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D4.1 Definition of new needs and specifications on current QC procedures and equipment

T4.1 Definition of new needs and specifications

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Summary

The present deliverable details the conclusions obtained from the review of current quality control procedures (QCP) carried out in PV plants and for each of its main elements as well as the best practices common in the industry. Additionally, the new QCPs required for future PV projects are evaluated. In this regard, two different type of needs have been identified: those that exist already but have not been regulated or standardized enough yet and those that will arise in the future years such as the ones coming from the use of new PV technologies (bifacial or floating), the use of energy storage in PV plants or the use of advanced QCPs for inverters.

The conclusions of this deliverable will be useful to set the basis, or to further define, the objectives to be accomplished in the following years as part of WP4. Moreover, this is closely related to WP3, as it will be useful to define what kind of data should be recorded or considered for the data analytic and toolboxes developed in it.

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

The present deliverable details the conclusions obtained from the review of current quality control procedures (QCP) carried out in PV plants and for each of its main elements, as well as from common the best of the industry. Additionally, the new QCPs required for future PV projects are evaluated. In this regard, two different types of needs have been identified: those needs that already exist but have not been regulated or standardized enough yet and those needs that will arise in the future years, related to the use of new PV technologies (bifacial or floating), the use of energy storage in PV plants or the use of advanced QCPs for inverters.

The elements identified as key components of a PV plant in order to review their corresponding QCPs are: a) PV modules and strings, b) solar trackers, c) inverters, d) batteries, e) transformers and e) weather stations. In order to review them, the international standards regulating their operation and maintenance have been compiled and are presented together with the best practices adopted by the industry. Therefore, this deliverable will be used as the cornerstone of WP4, setting the basis of what is already being properly qualified and what needs to be improved or developed for future PV projects.

Accordingly, the second part of the deliverable focuses on the new needs. However, pinning down what is actually identified as a need by the PV industry, or the PV community, is a cumbersome task. In order to try to find a complete list based on a heterogeneous mix of participants (plant owner, component manufacturers, EPC, O&M, etc.) different approaches have been followed. First, the partners involved in this task have identified what the new QCPs are, based on their previous expertise. Then, a survey has been designed to be sent to the PV community, taking advantage of the variety and diversity of the SERENDI-PV consortium and its dissemination potential. This considerably improve the reliability of the deliverable conclusions, as different roles (and therefore different points of view and needs) within the PV community are considered. Finally, the scientific publication trends and the records in the media have been analysed. This allows verifying what a hot topic among at the cutting-edge research is, as well as to determine what aspects are seen as critical from the PV industry point of view.

The conclusions of this deliverable are useful to set the basis, or to further define, the objectives to be accomplished in the following years as part of WP4. Moreover, this is closely related to WP3, as it will be useful to define what kind of data should be recorded or considered for the data analytic and toolboxes.

1.2 Reference material

This document is not based itself on any other document, apart from the information obtained from the references cited in the bibliography.

1.3 Relation with other activities in the project

Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within SERENDI-PV project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1: Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
T2.3	The modelling of new PV technologies (bifacial, floating) aimed in T2.3 will be benefitted by a better understanding of what must be characterised in such technologies.
T3.2	The specific data analytics for bifacial and floating PV pursued in T3.2 will be benefitted by a better understanding of what is identified as a key characteristic to be qualified, and eventually, by a better characterization of the modules.
T3.6	The digital twins for PV components (inverters and batteries) could use the new requirements for QCPs as hints of what should be implemented in these models. Afterwards, once the improved QCPs are developed, the better characterization will provide better input data for the model.
T4.2	D4.1 will be useful to define more accurately and to further understand what QCPs need to be developed in T4.2 regarding the soiling, degradation, and ageing of PV components.
T4.3	D4.1 will be useful to define more accurately and to further understand what QCPs need to be developed in T4.3 for floating and bifacial PV.
T4.4	D4.1 will be useful to define more accurately and to further understand what QCPs need to be developed in T4.4 for inverters.
T4.5	D4.1 will be useful to define more accurately and to further understand what QCPs need to be developed in T4.5 for batteries.
T5.2	D4.1 will be useful to provide a better understanding of the soiling on PV modules.

1.4 Abbreviation list

Table 1.2: Abbreviation list

Abbreviation	Meaning
AoV	Angle of View
EL	Electroluminescence
EMC	Electromagnetic Compatibility
EPC	Engineering, procurement and construction
EPI	Energy Performance Index
FAC	Final acceptance certificate
GHI	Global Horizontal Irradiance
GTI	Global Tilted Irradiance
HSA	Harness Sub-Array
IAC	Intermediate acceptance certificate

IEA	International Energy Agency
IEC	International Electrotechnical Commission
IRT	Infrared Thermography
I-V	Current-Voltage
LCOE	Levelized Cost of Electricity
LeTID	Light and Elevated Temperature Induced Degradation
LFP	Lithium Ferrophosphate
LID	Light Induced Degradation
LTO	Lithium-Titanate-Oxide
MPPT	Maximum power point tracking
NDS	Network Disturbance System
NMC	Nickel-Manganese-Cobalt
NREL	National Renewable Laboratory
PAC	Provisional acceptance certificate
PID	Potential Induced Degradation
POA	Plane of array
PR	Performance Ratio
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Programme
QCP	Quality control procedure
RSR	Rotation Shadowband Radiometers
SoC	State of Charge
SoH	State of Health
SPD	Surge protection device
STC	Standard test conditions (1000 W/m^2 under spectrum AM1.5 and 25 °C)
TCD	Transformer Control Device
THD	Total Harmonic Distortion
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
WMO	World Meteorological Organization

