INTERSOLAR – POWERFUL PIONEERS FOR 25 YEARS!

Intersolar Europe | Munich | June 22–24, 2016
Intersolar North America | San Francisco | July 12–14, 2016
Intersolar South America | São Paulo | August 23–25, 2016
Intersolar Middle East | Dubai | September 19–21, 2016
Intersolar India | Mumbai | October 19–21, 2016
Intersolar Summits | Worldwide

Discover the World’s Leading Exhibition Series for the Solar Industry
www.intersolarglobal.com
Foreword

All the evidence points towards the fact that Operations and Maintenance (O&M) are being recognized for their critical role in optimizing photovoltaic solar power assets. O&M has long evolved from the days of being an add-on to Engineering, Procurement and Construction (EPC) contracts and has charted its own course to become a standalone industry that is seen as a critical component in the solar energy value chain.

This, of course, has led to consolidation within the industry and a clear distinction between the competencies of service providers. In fact, as O&M industry leaders professionalize and establish new benchmarks, asset owners have seen the inevitable gap in knowledge and skills between services providers with varying capabilities.

This led to the recognition by the industry, represented by the members of Solar Power Europe, that a joint effort was required to collate, filter, and then communicate what should ideally be the universally accepted standard for professional O&M services. Thus, the Task Force on O&M Best Practices and Guidelines, led by First Solar and coordinated by SolarPower Europe, was born.

The collaboration of almost 3 dozen solar energy professionals has been outstanding and we are expecting, that this document will be enhanced and improved over time. We trust, that the experience of all participating professionals, allies as well as competitors, representing O&M Service Providers, Asset Owners, Asset Managers, Technical Advisors and manufacturers provides a very good overview of what the reader shall expect when considering O&M for utility-scale PV power plants.

The market for services around solar PV assets is changing and becoming increasingly mature. This leads to the observation, that O&M is becoming a business and is separating from EPC, which it was attached to in the early years of the industry. The O&M business across Europe is also consolidating and specialised companies are offering their services. In these guidelines O&M focuses on the technical operations and maintenance services for utility-scale PV power plants. Asset management, which is also a very important piece of PV plant ownership, is seen to cover all the commercial and administrative activities of importance during the lifetime of the plant. Since the responsibilities of O&M and asset management cannot be separated along a clearly defined line of tasks or items, SolarPower Europe welcome feedback on this document, which aims to capture the experience now. As our industry evolves there will always be room for improvement, also in the content of this document, please do take the time to let us know of your experience and the value of these guidelines.

Enjoy this report! Your feedback is more than welcome on any aspect, in order to improve the next version and make it more impactful for our industry.

Stefan Degener
Senior Director O&M
First Solar Energy Services
O&M Task Force Leader

James Watson
Chief Executive Officer

Task Force Coordinator
Ioannis Thomas Theologitis, SolarPower Europe

Contributions and co-authors
SolarPower Europe O&M Task Force members (see the full list in the next page)

Acknowledgements
SolarPower Europe would like to extend special thanks to all the Task Force Members that contributed with their knowledge and experience to this report. This work would never have been realized without their continuous support.

Project Information
The SolarPower Europe O&M Task Force officially started its work in April 2015 and continues with frequent exchanges and meetings. The first version of the Best Practices Guidelines is a product of one year and reflects the views of a considerable share of the O&M industry in the EU today. There has been no external funding or sponsoring for this project.

Supported
By Intersolar Europe

Disclaimer
Adherence to the “O&M Best Practices Guidelines” version 1.0 report and its by-products is voluntary. SolarPower Europe and the Task Force members hold no responsibility for misinterpretations or misuse of the content and will provide no indemnities. Any stakeholders that adhere to this version are responsible for self-certifying that they have fulfilled the guide requirements.

Please note that version 1.0 is subject to further changes, updates and improvements.
Task Force Members

Stefan Degener, First Solar
Achim Woyte, 3E
Stefan Jensen, 3E
Heinz Hackmann, Adler Solar
Patrick Wurster, tco-solar
Wolfgang Rosenberg, tco-solar
Vassilis Papaconomou, Alectris
Richard Jackson, Lark Energy
Paolo Chiantore, Kenergia Sviluppo
Paolo Di Ciaccio, Kenergia Sviluppo
Bengt Jaeckel, UL
Iain Davidson, Solarcentury
Jose Guinea, Martifer Solar
Vasco Vieira, Martifer Solar
Angus Campbell, British Solar Renewables
Lucie Garreau Iles, DuPont Photovoltaic Solutions
Anna Vidlund, Fortum
Ignasi Sospedra, Trinal Solar
Martin Nuemeyer, Meteocontrol
Tobias Knoblauch, Meteocontrol
Paolo Seripa, Enel Green Power
Angelo Guardo, Enel Green Power
Kenneth Heidecke, Conergy Services
Bjarn Roese, Conergy Services
Nicola Waters, Primrose Solar Management
Oliver Laufmann, Schneider-Electric
Adrian Timbus, ABB
Juan Carlos Gonzalez, Jinko Solar
John Messaritis, Messaritis
Martyn Berry, Enphase Energy
Etienne Lecompte, Powerhub
Aristotelis Biliouris, Iris Hellas
Table of Contents

EXECUTIVE SUMMARY 9

1 INTRODUCTION 10

1.1 Rationale, aim and scope 10

1.2 How to benefit from this document 11

1.3 Stakeholders and roles 11

2 DEFINITIONS 14

3 ENVIRONMENT, HEALTH & SAFETY (EH&S) 18

4 PERSONNEL & TRAINING 21

5 POWER PLANT OPERATIONS 23

5.1 Documentation Management System (DMS) 23

5.1.1 Information type and depth of detail / as-built documentation 23

5.1.2 Management and control 24

5.1.3 Record control 24

5.2 Data and Monitoring Requirements 27

5.2.1 Irradiance measurements 27

5.2.2 Module temperature measurements 28

5.2.3 Local meteorological data 28

5.2.4 String measurements 29

5.2.5 Inverter measurements 29

5.2.6 Configuration 29

5.2.7 Energy meter 30

5.2.8 AC circuit / Protection relay 30

5.2.9 Data loggers 30

5.2.10 Alarms 30

5.2.11 Dashboard / Web portal 31

5.2.12 Data format 31

5.2.13 Communication from the site to the monitoring servers 31

5.3 Plant Monitoring and Supervision 32
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4</td>
<td>Performance Analysis &amp; Improvement</td>
<td>32</td>
</tr>
<tr>
<td>5.5</td>
<td>Predictive Maintenance</td>
<td>32</td>
</tr>
<tr>
<td>5.6</td>
<td>Plant Controls</td>
<td>34</td>
</tr>
<tr>
<td>5.7</td>
<td>Power Generation Forecasting</td>
<td>34</td>
</tr>
<tr>
<td>5.8</td>
<td>Reporting</td>
<td>35</td>
</tr>
<tr>
<td>5.9</td>
<td>Regulatory compliance</td>
<td>36</td>
</tr>
<tr>
<td>5.9.1</td>
<td>Grid code compliance requirements</td>
<td>36</td>
</tr>
<tr>
<td>5.10</td>
<td>Management of change</td>
<td>37</td>
</tr>
<tr>
<td>5.11</td>
<td>Warranty management</td>
<td>37</td>
</tr>
<tr>
<td>5.11.1</td>
<td>Warranty of good execution of works and equipment warranties</td>
<td>38</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Performance Warranty</td>
<td>39</td>
</tr>
<tr>
<td>5.12</td>
<td>Insurance claims</td>
<td>39</td>
</tr>
<tr>
<td>6</td>
<td>SPARE PARTS MANAGEMENT</td>
<td>40</td>
</tr>
<tr>
<td>7</td>
<td>POWER PLANT MAINTENANCE</td>
<td>43</td>
</tr>
<tr>
<td>7.1</td>
<td>Preventative Maintenance</td>
<td>43</td>
</tr>
<tr>
<td>7.2</td>
<td>Corrective Maintenance</td>
<td>43</td>
</tr>
<tr>
<td>7.3</td>
<td>Extraordinary Maintenance</td>
<td>44</td>
</tr>
<tr>
<td>7.4</td>
<td>Additional Services</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>SOLAR PV PLANT SECURITY</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>CONTRACT MANAGEMENT</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>KEY PERFORMANCE INDICATORS (KPIS)</td>
<td>48</td>
</tr>
<tr>
<td>10.1</td>
<td>PV plant KPIs</td>
<td>48</td>
</tr>
<tr>
<td>10.1.1</td>
<td>Availability</td>
<td>48</td>
</tr>
<tr>
<td>10.1.2</td>
<td>Energy-based availability</td>
<td>50</td>
</tr>
<tr>
<td>10.1.3</td>
<td>Performance Ratio</td>
<td>51</td>
</tr>
<tr>
<td>10.1.4</td>
<td>Energy Performance Index</td>
<td>52</td>
</tr>
<tr>
<td>10.2</td>
<td>O&amp;M Contractor KPIs</td>
<td>52</td>
</tr>
</tbody>
</table>
10.2.1 Reaction Time 52
10.2.2 Reporting 53
10.2.3 O&M Contractor experience 53
10.2.4 Maintenance Effectiveness & Maintenance Support Efficiency 53

11 CONTRACTUAL COMMITMENTS 54

11.1 O&M Contractors Qualification 54

11.2 Responsibility and Accountability 54

11.3 Bonus Schemes and Liquidated Damages 55

REFERENCES 56
EXECUTIVE SUMMARY

The provision of Operation and Maintenance (O&M) services has been emerging as an important field for the photovoltaic (PV) sector. Over the last couple of years there have been major developments in this part of the value chain and there is no doubt that demand for O&M services worldwide will only increase. The universal recognition of the positive factual impact that professional O&M has on the technical and economic lifetime performance of solar PV system, especially in a period with many changes in the regulatory and support scheme environment, supports that forecast.

On the brink of the “post 100 GW solar PV” era, Europe has the potential to be positioned at the forefront of O&M provision within the solar sector, create value and be the beacon for other regions and markets. The boom and bust market development in many EU countries over the last years has left an aging fleet that requires proper “health care” for the rest of its “life” in order to meet its performance expectations and consequently strengthen the reliability of the PV system facilitating solar’s evolution into mainstream electricity supply.

Acknowledging the above, SolarPower Europe initiated a dedicated Task Force (TF) where leading stakeholders have come together to share knowledge and years of experience, with a sole objective to identify and develop industry-led Best Practices Guidelines on how to provide professional O&M services. Our motivation to set up this Task Force came from the following factors: The lack of standardisation in O&M service provision, the shortcomings and bad practices found in the field, the lack of awareness and negligence towards incorporating proper O&M services, the untapped opportunity to optimise assets and the impact on investment returns.

The companies involved come from across the supply chain – O&M contractors, asset managers, developers, manufacturers, monitoring solutions providers, consultants and utilities – covering the largest share of EU capacity which is under O&M provision and bringing valuable international experience.

The current version of the report (version 1.0) is a product of one year’s work and covers all the main responsibilities of the O&M contractor, classifying them when possible into minimum requirements and best practices. This distinction was deemed necessary in order to cover first the important tasks below which the O&M provision is considered as poor or insufficient and then suggest, when available, best practices which can add to the quality of the service. Minimum requirements form a quality benchmark for a professional and bankable service provider and of course a high level asset performance.

