Engineering, Procurement & Construction

Best Practice Guidelines

Version 2.0

SolarPower
Europe

Foreword

Welcome to the second edition of SolarPower Europe's Engineering, Procurement and Construction (EPC) Best Practice Guidelines. The EU has set a target of reducing its greenhouse gas emissions by 55% from 1990 levels, by 2030. In its *100% Renewable Europe* study, SolarPower Europe estimates that, to achieve this, an extra 870 GW of solar PV installations are required by the same year. To maintain public trust and investor confidence in PV technology, installations must be built according to high-quality standards that will ensure they run effectively and reliably over their lifecycle. Putting the best processes in place and getting the fundamentals rightduring the project design, engineering, procurement, and construction phases is key to driving down costs and improving reliability.

The Lifecycle Quality Workstream grew out of SolarPower Europe's O&M Task Force in 2020. It reflects the fact that quality assurance is an ongoing process throughout the lifecycle of an asset. In addition to the *O&M Best Practice Guidelines*, the Workstream now produces the *Asset Management, EPC Best Practice Guidelines*. This year, a new *Lifecycle Quality Best Practice Guidelines* has been added to the suite as a way to underpin the other three.

Building on 2020's first edition, this document is the result of year of intensive work by over 25 leading solar experts, from 20 companies. The contributors work across the solar PV industry and they include EPC and O&M service providers, Asset Managers, Asset Owners, renewable energy consultants, legal experts, digital solutions providers, technical advisors, and investors.

The latest version of the EPC Best Practice Guidelines take a new approach to occupational health & safety by combining these with security, environmental and biodiversity protection in a revamped Health, Safety, Security, and Environment chapter. Furthermore, given the growth in popularity of increasingly flexible solutions to demand-side supply, the contributors have created an entirely new chapter on EPC for PV power plants with storage. This year's edition has also seen the Definitions and Lifecycle of EPC Quality Management chapters move to the Lifecycle Quality Guidelines, reflecting the overall importance of common references and quality assurance practices to all stakeholders, at all stages of an asset's lifecycle. These are just some of the updates that can be found in this year's edition.

The Workstream has been busy in 2021, updating the EPC and *O&M Best Practice Guidelines* and writing the new Lifecycle Quality Guidelines. Members have also been involved in spreading the Best Practice Guidelines internationally and the South African edition of the *O&M Best Practice Guidelines* was published in October. Projects to create the Indian and Sub-Saharan African editions of the *EPC Best Practice Guidelines*, and a Jordanian edition of the *O&M Best Practice Guidelines* are also underway.

We thank our members for their extraordinary level of engagement, which reflects the importance of lifecycle quality for the solar industry. We will continue the work in 2022 and invite interested stakeholders to join our community to be part of this undertaking.

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Project Information: The SolarPower Europe O&M Task Force officially started its work in April 2015, and it became the Lifecycle Quality Workstream in 2020, to cover O&M, Asset Management and EPC. It operates through frequent exchanges and meetings. The Workstream's flagship reports are the *O&M Best Practice Guidelines*, the *Asset Management Best Practice Guidelines*, the *EPC Best Practice Guidelines*, and the new *Lifecycle Quality Guidelines*. They reflect the experience and views of a considerable share of the European solar industry today. There has been no external funding or sponsorship for these reports.

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AC	Alternating Current
AM	Asset Management
ASCE	American Society of Civil Engineers
BESS	Battery Energy Storge Systems
BOM	Bill Of Materials
BOS	Balance Of System
BRP	Balance Responsible Party
BTM	Behind-the-Metre
CAD	Computer Aided Design
CAPEX	Capital Expenses
CCTV	Closed Circuit Television
CFD	Computational Fluid Dynamics
C&I	Commercial & Industrial
CMM	Number of Critical Milestones Missed
COD	Commercial Operation Date
CPN	Cost Priority Number
DC	Direct Current
D/E	Debt-to-Equity Ratio
DEM	Digital Elevation Models
DoD	Depth of Discharge
DSM	Demand-side Management
EBIT	Earnings Before Interest and Taxes
EIA	Environmental Impact Assessment
EH&S	Environment, Health and Aafety
EL	Electroluminescence
EPC	Engineering, Procurement, Construction
ERP	Enterprise Resource Planning System
ESS	Energy Storage System
EVA	Ethylene-Vinyl Acetate; Economic Value Added
FAC	Final Acceptance Certificate
FAT	Factory Acceptance Test
FMEA	Failure Modes and Effects Analysis
FTM	Front-of-the-Metre
GPM	German association for Project Management
HAZOP	Hazard & Operability Study
H&S	Health and Safety
HV	High Voltage
HVAC	Heating, Ventilation, Air Conditioning
HVRT	High Voltage Ride Through
IEC	International Electrotechnical Commission
IECRE	IEC system for Certification to standards relating to equipment for use in Renewable Energy applications
IFC	Issue For Construction
IP	Inverter Protection, Internet Protocol
IRR	Internal Rate of Return
ISO	International Organisation for Standardisation
IVPD	Induced Voltage test with Partial Discharge measurement
KPI	Key Performance Indicator
kW	kilowatt
kWh	kilowatt-hour
kW_p	kilowatt-peak
LCOE	Levelised Cost Of Electricity
LD	Liquidated Damages
LeTID	Light and Elevated Temperature Induced Degradation
LFP	Lithium Ferro (iron) Phosphate
LID	Light Induced Degradation
LV	Low Voltage
MCC	Mechanical Completion Certificate
MTTR	Mean Time To Repair
MV	Medium Voltage
MW	Megawatt
NCU	Network Control Unit
NMC	Nickel Manganese Cobalt
NPM	Net Profit Margin
NTP	Notice To Proceed
O&M	Operation and Maintenance
OD	Operational Document
OPEX	Operational Expenses
PAC	Provisional Acceptance Certificate; Pac: AC Power
PCS	Power Conversion System
PD	Partial Discharge
PHSSER	Project Health, Safety, Security, Environment review
PID	Potential Induced Degradation
PLC	Programmable Logic Controllers
PMI	Project Management Institute
POD	Point Of Delivery
POI	Point Of Interconnection
PPA	Power Purchase Agreement
PPE	Personal Protective Equipment
PR	Performance Ratio
PV	Photovoltaic
QA	Quality Assurance
QC	Quality Control
QI	Quality Improvement
QM	Quality Management
QP	Quality Planning
QR	Quality Review
RACI	Responsible, Accountable, Consulted, Informed
RFSU	Ready for Start Up
RFP	Request for proposal
RFQ	Request for quotation
RFT	Request for tender
RPN	Risk Priority Number
ROCE	Return On Capital Employed
ROS	Return On Sales
SCADA	Supervisory Control And Data Acquisition
SLA	Service-Level Agreement
SLD	Single-Line Diagram
SOC	State of Charge
SPV	Special Purpose Vehicle
SSSP	Site-Specific Safety Plan
STC	Standard Test Conditions (1,000 W/m^2, 25°C)
STEM	Science, technology, engineering, and mathematics
TA/SWMS	Task Analysis/Safe Work Method Statement
TCU	Tracker Control Unit
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
UV	Ultraviolet
VPP	Virtual Power plant
WBS	Work Breakdown Structure

1 Introduction

1.1. Rationale, aim, and scope

Solar PV is a maturing industry. Its development globally has been phenomenal, with a sustained double-digit annual growth rate in excess of 10% for the last three decades (see Figure 1).

This is due to an equally impressive reduction in the cost of the energy produced by the technology (see Figure 2). Sustaining this cost reduction is critical for maintaining competitiveness against other energy technologies. This guide aims to contribute to further cost reductions.

FIGURE 1 GLOBAL SOLAR PV INSTALLED CAPACITY 2000-2020

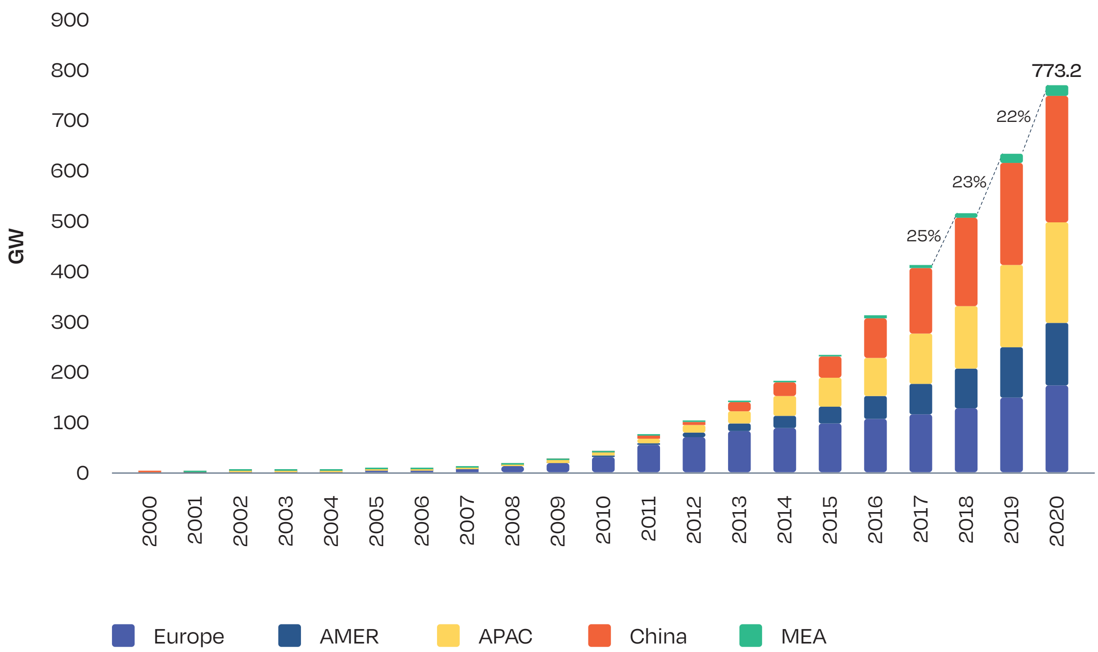
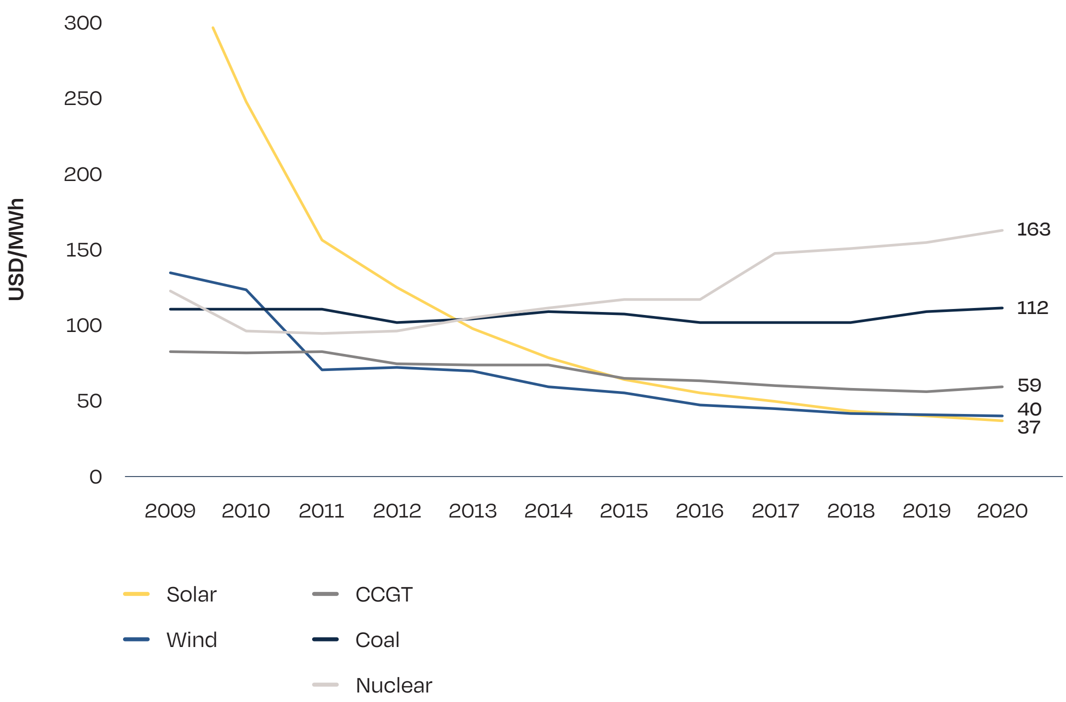


FIGURE 3 SOLAR ELECTRICITY GENERATION COST IN COMPARISON WITH OTHER POWER SOURCES 2009-2020



SOURCE: Lazard (2020). Historical mean unsubsidised LCOE values (nominal terms, post-tax).

The cost of PV energy is a function of CAPEX, OPEX, finance, and the amount of energy generated by the PV system. There is relentless competition in the marketplace, which mostly is played out on cost. The four contributions above are often seen as independent of one another and are optimised separately. This may not be ideal. Quality assurance is the link between these elements, as CAPEX savings may lead to higher OPEX or reduced energy generation. One idea behind these Guidelines is to minimise risks linked to this siloed approach to optimisation.

PV assets need to be cost effective to ensure broad acceptance of the technology. Simultaneously, they must deliver against performance expectations to prove their attractiveness to investors. To connect these two, there are different quality assurance strategies that are employed throughout the industry. These Guidelines allow for these different approaches, by detailing what is considered essential to assure a worthwhile asset and indicating optional and recommended additions.

The Guidelines systematically go through the Engineering, Procurement, and Construction (EPC) phases of a solar power plant. It is assumed that quality underpins the entire process, and often the earlier in the process it is introduced, the lower the overall system build, and Operation and Maintenance (O&M) costs will be. For more information on how quality underpins the lifcycle of a solar PV power plant, please refer to section *4.4 Quality Management* of SolarPower Europe's *Lifecycle Quality Best Practice Guidelines* (available at www.solarpowereurope.org). The links between the "E", "P" and "C" stages, as well as the links between Development and EPC, and the EPC and O&M phases are described in detail to minimise handover problems. Quality is often assured by the application of standards. There is a comprehensive list of these in Annex A. The Guidelines do not aim to substitute any of these, they aim to support the application of them and point out several relevant uses.

1.2. How to benefit from this document

These Guidelines include the main considerations for a successful and professional EPC service provision. Although they have not been tailored to individual stakeholders, the purpose of the Guidelines is similar for all - understanding the mandatory requirements and the necessity of high quality EPC services, as well as incorporating recommendations into service packages for more effective EPC services. Any of the directly relevant stakeholders (as described above) can benefit from this work, tailor it to their needs without lowering the bar and know what to ask for, offer or expect. The Guidelines are particularly useful for anybody in the industry involved in assessing or minimising risks of an asset. Although the focus is European, most of the content can be used in other regions around the world. The requirements described in the Guidelines apply without changes in other regions and additional requirements or modifications can easily be made for other regions with unique characteristics.

In line with other Best Practice Guidelines of SolarPower Europe the value proposition of this report is its industry-led nature, gathering the knowledge and experience of well-established and leading companies in the field of EPC, AM, O&M service provision, utilities, manufacturers, digital solution providers and insurance providers. The scope of the current second edition includes the utility scale segment and more specifically, systems above 1MW. The Guidelines are based on the experience of companies operating globally (with a focus on Europe) and identify high-level requirements that can be applied worldwide. Specific national considerations such as legal requirements are not included and should therefore be considered separately if the Guidelines are to be used in specific countries.

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

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

To differentiate between these three categories, verbs such as "should" indicate minimum requirements, unless specified otherwise, as in, "should, as a best practice" or "as a recommendation".

2

Risk Management from Ready-to-Build until COD

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This chapter builds on Chapter 4 of SolarPower Europe's Lifecycle Quality Guidelines, *Fundamentals of Lifecycle Project Management* by mapping out techniques for identifying and mitigating risks. Whilst risks are present throughout all stages of a project's lifecycle, they must be mapped and mitigated in the project development phase to reduce the likelihood of their occurrence and the weight of their impact further down the line. There are always multiple points of view on the size and likelihood of a risk. To better understand the risk perspective of an Asset Owner, consult SolarPower Europe's *Asset Management Best Practice Guidelines* (Version 2.0).

4.1. Quantification of risks

The typical approach in risk analysis in technical projects is to apply a classic Failure Modes and Effects Analysis (FMEA) where the various risks, belonging to a certain phase and component, can be prioritised through their Risk Priority Number (RPN). In the FMEA, each identified risk is typically evaluated for its severity (S), occurrence (O) and detectability (D); numbers are used to score each of these evaluation parameters. Typically, the RPN is then obtained by multiplying these three factors with the following formula:

RPN factors:

$$RPN = S_{RPN} \times O_{RPN} \times D_{RPN}$$

Technical risks are those that arise from the PV module, inverters, and other mechanical and electrical components, as well as system engineering, energy prediction, and installation. Some risks are confined to specific phases of development, such as construction risk, while others persist throughout the entire cycle from planning through operation, such as default risk. For more information on the quantification of technical risks, using FMEA, please refer to the Solar Bankability project at www.solarbankability.org.

The cost of mitigation measures needs to be included in a cost benefit analysis, which must consider the expectations of the stakeholders that are involved in a PV project.. Mitigation measures must be identified along PV the value chain and assigned to various technical risks. Typical mitigation measures during the design phase are linked to the component selection (e.g., standardised products, products with known track record), O&M friendly design (e.g., accessibility of the site, state of the art design of the monitoring system), LCOE optimised design (e.g., tracker vs. fixed tilt, central vs. string inverter, quality check of solar resource data). Mitigation during transportation and installation is linked to the supply chain management (e.g., well organised logistics, quality assurance during transportation), quality assurance (e.g., predefined acceptance procedures), grid connection (e.g., knowledge of grid code). These mitigation measures positively affect the uncertainty of the overall energy yield, increase the initial energy yield, and reduce the cost of O&M during the operational phase.

It is important that risk ownership is also considered to better understand which stakeholder is responsible for mitigation of a risk. Suitable planning, supervision, and quality assurance actions are critical at all stages of a PV project to minimise the risk of damages and outages, optimise the use of warranties, and the overall performance of the PV plant. . In practice, it is important to understand the combined effect of mitigation measures to be able to calculate their impact and assess their effectiveness. The cost-benefit analysis can include the combination of various mitigation measures and derive the best strategy depending on market segment and plant typology.

Particular attention needs to be paid to technical risks which are related to Health, Safety, Security, and Environment (HSSE) issues. Some HSSE risks are not linked to any performance loss, they must however be dealt with to reduce possible harm (risks leading to electrical fault, fire, etc.).

2.2. Financial risk factors and bankability

It is usually the equity side that is significantly compromised if a PV power plant project does not perform. This is because, across a project's lifetime, the development and the EPC phases have the highest risk. Financial risk involves market, modelling, credit, liquidity, operational and other risks (e. g. reputational, legal, IT, to name a few). In many projects, the financial modelling already poses an inherent risk, particularly when optimistic assumptions are taken, and no sufficient sensitivity scenarios with critical influencing factors are used. For the EPC part of a financial risk assessment, it is important to have an understanding of (however, not limited to) the following risks: market risks (particularly price and currency fluctuations from time of engineering/design through Commercial Operation Date (COD)) and cash related transaction risks, for example, how a pre-payment can effectively be secured against future deliveries. Examples of risk mitigation measures include performance bonds backed by internationally accepted financial institutions and escrow accounts. Another important aspect of financial risk analysis relates to solvency of the parties involved in the project and their individual business habits. Especially when it comes to a first-time interaction with a new business partner, business habits, including their value set, can have a significant impact on the financial stability of a project. There are several background checks that can help reveal the reliability of a new partner, such as references and financial health (credit) checks. One important point of consideration for financial risks is the bankability. It is important to note that different banks have different standards of assessing a project and its underlying risk. Two factors are essential from an EPC perspective: Firstly, it is essential to make sure that your own bank accepts any bonds issued by banks of your business partner. Secondly, it is important to understand the technical requirements of the lending bank (often only for the long term) of the buyer of the PV power plant and to adhere to these.

2.3. Country and regulatory risk factors

Country risk refers to the risk of investing or lending in a country. For example, financial factors such as currency controls, devaluation or regulatory changes, or stability factors such as mass riots, civil war and other potential events contribute to companies' operational risks. This term is also sometimes referred to as political risk. A differentiated country risk classification is offered by various institutions e. g. OECD, S&P, Moody's, Fitch, World Bank, and other institutions.

On the soft side, the cultural background in which a country is embedded also provides important hints that are usually not reflected in the country risk classification. As an example, in many countries, it may not be a general cultural exercise to admit to failing to fulfil a task.

For EPC service providers, the main tangible country risks directly affecting a project are given by customs clearance, local codes, local law (incl. labour law) and its effectiveness of enforcement (including when an EPC contract is subject to the law of a different country), local content requirements, local site conditions, currency risks (particularly also restrictions of currency trade), business habits (including bribery), and political stability (including violence). To evaluate the risk of being faced with bribery one can query a given country's corruption index on Transparency International. It is usually also reflected in countries' risk classification schemes mentioned above.

2.4. Contractual risk factors

Often contracts do not refer to the entire project or are not well defined, and therefore bear a significant risk of interpretation. To prevent unexpected risks and thus disputes during construction, international contractors should pay close attention to local project characteristics and contract practices. For details on this subject, refer to section *12.2. Contractual risk allocation*. For an off-the-shelf O&M contract template that equally distributes risk amongst the signatories, please refer to Open Solar Contracts (available at https://opensolarcontracts.org/).

2.5. Technical risk factors

The main technical risks associated with EPC are related to using key components properly. Key components are defined as the essential components that are needed to operate a PV system safely such that it performs to a minimum acceptable standard. Under this definition, key components of a PV system are:

- Modules
- Inverters
- Mounting structure
- Cabling – including connectors
- Transformers

Generally, international, and local standards and codes (e.g., IEC standards) are supporting documents to enable a minimum set of technical risk analyses. However, there are other technical risk aspects involved in an EPC project that are not covered by such standards.

While testing the key components is recommended as part of Quality Review (QR), correct installation of those components, using state of the art techniques, is more critical to building a high-performance power plant. Studies have shown that low plant performance is most likely due to system problems.

For more details on specific requirements, see Chapter *6. Engineering*, Chapter *7. Procurement* (section *7.5. Specific requirements per key component*) and Chapter *8. Construction*.

2.6. Other risk factors

Other risk factors that play a role in an EPC project that have not yet been addressed may include:

- Availability of components
- Transportation, transportation damages
- Delays, e. g. delays in shipments
- Local certifications, import rules
- Import taxes

2.7. Conclusions and recommendations

In conclusion, even though the upfront cost in Quality Management may add about 2% to the cost of a PV system, if properly performed, Quality Management, including proper conformity assessment, especially during the EPC phase (or the inception phase) of a PV project, pays off in the long run. There are too many examples of non-performing assets in the field, some of which even represent safety hazards. The bill after ostensibly benefitting from saving during the inception phase can result in severe, unplanned costs for taking corrective actions in the long run; see a case study outlined in figure 4-4. While this does not even represent the worst case, the 5 years of operation until failure represent less than 20% of a system lifetime, and the damage resulted in an additional, unplanned investment of approx. 38% in the fifth and sixthyears.

Proper quality and risk management should have their place in any PV power plant project throughout its lifetime. Getting the PV power plant inspected and rated in regular intervals is always confirmation of a healthy, well performing system – so is flagging any corrective measures to be taken early-on.

3 Health, Safety, Security, and Environment

Health, safety, security, and environment are key priorities for any solar PV project. This chapter will investigate specific areas of HSSE policy and coordination that relate to EPC service providers. For a general overview of the fundamentals of HSSE coordination, please refer to SolarPower Europe's Lifecycle Quality Guidelines V 1.0 (available at ww.solarpowereurope.org).

3.1. Health, Safety, and Security

To fully understand site hazards, mitigate them through inherently safe design, and manage any residual safety and operational risks during construction, the following best practices should be carried out across the full lifecycle of a project, and always be underpinned by strong HSSE leadership and personal ownership.

Establishing Leadership, Culture, Communication and Accountabilities

It is important that the EPC service provider (Principal Contractor) has a Health & Safety (H&S) policy statement that summarises its commitment to H&S throughout all levels of the organisation. The EPC service provider's organisational structure, with defined roles and accountability for leadership and service provider's personnel, related to the delivery of safe compliant and reliable operations, further demonstrates this commitment.

3.1.1. Pre-Construction and Design

Pre-construction & Design relates to activities taken to improve asset design that removes construction and operational risk and as such is Inherently Safe, one of the most effective risk mitigations.

Thorough subcontractor selection process (pre-qualification) and final selection informed by historical HSSE performance

Operational HSSE performance requires everyone on site to be equally focussed and committed to understanding day-to-day risks where they work, the preventions that have been put in place to minimise the chances of those risks materialising, and the mitigations that have been put in place to keep any impact as low as possible. In industry, when working with partners, contractors that share the same goals tend to develop a safety culture that delivers high HSSE performance.

Prior to selecting a contractor, a thorough review of their commitment to HSSE, HSSE performance and systems should be conducted.

Health and Safety Plan/File

The Health and Safety Plan/File is the EPC service provider's working document which sets out in detail how they will manage HSSE on the project and will include answers to any safety issues raised during Pre-Construction design. The purpose of a Health and Safety Plan on a project is to make everyone aware of the scope of the project, how the HSSE of the project affects them, and how the Health and Safety Plan affects others, including non-project related personnel.

The Plan/File details the following:

- Project description
- Residual hazards
- Structural/electrical design information

- Hazardous materials
- Safe O&M
- Location of services
- As-built drawings
- How to decommission the plant
- Waste management

Identifying and aligning on Environment, Health & Safety legal requirements

The Health & Safety Plan/File and the subsequent implementation needs to comply with local codes and regulations as well as all applicable international standards such as ISO 45001 and ISO 14001.

It is important that, to meet legal compliance to local law, the EPC service provider maintain a register of compliance obligations and be able to provide details demonstrating their compliance to partners, operators and for external and internal audits.

Safety in design: The industry continues to design and install new technology, seek construction efficiencies, reduce HSSE accidents and improve reliability and quality. It is important that every opportunity to de-risk an operation through Inherently Safe Design principles is taken. The following cross-functional check-ins are valuable formal reviews, and it is recommended that the EPC service provider follow the intent of the following workshops:

Project HSSE Kick-off: A meeting held at the start of the project between the Owner and EPC service provider's project teams to discuss HSSE expectations on the project.

Design Review: To gather designers, clients and other stakeholders and find ways to reduce construction, maintenance, repair, and demolition safety risks associated with design. This is usually attended by the project team and designers of the Owner and EPC service provider. This is conducted sufficiently in advance so any design changes identified can be easily implemented without material, commercial, or scheduling impact on the project.

Hazard & Operability study (HAZOP): A workshop to gather designers, clients and other stakeholders and identify and mitigate potential remaining hazards and operating issues with the design of equipment and plant. This phase generally produces the initial version of the site-specific Safety and Operational Risk Register that is maintained and handed over, along with site HSSE accountabilities, between teams throughout the entire lifecycle of a project.

Project Health, Safety, Security, Environment Review (PHSSER): A pre-mobilisation safety workshop to review site specific requirements and mobilisation details. It is the final Project HSSE cross functional check, ensuring all the design, permitting, risk registers, contractors and their interfaces are understood and addressed prior to starting construction.

3.1.2. Construction Phase

The following steps are carried out during construction.

Site-Specific Health and Safety Agreement

The Site-Specific Health and Safety Agreement is an agreement between businesses working on a specific site that determines how H&S will be managed. Answering the questions in the agreement will indicate which supporting forms are needed and which can be removed. Safety of all areas relevant to the development of the project should also be considered.

Safety and Operational Risk Register

This site-specific register is for the EPC service provider to record significant hazards that are involved in their work and cannot be eliminated. The register is a live document that should be kept up to date during the work period. The Site Job/Hazard and Risk Register relates to site-specific hazards and risks only and does not replace a company's overarching H&S hazard register.

Site Briefing Minutes and Toolbox Talks

Site/Briefings and Toolbox Talks provide a means of structuring briefings and meetings in a useful and logical way. The frequency should be based on need, but still at regular intervals. It is an extremely valuable meeting whereby a renewed focus on safe operations, and a discussion on upcoming risks and challenges for the day can be had between team members.

Holding daily Safety Conversations provides an invaluable opportunity to establish and maintain a Safety Culture on site.

Site Traffic Management Plan

The Site Traffic Management Plan is a live and detailed document that addresses site specific risk and is designed to:

- Keep people and vehicles apart
- Minimise vehicle movement including reversing
- Ensure vehicle handling competencies of staff
- Introduce turning and reversing vehicle controls
- Maximise people and plant visibility
- Define signs & Instructions
- Keep hazards away from the plant

It is important that the EPC service provider develops this plan, ensures that changes that occur over time are appropriately updated in the document, it is clearly communicated to all personnel on site and implementation check conducted regularly to ensure implementation.

Control of Work

An effective Control of Work process provides a work environment that allows high risk tasks to be completed safely and without unplanned loss. It contains:

- Written procedures for control of work
- Roles and accountability
- Training and competency
- Work plan
- Risk assessment of work
- Permit to Work
- Documentation, communication, and approval
- Work monitoring and management
- Safe conditions on completion/interruption of work
- Auditing the control of work process
- Lessons learned
- Obligation and authority to stop unsafe work

Where proposed work is identified as having a high risk, strict controls are required. The work must be carried out against previously agreed safety procedures and a 'permit-to-work' system.

The Permit to Work is a documented procedure that authorises certain people to carry out specific work (high risk in nature and not captured in a Method Statement) within a specified time frame. It sets out the precautions required to complete the work safely, based on a risk assessment. It describes what work will be done and how it will be done; the latter can be detailed in a 'method statement'.

The permit-to-work requires declarations from the people authorising and carrying out the work. Where necessary it requires a declaration from those involved in shift handover procedures or extensions to the work. Finally, before equipment or machinery is put back into service, it will require a declaration from the permit originator that it is ready for normal use.

Task Analysis/Safe Work Method Statement

The Task Analysis/Safe Work Method Statement (TA/SWMS) register is a job-planning tool for higher-risk activities. "Higher risk" refers to activities such as working in a confined-space, asbestos-related work, working at height, working in an excavation, working next to or over deep water, or working with any hazardous product or material. A principal or main contractor can request a TA/SWMS at any time, for any activity, not just those listed above. The TA/SWMS is written in accordance with and aligned to the Permit to Work process.

Risk Assessment Matrix and Hierarchy of Controls

The Risk Assessment Matrix allows you to assess the risk of a hazardous event occurring while certain tasks are being performed. The risk assessment defines the potential/severity and probability/likelihood of a specific risk so it can be compared across projects and against other risks, be effectively mitigated, tracked over time, and communicated.

The Hierarchy of Controls table takes you through a logical flow of options, from most effective to least effective to guide you in eliminating and minimising hazardous events.

For a template Risk Assessment Matrix, see *Annex D.*

Hazardous Works Notification

Certain activities are considered high risk and must be made note of before work begins. The Contractor controlling the site or activity must notify the authorities.

Hazardous Products and Substances Register

This register records every product, substance, and material that is brought to or used on the site by the subcontractor. You are required by national laws to record every product, substance, and material used on-site that contains potentially hazardous ingredients. The register must be completed before any work starts on-site and updated as changes occur.

Onsite Training and Competency Register

This register records the training, qualifications, experience, and competencies of your employees working on a particular site. It must be fully completed before any work starts on the site and updated as employees or circumstances change. This register is designed to be used in conjunction with a subcontractor's company-wide training and competency register.

Site Inspection Checklist

Inspection is a vital part of hazard management. An inspection can identify an issue before it causes harm. Inspections range from specific (vehicles) to broad (sites) and differ from one industry or trade to another. An inspection checklist therefore must be customised to meet the specific requirements of a job. Parties need to agree how and when inspections will be carried out. The frequency of these inspections is determined by the Site-Specific Safety Plan (SSSP) Agreement document.