2 QCP REVIEW

The state of the art of QCPs for PV plants and their components has been reviewed. For this purpose, international standards have been compiled together with the industry best practices. In order to perform a comprehensive assessment of the current scenario, the following key items have been identified:

- PV module
- Solar tracker
- Inverter
- Transformer
- Battery
- Weather station
- PV plant

In the following, each of these elements is studied and reviewed separately, pointing out the main QCPs carried out on each of them. As a side note, all the terminology and definitions related to PV applications are used when possible according to what has been defined by the international standard IEC 61836 [1].

2.1 PV module qualification

The performance of a PV module depends not only on its particular technology or state but on the operating conditions as well. Although current PV modules are based on already robust and stabilized technologies, their performance and condition need to be accurately assessed considering the strong impact it has on the energy generation of a PV plant. Apart from that, the continuous improvement towards better designs and more efficient devices requires adapting QCPs correspondingly.

In order to qualify a PV module, both its **performance** and **durability** must be assessed. In order to address the former, it is important to ensure that the module has been stabilized prior to its characterization. Otherwise, the performance measurement will not be representative of the actual performance. The pre-conditioning of the modules, as well as the guidelines and the proper order of the tests to qualify a PV module is defined in the standard IEC 61215 [2]. It is important to note that the preconditioning depends on the solar cell technology used in the module. Besides, every PV module should be compliant with the manufacturing requirements specified in the IEC standard 61730 [3]. Below, the main techniques and methodologies employed to analyse the quality of a PV module are reviewed.

2.1.1 Visual Inspection

The visual inspection intents to evaluate the PV module in a direct and straightforward way. Although it is a rather basic technique it can expose the root cause of the malfunctioning of a PV module that would be otherwise hard to pin down. The visual inspection of a PV module is described in the IEC standard 61215 [2], although the process defined is somehow limited. Nevertheless, the guidelines defined in this standard are further extended by other organizations such as the NREL [4] or the ZEEC [5]. These later documents provide a comprehensive list of the characteristics to be evaluated and how the evaluation should be done. The most important properties to be evaluated are:

- **Label** – The adherence of the label to the module must be checked together with the information depicted. It must be verified that all the required information, such as the module model and its main properties, appears on it.
- **Serial numbers** – The serial number of the module must appear and be legible on the front and the rear side, being both the same serial number.
- **Backsheet** – any sign of delamination or discoloration of the backsheet must be recorded.

- **Junction Box** – the isolation of the junction box must be ensured verifying that there are no cracks or breaks in the box together with a correct state of the sealant. Additionally, the polarity must be clearly indicated on it.
- **Wiring** – the state of the wiring shall be verified ensuring that the length is appropriate and that the connectors are the correct ones.
- **Frame** – Any damage or sealant failure in the frame must be recorded.
- **Front glass** – Any cracks or scratches on the front glass must be recorded.
- **Encapsulant** – any sign of delamination or discoloration of the encapsulant must be recorded.
- **Solar cells** – It must be verified that the module solar cells do not shown any cracks, scratches nor chipping. The homogeneity of solar cells (colour, brightness) should be evaluated as well together with the metallization. In this regard, the proper state of the busbars and fingers must be checked, together with interconnections and verifying that all the cells have the same metallization pattern. Finally, it must be ensured that the alignment of the cells is correct and that the cell-to-cell and cell-to-frame distances are appropriate.

2.1.2 I-V curve measurement

The I-V curve measurement is the basic technique to characterize the performance of a PV module. Although it is usually applied to measure the maximum power of a PV module, it can also provide information about the kind of defects affecting the PV module, if any, in the form of an "abnormal" I-V characteristic. A comprehensively documented list of classified PV failure modes, according to the I-V characteristic patterns, has been published by the IEA PVPS Task 13 experts [6], [7]. However, in order to pin down the specific failure mode it is highly advisable to use other characterization techniques, such as thermography (IRT) or electroluminescence (EL).

The main inconvenient to overcome when measuring I-V curves is that the measured performance depends on the operating conditions (mainly irradiance and temperature). Therefore, there are two possibilities: a) the module must be measured under the so-called Standard Test Conditions (STC, G=1000 W/m^2 under AM1.5 and T=25 °C) or b) the performance must be extrapolated from the operating conditions to STC (see section 2.1.3). The indoor characterization in field under STC involves mobile laboratories able to simulate STC and requires unmounting the modules from the supporting structure, although it is generally accepted that this approach provides the best results in terms of accuracy and repeatability. On the other hand, the direct I-V measurement of the modules (and subsequent extrapolation to STC) offers a fairly accurate quantitative measurement of the PV modules' electrical parameters, in a relatively simple way and without the need of removing the PV module from the supporting structure. Furthermore, the on-site characterization offers the possibility of measuring one or more modules, being even possible to measure the whole string. This is a noticeable advantage since it provides a straightforward method to measure the string performance integrating all the losses, such as the mismatch among the modules. The indoor characterization provides P_{Max} values with uncertainties in the range of ±2.5 % [8] whereas parameter studies with conservative assumptions have shown that the uncertainty for on-site I-V tracing measurements lies in the range ±3.5 % to ±5 % for the Pmax [9]. Nevertheless, some studies have reported that if the operating conditions can be restricted enough the outdoor measurement uncertainty can be in the range of the indoor one [10].