The scope of this version is ground mounted systems of 1MW and above (utility scale) which cover nowadays more than one third of the installed capacity in Europe. The report starts with clarifying the roles of the main stakeholders involved, building an understanding of the respective responsibilities and then dives into the main aspects of O&M and the tasks of the O&M contractor, covering both technical but mainly non-technical tasks. The Task Force has also identified shortcomings in the Operations field where standardization is less present and therefore, this report tries to list in a concise and simple way important steps that should be taken (e.g. how to do predictive, preventative and corrective maintenance, contract management, reporting, what are the monitoring requirements etc.).

Attached to this report, a suggested Maintenance Plan has been created (excel sheet) which covers all periodic actions to prevent failures and ensure optimal operating conditions of equipment and of the entire PV plant (Preventative Maintenance).

This report has been drafted to be primarily used by O&M contractors, asset managers and owners, investors, and developers, but it can be a valuable tool for all relevant stakeholders with interests both in the primary and secondary market.

In the future, the Task Force will extend the report, improve it with additional inputs, include national consideration and effectively promote it in- and outside of Europe, aiming at increasing the consensus.
Introduction

1.1 Rationale, aim and scope

A professional O&M service package ensures that the photovoltaic system will maintain high levels of technical and consequently economic performance over its lifetime. Nowadays, it is well acknowledged by all stakeholders that high quality of O&M services mitigates the potential risks, improves the levelised cost of electricity (LCOE) and Power Purchase Agreement (PPA) prices and positively impacts 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 phase.

- Development (typically 1-3 years)
- Construction (some months)
- Operation & Maintenance (typically 20-35 years)
- Dismantling or repowering (some months)

Therefore, the benefits for increasing the quality and in contrast the risks for neglecting O&M are high. The PV industry – a “young” industry that evolves also in the services part – offers a wide range of practices and approaches. Although this is partly logical, reflecting the specificities of each system, topologies, installation sites and country requirements, there is a confusion or lack of clarity and knowledge by many asset owners and the funding authorities (investors or/and banks) of what the minimum requirements should be. In cases, especially in the past where feed-in tariffs were very high and favourable, there was a clear lack of risk perception in combination with an underestimated performance metrics definition which hindered the proof of value of a professional and high quality service provision.

Existing standardisation still does not fill in the gaps, or clarify the requirements and their implementation. Although in the Maintenance part, there are a number of technical international standards that can be followed, in the Operations field where more planning, scheduling and administrative related tasks are also covered the shortcomings are many. Therefore, it is crucial to develop best practices in order to optimise the Operations, meaning the energy production, the power plant management, and resulting benefits. This will set the quality bar high and enhance the understanding and confidence of the investors.

SolarPower Europe and its respective Task Force aims at contributing with the present “O&M Best Practices Guidelines” to reach this objective and improve the communication among the different stakeholders. The value proposition of this report is that it is industry-led, containing the knowledge and the experience of well-established and leading companies in the field of service provision, project development and construction (EPC), asset management, utilities, manufacturers and monitoring tool providers.

The scope of the current work includes the utility scale segment and more specifically, systems above 1MW. The geographical focus is Europe. The ”O&M Best Practices Guidelines” version 1.0 provides the high level requirements that can be applied in all countries around Europe (and beyond). Specific national considerations are not included and should enhance this version if this is to be used in specific countries. Adoption is considered effortless.
The content covers technical and non-technical requirements, classifying them when possible into minimum requirements and best practices. This distinction was deemed necessary in order to cover first the important tasks below which the O&M provision is considered as poor or insufficient and then suggest, when available, best practices which can add to the quality of the service. Minimum requirements (whatever is not referred as best practice in the text) form a quality benchmark for a professional and bankable service provider and of course a high level asset performance.

1.2 How to benefit from this document

This report includes the main and important considerations for a successful and professional O&M provision. Although it has not been tailored for each stakeholder, the use is similar for all; understand the mandatory requirements and necessity of a professional O&M and incorporate accordingly those guidelines into the service package. Any of the directly relevant stakeholders (see chapter 1.3 below) can benefit from this work, tailor it to their needs without lowering the bar and know what to ask for, offer or expect.

Although the focus is European, most of the content can be used in other regions around the world, especially in those with similar conditions and moderate climate. Additional requirements or modifications can easily take place for other regions with unique characteristics.

1.3 Stakeholders and roles

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

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

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

Asset Manager
Asset management aims at ensuring optimal profitability of the PV power plant (or a portfolio of plants) by supervising energy sales, energy production, and O&M activities. It also ensures the fulfilment of all the administrative, fiscal, insurance and financial obligations of the SPVs. Therefore, this role has a financial as well as a technical aspect. Asset Managers report to Asset Owners. In some cases, in particular where SPVs belong to large Asset owners such as utilities or large IPPs, the Asset management activity is done in-house.

O&M Contractor
The entity that is in charge of O&M activities as defined in the O&M contract. In some cases, this role can be subdivided into:
- **Operations service provider (team)** who is in charge of monitoring, supervision and control of the PV power plant, management of maintenance activities, and reporting to Asset manager.
- **Maintenance service provider (team)** who carries out maintenance activities.

A comprehensive set of O&M activities (technical and non-technical) is presented in this report. *However, the two activities are often provided by a single entity through a full service O&M contract.*

**Technical Advisors / Engineers**
These are individuals or teams of experts that provide specialized services (e.g. detailed information, advice, technical consulting etc.). Their role is rather important since they ensure that procedures and practices are robust and of high quality – according to standards and best practices – to maintain high performance levels of the PV plant. Technical advisors can represent different stakeholders (e.g. investors, lenders)

**Specialised suppliers**
Such suppliers could be of specialised services (e.g., technical consulting) or hardware (e.g., electricity generating components, security system).

**Authorities**
These can be local (e.g., the mayor), 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).

**Off-taker**
The entity who pays for the produced electricity. This role is still evolving and is often subdivided according to national renewable power support resp. purchase schemes:

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

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

- Investor may take asset management responsibilities
- Asset manager may take over a more active role and intervene in operations
- Asset manager may even take over full O&M
- O&M contractor role may be subdivided as already mentioned but may also include some asset management activities (e.g. electricity sale, insurance, fiscal registrations, etc.)
- End customer (or electricity buyer) may be at the same time asset owner, asset manager, and O&M contractor (e.g. PV power plant on an industrial site to cover own energy needs)

In Figure 1 below there is an attempt to classify and distribute in a clear way the responsibilities among the different stakeholders and in particular among the Asset Manager (Asset management), the O&M Contractor (Operations Management & Maintenance) and the EPC (Engineering, Procurement, Construction). This was presented in a past study from GTM Research\(^1\) and is a simple and well-accepted allocation of tasks.

---

\(^1\) The figure is redesigned and based on a figure from GTM Research report: ”Megawatt-Scale PV Plant Operations and Maintenance: Services, Markets and Competitors, 2013-2017”, 2013
It is shown that the supervision of the O&M activities is under the “technical asset management” (when externalised\(^2\)) and in most cases the O&M Contractor will have a more technical role (energy output optimization) and the asset manager will undertake more commercial responsibilities (financial optimization).

However, experience shows that in cases, and due to the current developments of the O&M market in the PV sector, the role of the Asset manager as described above can overlap with the role of the O&M Contractor as this is described in current contracts. The O&M Contractor then, and when requested and if qualified, can be assigned to manage more commercial tasks or represent the Asset manager (even the Asset Owner) in front of third parties. In fact, today, most of the O&M Contractors are equipped to offer asset management services, having in-house financial/commercial skills.

This grey zone of responsibilities makes it difficult to standardize properly the responsibilities of each stakeholder. In 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 for Asset Managers to have technical skills in-house for a meaningful supervision and proper assessment of the technical solutions, and O&M Contractors to have the ability to cost-assess and prioritize their operational decisions and maintenance services.

\(^2\) It is acknowledged that nowadays there are entities which provide both asset managements and O&M services. However, in this report, it is assumed to be kept separately and provided by separate entities.
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 standardized as in the case for Maintenance. The chapter provides a short list (alphabetically ordered) below which is not exhaustive, but reflects the different sections of this document. For the definitions of the Maintenance the EN 13306 was used as a base.

1. Additional Services
   Actions and/or works performed, managed or overseen by the O&M Contractor, which are not (but can be if agreed) part of the regular services and normally charged “as-you-go”, e.g. ground maintenance, module cleaning, security services etc. Some of the Additional Services can be found as a part of the Preventive Maintenance, depending on the contractual agreement.

2. Contract management
   Activities related to the proper fulfilment of O&M contract obligations such as reporting, billing, contract amendments, regulator interaction, etc.

3. Contractual Commitments
   An agreement with specific terms between the asset owner and the O&M Contractor. This agreement defines in details the O&M services, both remote operations services and local maintenance activities, the management and interfaces of those services, as well as the responsibilities of each party. Liquidated damages and bonus schemes are also part of the contractual commitments.

4. Control Room Services/Operations Centre Services
   Comprehensive actions like PV plant monitoring, supervision, remote controls, management of maintenance activities, interaction with grid operators, regulators, Asset Managers and Asset Owner, as well as the preparation and provision of regular reporting performed by experienced and
5. Corrective maintenance

Actions and/or techniques (immediate or deferred) taken to correct failures, breakdowns, malfunctions, anomalies or damages detected during inspections, or through monitoring, alarming, or reporting or any other source. The actions are desired to restore the PV system back into regular and required operation mode.

6. Data and monitoring requirements

Hardware and software, technical and functional specifications to collect, transmit and store production, performance and environmental data for plant management.

7. Documentation management system

A management system that records, manages and stores documents required for O&M, such as technical plant and equipment documentation and drawings, maintenance manuals, photos and reports, including the various versions that are being created by different users, reviews and approvals. Documentation management system also defines a proper format and use (information exchange).

8. Environment Health & Safety (EH&S)

Environment, Health and Safety indicates the activities performed to ensure environmental protection, occupational health and safety at work and on site applicable to staff and visitors according to the national applicable laws and regulations.

9. 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.

10. Grid code compliance requirements

Equipment, procedures, actions and activities required by the respective grid operator(s) in order to comply to grid safety, power quality and operating specifications.

11. Insurance claims

Customer’s activities required to claim a reimbursement based on specific insurance policy terms.

12. Key Performance Indicator (KPI)

A technical parameter that helps the stakeholders to evaluate the successful operation of a PV plant and/or the success of the O&M Contractor’s activities.

13. Management of change

Management of change defines the way to handle necessary adjustments of design of a PV power plant after the Commercial Operation
Date. Changes require a close cooperation between the plant owner and the O&M Contractor.

14. Performance Analysis & Improvement

Measurements, calculations, trending, comparisons, inspections, etc. performed in order to evaluate PV plant, segments and/or single component performance, site conditions, equipment behaviour, etc., and to provide reports and assessment studies to whom it may concern (customer, public authority, etc.).

15. 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.

16. Plant Control

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).