HSSE Performance Monitoring of leading and lagging indicators

The tracking of HSSE performance against key performance indicators may identify emerging trends that require direct focus. It may also identify areas of high performance that others can look to replicate. Key performance indicators (KPIs) can be both lagging indicators of safety performance, built on historical performance that shows that performance has improved or deteriorated, or leading indicators the trends from which may indicate possible future performance change. See examples of Lagging and Leading HSSE KPIs in *Annex E*.

Management of Change

During construction it is not uncommon that conditions change, there are discoveries that compromise the original design or change the level of risk associated to the operation. While a number of these situations have negligible impact some may be material or may compromise some other part of the design.

Changes to design or changes in risk profile should be subject to a Management of Change review that is signed off by the same cross-functional team, Owner and EPC service provider that endorsed the original design and noted on all 'As-Builts'.

Emergency Response Plan

The Emergency Response Plan (ERP) saves lives. It must be in place before any work starts on-site and updated as changes occur. A comprehensive ERP is needed for any work that requires a TA/SWMS or a Permit to Work, such as harness rescue (above or below ground), extraction from a confined space, trench, or excavation collapse, and chemical or fuel spill. For an example ERP, see *Annex C*.

3.1.3. Project Review

Following the construction of the asset the EPC service provider and Owner should jointly hold a Post Construction Workshop. This workshop is to evaluate the effectiveness of the execution of the project against the aims and objectives. It should include H&S management provision, environmental protection, and general management of the overall project. Lessons from this workshop should be fed back into subsequent designs and handed over to O&M teams.

3.1.4. Decommissioning

Prior to commencing any dismantling or demolition works of the PV plant, a Structural Engineer should undertake an assessment of the risks together with a detailed investigation of the PV plant. The following consideration should be included:

- Whilst carrying out demolition consider different types of demolition to suit the structure i.e., Partial Demolition, Complete Progressive Demolition, and Demolition by Deliberate Collapse, Manual Demolition Techniques, and Mechanical Demolition.
- References should also be made to the O&M Manuals with regard to erection sequences and any future dismantling or modifications proposed to the plant installation.

- Demolition should be programmed and sequenced to avoid uncontrolled structural collapse. A set of operations should also be established which on a regular basis allow for debris to be cleared. Frequent checks to assess the stability of the remaining structure should be carried out. All workers should be withdrawn if the structure is unsafe. Danger points should be recognised such as floor loadings, falling debris, risk of fire hazards and the need for secure edge protection.

As a general guideline, any dismantling or demolition works should consider local recycling, based on the relevant local legislation.

3.2. Environment

Without precaution, the environment hosting the PV power plant may be affected during the project lifetime. Hence, an effective assessment of the associated impact of the proposed development project is a crucial aspect of any environmental and social impact assessment. Since a universal methodology might not apply to every project's environmental and social conditions, different approaches are adapted to suit the environmental context of each site.

There are several basic environmental authorisations including, but not limited to:

- Environmental impact assessment (EIA)
- Endangered/protected species
- Agricultural protection
- Historic preservation
- Forestry

Permitting and licensing requirements for solar PV power plants differ significantly from country to country and even, within different country regions.

All necessary environmental permits, licenses and requirements must be acquired prior to start of construction. It is a common practice to hire a specialist environmental consultant to provide advice on (1) the specific country requirements, laws, and regulations, (2) to consult with the relevant environmental agencies, planning and government authorities, and to determine any additional obligations relevant to the venture. One important aspect to already consider during the planning phase is the situation at the end of the lease term. In addition, equitable purchase/lease of land and water use for cleaning of solar modules should also be considered. The site-specific permitting shall be taken into consideration when moving towards decommissioning, repowering, acquisition to the landowner, etc.

3.2.1. Biodiversity

Biodiversity concerns the variety of living species, including plants, animals, bacteria and fungi on the site.

The *SolarPower Europe Sustainability Best Practices Benchmark* and *O&M Best Practice Guidelines* discuss how to make sure that a high level of biodiversity is maintained during plant operations. However, certain decisions during plant development and construction are important for ensuring that the PV project maintains or even increases pre-construction biodiversity levels. The biodiversity objective is to achieve the best possible synergy between technical and ecological systems on the site.

Perhaps the most important one of these decisions concerns the choice of where to build the plant. Several studies (for example BNE study, Enerplan et al.) have shown that biodiversity can be significantly improved, if the PV plant is built on a biologically degraded site. This does not necessarily mean, that PV plants should be built on contaminated soil – and the obligation to do so should only be accepted if the resulting risk is carried by the polluter. Furthermore, sites with polluted soil might nevertheless show a high level of biodiversity if industrial activity has been terminated a long time ago.

Other opportunities are agricultural sites with low productivity, because in this case the high potential to increase biodiversity combines well with an acceptable loss of agricultural potential. Occasionally it makes even sense to maintain agricultural activities in the PV plant. However, a clear decision should be made as to whether the purpose is energy-centric or agriculture-centric.

Construction can temporarily disrupt the existing natural ecosystem. So, after the site has been chosen, an initial survey of present species - before construction - should create a baseline, which makes later studies more meaningful. The design of this initial survey should be in line with later ones.

Certain design decisions contribute to higher biodiversity of a future PV plant. Air, land, and water are the main pillars in supporting animal and plant life, so the decisions focus on these points.

Some examples:

- Limiting soil sealing (foundations, tracks inside the plants etc.). For example, soil sealing could be limited to less than 2%.
- Roads in the PV plant should be water-bound.
- Avoiding terracing or at least limiting it to small problematic areas.
- Using the support structure as cable duct wherever possible, and hereby reducing buried cables and earth movements to a minimum.
- Avoiding the use of concrete fundaments for piles of the support structure.
- Biodiversity can help limit soil erosion (and increase soil fertility by avoiding nutrient run off), pest regulation and keeping vegetation height limited etc.
- Avoiding clearing trees and bushes wherever possible.
- Creating new hedges (for example at the Northern side of the PV plant, the hedge functions as habitat and visual screen).
- Several studies and best practice guidelines (for example, the BNE study and the Triesdorf biodiversity strategy) underline the importance of respecting minimum row distances.
- Vegetation under the panels instead of gravel may increase transpiration (water vapour as a by-product of photosynthesis), which, to some extent, can cool panels.
- Fences should allow small animals to pass (for example, presence of spaces of 15 cm between soil and fence). For larger animals passages should be planned, if the overall surface of the plant is bigger than, for example, 10-15 ha. The width of such passages should be at least 10 m. Security and biodiversity can here be in a trade-off situation, as animals can trigger motion sensors or cameras.
- During construction the integrity of the vegetational and upper soil layer should be maintained wherever possible.
- If sowing is nevertheless necessary, seeds should stem from regionally present plants. In any case, spreading of invasive alien species must be avoided.
- The use of fertilizers or herbicides must be avoided.
- Soil type and solar radiation will impact the type of wildlife and plants. Shadow from the panels impacts plants under or next to as well as can provide a refuge for animals.
- Bird and bat boxes might be considered to help create the right balance.

Given the specificities of protecting biodiversity, an external expert consultant should, where possible, be used to suggest strategies that are appropriate for a site's size and location.

To produce the best biodiversity results, the ecosystem of a site needs to be considered in its entirety when designing a strategy. This may not be achieved entirely in the first round and the strategy can require updating as the ecosystem is mapped more accurately.

4 Personnel & training

Having the right personnel with the right skills is crucial to the success of any project. This chapter touches briefly on the specific skills sets required by EPC service providers but for a more in-depth view of the skills required across a project's lifecycle please refer to SolarPower Europe's *Lifecycle Quality Guidelines V 1.0* (available for download at www.solarpowereurope.org).

The EPC service provider and its personnel should be able to prove that they have the necessary qualifications to do carry out the work required of them (refer to Chapter *5.2.2. References and expertise*). Despite the EPC phase being one of the shortest in a project's lifecycle, the range of work is large. It includes selecting modules; creating electrical wiring diagrams, which requires an awareness of local site regulations; civil engineering and construction work, which can include earth or mechanical work. Other examples involve supply chain management and logistics, including transportation; restrictions on work and access to sites; management of personnel, including handling local restrictions on travel and accommodation.

The personnel of the EPC service provider typically have the following skill profiles (for a useful skills matrix, see *Annex B*):

- Science, technology, engineering, and mathematics (STEM) e.g., electrical, or geotechnical
- Managerial and administrative e.g., finance, project management, supply chain management
- Technical e.g., doing groundwork, constructing frames, mounting panels

5 Transition from project development to EPC

Project requirements are generally set up during the development phase (which precedes the EPC phase). They are mainly regulated under project development agreements. These are executed between the Special Purpose Vehicle (SPV), as the Owner of the project (or the Asset Owner, when the SPV has not been established yet), and the local developer who is in the early development phase conducting the initial engineering activities including the setup of the layout. In addition to technical activities, the developer is also responsible for filing all the requests for the necessary authorisations and construction permits with the competent public administrations. For these reasons, the role of the EPC service provider is marginal in the early development stage. This is confirmed by the fact that the layout and the other prescriptions to be met are generally outside the EPC service provider's scope of work.

Therefore, in the present Guidelines, only three points are discussed because they are important for the transition from the development to the EPC phase:

- Before the beginning of the construction phase the different stakeholders, especially the investors and lenders, must assess the quality of the developed project, to come to a final decision to build the project, sign the relevant contracts (see Chapter *12. Contractual framework*) and utter the notice to proceed (NTP). Section *5.1. Selection of EPC projects* discusses some relevant points of this type of assessment.
- Then, the financial stakeholders have to choose an EPC service provider. Section *5.2. Selection of the EPC service provider* discusses some important selection criteria.
- Finally, the project has to be handed over to the EPC service provider without losing important information. Chapter *5.3. Handover from project developer to EPC* discusses this critical procedure.

5.1. Selection of EPC projects

To select EPC projects and assess their quality, investors and lenders scrutinise certain factors, which often condense into checklists and internal guidelines (also called "ex-ante KPIs"). The content of this support strongly depends on several stakeholder traits (strategy, experience, etc.). For example, for one investor an activity in a certain region might be excluded, whereas another investor might be specialised in that region. Furthermore, the content of such support depends on the size of the project, while the complexity of the assessment will increase with project price. In the selection of the EPC project risk analysis and mitigation will play an important role. For more information see Chapter *2. Risk Management: from Ready-to-build until COD*.

5.1.1. Profitability

An important point for all stakeholders is the assessment of project profitability. Since the business plan needs to be realistic and solid, it is important to make sure that all important cost parameters have been considered. At least one yield study, done according to industry standards, should underpin expected production. Technical and legal due diligence studies must make sure that this production can be converted into revenue.

Quantitative assessment of a project's profitability follows these qualitative verifications. An important KPI for a project's profitability is the Internal Rate of Return (IRR). "Internal" refers to the fact that the calculation excludes external factors like inflation and cost of capital. According to the IRR formula, a project can be pursued if the internal rate of return is greater than the minimum required rate of return.

5.1.2. Technical quality

One of the overarching engineering KPIs is expected performance ratio (PR) / expected yield, which is an input parameter into the business plan. Multiple parameters determine expected PR. We can only mention some of them here. A more detailed list is part of a technical due diligence / yield study. However, other aspects may be equally important, for example pre-qualification metrics (such as e.g., manufacturer, and main component ratings) and design rating.

The technical quality of a project depends strongly on procurement decisions. For more information, see Chapter *7. Procurement*.

5.2. Selection of EPC service provider

The following criteria (also called "ex-ante KPIs"), among others, help to assess EPC service providers: financial stability, expertise, prices, and procurement performance.

5.2.1. Financial stability

One important factor is the financial stability of the EPC service provider. It is important to get as close as possible to the present-day financial situation of the company. Credit ratings (seen in relation to the country/market the EPC service provider operates in) as well as audited statements from the last 2-3 years are typically the most solid and indisputable financial information. Since accounting definitions can vary from country to country, comparisons might be difficult.

An alternative to this is a bank guarantee where the investor moves the evaluation over to a bank partner. This does not necessarily give a better evaluation of the financial viability than one's own evaluation, but it gives the financial insurance of a bank. This obviously comes with a cost. The mere demand for a bank guarantee can be prohibitive for some projects and can eliminate smaller, competent EPC service providers from participating, even though they are financially solid for their size.

Assessment of the following four areas provides insight into the financial situation of a company: liquidity, solvency, operating efficiency, and profitability.

An important KPI for **liquidity** is the quick ratio (also referred to as acid test). It is defined as the ratio between quickly available or liquid assets and current liabilities.

Quick Ratio:

$$QR = \frac{\text{Cash} + \text{Cash equivalent} + \text{Marketable securities} + \text{Accounts receivable}}{\text{Current liabilities}}$$

QR should be > 1, more preferable >1.1.

Solvency is a company's ability to meet its debt obligations on an ongoing basis, not just over the short term. The debt-to-equity ratio (D/E) indicates the relative proportion of shareholders' equity and debt used to finance a company's assets. The lower the D/E ratio, the more of a company's operations are being financed by shareholders who do not charge interest, but more importantly, may enable the company to raise debt capital in case needed. On the flipside, a decreasing D/E indicates increasing financial solidity of the company.

A good indicator of a company's **operating efficiency** is reflected by its Return on Sales (ROS, also called EBIT margin):

Return on Sales:

$$ROS = \frac{EBIT}{Revenue} \times 100\%$$

Where EBIT = Earnings Before Interest and Tax

Return on Capital Employed:

$$ROCE = \frac{EBIT}{CE} \times 100\%$$

Where CE = Capital Employed = Total assets – Current liabilities

However, it is to be noted that EBIT may contain tangible book value and depreciation risks. Therefore, EBIT may be a misleading metric where there have been inappropriate depreciation or book value assumptions. Financial return KPIs based on cash flow (like EBIT) positions may reflect a more reliable evaluation base, though the percentage must naturally be higher.

A good KPI for evaluating a company's **profitability** is its Net Profit Margin (NPM):

Net Profit Margin:

$$NPM = \frac{\text{Net profit}}{\text{Revenue}} = \frac{\text{Revenue - Cost}}{\text{Revenue}}$$

A low NPM means a higher risk of the company running into difficulties quickly if operating cost or competition increases. A larger net margin indicates its higher potential to invest capital into growth (but should be seen in relation to fixed costs).

Apart from the financial stability of the EPC service provider, other means may secure the investor: bank guarantees (e.g., performance bonds), insurance cover solutions, or cash retentions. Bank guarantees, in this example a performance bond, ensure that the EPC service provider is able to pay for liabilities and warranties that might arise from the EPC contract. To receive this type of bank guarantee, the EPC service provider has to pay a percentage to the bank. The downside is that, besides the cost of the performance bond incurred by the EPC service provider, the impact on their available free liquidity. Small EPC service providers, in particular, often face challenges in accessing bank guarantees. In this case cash retentions may secure the investor, i.e., the last payment only occurs after the Final Acceptance Certificate (FAC) is issued.

5.2.2. References and expertise

Experience of the EPC service provider in the construction of PV power plants in a particular country, region, grid environment, for a specific installation type (ground-mounted, rooftop), size and technology can play an important role in the selection procedure. The EPC service provider may provide their references in a track record, to document their experience.

Furthermore, the EPC service provider should document that its staff has the necessary training and certifications to be qualified to build the PV plant. In the case of subcontractors, their experience in the field of activity should also be proven.

Another sign of expertise is the quality approach of the EPC service provider. Apart from potential verifications at the manufacturer's production site, non-mandatory quality checks during the construction phase are recommended (for more information, see *Chapter 7. Procurement*). The extent of checks needs to be adapted to the size of the project.

As part of the expertise, it should be made sure that the EPC service provider has a proper quality management procedure in place.

5.2.3. Price and performance of procurement

Those EPC service providers that are preferred partners of their suppliers get better conditions. This may be a better price, but also better delivery time, secured delivery in case of shortage or favourable warranty conditions and claim solving.

5.3. Handover from project developer to EPC service provider

At the contracting stage, when selecting or appointing an EPC service provider, the developer should hand over all the important documentation about the project and preliminary works (see *Annex F, section Basic Design – Development Documentation*). This will be the basis for the scope of work negotiation with the EPC service provider and the share of responsibilities between the Asset Owner and the EPC service provider. The main topics to be discussed by both parties include the site description with its particularities, the permitting process and the associated constraints from legal authorities and the technical specifications from the grid connection side.

5.3.1. Site description (including site surveys and site data)

To ensure the best understanding and the most accurate design of the PV plant, a detailed description of the site and all associated constraints should be delivered to the EPC service provider. To pass on responsibilities to the contractor all preliminary studies and surveys should be shared. These documents will allow identifying the requirements and identifying the need for extended study. The main information to be shared is listed in *Annex F, section Basic Design.* If applicable, some documents from the Pre-Construction Documentation should also be considered.

5.3.2. Permitting process

The developer is typically in charge of obtaining the building permit and all authorisations (e.g., from environmental authority) related to the execution of the works. In the EPC contract it should be mentioned that the contractor needs to comply with the above related permits and authorisation to maintain them. Specific aspects related to the construction period or design of the PV installation can be requested by the relevant authorities and might be made the responsibility of the contractor during the construction stage:

- Environmental mitigation measures to be implemented (plant trees, restoring grass, exclusion zones for levelling and grading works, measures towards flora and fauna)
- Aesthetic measures for visualisation of the project, landscape integration or sight impact on the neighbouring buildings (electrical cabinet design, height of structures, hedges to be planted)
- Fire and emergency mitigation measures

5.3.3. Grid connection process

The development stage also involves identifying the most suitable point of interconnection with the local network and the best strategy for connecting. This is often discussed at early stages with the network or grid operator, who is normally involved in the technical specification definition, and sometimes (in some countries systematically) in the completion of the works. To ensure timely grid connection and smooth communication between the network operator and the EPC service provider it is important to share the following:

- Grid connection technical specifications, often prepared by the local network operator.
- Network operating conditions to be complied with during the operation phase.

Additionally, in case of a specific Power Purchase Agreement (PPA), it is recommended that this information is shared with the EPC service provider. If commercial aspects need to be kept confidential then the technical specifications with which the EPC service provider has to comply should be shared, at the very least.

6 Engineering

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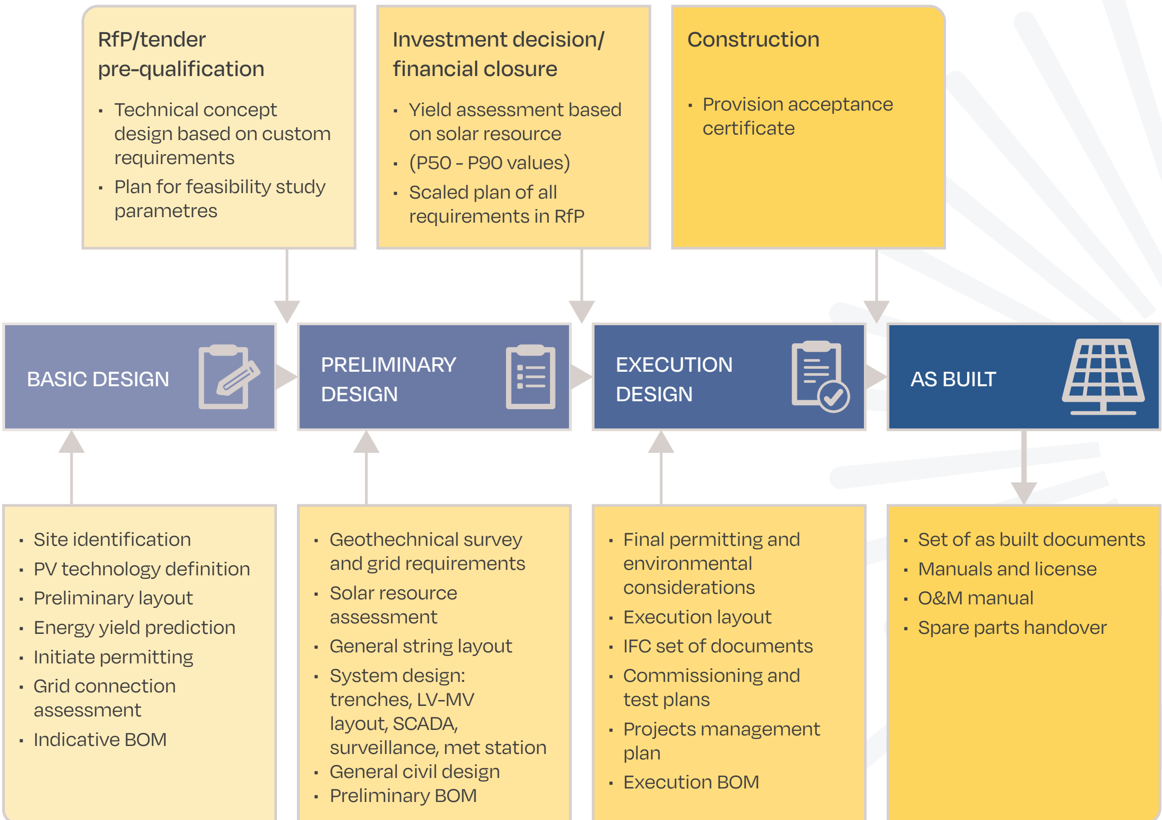
The engineering design and modelling of a PV plant is a crucial element of the EPC lifecycle, as it guides the whole process of EPC, from conceptualisation to investment decisions and to the actual construction of the solar power plant. It is also a highly iterative process in which inputs from all the main stakeholders are considered, to generate the most suitable project plan for a successful and efficient PV plant.

As a best practice, all locally applicable standards and permitting procedures shall be clearly described and considered at the very start of the design process. Later, different stakeholders may have different

FIGURE 3 OVERVIEW OF ENGINEERING DESIGN STAGES, MILESTONES AND DELIVERABLES



engineering and design requirements to perform their respective services. Good communication and timely adjustments of the engineering design along the way are strongly recommended to ensure quality throughout the entire process.

In the following chapter, the engineering stage of the project has been divided into four sub-phases, which are considered the common flow for PV project development. However, some of these phases (and milestones) may differ from the reader's project due to different companies' business approaches or philosophies, types of project finance, number of stakeholders and project size.

Starting off as a basic technical concept, the engineering design is itself a process that evolves and is constantly refined as the project development advances. It evolves into a detailed execution design blueprint issued for construction. Once construction and commissioning are completed, a detailed set of "as built" documents is handed over to the O&M service provider.

6.1. Basic design

The basic design concept is the first assessment of the engineering design, and it is sometimes considered to be a part of the early "project development" (see Chapter *2. Definitions in SolarPower Europe's Lifecycle Quality Guidelines*). At this stage, the developer may not have a clear understanding of the project site characteristics such as topography, hydrology, and obstacles. The main objective of the design concept at this early stage is to verify the project feasibility.

Generally, the basic design concept includes an initial layout (preliminary layout in Fig.4) for the plant, energy yield simulation, grid connection assessment and an indicative bill of materials (BOM in Fig.4) for the main components only:

- PV modules – manufacturer, model, and power class(es)
- Inverters - manufacturer and model
- Tracking system (if present) - manufacturer and model.

Using simulation software to compare different sets of module or inverter technologies, as well as mounting structures and different plant layouts can be beneficial in choosing the optimal design in terms of predicted energy yield and cost structure.

Usually, the basic design concept with total installed capacity, indicative layout design and single line diagram (SLD) is sufficient to start the permitting process.

However, more detailed versions of the basic design concept may be produced to facilitate early development permitting milestones or bidding in tender procedures, depending on the concrete case requirements.

Establishing design requirements and conducting requirement analysis are the most important elements in the design process, and this task is often performed at the same time as a feasibility analysis.

On top of basic things like the functions, attributes, and specifications, determined after assessing user needs, some design requirements may also include hardware and software parameters, maintainability, availability, and testability.

Maintainability requirements:

- The support structure should allow grass cutting, panel cleaning, and preserve a sustainable ecosystem
- There should be enough space between PV rows, and between rows and fences
- On roofs, there should be maintenance walkways
- The fixation of string cables should keep the connectors far from rain
- The drainage system should be designed to remove water in an efficient way without high OPEX and to avoid flooding
- The security system should be designed to allow for efficient protection of the plant at moderate OPEX
- The monitoring system should allow for quick error detection and efficient fault analysis (see SolarPower Europe's *O&M Best Practice Guidelines* for requirements)
- It should be possible to have affordable service contracts for core elements like inverters and switch gear

As the project advances, the developer will acquire more information, provided that the following studies are performed: site assessment, solar resource analysis, environmental studies, permitting requirements and interconnection assessment.

The design can be updated respectively with:

- Preliminary Layout with Installed Capacity: W_p and W_{ac}.
- Layout constraints and boundaries
- Indicative bill of materials of major equipment: modules, inverters, type of structure, transformers
- Preliminary SLD
- Yield simulations with proposed losses assumptions for availability, soiling, cabling losses.

Then, project documentation is ready for the technical due diligence usually required by investors, especially, if the power plant is financed through project finance.

An indicative list of documents is provided at the Annex F, *section Basic Design*, as a guideline for the developers on how to initiate a project, seek permitting and advance to the technical due diligence stage.

It is a best practice that the design development is done in close coordination with the stakeholders involved such as investors, local communities, banks, suppliers, grid operators, national and local authorities, etc. The more detailed and stakeholder-agreed the design is, the better it will support the development of the project's financial model.

As a best practice, the technical viability of the design needs to be confirmed. The proposed suppliers of the main components need to be checked for a satisfactory track-record and relevant warranties. These steps are especially important when utility scale and commercial & industrial (C&I) projects are considered. Those financial stakeholders who do not have their own internal technical teams may instead rely on specialised technical advisors to conduct the relevant studies and reports and confirm the quality of the basic design.

6.2. Preliminary design

A detailed basic design usually provides sufficient basis for taking an investment decision or arranging finance. However, depending on the stakeholders involved, clearing that milestone may require more precise site topography measurements as well as regulatory and financial closure aspects to be accounted for in a preliminary design concept.

A key element of preliminary designs is a topographical survey. A ground-based site survey should be enhanced through a full topographical survey using a drone, which can produce site orthomosaics, Digital Elevation Models (DEM), and Point Cloud maps. Using a drone to collect the terrain and shading scene (both near and horizon) is vital in ensuring an optimal array design for a given area of land. If an EPC service provider is contemplating using bi-facial modules, then an albedo estimate can also be made from the drone photogrammetry.

Computer Aided Design (CAD) based software will ingest these 3D models to produce the topographical layouts of the PV plants where all elements are in their true geographical locations, to an extremely high level of accuracy and precision.

In any situation, the present section, and the Annex F, *section Preliminary Design* are an indicative guideline for the phase's steps and documentation.

The preliminary design shall be part of the Pre-Construction Documentation, where the layout shall propose:

- PV Array sections
- Inverter Stations
- Mounting systems or trackers
- Substation
- Communication systems
- Monitoring systems[1]
- Cable routes
- Access roads
- Laydown areas
- Meteorological stations
- Site tracks
- Manholes
- Construction area
- Permanent and temporary buildings

The preliminary design shall include a preliminary bill of materials (preliminary BOM in Fig.4) for budgeting purposes. The bill of materials gives quite a precise

1 For the selection of the Monitoring System, see Chapter 10 of the *O&M Best Practice Guidelines* on *Data and monitoring requirements*, as well as the best practice checklist for monitoring tools, available at www.solarbestpractices.com.

indication of quantities, so that (binding or non-binding) term sheets can be collected from suppliers and contractors.

The topographical survey and layouts of PV plants can be used as a 3D model to generate a preliminary digital twin of a PV plant, intended as a tool to visualise the asset. The information related to the choice and selection of components are part of the PV Information Modelling can also be visualised within the digital twin.

In projects where a turnkey EPC contract is signed, the design is only approved by the Asset Owner or the developer, and the EPC service provider is responsible for providing all the contracts and suppliers.

If an EPC service provider has already been involved in the design phase, the set of documentation shall include the projects' buildings, amenities, preliminary studies, quality and testing plans, as well as the method statement, in addition to the layout and equipment specification.

At this stage, the Owner/Developer shall also agree with the EPC service provider on the Project Management Plan, including the project reporting, EHS, quality, changing plans and document register.

A detailed overview of the documentation of this stage can be found at *Annex F, section Preliminary Design*.

6.3. Execution design

As the preliminary design is changed and/or approved by the Owner, the EPC service provider shall move to the execution design stage, incorporating all the relevant construction blueprints and working instructions.

Once the design is finalised, it shall provide all the information necessary to request a grid connection, as well as all the necessary parameters for a grid impact analysis (if required).

A fully detailed specification of equipment and bill of materials (including the spare parts) shall be produced. As part of the execution design, the construction plans would have the final reports of calculations and assessments for all electrical and civil structures.

Factory acceptance plans shall be defined for major equipment. In addition, commissioning and testing procedures shall be provided to the Owner/developer for verification and approval.

It is recommended that a list of companies, major machinery, number of personal involved in the construction phase and quality assurance measures planned be included in project management plans. A method statement shall be clearly defined for each project phase.

A detailed overview of the documentation of the execution stage shall be found at *Annex F, section Execution Design*.

For large assets drone-based construction monitoring is recommended during construction. This data provides an excellent risk management tool and helps ensure the integrity of construction vs design plans by capturing any deviations or design changes as they occur.

6.4. As-built design

After the PV plant is accepted by the Asset Owner or the developer via the Provisional Acceptance Certificate (PAC) (see also section *9.3. Provisional Acceptance Certificate*), the project enters the handover stage. This is the phase of the project where the EPC service provider shall deliver all the design documentation that details how the PV plant has been built (as-built design documentation). This is important to emphasise, because during the construction phase some of the execution design may change due to unexpected events, mistakes on the design, terrain, or underground difficulties.

A dimensionally and geospatially accurate 'as-built' model of the asset can be generated from the drone-captured construction monitoring data, which can be used to update the digital twin. If construction monitoring has not been undertaken, then a single photogrammetry flight can produce an as-built record of the visible array layout. It is also possible to generate a 3D model of the new asset for onward yield modelling and verification by using more enhanced photogrammetry approaches. Such data capture and modelling can be valuable as part of the handover documentation from the EPC service provider to the Asset Owner and the O&M service provider.

A detailed overview of the as-built documentation can be found in *Annex F, section As-built Design* (consider also IEC standard 62446).

In addition to the as-built design, the EPC service provider should also organise other handover documentation, such as the O&M manuals, for the Asset Owner and the O&M service provider. For more information, see Chapter *10. Handover to O&M*.

The Procurement phase covers purchasing components such as PV modules and inverters, as well as identifying and mitigating risks. It involves supplier selection and onboarding, and conducting inspections, and tests to qualify materials to be used in construction throughout the procurement process..

This chapter will help stakeholders to identify risks in the procurement process of components (such as PV modules, inverters) and to mitigate them through suitable inspection, testing and qualification mechanisms for individual projects. The procedures shall be underlined with definitions of acceptance level and criteria.

7.1. General procurement guidelines

This section addresses general guidelines applicable to the procurement of any component of a system and provides guidance on how to integrate quality aspects into the procurement process. It is recommended to apply the general requirements, where relevant, to subcontracted activities such as engineering, construction, or quality management activities. This section follows the different steps of procurement, from supplier onboarding to inspection and tests until completion of the procurement process. The guidelines are independent from the procurement process itself and remain applicable whether the EPC service provider decides to work through recurring orders, single purpose contracts or project-based procurement.

7.1.1. Use of third parties

Involving third parties in the procurement process can lead to the delivery of better products as they can bring quality expertise and objectivity to the judgement of products and suppliers. The contractual agreement on the Quality Monitoring measures, be it by third-party or other means, often leads to more quality awareness on the supplier's side and to more stringent application of quality standards. A contractual agreement should address the scope of the responsibility assigned to the third party and their authority to make decisions on quality. In general, involving third parties in the procurement process is best practice but not an outright necessity.

Third party technical assessments vary significantly in terms of thoroughness, accurateness, completeness, reliability, validity, and transparency. A good guide to identifying a credible third-party service provider may be the proof of an accreditation according to ISO 17020, ISO 17025 or acceptance by IECRE.

7.1.2. Integration of Quality Management into the procurement process

Regardless of the procurement process they have defined, the EPC service provider is ultimately responsible for providing the required quality level for the activities and components provided by its suppliers. The EPC service provider must ensure that the quality of the components and services procured from external sources fulfil their internal quality standards, and that risks related to procurement activities are identified and mitigated.