The I-V tracing requires specific equipment, usually referred as I-V analysers or I-V tracers. The I-V acquisition is accompanied with two additional real-time inputs: the plane-of-array (POA) irradiance and cell operating temperature, measured with calibrated suitable sensors (e.g. pyranometer, reference cells or reference modules for irradiance and PT-1000, IR thermometers or reference modules for temperature). These inputs are indispensable to guarantee that the measurement is carried out under STC for indoor measurements or to correct the in-field I-V measurement to STC. For outdoor measurements it is recommended that the I-V tracer stands voltages and currents up to 1500 V and 30 A to allow the measurement of strings [6].

The I-V curve measurement should be done in accordance to the standard IEC 60904-1 [11] whether it is carried out indoor or outdoor, being the particularities of each type of measurement further defined in the IEC standards 60904-9 [12] and 61829 [13] respectively.

In brief, the best practice recommendations are:

- Pre-check for soiling or any unwanted shading prior to the I-V measurement
- Ensure a co-planar alignment of the irradiance sensor, within ±2˚ (IEC 61829)
- If the temperature is measured with a temperature sensor adhered to rear face of the module correct it considering a difference of 2°C under 1000 W/m^2 as detailed in the IEC 61829
- Measure 4-wire I-V measurements at both module level and string level
- Measure the module temperature at multiple positions of the module (according to the IEC standard 61853), to acquire a representative average value
- For outdoor measurements ensure a global plane-of-array irradiance higher than 800 W/m^2, clear sky, and a steady thermal state of the PV module/array.

2.1.3 I-V curve extrapolation to STC

Although the ideal scenario is to characterize the PV module performance under STC, this is not always feasible. Accordingly, different extrapolation processes have been developed in order to fulfil these needs.

The IEC standard 60891 depicts three methods to extrapolate the performance of a PV module to STC from the irradiance and temperature measurements. The first method corrects the performance with the temperature coefficients whereas the second one incorporates the correction of the voltage with the irradiance. Finally, the last one is a phenomenological method based on the linear interpolation/extrapolation after measuring at several operating conditions. In this standard it is also suggested how to calculate the temperature coefficients of a PV module. However, the procedure depicted to calculate these parameters lack some details about its practical implementation in a PV plant, such as the acceptable module-to-module variation, or the range of operating conditions under which these parameters can or should be obtained.

2.1.4 I-V curve measurement for bifacial PV modules

The assessment of bifacial PV modules is detailed by the IEC standard 60904-1-2. The standard defines what needs to be additionally implemented into the aforementioned standard for monofacial modules (IEC 60904-1) in order to be valid for bifacial PV modules. The procedure defines several methods to characterize the power generation of a bifacial module:

- One-side solar simulator
- Two-sides solar simulator
- Sunlight
- Background compensation

which will be used to characterize the bifaciality (relation between the front and the rear side) of the PV module for the I_{SC} the V_{OC} and the P_{Max}. Although the standard warns against possible non-linearities coming from the fit of the power generated by the rear face of the module, it does not provide any guideline to deal with it or to minimize the uncertainties coming from it. Moreover, the characterization is incomplete as it does not address the determination of the temperature coefficients of a bifacial module. Furthermore, even if the characterization of the bifacial PV module when isolated is defined, how it should be evaluated when mounted on a structure is not clear. Finally, it is also not clear how the I-V curve of a bifacial module should be extrapolated to STC, which is absolutely mandatory according to the previous point (2.1.3).

2.1.5 Thermography

The thermal inspection of a PV plant is a practical tool that provides a quick overview of potentially degraded areas. It is based on the principle that all the PV modules (and the cells inside them) should be at a similar temperature. Although this principle can be applied to any element within the PV plant (such as a string combiner box), the main focus is the analysis of the PV modules due to the large number of devices that can be inspected at once. Moreover, this technique does not significantly impact the performance of the PV plant, allowing to identify, in field, modules that need a deeper and more thorough characterization.

Infrared thermography (IRT) inspection in field must be carried out in line with the IEC TS 62446-3 [14] although, compared to lock-in thermography or other indoor PV characterization and inspection techniques that are held in controlled laboratory environment, the accuracy of field IR inspections is largely affected by diverse parameters and conditions. In this sense, it is imperative to identify and understand sources of measurement errors and uncertainties throughout the IR inspections, as well as to control and mitigate (or compensate) them, to the greatest feasible extent (practically and technically), through an efficient testing protocol. Additionally to the aforementioned standard (IEC TS 62446-3), some best practices usually employed were described in the IEA PVPS Task 13 [6].

