity check & cleaning	Minimum requirement					x		T
	Check correct operation	Minimum requirement					x		T
PV support structure	Integrity inspection	Minimum requirement					x		R
	Check tightening	Minimum requirement					x		R
	Check potential equalization	Minimum requirement						2	T
Tracker system	Integrity check & cleaning	Minimum requirement					x		T
	Check correct operation	According to manufacturer›s recommendations					(x)		T
	Check tightening						x		R
	General maintenance						x		T
	Mechanical lubrication					x			T

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Weather station	Integrity check & cleaning	According to manufacturer>s recommendations					(x)		T
	Functional test of sensors						x		T
	Check correct operation						x		T
	Check batteries (if applicable)						x		T
	Monitoring operation test						x		T
Irradiation sensors	Integrity check & cleaning	According to manufacturer>s recommendations and local requirements			(x)				T
	Calibration							2	T
	Monitoring operational test						x		T
Communication Board	Functional communications check	Minimum requirement	x						T
Intrusion detection and verification system	Integrity check & cleaning	Minimum requirement					x		T
	Functional verification of intrusion detection	According to manufacturer>s recommendations					(x)		T
	Functional verification of alarming						x		T
	Functional verification of cameras			x					T
	Specific maintenance						x		T
Stock of spare parts	Inventory of stock	Minimum requirement					x		T
	Visual inspection of stock conditions	Minimum requirement					x		T
	Stock replenishment	Minimum requirement	x				x		T

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