Therefore, the EPC service provider shall define and deploy the appropriate procedures for:

- The selection, evaluation and monitoring of its suppliers
- The monitoring it intends to apply on the products and services procured from external sources, such as quality requirements and evaluation criteria, products release procedures, auditing processes.

7.2. Management of suppliers

7.2.1. Selection of suppliers

Prior to signing a contract with a supplier, the EPC service provider should determine the ability of the supplier to consistently deliver products and services that can meet the requirements in sufficient quantities. Alongside this, suppliers' performance on technical, financial, legal, and social regulation and standards should be assessed. This requires cooperation from suppliers along all these lines. There is a severe risk of reputational damage linked to a lack of supply chain transparency. For more information on building sustainable and transparent supply chains, please refer to SolarPower Europe's *Sustainability Best Practices Benchmark*. In addition, SolarPower Europe is currently (as of December 2021) developing a supply chain monitoring programme that will further this effort.

When selecting a supplier, TIER-ratings give an overview of the track record of the manufacturer, but only provide limited information on the quality of a product. Therefore, selecting products just on their TIER rating is insufficient. Consequently, the selection must be based on product testing accompanied by factory audits and a documentation review.

A technical rating of products can be based on accessible product data and quality assurance information provided by the manufacturer. It can be used as preselection criteria as a part of an overall quality review process for PV power plants. The rating or scoring system of suppliers should start before the sourcing phase. A rating may be based on a questionnaire, which should include the product-related data as well as quality assurance information, including:

- Technical Specifications
- Bill of Materials
- Certificates
- Warranties
- Any beyond standard quality assurance/quality control measures (e. g. extended reliability test programmes)
- Manuals, labels, and data sheets
- Quality management in the production

7.2.2. Qualification of suppliers

While all products are usually qualified and manufactured under a valid quality management system, variations in production lines, bills of material, and general fluctuations in quality are still common in the solar industry. Quality measures should be monitored during manufacturing and shipping to get a full assessment of the quality of the procured goods. It is recommended that one carries out quality review measures for production supervision that are in line with international conformity assessment standards. Alternatively, on-site assessments, and product testing should be done before signing a contract with a supplier.

Documentation Review

A general document review, submitted by the supplier, should contain:

- Product certificates and associated reports (all relevant market access documents)
- Factory certificates (management system, laboratory accreditations)
- Warranty condition
- Review of recalls / claim handling

Factory Inspection

Before production starts, a pre-production factory inspection is recommended. The aim is to identify issues in the manufacturing and quality assurance processes that can have a negative impact on the quality of the components. The inspection should consist of verification and evaluation of the following processes and procedures:

- Incoming inspections and preparation of materials – warehouse
- Production process assessment
- Electrical safety tests
- Outgoing performance / output power verification
- Evaluation of equipment and procedures for quality control tests (such as solar simulators, visual inspection tools, electroluminescence (EL), insulation test)
- Quality assurance/control (storage and handling of materials, production areas, staff training, claim handling)
- Handling of test and calibration equipment
- Documentation of process data
- Process for handling faulty products
- Conditioning of the finished product
- Review and comment on the warranty claim list
- Product traceability

Product qualification testing

While type approval and safety certification are the minimum requirements to market any product, series production might show fluctuations in production quality based on production lines or material variations.

It is therefore recommended to fix a particular bill of materials and factories / production lines in the purchasing agreements and pre-test products accordingly. The product qualification testing shall be based on standards and be product / component specific. Depending on the size of the project, extensive factory inspections may be performed, as well as a conformity testing, to ensure that the components arriving on site have been manufactured using the correct bill of materials, and the manufacturing process has delivered the specified quality requirements. Further details are listed in section *7.5 Specific requirements per key component*.

7.3. Supply Review

When large quantities are procured with a specific deadline, it is important to assess the supplier's ability to meet it by checking material supply as well as actual production capacity.

7.3.1. Pre-production Review

Prior to production, it is advisable to assess the factory's readiness to supply the products ordered within the agreed lead-time and at the right quality level.

Focus shall be put on:

- The availability of agreed components (bill of materials)
- The status of maintenance and calibration of the production and testing equipment
- The communication of specific quality requirements of the project and availability of related documentation
- The qualification of the production manager to apply the specific quality requirements

7.3.2. During Production Inspections

During production inspections are performed after production of the components for the PV project (e.g., modules) has started.

The inspection shall focus on the following topics:

- Verification of production on the agreed manufacturing lines
- Use of material in accordance with the agreed bill of materials
- Quality Monitoring during the manufacturing process
- Verification (spot-check basis) through in-line tests
- Verification of performance determination test on a spot-check basis
- Verification that contractually agreed specifications are met

Sampling plans and the acceptance criteria for required verification tests and inspections shall be agreed upon in advance. Any production inspection process is a compromise between cost and thoroughness. Ideally, manufacturers should be monitored closely enough to ensure that no significant unobserved material deviation from the agreed features goes unnoticed.

7.4. Delivery

7.4.1. Post-production Monitoring

Contractually agreed upon monitoring for post-production (before dispatch, after receipt, during construction) is an important tool for assessing the consistency of quality and thus the degree of fulfilment of the contract. Sound statistical sampling at this early stage of the project helps avoid long-term failures. For example, if the components have already been installed and show early faults, the cost of handling complaints and, if necessary, subsequent replacement is more expensive. Comprehensive testing would add significant costs to the project thus a standard like ISO 2859 should be applied. The case to be considered in testing should be agreed with the component suppliers in the contracts. The level of a batch conformity should also be agreed with the component supplier in the contracts as this may influence the financial risk assessment and thus affect the overall cost of funding. Typically testing will be in the production line, but should be witnessed and verified through sample third party testing (see *7.4.3 Pre-shipment testing, factory acceptance testing*). Typically General Inspection Level I (visual and electric properties) and Special Inspection Level 2 (insulation and dimension checks) with AQL Major 1.5 and Minor 2.5 is used for sample size definition.

7.4.2. Pre-shipment inspection

Pre-shipment inspections are carried out on a sample basis and used to release finished goods for shipment if they meet the agreed requirements. The inspections include:

- Visual inspection
- Power verification
- Electric insulation
- Label verification
- Verification of packaging and fit for shipping

7.4.3. Pre-shipment testing, Factory Acceptance Testing

Critical tests that determine the conformity to agreed ratings as well as quick quality monitoring tests are performed on random samples taken from packages ready for shipment. It is important to agree on pass/fail criteria and clear criteria for shipment rejection. Testing / inspection can be done at the factory site (Factory Acceptance Testing, FAT) or at a warehouse, depending on access and availability of testing equipment.

A FAT shall include the following aspects:

- Assessment of quality standards of production line / manufacturing site
- Verifying the quality system in place in the production line, considering procedures, compliance of all staff and processes, traceability, and problem mitigation
- Mechanical specifications of the product
- Electrical specification of the product
- Documentation, including manuals, SLDs and warranty
- Service and support quality
- Data management and display

7.4.4. Post-shipment inspection

Post shipment inspections are performed to check whether the received goods hold all necessary documentation and import papers / certifications (e. g. Certificate of Conformity). Furthermore, the post-shipment inspection shall document any transportation damages to enable claims based on such damages. Again, a prior agreement on acceptance criteria is of major importance.

7.5. Specific requirements per key component

Generally, spelling out solid requirements for key components is one of the most mission critical items. The importance of this topic can hardly be underestimated when it comes to the long term technical and financial success of a PV project. Going into great detail is outside the scope of this document and therefore, the following subchapters only give an outline. One of the biggest challenges comes from time pressure during the construction phase combined with manufacturing or delivery problems that may occur during the project execution. An additional challenge is related to reviewing quality, as the variety of testing and inspection services offered in the market is quite wide when it comes to reliability, accuracy, validity, viability etc.

There is no principal reason behind underperforming PV assets. System faults occur the most frequently, but individual components can also have defects. It is absolutely crucial for EPC service providers to ensure the quality and reliability of all the components that they use.

7.5.1. Modules

Modules are the engine of the final system and represent a significant proportion of a project's CAPEX and labour corrective maintenance measures need to be carried out. In the planning phase one should verify that modules are, in theory at least, capable of operating in the given working environment for the anticipated lifetime and with the assumed durability. It is often wrongly assumed that this will be the case if the module type has passed the IEC 61215 / IEC 61730 type/safety approval test. These standards have been one of the most successful contributions to reducing problems in the array field but are only a design qualification standard. They are limited to evaluating known failure mechanisms and assume a moderate climate. Examples of failure modes being missed include backsheet issues or PID and Light and elevated Temperature Induced Degradation (LeTID) related issues. The main impact has been to reduce early failures in the first few years in operation. It does not give any information on the durability of a module, nor does it verify the quality of the product actually being installed, just the general suitability of the product family for the intended application.

Ideally one should verify whether the modules will operate at conditions represented by the tests they have undergone or account for an increased quality risk if conditions in the field are expected to be out of the test standard's scope. An example of modules potentially operating outside tested specification could be building integrated mounting or systems in arid climate zones, as such systems may run much hotter than they have been tested for. IEC TS 63126 *Guidelines for qualifying PV modules, components, and materials for operation at high temperatures* gives guidance on testing modules and components for high temperatures. As some standards also allow variants of test conditions based on manufacturer's definition, reviewing the testing protocol alongside the certificate is recommended.

Integrating testing requirements for PV modules in the procurement conditions allows for claims against underperformance as well as identifying design deficiencies. PV modules from one system supplied by various production sites or batches may require separate assessment.

There are three groups of quality tests described:

1. Performance characterisation testing
2. Qualification testing
3. Module Reliability Tests
   Stress Tests, Accelerated Aging Tests)

Performance characterisation testing mainly addresses the electric performance of the PV modules and the condition of the cell interconnection circuit (cell cracks or interrupts). Regarding the power warranty, the performance of the entire delivery can be deduced from a random sample according to ISO 2859-1. As budget and timing is usually critical, mostly General Inspection Level based on the total number of modules per production batch is applied. As an alternative, a combination of a smaller sample size (e.g., 50 per batch) and the manufacturer's flash list will allow a robust product verification if the measurements have been carried out with a sufficiently low uncertainty and the service provider has an appropriate quality system. It is advisable to combine power measurement with electroluminescence imaging for crack detection. The performance at low irradiance is something needed for the energy yield calculation, but samples size can be small (e.g., S 1). In the absence of third party verified PAN files it is advisable to base PAN files on independent measurements as simulations based solely on data sheet information may lead to high uncertainties in energy yield simulation.

Product qualification tests are typically destructive or longer-term tests and sample sizes are kept smaller. It is important to perform tests on modules that represent the material combinations (bill of materials) of the module type. The tests shall check the functioning manufacturing processes, the production control and are helpful in determining general workmanship. Some suitable qualification tests are defined in the standard IEC 61215-2, which is the basis for type approval and design qualification of PV modules. The sampling method is typically Special Inspection Level S 1 to S 3 acc. to ISO 2859-1 with consideration of all bills of materials and potentially different production lines to be represented. Induced degradation tests (such as PID and LeTID) are screening tests and are suggested if sufficient proof of resistance to such degradation is not provided. Here sampling rate could be reduced to two modules per bill of materials to minimise testing cost.

Product reliability tests shall evaluate the long-term behaviour with a focus on module performance but also on electrical safety. Several test sequences for investigating a module's resistance to environmental conditions, such as high UV level, strong temperature changes, high temperatures combined with high relative humidity and mechanical stress both from

TABLE 2 TYPES OF QUALITY TESTS FOR PV MODULES

TYPE OF TESTING	SAMPLING RATE ACC. TO ISO 2859-1
Performance characterisation testing	
Maximum power determination at Standard Test Conditions (STC)	G I
Efficiency loss at low irradiance	S 1
Electroluminescence inspection	G I
Qualification testing	
Visual Inspection	S 3
Insulation test under wetting (wet leakage test)	S 3
Degree of ethylene-vinyl acetate (EVA) cross linking	S 1
Adhesion strength EVA/backsheet	S 1
Power loss due to light induced degradation (LID)*	S 1
Power loss due to power induced degradation (PID)**	2 modules per BOM and test
Power loss due to light and elevated temperature induced degradation (LeTID)	2 modules per BOM and test
Reliability testing	
Design suitability (extended stress testing i. e. damp heat, thermal cycling, humidity freeze, UV exposure, mechanical load), relevant for all BOM used	2 modules per BOM and test

Example:
Sampling for a 50 MW PV Plant with 400 Wp modules and two different BOMs.
Total number of modules: 125,000

Performance characterization testing:

- G I level would lead to a sample size of 200 modules.

Qualification testing:

- S 1 level would lead to a sample size of 8 modules; considering 1/2 of the modules are of each of the 2 BOMs, sampling rate S 1 for 62,500 modules comes to the same sampling rate. Hence 8 modules would be chosen per BOM.
- S 3 level would lead to a sample size of 32 modules; considering 1/2 of the modules are of each of the 2 BOMs, sampling rate S 3 for 62,500 modules comes to the same sampling rate. Hence 32 modules would be chosen per BOM.

Induced degradation and reliability testing:

- 2 modules per BOM per test would mean 4 modules per chosen test sequence are to be selected.

Testing can mostly be organized pre-shipment at a test centre close to production. Sampling should always be random or organized by an independent third party. Post-shipment testing can make sense, if pre-shipment was not possible, timelines did not allow it, or transportation damages are to be assessed.

*Can be less considered for n-type technology. **Can be less considered for systems that have anti-PID solutions.

wind forces and snow loads are described in IEC TS 63209 *Photovoltaic modules - Extended-stress testing - Part 1: Modules*. Depending on the application and the project region the stress level may vary. The suggested sample size is two modules per test and bill of materials. In particular polymeric material degradation has caused major reliability concerns in the recent years. Here the technical specification, issued in 2021, provides a combination of damp heat testing, UV testing and thermal stress in its sequence three that is designed to screen for long-term backsheet failures.

7.5.2 Inverters

The inverter is one of the most complex components in a PV power plant and includes multi-functional power electronics for optimising the power output. This element is the interface with the grid and reads and communicates operational data to the monitoring system. A fault with the inverter leads to an immediate decrease in power output, which grows in proportion to the size of the inverter. Owners should not simply rely on data sheets but invest in quality review services, conducted by experienced technical advisors. In a quality assurance process, the key steps of design, manufacturing, installation, and commissioning are independently evaluated, to prevent potential issues that could decrease performance across the inverter's lifecycle.

The key risk mitigation steps are a factory audit, the review of a manufacturer's factory-out inspection and the commissioning, which are presented in sections *7.3. Supply Review* and *7.4. Delivery.*

Aside from the general comments above, key areas for potential issues with inverters include:

- Adaptation to voltage and power design
- Isolation issues
- Blocked air vents, filters etc.
- Derating characteristic of inverters, high temperature shut off
- Rating or spacing not suitable for location (e. g. high altitude)
- Grid code compliance
- Unavailable required national certification
- Inverter metrology
- Interference with radio signals etc. (electromagnetic compliance and adaptability)
- Optimisers
- Local transportation including unloading opportunities
- Local service

Inverters need to be chosen depending on system topology. There is no formal assessment available currently, but a risk assessment when choosing a system topology considering performance, maintainability, impact of failures, likelihood of failure and reparability. As an example, a central inverter may have a higher efficiency, be cheaper to install, but in case of a failure takes down the system and will take weeks to repair, while spare string inverters could be stocked, and any failure could be corrected in a short time. The evaluation of risks will depend on design objectives, but it should be documented for later verification and any future process improvements.

When planning a system, it is critical to match the operating characteristics of the inverter (efficiency, load-related derating, voltage window) to the real operating conditions.

Sufficient diligence needs to be exercised when it comes to:

- Specific requirements for inverters, e.g., compliance with (EU) 2016/631 for Europe
- Performance characterisation testing (INV File generation for energy yield simulations)
- Product qualification testing
- Product reliability testing according to appropriate standards

7.5.3. Mounting structure (fixed tilt)

Racking systems hold valuable modules in place and ensure stability of the installation of the PV system. Mounting components consist of various metal parts with different coatings or materials, such as aluminium, alloy, stainless steel, or galvanised steel. Corrosion can occur due to the constant and long-term exposure of these materials to each other, to soil conditions and to environmental stresses, such as rain and moisture and other atmospheric pollutants like chlorides in marine environments or sulphur dioxide and nitrous oxides in industrial locations. As corrosion intensifies over time, serious structural failures in racking and mounting components can result in instability in the PV system and cause it to malfunction. It lays at hand that quality of mounting systems plays a tremendous role in each step from manufacturing to installation, maintenance, and recycling.

As lifespans of solar PV systems can reach up to 30 years, racking manufacturers must target a similar life span for the racking materials. The following norms and guidelines are of great significance and should be adhered to during the project development and during the construction stage:

- The manufacturing process of mounting systems should be in accordance with Eurocodes 1991 1-1 - 1-6 Actions on Structures. The norm includes guidance on the actions to be performed on structures designed for use in buildings and other civil engineering works
- In addition, to prevent corrosion of the mounting structure, manufacturers should comply with the standards "Specifications and test methods on hot dip galvanised coatings on fabricated iron and steel articles" (EN ISO 1461) and "Continuously hot-dip coated steel flat products for cold forming - Technical delivery conditions" (EN 10346). The two quality standards underline the importance of corrosion free purlins, aluminium mounting brackets and bolts and focus on the chemical composition and mechanical characteristics of the components for racking systems in general. Information on coating thickness (e. g., zinc coated steel, anodised aluminium, etc.) can be determined by measurements in testing labs or on site
- A third standard, the "Execution of steel structures and aluminium structures - Part 1: Requirements for conformity assessment of structural components" (DIN EN 1090-1), assures the quality of steel components, aluminium components, and kits in the manufacturing process
- The material quality should be verified on documentation basis (alloy, etc.). Spot checks of the anti-corrosion coating thickness can be performed in factory or onsite. Further the dimensions and tolerances of the delivered parts shall be verified against the available documentation

7.5.4. Mounting structure (trackers)

Tracker systems offer a significant additional complexity to a PV power plant system as it entails moving parts being added to an otherwise static system. When considering tracking, be it single axis or dual axis tracking, in addition to the previous section, the following points should be considered:

Tracker system selection

- Structural calculation according to applicable standards in the country of the project and international codes like ASCE or Eurocodes. This calculation should consider the specific conditions known or foreseen for the soil conditions. It is highly recommended to check whether the tracker system has undergone wind tunnel testing, and in addition, CFD (computer fluid dynamics) modelling to simulate wind situations. This is particularly important for resonant frequency conditions that can occur at wind angles of attack that can hardly be simulated in a wind tunnel. Note that catastrophic failure at resonant frequencies does not necessarily require high wind speeds
- Certification of the PV tracker against relevant standards like IEC 62817, UL 3703 or UL 2703. Specific confirmation that the components used in the trackers to be supplied are listed in those certificates
- Accelerated lifetime tests beyond those associated with the certifications mentioned above
- Justification in the form of studies, wind tunnel measurements or tracker measurements showing that all the aero-elastic stabilities are properly added to the structural calculation mentioned above. Particularly, the following instabilities should be considered as a minimum: flutter/galloping, torsional divergence, buffeting, vortex-induced vibrations, and aero-elastic deflection. Justification of the values used for the damping ration and natural frequency should be provided.

Tracker system reception and installation

Once on site, the delivered equipment should be verified by collecting a sample of each element of the structure which is then measured and verified against the specifications. Certificates for the steel and galvanisation are provided directly from the manufacturer's sub-suppliers with site measurements of dimensions and thickness.

It is recommended that the installation process should be overseen by a representative of the manufacturer and the following recommendations should be a general checklist for this stage, being part of the project commissioning stage.

1. Torque verification according to manufacturer specifications.
2. Tolerances in installation are within the levels accepted by the manufacturer.
3. Piles driving are tested (pull-out) showing minimum recommendation by the manufacturer.
4. Tracker Control Units (TCUs) and Network Control Units (NCUs) are installed and connected with configuration approved by the manufacturer and Owner's engineer.
5. Meteorological stations are commissioned according to manufacturer recommendations and testing to see whether the stowing strategy is working.

Special care should be taken if material is galvanised. To maintain the corrosion protection, the galvanisation must not be damaged by scratching or any machining.

7.5.5. Cabling (including connectors)

Proper cabling and connections must be ensured. The list of partially serious problems is virtually endless but here are a few examples:

- Cabling specification
  - Cable cross-sections are undersized
  - Cross sections of safety fuses are undersized
  - Cables sheathing is made of inferior material not capable of weathering (e.g., low UV light resistance, low permeability)
  - Cable wire material is inferior (e.g., not compliant with strand construction class 5 or 6 as per IEC 62930:2017 or not compliant with stranding class B or higher as per UL: ZKLA or PV-wire requirements).
- String / combiner boxes
- Non-matching or "compliant" or "compatible" connectors
  - Connections have a too small contact surface or are not suitable for the specific current (and voltage) application
  - Materials used between different manufacturers can be slightly different causing contact corrosion
  - Metal contact size not fitting with the cable conductor cross section
  - Seal gasket not fitting with the PV cable outer diameter
- Fuses (e. g. power rating/wire diameter, housing, temperature derating)
- Earthing, potential bonding

Various standards refer to proper cabling and connection practices, such as IEC 62930:2017 resp. EN 50618 (Electric cables for PV systems), IEC 62790 (junction boxes for PV modules), IEC 62852 for DC connectors and IEC 62738 (Design guidelines). There are also other international and national standards and codes related to cabling and connectors. In addition to the pertinent standards, the IECRE offers a conformity assessment system referring to most relevant standards, like IECRE OD-401 and OD-403.

Qualification requirements may depend on the application. For example, when cables are planned to be laid underground, they must be qualified and tested for this application. Having systems close to the coast or on floating systems, will bring additional requirements like resistance to salt laden atmospheres.

When defining system components, it is also important to check compatibility of components and their interfaces. For example, a connector on a module might mate to a connector on a string cable, but its connection with the "mating" connector of another make may not be approved. Warranties may exclude such cross connection, so caution should be taken.

7.5.6. Transformers

The power transformer testing (Factory Acceptance Test) should be performed once the assembly is completed at the manufacturing facility. The power transformer procurement process should include a design review and quality control of the manufacturing process. Factory Acceptance Tests are done at the factory to make sure that applicable standards are met, to assure high quality products, considering IEC 60076-1, 2, 3, 10, 18.

The table on the following page summarises the tests to be performed for the transformers to be provided.

TABLE 2 TESTS TO BE PERFORMED FOR TRANSFORMERS

	TEST DESCRIPTION	TESTING REQUIREMENT
Routine tests	Measurement of ratio and check of vector group	To be conducted on all transformers supplied
	Measurement of DC winding resistance	
	Measurement of No loss and current	
	Measurement of load loss and impedance	
	Measurement of Insulation resistance of windings to earth and between windings	
	Separate source voltage withstand test on HV and LV windings	
	Pressure test on assembled transformer	
	Paint thickness test	
	Visual Inspection and dimensional checks	
	Functional test on auxiliary circuits	
	Measurement of Insulation Resistance of windings to earth and between windings	
Type tests	Measurement of Acoustic Noise level of the transformer	To be conducted on one transformer of each design
	Impulse voltage withstand tests-Chopped and plain wave impulse tests	
	Temperature rise test	
Special Tests	Induced Voltage test with PD measurement (IVPD) prior to impulse tests	To be conducted on all transformers supplied
	Induced Voltage test with PD measurement (IVPD) after the impulse tests- long duration 1 hour	
	Induced Voltage with PD measurement for 60 minutes	
	Induced Voltage with PD measurement for 5 minutes	
	Measurement of Sweep Frequency Response Analysis	
	Dissolved Gas Analysis of Transformer Oil prior to and post dielectric tests and all tests	
	Chemical Analysis of Transformer Oil	

This chapter describes the main activities, concerns, and requirements to be met during the construction phase of a PV plant. In this phase, the solar power plant is installed based on installation manuals provided by suppliers to assure the proper storage, handling and installation of mounting systems, PV modules, inverters, transformers, cabling, monitoring system/sensors and other balance of system components. It also ensures the quality of the installation as well as the long-term stability of the PV system.

A proper schedule and preparation of several activities around the construction are important and should preferably be organised according to common project management techniques. This includes clear definition of objectives, activities, and responsibilities (who does what?), time plans and milestones (when?), cost planning, and quality assurance. To achieve this, an effective and efficient communication, documentation and reporting flow between the Asset Owner, the EPC service provider and the subcontractors is necessary. This will help encourage accountability, potential construction defects are promptly identified, high standards upheld, and monitoring the EPC service provider's performance is easier.

The overall construction activity can be divided into two phases: firstly, the preparatory phase, related to the preliminary activities and secondly, the construction implementation phase, including site preparation, civil, mechanical, and electrical works necessary to complete the plant and bring it to the production phase.

8.1. Construction preparatory phase

The construction preparatory phase includes those planning and preparatory activities that ensure the smooth realisation of the PV plant. For this purpose, it is important that the construction project is correctly set up according to project management principles: the Asset Owner and the EPC service provider define project organisation and objectives, arrange main parts of the project in a work-breakdown structure (WBS), deduce a time schedule with clearly defined work packages, including responsibilities/accountabilities (responsibility matrix, for example, a RACI matrix), interdependencies, duration and resources. This time schedule shall be the reference for monitoring the project's progress from both a physical and cost control perspective and needs to be regularly updated.

8.1.1. Site survey

The site survey aims at checking that there are no physical and geographical constraints or inconsistencies with the assumptions and technical details defined in the Execution design (see Chapter *6. Engineering*). If there are inconsistencies between the execution design and the site survey, the EPC service provider should consider doing another topographical survey with a drone.

The survey is also necessary for checking the actual status of the site and for planning the preliminary activities necessary to prepare the site for the mobilisation of personnel and equipment and the start of the main construction activities.

While the effective mobilisation of the EPC service provider and their subcontractors usually takes place once contracts enter into force (in general when a notice to proceed is issued by the Asset Owner), the execution of certain early works, sometimes also called preliminary works, is a project strategy that is becoming more frequent.

With reference to construction activities set-up, the key topics to be investigated during the site survey are:

- Mapping of the construction site (allotment and boundaries, topography, etc.).
- Definition of the area for temporary facilities and storage/warehouse.
- Identification and mapping (geolocalisation) of interferences to be considered during construction, for which drones can be used.
- Assessment of critical elements for construction and identification of mitigating actions (technical risks, rests of bombs, hazardous waste, but also archaeological discoveries).
- Detailed survey of transportation facilities and routing and other logistic items.
- Execution of the pull-out test, necessary for the final test of the selected foundation design of the mounting structures.

8.1.2. Stakeholders management

The primary tool for understanding the context in which the project is implemented is to identify and understand the stakeholders involved in, or affected by, the project. This allows one to become aware of their expectations and to determine the effective, potential, or perceived impact that the project can have on them identifying methods for involving them.

The identification of the stakeholders and their needs and expectations requires suitable knowledge of the relationships that exist between the different actors that are present and active in a given context. For this purpose, all subjects that could influence or be influenced by the project must be considered.

It is important that the identification of the stakeholders is not limited to local and administrative authorities but should also consider people and organisations that are relevant for local communities, as they represent their interests and identity.

8.1.3. Construction plan preparation

Construction Planning aims at planning all construction activities properly and guaranteeing that resources are available and scheduled consistently with activities. This avoids any unplanned stops.

After definition of the project scope of work, the project management team structures the project by organising the activities in a hierarchical structure, the **Work Breakdown Structure (WBS).** Only the activities identified with the WBS shall be within the project scope and, therefore, can be planned and controlled. There is only one WBS per project. A well-defined WBS:

- Provides complete definition of the project scope at different levels.
- Allocates tasks and responsibilities.
- Defines a numbering system, which is used as reference in project plans, reports, and technical documentation.
- Provides an input to integrate cost and schedule data.
- Ensures the alignment with the contracting execution strategy.
- Facilitates the roll up of cost, progress, and schedule performance information for reporting purposes.

All parties (the Asset Owner, the EPC service provider and other service providers) involved in the project should comply with the WBS and related coding system. Clear and effective communication between the Asset Owner, the EPC service provider and other service providers (and in general, all third parties involved in the project), and constant monitoring of the construction work progress according to the WBS, are key to ensuring full alignment on scope of work, objectives, deliverables, and timing.

WBS's lowest hierarchical items are the work packages (WP). By defining each WP in detail and considering dependencies, the project plan is created. Each WP should contain at least the following information:

- Name
- Unique number/code
- Version and status information
- Description of content and results to be obtained
- Prerequisites and dependencies (deliverables required etc.)
- Projected duration
- Resource requirements (people, material, tools, vehicles, etc.)
    - Person responsible for the WP

A detailed scheduling of the activities, including milestones, is essential to completing the work in a timely manner. Proper scheduling of the works is mandatory for correctly managing and controlling the progress of the project. If the work plan has not been prepared appropriately, mistakes and delays cannot be identified, and corrections cannot be implemented. Furthermore, the project plan needs to be updated regularly.

Project managers derive subordinate plans and documents from the central project plan. For example, the EPC service provider and other service providers will have planning, scheduling, reporting, and documentation obligations, according to the stipulated contract. With reference to the WBS, contractors should be responsible for the lower-level activities schedules and plans. A typical document for this phase is the mobilisation plan, which includes:

- Construction site organisation chart: the subcontractors (civil and electro-mechanical) need to provide the construction site organisation chart which indicates all the expected positions, the staff residence times and the expected hours.
- List of site vehicles and equipment: subcontractors must provide the list of vehicles and equipment they intend to use for different kinds of work, accompanied by certificates of suitability and maintenance and/or testing sheets.

Work plan and mobilisation plan guarantee in-time arrival and accommodation of construction site personnel and assembly materials. They also ensure that the different elements of the construction phase are properly coordinated.

Based on the defined project schedule (baseline), the associated physical progress curve should be determined, to establish a reference plan for the percentage of physical completion of the project at each date. This is key for proper project monitoring.

To calculate the project's physical progress, one must define specific calculation rules to apply to each elementary activity type, as well as determine the weighting criteria (see details in the chapter *11.1. Project Performance KPIs*).

The construction plan should also define processes and procedures relating to the interface of the construction team with the rest of the project staff, in particular with the engineering, EHS and quality management teams. It should be assured, for example, that all the project changes proposed by the EPC service provider and other service providers are checked and approved by engineering department (change management). Furthermore, the construction activities should be verified in accordance with the quality control plan and HSSE procedures (quality management). Other control activities concern cost/budget, HSSE compliance, documentation, etc.

8.1.4. Check and finalisation of works permits

Country-specific legislation and regulations around HSSE and construction activities are continuously evolving. It is critical to be sure that all works, administrative permits, and authorisations have been obtained to avoid breach of any legal provision. Such a breach could result in severe consequences, both in terms of personal and administrative sanctions and in downtime and delay in the execution of the activities.

A useful tool to ensure full compliance is the prescription and authorisation checklist which should identify all the relevant legislation and regulations applicable to the specific project and location. It also lists all requisites necessary to start the construction activities (authorisations, particular training requirements for certain works, such as works at height, land lease agreements, etc).

8.1.5. Activation of external suppliers (services and materials)

Once all preliminary activities have been assessed and completed, the construction activities are ready to start. All subcontractors and suppliers must be activated according to the specific clauses of the relevant contracts and based on the scheduled activities. The scope of this phase is to ensure that all resources are present at the site in a timely manner to avoid any downtime and delay.

8.2. Construction implementation phase

Construction site activities must be supervised by the EPC service provider's Construction Manager. They should coordinate with the Asset Owner's Construction Manager and the Construction Supervisor on the monitoring and control of subcontractors. Throughout construction, drone construction monitoring flights should be carried out periodically to monitor, record and report on construction progress and quality. The data from these scans can also provide valuable support to H&S, stock management, and adherence to local planning and environmental regulations. For HSSE-related best practices, refer to Chapter *3. Health, Safety, Security, and Environment*.

8.2.1. Construction site organisation

Construction site organisation refers to the preparation of the site for the start of civil, mechanical, and electrical works.