In order to carry out the IRT inspection and extract valuable conclusions it is useful to count with some information such as the PV modules' type, their technical (OEM's) datasheet and the elapsed time since commissioning, as well as some other basic information of the monitoring system for cross-validation purposes. Finally, the module cleaning state should be registered. Usually, it is recommended to carry out cleaning actions prior to the IRT assessment (removal of excess soiling/dirt) unless IRT-based soiling assessment is intended. This inspection should also ensure that no shadowing nor vegetation would be present during the IRT measurements.

The aerial IRT assessment by means of UAVs or drones is considered in the IEC TS 62446-3, although there are no distinct technical specifications or standardized protocols for it, which would be highly desirable considering its huge potential to measure large amounts of PV modules. This is of particular importance since for the aerial IR assessment some additional requirements, such as an up-to-date layout of the PV plant with information on potential technical constraints (e.g. presence of physical obstacles, safety risks, proximity to flight restricted zones, etc.) or further specifications regarding the image acquisition (resolution, frames per second) are needed.

Upon inspection, the requirements on the real-time environmental conditions and the IRT inspection itself follow the principles described in the Report IEA PVPS T13-24:2021 [6] and IEC TS 62446-3:2017 [14], whereas the recommended applicable safety regulation is the EN 50110-1 [15]. The PV plant must be under operating condition (i.e. at MPPT), in electrical/thermal steady-state condition and free of any partial shading, throughout the whole duration of the IRT inspection. Especially in soiling prone PV sites (e.g. areas with nearby agricultural activity, dusty/arid or coastal areas, etc) a pre-check should be done to ensure that soiling remains low and homogeneous, so that I_{sc} losses do not exceed 10%, while no partial shading is observed. In the case of any transient effect such as passing cloud(s) during and IRT inspection, it is highly recommended to allow at least 15 minutes "waiting time" to ensure that the PV plant returns to its steady thermal/electrical state condition.

The emissivity (ε) adjustment of the IR camera should be performed upon each inspection or applied upon the IR image analysis (i.e. post treatment). For PV inspections, typical values are ε=0.85-0.90 for either front (glass) or back (glass or backsheet) measurements. In case a very accurate measurement is required, an emissivity calibration process is highly recommended. In case the inspection is carried via drone, there are four key conditions to control: a) the Angle-of-View (AoV), b) the Distance-to-Target, c) the definition of Delta-temperature (ΔT) and d) the optimal drone navigation (to ensure that image data acquisition within a 5-min timeframe, for the same PV string, to minimize the influence of any fluctuating environmental conditions).

Next to the measurement conditions related to the IRT layout, there are specific requirements and conditions related to the environmental conditions (and the provision of weather data). The key requirements related to the environmental conditions refer to the global POA irradiance, the ambient (air) temperature, the wind speed, the cloud coverage and (optionally) the relative humidity. The specific ("boundary") conditions and remarks related to these parameters are also detailed in the IEA PVPS T13-24:2021 and IEC TS 62446-3:2017. With all requirements in mind, in terms of overall weather/operational conditions, the average "effective" time window for IRT inspections of PV plants ranges from 3 to 6 hours per day (depending on the season, the latitude and the far/near horizon).

Finally, the IRT can also be used as a diagnostic procedure rather than just an inspection tool such as reported by some patented techniques to evaluate the power loss [16] or other publications from in-field inspections [17]. Studies regarding the fault classification and the correlation of IR image data and I-V data patterns have also been published [18], [19] although these correlations have to be further verified and extended based on the reported results.

2.1.6 Electroluminescence

The electroluminescence (EL) measurement is an unequalled technique to detect cracks or defective areas in the solar cells of a PV module. It is based on the light emitted by a solar cell when biased under forward voltage. Therefore, this technique offers a direct visualization of those areas of good quality showing high emission. Besides, it can also show series resistance effects, as the luminescence is directly related to the current going through the solar cell in a given area. Therefore, if series resistance hinders the homogeneous distribution of the current, that will be easily appreciated in the luminescence homogeneity. The EL characterization is thoroughly assessed in the IEC standard 60904-13, analysing the camera and lenses requirements, the target currents to evaluate the module, the image correction, processing, analysis and providing guidelines on how to evaluate quantitative and qualitatively the EL of a PV module. A complementary report in this matter has also been published by the IEA [19].

2.1.7 Ageing and degradation

In order to detect potential weaknesses of PV modules and the underlying degradation mechanisms, accelerated ageing or degradation tests can be carried out in climatic chambers. The degradation processes are accelerated by subjecting the PV module to certain operating conditions (temperature, humidity, current/irradiance, etc.) where the variable under study is usually overstressed (higher temperature or current usually). Then, the impact on the PV module can be evaluated making use of the aforementioned techniques (specially the EL or the I-V measurements) to identify the failure modes activated by each of the stressors by measuring the module before and after the ageing process [7]. These degradation processes, which some can be done in sequence in order to assess the combined effects of different stressors, must be carefully designed in order to test accurately the sensitivity of modules to some stressor(s) in a short period of time.