17. Plant Monitoring

Overall monitoring of the functioning, energy generation and reference data of the PV plant and its components, which is performed through real-time (web based) monitoring software. The monitoring operates 24h/365d and is fed by in-plant data-logging systems that collects data from different plants as well as by irradiation and temperature measurements from particular sensors and other sources such as meteorological information (data acquisition 24h/365d).

18. Plant Supervision

The activity to supervise and analyse data provided by the monitoring system which is performed by experienced human resources during daylight hours and managed by one or more control rooms (365 days/year). The reception and qualification of the alarms from the monitoring tool is also considered to be part of the supervision.

19. 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 respective expert knowledge base is used to identify the appropriate actions based on a cost benefit analysis.
20. Preventative maintenance

Actions and/or testing and/or measurements to ensure optimal operating conditions of equipment and of the entire PV plant and to prevent defects and failures. Those take place periodically and according to a specific maintenance-plan and maintenance schedules.

21. Power Generation Forecasting

Adoption of forecasting tools calculating expected power production for a certain timeframe from weather forecasts in order to supply the expected power production to owner, grid operator, energy traders or others. This is normally country and plant dependent.

22. Regulatory compliance

Compliance to any law, statute, directive, bylaw, regulation, rule, order, delegated legislation or subordinate legislation directly applicable in the country where the service is provided, as well as to any mandatory guidelines and measures issued by a utility and any other competent public authority.

23. Reporting and other deliverables

Deliverables produced periodically, according to requirements detailed in the O&M agreement or following best market practices, including PV plant performance, Key Performance Indicators, maintenance activities and work orders performed, alarm handling, equipment status, warranty handling activities and spare parts tracking and any other Analysis performed in compliance with the O&M contract requirements.

24. Security

Actions, procedures, equipment and/or techniques that are adopted on site and remotely in order to protect the plant from theft, vandalism, fire, etc.

25. Spare parts management

Activities that ensure availability of the right amount and type of components, equipment, parts, etc. either on site or in warehouses or in manufacturers' consignment stocks, for prompt replacement in case of failure and/or to meet guarantees under O&M contracts.

26. Warranty management

Warranty management usually aggregates activities of diverse nature which are linked to areas such as supply of equipment and services, and project construction. All these responsibilities (warranties) are usually materialized with the issue of the Provisional Acceptance Certificate (PAC) by the EPC. Warranty Management is the activity that manages these warranties with the objective of reducing the costs and response times after warranty claims for repair or replacement of certain PV system components (under the warranty of the EPC and/or the components manufacturer).
Environment, Health & Safety (EH&S)

The Asset Owner has the ultimate legal and moral responsibility to ensure the health and safety of people in and around the solar plant and for the protection of the environment around it. The practical implementation is normally subcontracted to the O&M Contractor.

Environment

Renewable energies are popular because of their low environmental impact and it is important that solar plants are operated and maintained to minimise any adverse effects. Environmental problems are normally avoidable through proper plant design and maintenance – for example, bunds and regular inspection of HV transformers will reduce the chances of significant oil leaks – but where issues do occur the O&M Contractor must detect them and respond promptly. As well as the environmental damage there may be financial or legal penalties for the owner of the plant.

Other aspects that need to be taken into account are recycling of broken panels and electric waste so that glass, aluminium and semiconductor materials can be recovered and reused. In areas with water scarcity, water use for module cleaning should be minimized.

In many situations, solar plants offer an opportunity, where managed sympathetically, to provide a valuable natural habitat for plants and animals alongside the primary purpose of generation of electricity. A well thought out environmental management plan can help promote the development of natural habitat, as well as reduce the overall maintenance costs of managing the grounds of the plant. It can also ensure the satisfaction of any legal requirements to protect or maintain the habitat of the plant.

Health and Safety

The risk to the health and safety of people from the solar plant is a primary concern of the O&M Contractor. Solar plants are electricity generating power stations and have significant hazards present which can result in permanent injury or death. Through proper hazard identification, careful planning of works, briefing out of procedures to be followed, documented and regular inspection and maintenance, risks are reduced (see also Solar PV Plant Security chapter 8).

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 coming on to a solar farm should expect some form of induction to ensure they are briefed on any hazards and risks. Staff actually 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 marking to warn personnel of possible hazards and wiring sequence. Such marking 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 as a whole when working on the plant. An up to date plan of
hazards is important for the O&M Contractor to use to plan and 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 on 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 the responsible for the compliance of H&S regulations within the site/plant. He will make sure at all times that the installation and all equipment meets all the relevant legislations of the country and also, that all contractors, workers and visitors respect the H&S Legislation by strictly following all the established procedures, including the use of established personal protective equipment (PPE).

At the same time, the O&M Contractor shall 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 shall ensure that it complies, and that all of its subcontractors comply, at all times 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 a 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 updated the H&S file of each site.

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.).

However, there are some basic cross cutting considerations that apply to each country and will ensure proper compliance with basic requirements around H&S matters. Those can be found in Table 1 below:

### Table 1: Examples for typical/minimum requirements for H&S

<table>
<thead>
<tr>
<th>Qualifications</th>
<th>Minimum level of entry and demonstration that the O&amp;M Contractor and respective personnel have served an apprenticeship. Provision of relevant documentation (proof) is required.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A certification scheme that covers technical and safety requirements for PV when available in the respective country. <strong>It is important for the solar industry to work towards that direction in Europe, in order to raise the bar and ensure high quality of trained and professional people.</strong> The skills’ matrix in chapter 4 could be a starting point to filter the requirements needed.</td>
</tr>
<tr>
<td>Personal Protective Equipment</td>
<td>Minimum requirements for PPE are listed below (not exhaustive). The list includes mandatory items and bespoke items based on risk assessment:</td>
</tr>
</tbody>
</table>

3 It should be noted that the content of this table is only indicative and based on typical but important requirements that are found in all national regulations. **However, this list is not exhaustive and therefore the reader should not treat it as such and always refer to the relevant national standards related to H&S.** The authors and contributors of this report will hold no responsibility if the reader acts otherwise.
<table>
<thead>
<tr>
<th>Equipment</th>
<th>Only certificated and calibrated equipment that has full documentation should be used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Safety shoes</td>
</tr>
<tr>
<td></td>
<td>High visibility (Hi-Vis) clothing</td>
</tr>
<tr>
<td></td>
<td>Helmet</td>
</tr>
<tr>
<td></td>
<td>Gloves (and/or insulated gloves for live work)</td>
</tr>
<tr>
<td></td>
<td>Flash masks and glasses (depending on the site)</td>
</tr>
<tr>
<td></td>
<td>Fire retardant and/or arc flash rated PPE where necessary</td>
</tr>
</tbody>
</table>
Personnel & Training

It is of critical importance that both 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 and in general not advisable to be rigid with the profile of the employees suitable to carry out the work and meet the necessary requirements. Indeed, the necessary knowledge and experience can be gained through different career developments and by different engagements.

The O&M teams benefit from a 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. Obviously, there are some cross cutting requirements such as everyone needs to be suitably educated and experienced to understand the range of hazards on a park with the works he is carrying out, it also needs to meet the local regulations, to strive for personal development and to stay updated (shared responsibility with the employer). Awareness of the necessary health and safety regulations is a must.

In an attempt to identify the requirements for the core group of specialists and technical personnel:

- Operations (Centre) specialists working remotely should have an electromechanical or similar education with proven analytical skills; supervisors for Operations and senior personnel are recommended to be electrical or electromechanical engineers (Educational level ≥ Level 4) with certain practical working experience in the field or in control centres. Experience with DC electrical equipment is critical to allow operations staff to draw the right conclusions from their data evaluation and analysis and provide the correct recommendations to maintenance personnel on site. Experience with grid codes and standards is required for operators actively managing PV plants locally or remotely. Availability and continuous update of local / regional Electrical Operators licenses and permits is required in legislations where authorities ask for compliance. Ability for data-driven financial and business decisions are also required, especially for senior personnel.

- Plant Operators and Maintenance Personnel shall also have the appropriate technical knowledge, usually of an electrical or electromechanical nature (Educational level ≥ Level 3). Working experience with electrical circuits and systems is necessary and ability to read the respective drawings. As for the Operations personnel, knowledge and experience with DC power and the specifics of PV plants will facilitate the service provision and right decisions. Troubleshooting is a needed skill for the maintenance personnel.

Regular training schemes should be designed and available to the personnel for maintaining the high quality of staff and service provision. Proper documentation of training procedures is also expected and shall be made available to interested parties.

In order to ensure compliance of competence the principal of a skills’ matrix is proposed below in Table 2. The matrix goes beyond any educational background and focuses on the skills required by the O&M company in a specific country. Therefore, many of the skills/requirements are adjustable due to different practices and regulations across Europe.
<table>
<thead>
<tr>
<th>Employee Type</th>
<th>Health &amp; Safety</th>
<th>Environmental</th>
<th>Monitoring &amp; Metering</th>
<th>Inverter</th>
<th>Electrical</th>
<th>Data &amp; Commns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Company &amp; General</td>
<td>Site &amp; Event Management</td>
<td>Health &amp; Safety</td>
<td>Monitoring &amp; Metering</td>
<td>Inverter</td>
<td>Electrical</td>
</tr>
<tr>
<td>Manager</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Manager</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Manager</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Administrator</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Administrator</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Electrician</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Electrician</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Electrician</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Trainer</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Trainer</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
<tr>
<td>Trainer</td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
<td><img src="#" alt="Not applied" /></td>
</tr>
</tbody>
</table>

* Table 2: Proposed skills' matrix for O&M personnel

---

<table>
<thead>
<tr>
<th>Legend</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Not applied</td>
</tr>
<tr>
<td>Red</td>
<td>Applied</td>
</tr>
<tr>
<td>Yellow</td>
<td>Partially</td>
</tr>
<tr>
<td>Orange</td>
<td>Not required</td>
</tr>
</tbody>
</table>

22
5

Power Plant Operations

5.1 Documentation Management System (DMS)

Solar PV plant documentation is crucial for an in-depth understanding of the design, configuration and technical details thereof. It is the Asset Owner’s responsibility to provide those documents and if not available, they should be recreated at his/her 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 is needed over the lifetime of the plant. This is what is called here:

- Record control (or records management)

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

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

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

In general, for optimum service provision, the O&M Contractor should have access to all possible documents (from the EPC phase). The Site Operating Plan is the comprehensive document prepared and provided by the plant EPC, which lays out a complete overview of the plant location, layout, electrical diagrams, components in use and reference to their operating manuals, EH&S rules for the site and certain further topics. All detailed drawings from the EPC need to be handed over to the O&M Contractor and being stored safely for immediate access in case of PV plant issues or questions and clarifications with regards to permits and regulation.
5.1.2 Management and control

As regards the document control, the following guidelines should be followed:

- Documents should be stored either electronically or physically (depending on permits/regulations) in a location with controlled access. **An electronic copy of all documents should be available for all documents.**

- Only authorized people should be able to view or modify the documentation. A logbook of all the modifications should be kept. Such a logbook should contain minimally the following information:
  - Name of person, who modified the document
  - Date of modification
  - Reason of modification and further information, e.g. link to the work orders and service activities

- Versioning control should be implemented. Involved people should be able to review past versions and be able to follow through the whole history of the document

5.1.3 Record control

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

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

Last but not least, there should be a proper documentation for the curtailment periods as well as the repairing periods when the plant is fully or partly unavailable. This will all be recorded by the monitoring system in order to be able to measure lost energy during maintenance activities. For this, having the correct reference values at hand is crucial. Table 3 below summarizes important examples of input records that should be included in the record control.