The effective mobilisation of the EPC service provider and related subcontractors usually takes place approximately 60 days from the signature of the contract. However, preliminary site preparation and executive engineering may begin immediately after signing.

In the mobilisation phase, contractors will begin to mobilise direct and indirect labour, equipment and means so that all planned activities can start as scheduled.

Site preparation main activities are:

- Opening of the construction site.
- Archaeological survey may be requested by local authorities depending on the historical interest of the site.
- Removal of vegetation removal and the superficial part of soil where foreseen (this kind of activity should be minimal in accordance with a positive biodiversity strategy).
- Staking and beating of the poles of the structures.
- Visual mitigation works planned.

8.2.2. Civil works

Civil works refers to excavation for the construction of cable ducts, including foundation, MV overhead line supports, preparation of the areas where inverters and DC boxes will be installed, distribution station, road construction, and any earthworks in general.

They must be planned and implemented to minimise the interference and the overlap with the electro-mechanical activities described below, which are often difficult to manage from a safety point of view.

Biodiversity issues (see section *3.2.1. Biodiversity*) need to be considered to minimise the impact of civil works. Where this is not possible, restoration or compensation measures should be taken, but it is always better to reduce destruction during works. Raising the awareness of personnel and clear guidelines can help to achieve this.

8.2.3. Electro-mechanical works

Mechanical activities mainly consist of:

- Withdrawal of materials from the Contractor warehouse.
- Assembly of metal structures.
- Installation of PV equipment / panels.
- Package / cabin assembly.
- Tests and inspections.

Electrical activities mainly consist of:

- Laying ground network (equipotential bonding).
- Laying DC (LV) solar cabling and related components for connecting PV module strings to inverters using tools certified/qualified by the manufacturer for PV cable-connectors assembly. At present DC cabling configurations can vary a lot but nevertheless, laying DC cabling is a key element of the electrical works.
- Laying MV cables from transformer stations to the distribution station.
- Laying LV auxiliary cables.
- Cabin and field connections.
- Tests and inspections.

8.2.4. Ancillary works

Ancillary works are activities that are not directly connected with the assembly of the "electric generation plant". They refer in general to security (fencing, CCTV, lighting, …), vegetation care, internal roads, signposting, and so on and so forth.

These works, even if not prioritised, must not be underestimated because they could delay the handover of the entire plant.

8.2.5. Grid connection

Utility scale PV plants need to be connected to the network, usually managed by the Transmission

System Operator (TSO). Connection complexity depends on the distance between the plant and the substation, its conditions and the technical solution identified for the connections. These works are the final stage of the construction activities and normally require the involvement of the TSO, which should be scheduled well in advance.

8.2.6. Checks and functional tests

Once the plant is completely built and connected to the grid, one must test that it works properly. It is important that tests are carried out according to a detailed procedure agreed between the EPC service provider and the Asset Owner.

To this end, the EPC service provider must send the Asset Owner a detailed plan of execution of all the work necessary to reach Start-up (Start-up Plan), before the start of the Mechanical Completion and Pre-Commissioning activities of the plant.

The plan should include the following minimum requirements:

- Definition of a start-up team.
- Definition of the project functional units and related sub-units.
- Definition of the plant sections that can be put into production in sequence.
- Definition of the schedule and procedures for carrying out the preparatory tests for the start-up for each functional unit and plant section.
- Description of how to perform the Mechanical Completion and Pre-Commissioning tests on the functional units.
- Description of the execution of the Commissioning tests on the functional units and on the entire system.

8.2.7. Mechanical completion

When the plant is completely built and connected to the grid, after a visual inspection, the Asset Owner issues the Mechanical Completion Certificate (MCC). (See also section *9.1. Pre-commissioning*)

The aim of the visual inspection is to verify:

- That all components and materials are present and in accordance with the project documentation.
- The compliance of the completed project with the project documentation, the Technical Specification, and the current legislation.
- The electro-mechanical completion of the plant.
- That all components are free of visible damages that could compromise the safety of the components and personnel.
- That the components have been installed correctly.
- The correct identification and labelling of all components such as inverters, DC boxes, cables, support structure rows, switches, communication devices, monitoring elements, etc.
- The correct execution of the connections (see also section *9.1. Pre-commissioning*)
- An aerial survey to validate the asset against its design layout.

8.2.8. Training of asset owner and O&M provider

As soon as the plant is ready for operation, after MCC has been issued, the EPC service provider should arrange for a specific training for the Asset Owner and the O&M service provider's personnel (that could be a third-party or the O&M division of the EPC service provider). This training can transfer the knowledge and philosophy with which the plant has been designed and constructed.

Training is important as it allow the O&M service provider's staff to familiarise themselves with the plant and its operations. Poor training standards can result in lower performance of the plant, due to delays in detecting system malfunction signals, resulting in longer downtime as faults are resolved. This is also an opportunity for the O&M service provider to give feedback to the construction (and engineering) team, especially if both belong to the same company.

The Asset Owner's personnel should also receive training. This will help avoid misunderstandings between the Owner and O&M service provider and make their collaboration more efficient and effective.

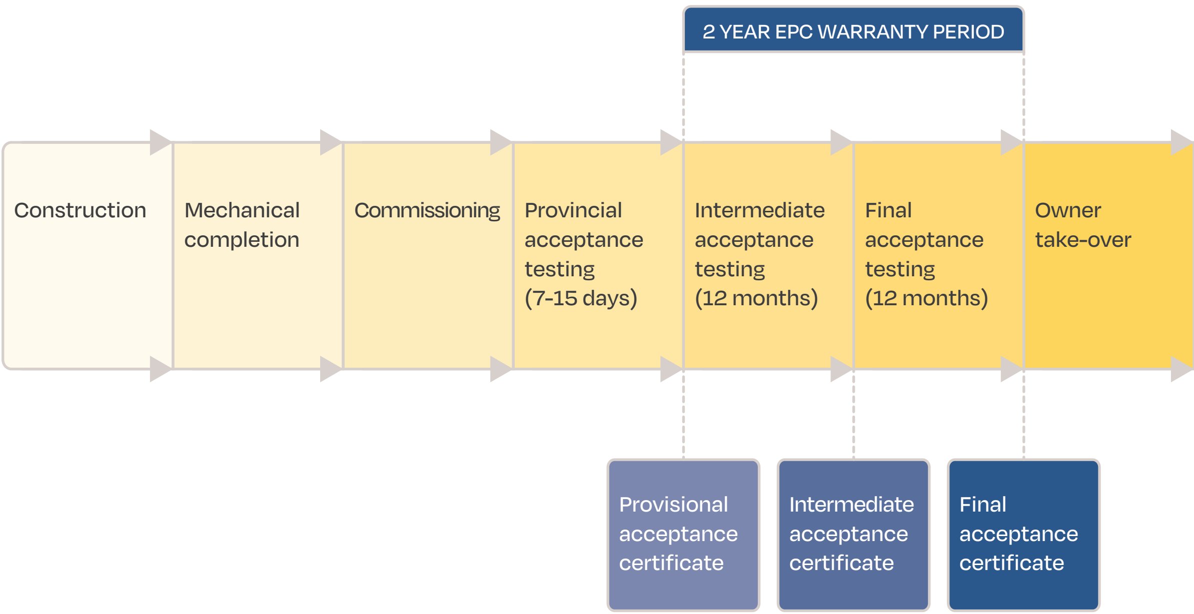
A comprehensive and detailed as-built documentation (*Annex F*), manuals and procedures (*Annex C "Documentation set accompanying the solar PV plant" of the* *O&M Best Practice Guidelines*) should be part of the training activities. For more information on the handover to a specialised O&M service provider, please refer to Chapter *10. Handover to O&M*.

9 System commissioning

System commissioning is one of the most important stages of the EPC service provider's work as it closes the construction period and prepares the PV plant for commercial operation. This crucial step of the project includes performance and reliability tests.

These make sure that the PV plant is built according to the international standards and industry best practices, and that it complies with the requirements as agreed with the Owner, grid specifications and guaranteed performance levels. Tests are undertaken for all individual components from checking that components function to more detailed measurements and verifications of the overall system. Successful commissioning and timely achievement of the Commercial Operation Date (COD) is linked to the release of a milestone payment as defined in the contract as well as the release of the performance bond. It is, therefore, very important that the contract clearly describes the requirements, criteria, documentation, and reporting required to complete the EPC service provider's scope of work and handover to the Asset Owner and the O&M service provider's team.

FIGURE 4: SYSTEM COMMISSIONING MILESTONES



SOURCE: World Bank Group.

9.1. Pre-commissioning

Mechanical completion happens the final construction stage (see section *8.2.7. Mechanical completion*) meaning that all principal components that are part of the PV plant have been erected or installed. At this point, the EPC service provider will usually conduct a detailed inspection of the works, possibly accompanied by the Owner or any third-party representative (such as a technical advisor). This option should be clearly stated in the EPC contract clause referring to commissioning (if the Owner intends to apply it). Activities carried out under pre-commissioning should be detailed and agreed in advance with the Asset Owner in a specific document.

The pre-commissioning activities fall within the construction phase and are mostly undertaken in parallel to the last steps of electro-mechanical works. In large scale projects, the first blocs are ready under pre-commissioning while other parts are still being erected.

The pre-commissioning phase includes the following main activities:

- Systematic compliance checks performed on each component of each system, performed in a non-energised state.

Testing of appliances, energisation of cables, testing of instrumental circuits, testing of circuit breakers, etc During the pre-commissioning phase, the following tests should be performed, as a minimum requirement:

- Mechanical integrity of the modules with visual inspection and the correct wiring. Thermographic analysis (via drones) can be added at this stage as a best practice.
- Verification of the nominal power of the installed system carried out as the sum of the nominal power at STC of all the installed modules.
- Verification of the correct operation of all auxiliary services (fire system, rodent protection, forced ventilation of transformers, temperature sensors, UPS systems and related storage systems, lighting systems, etc.).
- Control of all input signals to the SCADA system.
- Verification of all power supplies of the auxiliary services of the cabins.
- Commissioning of UPS systems and related storage systems, SCADA system and of weather stations and environmental sensors.
- Verification of IP addresses on all equipment.
- Setting of all alarm thresholds on the equipment.
- Verification of the correct polarity and electrical continuity of all the strings.
- Check all electrical connections.
- Completion and functional verification of the earthing system.

After execution of pre-commissioning activities, the plant will be ready for energisation and for the commissioning activities.

Usually, a detailed checklist covering all components and parts is used to make sure that nothing is missing or incomplete. The works are thoroughly checked through the following items:

1. Inverters
2. Modules
3. Foundations
4. PV Module Mounting Structures
5. LV and MV Cabling
6. Transformers
7. Protection, distribution centres and switch gear at the substation
8. Combiner boxes
9. Civil works
10. Low and medium voltage installation works
11. Monitoring and security systems

Finally, the checklist should be provided to the Owner and their advisors, together with the compilation of an initial list of construction defects (commonly referred to as a "punch list" or "snagging list"). Counterchecking the EPC service provider checklist and providing own observations and items to add, as defined by the Owner or their advisors, is recommended. This punch list should include only minor finishing works, the cost of which usually equates to a small percentage of the overall contract value. The contract also needs to specify the timeframe for correcting punch list items, and what the conditions are for granting Provisional Acceptance if punch list items remain unfinished.

Once the punch list has been issued by the Owner's representative a meeting is required between them and the EPC service provider to agree specific resolution for each item and determining if any items are disputed.

Mechanical completion, as described in section 8.2.7., allows for further testing activities to commence. In large scale projects, this is often undertaken by batch and delayed over time, as different parts of the plant are in different stages of construction.

9.2. Commissioning, off-grid and on-grid tests

9.2.1. Commissioning activities

Commissioning activities include operational checks and tests executed on energised electrical systems. The Test Protocol must be agreed between the parties before the start of the tests as part of a Start Up Plan, defined before the start of the Mechanical Completion and Pre-Commissioning activities.

The Test Protocol must respect all the requirements contained in the contract and its basic content should include:

- Results of the visual inspection and related checklist
- Test methodologies
- Instrumentation used for testing
- Test program
- Test conditions
- Test data
- Results of the Pre-Commissioning and Commissioning tests
- The start-up protocols issued for the key components (inverters, transformers, etc.)

This testing aims to verify and certify that the plant has been constructed professionally, according to the pre-established technical prescriptions, and in accordance with the project and any approved variants.

Before the plant is energised, a series of functional tests and measurements should be undertaken as per the reference norm IEC 62446: *Grid connected photovoltaic systems. Minimum requirements for system documentation, commissioning tests and inspection for all electrical commissioning.*

The testing procedure should be handed over to the Owner prior to commencing the tests, as is usually defined in the EPC contract. This allows the Owner or advisors to review and comment on the testing procedure before implementation. At the end of the commissioning phase, the EPC service provider submits a Test Protocol to the Asset Owner, summarising the results of the Pre-Commissioning and Commissioning tests.

The following test regime shall be performed on all systems. Any test indicating a fault should lead to default rectification and re-testing of the components.

On the AC side, all AC circuits, including AC cables from inverters to transformers, transformers themselves, and main MV switchgear should be tested according to the requirements of IEC 60364-6.

On the DC side, the following tests shall be carried out on the DC circuits and components forming the PV array:

- Continuity of earthing and/or equipotential bonding conductors, where fitted
- Polarity test
- Combiner box test
- String open circuit voltage test
- String circuit current test (short circuit or operational)
- Functional tests
- Insulation resistance of the DC circuits

Some expanded test, not mandatory but often included in the EPC service provider contractor scope, can also be carried out to ensure the best system performance and reliability:

- String I-V curve measurements on a selected sample (10% of the plant at 500W/m^2)

It is a best practice to take a pragmatic approach to tests which require minimum levels of irradiance. String tests and thermography should be carried out above certain irradiance minimums. Conducting them at lower levels will provide reduced value from the results. If necessary, some tests may need to be deferred until high season to be valid.

In addition to the above electrical tests, all other equipment should be tested according to the manufacturer's guidelines and industry best practices to ensure that it functions properly before the energisation of the PV plant. All other equipment and materials include:

- Meteorological stations and monitoring system
- Low voltage installation, civil works, and medium voltage installation
- Security system as well as cyber-security system
- Sanitary system
- Firefighting system

9.2.2. Off-grid testing

The first tests to be conducted are the polarity and combiner tests which need to be undertaken while all strings are still disconnected.

The off-grid tests should include measuring 100% of the open circuit voltage (V_{OC}) and the short circuit current (I_{SC}) of the module strings according to IEC 62446. Prior to starting testing, the Owner must confirm the adequacy of the measurement devices to be used by the EPC service provider (measurement uncertainty, calibration, etc.). A report with measurement results from all the strings will be presented by the EPC service provider in digital form, as an Excel file.

The V_{OC} test is passed if all the $V_{OC,\ string}$ on the tested strings is within 5% of the expected value derived from the module datasheet. Note that most of the time, the theoretical value should be adjusted with the actual temperature recorded at the time of the measurements as it may be far from STC (25°C).

A commonly used formula is:

Open circuit voltage test formula:

$$0.95 \times V_{th} \leq V_{OC,\ string} \leq 1.05 \times V_{th}$$

Where V_{th} is the theoretical open circuit voltage for the strings and calculated as follows:

V_{th} is calculated as:

$$V_{th} = n \times V_{OC} \times [1 + (T_{MOD} - T_{STC}) \times \mu V_{OC}]$$

Where:

- n = is the number of the modules of the tested string.
- V_{OC} = is the open circuit voltage of the module as of the module manufacturer data sheet [V].
- T_{MOD} = is the temperature recorded on a module representing the tested string [°C], measured with a precision better than 1%.
- T_{STC} = is the temperature under standard test conditions and equal to 25°C.
- μV_{OC} = is the value of the power temperature coefficient as of the module manufacturer data sheet [%/°C]. Negative value.

The I_{sc} test is passed if all the $I_{sc,string}$ on the tested strings satisfy the following condition:

The I_{sc} test is passed if :

$$I_{SC,string} \geq 0.9 \times I_{th}$$

$$I_{th} = I_{SC} \times \frac{G_i}{G_{STC}}$$

Where:

- I_{SC} = is the short circuit current of the module as on module manufacturer data sheet.
- G_i = is the instantaneous irradiation on the plane of array of the tested module string [W/m²], measured with pyranometers with max 2% measurement uncertainty.
- G_{STC} = is the irradiation under standard test conditions and is equal to 1,000 W/m².

It should be noted that the short circuit current test is not intended to detect system underperformance but only used for fault detection in string cabling.

Once the commissioning phase of all the plant sections has been completed and the protocol test issued, the Ready For Start Up (RFSU) certificate of the plant is released by the Asset Owner and then the On-Grid performance and functional tests can be started.

9.2.3. On-grid testing

Once the above off-grid tests have been successfully performed, the PV plant can be energised at inverter level and main switchgear level at the point of interconnection with the grid. The EPC service provider shall demonstrate that the overall system and equipment operates in accordance with the:

- Equipment manufacturer specifications especially for inverters, transformers and MV equipment
- Grid Connection Agreement which should be annexed to the EPC contract, or at least its technical annexes regarding testing and commissioning specifications
- Specifications set out in the EPC Contract
- Any relevant Applicable Standard, mainly IEC 61727 and local grid code

Inverters and transformers shall be commissioned by their manufacturer or an authorised representative of the manufacturer, using the manufacturer's specified procedures. Commissioning reports shall be issued in a format provided by the manufacturer.

All SCADA system equipment shall be commissioned and tested using the manufacturer's specified procedures. Tests shall verify the correct operation of the SCADA system, meters, sensors, weather station instruments, and all inverters, while verifying the correct data input logging from trackers (if any), breakers, and other components monitored by the system. The SCADA system shall be fully remotely accessible. A SCADA system commissioning protocol or report shall be provided.

Before energisation, the EPC service provider shall verify the completeness of the substation and the correct installation of all components. A detailed inspection of the substation shall be executed. The testing and commissioning of the PV plant substation connection to the grid system should be performed, including but not limited to:

- MV equipment
- Control and Monitoring System
- Protection system
- Telecommunication system
- Metering devices
- Auxiliary supply equipment and back-up (UPS, diesel, etc.)

In some countries, compliance with the grid code and local safety standards need to be validated by an independent body, and a certificate provided to the grid operator to allow power injection. These compliance tests may also be carried out by the grid operator themselves.

9.3. Provisional acceptance certificate

Prior to achieving Provisional Acceptance, it is common practice to carry out module thermography, using aerial inspections as best practice. 100% module thermography should be carried out at this stage according to IEC 62446-3:2017. Issues identified from this inspection will need to be resolved to pass PAC. These inspections and the reports generated should form part of the handover documentation.

The Provisional Acceptance stage marks the end of the construction works and obligations of the EPC service provider. It means the Asset Owner is giving their conditional acceptance of the works. This triggers the two-year standard warranty period, across which the EPC service provider must prove a minimum level of performance from the PV plant, as defined in the contract. At this stage, the plant is also handed over to the Owner and the O&M service provider which may be the same company as the EPC service provider or a third-party.

The conditions for issuing the PAC may differ from contract to contract but the key elements are as follows:

- All commission tests have been successfully completed, including Mechanical Completion, grid connection and energisation of the plant.
- The noncritical punch list items have been identified and signature have been provided for corrections. The value of this remaining work does not exceed a certain proportion of the contract price (typically 2-5%).
- The Provisional Acceptance performance tests have been passed (PR but also functional and capacity tests in some cases).
- All equipment and sub-contractor warranties are transferred to the Owner.

- The EPC service provider has provided the Owner with the initial or minimum stock of spare parts, as defined in the contract (see also section *10.6. Setup of strategic spare parts warehouse*).
- All as-built documentation has been provided to the Owner (see also section *6.4. As-built design*).
- Training of the O&M service provider's teams has been performed and relevant O&M manuals issued.
- Liquidated damages (LDs) related to performance or delays have been paid by the EPC service provider.
- Any performance security or warranty bond required during the EPC warranty period has been delivered to the Owner.

The PAC is signed off by the Asset Owner and, if stipulated in the contract, can also be validated and signed by an independent advisor.

9.3.1. Performance ratio test

After the functional test, the PV system's performance, in terms of energy and power, is evaluated in the Start-Up phase. To validate the PV plant performance at Provisional Acceptance phase, the PR test is conducted over a limited period and compared to the guaranteed PR, set based on simulations. The usual duration of PR tests is 7 to 15 days, depending on the contract. From an Owner's perspective, having the longest testing period possible is recommended, as this helps to check performance in a wide range of climatic conditions, and facilitates comparisons with simulated values.

Usually, the testing period needs to fulfil minimum requirements regarding weather conditions and plant availability such as:

- Minimum irradiance threshold in daily values on a certain number of days (e.g., 8 days over a 15-day period with irradiance greater than 5kWh/m²/day) which should be adapted depending on the season of the test and specific conditions of the project location.
- Minimum irradiance threshold on a single day for consecutive hours (e.g., irradiance over 500W/m² during at least 3 consecutive hours in 8 days over a 15-day testing period), also to be adapted to the season and project location.
- Total number of testing hours with irradiance above a certain threshold (e.g., 500W/m² for at least 20 hours in a 15-day period).
- Availability should be 100% during the testing period at least at inverter level. Grid availability should also be 100%. The SCADA and the environmental monitoring system must also guarantee 100% availability of data throughout the test period.

If the above conditions are not fulfilled within the testing period, it is generally extended until they are. Conditions should be set pragmatically and potentially adjusted to avoid delaying the PAC and leading to difficult negotiations and distrust between parties. The time of year should be considered so that unrealistic thresholds are avoided. The performance tests should ideally be performed during spring as this is usually when performance is at its peak due to better weather conditions. Poor weather conditions can penalise performance compared to simulated values (high summer temperatures, winter shadows or low irradiance).

If the continuity of the test is interrupted due to faults or events related to the malfunction of the plant or one of its parts, the test will be suspended and repeated from the beginning.

If the causes of the interruption are not attributable to the EPC service provider, the test will be suspended and will resume at the end of the interruption.

The PR calculations are based on the mathematical definition formula, but each parameter can differ and have its own specifications from contract to contract. It is important to check the consistency of the formula and the input values definitions and measurement rules.

Performance Ratio is defined as:

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

Where:
PR = Performance Ratio over a year (%)
Y_f = Specific Yield over a year expressed in (kWh/kW$_P$) or peak sun hours (h)
Y_r = Reference Yield over a year expressed in (kWh/kW$_P$) or peak sun hours (h)

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

For projects located in regions with high temperatures and temperature variability, a temperature-corrected PR methodology needs to be implemented to account for the weather effects.

Temperature-corrected PR can be defined as follows:

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

Where:
$PR_{TO}(i)$ = Temperature-corrected Performance Ratio for the period *i* (%)
$Y_f(i)$ = Plant Specific Yield for the period *i*, expressed in (kWh/kW$_p$) or peak sun hours (h)
$Y_r(i)$ = Reference Yield for the period *i*, expressed in (kWh/kW$_p$) or peak sun hours (h)
β = Temperature coefficient of the installed modules (%/°C)
P_0 = Plant Peak DC power (nominal power) (kW$_p$)
$T_{MOD}(i)$ = Average module temperature for the period *i*, weighted according to Specific Yield $Y_f(j)$ (°C) - *see formula below.*

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

$T_{MOD}(i)$ = See above
$Y_f(j)$ = Plant Specific Yield for the period *j*, expressed in (kWh/kW$_p$) or peak sun hours (h)
$T_{MOD}(j)$ = Module temperature for the period *j* (°C)

Finally, the measured PR is compared to the guaranteed value based on the pre-construction yield assessment simulations. A buffer between the simulated value and the guaranteed one is generally used by the EPC service provider. It is important to ensure that the design reference yield has been updated to reflect any changes made during the project. More specifically, the internal and self-shading factor should be checked for accuracy. The guaranteed PR at Provisional Acceptance should be presented as a monthly breakdown of the yearly simulation to ensure accurate comparison with the measured PR for the testing period. Given the short duration of the test, guaranteed PR at Provisional Acceptance is only used as a validation criterion for the Owner's "take over". It does not usually trigger performance liquidated damages as they are linked to the results of annual PR tests. If PR is below the guaranteed threshold, corrective action might be undertaken, and testing should be repeated.

Once the PR criteria and any other requirements have been met, the PAC is issued. The project reaches the handover phase, which is the start of the operational phase and O&M activities.

9.3.2. Other tests

In some contracts, complementary tests can be performed at the Provisional Acceptance stage. These tests can reflect the requirements of the energy off taker with the Power Purchase Agreement (PPA), whether or not the system functions, or simply be used as additional quality assurance measures.

To prove the project's ability to perform to its maximum capacity, a Reliability Test can be undertaken. This means the project must go a certain period (e.g., 7 consecutive days, or 100 consecutive hours) without significant system failure or malfunction. Furthermore, the project must prove that it can run for a certain amount of time without inverter failures or shutdowns, with full availability of AC and DC equipment, and less than a certain threshold (typically 2%) of string or tracking system failure (if any). If a system failure or malfunction occurs, corrective action shall be taken by the EPC service provider and the Reliability Test is restarted the following day.

Additionally, a Capacity Test may be required to prove that the installed capacity can reach the level promised to the off taker. This is usually based on the DC capacity of the plant, calculated based on the peak powers of the installed PV modules, as stated on the manufacturer's data sheets. Alternatively, this is calculated from the sum of the peak powers of the Flash Test of the PV modules, provided by the manufacturer at shipment. These values must be signed off by an independent third-party.

9.3.3. Start of plant commercial operation

Once all performance tests described in the above sections have been completed, the Asset Owner issues the PAC and commercial production starts (Commercial Operation Date).

To ensure a smooth and efficient handover to operation activities, the Asset Owner should be involved well in advance and participate in the commissioning phase and performance tests. It is also a best practice to involve the operations function of the Asset Owner during the development and engineering phase, so that an O&M perspective can also be taken into consideration.

Comprehensive and detailed as-built documentations (*Annex F*), manuals and procedures (*Annex C "Documentation set accompanying the solar PV plant"* of the *O&M Best Practice Guidelines*) should be part of the training activities. For more information on the Handover to a specialised O&M service provider, please refer to Chapter *10. Handover to O&M*.

9.4. Intermediate and Final Acceptance Certificate

There is a standard duration of 24 months (depending on the EPC contract) between the start of the Taking-Over phase to the Defects Notification Period. The EPC service provider is usually responsible for O&M and rectifying any defects that may be identified during this period. However, this may vary from market to market. During this period, a performance warranty based on a guaranteed PR is still in place and can be reviewed on a yearly basis. Annual PR tests are crucial for checking the PV plant performance, as they do not include seasonal bias. For smaller scale projects, this Defects Notification Period can be reduced to 12 months. It is always recommended to carry out PR verifications for at least one full year.

The calculation methodology is different to Provisional Acceptance and should be based on long-term PR tests. The guaranteed performance ratio should be adjusted to account for module degradation over the first and second years of operations. Should the measured PR be above the expected threshold of guaranteed value, then Intermediate and Final Acceptance certificates are issued accordingly. The Owner can then issue a performance certificate and release the performance warranty bond of the EPC service provider. This performance certificate constitutes the full acceptance of the PV plant by the Owner and the release of the Contractor's obligations.

The guaranteed PR (and therefore the guaranteed energy) takes into account any event causing non-production due to periods of plant downtime. Owner and EPC service provider may agree, and provide for this in the EPC contract, not considering certain special events. In general, it is reasonable to exclude certain events that are outside the control of the EPC service provider (e.g., vandalism, plant stop imposed by the Transmission System Operator) and Force Majeure events.

The EPC contract shall include provisions on how to deal with cases where actual performance is lower than guaranteed performance. These provisions in general are included in the penalty clause.

Where actual performance is lower than guaranteed performance, EPC service provider shall:

- Make all interventions necessary to ensure that guaranteed process parameters are achieved
- Liquidate both the production lost (difference between actual and theoretical production during the period from PAC to the Final Acceptance Test) and the estimate of the lost production expected for the remaining useful life of the plant

If the measured PR is below the guaranteed levels, the EPC service provider is required to pay performance Liquidates Damages (LDs) up to a certain amount (see chapter *12.5 Limitation of liability and Liquidated Damages)* to the Owner for the compensation of revenue losses. During the Intermediate Acceptance phase, the LDs are based on the annual production shortfall and the electricity selling price of the PV plant. During the Final Acceptance phase, the LDs are also calibrated to reflect the loss of revenues that are expected for the full project lifetime or duration of the Power Purchase Agreement. This is usually calculated as the Net Present Value of future revenues shortfall linked to the PR shortfall. Below is an example formula for additional LDs at Final Acceptance:

NPV of future revenue (formula for LDs at FAC):

$$R_f = NPV\left(\frac{H_{POA} \times P_{STC} \times (PR_{jguaranteed} - PR_j)}{G_{STC}}\right)$$

Where:

- R_f = the Net Present Value of future revenue generated by the electricity expected to be produced by the plant during the 18-year period after successful completion of the Final Acceptance Tests.
- j = the year index, starting from 1 and increasing by one until 18 (if 20 years lifetime).
- H_{POA} = the annual expected irradiance on the modules plane, as estimated in pre-construction energy yield assessment (P50) and validated by an independent third-party.
- P_{STC} = the peak nominal rated power of the installed modules in standard measuring conditions as per the datasheet in kW_p.
- PR_j = the effective PR during the period between successful completion of the Intermediate Acceptance Tests and the Final Acceptance Tests and adjusted for each j-th year following Final Acceptance to allow for module degradation.
- $PR_{jguaranteed}$ = the guaranteed PR for each j-th year following Final Acceptance adjusted to allow for module degradation.
- G_{STC} = the global radiation impinging on STC (1 kW/m²).

Other requirements at Final Acceptance stage should include an inspection of the whole plant, including the civil works, electrical infrastructure, every piece of equipment and device installed, and the auxiliary systems, to verify that the EPC service provider is leaving the plant in optimum condition. This should ideally be done in the presence of the Owner and an independent third-party (technical advisor). All existing defects must be solved as a condition for acquiring the Final Acceptance Certificate (FAC). Spare parts can also be replenished in accordance with the O&M contract requirements to ensure a smooth transition between both service providers.

Additionally, further testing such as repeated module thermography, across all modules, should be performed as a best practice, preferably using aerial inspections during the period between PAC and FAC. This is to ensure that any issues identified can be resolved before the date for Final Acceptance. It will enable the identification of any early-stage degenerative issues. These activities can be included within the EPC service provider's scope or under the responsibility of the Owner at their own costs.

After the Final Acceptance Test the Owner shall issue the FAC and shall take over the full responsibility of the plant.

10 Handover to O&M

This chapter describes the procedures for properly transferring the O&M activities of a PV plant from the EPC to the O&M service provider.

After the FAC, when the Asset Owner takes over the full contractual responsibility for the plant operation, it is industry practice to hand over the long-term O&M activities to specialised third-party O&M service providers. These specialised service providers are organised to provide best in class O&M activities. Their technical departments are designed to provide high level remote monitoring of failures and performances, timely on-site maintenance activities, project management services, and strategic spare parts management etc. (For more information and best practices, please refer to SolarPower Europe's O&M Best Practice Guidelines.)

The handover process between the EPC service provider's O&M phase and the specialised O&M service provider is critical and must be properly managed by the Owner. This avoids loss of information, prevents possible underperformance, and avoids hidden costs. The handover includes several steps, which are mainly attributed to three macro-categories of activities:

1. Providing documentation such as drawings, specifications, projects, diagrams, policies, standards, procedures, parts lists, and reports of construction monitoring, commissioning tests etc. in appropriate file formats, necessary for the functional, safe, and efficient operation of the system (see also *Annex C "Documentation set accompanying the solar PV plant"* of the O&M Best Practice Guidelines).
2. Granting access to the plant site, to familiarise the O&M service provider with the facilities and the equipment and components installed. One should allow the O&M service provider sufficient time on site to explore the facilities and perform all the required measurements, to avoid hidden issues afterwards.
3. Starting the O&M activities including the set-up of a proper organisational structure, including control room service, project managers, site technicians, subcontractors, etc. The O&M service provider must also handle the related logistics such as warehouses, provision of spare parts, and relations with third parties such as the security service provider, and grid operator, as described in the O&M Best Practice Guidelines.