The following list describes the different conditions used to test the modules:

- Damp heat (resistance to humidity)
- Thermal cycling (resistance to thermal cycling occurring from day/night cycles)

- UV irradiation (resistance to the photochemistry activated by UV photons)
- Humidity freeze (resistance to combined thermal cycling and humidity)
- Dynamic mechanical load (resistance to mechanical stress)
- Potential induced degradation (PID, resistance to high voltage)
- Light induced degradation, (LID, resistance to illumination)
- Light and elevated temperature induced degradation (LeTID, resistance to illumination at high temperatures)

In order to respond to the specificities of unusual environments, some parameters of these tests might be cleverly adapted for these conditions. In any case, the requirements of the climatic chambers are defined in the IEC standards 61215 and 61730 [2], [3]. Additionally, the PID and LID test are defined in the IEC standards 62804 and 63202 respectively. On the other hand, the LeTID is relatively new degradation process which is still being understood and the corresponding IEC standard to evaluate it is currently under development (future IEC 63342). However, all of these degradation tests are only designed for laboratory environments whereas an in-field evaluation test would also be highly recommendable. In this regard it would be also advisable to define methodologies to accurately measured the yearly degradation in-field, as the degradation rate is usually a rather low value and commonly within the measurement uncertainty. Moreover, a procedure to evaluate the degradation of a string should be proposed as well.

2.1.8 Soiling testing & mitigation (cleaning)

In order to quantify the impact of soiling on the energy production in outdoor conditions, two possible approaches have been proposed:

1. Compare the irradiance measured by two pyranometers or reference cells
2. Compare the performance of two PV modules

In both cases one of the devices is cleaned on a similar basis to that established for the overall PV plant by the O&M contract, while the other one is subjected to a cleaning routine frequency high enough to ensure that there is no significant soiling or dust accumulated atop of the device. In this regard, it is important to note that both frequencies depend on the location of the PV plant and even on the period of the year.

For the first approach, the signals coming from the two devices are compared. For the latter, the most common approach, due to its simplicity, is the use of soiling kits, which consists of two similar modules and an I-V tracer. The general guidelines about how to carry out this process are described in the IEC standard 61724-1 [20]. The soiling comparison can be carried out by measuring the I_{SC} or the P_{Max}, although it is highly encouraged to use the latter one as it shows the actual power loss (especially when soiling is not homogeneous throughout the modules). Additionally, it is also recommended to use the same modules used in the PV plant to ensure that the impact of the dust measured by the soiling kit is actually representative of that of the PV plant.

Finally, although it is suggested by the IEC standard 61724-1 to correct the measurement with the module temperature and the measured irradiance, the direct measurement provides a straightforward indicator of the energy loss in the PV plant. As long as the model and the temperature of the modules used in the soiling kit are the same ones (or similar in the case of the temperature) to those used in the PV plant, there is no need to extrapolate the measurement with irradiance or temperature. This indicator is indeed superior as a loss metric to the soiling rate from extrapolated I-V curves because it captures the actual energy loss due to the soiling (taking into account whether soiling occurs during high or low irradiance periods, for instance). In this regard, it is beneficial to have periodic measurements during the day, as it has been reported that the influence of the dust changes depending on the time of the day. However, the counterpart of this approach is that the clean device is exposed to the environment during more time (and thus requiring more frequent cleaning processes).

Additionally to the measurement in field, artificial soiling bench aims to reproduce and to accelerate the various natural soiling phenomena. This type of laboratories makes it possible to quickly assess the impact on the loss of transparency and the loss of photoelectric current for defined and well-controlled configurations.

With these procedures, the soiling is evaluated by means of:

1. Spectrophotometry
2. I-V measurement on solar simulator
3. Visual inspection and image processing to highlight the shape of the particles or specific configurations like, for instance, cementation or caking.

Finally, the cleaning process can be evaluated as well. In order to carry out this kind of studies the natural self-cleaning events (rain, wind) can be reproduced as well as the standard cleaning processes (whether dry or wet). The desirable features for each of the aforementioned cleaning processes are:

- <u>Cleaning rain process:</u>
    - Raining liquid solution
    - Demineralized water eventually mixed with mineral particles
    - Miser and densimetering control
    - Solution temperature
    - Recycling system
    - Adjustable raining intensity
- <u>Dry cleaning process:</u>
    - Rotative brush
    - Easy and fast brush change over
    - Rotative speed and sense of the rotation
    - Speed advance
    - Pressure of the brush on the sample
    - Adjustable pressure blow system
    - Antistatic bar
    - Highly efficient industrial vacuum cleaner
    - Chamber temperature control
    - Humidity control
    - Temperature of the tested sample
    - Tilt of the sample can be adjusted
- <u>Wet cleaning process:</u>
    - All the features presented for dry cleaning processes
    - Cleaning liquid solution
    - Demineralized water eventually mixed with one or two additive chemical solutions.
    - PH control and automatic adjustment
    - Solution temperature
    - Recycling system
    - Squeegee device with pressure adjustment

Then, the performance of the PV modules can be evaluated in a similar manner to that explained for the indoor soiling characterization to evaluate the effectiveness and consequences of any cleaning process.

2.2 Solar tracker

The two main characteristics of a solar tracker for PV applications are its accuracy and robustness. The basic parameters to be characterized and the main recommendations for its measurement were initially defined in the IEC standard 62727 [21] (withdrawn), although a more thorough compilation of the terms and definitions as well as a complete set of tests to validate a solar tracker was then established in the IEC standard 62817 [22]. Which defines how to properly carry out the following tests:

1. Visual inspection
2. Verification of factory parameters
3. Performance test
4. Mechanical test
5. Environment influence

This standard has been tested and checked with excellent results suggesting that the characterization of a solar tracker has been define accurately and thoroughly [23].