**As in the case of the as built documentation, all records, data and configuration of the monitoring tool and any sort of documentation and log that might be useful for a proper service provision must be backed up and available when required. This is also important when the O&M Contractor changes.**
### Table 3: Important examples of input records included in the record control

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity Type</th>
<th>Information Type</th>
<th>Input Record</th>
<th>References/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alarms / Operation Incidents</td>
<td>Alarms description</td>
<td>Date and Time, Aﬀected Power, Equipment Code / Name, Error messages / Codes, Severity Classiﬁcation, Curtailment Period, External Visits/Inspections from third parties</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Contract Management</td>
<td>Contract general description</td>
<td>Project Name / Code, Client Name, Peak Power (kWp)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Contract Management</td>
<td>Asset description</td>
<td>Structure Type, Installation Type</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Contract Management</td>
<td>Contract period</td>
<td>Contract Start and End Date</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Contract Management</td>
<td>Contractual clauses</td>
<td>Contract Value, Availability (%), PR (%), Materials / Spare parts, Corrective Work Labour</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Corrective Maintenance</td>
<td>Activity description</td>
<td>Detailed Failure Typosication, Failure, Fault Status, Problem Resolution Description, Problem Cause</td>
<td>EN 13306 - Maintenance. Maintenance terminology</td>
</tr>
<tr>
<td>7</td>
<td>Corrective Maintenance</td>
<td>Corrective maintenance event</td>
<td>Associated Alarms (with date), Event Status</td>
<td>EN 13306 - Maintenance. Maintenance terminology</td>
</tr>
<tr>
<td>8</td>
<td>Corrective Maintenance</td>
<td>Corrective maintenance event log</td>
<td>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</td>
<td>EN 13306 - Maintenance. Maintenance terminology</td>
</tr>
<tr>
<td>9</td>
<td>Corrective Maintenance</td>
<td>Intervention equipment/Element name</td>
<td>Aﬀected Power and Aﬀected Production, Equipment Code / Name</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Inventory Management</td>
<td>Warehouse management</td>
<td>Inventory Stock Count and Movement, Equipment Code / Name</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Monitoring &amp; Supervision</td>
<td>Equipment status</td>
<td>Date, Status log (protection devices, inverters, monitoring systems, surveillance systems)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Monitoring &amp; Supervision</td>
<td>Meteo data</td>
<td>Irradiation, Module temperature, Other meteo variables (ambient temperature, air humidity, wind velocity and direction, ...)</td>
<td>IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis</td>
</tr>
<tr>
<td>13</td>
<td>Monitoring &amp; Supervision</td>
<td>Production / consumption data</td>
<td>AC active and reactive power at PV Plant Injection Point and other subsystems or equipment, Consumption from auxiliary systems,</td>
<td>IEC 61724 - Photovoltaic system performance monitoring -</td>
</tr>
<tr>
<td></td>
<td>Monitoring &amp; Supervision</td>
<td>Performance data</td>
<td>Other variables (DC/AC voltages and currents, frequency), Power from DC field</td>
<td>Guidelines for measurement, data exchange and analysis</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------</td>
<td>------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>14</td>
<td>Preventative Maintenance</td>
<td>Intervention equipment/Element name</td>
<td>Affected Power and Affected Production, Equipment Code / Name, Intervention Start and End Date</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Preventative Maintenance</td>
<td>Maintenance description</td>
<td>Measurements, Preventative Maintenance Tasks Performed, Problems not solved during activity and its Classification and Typification, Technicians and Responsible Names and Function</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>PV Plant Documentation</td>
<td>Commissioning</td>
<td>Commissioning Documentation and Tests Results</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>PV Plant Documentation</td>
<td>Operation and maintenance</td>
<td>Equipment Manuals, PV Plant O&amp;M Manual</td>
<td>IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection</td>
</tr>
<tr>
<td>18</td>
<td>PV Plant Documentation</td>
<td>System Documentation</td>
<td>As built documentation (Datasheets, wiring diagrams, system data)</td>
<td>IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection</td>
</tr>
<tr>
<td>19</td>
<td>PV Plant Documentation</td>
<td>System Documentation</td>
<td>As built documentation (Datasheets, wiring diagrams, system data)</td>
<td>IEC 62446 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection</td>
</tr>
<tr>
<td>20</td>
<td>Warranty Management</td>
<td>Claims registration</td>
<td>Affected Equipment, Claim Description, Occurrence Date; Communications between O&amp;M, client and manufacturer/supplier</td>
<td></td>
</tr>
</tbody>
</table>
5.2 Data and Monitoring Requirements

The Asset Owner (or SPV) owns the data from the monitoring system and data loggers, separate to the O&M Contractor.

In general, the monitoring system should allow follow up on the energy flow in a photovoltaic system. In principle it reports 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 2. These yields and losses are always normalized to installed PV power at standard test conditions in kilowatt-peak.

**Figure 2:** Energy flow in a grid-connected photovoltaic system with parameters, yields and losses

5.2.1 Irradiance measurements

**Irradiance Sensors**

Solar irradiance in the plane of the PV array (POA) is measured on site by means of at least one irradiance measurement device according to Secondary Standard or First Class quality classification and ISO 9060:1990 (ISO 9060 1990). The higher the quality of the pyranometer, the lower the uncertainty will be. Best practice is to apply at least two pyranometers in the plane of the PV array. In case of different array orientations within the plant, at least one pyranometer is required for each orientation. Ensure that the pyranometers are properly assigned to the different arrays for the calculation of the Performance Ratio (PR) and expected yield.

Pyranometers are preferred over silicon reference cells because they allow a direct comparison of the measured performance of the PV plant with the performance figures estimated in the energy

---

4 The figure is redesigned and based on a figure produced by 3E and published at (Woyte et al. 2014)
yield assessment. For plants in Central and Western Europe, measuring irradiance with silicon cells yields approximately 2 to 4% higher long-term PR than with a thermopile pyranometer (N. Reich et al. 2012).

Irradiance sensors must be placed at the least shaded location. They must be mounted and wired in accordance with manufacturers’ guidelines. Preventative maintenance and calibration of the sensors must follow the manufacturers’ guidelines.

*The irradiance is recorded with averages over 15 minutes (minimum requirement) or down to 1 minute or less (best practice).*

**Satellite-based Irradiance Measurements**

*In addition to the irradiance sensors, to record irradiance data from a high-quality satellite-based data service as a complement to data from ground-based sensors can be considered as best practice. For daily irradiation values, the error of satellite-based irradiation data is relatively high with root-mean-square error (RMSE) values of 8 to 14% in Western Europe. For monthly and annual values it is largely below 5 and 3%, respectively, which is not worse than an on-site sensor (Richter et al. 2015). Moreover, satellite-based data services are often more reliable and less subject to systematic errors than on-site sensors.*

Satellite-based irradiance data should at least (minimum requirement) have hourly granularity with a trend towards 15 minutes. The data must be retrieved once per day at least.

**5.2.2 Module temperature measurements**

The direct measurement of the module temperature is required. The temperature sensor should be stuck with appropriate and stable thermally conductive glue to the middle of the backside of the module in the middle of the array table, positioned in the centre of a cell, away from the junction box of the module (Woyte et al. 2013). The installation should be in accordance with manufacturer guidelines (e.g. respecting cabling instructions towards the datalogger). The accuracy of the temperature sensor, including signal conditioning, should be < ±1 °C.

Very large plants should have measurement of module temperature at different places across the PV array. For large arrays, the module temperature should be measured at different representative positions, e.g., for a module in the centre of the array and for modules at edge locations where temperature variation is expected.

**5.2.3 Local meteorological data**

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

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

For plants >10 MWp, automated data collection of independent hourly meteo data should be present (ambient temperature, wind speed, snow coverage) from an independent meteo source. The reason for this is that on-site meteorological stations are subject to local phenomena and installation-specific results. Data from an independent meteo-station is less subject to this while being also more stable and robust with respect to long-term drift.

Therefore, for both performance assessment and detailed analysis purposes, it is recommended to enable automated data collection from a nearby independent meteo reference.
However, for performance assessment the most important measurement remains the in-plane irradiation (see also chapter 10).

5.2.4 String measurements

PV arrays that are not subject to DC input current monitoring at inverter level, should have current monitoring at string level. Depending on module technology used in the plant, strings are combined (harnesses) which can help reducing operation costs.

As best practice, it is recommended to increase up-time for timely detection of faults. Measurement requirements using 1 second sampling and 1-minute averaging at data logger are being used more and more, with a maximum two strings current measurement in parallel.

5.2.5 Inverter measurements

At AC level, energy and power data should be collected. The energy data to be measured and sent to the monitoring system should be cumulative values over the lifetime of the inverter. This allows to follow the overall electricity generation of each inverter over time, even during outages of the monitoring system.

It is very important to collect all inverter alarms. Inverter alarms are a valuable source of information for fault detection, organisation of the maintenance and even setting up preventive maintenance actions.

Monitor all control settings of the plant at inverter level 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 PV generation portfolio (remote control). These settings need to be monitored for reasons of contractual reporting or performance assessment.

Measurement of the input DC voltage and current to the inverter based on a <1s sampling and <1min averaging. For ad-hoc performance analysis purposes e.g. to allow the analysis of PV array performance, root cause analysis or possible MPP-tracking problems, the input DC voltage and current need to be measured and stored separately.

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

Inverters should detect inverter overheating. Therefore, it is advisable to record the temperature as provided by the inverter or measure it using a suitable thermocouple so that the requirement for additional ventilation can be assessed.

5.2.6 Configuration

The configuration of the monitoring systems and data loggers needs to be checked in order to avoid mistakes. This is normally done at commissioning phase or at plant take over by a new O&M Contractor (recommissioning of the monitoring system).

As best practice auto-configuration is recommended if technically possible. The monitoring solution captures automatically the device configuration information (plug-and-play). This also allows for inverter replacement detection. An example could be that all inverter labels such as serial number, inverter ID and inverter input are collected. Furthermore, as best practice the ID of all sensors should be collected. Back up of this configuration data should be in place.
5.2.7  **Energy meter**

Automated collection of meter data with at least daily frequency and 15 min granularity should be included in the monitoring system. Energy meter data are required for invoicing purposes but also serve as an independent reference versus the inverter yield for benchmarking, analysis purposes and loss detection. A high accuracy energy meter for the total output of the plant with an uncertainty of ± 0.5% is required for plants > 100 kWp and highly recommended for all plants – also below 100 kWp (best practice).