When the O&M contract includes guarantees, such as availability or PR, it is essential to have enough historical performance data to get a proper understanding of component status at take-over, and avoid the risk of paying liquidated damages. The availability of centralised, cloud-based data collection and analysis systems are an emerging best practice which allows data (both historical and real-time) to be consistently captured, shared, and used by all stakeholders.

In the following sections, best practices for handovers are described.

10.1. Transfer of the documentation

A proper and complete set of documentation is crucial to ensuring proper management of the lifecycle of a

PV plant. The O&M service provider will use it for O&M while the Asset Owner may need it for administrative or commercial purposes. Therefore, at this stage it is best practice to involve the Asset Owner, or a representative, to make sure all parties have full copies of the documentation.

1. A list of all required documents can be found in *Annex F* and *Annex C "Documentation set accompanying the solar PV plant"* of the *O&M Best Practice Guidelines*. It is important to underline the file format that must be used. All the technical drawings should be received both as a PDF with stamp and signature and as an editable format (.dwg). Having an editable format of the drawing has two main benefits: (1) it makes it simple for the O&M service provider to update the as-built documentation following any major interventions or revamping, (2) it limits the extra cost for the Asset Owner of redoing of the documentation. Unfortunately, often much of the plant engineering information is provided in formats such as PDF, JPEG, TIF instead of AutoCad. While these formats are useful for human readers, they are of limited value to modern O&M systems as they require conversions or manual data entry to convert unstructured documents. Data integrity problems often follow, which can result in operating mistakes.
2. In addition to the documentation package described above it is important to give full visibility to the O&M work done during the warranty period. Therefore, the following list of information should also be handed over:
   - Maintenance reports done by the EPC service provider
   - Hourly production data of each inverter and meter
   - Hourly irradiation values measured on site
   - Description of any force majeure event that occurred, such as thefts, grid failures or outages, equipment replaced under warranty
   - Output of any measurement test conducted

10.2. Transfer of existing contracts

Contracts require special handling during handovers. They may have been executed with subcontractors such as local field electricians, companies who take care of the vegetation, specialised support companies, internet service providers etc. Further examples include service contracts with manufacturers of inverters or security systems.

The transfer of contracts is critical because the obligations and responsibilities therein are also transferred. Furthermore, the new service provider cannot choose counterparts and renegotiate conditions easily. Therefore, the transfer of contracts needs some time; three months is a reasonable period. In some cases, a contract needs to be terminated and a new service provider needs to be found.

It is best practice for contracts to include a clause about this kind of transfer from the beginning. This helps avoid degradation of contract conditions as a result of the handover. A common inspection with the new contract parties should allow for better understanding of the current situation and help define priorities for the coming period.

10.3. Access to monitoring and communication systems

Adequate time for the transfer of Monitoring and communication systems should be factored into any handover. Common problems include passwords not being given to the new O&M service provider and proprietary code in the Programmable Logic Controllers (PLC). Another problem may be the use of the EPC service provider's communication infrastructure for certain functionalities. For example, the use of the EPC service provider's VPN to give secure access to network devices.

The most problematic point is probably the existence of proprietary PLC codes. Even if the EPC service provider agrees to give access to this code (which is normally not the case), it will be difficult for the new O&M service provider to understand and develop it further. This requires thorough documentation of the existing code, and the EPC service provider would have to agree to hand this over to the new O&M service provider. If this is not the case, the only solution is to replace the existing PLCs with those of the new O&M service provider.

As an alternative, one could use a monitoring service supplier from the beginning. In this case the transfer of the Monitoring System can be handled like the transfer of a service contract. Or, if the contract is with the SPV, the transfer would involve the provision of user ID and password to the O&M service provider. On the other hand, this alternative has inherent disadvantages like a different cost structure, and less flexibility.

Using open solutions with open interfaces, freely accessible documentation and specialised support companies is best practice. However, this still needs to be developed on a large scale.

Due to the complexity of the handover or migration of the Monitoring and communication systems, a sufficiently long transition period should be planned, for example 6 months. During this period, the EPC service provider should be obliged to cooperate with the new O&M service provider. The conditions of this cooperation should be described in the EPC contract.

10.4. Organisation of an inspection

On-site technical inspections are an essential step of the handover process because they allow the O&M service provider to document and assess the PV plant's status. These procedures go beyond the as-built consistency checks, which are based on the set of documents accompanying the PV plant (see the complete list of documents in Annex F). These inspections are also useful for familiarising the O&M service provider with a site's geographical features, logistics, and surroundings.

From a technical perspective, handover inspections (in compliance with the inspection criteria defined in the IEC 62446-1:2016), despite their similarity to the inspections done during (re)commissioning, have a slightly different approach and focuses on the aspects below.

To ensure an accurate and complete inspection on-site, the EPC service provider and the Asset Owner should allow the O&M service provider sufficient time to perform all the detailed checks that are requested. This means that the handover inspection may last several days, depending upon the size and characteristics of the plant. As best practice, O&M and EPC service providers should plan the inspection well in advance, agreeing upon a written schedule for the activities to be performed on-site, with an indication of the role that the personnel of each party will have during the visit.

The inspection should at least cover the following aspects:

- Health & Safety check: Checks should be aimed at ensuring the safety of field personnel while maintaining the uninterrupted operation of the plant. This must be considered a minimum requirement and must be performed following the regulations of the jurisdiction where the plant is located.
- Consistency of plant construction with as-built project documentation: As a minimum requirement, the inspection team of the O&M service provider shall check the entire site. The team should review all the main installed components and materials to verify the correctness of the as-built project documents. In the case of a discrepancy, the EPC service provider should update the as-built project documentation. If drones were used to undertake construction monitoring and reporting (as per best practice), the documentation generated through this serves as a useful asset to refer to.
- Identifying potential issues with contractual guarantees: One of the main purposes of the O&M service provider inspection is to ensure that the performance guarantees included in the service contract can be achieved properly. As specified in Chapter *10. Key Performance Indicators* and Chapter 11 of the *O&M Best Practice Guidelines* on the *Contractual framework*, this may include Availability and Response Time and, in some cases, PR guarantees.

  SolarPower Europe's *O&M Best Practice Guidelines* highlight the potential shortcomings of including a PR guarantee in the O&M service contract and suggest possible alternatives, such as Availability and Response Time guarantees. However, the decision on what types of guarantees to include ultimately needs to be negotiated between the Asset Owner and the O&M service provider prior to the handover. If a PR guarantee is included, as a best practice, the O&M service provider should be invited to attend the Final Acceptance tests, so they can get an accurate idea of the plant's actual PR. Alternatively, if the O&M service provider is unable to attend the Final Acceptance tests, the PR should be recalculated during the handover as precisely as possible. Proper calculation of PR is especially relevant because the O&M service provider will carry on the risks of a project.[2]

- Subcontracted services: It is common practice for large O&M service providers to make use of local specialised companies to carry out activities such as vegetation control, module cleaning, HV substation maintenance and security and surveillance. As mentioned previously, these companies could be the same as those already in charge of such activities during the EPC phase. As best practice they should be involved in the handover inspections to advise the main O&M service provider on their specific area of responsibility.
- Collect verbal information from current operator: Although not a formal activity, the site visit should be used to confirm information included in the O&M reports that are provided as described in section *10.1. Transfer of the documentation*. This should be done by asking the hosting personnel of the EPC service provider about details of extraordinary events and major repair/substitution interventions that occurred in the past, security related aspects (e.g., theft), force majeure events (e.g., flooding and drainage issues) and component related issues (e.g., serial defects on modules). Best practice assumes full transparency between the EPC service provider and the new O&M service provider.
- Visit and access to the warehouse used by the EPC: To set up the spare part management strategy as described in section *10.6. Set up of strategic spare parts warehouse*, a visit to the warehouse used by the EPC service provider should be part of the inspection. Moreover, the inventory of material and components will be made available to the O&M service provider for its activity.
- Additional inspections: The handover by the EPC service provider generally does not require extremely detailed component inspection if they are new and the manufacturer guarantee is still valid. However, PV modules are the core producing units of a PV plant and could have hidden problems that do not show up immediately. As minimum requirement, visual inspections of all the modules (the inspection procedures in IEC 61215-1:2016 may be useful reference) are recommended. Aerial infrared thermography (in compliance with IEC TS 62446-3:2017) should be used for this as best practice. For the O&M service provider and Asset Owner, having a comprehensive aerial visual and thermographic inspection report serves as a valuable baseline against which future performance of the PV plant can be benchmarked. In addition, further inspection techniques such as[3] should be done on a representative sample of modules.
- Retrofitting and revamping/repowering opportunities: Given that these Guidelines consider the handover of the O&M activities after FAC, it is unlikely that the plant requires retrofitting or revamping/repowering. However, it is recommended that site evaluations should be done with a prospective view on how to extend an asset's lifetime and increase its productivity. This can be translated into mid- to long-term plans for retrofitting and revamping interventions.

10.5. Preliminary handover report and punch list

The handover on-site inspection produces a detailed report that includes a Punch List. This document is a technical report that describes all the existing issues and inconsistencies that were discovered and defines a simple pass criterion for each plant component. This report is of great importance to the handover process because it might trigger important conversations with the Asset Manager or the Asset Owner to tailor or amend the O&M contract (e.g., price negotiation). A standard handover report should contain the following information seen in Box 1 on the following page.

2 As recommended by *O&M Best Practice Guidelines*, section 10.3.4., the PR formula should be corrected for temperature to neutralise short-term fluctuation due to temperature variations from STC (25°C). As a best practice, temperature should be registered with a granularity of up to 15 minutes and the average temperature should be calculated by weighting the mean temperatures according to the specific yield of the period.

3 For an overview of relevant international standards, see *Annex a*.

BOX 1
Handover report template

HANDOVER REPORT

A. Site Information
(including description of plant access, surroundings, vegetation inside and outside the fencing, etc.)

B. Document check list
(as per *Annex F* of the *EPC Best Practice Guidelines* and *Annex C* of the *O&M Best Practice Guidelines*)

C. Plant components details:

i. Modules
ii. Inverter(s)
iii. String-boxes
iv. Transformer(s)
v. Trackers
vi. Plant Layout verification
vii. Module orientation and inclination
viii. Foundations
ix. Mounting structures
x. Inverter Cabin
xi. Transformer cabin
xii. Video surveillance, access-control system and perimetral fence
xiii. Energy meters
xiv. SCADA and monitoring

For each of the above component the following table shall be included:

Yes	No	
☐	☐	System corresponding to what is specified in the as-built documentation
☐	☐	System installed correctly
☐	☐	The system status is sufficient

Visual inspection notes (for each of the above categories ....

D. Information and recommendations for the activities of vegetation control and module washing

E. Preliminary Punch List
For each plant component or plant section requiring an intervention, the following information should be included in the Punch List:

i. Description of the activity required
ii. Preliminary bill of material
iii. Budget cost
iv. Notes

Any other additional information and recommendations for teams involved in future activities could be added as an additional note to this report.

10.6. Set up of strategic spare parts warehouse

Spare parts management is a key activity to ensure a high level of availability and minimise downtime and is typically included in the O&M service provider's scope of work. The starting point of this process is the setup of a strategic spare parts warehouse. A detailed description of this process can be found in Chapter 8 of the *O&M Best Practice Guidelines* on *Spare Parts Management*. Below is a summary of it.

Spare parts should be bought by the EPC service provider together with all the other components for the installation of the power plant as this ensures maximum efficiency. Typically, the initial spare parts should last at least for two years from Commercial Operation Date (COD). The volume should be in line with the requirements of the Asset Owner and O&M service provider, as the O&M service provider might recommend additional spares that they deem necessary to meet contractual obligations (e.g., availability guarantees). Generally, it is not economically feasible to stock spare parts for every possible failure in the plant. Therefore, the O&M service provider, together with the Asset Owner, should define the stocking level of specific spare parts that make economic sense (Cost-Benefit Analysis). For a minimum list of spare parts, see the table below. This list is not exhaustive and system requirements and technology developments can lead to this list being updated following discussion with manufacturers, amongst others.

Another aspect to be considered is the warehouse location and condition: components leftover from construction such as structural elements and electrical boxes may not be needed regularly and can be stored in a remote warehouse. However, most useful components should be stored on site or be easily accessible in case of need.

During this preliminary stage it is also important to identify equipment requiring particular storage conditions, such as controlled temperature and humidity, so that the O&M service provider can organise the warehouse accordingly.

Once the preliminary list is agreed, it is best practice to allow the O&M service provider to operate the plant for a period of 3 months before defining a final list of spare parts. During this period the O&M service provider shall evaluate the progress of equipment degradation and recurrent outages.

TABLE 4 MINIMUM LIST OF SPARE PARTS (NON-EXHAUSTIVE)

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

10.7. Training of Asset Owner and O&M service provider (after FAC)

As already highlighted in paragraph *8.2.8.*, the EPC service provider should arrange an introduction to the site and a specific training program for the Asset Owner and the O&M service provider as part of the handover process. This is even more important when handing over to a third-party O&M service provider. In this case, as best practice, this process should be structured in two parallel streams:

- HSSE training: The O&M service provider's staff and the Asset Owner HSSE coordinator should be involved in a dedicated on-site visit where the EPC service provider explains and shows all the H&S procedures. During this, the O&M service provider's staff and the HSSE coordinator can identify additional hazards and implement new procedures if necessary. It is common for O&M service providers or Asset Owners having stricter HSSE standards than the regional regulations. For this reason, the inspection before the handover is beneficial for all parties.
- O&M manual and procedure: The O&M service provider's staff need to be trained on specific site requirements. Therefore, having training sessions in which the EPC service provider explains the content of the O&M manuals for major systems and equipment is recommended.

10.8. Confirmation of the Punch List and of KPIs after 3 to 6 months from start of O&M

The transition period (i.e., the initial period of the O&M contract during which the O&M service provider becomes familiarised with the site) ends after 3 months as a minimum requirement. However, a 6-month period is recommended as best practice. At the end of the transition period a final Handover Report is drafted by the O&M service provider. This should include the final revision of the Punch List and compare current plant KPIs with historical ones. Other elements or information resulting from the observation and the events that occurred during the transition period can be added, if required.

11 Key Performance Indicators

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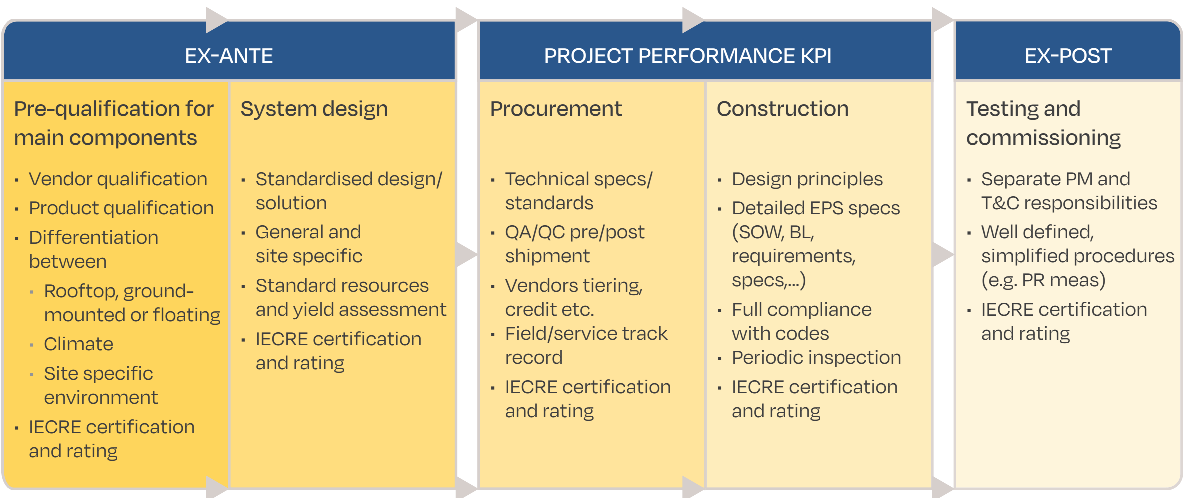
There are different types of Key Performance Indicators (KPIs) relevant to EPC, depending on project phase and relevant stakeholders. KPIs related to EPC can be grouped into three categories:

1. **Ex-ante KPIs** allow the (future) Asset Owner (or project developer) to decide whether to invest in a project that is being developed and trust a particular EPC service provider. They also help lenders to assess projects for financing. These aspects are important during the transition from the development to the construction phase and are considered in section *5.1. Selection of EPC projects* and section *5.2. Selection of EPC service provider.*
2. **Project performance KPIs** help all stakeholders to track project progress, and EPC service providers to optimise their processes.
3. **Ex-post KPIs** deliver a final assessment on a built project. For EPC service providers these KPIs may also be helpful when presenting their references to potential new clients.

The number of criteria to be looked at depends on the value of the project: big projects need to be examined in more detail.

FIGURE 5 KEY PERFORMANCE INDICATORS IN DIFFERENT PROJECT PHASES RELEVANT FOR EPC



11.1. Project performance KPIs

During the construction phase, the performance of the project should be tracked closely. There are available project management standards for this, such as ISO 21500, or publications of associations like the German Association for Project Management (GPM), or the Project Management Institute (PMI). In principle, project management tracks deadlines, budget, and quality, to achieve planned results.

There exist multiple KPIs for project performance. Here we focus on those which track the three essential elements of the 'project management triangle': (1) time, (2) budget, (3) quality. To achieve customer satisfaction, the planned goals concerning these elements have to be respected. The sections below discuss KPIs related to these aspects in more detail.

11.1.1. Deviation in time

Milestones are used in project management to mark specific points along the project timeline. These points may signal anchors such as project start and end date, or the need for external review, input, and budget checks. Therefore, one important KPI concerning time is the Deviation in Time expressed as percentage of milestones missed:

Deviation in Time:

$$\Delta T(i) = \frac{\#M_a(i)}{\#M_p(i)} \times 100\%$$

Where:

- $\Delta T(i)$ = Deviation in Time, expressed as a percentage (%).
- $\#M_a(i)$ = Number of Milestones achieved at the point of time *i*.
- $\#M_p(i)$ = Number of Milestones that should have been achieved at the point of time *i* according to the plan.

The value of this KPI increases if the granularity of milestones becomes finer and milestones are well distributed over the whole construction phase.

On the contractual side, Liquidated Damages may be linked to Deviation in Time – see section *12.5. Limitation of liability and Liquidated Damages*.

Since the importance of different milestones may differ, another KPI should be introduced: the number of Critical Milestones Missed (CMM). A critical milestone is one that must not be missed, because of its significance to the project. Examples include the date of receipt of construction permits or of grid connection. In a normal project CMM should be 0. Additional KPIs may include Deviation of Planned Hours of Work.

11.1.2. Deviation in budget

At defined moments in the project, usually at milestones and after (or even before) purchase of important components (like modules) or services, current accumulated costs $C_{ca}(i)$ should be compared to costs according to the business plan $C_{pa}(i)$. The resulting KPI Deviation in Budget can be defined as:

Deviation in Budget:

$$\Delta B(i) = \frac{C_{ca}(i)}{C_{pa}(i)} \times 100\%$$

Where:

- $\Delta B(i)$ = Deviation in Budget, expressed as a percentage (%).
- $C_{ca}(i)$ = Current accumulated costs at the point of time *i*.
- $C_{pa}(i)$ = Planned accumulated costs according to the business plan at the point of time *i*.

In this case the value of the KPI depends again on the choice of the measurement points *i*, their granularity and distribution over the period of the project.

11.1.3. Deviation in quality

Quality KPIs measure the quality of construction as well as the construction process and are therefore quite technical. A general KPI for quality tracking is the Deviation in Quality, which can be defined as:

Deviation in Quality:

$$\Delta Q(i) = \left(1 - \frac{\#NC(i)}{\#QC(i)} \times 100\%\right)$$

Where:

- $\Delta Q(i)$ = Deviation in Quality, expressed as a percentage (%).
- $\#NC(i)$ = Number of detected non-conformities at the point of time *i*.
- $\#QC(i)$ = Total number of quality checks at the point of time *i*.

The value of this KPI depends on the definition of quality checks, their number, and distribution over the project period. Non-conformities may include:

- Deviations from execution plans
- Construction defects
- Deviations from norms, standards, grid code, and industrial best practice (the documents to be considered should be listed in the tender document)
- Deviations from permits

Tracking certain quality aspects separately, like conformity with HSSE protocols, is recommended. In this case we would count non-conformities in HSSE and only compare it to the number of all HSSE checks.

Since the importance of different quality aspects may differ, it is best practice to assign a weighting factor for each conformity check.

Other aspects of project quality may be examined, for example:

- The number of change requests (indicates the quality of project development and preparation).
- KPIs describing the quality of communication between the stakeholders (surveys).
- The completeness of required documents for the O&M phase (see Annex C of the *O&M Best Practice Guidelines*).

This list should be completed according to the necessities of the specific project.

It is also important to establish feedback loops to create an atmosphere where continuous improvement can flourish.

11.2. Ex-post KPIs

Ex-post KPIs are the KPIs that help evaluate EPC projects after the construction phase.

11.2.1. Performance Ratio

There are several KPIs that can be used to evaluate overall plant performance, such as PR, and overall Availability of the PV plant.

PR describes the efficiency of the energy conversion system of a PV plant. When calculating PR, one must bear in mind that the efficiency of PV modules also depends on temperature. For a detailed explanation and formulas, please refer to section *10.3.4. Temperature-corrected Performance Ratio* of the *O&M Best Practice Guidelines*.

Availability focuses on the time that a plant spends generating electricity. For a detailed explanation and formulas please refer to Chapter *10. Key Performance Indicators* in the *O&M Best Practice Guidelines*.

11.2.1. Overall project performance

KPIs regarding overall project performance are, in most cases, identical to the Project performance KPIs described in section *11.1.*, with *i* being the concluding milestone of the project.

11.2.3. Warranty KPIs

Additional ex-post KPIs after FAC measure the handling of warranty claims by the EPC service provider, for example:

- Number of broken components/Total number of components.
- Number of broken components replaced in warranty procedure/Total number of broken components.

12 Contractual framework

This chapter describes the best practice for a "full-wrap" EPC contract, under which the EPC service provider undertakes to build and deliver the plant in compliance with the agreed time-schedule. The EPC service provider also manages the supply of the necessary equipment, and all the necessary ancillary works and activities. For other approaches such as "split contracts", see the box on *Split EPC contracts*.

Under a standard EPC contract, the service provider will typically have to meet a precise deadline to reach the Commercial Operation Date (COD). Setting this deadline right is particularly crucial when the plant is willing to apply for feed-in tariffs (considering that, quite often, this is dependent on reaching COD within a certain date) or has to meet contractual deadlines within the terms of a corporate power purchase agreement (which might result in liquidated damages being payable to the off-takers of the Power Purchase Agreement).

By executing an EPC contract, the Owner of a plant aims to reduce the risks derived from hiring several contractors in the construction phase. The Owner of the plant also strengthens their position by creating a single point of liability with the service provider, who will be liable and accountable for the timely and accurate execution of all the construction works carried out on-site, even when executed by sub-contractors (if allowed by the EPC contract). In this respect, all the relevant legal guarantees (e.g., time to complete the works, or performance related guarantees) associated with the execution of construction works will be issued by a sole entity, which will take full responsibility for the EPC contract. This results in one creditworthiness check rather than several and is especially useful when a parent company guarantee is chosen over bank guarantees.

BOX 2

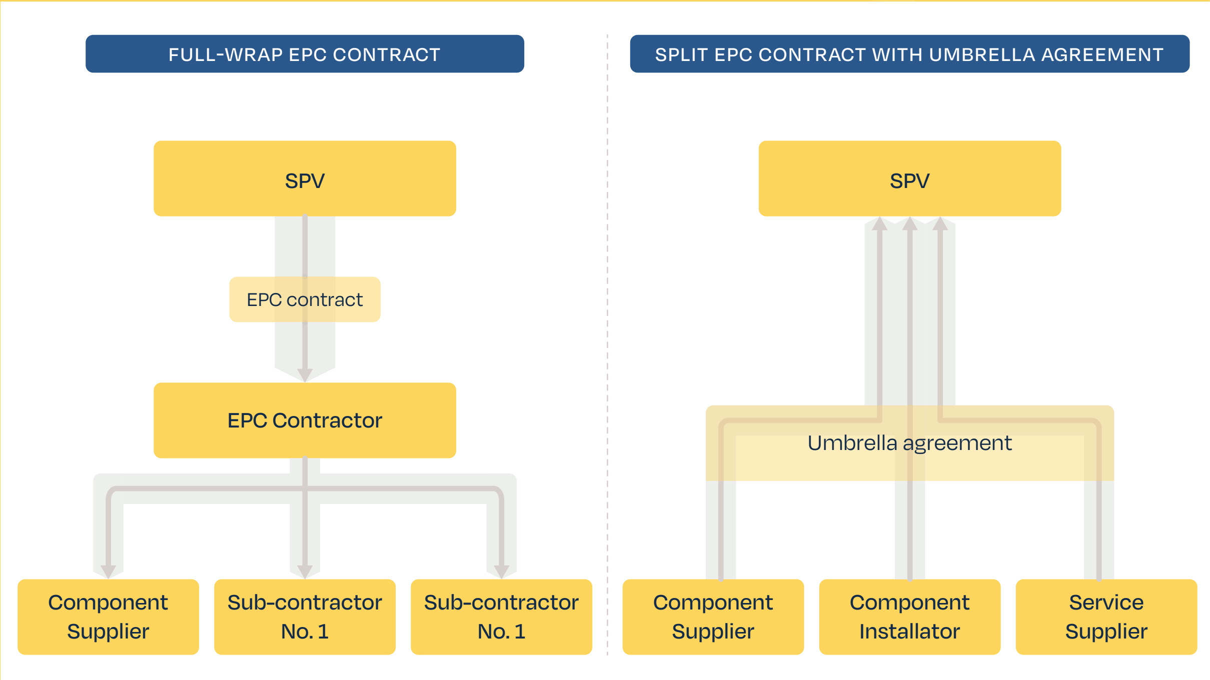
Split EPC contracts

The EPC contract may be construed either as a full-wrap contract or a split contract. In the latter case, the supply and installation of the components are carried out by different service providers. In this case, the Asset Owner (SPV) enters into different contracts for the supply and installation of the components. The choice of executing a full-wrap or a split EPC contract is up to the Asset Owner, who must evaluate how to allocate the risks associated with the individual activities. The Asset Owner's choice should comply, as much as possible, with the Lenders' requests and interests, who tend to prefer a single reference point for the construction of the project. As previously stated, the contract structures are one of the bankability criteria to be respected to ensure that the SPV receives the necessary funds for covering the construction and operating costs. Also, a mix between the two contracts is possible. For example, the SPV could chose to buy the modules directly, as they are the most expensive component. This solution is often referred to as "EPC light".

A split contract is mainly chosen when the Asset Owner has the necessary in-house resources, skills, and personnel to deal with some of the tasks that would otherwise be outsourced through a full wrap contract. Outsourcing some activities to contractors located in other jurisdictions and shifting profits to other countries may have advantages in terms of tax optimisation and cost savings.

To maintain the single point of liability and efficiently coordinate the different processes, a third agreement is usually executed between all service providers to determine how the risks and the liabilities must be allocated. This is referred to as an "umbrella agreement" and ensures that no derogation from the overall turnkey covenant concept occurs, and the bankability criteria are respected. Moreover, it should be noted that an umbrella agreement is frequently used in conjunction with parent company guarantees, which ensures the service providers perform all their obligations.

FIGURE 6 FULL-WRAP CONTRACT VS SPLIT EPC CONTRACT WITH UMBRELLA AGREEMENT



BOX 2 - *Continued*

Split EPC contracts

To avoid disputes in the case of a split contract and an umbrella agreement, the following areas should be covered:

1. Scope of works: It is important that no "gaps" arise between the scopes of work in each single agreement, as it is not unusual that technical inconsistencies may occur between different agreements. Such mismatches may be mitigated by defining the project specification in the main contract (usually the installation agreement) and by defining the other scopes of work by reference to it. Thereby the main contractor shall remain responsible for all the further activities.
2. Testing and commissioning: (mismatch in responsibilities) The main contractor must wrap the completion risk and assume the risk of performing all the testing activities and the economic burden of the related Liquidated Damages.
3. Cross-contract claims: It needs to be agreed when contractors should be entitled to claim against the SPV for time extensions or cost revision if other contractors default.
4. Caps on liabilities: The SPV should not be negatively impacted by the sub-division of any liability caps in the splitting process. It may be possible to retain an overall liability cap for each contract on the understanding that the different contractors are not jointly and severally liable.
5. Termination: The termination of one of the contracts should not have an impact on the other agreements and should not lead to chain resolutions.

For a turnkey approach a full-wrap contract is the preferred option due to the single point of liability principle. Lenders frequently prefer to have one financially robust party to take full responsibility in respect to all aspects of the construction works regarding time, budget, costs, and technical and performance requirements.

12.1. Interface between the EPC contract and the regulatory framework

The EPC service provider's activities are also defined by the applicable regulatory requirements and permits obtained by the developer.

The construction of a PV plant requires a myriad of permits and approvals from public authorities and other regulated bodies. In this respect, the EPC service provider is responsible for maintaining the vast majority, if not all, of said permits and approvals. In fact, even if they are not responsible for obtaining the construction permits (zoning permits, nihil obstat from public authorities, environmental impact assessment decree) which are procured by developers in the pre-construction phase, the service provider must make sure that such authorisations will remain in full force for the entire EPC contract's term. The termination of one of them may constitute a termination event under the EPC contract. Even if the plant's Basic Design is not included under the scope of work of the EPC Contract, the EPC service provider is obliged to faithfully comply with it, as it has been validated by the public authorities during the authorisation process. As many European countries' grid requirements are strictly defined, the contractor has limited flexibility for altering the design and specifics of the PV power plant. In addition, the EPC service provider is also in charge of applying for and pursuing all other permits strictly necessary for the construction of the project (e.g., filing design amendments or other requests to the competent authority). Moreover, during the construction phase, the EPC service provider is also responsible for satisfying any conditions, listed under the permits, upon which the entry into the operation of the PV plant is conditional.

An example of the interaction between a service provider and public bodies occurs at the end of the construction phase, when the PV plant is connected to the grid. Here, the EPC service provider is liable to the SPV and the grid operator for:

1. Respecting the requirements detailed under the grid rules and concerning the technical

requirements with which the PV plant must comply (i.e., voltage, reactive power to be injected into the grid).

2. Constructing part of the power line. It is not unusual that the construction of part of the infrastructure network (i.e., the segment that connects the power plant to the primary cabin) is outsourced to the EPC service provider. When this is the case, the service provider must also coordinate activities with the grid operator during the testing process.

12.2. Contractual risk allocation

The EPC contract is one of the most important elements of a solar project and it has a major impact on project financing and bankability. The EPC contract has mandatory principles and contains certain provisions which ensure the bankability of the entire transaction. The presence of these characteristics in the contractual framework makes it possible to carry out a risk allocation (both cost and technical risk allocation) between the EPC service provider(s) and the Asset Owner (or SPV). An appropriate and clear risk allocation, with a single point of reference, are the fundamental expectations of most Lenders. This makes it possible to shift the economic risk related to increasing costs directly onto the Asset Owner. The less well defined the risk allocation of a project is, the more equity support will be demanded from the Asset Owner (investor).