Regarding the maintenance best practices, the most important tasks to be carried out periodically (at least on a yearly basis) by the O&M contractor are:

- Torque check, ensuring a maximum tolerance of ±15%
- Driver's check
- Foundation verification
- Structure inspection, if necessary, it will be repainted with Zinc-rich painting
- Check of operating parameters (inclination angle, anemometer signal, backtracking, and UTC time synchronization)
- Revision of the actuator
    - Absence of structural damage, due to deformed, cracked or broken components
    - The end of the rod is not observed with rust stains. The shaft is not rusted
    - The bearings are in good condition
    - No grease leakage. Pay attention to the following areas: worm gear box, outer tube, bar sealing and sealing system and bar end
    - Presence of grease/degreasing plugs on the worm gearbox, outer tube and rod end
    - The connecting screws between the gear motor and the worm gearbox are tightened and there is no free play

The most frequent energy losses suffered in solar trackers are related to climatic conditions. Mainly, a lack of battery due to absence of solar radiation and strong winds bring trackers to operate in stow position. This may lead to dramatic energy losses, and thus economic. Despite it is not possible controlling the climatic conditions, the first energy losses cause could be minimized by installing batteries with greater capacity.

Additionally, the evaluation of the tracking strategy and its adaptation to the particular orography of a PV plant is not usually assessed and there is no standard regulating it, despite the influence it has on the generated energy. In a similar manner, the effectiveness of the backtracking should be study taking into account the deviations from the ideal scenario due to the PV plant orography.

2.3 Inverter

A PV inverter is meant to transform the DC power of a solar array to AC power while it forces the PV array to operate at the maximum power point of its I-V curve (MPPT) and adjusts the output power to the required frequency of the grid minimizing the amount of harmonics.

During the design and the manufacturing of a PV inverter several properties must be evaluated. Among them we can find:

- Performance
- Reactive power injection
- Power consumption in idle mode
- Operating temperature
- Harmonics generated at critical points
- Current control
- Night-time shutdown
- MPPT
- Grid voltage surge test
- Protections tests:
    - V_{DC} voltage
    - V_{AC} voltage
    - I_{AC} current
    - Grid frequency
- Control tests:
    - Current control
    - Input voltage control
- Normal operation tests
    - Connection tests
    - Magnetization tests
    - MPPT tests
    - Tests for the regular scanning of the solar array
    - Maximum power limitation tests
    - Shutdown due to low power
    - Reactive power control
    - Reactive power injection
    - Accuracy in the reactive power measurement
    - Reactive power control monitoring
    - Correct set point recording
- Tests for exceptional operation
    - Connection of the inverter at low temperature
    - Power regulation at high temperatures
    - Operating tests in short mode
- Data storage tests
- Configuration tests
- Communication tests
- Temperature measurements.
- Network Disturbance System (NDS) tests

Regarding the approval tests that an inverter must pass, we can find the electromagnetic compatibility tests, mostly regulated by the IEC 6100-3-11:12 [24], [25], the IEC 61000-4-2:8 and the IEC 61000-6-4, the electrical safety tests, defined by the IEC 50178 and IEC 62109-1, or the tests for grid code compliance, a group of standards, particular for each county or region where the inverter will be connected. Additionally, in case the device is going to be sent to the United States the devices need to pass the UL1741-43:61 tests.

However, most of the aforementioned points are common for any inverter no matter its purpose. For PV inverters the following four characteristics are of particular importance:

- MPPT efficiency
- DC/AC conversion efficiency
- Total harmonic distortion (THD)
- Temperature boundaries and its influence on the three previous points

The efficiency of the MPPT is defined by the IEC 50530, defining a methodology to evaluate the MPPT of the inverter at the factory (or at least in a controlled environment with a PV simulator). However, there is no counterpart about how to evaluate its efficiency in a PV plant, and the method defined in the standard is not applicable straightforward in field. Furthermore, even if it could be applied, there would be non-idealities consequence of working with an actual PV generator that would keep from comparing the in-field measurements with the factory test.

Regarding the DC/AC conversion efficiency it is usually calculated as a function of the inverter load as defined in the IEC standards 50530 and 61683. In order to define a unique efficiency value, the different efficiency values are weighted according to the aforementioned standard as:

- European efficiency

$$\eta_{EUR} = 0.03 \cdot \eta_{5\%} + 0.06 \cdot \eta_{10\%} + 0.13 \cdot \eta_{20\%} + 0.1 \cdot \eta_{30\%} + 0.48 \cdot \eta_{50\%} + 0.2 \cdot \eta_{100\%}$$

- California energy commission efficiency

$$\eta_{CEC} = 0.04 \cdot \eta_{10\%} + 0.05 \cdot \eta_{20\%} + 0.12 \cdot \eta_{30\%} + 0.21 \cdot \eta_{50\%} + 0.53 \cdot \eta_{75\%} + 0.05 \cdot \eta_{100\%}$$

being the European efficiency the most common one outside the United States. This can be carried out for a number of input voltages, and then interpolated to the particular range of voltages of interest. Similarly to the MPPT efficiency, there is no equivalent procedure clearly defined to measure the conversion efficiency of the inverter in field.