*As a best practice recommendation for plants > 1 MWp, the meter should have two communication bus channels to allow data collection via digital meter communication (bus) or via Automatic Meter Reading (AMR) service and it is advisable that the meter sends total cumulative values.*

5.2.8  **AC circuit / Protection relay**

*As a best practice, the AC switch positions as for (sub) plants should be monitored and also it should be possible to read the alarms from the protection relay via the communication bus.*

5.2.9  **Data loggers**

*As minimum requirement, data loggers should have sufficient memory to store at least one month of data. Historical data should be backed up. After a communication failure, the data logger should automatically resend all pending information.*

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

*As best practice the system should use an open protocol, in order to enable easy transition between monitoring platforms.*

In cases and depending on the data logger, it should be rebooted by itself (firmware solution, soft reset) once a day during night time in order to increase its reliability. Alternatively, dataloggers and routers could be monitored (response to ping pos./neg.) by appropriate hardware on site. In case of no response to the control unit, the power supply has to be interrupted (by the control unit) as a hard reset.

The entire monitoring installation should be protected by an uninterruptable power supply (UPS). This includes measurement devices, data loggers and signal converters.

5.2.10  **Alarms**

*As a minimum requirement, the monitoring system will have the following alarms sent by email:*  
- Loss of communication  
- Plant stop  
- Inverter stop  
- 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 UPS operation  
- Intrusion detection
Fire alarm detection
Discretion Alarm (or Alarm Aggregation)

The above lists are not exhaustive.

5.2.11 Dashboard / Web portal

As minimum requirement, the monitoring system will have the following features:

- Web portal accessible 24 hours 365 days
- 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 system:

- User configurable dashboard
- User configurable alarms
- User configurable reports
- Ticket management

The above lists are not exhaustive.

5.2.12 Data format

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

5.2.13 Communication from the site to the monitoring servers

The Asset Owner should make sure to provide the best possible network connectivity to the O&M Contractor with sufficient bandwidth according to the installed monitoring system.

Whenever a DSL connection is available within the PV-site area, this should be the preferred way to connect to the internet; industrial routers can be seen as standard. In case a DSL connection isn’t available, satellite communication is preferred. An additional GPRS-connection as a back-up system can be seen as best practice. Any subscriptions should allow for the data quantity required and should foresee the amount of data (e.g. Closed-Circuit Television (CCTV) or not) and the granularity of data.

For sites > 1MW it is advised to have a LAN connection and as an alternative an industrial router that allows for GPRS or satellite communication back-up in case the LAN connection fails. A router with an auto-reset capability in case of loss of internet connection is recommended.

A direct connection to a monitoring server with a service-level agreement (SLA) guarantees continuous data access. If data passes via alternative monitoring servers without SLA, (e.g. monitoring portal of the inverter manufacturer), this SLA can no longer be guaranteed. The automatic firmware updates of the data logger should be disabled. Firmware updates are subject to acceptance procedure with the monitoring service.

Data security is very important and is becoming increasingly a concern, especially for bigger clients. Therefore, respective considerations and measures should be taken to assure data security.

As minimum requirements loggers should not be accessible directly from the internet or at least be protected via a firewall. Secure and restrictive connection to the data server is also important.
All communication cables must be shielded. Physical distance between (DC or AC) power cables and communication cables should be ensured, as well as that communication cables are protected from direct sunlight.

Furthermore, cables with different polarities must be clearly distinguishable (label or colour) for avoiding polarity connection errors.

5.3 Plant Monitoring and Supervision

The Operations team of the O&M Contractor is responsible for continuous monitoring and supervision of the PV power plant conditions and its performance. This service is done remotely through the use of monitoring software system and/or plant operations centres. The O&M Contractor should have full access to all data collected from the site in order to perform data analysis and provide direction to the Maintenance service provider/team.

Besides the data from the site, if a CCTV system is available on site, he/she should be able to access it for visual supervision and also have access to local weather information.

The O&M Contractor is responsible for being the main interface between the plant owner, the grid operator and the regulator (if applicable) over the lifetime of the O&M contract regarding production data. The Operations team should be staffed to provide services during daytime, when the system is expected to generate electricity and is responsible to coordinate accordingly with the Maintenance service provider/team.

5.4 Performance Analysis & Improvement

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

1. Portfolio level (group of plants)
2. Plant level
3. Inverter level
4. String level

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

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

In particular, the agreed KPIs should be computed and reported (see Chapter 10 for main KPIs). Special attention should be paid to the fact that such KPI calculations should take into consideration the contractual parameters between O&M Contractor and Asset Owner, in order to provide an accurate and useful calculation for evaluation and eventually liquidated damages or bonuses.

5.5 Predictive Maintenance

*Predictive maintenance is a special service provided by O&M Contractors who follow best practices principles.*

The Operations team of the O&M Contractor is doing thorough monitoring, supervision, forecast and performance data analysis (e.g. historical performance and anomalies) of the PV plant in order to
identify subtle trends that indicate upcoming component and system failures (e.g. module, inverter, combiner boxes etc.). Following such analysis, the Operations team alerts the Maintenance team who should decide which predictive maintenance activities to perform to prevent any possible failures which can cause energy generation loss.

The Asset Owner or interested party that wants to apply predictive maintenance should have a monitoring software system in place which should be able to provide basic trending and comparison (timewise or between components) functionality (minimum requirement).

Before deciding which predictive maintenance actions to do, the Operations team should implement and develop procedures to effectively analyse historical data and faster identify behaviour changes that might jeopardize systems performance. These changes of behaviour are usually related to the pre-determined or unpredicted equipment degradation process. For this reason, it’s important to define and to monitor all significant parameters of wear status.

To carry out an efficient conduct of this type of maintenance, it is required that a certain level of maturity and experience which is at best a combination of systems’ performance knowledge, equipment operation behaviour and of course relevant accumulated experience and track record from the service provider. Normally it is a process that starts after the implementation of an appropriate monitoring system and recreation of a base line that represents the entire PV system operation and also how equipment interact with each other and how this system reacts to "environmental" changes.

Predictive maintenance is condition-based and has several advantages, including:

- Anticipate maintenance services;
- Eliminate some maintenance activities;
- Increase availability;
- Reduce emergency and non-planned work;

The analysis of the "DC health” of the system (at the DC array, transformer, inverter, combiner box or/and string level) on a regular basis in order to detect underperformance conditions that would otherwise go unnoticed until the next circuit testing or thermal imaging (several months later) is important. For the Asset Owner this normally translates into lower capital equipment replacement costs and higher energy production levels.

The following two specific examples show how predictive maintenance might be implemented.

**Example 1** – An O&M Contractor signs a new contract for a PV plant equipped with central inverters.

Analysing its back-log of maintenance, the O&M Contractor knows that these inverters showed several times in the past signs of power loss due to overheating. This might be related to problems in the air flow, filter obstructions, fans or environmental changes (high temperature during summer).

It was decided to monitor the temperature of IGBT’s. Before any emergency action might be needed, in case these components have some variations in their behaviour, an "air flow inspection" is performed to detect if this change is related to the air flow.

This type of activity, “air flow inspection”, 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’s any type of air flow obstruction or even if it is required to anticipate the filters’ substitution or cleaning.

**Example 2** – The Operations team detects a possible underperformance of one of the sections inside the PV plant.

This could be the power transformer, the inverter or some particular PV generator area that presents a lower performance when compared with others in the same conditions (or past behaviours evidence

---

5 IGBT = Insulated-Gate Bipolar Transistor
of loss of production). After the anomaly detection or recognition, an incident is created and instantaneously sent to the Maintenance team.

Before anything happens that might jeopardize contractual issues and might need urgent interventions, the O&M Contractor decides to do a “General Infrared Inspection” in the PV field taking RPAS\(^6\) general pictures.

This inspection has as main purpose to identify possible problems related to PV modules that might justify the loss of performance. *This is considered as a type of predictive maintenance.*

### 5.6 Plant Controls

If applicable, the Operations team is the responsible contact for the grid operator for plant controls. The Operations will control the plant remotely (if applicable) or instruct the qualified maintenance personnel to operate breakers/controls on site. The O&M Contractor is responsible for the remote plant controls or emergency shut-down of the plant, if applicable and in accordance with the respective grid operator requirements and regulations (see also 5.9.1 for grid code compliance). The plant control function varies from country to country and in some case from region to region. The respective document refers to details in PV plant controls regulation which are issued by the respective grid operator and (energy market) regulator.

### 5.7 Power Generation Forecasting

If required by regulation or the Asset Owner, the O&M Contractor shall be responsible to supply Power Generation Forecasts (at the moment normally for large scale plants). Forecasting services for PV power generation are generally offered by operators of PV monitoring services. The O&M Contractor should always insist on a service level agreement with the forecast provider. For the state of the art of PV power forecasting, the paper of (Pelland et al. 2013) can be used as reference.

The requirements for such forecasts may differ from country to country. They are characterized 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. Intraday forecasts are delivered and updated several times per day for the rest of the day.

For long-term planning of unit commitment and maintenance decisions, forecasts with longer time horizons are used, typically one week or more.

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

The most common KPIs for forecast quality are the root mean square error (RMSE) and the mean absolute error (MAE). They are normalized to peak power and not to energy yield.

---

\(^6\) RPAS = Remotely Piloted Aircraft Systems
5.8 Reporting

The Operations team is responsible to prepare and provide the regular reporting to the Asset Owner and further addressees as being agreed upon in the O&M contract.

The time spent for extracting data for a report depends on the performance of the internal scheduled processes that query all necessary information from a storage centre (typ. Database server) to populate specific sections of the report template automatically (typ. spreadsheet or text documents) and provide the Operations team member the report to be checked. Manual modification is applied where necessary in the report for flexible input and output of data to suit specific client or project related requirements. The frequency of the reporting can be set to a daily, weekly, monthly, quarterly or annually basis (with monthly being the most common) – also with specifically defined content for each of these reports. Generating a report for any specific time range in the past can be also possible.

Table 4 includes some proposed quantitative indicators which should be in reports. The type (predicted, measured or estimated) of the reporting value is also cited. The list is not exhaustive. Furthermore, additional information is part of the periodic reporting such as development of spare parts/inventory (minimum requirement), status of all security and surveillance system (best practice) etc.

Table 4: Proposed indicators/values required for the reporting

<table>
<thead>
<tr>
<th>No.</th>
<th>Proposed Indicator</th>
<th>Predicted</th>
<th>Measured</th>
<th>Estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insolation</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Active Energy Produced</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Active Energy Consumed</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Reactive Energy Produced</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Reactive Energy Consumed</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Peak Power Achieved</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Performance Ratio</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Energy Performance Index</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>Balance of System Efficiency</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>10</td>
<td>Plant External Energy Losses</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>11</td>
<td>Plant Internal Energy Losses</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>12</td>
<td>Energy-based Availability</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>13</td>
<td>Time-based Availability</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>14</td>
<td>Inverter Specific Energy Losses</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>15</td>
<td>Inverter Specific Efficiency</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>16</td>
<td>Module Soiling Losses</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>17</td>
<td>Module Degradation</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

● Minimum Requirement
✓ Best Practice
The O&M Contractor is responsible to ensure the operation of the PV plant in compliance with the regulations. Several levels of regulation have to be considered besides the grid code (see chapter 5.9.1).

Furthermore, many countries have a governing law for the operation of energy generating assets or renewables/PV in particular.

Power Purchase Agreements (PPA) and Interconnection Agreements also form a part of the regulation, which needs to be known and respected by the O&M team.

Particularly, power generation license agreements need to be made available by the Asset Owner to the O&M Contractor in order to allow him to act in compliance with the regulations of these licenses.