For achieving a balance between the Lenders' demands, and the Asset Owner's interests, the key clauses regarding timing, cost and quality of the works should be aligned to market standards. In this regard, the main drivers – which are the bankable standards - are:

- Single point of liability: The EPC service provider should be the only one responsible for the Engineering, Procurement, Construction and Commissioning of the PV plant. This allows a total shift of the technical risk from the Asset Owner (SPV) towards the EPC service provider who must face any claims that may arise. This principle is considered a key element as it represents the first tool for the lenders in assessing the creditworthiness of the entire project. However, the Asset Owner (SPV) may enter into different agreements for the procurement and installation of components.
- Fixed price provision excluding or limiting price adjustments: This element prevents small technical variations, or small alterations to the design leading to a revision of the price. It allows Lenders to easily assess and define all the costs in the banking base case and the Asset Owner to transfer most of the construction cost risk[4] to the EPC service provider.
- Fixed completion date provision which excludes any request for time extension.
- Pre-agreed construction standards and criteria: This requirement assigns the responsibility for achieving minimum standards on parameters like PR and peak power to the EPC service provider. It also makes the EPC Service provider responsible for ensuring compliance with the relevant grid regulatory framework. If a plant fails to meet the minimum guaranteed performance, the Asset Owner is usually granted the right to reject the plant and to be reimbursed the amounts already paid under the EPC contract. However, performance risk shifting is mitigated through the insertion of a cap on the service provider's maximum liability for payment of liquidated damages ("performance LDs").
- Commercial risk shifting (procurement, inventory, and warranty of components): As the EPC service provider is the key point of contact for others involved in the construction phase, they may provide a warranty on quality of electromechanical systems, in addition to the product warranty granted by the relevant component producer under national law.
- Issuance of securities: These can take the form of advance payment bonds, performance bonds and warranty bonds, of 5-10 % of the contract price, to be delivered by the EPC service provider to secure the relevant payments of the relevant LDs or the performance of the relevant works.

In addition to the points above, the EPC service provider's duty to rectify the constructed works are not generally included in all EPC contracts but limited to agreements executed to build large-scale plants. As EPC contracts tend to be tailored to the size of the project, often smaller plants are not expected to fulfil the same performance guarantees as bigger projects.

4 It is generally accepted that certain events like force majeure or change in law may trigger a revision of some contractual previsions as the price or the duration or may constitute a termination event.

12.3. Price and payment

As for the payment, the EPC contracts typically provide for a payment schedule running in parallel with the construction milestones agreed between the parties.

It is not unusual to have a down-payment of around 10% of the full price, paid upon the execution of the contract (or upon satisfaction of specific conditions required for the contract to take effect). Afterwards, payments tend to be tranches of the full price, paid when relevant milestones have been met. Parties may also agree – in case there is no performance or warranty bond – to postpone the payment of the last 5% of the price until after completion of the works, and the expiry of the warranty period (usually 24 months after the PAC is issued).

EPC contracts are usually drafted including a fixed price clause which binds the parties to the total price agreed under the contracts. However, occasionally external factors, outside of anyone's control can have a pronounced effect on a project. In these cases, a flexible approach to allocating responsibility for resolving issues should be taken, with the stakeholder most able to handle the issue taking the lead.

However, parties may negotiate specific cases and scenarios when a change in the price is allowed. In certain cases, the Asset Owner may retain the right to withdraw from the contract.

Events justifying a revision of price are generally limited to unforeseeable changes in conditions such as relevant and applicable changes in legislation, or natural events which make the execution of the works particularly burdensome on the service provider.

Every provision that could have an impact on the fixed price of the contract should always be carefully drafted and evaluated from a bankability perspective. This is because banks prefer stability in the price throughout the entire contract. Therefore, there should only be a very limited set of cases where a price adjustment is justifiable for solid reason or project specifics.

In case of delays in the execution of the works or technical defects in the operation, the Asset Owner may have the right to call for a reduction of the price and, under certain conditions, liquidated damages, provided under the contract.

In case of disputes over the payments, parties shall firstly meet to try and amicably settle the dispute. If a technical issue is the basis for a payment dispute, a technical third-party –agreed before in the contract negotiations – should make a judgement regarding the technical issue. It should be noted that in the price determination, any review mechanism is generally excluded between the parties. Therefore, even in the event of an increase in the cost of materials, labour, or other unforeseeable factors, the agreed price shall not be subject to any change and no other arrangement in the payment mechanism may be adopted.

12.4. Bonds and guarantees

A standard EPC contract will provide for the issuance of the following bonds on the service provider's side to secure all its obligations under the EPC:

- Advance Payment Bond: This is generally issued upon payment of the down-payment or as a condition for making such a payment. The Advance Payment Bond will usually cover 10-15% of the price.
- Performance Bond: This is generally issued upon release of the Advance Payment Bond or issued directly upon execution of the EPC contract if no advance payment is provided and there is no issuing of an Advance Payment Bond. The Performance Bond will usually cover 10-15% of the price and will remain in full force until the PAC has been issued and the delivery of the Warranty Bond.
- Warranty Bond: This is generally issued upon release of the Performance Bond and issuance of the PAC. The Warranty Bond will usually cover 5% of the price and will remain in full force and effect until the expiry of the 24-month EPC warranty period, usually ended by the FAC being issued.

All the guarantees above are typically issued as irrevocable, first-demand, autonomous guarantees by a bank, or another acceptable financial institution with an appropriate credit ranking. Depending on the reliability of the service provider, the Asset Owner might consider accepting parent company guarantees. However, this should be reviewed from a bankability perspective before any decision is made.

- EPC parent company guarantee: In addition to the above, the EPC service provider may be asked to deliver a parent company guarantee which will be in place for the entire duration of the EPC and will usually cover around 70% of the price.

- **Asset Owner's parent company guarantee**: The EPC service provider may ask for the issuance of a guarantee securing all the Owner's payment obligations throughout the contract. This is usually done through the issuance of a parent company guarantee. The Asset Owner's parent company guarantee is generally issued upon execution of the contract and will be in place for the entire duration of the EPC phase, usually covering around 70% of the price.

12.5. Limitation of liability and liquidated damages

Under the EPC contract it is common to set general limitations on the liability applying to both parties. The EPC service provider's liability should not exceed 100% of the total price agreed under the EPC contract, with exclusion of any limitation for willful misconduct or gross negligence. The same goes for the Asset Owner but with a cap which is generally lower than the one set for the EPC service provider.

Liability for indirect damages or losses, and punitive or consequential damages is always excluded for both parties. Under standard EPC contracts, the service provider will also be liable for payment of specific LDs provided to remedy the damages suffered by the Owner for specific violations of the contract. LDs should not exceed the general cap on the service provider's liability, as agreed between the parties.

Standard Liquidated Damages (LDs) are the following:

- **Delays Liquidated Damages**: These are often calculated as a fixed amount due per each day/week of delay on the deadline set for reaching the COD. The amount should be linked to the potential loss of revenue suffered by the Asset Owner.
- **Technical Delay Liquidate Damages**: These are generally linked to a failure to meet certain technical thresholds for productivity, power curve or PR, agreed between the parties, during the 24-month warranty period

The LDs reflect the loss of revenue or increase in operating costs (or both) resulting from failure to achieve the required performance over the life of the project, or in the agreed deadline.

It is worth noting that the EPC contract will state a maximum amount payable as liquidated damages for each category (which is usually a percentage of the price comprises between 5-15%, that in some cases may reach 20% of the single category price). Should this be reached, the owner should have the right to terminate the contract and to ask for full repayment of the accrued liquidated damages.

12.6. Termination, withdrawal and force majeure

Termination clauses are very sensitive and are typically negotiated over a long period between the parties. Generally, the EPC service provider has very limited contractual termination rights, which are predominantly linked to failure of payments that are not remedied within the relevant cure period.

If a bank is financing the project, a direct agreement will likely be put in place between the bank, the EPC service provider and the Asset Owner. Under the direct agreement, the EPC service provider's termination right will be further limited. This is because the EPC service provider will have to inform the bank in advance about its intention to terminate the agreement and the bank will have the right to cure the issue.

At the same time, the Asset Owner will typically have the right to terminate the EPC contract for any relevant failure by the EPC service provider in meeting its obligations including deadlines, payments of liquidated damages and quality standards.

In case of termination for violations of the relevant obligations, the non-defaulting party will be entitled to claim for damages within the limits set forth under the contract.

Another case that may lead to the termination of an EPC contract is the occurrence of a **force majeure** event. This can be a natural event (or any other event) which is out of any party's control and has a negative impact on the fulfilment of both Owner and service provider obligations. The EPC contract generally provides an exhaustive list of force majeure events. Each party shall have a duty to mitigate the impacts of force majeure events, to minimise the suspension time and restart the performance of services as quickly as possible. However, if the force majeure clause is triggered, the affected party is exempted from any obligation and liability due to its default. To invoke this mechanism the affected party has to inform the other of the forecasted restart day and the measures to be adopted to preserve the balance of obligations originally set forth under the contract. To protect the interests of each party, both may have the right to withdraw from the contract should the force majeure last for a period longer than a determined threshold (generally 45 consecutive days or 90 days in aggregate), or it jeopardises the performance of the relevant obligations.

Force majeure clauses have recently taken on particular importance following the outbreak of the COVID-19 pandemic due to its material impact on the execution and performance of services under the contracts. In response to the pandemic, many governments have adopted highly restrictive measures to reduce the spread of the contagion, such as lockdowns which led to partial or full freezing of some industrial activities. National lockdowns made travel for EPC service providers impossible in some countries and their lack of presence on the plant sites completely halted construction works. Due to the wide range of cases, a deeper analysis of a force majeure event's impact on an EPC contract must be carried out on a case-by-case basis. In fact, a definition of force majeure is missing from European legislation and therefore the direct and indirect effects need further investigations. Fortunately, the energy sector has been considered as essential for national economies, for the most part, and no extreme measures have been directly imposed on the contractors. However, there have been some delays in construction timelines as the contractor's obligations have been prevented or obstructed by consequential events such as strikes and discontinuation in the supply chain. For the future it should be noted that COVID-19 restrictions cannot be seen, in general, as an unforeseen event and are, therefore, unlikely to fall under force majeure events.

Another sensitive clause is the right to withdraw or terminate an EPC contract. Like termination events, withdrawal events are few and well-defined. They generally occur when a force majeure event lasts more than the agreed maximum period, or one of the parties is subject to insolvency proceedings or other similar procedures (depending on the crisis, these can range from difficulty in meeting obligations to the bankruptcy of the service provider or Owner). Other withdrawal events may occur if a change in the applicable law leads to the introduction of further compliance requirements, or other unforeseeable charges, so burdensome that they affect the contractual relationship. In these cases, the affected party must notify the other party in writing, indicating the date of effective withdrawal, and the description of the withdrawal event. This is to give the other party the necessary time to find a reliable replacement.

12.7. Ownership, expiration of warranties and transfer of risk

The Asset Owner acquires full title on the rights and guarantees over the components to be installed (except the mounting system, panels, and inverters) upon delivery to the site. For the main components (PV modules, mounting system, transformers and inverters), the timing of transfer is the issuance of the PAC, as they must be installed and tested by the EPC service provider. Until the PAC issuance date, the EPC service provider retains full title on the main components by virtue of its role as installer and operator of the plant.

As the EPC service provider is the only responsible subject for the operation of the plant until the PAC, they also retain the risk of loss. After that, the Asset Owner can only claim any defect and malfunction within the limits of the guarantees provided under the EPC contract.

12.8. Assignment and set-off

In general, the EPC contract should exclude each party from reassigning the contract without the prior consent of the other party. The rationale for this is maintaining the same set up as on the date of execution. This principle is based on the Owner's interest in having a solid and reliable counterpart for the construction of the plant. The same key concept is the rationale applicable to the limitation of subcontracting. Also, in this case, the contract generally provides for a total exclusion or a maximum threshold of the services to be subcontracted. In any case, the EPC service provider shall remain fully responsible for the services performed by its subcontractors.

Since solar power plants are increasingly financed through non-recourse financing schemes, the EPC service provider cannot set-off its claims and assign its rights against the Asset Owner. On the other hand, the Owner is always entitled to assign the receivables arising from the EPC contract in favour of lenders.

13 EPC for PV Power plants with Storage

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Energy storage technologies are instrumental in enabling the transition to a climate-neutral and renewable energy-based economy. As more renewable energy capacity is connected to the grid, the need for grid flexibility solutions is increasing. Energy storage technologies offer a solution that is commercially proven to increase the penetration rate of fluctuating renewable energy in the electricity system. One of its uses is storing surplus power when demand is low and shifting its use for times when demand is higher. In addition, energy storage systems (ESS) provide a wide range of ancillary services to the grid (e.g., balancing power, frequency, and voltage control, "black start", etc.), thus ensuring a stable, secure, and efficient operation of the energy system.

In this chapter, we will focus on ESS that are part of hybrid facilities (where generation and storage are either integrated or co-located) and how these systems can be used to better integrate solar power generation in the electricity system.

13.1. Types of storage systems

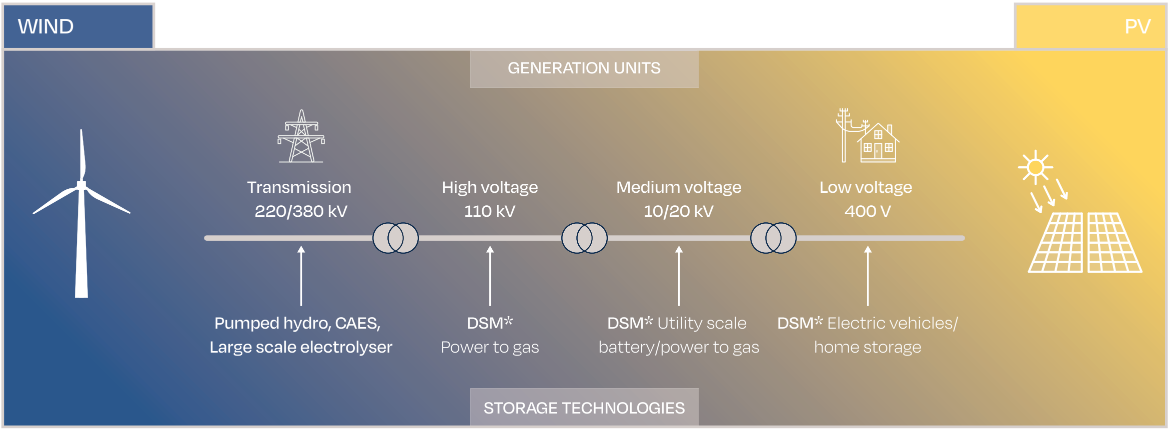
There are many forms of ESS: pumped hydro, compressed air, hydrogen, thermal, flywheels, supercapacitors, etc.

Green hydrogen, i.e., hydrogen produced from renewable sources, offers strong potential: it can be used for long-term (seasonal) storage, can be used in centralised or decentralised configurations (providing flexibility), solves intermittency issues, all by using existing gas storage technologies.

Another important, economically viable solution for utility scale solar plants in Europe are electrochemical storage systems. In the rest of the chapter, we will concentrate on the EPC aspects of these. The success of electrochemical storagex systems in utility scale PV plants can be explained by the high compatibility of the size of typical storage solutions, and the voltage levels of both systems. Within this segment, Lithium-ion based solutions currently hold the biggest market share. During the last three years the deployment of redox-flow batteries (e.g., vanadium-based solutions) have increased. Lead-acid batteries, on the other hand, are still often the most economic choice for off-grid and smaller capacity systems in the residential sector and C&I solar plus storage systems.

At present, lithium-ion chemistries are the dominant storage technology for short-duration applications (i.e., 1 – 4 hours), representing ~90 % of the market (Lazard's Levelized Cost of Storage Analysis (LCOS 6.0)). While lithium-ion chemistries currently dominate the utility-scale market, redox-flow batteries, based on their unique capability to decouple power and energy, are also gaining traction, particularly in use cases with long discharge times (several hours) and long storage durations (several days). In applications where high reaction speeds and partial power capabilities are a must (ancillary services) lithium-ion solutions have currently better overall efficiency values. In this case, partial power processing is technique that allows greater control over the battery charging current, improving the efficiency of the system whilst reducing power losses.

FIGURE 7 SIMPLIFIED OVERVIEW OF VOLTAGE LEVEL IN THE ELECTRICITY SYSTEM (EXAMPLE HERE GERMANY) AND THE USUAL CONNECTION POINT OF PV, WIND ON-SHORE, WIND OFF-SHORE AND DIVERSE FLEXIBILITY TECHNOLOGIES



*Demand side management.

The type of a storage system can significantly influence a project's overall design. Technical parameters such as battery lifetime, efficiency, charge/discharge rates and/or power density, should be taken into consideration at the development stage when selecting the most appropriate ESS design, coupling topology (AC vs. DC connection) and technology. The annual degradation rate of the battery should also be considered to determine if and when augmentation (battery replacement) will be needed. For this a clear use profile of the battery should be assumed.

Typically, the useful life of lead-acid batteries is estimated at between 1,000 and 1,500 cycles while lithium-ion batteries last between 2,000 and 6,000 cycles, and redox flow batteries can reach 15,000-20,000 cycles. The exact lifetime of the ESS is difficult to predict because it depends on the cumulative effect of multiple factors such as the number of cycles per year or day, average state of charge (SOC), depth of discharge (DoD), temperature and current ratings. Depending on the battery availability required, there are different recommendations for the percent of remaining capacity that triggers a replacement, generally ranging from 60 to 80 % of the initial capacity.

When evaluating Li-ion options for a solar plus storage project, battery chemistry should also be considered. In 2021, the two leading choices are lithium nickel manganese cobalt (NMC) and lithium ferro (iron) phosphate (LFP).

NMC has a higher energy density, which makes them better suited for electric vehicles and ESS that require frequent cycling for a relatively short period of time. On the other hand, the higher energy density carries higher risk for overheating and fire risk.

LFP, in contrast, is perceived as a safer option because it has high thermal stability. However, since LFP cells have lower energy density than NMC cells, they typically require more space to store the same amount of energy. Furthermore, the long-term performance of stationary storage systems based on LFP cells still needs to be proven.

13.2. Environment, Health & Safety

Most batteries are subject to environmental regulations that require recycling or proper disposal at the end of performance period. The most relevant one for Europe will be the upcoming regulation on batteries and waste batteries. This is still subject to negotiations between Member States and the European Parliament.

The ESS mentioned above are electrical appliances and carry significant H&S risks (DNVGL 2015). To prevent hazards (e.g., uncontrolled release of energy), an appropriate risk assessment must be performed during the design and planning phases, and necessary safety precautions implemented. The hazards must be identified during these stages and appropriate measures taken to mitigate risk and to protect those operating the system.

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

- **Electrical**, occurring when there is direct contact between a person and the system (battery systems are typically designed to follow the low-voltage directive with a voltage range of 75-1500 V DC and 50-1000 V AC.
- **Mechanical**, occurring after a physical collision.
- **Chemical -** poisoning or exposure to hazardous materials through leaking of chemical components from the system, for example. This could be the non-aqueous electrolyte mix of a lithium-ion battery or the sulfuric acid in lead-acid or redox-flow batteries.
- **Other**, occurring due to an explosion, fire, thermal runaway.

To avoid risks, the system should not overheat or freeze, come into contact with water, or suffer from either electrical stress or high humidity. The risk of electrical shock can be mitigated - as is common practice in photovoltaic plants - with appropriate electrical insulation: for instance, by wearing appropriate personal protective equipment (PPE). The energy storage system should be maintained by trained technicians since improper handing increases the risk of electrical shock. For personnel qualifications during the installation and maintenance of stationary batteries, refer to IEEE 1657 - 2018.

Safety data sheets should be provided to those operating the system. In case of repair or replacement, addition or alteration of the system, the safety protocol should be re-evaluated and, if necessary, additional measures implemented.

It is good practice to design the system in a way that allows straightforward removal and replacement of modules, and separation between battery components and other equipment such as the Heating Ventilation, Air Conditioning (HVAC) or power conversion system (PCS) including inverter and transformer. The system itself should be easily accessible for inspection without needing to significantly disassemble the ESS system. Disposal of hazardous material should comply with local and national rules and regulations.

13.3. Engineering

Stationary energy storage can be separated into two categories based on the point of grid interconnection: Front-of-the-Meter (FTM); and Behind-the-Meter (BTM). The FTM applications focus on the operation of the electricity grid where energy storage systems are employed to maintain a smooth and continuous flow of electricity to the consumers. BTM applications are generally used to increase the self-consumption of a renewable unit behind the grid connection point of a consumer. When referring to utility-scale solar plus storage installations, BTM applications primarily use the ESS for energy shifting and/or self-balancing (See Table 5 on the following page).

The first thing to consider at the start of the design and engineering process of a solar plus storage system is its application/use case and the related duty cycle specification, including a typical daily duty cycle over the lifetime of the system. The **duty cycle analysis** helps determine the minimum requirements for the energy capacity, power capability, and number of daily cycles, which are used as a starting point for the dimensioning. This phase is typically iterative as different commercially available solutions are evaluated in terms of their performance, lifetime, and cost. Software-assisted simulations are often used in

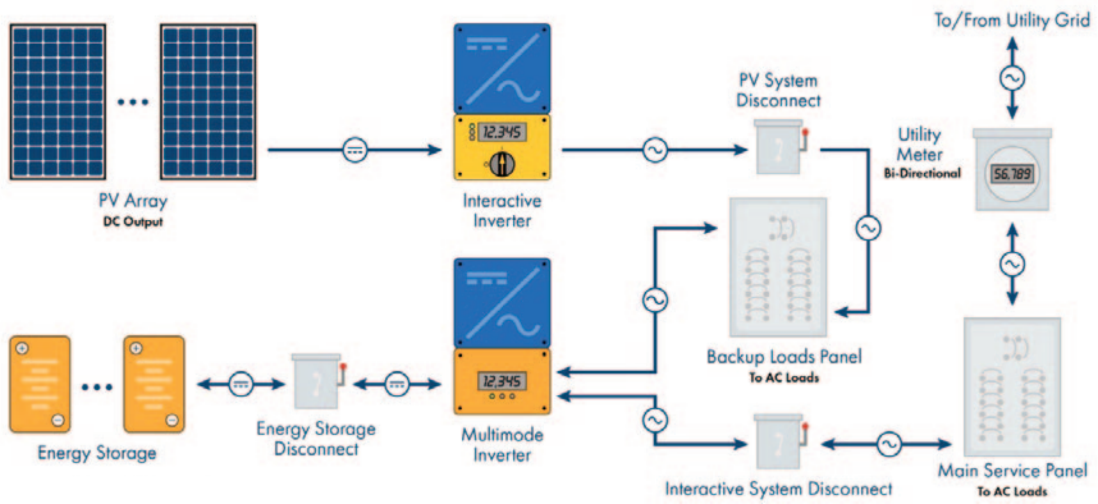
TABLE 5 OVERVIEW OF FRONT-OF-THE-METER (FTM) AND BEHIND-THE-METER (BTM) APPLICATIONS AND DEFINITIONS

CATEGORY	APPLICATION/USE CASE	DEFINITION
FTM	Ancillary services	Provision or absorption of power to balance supply and demand and thus maintain the frequency of the grid at a reference value or reduce grid constraints: ▪ Frequency regulation ▪ Replacement for reserve spinning, non-spinning, and supplemental thermal generators ▪ Voltage support ▪ Reactive power compensation ▪ Black start (recovery from a total or partial shutdown of grid)
FTM/BTM	Energy shifting (arbitrage)	EES is charged when market selling prices are low or energy would be clipped for other reasons (high DC/AC ratio at the inverter, maximum power limit for injection into grid, etc.). It is discharged to meet demand, sell at higher prices and/or smooth the production curve. Renewable energy assets coupled with storage essentially become dispatchable generation assets.
FTM/BTM	Self-balancing portfolio optimization (Virtual Power plant)	Balance responsible parties (BRPs) and distribution system operators could use energy storage to reduce imbalance within portfolios to avoid imbalance charges. The BRP does not actively bid on the imbalance market using its load flexibility but uses it within its own portfolio. The combination of several assets at different grid connection points is known as virtual power plant (VPP).
BTM	C&I / Residential energy storage	Energy storage that is used to increase the rate of self-consumption of a PV system from C&I or residential customers or to reduce power consumption at the grid connection point to reduce grid connection costs.

this performance assessment in combination with yield assessments for the PV-plant. This step is important as it defines the required capacity of the system at the start of operation and influences the assumed oversizing and thus the capital expenditures of the project.

Another important aspect of the solar plus storage system engineering is deciding on the approach to be used for the ESS coupling (AC or DC) to the PV power plant. In **AC-coupled** systems, the solar and storage systems are connected to separate inverters. They can be dispatched together or independently.

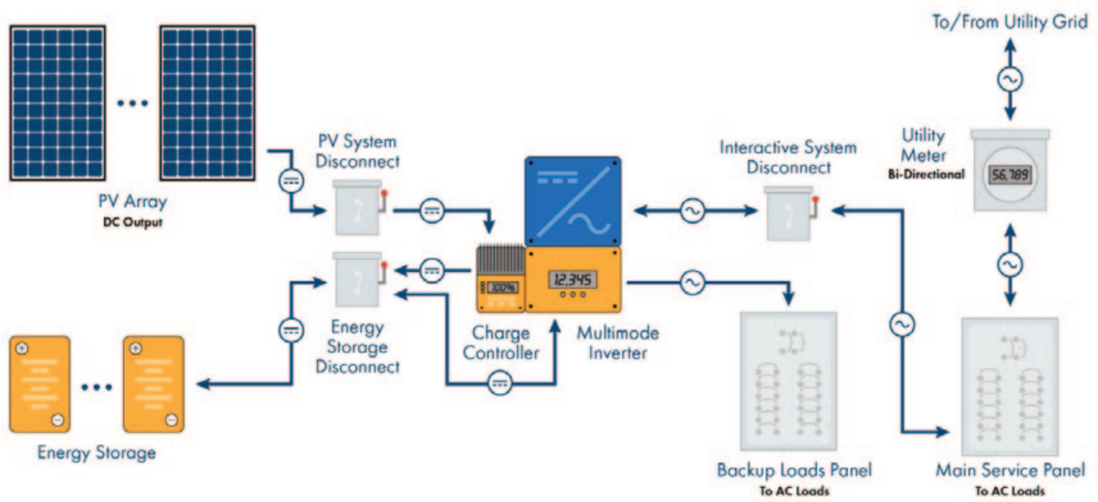
FIGURE 8 AC COUPLED ESS



SOURCE: Mayfield Renewables, 2020.

In **DC-coupled systems**, solar and storage systems are connected on the same DC busbar and use the same inverter. They can only be dispatched together, as a single facility. DC-coupled systems further subdivide into loosely or tightly coupled – **loosely coupled** systems use a bidirectional inverter, so that the battery can charge from either the grid or the PV plant, while **tightly coupled** systems use a unidirectional inverter, meaning the battery can only charge from the PV plant.

FIGURE 9 DC COUPLED ESS



SOURCE: Mayfield Renewables, 2020.

Depending on the application, each approach has its advantages and disadvantages. The most common of these are listed in table, though each project will also have its own specific considerations, including the applicable regulatory framework and procurement choices.

The applicable interconnection regulations, electrical standards and environment-related constraints must also be considered in the design process and may even have a decisive role in determining the optimal design of the system.

During engineering phase, the components should also be based on their noise emission and possible influences on the surrounding. Larger inverter and cooling systems of BESS have a noise power level that needs to be checked against local noise emission constraints.

13.4. Procurement

When moving to the procurement phase, the requested scope of work should be clearly defined. Clarity on the battery technology required and how it will be used will help EPC service providers go deeper into the value chain. The procurement could then be based on a Request for Tender (RFT) or Request for Quotation (RFQ). If the purpose of the overall system is not yet clear and further engineering tasks or financing risks are associated a request for proposal (RFP) could be the right form of procurement.

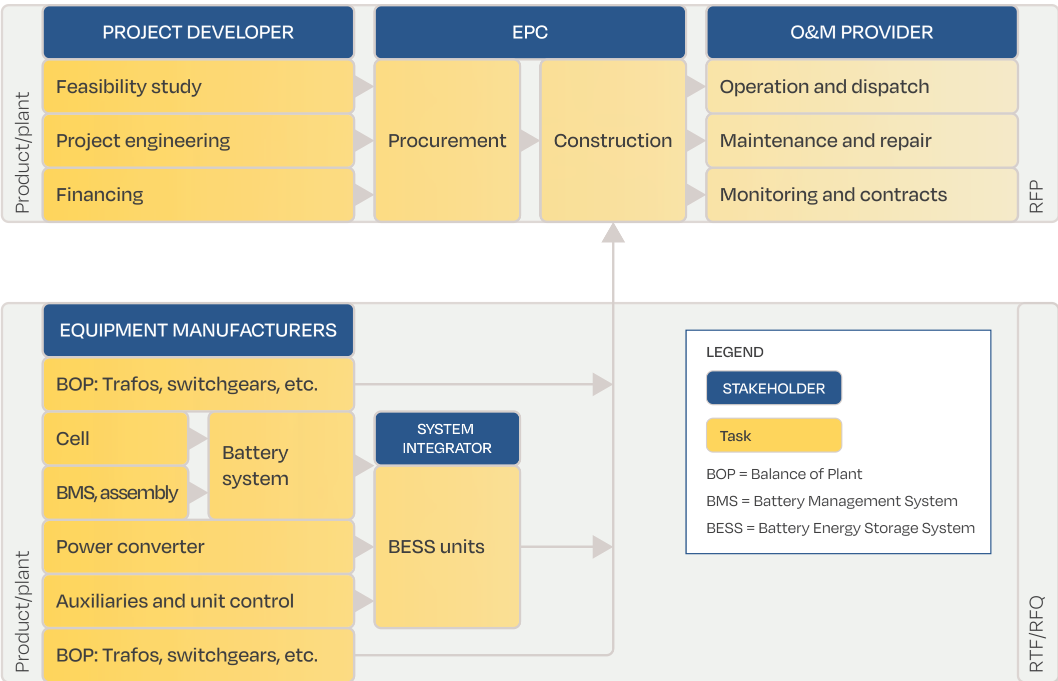
The risk profile of the project developer is a main determinant in defining value chain integration. A System integrator delivers typically a fully integrated BESS ,with all requisite components, up to a low or medium AC voltage level. Another key point to consider in procurement is the responsibility for communication between inverter and BESS as well as external parties (e.g., trader, grid operator). Furthermore, all components must be compliant with any local requirements. One main risk is that battery systems (especially the inverter) currently only have a prototype certificate instead of a unit certificate. The latter is required to be completely certified for European grids.

Product guarantees (here product guarantees with typical 2 years + 12 months) and performance

TABLE 6 DECIDING ON AC OR DC COUPLING – ADVANTAGES AND DISADVANTAGES

AC-COUPLED ESS	DC-COUPLED ESS
Advantages: ▪ Higher operational flexibility - AC-coupled systems have the same efficiency when charging the battery from PV or the grid, and discharging is independent of the PV inverter ▪ Faster reaction speed for ancillary service provision of battery system possible ▪ To date, utility-scale systems have relied primarily on AC-coupled structures so more references are available ▪ Easier to install when retrofitting existing PV plants	Advantages: ▪ Higher round trip efficiency when charging from solar ▪ Eliminates the need for one set of inverters, MV switchgear, and other balance of plant costs ▪ Better suited to take advantage of oversizing PV (higher DC/AC ratio) and store otherwise clipped energy
Disadvantages: ▪ Lower round-trip efficiency (more conversions are needed - PV inverter DC-AC, battery inverter AC-DC when charging, DC-AC when discharging) ▪ Cannot take advantage of clipped energy, so it does not make sense to oversize the PV part much	Disadvantages: ▪ Lower operational flexibility - the combined output of the PV and battery is limited by the size of the inverter, and if the inverter has a failure, both the energy storage and the PV generation is lost ▪ More complex design & installation process (with DC coupling, the PV and batteries are paired on each inverter) ▪ Certification of some components does not exist yet

FIGURE 10 VALUE CHAIN OF A BESS UNIT WITH STAKEHOLDERS AND TYPICAL TASKS ASSOCIATED



guarantees (mainly on the battery capacity at a given duty cycle for 10 or 15 years) are a further important aspect of the selection process.

Finally, the delivery periods of the components should be considered. The battery modules are commonly sourced from South Korea or China and currently have delivery periods of five to nine months (this is due to rise). Due to the market force of a handful of suppliers, smaller volume sourcing is becoming increasingly complex.