In respect to the THD, it should be lower than 5 % for the current and 2 % for the voltage (with a maximum of 1 % for each harmonic) according to the IEC 61727 [26].

Finally, the maximum temperature at rated power and reduced power should be verified as well as the minimum temperature for the proper operation of the inverter. Additionally, the dependence of the conversion efficiency with the operating temperature and voltage should be accurately assessed, as the operating conditions will vary significantly from one location to another. However, no procedures nor guidelines have been defined to carry this out. This makes it extremely difficult to correlate the measurements in field to factory test values, increasing the uncertainty of the inverter characterisation in field.

Regarding the O&M, the best practices in the industry recommend to execute the following maintenance tasks once a year:

- Check that the enclosures are in good condition and do not have any impact, signs of oxidation or other marks due to weather effects.
- Check that the locks are working properly, that the doors are sealed and that all the keys are in the locks. Check hinges, foams, keys, doors and locks.
- Check that the inverter shows no signs of dust, moisture, or the presence of animals.

- The DC input wiring is in good visual condition and properly sealed in the inverter's DC cabinet.
- Check that the power connections are in good condition and that the screws are correctly marked. Also check the ground connections. There are no visual signs of overheating. Correctly re-tighten only if necessary, which will be when the markings are not in place.
- Check the balanced values of the LCL filter capacitor readings on the inverter phases. Due to the voltage peaks of the low isolation PV field and the transient effects on this element, capacity is a crucial value that must be monitored.
- Check that all cabinets (both DC and AC cabinets) are temperature balanced. Thermography is a tool that helps to detect hot spots due to temperature imbalance between phases and/or in devices. The inverter must be working previously at least 100 min at high/full power (90% of average or more), then stopped and isolated. Make sure that all modules have been generating.

Additionally, every 6 months the voltages of the output DC control sources should be checked (voltages around +/- 1% of 24V in the SW registers) together with the DC leak detector.

2.4 Transformer

Transformers modify the AC power from low to medium or high voltage grids. In order to guarantee a proper functioning, it should comply with all the requirements specified by the inverter manufacturer, such as impedance values, special harmonic profiles, or load profiles detailed in the IEC standards 60296, 60076:1-10, 60137, and 60085 [27]–[30]. Apart from that, the best practices for its maintenance are split into four different types of tasks:

- Quarterly QCPs
- Annual QCPs
- Annual off-power QCPs
- Biannual off-power QCPs

2.4.1 Quarterly QCPs

During the operation of the transformers the following tasks are carried out:

- Check the noise produced by the main and ancillary transformers as well as the fans.
- General cleaning of the equipment for a correct operation.
- Gas pressure verification
- Oil level checking

2.4.2 Annual QCPs

During the operation of the transformers the following tasks are carried out:

- The reading measurements by the inverter are balanced and similar to the certified values of the main AC transformer.
- Check that the phase indicators lights blink during operation.
- Check that the voltage of the DC output sources is correct (± 1 % of 24 V).
- Test hygrostat and thermostat, moving the rheostats to the minimum and checking the activation of the fans/heaters. The hygrometers should be set at 5 °C - 65 % humidity and the thermostat at 35 °C.

- Check that temperatures are balance in all the cabinets and main transformer. The thermography helps to identify unbalanced hot spots in phases or devices. The station should be 100 minutes at least at full power (>90% on average). The temperatures of the transformers must be below 75 °C.

2.4.3 Annual off-power QCPs

With the transformers completely shut off, isolated, and blocked, the following tasks are carried out:

- Measure the Low-Voltage transformers' inductances – ground, Medium-Voltage transformers' inductances – ground and High-Voltge transformers' inductances and Low-Voltage transformers' inductances with an acceptance criterion of 15 MΩ/kV.
- Measure the resistance between the station and grounding installation less than 10 Ω and record it.

2.4.4 Biannual off-power QCPs

With the transformers completely shut off, isolated, and blocked, the following tasks are carried out:

- Check the status of the different elements of the doors of the transformer visually, paying special attention to the lock key of the medium voltage cell.
- Visual inspection and verification of the good conditions of the control cables, checking that the AC screws are correctly marked, and connectors are correctly inserted;
- Check if there are signs of overheating.
- Visual inspection of any oil leakage.
- Visual inspection of the paint of the main transformer.
- Check that the temperature alarm is set at 75 °C, and rings at 95 °C, and verify the maximum temperature reached.
- Correct operation of the TCDs pushing the test button and the SPDs are operative and not fused.
- Check the connections of the ancillary transformer and continuity between neutral and ground
- Clean the air filter
- Check visually the oil filter health, replace it every two years.

2.5 Battery

Batteries are the leading technology to developed energy storage solutions for PV plants. This energy storage solutions are meant for two different purposes, **power balance** and **energy storage**. Power balance requires batteries with a quick response that can react to the requirements of the grid almost instantly, such as those made of lithium-ion batteries based on LTO or Supercaps. On the contrary, those batteries meant to storage the energy for long periods in order to supply in a more convenient situation are usually based on LFP or NMC Lithium-ion cells. Beyond the kind of battery employed, all energy storage connected to the grid must comply with the IEC standard 61427-2 [31]. Additionally, the charge controller employed in PV applications should pass the tests defined in the standard IEC 62509 [32]. In the following each of these elements (the battery itself, batteries for energy storage for renewable energy, and charge controller) is reviewed.