Building permits, environmental permits and regulations form the specific regulation for the site and can contain certain requirements and the need to cooperate with the local administration. Examples can be: restrictions to the vegetation management and the disposal of green waste which are being ruled by the environmental administration body. Or the building permit may contain stipulations to restrict working time on site, storage of utilities etc.

The minimum requirement should be, that the O&M contract lists all the relevant permits and regulations and that the asset owner makes the relevant documents available to the O&M Contractor.

The management of all regulations, permits and stipulations within the electronic document management system is expected to be best practice. This allows the O&M party to track reporting and maintenance requirements automatically and report back to the asset owner or administration bodies.

### 5.9.1 Grid code compliance requirements

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

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

Most of the utility scale PV plants in Europe connected to a grid are required to be controllable to meet the grid operator requirements. Such plant controls allow the grid operator to adjust the power output from the PV plant according to the grid capacity and power frequency requirements.

It is expected, that the O&M Contractor 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.
5.10 Management of change

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

In any such case, the O&M Contractor needs to be involved in such changes to the PV power plant right from the beginning. Concepts, design works and execution need to be coordinated with ongoing O&M activities. Implementation to the plant SCADA and monitoring system is required. Adjustments to the Site Operating Plan, the Annual Maintenance Plan and the Annual Maintenance Schedule need to be applied and the O&M Contractor needs to familiarize his staff with the operating manuals of the new equipment. Such change will have a definite impact on the spare parts management and inventory (replacement). Depending on the significance of such changes, the O&M annual fee might need to be adjusted.

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

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

5.11 Warranty management

The Operations team from the O&M Contractor shall act as the Asset Owner’s representative for any warranty claims vis-à-vis the OEM manufacturers of such components. The O&M Agreement is expected to rule the level of responsibility for warranty management between the Asset Owner and the Operations team and certain thresholds under which the Operations service provider is empowered to act directly or seek the owner’s consent. The Operations team will direct the Maintenance team to perform warranty related works on site. Usually the warranty management scope is limited by Endemic Failures (see 5.11.1). 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 (see Record control) for compliance and traceability reasons.

Objectives of Warranty Management:

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

Types of warranties on a PV Plant:

• Warranty of Good Execution of Works
• Warranty of Equipment
• Performance Warranty

5.11.1 Warranty of good execution of works and equipment warranties

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

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

• **Pending Works**, in accordance to the List of Pending Works agreed with the client;

• **Insufficiencies**, these being understood as any pathology in the facility resulting from supplies or construction, that although done according to the project execution approved by the client, has proven to be inadequate, unsatisfactory or insufficient;

• **Defects**, these being understood as any pathology resulting from supplies or construction executed in a different way from the one foreseen and specified in the project execution approved by the client;

• **Failure or malfunction of equipment**, being understood as any malfunction or pathology found in the equipment of the photovoltaic facility – Modules, Inverters, Power transformers or other equipment;

Anomalies Handling

During the Warranty Period, all the Anomaly processing should be centralized by the O&M Contractor, who is responsible for the first acknowledgment of the problem and its framework according to its type, having in this manner, the role of a pivot and linking element between the internal organizational structure and the client in accordance to the criteria defined below:

Pending Works, Insufficiencies and Defects

In the case of anomalies of the type “Pending Works”, “Insufficiencies” or “Defects”, the O&M Contractor must communicate the occurrence to the EPC provider, who shall be responsible to assess the framework of the complaint in the scope of the EPC contract, validating its grant and determine the action to be taken.

Resolution of failures in the case of anomalies of the type “Failures”

The O&M Contractor shall present the claim to the equipment supplier and follow the claiming process.

Endemic Failures

Means 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.
5.11.2 **Performance Warranty**

During the Warranty Period, it is the responsibility of the Operations team to monitor, calculate, report and follow-up the values of Performance Ratio and other guaranteed KPIs.

Within this scope, it is the responsibility of the O&M Contractor to:

- Manage the interventions done within the scope of the warranty in order to safeguard the performance commitments undertaken under the contract;
- Periodically inform the owner about the condition of the contracted performance indicators;
- Immediately alert the owner whenever the levels of the indicators present values or tendencies that could indicate a risk of failure.

5.12 **Insurance claims**

The Operations team can act as the Asset Owner’s representative for any insurance claims vis-à-vis the insurance provider. In some cases, this task is being awarded to the asset management company rather than the O&M Contractor.

The O&M Agreement is expected to rule the level of responsibility for insurance management between the Asset Owner and the Operations team. The Operations will at least be responsible for the coordination of site visits by an insurance provider’s representative or technical/financial advisors in connection with the information collection and damage qualification, as well as for the drafting of technical notes to support the reimbursement procedure.

For any insurance claims the formal procedure provided by the insurance provider should be followed. All communications and reports should be archived (see Records control) for compliance and traceability reasons.
Spare Parts Management

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

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

Depending on the agreement between the Asset Owner and the O&M Contractor, spare parts management may be a responsibility of one of the two. Ownership of spares is with the Asset Owner while normally the storage (and hence insurance) responsibility is on the shoulders of the O&M Contractor. Besides ownership matters, it is above all important to make sure (upon mutual agreement) that one of the parties undertakes the responsibility of insuring the spares.

The O&M Contractor shall act as the main interface for the spare parts management. Access to the spare parts inventory books should be ensured and responsibility to order spare parts and goods for the replenishment of the spare parts inventory should be assumed.

For a new PV plant, the initial spare parts are procured by the EPC. However, it is best practice, if the EPC and O&M Contractor have agreed upon the list. The O&M Contractor is free to add additional spares that he deems necessary to meet the contractual obligations (e.g. reaction time, availability guarantees etc.).

Regarding the stocking level, due to the very different configurations and sizes of solar PV plants, it is very difficult to define a hard number for stocking specific spare parts. Furthermore, the regional portfolio of the O&M Contractor might also influence this and as it was mentioned above, the determination of spare items and quantity is also driven by the O&M Contractor’s contractual commitments on reaction time and/or plant availability and related Liquidated Damages (LDs).

*It is important at this point to differentiate between Consumables and Spare Parts.* Consumables are low cost and frequently used spare parts, like for example fuses, that the O&M Contractor should have always on stock and maintenance crews should carry with them, together with the relevant tools, during every site visit.

---

7 If the O&M contract does not include any of such obligations also the leverage of the asset owner to hold the O&M Contractor accountable may be weak.
In an attempt to define the stocking levels of Spare Parts and Consumables, the following parameters should be taken into consideration:

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

Generally, it is not economically feasible to stock spare parts for every possible failure in the plant. Therefore, the O&M Contractor together with the Asset Owner should define the stocking level of specific spare parts that make economic sense (Cost Benefit Analysis). For example, if a specific part in a solar PV plant has a frequency of failure at least of once every year or more and the loss of revenues due to such failure is greater than the spare part cost, such spare is important to have it available.

However, for any given utility scale solar PV system (either small or big) there are certain spare parts that could be considered as essential to have – no matter the cost which is normally system size dependent. Table 5 below summarizes a minimum list. This list is not exhaustive and system requirements and technology developments can impose additional updates.

*Table 5: Minimum list of spare parts (non-exhaustive)*

<table>
<thead>
<tr>
<th>No.</th>
<th>Spare part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuses for all equipment (e.g. inverters, combiner boxes etc.) and fuse kits</td>
</tr>
<tr>
<td>2</td>
<td>Modules</td>
</tr>
<tr>
<td>3</td>
<td>Inverter spares (e.g. power stacks, circuit breakers, contactor, switches, controller board etc.)</td>
</tr>
<tr>
<td>4</td>
<td>Uninterruptible Power Supply (UPS)</td>
</tr>
<tr>
<td>5</td>
<td>Voltage terminations (MV)</td>
</tr>
<tr>
<td>6</td>
<td>Power Plant controller spares</td>
</tr>
<tr>
<td>7</td>
<td>SCADA and data communication spares</td>
</tr>
<tr>
<td>8</td>
<td>Transformer and switchgear spares</td>
</tr>
<tr>
<td>9</td>
<td>Weather station sensors</td>
</tr>
<tr>
<td>10</td>
<td>Motors and gearboxes for trackers</td>
</tr>
<tr>
<td>11</td>
<td>Harnesses and cables</td>
</tr>
<tr>
<td>12</td>
<td>Screws and other supplies and tools</td>
</tr>
<tr>
<td>13</td>
<td>Security equipment (e.g. cameras)</td>
</tr>
</tbody>
</table>

Regarding the storage and warehousing, this should be done in locations where the spare parts cannot be damaged (e.g. from humidity or high temperature variations). Additionally, the store sites should have appropriate security measures.

The decision for having either onsite or a 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.
While proximity to the plant is a parameter that needs to be evaluated on a per case basis, Security and Environmental conditions are very important as they could lead to a loss of property either through thefts or damage.
7

Power Plant Maintenance

7.1 Preventative Maintenance

Preventative Maintenance activities are the core element of the maintenance services to a PV plant. It comprises regular visual and physical inspections, as well as verification activities with a specific task periodicity of all key components which are necessary to comply with the operating manuals and recommendations issued by the Original Equipment Manufacturers (OEMs). It must also maintain the equipment and component warranties in place and reduce the probability of failure or degradation. The activities should also comply with respective legal issues e.g. national standards for periodic inspection of certain electrical components. Technical experience and relevant track records will optimise the activities further. The O&M contract should include this scope of services and each task periodicity.

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

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

The “Annual Maintenance Plan” 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.).

Examples of preventative maintenance can also be irregular replacement of parts of inverters or sensors (Predictive Maintenance). In general, outside of the equipment warranty terms or after its expiration it is important to follow detailed preventative maintenance procedures, which are agreed upon in the Annual Maintenance Plan.

In cases, where downtime is necessary to perform preventative maintenance, the execution of preventative maintenance activities during the night would be considered best practice as the overall power generation would not be affected.

7.2 Corrective Maintenance

Corrective Maintenance (CM) covers the activities performed by the Maintenance team in order to restore a PV plant system, equipment or component to a status where it can perform the required function. The CM takes place after a failure detection either by remote monitoring and supervision
or during regular inspections and specific measurement activities (see also the "Annual Maintenance Plan" attachment).

The CM includes three maintenance activities: Fault Diagnosis also called troubleshooting to identify fault cause and localization, Repair and Temporary Repairs. The last two actions are physical actions taken to restore the required function of a faulty item. After Temporary Repairs the items are able to perform the required function for a limited interval and until a Repair is carried out.

The scope of CM activities and its "border" with preventative 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 tightening activity using a cable for the correct fixation should be under the preventive maintenance scope of works, but depending on the quantity and/or frequency, it could be considered in the scope of Corrective Activity;

Usually the corrective maintenance is contractually obliged to comply with certain response times and/or minimum repair times (refer to section 10.2.1).

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

Contractual agreements can foresee that the corrective maintenance will tend to be capped on a per year basis. This provides a risk for the Asset Owner when the CM works are very extensive. Depending on the type of the Asset Owner being a pure financial investor or an energy producer (utility, IPP) the requirements for coverage under the corrective maintenance will vary.