13.5. Construction

The currently typical design of stationary storage systems in the range from 1 MW to 100 MW are container solutions with either all equipment in an ISO standard container, or part of the PCS equipment outside (skid-solution). Important variables to be considered are container sizes and type of to the cells is guaranteed. Newer formats are compact module blocks in outdoor housings that can be electrically interconnected to different topologies.

Battery containers need foundations, such as plinths or stripe foundations. In areas where high levels of ground protection are necessary (e.g., in water safety zones) special foundations to collect extinguishing water can be required. In usual circumstances this is not necessary if the container allows save flooding and includes a drainage system. The weight of the container depends on the equipment included when delivered (e.g., modules already pre-installed) and can go up to ~30 tonnes for a ~12 metre (40 ft) ISO container. Thus, in the overall plant design, space for a crane pad should be considered and access roads must be appropriate.

Furthermore, the location of the battery should be accessible for the fire brigade.

For the installation of containers without pre-installed modules one can calculate 2-3 person-days for one ~12 metre (40 ft) container, which equates to 500 modules.

The duration for commissioning depends on local conditions and should cover the electrical tests, communication tests, grid code compliance tests (depending on the country) and tests of the actual service to be provided (depending on application and country).

References

SolarPower Europe's Lifecycle Quality Best Practice Guidelines series – *available at:* www.solarpowereurope.org and www.solarbestpractices.com

- SolarPower Europe (2021), *"Operation & Maintenance Best Practice Guidelines Version 5.0"*
- SolarPower Europe (2020), *"Asset Management Best Practice Guidelines Version 2.0"*
- SolarPower Europe (2021), *"Engineering, Procurement and Construction Best Practice Guidelines Version 2.0"*
- SolarPower Europe (2021), *"Lifecycle Quality Best Practice Guidelines V1.0"*
- **SolarPower Europe's best practice checklists** – *available at:* www.solarbestpractices.com
  - Operation & Maintenance best practices checklist
  - Asset Management best practices checklist
  - Solar monitoring best practices checklist
  - Aerial thermography best practices checklist

Additional resources:

- **Badeda et al. (2021).** "How to efficiently procure battery energy storage systems for hybrid energy systems through a tender process". *5th Hybrid Conference, 2021*.
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- **SolarPower Europe (2021).** "Sustainability Best Practices Benchmark". https://www.solarpowereurope.org/solar-sustainability-best-practices-benchmark/
- **Spagnuolo, G.; Petrone, G.;** Mattavelli, P.; Guarnieri, M. (2016). "Vanadium Redox Flow Batteries: Potentials and Challenges of an Emerging Storage Technology". *IEEE Industrial Electronics Magazine*. 10 (4): 20–31
- **World Bank Group (2020),** General EHS guidelines references and sources. Web: https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines

A Annex

A. List of applicable standards

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
1			EN 50380	Datasheet and nameplate information for photovoltaic modules	PV Module	This European Standard describes marking, including nameplate and documentation requirements for non-concentrating photovoltaic modules. This European Standard provides mandatory information that needs to be included in the product documentation or affixed to the product to ensure safe and proper use. Best practices are included in this document giving guidance on additional information, for example module's performance at different irradiance levels.					X	X	X					
2			IEC 60044-8	Instrument transformers – Part 8: Electronic current transformers	System	This part of IEC 60044 applies to newly manufactured electronic current transformers having an analogue voltage output or a digital output, for use with electrical measuring instruments and electrical protective devices at nominal frequencies from 15 Hz to 100 Hz.									X			
3			IEC 60364-7-712	Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems	System	IEC and EN/HD are not the same.						X		X	X			
4			IEC 60364-7-712	Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems	System	EC 60364-7-712:2017 applies to the electrical installation of PV systems intended to supply all or part of an installation. The equipment of a PV installation, like any other item of equipment, is dealt with only so far as its selection and application in the installation is concerned. This new edition includes significant revisions and extensions, taking into account experience gained in the construction and operation of PV installations, and developments made in technology, since the first edition of this standard was published.						X		X	X			
5	405-2	X	IEC 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	Characterization	IEC 60891 defines procedures to be followed for temperature and irradiance corrections to the measured I-V (current-voltage) characteristics of photovoltaic devices. It also defines the procedures used to determine factors relevant for these corrections. Requirements for I-V measurement of photovoltaic devices are laid down in IEC 60904-1. The main technical changes with regard the previous edition are as follows: • extends edition 1 translation procedure to irradiance change during I-V measurement; • adds 2 new translation procedures; • revises procedure for determination of temperature coefficients to include PV modules; • defines new procedure for determination of internal series resistance; • defines new procedure for determination of curve correction factor.									X	X	X	
6	405-2	X	IEC 60904-serie	Photovoltaic devices Part 1: Measurement of photovoltaic current-voltage characteristics Part 1-1: Part 1-2: Part 2: Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data IEC 60904-4:2019 RLV IEC 60904-5:2011 IEC 60904-7:2019 RLV IEC 60904-8:2014 IEC 60904-8-1:2017 IEC 60904-9:2007 IEC 60904-10:2009 IEC TS 60904-13:2018	Characterization	Defines PV module measurement techniques, mainly focused on testing performance of PV modules.					X				X			

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
7			IEC 60947-3	Low-voltage switchgear and control gear - Part 3: Switches, disconnectors, switch disconnectors and fuse-combination units	BOS	IEC 60947-3:2020 applies to switches, disconnectors, switch-disconnectors and fuse-combination units and their dedicated accessories to be used in distribution circuits and motor circuits of which the rated voltage does not exceed 1 000 V AC or 1 500 V DC. This fourth edition cancels and replaces the third edition published in 2008, Amendment 1:2012 and Amendment 2:2015. This edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition: • Addition of critical load current tests for DC switches (see 9.3.9). • Addition of requirements for a conditional short-circuit rating for disconnectors, switches, and switch-disconnectors protected by circuit-breakers (see 9.3.7.2). • Addition of new categories for high-efficiency motors switching (see Annex A). • Addition of new Annex E for connection to aluminium conductors. • Addition of new Annex F for power losses measurement.						X	X	X				
8			IEC 61173	Overvoltage protection for photovoltaic (PV) power generating systems - Guide		Gives guidance on the protection of overvoltage issues for both stand-alone and grid-connected photovoltaic power generating systems. *Note: Standard is withdrawn and replaced by requirement of IEC 60364-7-712*						X						
9	401, 401-1 405-2	X	IEC 61215-series	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval	PV Module	IEC 61215-1:2016 lays down requirements for the design qualification and type approval of terrestrial photovoltaic (PV) modules suitable for long-term operation in general open-air climates, as defined in IEC 60721-2-1. This standard is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules. The objective of this test sequence is to determine the electrical and thermal characteristics of the module and to show, as far as possible within reasonable constraints of cost and time, that the module is capable of withstanding prolonged exposure in climates described in the scope. This edition of IEC 61215-1 includes the following significant technical changes with respect to the second edition of IEC 61215:2005: new standard series structure consistent with other IEC standards: Part 1 lists general requirements, Part 1-x specifics for each PV technology and Part 2 defines testing. All tests defined in Part 2 are MQTs (module quality tests).	X				X							
10			IEC 61701	Salt mist corrosion testing of photovoltaic (PV) modules	PV Module	IEC 61701:2011 describes test sequences useful to determine the resistance of different PV modules to corrosion from salt mist containing Cl- (NaCl, MgCl2, etc.). All tests included in the sequences, except the bypass diode functionality test, are fully described in IEC 61215, IEC 61646, IEC 62108, IEC 61730-2 and IEC 60068-2-52. This Standard can be applied to both flat plate PV modules and concentrator PV modules and assemblies. Salt mist test is based on IEC 60068-2-52 rather than IEC 60068-2-11 as in edition 1 since the former standard is much more widely used in the electronic component field. According to this change the new edition 2 includes a cycling testing sequence that combines in each cycle a salt fog exposure followed by humidity storage under controlled temperature and relative humidity conditions. This testing sequence is more suitable to reflect the corrosion processes that happen in PV modules subjected to permanent or temporary corrosive atmospheres.	X				X							
11	01, 01-1, 02, 03, 04, 07	X	IEC 61724-series	Photovoltaic system performance Part 1: Monitoring Part 2: Capacity evaluation method Part 3: Energy evaluation method Part 4: Degradation rate evaluation method	Performance - System	IEC 61724 outlines equipment, methods, and terminology for performance monitoring and analysis of photovoltaic (PV) systems. It addresses sensors, installation, and accuracy for monitoring equipment in addition to measured parameter data acquisition and quality checks, calculated parameters, and performance metrics. In addition, it serves as a basis for other standards which rely upon the data collected.						X		X	X			
12			IEC 61727	Photovoltaic (PV) systems - Characteristics of the utility interface	Inverter	Applies to utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC. Lays down requirements for interconnection of PV systems to the utility distribution system.					X							

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
13	401, 401-1, 405-2	X	IEC 61730-serie	Photovoltaic (PV) module safety qualification Part 1: Requirements for construction Part 2: Requirements for testing	PV Module	IEC 61730-1:2016 specifies and describes the fundamental construction requirements for photovoltaic (PV) modules in order to provide safe electrical and mechanical operation. Specific topics are provided to assess the prevention of electrical shock, fire hazards, and personal injury due to mechanical and environmental stresses. This part of IEC 61730 pertains to the particular requirements of construction. IEC 61730-2 defines the requirements of testing. This International Standard series lays down IEC requirements of terrestrial photovoltaic modules suitable for long-term operation in open-air climates. This standard is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules. This new edition includes the following significant technical changes with respect to the previous edition: • Adaption of horizontal standards and inclusion of IEC 60664 and IEC 61140. • Implementation of insulation coordination, overvoltage category, classes, pollution degree and material groups definition of creepage, clearance and distance through insulation.	X					X		X				
14			IEC 61829	Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics	Performance - System	IEC 61829:2015 specifies procedures for on-site measurement of flat-plate photovoltaic (PV) array characteristics, the accompanying meteorological conditions, and use of these for translating to standard test conditions (STC) or other selected conditions. This new edition includes the following significant technical changes with respect to the previous edition: • It addresses many outdated procedures. • It accommodates commonly used commercial I-V curve tracers. • It provides a more practical approach for addressing field uncertainties. • It removes and replaces procedures with references to other updated and pertinent standards, including the IEC 60904 series, andIEC 60891.						X			X			
15	405-2	X	IEC 61853-serie	Photovoltaic (PV) module performance testing and energy rating Part 1: Irradiance and temperature performance measurements and power rating Part 2: Spectral response, incidence angle and module operating temperature measurements	Performance - Module	IEC 61853 describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures followed by the transition towards kWh. The object is to define a testing and rating system, which provides the PV module power (watts) at maximum power operation for a set of defined conditions. A second purpose is to provide a full set of characterization parameters for the module under various values of irradiance and temperature.	X				X	X						
16			IEC 62093	Balance-of-system components for photovoltaic systems - Design qualification natural environments	BOS	Establishes requirements for the design qualification of balance-of-system (BOS) components used in terrestrial photovoltaic systems. Is suitable for operation in indoor, conditioned or unconditioned; or outdoor in general open-air climates, protected or unprotected. Is written for dedicated solar components such as batteries, inverters, charge controllers, system diode packages, heat sinks, surge protectors, system junction boxes, maximum power point tracking devices and switch gear, but may be applicable to other BOS components.						X	X					
17	401, 401-1	X	IEC 62109-series	Safety of power converters for use in photovoltaic power systems Part 1: General requirements Part 2: Particular requirements for inverters Part 3: Particular requirements for electronic devices in combination with photovoltaic elements	Inverter	IEC 62109 applies to the power conversion equipment (PCE) for use in photovoltaic systems where a uniform technical level with respect to safety is necessary. Defines the minimum requirements for the design and manufacture of PCE for protection against electric shock, energy, fire, mechanical and other hazards. Provides general requirements applicable to all types of PV PCE.					X	X						
18	401, 401-1, 404, 407, 408-4	X	IEC 62446-series	Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance Part 1: Grid connected systems – Documentation, commissioning tests and inspection Part 2: Grid connected systems - Maintenance of PV systems Part 3: Photovoltaic modules and plants – Outdoor infrared thermography	System	IEC 62446 defines the information and documentation required to be handed over to a customer following the installation of a grid connected PV system. It also describes the commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system. It is for use by system designers and installers of grid connected solar PV systems as a template to provide effective documentation to a customer.						X			X	X		

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
19			IEC 62477-series	IEC 62477-1 Ed.1: Safety requirements for power electronic converter systems and equipment Part 1: General Part 2: Power Electronic Converters from 1,000 V a.c. or 1,500 V d.c. up to 35 kV a.c	Inverter	open (0,4-20 kV AC Hungary)					X	X						
20	401, 401-1, 403	X	IEC 62548	Photovoltaic (PV) arrays	System	EC 62548 sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads. An exception is that provisions relating to power conversion equipment are covered only where DC safety issues are involved. The interconnection of small DC conditioning units intended for connection to PV modules are also included. The object of this document is to address the design safety requirements arising from the particular characteristics of photovoltaic systems. Direct current systems, and PV arrays in particular, pose some hazards in addition to those derived from conventional AC power systems, including the ability to produce and sustain electrical arcs with currents that are not greater than normal operating currents.						X						
21			IEC 62716	Photovoltaic (PV) modules - Ammonia corrosion testing	PV Module	IEC 62716 describes test sequences useful to determine the resistance of PV modules to ammonia (NH3). All tests included in the sequences, except the bypass diode functionality test, are fully described in IEC 61215, IEC 61646 and IEC 61730-2. They are combined in this standard to provide means to evaluate possible faults caused in PV modules when operating under wet atmospheres having high concentration of dissolved ammonia (NH3).	X											
22			IEC 62782 TS	Cyclic (Dynamic) mechanical load testing for photovoltaic (PV) modules	PV Module	IEC TS 62782 provides a test method for performing a cyclic mechanical load test in which the module is supported at the design support points and a uniform load normal to the module surface is cycled in alternating negative and positive directions. This test may be utilized to evaluate if components within the module including solar cells, interconnect ribbons and/or electrical bonds within the module are susceptible to breakage or if edge seals are likely to fail due to the mechanical stresses encountered during installation and operation. This test can be performed at any module temperature within the normal operating temperature range. *NOTE: This test protocol has been written as a standalone technical specification, but it is likely to be used in conjunction with other test standards. For current multi-busbar c-Si technologies the set specifications typically do not induce any damage. Impovement of specification needed!*	X				X	X						
23			IEC 62788-2		PV Module	IEC TS 62788-2 defines test methods and datasheet reporting requirements for safety and performance related properties (mechanical, electrical, thermal, optical and chemical) of non-rigid polymeric materials intended for use in terrestrial photovoltaic modules as polymeric frontsheets and backsheets. The test methods define how to characterize backsheet and frontsheet materials and their components in a manner representative of how they will be used in the module, which eventually includes combination with other matched components such as encapsulant or adhesives. The methods described in this document support the safety and performance related tests defined on PV module level as defined in the series IEC 61730 and IEC 61215. This document also defines test methods for assessment of inherent material characteristics of polymeric backsheets and frontsheets or their components.							X					
24			IEC 62790	Junction boxes for photovoltaic modules - Safety requirements and tests. EN 50548 Junction boxes for photovoltaic modules - Safety requirements and tests	BOS-Module	IEC 62790 describes safety requirements, constructional requirements and tests for junction boxes up to 1 500 V dc for use on photovoltaic modules according to class II of IEC 61140:2001. This standard applies also to enclosures mounted on PV-modules containing electronic circuits for converting, controlling, monitoring or similar operations.					X	X	X					

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
25	401	X	IEC 62804-series	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation Part 1 System voltage durability qualification test for crystalline silicon modules Part 1-1: Delamination for crystalline silicon PV modules Part 2: Thin-film	PV Module	IEC TS 62804 defines procedures to test and evaluate the durability of photovoltaic (PV) modules to the effects of short-term high-voltage stress including potential-induced degradation (PID). Test methods are defined that do not inherently produce equivalent results. They are given as screening tests; neither test includes all the factors existing in the natural environment that can affect the PID rate. The methods describe how to achieve a constant stress level. The testing in this Technical Specification is designed for crystalline silicon PV modules with one or two glass surfaces, silicon cells having passivating dielectric layers, for degradation mechanisms involving mobile ions influencing the electric field over the silicon semiconductor, or electronically interacting with the silicon semiconductor itself.	X				X	X						
26			IEC 62852	Connectors for DC-application in photovoltaic systems - Safety requirements and tests EN 50521 Connectors for photovoltaic systems - Safety requirements and tests	BOS	IEC 62852 applies to connectors for use in the d.c. circuits of photovoltaic systems according to class II of IEC 61140:2001 with rated voltages up to 1 500 V d.c. and rated currents up to 125 A per contact. It applies to connectors without breaking capacity but which might be engaged and disengaged under voltage.					X	X						
27			IEC 62909-series	Bi-directional grid connected power converters Part 1: General requirements Part 2: Interface of GCPC and distributed energy resources and additional requirements to Part 1	Inverter	IEC 62909-1:2017 specifies general aspects of bi-directional grid-connected power converters (GCPC), consisting of a grid-side inverter with two or more types of DC-port interfaces on the application side with system voltages not exceeding 1 000 V AC or 1 500 V DC. In special cases, a GCPC will have only one DC-port interface, which is connected to a bidirectional energy-storage device. This document includes terminology, specifications, performance, safety, system architecture, and test-case definitions. The "system architecture" defines interaction between the inverter and converters. Requirements which are common, general, and independent of special characteristics of individual generators and bi-directional storages are defined. This document does not cover uninterruptible power supply (UPS) systems, which fall under the scope of IEC 62040 (all parts). Requirements for internal and external digital communication might be necessary; the interface requirements including communication with distributed energy resources are provided in a future part of IEC 62909. All EMC requirements are defined by reference to existing IEC standards. External communication requirements are out of scope of this document.						X						
28			IEC 62910	Test procedure of Low Voltage Ride-Through (LVRT) measurement for utility-interconnected photovoltaic inverter	Inverter	IEC TS 62910 provides a test procedure for evaluating the performance of Low Voltage Ride-Through (LVRT) functions in inverters used in utility-interconnected PV systems. The technical specification is most applicable to large systems where PV inverters are connected to utility HV distribution systems. However, the applicable procedures may also be used for LV installations in locations where evolving LVRT requirements include such installations, e.g. single-phase or 3-phase systems. The measurement procedures are designed to be as non-site-specific as possible, so that LVRT characteristics measured at one test site, for example, can also be considered valid at other sites. This technical specification is for testing of PV inverters, though it contains information that may also be useful for testing of a complete PV power plant consisting of multiple inverters connected at a single point to the utility grid. It further provides a basis for utility-interconnected PV inverter numerical simulation and model validation.									X	X		
29	405-2	X	IEC 62915 TS	Photovoltaic (PV) Modules - Retesting for type approval, design and safety qualification	PV Module	IEC TS 62915 sets forth a uniform approach to maintain type approval, design and safety qualification of terrestrial PV modules that have undergone, or will undergo modification from their originally assessed design. Changes in material selection, components and manufacturing process can impact electrical performance, reliability and safety of the modified product. This document lists typical modifications and the resulting requirements for retesting based on the different test standards. This document is closely related to the IEC 61215 and IEC 61730 series of standards.	X					X	X					

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
30			IEC 62930	Electric cables for Photovoltaic systems EN 50618	BOS	IEC 62930 applies to single-core cross-linked insulated power cables with cross-linked sheath. These cables are for use at the direct current (DC) side of photovoltaic systems, with a rated DC voltage up to and including 1,5 kV between conductors and between conductor and earth. This document includes halogen free low smoke cables and cables that can contain halogens. The cables are suitable to be used with Class II equipment as defined in IEC 61140. The cables are designed to operate at a normal continuous maximum conductor temperature of 90 °C. The permissible period of use at a maximum conductor temperature of 120 °C is limited to 20,000 h.					X	X	X					
31			IEC 62938	Non-uniform snow load testing for photovoltaic (PV) modules	PV Module	IEC 62938 provides a method for determining how well a framed PV module performs mechanically under the influence of inclined non-uniform snow loads. This document is applicable for framed modules with frames protruding beyond the front glass surface on the lower edge after intended installation and as such creates an additional barrier to snow sliding down from modules. For modules with other frame constructions, such as backrails formed in frames, on the side edges, on the top edge and on the lower edge not creating an additional snow slide barrier, this document is not applicable. The test method determines the mechanical non-uniform-load limit of a framed PV module.	X					X	X					
32	401-1, 405-1, 405-2	X	IEC 62941	Terrestrial photovoltaic (PV) modules - Quality system for PV module manufacturing	QM	IEC 62947 is applicable to organizations manufacturing photovoltaic (PV) modules certified to IEC 61215 series and IEC 62108 for design qualification and type approval and IEC 61730 for safety qualification and type approval. The design qualification and type approval of PV modules depend on appropriate methods for product and process design, as well as appropriate control of materials and processes used to manufacture the product. This document lays out best practices for product design, manufacturing processes, and selection and control of materials used in the manufacture of PV modules that have met the requirements of IEC 61215 series, IEC 61730, or IEC 62108. These standards also form the basis for factory audit criteria of such sites by various certifying and auditory bodies. The object of this document is to provide a framework for the improved confidence in the ongoing consistency of performance and reliability of certified PV modules. The requirements of this document are defined with the assumption that the quality management system of the organization has already fulfilled the requirements of ISO 9001 or equivalent quality management system. This document is not intended to replace or remove any requirements of ISO9001 or equivalent quality management system. By maintaining a manufacturing system in accordance with this document, PV modules are expected to maintain their performance as determined from the test sequences in IEC 61215 series, IEC 62108, or IEC 61730.	X				X	X	X					
33			IEC 62979	Photovoltaic module bypass diode thermal runaway test	BOS-Module	IEC 62979 provides a method for evaluating whether a bypass diode as mounted in the module is susceptible to thermal runaway or if there is sufficient cooling for it to survive the transition from forward bias operation to reverse bias operation without overheating. This test methodology is particularly suited for testing of Schottky barrier diodes, which have the characteristic of increasing leakage current as a function of reverse bias voltage at high temperature, making them more susceptible to thermal runaway.						X	X	X				
34			IEC 63126 TR	Guidelines for qualifying PV modules, components and materials for operation at high temperatures	Module	This Technical Specification defines additional testing requirements for modules deployed under conditions of higher temperature which are beyond the scope of IEC 61215 and IEC 61730 and the relevant component standards, IEC 62790 and IEC 62852. The testing conditions specified in IEC 61215 and IEC 61730 (and the relevant component standards IEC 62790 and IEC 62852) assumed that these standards are applicable for module deployment where the 98th percentile temperature (T 98th), that is the temperature that a module would be expected to equal or exceed for 175,2 hours per year, is less than 70 °C.												
35			IEC 63209	Extended-stress testing of photovoltaic modules for risk analysis		This technical specification is intended to provide a set of data to be used for qualitative reliability risk analysis, highlighting potential failure modes and areas possibly in need of improvement. It is only useful for rank ordering modules and materials for special cases, for very large differences in performance, or with respect to specific understood failure modes and mechanisms. A robust module level rank ordering or service life prediction is beyond the scope of this document. A series of component test suites is in development to complement the module level testing in this specification.		X										

#	IECRE OD's 4xx	IECRE OD 411-series	Standard reference	Title	Related component	Short description for most relevant documents [most descriptions are taken from IEC.ch, ISO.org and VDE-Verlag.de webpage]	Lifecycle of Quality Management	Risk Assessment	Environment, Health & Safety	Personnel & training	Development	Engineering	Procurement	Construction	Commissioning	Handover to O&M	Key Performance Indicators	Contractual framework
36			IEC 63225 TR	Incompatibility of connectors for DC-application in photovoltaic systems	System	This docuememt highlights the problem of incompatibility of connectors for DC-application in photovoltaic systems (DC connectors) produced by different manufacturers. It addresses four particular issues in that context: • Background information on incompatibility of DC connectors from different manufacturers. • Observations and challenges concerning the handling of DC connectors from different manufacturers. • Stakeholders concerned by the incompatibility of DC connectors. • Recommendations for long-term standardization and interim measures to address incompatibility of DC connectors					X	X						
37			IEC 63279 TR	Sequential and combined accelerated stress testing for de-risking photovoltaic modules	Module	This Technical Report reviews research into sequential and combined accelerated stress tests that have been devised to determine the potential for degradation modes in PV modules that occur in the field that single-factor and steady-state tests do not show. This document is intended to provide data and theory-based motivation and help visualize the next steps for improved accelerated stress tests that will derisk PV module materials and designs. Any incremental savings as a result of increased reliability and reduced risk translates into lower levelized cost of electricity associated with the PV power plant. Lower costs will result in faster adoption of PV and the associated benefits of renewable energy.												
38			ISO 2859-1	Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection	System	ISO 2859-1 specifies an acceptance sampling system for inspection by attributes. It is indexed in terms of the acceptance quality limit (AQL). Its purpose is to induce a supplier through the economic and psychological pressure of lot non-acceptance to maintain a process average at least as good as the specified acceptance quality limit, while at the same time providing an upper limit for the risk to the consumer of accepting the occasional poor lot.												
39			ISO 9001	Quality management systems — Requirements	QM	ISO 9001 sets out the criteria for a quality management system and is the only standard in the family that can be certified to (although this is not a requirement). It can be used by any organization, large or small, regardless of its field of activity. This standard is based on a number of quality management principles including a strong customer focus, the motivation and implication of top management, the process approach and continual improvement. These principles are explained in more detail in ISO's quality management principles. Using ISO 9001 helps ensure that customers get consistent, good-quality products and services, which in turn brings many business benefits.	X	X	X	X								
40			ISO 14001	Environmental management systems — Requirements with guidance for use	QM	ISO 14001 specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance. ISO 14001:2015 is intended for use by an organization seeking to manage its environmental responsibilities in a systematic manner that contributes to the environmental pillar of sustainability.	X	X	X									
41			ISO 17020	Conformity assessment — Requirements for the operation of various types of bodies performing inspection	QM	ISO/IEC 17020:2012 specifies requirements for the competence of bodies performing inspection and for the impartiality and consistency of their inspection activities. It applies to inspection bodies of type A, B or C, as defined in ISO/IEC 17020:2012, and it applies to any stage of inspection.							X					
42			ISO 17025	General requirements for the competence of testing and calibration laboratories	QM	ISO/IEC 17025:2005 specifies the general requirements for the competence to carry out tests and/or calibrations, including sampling. It covers testing and calibration performed using standard methods, non-standard methods, and laboratory-developed methods. It is applicable to all organizations performing tests and/or calibrations. These include, for example, first-, second- and third-party laboratories, and laboratories where testing and/or calibration forms part of inspection and product certification.							X					

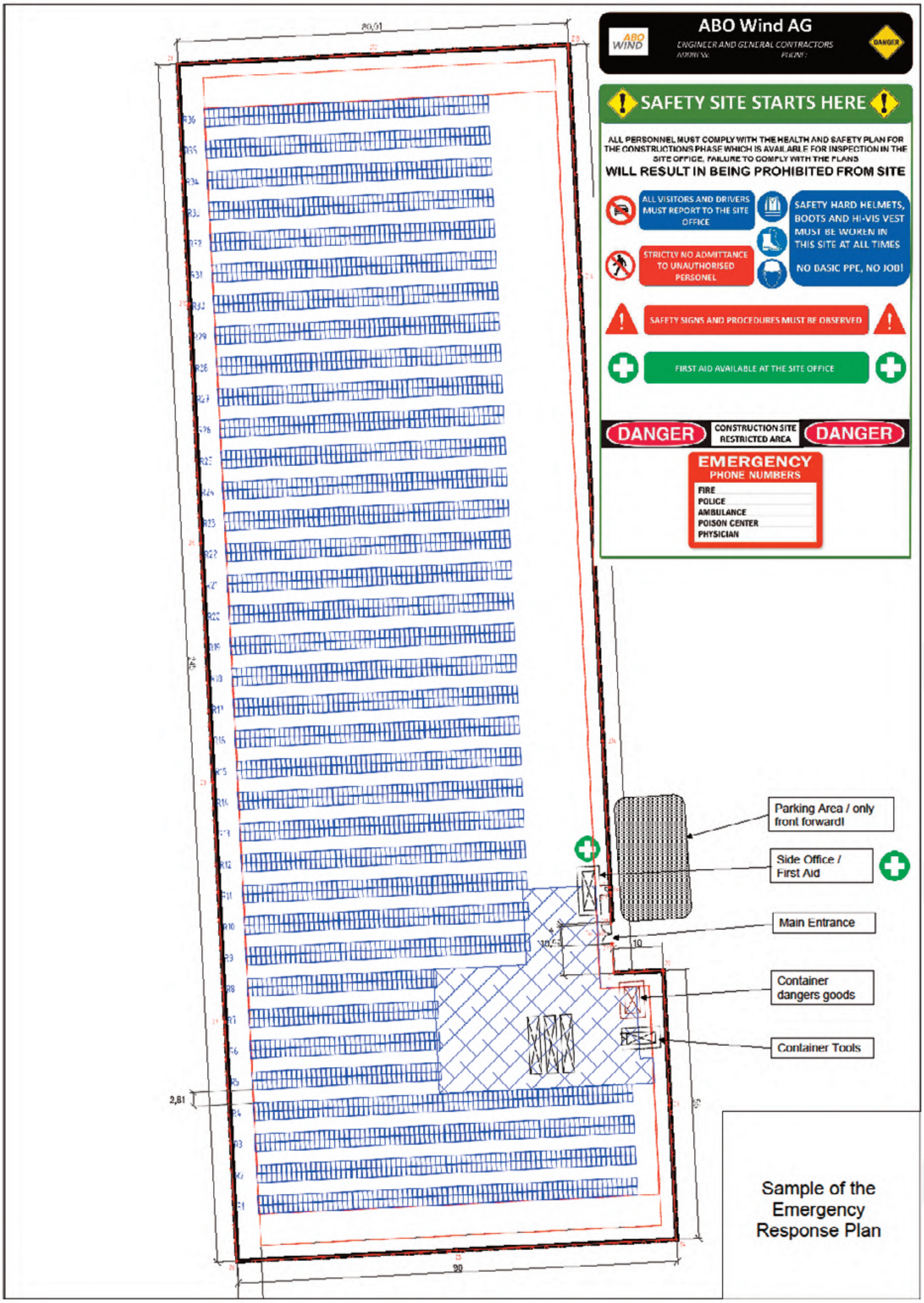
B. Skills matrix - Personnel and training

	Tasks	Required certification	Required skills	Function: Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Static engineer	Geographical - Geotechnical
Site assesment	Risk Assesement - health and	Certification (postgrad) of Occupational Health &									X		
	Risk Assesement - mechanical	Static engineer		X								X	
	Related partly solar specific regulations (heritage protection, building authority)			X		X							
Authorisation	Communication with Electricity Provider	Certified electric engineer	Knowledge about actual standards and regulation, managerial and communication skills	X		X							
	Create and submit authorization documentation	Country related licence for designing renewable energy structures				X							
Procure -ment	Purchasing PV modules, Frames, Inverters, electrical materials etc. Manage Supplier			X	X								
Logistics, Organisation	Managing transportation of personnel, materials and tools				X								
	Organization planning on site						X	X					
Construction	PV Module	Certified electrician	Basic knowlege about the installed product (e.g. handling, general sefety guidlines, installation etc.; see also recommendations by module manufacturer/installation manual, thermography, power measurements)				X	X					
	Inverter	Certified electrician	Power Electronics (e.g. experience with specific product and type of inverter)				X						
	Electric - General	Certified electrician	Other relevant skills (e.g. Specific Inspection & Test training, relevant accredited courses etc.)				X						
	Data & Communications	Certified electrician	Termination of specific communication cabling, monitoring/SCADA, satelite/broadband system				X			X			
	Mounting	Company or country relevant requirements (e.g. working at height, Certified industrial alpinist, asbestos awareness, use of specific equipment, construction/installation certificate etc.)	Basic knowlege about the installed product (e.g. handling, general sefety guidlines, installation etc.; see also recommendations by supplier/installation manual), technical experience					X					
	Preparatory works if needed (e.g. earthwork, roof works etc)	Specific job-related certification	Specific job-related skills	X								X	X
	Technical Lead - Electrical (Responsible for all electrical works and guides electric installers.)	Certified electrician. Country related licence and certification	Advanced knowledge and experience in solar system's electric works. Managerial skills, experience in supervision and coordination of teams				X						
	Technical Lead - Mechanical (Responsible for all mechanical works (mounting) and guides installers.)	Country related licence and certification	Advanced knowledge and experience in mounting solar systems. Managerial skills, experience in supervision and coordination of teams					X					
	Mechanical - Structural								X			X	

B. Skills matrix - Personnel and training *continued.*

	Tasks	Required certification	Required skills	Function: Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Static engineer	Geographical -
Health & Safety	High Voltage (HV) Substation Access									X			
	Inspection - electrical work (Touch protection, tests etc)	Certified electrician. Country related licence and certification for touch protection control	Accuracy, advanced knowledge about related standards. Experience in measuring process.						X				
	Risk Assessment	Certification of Occupational Health & Safety											
	Occupational Health & Safety training course	First Aid at Work											
	Managing contractors												
	Other task, company or country relevant requirements (e.g. working at height, asbestos awareness, use of specific equipment, construction/installation certificate etc)												
Environment	Training course and/or certificate	Certificate of Environmental Management											
Monitoring and metering	Installing monitoring system (WIFI, SCADA, Connection, Settings)	Knowledge of using monitoring tools	Monitoring tool training. Other relevant skills (e.g. data handling tool)				X			X			
	Meter accreditation and calibration	Only elecricity providers authorized person				X							
Warranty sevices	Handling during construction as well as ensure warranty conditions are kept.			X			X	X		X			

C. Example for Emergency response plan



SOURCE: ABO WIND.