Best Practices of O&M agreements in regard to CM activities refer to a table in which specific detection and repair times are agreed (see example Table 6 in 10.2.1 chapter). A failure of the O&M Contractor to meet such agreed repair times will lead to Liquidated Damages, described in chapter 11. In cases, where the PV plant or segments need to be taken offline, the execution of scheduled corrective maintenance during night or low irradiation hours would be considered best practice as the overall power generation would not be affected.

### 7.3 Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant site, that require substantial activities and works to restore the previous plant conditions.

Generally, these activities are being 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 purpose.

Extraordinary maintenance interventions are required for:

- damages that are a consequence of a Force Majeure event;
- damages as a consequence of a theft or a fire;
- serial defects on equipment, occurring suddenly and after months or years from plant start-up;
- modifications required by regulatory changes;

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

- major issues of which O&M Contractor becomes aware during its ordinary activity i.e. defects or other problems that are not a consequence of equipment wear or deterioration and that
are not of the O&M Contractor’s responsibility because are reasonably caused by design mistakes (e.g. “hidden” defects that require re-engineering).

Although not necessarily maintenance interventions, also the following can be included in the extraordinary maintenance list, or at least managed with same rules:

- improvement, revamping (restoring and optimization) activities, etc.

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

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

**Best Practices of O&M agreements in regard to extraordinary maintenance activities include:**

- general rules to quantify price and schedule to perform repair activities, and the right of the Asset Owner to ask for third parties quotations to compare the one of the O&M Contractor; in this case a “right-to-match” option should be granted to the O&M Contractor
- the obligation for the Asset Owner to have in place a consistent “All Risk Property” Insurance including loss of profit

### 7.4 Additional Services

The O&M agreement can foresee additional services to be performed by the O&M Contractor upon the Asset Owners or Asset Manager’s request. These services are being 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. The following *non-exhaustive list* provides an overview of additional services:

- Module Cleaning
- Vegetation Management
- Road Maintenance
- Snow Removal
- Pest Control
- Waste Disposal
- Maintenance of buildings
- Perimeter fencing and repairs
- Maintenance of Security Equipment
- String Measurements – to the extent exceeding the agreed level of preventative maintenance
- Thermal Inspections – to the extent exceeding the agreed level of preventative maintenance
- Meter weekly/monthly readings and data entry on fiscal registers or in authority web portals for FIT tariff assessment (where applicable)

*It should be noted that some of these items are to be found as a part of the preventive maintenance. This depends on the agreement between the Asset Owner and the O&M Contractor.*
Solar PV Plant Security

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

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

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

Within the solar plant, there may also be additional areas with restricted access, for example locations containing High Voltage equipment. When authorising access to the parks it is important that all workers or visitors are appropriately informed of the specific access and security arrangements and where they should or should not be. Warning signs and notices can form an important part of this and may be mandated depending on local regulations.

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

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

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

O&M Contractors will be responsible for the correct functioning of all the security equipment including intrusion and surveillance systems. He will be also responsible for any site patrolling or other relevant services. These normally considered as part of the additional services described in 7.4.

Surveillance providers will be responsible for processing the alarms arriving from the security system by following the Security Protocol and the use of the surveillance systems installed on site.
Contract Management

Regardless of breadth of scope, the solar O&M Contractor (be it as a full Operations and Maintenance vendor or only as a partial subcontractor) is almost always tasked with some form of contract management responsibilities. This oversight of the contractual parameters, responsibilities, and obligations, varies widely depending on geographic location, project size, construction, off-taker arrangements, etc. of the project.

As a minimum requirement the initial step in this process is a comprehensive analysis of the contract followed by a well-defined Division of Responsibility (“DOR”) matrix that clearly delineates which entity is responsible for commercial, operational, and maintenance actions both 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.

Although highly dependent on the extent and complexity of the agreement in question, the O&M Contractor is often tasked with a wide range of activities including operations, maintenance, data analysis, communication with the off-taker, invoicing, regulatory compliance, etc. Frequent (if not daily) correspondence with the owner on many of these topics is implicit in the contractual terms. Further responsibilities – often treated as non-fixed fee items – can also be included (such as weed management, spare parts inventory oversight and replacement, and soiling mitigation).

As a form of best practice, the Contract Manager’s responsibilities often also extend to functioning as the initial, and triaging, portal for all external questions. This allows for optimal access by the owner to all areas of the service provider’s organization, and ensures that adherence to the contractual responsibilities occurs. Also the Contract Management group assumes responsibility for invoicing of the O&M fees to the Asset Owner.

For reasons of quality, the O&M Contractor should also bear the responsibility to track own compliance with the content of the contract and report back to the client in full transparency.

Upon agreement O&M Contractor could also handle the contract management of contracts between the Owner/Asset Manager and component suppliers. This however is considered as an additional service and can be assumed best practice.
10 Key Performance Indicators (KPIs)

This section deals with Key Performance Indicators (KPIs), which provide the Asset Owner with a quick reference on the performance of his asset(s). The KPIs are distinguished between the PV plant KPIs which directly reflect the performance of the plant and are under the duties of the O&M Contractor and the O&M Contractor KPIs which reflect the performance of the service.

While the Plant Performance KPIs are quantitative and measure the plant performance ratio, the plant availability, uptime and the energy output, the O&M Contractor KPIs are both quantitative and qualitative.

10.1 PV plant KPIs

10.1.1 Availability

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 Contractor (listed below in the same section). The total possible time is considered the time when the plant is exposed to irradiation levels above the generator’s Minimum Irradiance Threshold (MIT).

Availability is then defined and calculated as:

$$ A [\%] = \frac{\sum T_{useful} - \sum T_{down} + \sum T_{excluded}}{\sum T_{useful}} \times 100 $$

where:

- $T_{useful}$ [h] = period of time with irradiation above MIT
- $T_{down}$ [h] = period of $T_{useful}$ when the system is down (no energy production)
- $T_{excluded}$ [h] = part of $T_{down}$ to be excluded because of presence of an exclusion factor (see below)

The figure below illustrates the various periods in time mentioned above.
Figure 3: Various periods of time for the calculation of availability\(^8\)

Normally only the time where irradiance is above the MIT is considered and this is noted above as \(T_{\text{useful}}\), where \(T_{\text{useful}} = T_{\text{total}} - T_{(\text{irr}<\text{MIT})}\). Typical MIT values are 50 or 70 W/m\(^2\). MIT shall be defined according to site and plant characteristics (e.g. type of inverter, DC/AC ratio etc.).

In practice, it is often required to measure availability on the level of a subcomponent \(i\) (for example, inverter) and to weight availability of the subcomponents \(A(i)\) according to their respective installed DC power \(P_{\text{dc}}(i)\).

In this case availability of the total PV power plant \((A_{\text{total}})\) with an installed total DC power of \(P_{\text{dc}}(\text{total})\) can be defined as follows:

\[
A_{\text{total}} [%] = 100 \times \sum (A(i) \times \frac{P_{\text{dc}}(i)}{P_{\text{dc}}(\text{total})})
\]

For the calculation of availability typically 15 min irradiation and production data are taken as basis, if granularity of components remains at the level of inverter or higher. Anything below the level of inverter is then captured with the performance ratio calculation which is presented below (10.1.3).

Normally, any failure time only begins to run when the O&M Contractor receives the error message. If the data connection to the site was not available, failure time shall only begin after reestablishment of the link.

Often Asset Owners and O&M Contractors agree upon certain failure situations that shall not be taken into account (exclusion factors). Some good examples that are found in contracts are:

- Force majeure;
- Snow and ice on the PV modules;
- Damage to the PV plant (including the cables up to the feed-in point) by the customer or third parties who are not sub-contractors of O&M Contractor, including but not limited to vandalism;
- Ambient conditions (for example, air quality, temperature, humidity) outside permissible value ranges of inverters and transformers;

\(^8\) The \(T_{\text{down}}\) represents the whole downtime, before the exclusions are applied. Therefore, \(T_{\text{excluded}}\) is a part of \(T_{\text{down}}\) in the diagram. In practice you often first see that a plant is down (= measurement of \(T_{\text{down}}\)) and only in the course of troubleshooting one gets the information whether you can exclude part of the downtime.
- Disconnection or reduction of energy generation by the customer or as a result of an order issued to the customer by a court or public authority;
- Operational disruption by grid disconnections or disruptions in the grid of the grid operator;
- Disconnections or power regulation by the grid operator or his control devices;
- Downtimes resulting from failures of the inverter or MV voltage components (for example, transformer, switchgear), if this requires
  - Technical support of the manufacturer and/or
  - Logistical support (for example supply of spare parts) by the manufacturer;
- Downtimes due to scheduled maintenance measured per year and component.
- Outages of the communication system.
- Delays of approval by the customer to conduct necessary works;
- Downtimes for implementation of measures to improve the PV plant, if this is agreed between the parties;
- Downtimes caused by the fact that the customer has commissioned third parties with the implementation of technical work on the PV plant.

Note that variants of the above-defined availability are:
- Uptime (availability without correction for exclusion factors)
- Energy-based availability which is presented below in 10.1.2

### 10.1.2 Energy-based availability

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

\[
EA \% = (1 - \frac{\sum_i E_{\text{loss}(i)}}{E_{\text{total}} + \sum_i E_{\text{loss}(i)}}) \times 100
\]

where:
- \(E_{\text{loss}(i)}\) [kWh] = calculated lost yield per event (i)
- \(E_{\text{total}}\) [kWh] = absolute yield in the period under review according to feed-in meters

The challenge of this method is to accurately determine the lost yield. The following cases can be distinguished:

- **Failure of the whole system**, where lost yield can be calculated via performance ratio (PR – see 10.1.3) and irradiation according to the formula below:

  \[
  E [kWh] = PR \times H \times P
  \]

  where:
  - \(PR\) = performance ratio. The PR is determined from the average PR over the last ten days during which the PV system fed into the grid without faults.
  - \(H [kWh/m^2]\) = irradiation measured in module plane
  - \(P [kW_p]\) = the nominal power of the system

- **Failure of an inverter or module string**, where the expected yield of the failed inverter/module string for the period of the failure is ascertained by comparing the specific yields in kWh/kW_p of the other inverters or module strings with the same alignment/inclination/configuration.

The periods for which the Contractor cannot accept any responsibility and that are not included in the calculation of technical system availability are listed in section 10.1.1.
10.1.3 **Performance Ratio**

The Performance Ratio (PR) is a quality indicator of the PV plant. It is reported as a percentage and indicates the overall effect of losses of the PV generator by normalizing produced AC energy with respect to installed PV peak power and irradiance. The higher the PR is, the more energy efficient the plant is. In reality the PR cannot be 100% due to losses (e.g. thermal losses, conversion losses, wiring etc.)\(^9\).

Performance Ratio is defined as:

\[
PR \ [%] = \frac{\text{Final Yield in } \text{h per year} \ (Y_f)}{\text{Reference yield in } \text{h per year} \ (Y_r)} \times 100
\]

The final system yield that can be read from the grid export meter is defined as:

\[
Y_f = \frac{\text{The energy to the utility grid in kWh per year} \ (E_{AC})}{\text{The installed PV peak power} \ (P_{peak})}
\]

The installed capacity (DC power) is eventually corrected by module degradation.

The reference yield (nominal plant output) is defined as:

\[
Y_r = \frac{\text{The plane of array irradiation} \ (H_{POA})}{\text{The reference irradiance at standard test conditions} \ (G_{STC}^{10})}
\]

These definitions are based on (Woyte et al. 2014) in line with the IEC 61724 (ed1.0 1998) and are common practice.

Notably, the above definitions are purely technical. However, as for KPI used for the verification of contractual terms, the PR definition excludes periods during which the PV plant experienced external disturbances. Therefore, the computation of final yield and reference yield for PR should exclude periods during which the power generation of the plant was reduced due to force majeure, grid disconnection or activities ordered by the client (non-available). Detailed provisions for contractual PR differ from contract to contract.

*It should be noted that PR is considered a KPI of the PV plant and not purely of the O&M Contractor, due to the fact that certain parameters for its calculation have to do for instance with design aspects. Therefore, PR underlines the significance of having a close communication link established between the EPC/installer and the service provider during the design phase.*

However, PR is used as a primary KPI in contracts with penalties and incentives when PR thresholds are exceeded and therefore the O&M Contractor is responsible to measure this as one of his/her key operational duties. For this reason, the quality of the underlying data needs to be warranted by both contractual parties jointly.

The O&M Contractor may provide guarantees on PR (with bonuses and liabilities) under certain conditions and specifically:

- based on design/PAC\(^{11}\)/FAC\(^{12}\) data if the O&M Contractor has been the same entity as the EPC
- based on a specific procedure, preliminary to guarantee commencement, designed to objectively assess PR of the plant at take over
- with a formula that clarifies exceptions to the calculation (same exceptions as with availability)

\(^9\) In theory PR can be higher than 100%. Panel nominal power is measured at STC, so under more favorable conditions (higher irradiation, lower temperature than STC) the PR can be higher than 100%. Such values have been measured for short periods of time.

\(^{10}\) STC = 1000 W/m\(^2\)

\(^{11}\) Provisional Acceptance Certificate

\(^{12}\) Final Acceptance Certificate
by defining whether periods of low irradiation or non-availability have to be taken into consideration (not recommended), and which kind of measurement device is used for irradiance measurement

with a procedure that describes how to consider module degradation

**Note** that if it is decided to introduce a correction factor for non-availability (in order to exclude periods of non-availability for PR calculation), energy-based availability (see below) should be used.

Based on PR, the O&M Contractor provides recommendations to the plant owners on eventual investment or interventions.

### 10.1.4 Energy Performance Index

The Energy Performance Index (EPI) is defined as the ratio between the final system yield \(Y_f\) and the expected yield \(Y_{exp}\) as determined by a PV model, using the actual weather data as input to the model over the assessment period (typically day/month/year). The concept was proposed, e.g., in (Honda et al. 2012).

\[
EPI \ [%] = \frac{\text{The Final yield in } h \ (Y_f)}{\text{The Expected yield by PV model } (Y_{exp})}
\]

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 expected model. Unfortunately, there are more than one established models for the expected yield of PV systems in operation and not all of them are transparent. Therefore, the use of EPIS is recommended mainly for identification of performance flaws and comparison of plants to each other.

### 10.2 O&M Contractor KPIs

#### 10.2.1 Reaction Time

The O&M Contractor is committed to react on alarms received from the plant through the monitoring and supervision system within a certain period of time. The duration of required reaction time is usually tied to the (potential) loss of energy generation capacity and can be classified according to this requirement (see examples in Table 6 below). Definitions:

*Acknowledgement Time* is the period of detecting the problem (receipt of the alarm) but also the period of assessing the failure (remotely or on-site) in order to organise the proper response.

*Response Time* means that the O&M Contractor shall have the necessary employees addressing the failure and in the performance of corrective maintenance.

Normally acknowledgement and response times are guaranteed. It is difficult to guarantee resolution time, because resolution often does not depend totally on the O&M Contractor.

**Table 6:** High level classification of failures and the respective Acknowledgement and Response Time (average examples)

<table>
<thead>
<tr>
<th>Failure Class</th>
<th>Definition</th>
<th>Acknowledgement Time</th>
<th>Response Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Any event that causes a plant-wide outage during expected production periods, or the loss of communications resulting in an</td>
<td>[2 hours]</td>
<td>[12 hours]</td>
</tr>
</tbody>
</table>
2  Inability to monitor or control the Plant.  

Any event that causes a Power Conversion Station (PCS) outage during expected production periods, or the loss of communications with a Plant component resulting in an inability to monitor or control the Plant.  

[4 hours]  [24 hours]  

3  Any event that causes the outage of one or more inverters during expected production periods at the plant.  

[6 hours]  [36 hours]  

The above times will vary greatly depending on the location of the plant and the contract.

10.2.2  Reporting

It is very important for the O&M Contractor to comply with reporting requirements and reporting timelines. Content of the reporting should be expected to be consistent and any change in content or format needs to be explained by the O&M Contractor (see also 5.8 chapter). Delivery of reports per the agreed upon timeline is an important indicator for reliability and process adherence within the O&M Contractors organization.

10.2.3  O&M Contractor experience

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

10.2.4  Maintenance Effectiveness & Maintenance Support Efficiency

To evaluate preventative maintenance there are two main indicators that may be considered according to the best practices (see chapter 7.1):

- Maintenance Effectiveness: Is the ratio between the maintenance performance target and actual result.
- Maintenance Support Efficiency: Is the ratio between the planned or expected resources and those that are actually used.
11

Contractual Commitments

11.1 O&M Contractors Qualification

The Asset Owner follows the interest, that he is contracting with an O&M Contractor, who is professional in his job and has the capabilities to operate and maintain the plant in accordance with the contractual obligations. Experience and availability of a professional organization, skilled teams and access to spare parts are criteria for the selection of the O&M Contractor. As O&M services are a combination of remote operations services and local maintenance activities, the Asset Owner should make sure, that both components are well managed and interfaces between operations services and maintenance services are well defined, especially when the O&M works are not contracted with one single entity and each entity is responsible and can be held accountable for the overall O&M performance.

11.2 Responsibility and Accountability

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

Corrective maintenance activities, which will be performed in case of any component failure or energy generation shortfall are controlled by performance commitments signed by the O&M Contractor. Based on the KPIs explained in chapter 10, the Asset Owner and the O&M Contractor can define the level of accountability of the O&M Contractor.

The minimum level is to agree on certain reaction times. These reaction times can be used to measure the time of the detection of any failure, the reporting time between the Operations team and the Maintenance team, the time, until the Maintenance provider is on site and the time to fix a certain component failure and/or restore the plant back into proper function (see 10.2.1).

A more comprehensive measure for accountability is the plant availability. Besides the possibility to agree on minimum reaction times, the O&M Contractor’s performance can be measured through a commitment to certain plant availability ratio. Based on the definition of plant availability, usually measured on an annual basis, the O&M Contractor will be held accountable against a to be agreed plant availability threshold. The level of such threshold is negotiable and determined by the Asset
Owner’s expectation of minimum energy production and the O&M Contractor’s willingness to agree. A higher level of plant availability commitment is expected to have an effect on the pricing of the O&M contract, since the O&M Contractor will calculate for a risk premium.

11.3 Bonus Schemes and Liquidated Damages

The accountability of the O&M Contractor will finally be translated into Bonus Schemes and Liquidated Damages. These ensure, that the Asset Owner will be compensated for shortfalls under the reaction time or availability commitments.

Since the O&M Contractor’s responsibility is focused on the operations and maintenance works for the PV asset, other influencing factors like force majeure events, grid operator activities to reduce the plant output, grid instability or offline periods or any weather related power generation shortfall shall be exempted from the O&M Contractor’s responsibility and therefore from any Liquidated Damages.

Liquidated Damages shall usually be tied to a reduction of the O&M Annual Fee and are limited by the Liquidated Damages Cap. This can for example be 100% of an annual fee per year or a multiple of an annual fixed fee in aggregate. If the Liquidated Damages Cap is reached, this usually translates into termination rights for the asset owner and O&M Contractor.

If the O&M Contractor is overachieving the reaction time or availability threshold levels, his compensation can be improved according to agreed Bonus Schemes. Especially in cases, where the O&M Contractor commits to a certain plant availability, his motivation to provide best-in-class services and performance will be triggered by a Bonus, which can be agreed as a certain increase of his annual fixed fee. Higher plant availability usually leads to higher power generation and an increase of revenues for the benefit of the plant owner. Hence the Bonus Scheme agreements lead to a win-win situation for both parties and ensures that the O&M Contractor is highly motivated.

Example for Availability Commitment related Bonus Schemes and Liquidated Damages can be found in Table 7 below:

<table>
<thead>
<tr>
<th>Plant Availability</th>
<th>Availability Commitment Bonus  (as percentage of O&amp;M Service Fees for applicable Reporting Period)</th>
<th>Availability Commitment Liquidated Damages  (as percentage of O&amp;M Service Fees for applicable Reporting Period (1Y))</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.00% ≤ x ≤ 100.0%</td>
<td>+15%</td>
<td>-</td>
</tr>
<tr>
<td>98.00% ≤ x &lt; 99.00%</td>
<td>+10%</td>
<td>-</td>
</tr>
<tr>
<td>97.1% ≤ x &lt; 98.00%</td>
<td>+5%</td>
<td>-</td>
</tr>
<tr>
<td>97.00% ≤ x &lt; 98.00%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>96.00% ≤ x &lt; 97.00%</td>
<td>-</td>
<td>-10.00%</td>
</tr>
<tr>
<td>95.00% ≤ x &lt; 96.00%</td>
<td>-</td>
<td>-20.00%</td>
</tr>
<tr>
<td>94.00% ≤ x &lt; 95.00%</td>
<td>-</td>
<td>-30.00%</td>
</tr>
<tr>
<td>93.00% ≤ x &lt; 94.00%</td>
<td>-</td>
<td>-40.00%</td>
</tr>
</tbody>
</table>
References


## Annex – Documentation control

### Information type and depth of detail / as-built documents

<table>
<thead>
<tr>
<th>No.</th>
<th>Minimum Requirements</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 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 | |
| 6   | Inverters            | - O&M Manual  
- Commissioning Report  
- Warranties & Certificates | |
| **7** | **Medium Voltage/Inverter Cabin** | • Factory Acceptance Test  
• Inverter settings  
• Dimensional drawings  
• 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  
• Protection relays settings  
• Switching procedure (according to national regulations) |
| **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  |

"Protection relays settings" and "Switching procedure" are considerations for the **MV Switchgear**.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
</table>
| Interlock study | • Interlock study  
• Switching procedure (according to national regulations)  
• Warranties & Certificates |
| UPS & Batteries | • Installation & O&M Manual  
• Commissioning report  
• Warranties & Certificates  
• Datasheets  
• Dimensional Drawings |
| Mounting Structure | • Mechanical Assembly Drawings  
• Warranties & Certificates |
| 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 |
| 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 |
| 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  
I/O list includes e.g. sensor readings that are collected by data loggers. |
| 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 |
| Communication system | • Installation and O&M manual  
• System internal communication  
• External Communication to monitoring system or Operations Centre  
• IP network plan  
• Bus network plans |