D Annex

D. Risk assessment matrix and hierarchy of controls (template)

Consider the severity of injury/illness	Consider the likelihood of a hazardous even occuring				
	Very unlikely to happen	Unlikely to happen	Possibly could happen	Likely to happen	Very likely to happen
Catastrophic (e.g. fatal)	Moderate	Moderate	High	Critical	Critical
Major (e.g. permanent disability)	Low	Moderate	Moderate	High	Critical
Morderate (e.g. hospitalisation/short or long term disability)	Low	Moderate	Moderate	Moderate	High
Minor (e.g. first aid)	Very low	Low	Moderate	Moderate	Moderate
Superficial (e.g. no treatment required)	Very low	Very low	Low	Low	Moderate

Eliminate:		Most effective
1. **Eliminate the hazard.** Remove it completely from your workplace.	If this isn't reasonably practicable, then...	↓
Minimise:		
2. **Substitute the hazard.** Wholly or partly, with a safer alternative. **Isolate the hazard.** Using physical barriers, time or distance. **Using engineering controls.** Adapt tools or equipment to reduce the risk.	Minimise the risk so far as reasonable practicable, by taking 1 or more of these actions that is the most approprate.	
3. **Use administrative controls.** Develop methods of work, processes and procedures.	If a risk then remains, you must minimise the remaining risk, so far as reasonably practicable.	
4. **Use personal protective equipment (PPE).** This is the last option after you have considered all the other options for your workplace.	If a risk then remains you must minimise the remaining risk by using PPE.	Least effective

E. Examples of Lagging and Leading HSSE KPIs.

Lagging Indicators	
Property/equipment damage	Permits necessary for project construction and operation, including: • Damage to array frame • Damage to buildings • Damage to fence line after a tree is blown over Restricted Work Cases: Any work-related injury or illness when an employer, physician or other licensed health care professional keeps or recommends keeping a member of the workforce: • (A) from performing one or more of the routine functions of his or her job; or • (B) from working the full workday that he or she would otherwise have been scheduled to work or is transferred to a different job for all or part of his/ her period of recuperation. • A routine function is considered to be a work activity the person regularly performs at least once per week as part of his or her job.
First Aid	A first aid case occurs when the treatment of the resultant injury or illness is limited to one or more of the 14 specific treatments below: 1. Using a non-prescription medication at non-prescription strength. 2. Administering tetanus immunizations. 3. Cleaning, flushing or soaking wounds on the surface of the skin. 4. Using wound coverings such as bandages, gauze pads, etc.; or using butterfly bandages. 5. Using hot or cold therapy. 6. Using any non-rigid means of support, such as elastic bandages, wraps, non-rigid back belts, etc. 7. Using temporary immobilization devices while transporting as accident victim. 8. Drilling of a fingernail or toenail to relieve pressure or draining fluid from a blister. 9. Using eye patches. 10. Removing foreign bodies from the eye using only irrigation or a cotton swab. 11. Removing splinters or foreign material from areas other than the eye by irrigation, tweezers, cotton swabs or other simple means. 12. Using finger guards. 13. Using massages. 14. Drinking fluids for relief of heat stress.
Medical Treatment Case	Medical treatment (MT) means the management and care of a patient to combat disease or disorder. Medical treatment does not include visits to a physician or other licensed health care professional solely for observation or counselling, the conduct of diagnostic procedures, such as x-rays and blood tests, including the administration of prescription medications used solely for diagnostic purposes (for example eye drops to dilate pupils), or first aid.
Days Away From Work Case	Any work-related injury or illness which, based on a recommendation by a physician or licensed health care professional, results in a member of the Workforce or contractor being unable to work on any day after the injury or illness. In such cases, an injury or illness is considered to be a DAFWC regardless of whether or not the person was scheduled to work on those day(s) or if the person actually reports to work or not.
High Potential HiPo	Any incident or near miss that could, in other circumstances, have 'realistically' resulted in one or more fatalities e.g.: • Flash over occurred with someone stood in front of the failed equipment and only suffered minor injuries. • Live Overhead or Underground Line Strike with no injuries • Vehicle accident • Failure of lifting equipment whilst lift is being performed
Major Incident	Major Health/Safety incident - 1 or more fatalities, 3 or more injuries or health effects requiring hospital treatment for more than 24 hours.
Reportable	Relevant country specific incidents that must be reported to external authorities e.g.: • Aus – WorkSafe Notifiable Incident, EPA Notifiable • UK – RIDDOR Dangerous Occurrence, or • Have been reported to an external authority by a third party as a compliant and on investigation that complaint could be upheld e.g.e.g., US – OSHA Reportable Incident / Whistle Blower Complaint

E. Examples of Lagging and Leading HSSE KPIs.

Lagging Indicators *continued*	

Recordable	Recordable: An injury or illness and injury incidents that meet any of the listed criteria in either the 'general' or 'specific' categories must be considered recordable:
	• General
	  • Death
	  • One or more days away from work
	  • One or more days of restricted work
	  • One or more days of transfer to another job
	  • Medical treatment beyond first aid
	  • Loss of consciousness
	A significant injury or illness diagnosed by a physician or other licensed health professional, such as:
	  • Cancer
	  • Chronic irreversible disease
	  • Fractured or cracked bone
	  • Punctured eardrum
	• Specific
	  • Needlestick injuries and cuts from sharp objects that are contaminated with another person's blood or other potentially infectious material.
	  • Work-related Standard Threshold Shift (STS) based on current hearing test indicating a 10dBA shift from current baseline in one or both ears, and a total cumulative hearing loss must be 25dBA or more above audiometric zero in the same ear(s) as the STS.
	  • Medical removal under Government standards.
	  • Tuberculosis infection as evidence by a positive skin test or diagnosis by a physician or other licensed health care professional after known exposure in the LSBP work environment.

Leading Indicators	
Leadership site visits	Number of audits and reviews conducted
Actions identified	Actions identified and tracked to closure
Near Miss	An incident that did not, but had the potential to, affect the health, safety or security of people, assets or the environment.
Unsafe Condition	Any performance or condition of equipment, procedure, process operations, or working environment that did not, but could have either resulted in an incident or made an incident more likely and/or severe that can be immediately rectified e.g.: • Loose panel on the array that is immediately tightened to the correct torque • Access gates/door to HV/MV areas that are left unlock and unattended • Any live electrical cabinet/box that has been left open and unattended
Good Catches	Good catches

F Annex

F. Design documentation.

Basic Design – Development Documentation – Level A			
ID Level-#	Document(s) Title	Description/Comment	Requirement
A-1	Site assessment	• Topographical, archaeological and geotechnical (including seismic risk) • Hydrology • Soil conditions inclusive of any contamination for development • Logistics impact Study • Land cost • Proof of land ownership or lease • Restrictions and access information	Minimum requirement
A-2	Solar resource analysis	The study of the long-term solar resource to determine the long-term average irradiation and temperature at the site using long-term reference sources.	Minimum requirement
A-3	Environmental studies	• Studies required for compliance with county, state and federal requirements are underway or completed; these studies include but are not limited to environmental survey, wildlife studies, wetland and water studies, rare plant studies, cultural/historic resource reports, etc. • Identify potential environmental or social risk to the project. • Presence of built structures, residences or communities on-site or near project site or observations/visual evidence of recent or current land use.	Recommendation
A-4	Permitting	Permits necessary for project construction and operation, including: • Requirements related to environmental regulations • Local entitlements • Electrical contracting permits • Building permits	Minimum requirement
A-5	Logistics impact study	Equipment transportation route and access road and transmission line route and right of way	Recommendation
A-6	Interconnection assessment	Grid connection study verifying: • The impact of the project connection • Potential structure necessary for its connection in the proposed POI • Communication system requirement • Power factor requirements • Current policies	Best practice
A-7	Technical Concept	Preliminary Project Design providing: • Installed Capacity: Wp and Wac • Major Equipment: Modules, Inverters, type of structure, Transformers • Preliminary SLD and Layout	Minimum requirement
A-8	Interconnection agreement	Transmission and interconnection agreements, relating also to the direct and ancillary infrastructure	Recommendation
A-9	Offtake agreement	An executable agreement between Project Company and the energy offtake. If the project is in a regulated market, approval by a public utilities or other agencies may also be required.	Recommendation
A-10	Contracts	Definition of the project contracts structure: • EPC contract • O&M Contract • Owner's engineering Contract • Procurement agreements • Lender's agreement	Best practice
A-11	Financials	Financial Model considering all the costs and revenues from the items of the present list, for the project lifetime	Best practice

Preliminary Design – Pre-Construction Documentation – Level B				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
B-1	Contractor's Specification(s), Site layout	Proposed aggregation and layout of the: • PV Array sections • Inverter Stations • Substation • Cable routes • Access roads • Laydown areas • Meteorological stations • Site tracks • Pits • Construction area • Permanent and temporary buildings	Before Construction Stage	Minimum requirement
B-2	Contractor's Specification(s)	As Project documentation the Contractor shall provide a list of: • Standards relevant to the Works • Equipment suppliers of Project major components • Sub-contractors	Before Construction Stage	Best practice
B-3	Contractor's Specification(s), Amenities Building	Functional description and conceptual design specification	Before Construction Stage	Minimum requirement
B-4	Contractor's Specification(s), Control Building, including MV Switch room	Functional description and conceptual design specification	Before Construction Stage	Minimum requirement
B-5	Grid Connection Performance Standard Template	The Contractor shall supply a completed performance standard template stating the proposed level of compliance to each access standard in accordance with utility standards	Before Construction Stage	Recommendation
B-6	Design Life	• Design Life for PV Modules, Inverters, PV Mounting Structures and other major components • Design Life of components that do not meet the requirements of Design Life	Before Construction Stage	Best practice
B-7	Loss of grid power - Method statements and procedures	Provide method statements and procedures to achieve the aim of ensuring the Works are able to withstand periods without grid electrical power	Before Construction Stage	Minimum requirement
B-8	Training package and programme	Training plan as required to support the off-site and in-field training of the Employer's personnel	Before Construction Stage	Best practice
B-9	PV Module specifications	The following documents shall be submitted by the Contractor. • Datasheets • Type test certificates to Applicable Standards and test reports • Accelerated test certificates • Proposed module bill of material (if available) • Warranty terms	Before Construction Stage	Minimum requirement
B-10	Inverter specifications	The following documents shall be submitted by the Contractor. • Datasheet • Type test certificates to Applicable Standards and test reports • Test certificates • Warranty terms	Before Construction Stage	Minimum requirement
B-11	Mounting Structure	The following documents shall be submitted by the Contractor. • Datasheet • The latest installation figures for the proposed PV Module Trackers along with an indication of the operational track record • Type test certificates to Applicable Standards and test reports • Test certificates • Warranty terms	Before Construction Stage	Minimum requirement
B-12	Mounting Structure – Preliminary study	Preliminary design information including footing design, construct; general arrangement drawings	Before Construction Stage	Minimum requirement
B-13	Civil Works, Specifications	Where not covered by the site layout an outline of proposed BOP Civil Works, including Overview specifications	Before Construction Stage	Minimum requirement

Preliminary Design – Pre-Construction Documentation – Level B *continued*				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
B-14	Amenities Building	Functional description and conceptual design specification	Before Construction Stage	Minimum requirement
B-15	Other Parts (e.g. transformer, switchgear, cables, DC Combiner Box, Met Station, etc.)	The following documents shall be submitted by the Contractor: • Datasheet • Track records • Type test certificates to Applicable Standards and test reports • Warranty terms	Before Construction Stage	Minimum requirement
B-16	Electrical System, Specifications (as part of the Contractor's Specification)	Outline of proposed electrical systems up to and including the Point of Connection, including all single line diagrams, cable routes, cable specifications and protections	Before Construction Stage	Minimum requirement
B-17	Electrical System, HV/MV Transformer Specifications (if applicable)	Proposed substation transformer specification	Before Construction Stage	Minimum requirement
B-18	SCADA & communications system	Information on the SCADA & communications system, including specifications and drawings	Before Construction Stage	Minimum requirement
B-19	Met Station	Information on the Met Station installations including number of Met Stations, location and instrumentation specifications.	Before Construction Stage	Minimum requirement
B-20	Commissioning and Testing, Plan	Proposed testing plan for Section and/or Practical Completion including but not limited to: • List of the Commissioning Tests (Civil, Mechanical, Electrical and Communication) • Acceptance Criteria for each Commissioning Tests • Checklists and procedures for each Commissioning Tests • Performance Tests methodology • SCADA Commissioning Tests	Before Construction Stage	Best practice
B-21	Recommended spares	List of components and consumables that do not satisfy the Design Life for the Works	Before Construction Stage	Recommendation
B-22	Special tools and vehicles	List of all the tools, vehicles or equipment required for the safe and effective operation and maintenance of the Plant	Before Construction Stage	Recommendation
B-23	Project Management, Project Plan	Proposed Project Plan including list of key personnel with CVs and project organisation diagram	Before Construction Stage	Recommendation
B-24	Project Management, Project Schedule	Proposed Schedule Including milestone dates for completion	Before Construction Stage	Minimum requirement
B-25	Sub-contractors	A list of all sub-contractors	Before Construction Stage	Best practice
B-26	Work Method Statement	Draft work method statement for the construction of the Solar Farm	Before Construction Stage	Best practice
B-27	Quality Management, System Description	Description of the Contractor's quality management system and associated certificates	Before Construction Stage	Recommendation
B-28	Quality Management, Plans	Proposed Quality Management Plans applicable to: • Design of the Works • Manufacture of the Works • Installation and erection of the Works • Testing, commissioning, and Practical Completion of the Works Shall include, where appropriate, references for FATs of major components.	Before Construction Stage	Best practice
B-29	EH&S Management system	• EH&S Policy (dated and signed) • Description of the Contractor's EH&S System • Health, Safety, and Environment management plans	Before Construction Stage	Recommendation
B-30	Document Register	Proposal defining the contract drawings and documents in the form of a Document Register	Before Construction Stage	Minimum requirement
B-31	Energy Generation Summary	Report summarising loss parameters and energy estimates for the Solar Farm	Before Construction Stage	Minimum requirement
B-32	PVsyst model	The Contractor will provide their PVsyst model file (including all supporting component, horizon and other necessary files) to support their energy production figure	Before Construction Stage	Minimum requirement

Execution Design – Construction Documentation – Level C				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
C-1	Grid Connection Data and Settings	The Contractor shall provide, and update as required, data and settings as required by the utility	Duration of the Contract	Minimum requirement
C-2	Grid Connection Documentation	All required information to assist the Principal in its application for Grid Connection	Duration of the Contract	Minimum requirement
C-3	Grid Connection Performance Standard Template	The Contractor shall supply a completed performance standard template stating the proposed level of compliance to each access standard in accordance with the utility	In time required to allow Employer review in accordance with the EPC Contract but no less than 4 weeks prior to start of relevant work	Minimum requirement
C-4	Work Method Statements	For all parts of the Works	By the time required to allow the Employer review in accordance with the EPC Contract but no less than 8 weeks prior to start of relevant work	Minimum requirement
C-5	Detailed Specifications	Full specification of the PV Module, Inverters, Transformers, MV and HV Switchgear, SCADA and Met Stations including specifications of all main components	2 months after contract award	Minimum requirement
C-6	PV Array Design Report	The Contractor shall submit PV Design Report describing the Contractor's approach in addressing Project design risks, such as PID, shading and others	2 months after contract award	Best practice
C-7	PV Array, General Arrangement Drawings	Includes the general arrangement drawings of all elements and structures and buildings	4 weeks after contract award	Minimum requirement
C-8	PV Mounting Structures, Civil / Structural Design Report	• Design calculations • Demonstration of suitability of all structural components in extreme wind conditions and over the design life • Detailed foundation specifications and design • Borehole logs and geotechnical test results	2 months after contract award	Minimum requirement
C-9	PV Mounting Structure, 3rd party structural design report	3rd Party and manufacturer Report confirming the suitability of the PV Mounting Structure for the site conditions	In time required to allow Employer review in accordance with the EPC Contract but no less than 8 weeks prior to start of relevant work	Minimum requirement
C-10	Civil Works, Geotechnical investigation report	Comprehensive geotechnical investigation, including all different sections of the project	After contract award but prior to design and construction of the related items of Works	Minimum requirement
C-11	Civil Works, Hydrology and flood study	To confirm the design for flood requirements for a 1 in 100-year flooding event	After contract award but prior to design and construction of the related items of Works	Minimum requirement
C-12	Civil Works, Civil / Structural Design Report	The design report shall contain, as a minimum, all method statements, design inputs, design calculations, specifications, design drawings, cross sections, layouts and studies	2 months after contract award	Minimum requirement
C-13	Civil Works, Method statement	Method statement for all Civil Works	2 months after Contract award	Minimum requirement
C-14	Civil Works, Concrete and Grout Design Supporting Information	The Contractor shall provide evidence from field, production or trial tests to justify the design of the concrete or grout mix proposed	2 months after contract award	Minimum requirement
C-15	Civil Works, Civil/structural designs – 3rd party approval	All civil/structural works shall be independently checked and approved by a certified structural engineer	In time required to allow Employer review in accordance with the EPC Contract but no less than 8 weeks prior to start of relevant installation work	Minimum requirement
C-16	Electrical Works, Electrical power system studies and design calculations reports	Electrical design report(s) with detailed calculations indicating method, assumptions and outcomes of design and dimensioning of all elements in the Electrical System, having regard to the potential output of the PV Module, Inverter, the Employer's reliability and availability requirements and good electricity industry practice	2 months after contract award	Minimum requirement
C-17	Electrical Works, Electrical system design report	Design of proposed electrical systems AC design, DC design and Earthing drawings	2 months after contract award	Minimum requirement
C-18	Electrical Works, Cable route layout and associated design	Cable Route Layout and associated design drawings	2 months after contract award	Minimum requirement

Execution Design – Construction Documentation – Level C *continued*				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
C-19	Electrical Works, Detailed specifications and design drawings	Full specification and design drawings of all elements of the Electrical System	4 weeks before commencement of the relevant works	Minimum requirement
C-20	Electrical Works, Electrical System optimisation report	Final optimisation of power cable conductor size.	2 months after contract award	Minimum requirement
C-21	Electrical Works, Lightning protection study and risk assessment	Detailed assessment of lightning risk to personnel and Works in accordance with Applicable Standards. Diagrams (plan and elevation) showing lightning mast locations (if applicable) and lightning protection zones using rolling sphere method	8 weeks before commencement of the relevant works	Minimum requirement
C-22	Electrical Works, Protection settings signoff	Written endorsement by the Employer and/or the utility for the protection system	Prior to energisation	Minimum requirement
C-23	Electrical Works, Electrical certification	Electrical Safety Certificates for all electrical works to Applicable Laws, Regulations and Standards	Prior to energisation	Minimum requirement
C-24	Electrical Works, Method statement	Method statement for all Electrical Works	2 months after Contract award	Minimum requirement
C-25	Electrical Works, Earthing verification report	Earthing verification report	2 months prior to energisation of the Works.	Minimum requirement
C-26	Electrical Works, Reactive Plant voltage regulation & reactive power control design report	Voltage regulation and reactive power flow control design report	2 months after Contract award	Minimum requirement
C-27	Electrical Works, Electrical / Control Drawings & Documentation	Single line diagram of the Solar Farm using Standard electrical symbols, in sufficient detail to show all protective devices, overvoltage protection, isolation and earthing facilities	During Contract duration	Minimum requirement
C-28	Electrical Works, MV/HV Works Electrical System Design Report	Design of proposed electrical MV/HV systems	6 months after Contract award	Minimum requirement
C-29	SCADA, Design report	Details of inverter station interfacing, Solar Farm and Substation and XX kV equipment with design inputs, design criteria, design outputs	6 months after Contract award	Minimum requirement
C-30	SCADA, Warranty calculation method & results	Documentary evidence that the SCADA system is sufficient for recording and analysis of the data for the warranty tests	6 months after contract award	Best practice
C-31	SCADA, Detailed function specifications and design drawings	Detailed functional specification and design drawings of all elements of the SCADA & Communications System Documentation including manuals, quality control, installation, commissioning and testing procedures	6 months after contract award	Minimum requirement
C-32	Met Station, Design report	Specification and drawings for meteorological masts including but not limited to: • Instrumentation specifications and calibrations • General layout • UPS • Power supply and SCADA connection.	2 months prior to commencement of relevant works	Minimum requirement
C-33	Method statement – Delivery to Site	An installation report for each met station		Minimum requirement
C-34	Transport route	For Inverter Stations and other critical equipment and oversize	6 weeks before commencement	Best practice
C-35	Pre-delivery condition survey of the transport route	loads A report that details the proposed access roads to be used	of shipping or transport of any items	Recommendation
C-36	Inspection and Test Plan (ITPs)	together with any off-Site road improvement required and conditions of transportation.	1 month prior to site mobilisation	Recommendation
C-37	Type test certificates	Condition survey of the transport route to the Site Access Point.	1 month prior to site mobilisation	Minimum requirement
C-38	Factory acceptance test schedule	Type test certificates for all Plants or Equipment	2 weeks prior to first FAT	Recommendation
C-39	Factory acceptance test results	Test schedule for all major equipment	8 weeks before commencement of the relevant Site works	Recommendation
C-40	Factory Acceptance Tests, Certificates and Reports, Electrical Works	Copies of test certificates for all routine factory tests applied to all major items included in the Works	Prior to delivery to Site	Best practice

Execution Design – Construction Documentation – Level C *continued*				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
C-41	Method statement – Commissioning	FAT certificates to be provided by the Contractor	1 month after contract award	Best practice
C-42	Method statement – Capacity test	Method Statement describing pre-commissioning and commissioning tests on all items in preparation for completion of individual Section of Works and to reach Practical Completion	2 months after Contract award	Minimum requirement
C-43	Method statement – Performance test	Method Statement describing the Contractor's proposal to perform Capacity Test and Availability Test	2 months after Contract award	Minimum requirement
C-44	Recommended spares	Method Statement describing the Contractor's proposal to perform Performance Test	2 months after contract award	Minimum requirement
C-45	Special tools listing	Updated list of components and consumables that do not satisfy the Design Life for Works including additional information	2 months after contract award	Best practice
C-46	Project Management, Project Plan	Project Management, Project Plan	2 months after contract award	Minimum requirement
C-47	Project Management, Project Schedule (or Programme)	Project Plan including list of key personnel, CVs, and project organisation diagram	2 months after contract award	Recommendatio n
C-48	Landowner works schedule	Updated and final Project Schedule	Prior to commencing Works on the property	Minimum requirement
C-49	Quality Management, System Description	Report outlining the works for each specific landowner's property	2 months after contract award	Best practice
C-50	Quality Management, Plans	Updated and final Project specific quality management system for the Works	2 months after contract award	Recommendatio n
C-51	Quality Management, Plans, Documentation	Quality Management Plans applicable to: • Design of the Works • Manufacture of the Works • Transportation and Storage of the Works • Installation and erection of the Works • Testing, Commissioning, and Practical Completion of the Works	Submitted to the Employer for comment 8 weeks prior to relevant site works.	Minimum requirement
C-52	EH&S Management Plan	Quality Management Plans updated to include for all Works: • Factory Acceptance Testing and monitoring • Detailed Construction/Installation procedures and check sheets • Detailed Pre-Commissioning procedures and check sheets • Detailed Commissioning procedures and check sheets • Detailed Performance Test procedures and check sheets	2 months before NTP	Minimum requirement
C-53	EH&S, Management System	• ESMS Plan • Forced and Child Labour, non-discrimination and equal opportunities, worker rights, worker organisations, worker grievance mechanism, worker code of conduct • Worker Management Plan / Worker Accommodation strategy • Security Management Plan • Traffic Management Plan • Waste Management Plan • ESMS Legal Register • EH&S Organisational chart • Emergency Preparedness and Response Plan	1 months before NTP	Best practice
C-54	EH&S, Risk Assessments and Register	Updated and final full Health, Safety, Environment and Social Management System (including all the procedures, templates of the reports and checklists to be filled in during the construction period) in compliance with the IFC requirements	4 weeks after each respective risk assessment workshop.	Best practice
C-58	For Construction documentation and drawings, 100% or Final Detailed Design	Documentation shall be submitted in document package in accordance with major sections of the Works for review by the Principal	By the time required to allow Principal review in accordance with the EPC Contract but no less than two weeks prior to start of relevant work	Minimum requirement
C-60	Document Register	For Construction documentation and drawings produced to provide all required information to construct the Works. Documentation shall include updates to rectify any issues not otherwise resolved in the Final Detailed Design documentation	1 month after contract award	Minimum requirement

As-Built Design – Level D				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
D-1	Grid Connection Documentation	Update to all required grid connection documentation	Prior to Practical Completion	Minimum requirement
D-2	Software Licenses	All licenses, software keys, hardware keys (dongles) and the like for all software included in the Works	Prior to Practical Completion	Minimum requirement
D-3	Training Package and Programme	Training programme required to support the off-site and in-field training of the Principal 's personnel including hard and electronic copies of all training material	Prior to Practical Completion	Best practice
D-4	O & M Manuals	Final - Fully indexed and linked - comprising overview of the Solar Farm, specifications and all details for the safe and effective use, operation and maintenance of the complete Solar Farm	Prior to Practical Completion	Minimum requirement
D-5	Safety Report (or Safety in Design)	The Contractor shall update and submit the final Safety Report for all Permanent Works	4 weeks Prior to Practical Completion	Best practice
D-6	Civil Works, 3rd party civil/structural design certificate	3rd Party Civil/Structural Chartered Engineer's Certificate confirming the suitability of the PV Array Mounting Structure and all Civil Works, that they are in accordance with the As-built drawings and documentations and as required under the Applicable Laws, Regulations and Standards in respect of the entire Solar Farm and site building electrical works	4 weeks Prior to Practical Completion of the relevant Section	Best practice
D-7	Electrical Works, Updated Electrical Design Report	Updates to Electrical Design Report (submitted under Level B documents), following any design changes during construction	4 weeks Prior to Practical Completion	Best practice
D-8	Electrical Works, Certificates of compliance	All Electrical Certificates of Compliance (ECoCs) are issued for all electrical works required under the Applicable Laws, Regulations and Applicable Standards in respect of the entire Solar Farm and site building electrical works	4 weeks Prior to Practical Completion	Recommendation
D-9	SCADA	Complete I/O database including description of each I/O	4 weeks Prior to Practical Completion	Minimum requirement
D-10	SCADA, Instrumentation	Copies of calibration sheets for all sensors/transducers as appropriate in accordance with the appropriate calibration standards	4 weeks Prior to Practical Completion	Minimum requirement
D-11	Met Station, Maintenance log(s)	Each installed Met Station shall have a maintenance log detailing all work carried out on the instruments	4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement
D-12	Post Delivery Condition Survey of the Transport Route	Condition survey of the transport route to the Site Access Point post-delivery of all major loads & equipment	1 month after the last major load or component has been delivered	Recommendation
D-13	Acceptance Certificates	All completed Acceptance Certificates for a Section of Works prior to Section milestone Practical Completion	Prior to Practical Completion of the Section	Best practice

D-14	Final Practical Completion test reports	Completed installation and commissioning checklists, including commissioning test results, for the entire Electrical Works. This shall include all the specifications below as well as any regional requirement or other evidently relevant tests
		• Low voltage DC circuit functional tests according to IEC 62446 which shall comprise as minimum the following:
		  • Continuity of protective earthing and/or equipotential bonding conductors
		  • Polarity test
		  • String open circuit voltage test
		  • String short circuit current test
		  • Functional tests
		  • Insulation resistance DC circuit test
		• Inverter Commissioning Certificate, issued and signed by the manufacturer following the protocol described at the manufacturer's installation manual. Commissioning protocols. Cold and hot commissioning tests
		• Transformers Commissioning Certificate, issued and signed by the manufacturer following the protocol described at the manufacturer's installation manual. Commissioning protocols
		• Insulation Resistance test report (i.e., cabling pressure test) of High Voltage circuits
		• Commissioning certificate of the grid operator
		• Commissioning document issued by the EPC contractor related to all HV equipment installed at the plant. Any related commissioning procedure, testing protocols and testing results should be included.
		Commissioning document issued by the EPC contractor related to all LV equipment installed at the plant. Any related commissioning procedure, testing protocols and testing results should be included
			4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement

As-Built Design – Level D *continued*				
ID Level-#	Document(s) Title	Description/Comment	Submission	Requirement
D-15	Capacity and Availability test report	Upon satisfactory completion or upon failure of the Capacity and Availability Test, as the case may be, the Employer will issue an Acceptance Test Certificate to that effect	Not later than one month after the conclusion of the Capacity Test	Minimum requirement
D-16	Performance test report	Upon satisfactory completion or upon failure of the Performance Test, the Employer will issue an Acceptance Test Certificate to that effect	Not later than one month after the conclusion of each Performance Test	Minimum requirement
D-17	Installation and Commissioning, Reports	The results of all inspections, checks and tests carried out, together with any subsequent analysis	4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement
D-18	EH&S reporting documents, Risk Register,	Evidence of compliance with the EH&S Management Systems. Final risk register	2 months' post Practical Completion	Best practice
D-19	Final As Built Drawings and	As-built drawings of the site showing the exact location of all project elements and structures	4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement
D-20	Documentation, Site layout As-built Drawings and Documentation, Electrical Works	The Contractor shall submit for the Employer's review: • All as-built diagrams • Protection schematics • Control schematics • UPS schematic • Cable schedules (MV and LV) And General Arrangement drawings including: • As-built MV/HV Substation drawings • As-Built MV Switch room drawings • SCADA, battery / UPS drawings As-built transformer including LV cabling between Inverters and PCS transformers	4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement
D-21	As-built Drawings and Documentation, Civil Works	Final as-built drawings for all project elements and structures, including: • Site drainage • Site landscaping • Site reinstatement	4 weeks Prior to Practical Completion of the relevant Section	Minimum requirement
D-22	As-built Drawings and Documentation, SCADA system	Comprehensive and complete SCADA drawings. The SCADA system shall be supplied with three sets of comprehensive, complete and up-to-date documentation packages relevant to all the hardware and software supplied, including manuals and diagrams	4 weeks Prior to Practical Completion	Minimum requirement
D-23	Instrumentation	Copies of calibration sheets and data logger settings for all sensors/transducers as appropriate in accordance with the appropriate calibration standards	4 weeks Prior to Practical Completion	Minimum requirement
D-24	Organisation Chart	Organisaiton chart of the project including EPC, subcontractors, DNO, ICP, CDMc		

SolarPower Europe

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