2.5.1 Battery qualification

The batteries must comply with the general requirements of the IEC standard 62093 [33] for their qualification, together with any other extra requirements according to their technology. For instance, one of the technologies with the highest potential for PV plants are lithium-based batteries which should follow the safety requirements defined in the IEC standards 62619, 63056 [34], [35] and be tested based on the procedures defined in the standard IEC 62620 [36] in order to qualify the following properties:

- Discharge performance at ambient temperature
- Discharge performance at low temperature
- Discharge at high current
- Charge loss over time and recovery after recharge
- Internal D.C. resistance
- Battery capacity after 500 cycles
- Battery capacity after 90 days stored at test temperature and constant voltage

These tests defined very specific conditions for the charging process, storage and discharging of the battery, which are almost impossible to replicate in a PV plant under operation making it complicate to correlate the evaluation of a battery in-field according to these tests.

Regarding photovoltaic applications, the three key parameters that influences the most the performance of a battery are:

- Charge and discharge power levels
- Operation in a state of charge (SoC) of less than 100 %
- Number of duty cycles to be accomplished over the service life

Which would depend substantially on the purpose of the energy storage system, namely:

- Frequency regulation
- Load-following service
- Peak-power shaving service
- Energy storage (time-shift)

For each of them, the IEC standard 61427-2 defines several procedures to simulate the performance of a battery in a PV plant connected to the grid in order to test the following characteristics:

- Discharge performance at ambient temperature
- Energy storage efficiency at ambient temperature
- Energy efficiency at minimum and maximum operating temperatures
- Heat generated at maximum operating temperature
- Energy consumption in idle state at ambient temperature

2.5.2 Charge controller for PV applications

The charge controller is the device in charge of controlling how and when the battery is charged or discharged according to its charge state as well the generated energy by the PV plant in particular moment, being the charge/discharge strategy defined according to the purpose of the battery. In order to guarantee the reliability of the charge controllers as well as the durability of the battery, the IEC standard 62509 was defined (although it focuses in lead-acid based batteries). This standard defines a number of guidelines related battery charge by means of a PV generator, the consumption control, protection features, or the user interface of the charge controller. In particular, the following topics are covered:

- Requirements related to the battery protection
- Basic recharge features
- Security settings
- Load disconnection

- Energy performance
- Self-consumption
- Thermal behaviour
- Over-current protection
- Inverse bias protection of the PV generator/battery
- Open circuit on the battery side
- User interface requirements

2.6 Weather Station

The weather station in a PV plant accomplishes a key task, as it records the operating conditions (solar radiation, air temperature, PV module temperature, relative humidity, air pressure, albedo and rainfall) with the main target of recalculate, or extrapolate, the energy generation to STC and thus, verifying the actual performance of the PV plant. Additionally, some of the measurements such as the rain gauge can be helpful to adjust, for instance, the cleaning tasks required by the O&M contractor.

As part of the monitoring system most of the requirements regarding the installation, recalibration or accuracy of the devices are defined in the IEC standard 61724 (see Section 2.7 for further details).

The key components usually found in the weather station of a PV plant are:

- Solar sensors

  Among the most common solar sensors we can find pyranometers, pyrheliometers, and the rotation shadowband radiometers (RSR). Usually, there are two pyranometers in each weather station to measure the global horizontal irradiance (GHI) and POA irradiance (also referred to as global tilted irradiance, GTI). Although if possible, it is also a good practice to measure direct and diffuse irradiation components. This kind of devices are generally advised to be recalibrated every year. The errors of the equipment measuring solar radiation come from the measuring device itself (cosine and azimuth effects, temperature response, spectral sensitivity, stability, non-linearity) from the setup of the entire system (sun tracking or shade-ring misalignment, instrument levelling, cabling, data logging and problems in the data transfer or storage) or from the maintenance (dust, snow, water droplets, bird droppings, shading by surrounding structures or vegetation, mechanical or electrical field effects, system shutdowns).

- Reference solar cell

  This should be a solar cell of a similar technology to that of the PV array, that are spectrally matched to the modules being tested, with red/blue response ratio to match that of modules and arrays. Usually, this sensor is set in the POA, although sometimes there is another one set horizontally or at a fix angle to evaluate the gain due to the solar tracker.

- Soiling sensor

  This sensor is meant to measure the loss caused by the soiling on PV modules. It is usually made of two reference solar cells on the POA, one of them is always kept clean while the other one is cleaned on a similar basis to that stablished in the O&M contract for the PV plant (see Section 2.1.8).

- Anemometer
- Ambient air temperature sensor

  The air temperature is recommended to be measured at about 2 m height, with enough distance from any heat or cold source that would falsify the results otherwise. This device must be shielded from the solar radiation to avoid overheating. Generally, temperature sensors are expected to be recalibrated every 2 years, with a measurement uncertainty up to ±1 °C.

- PV module temperature sensor

  This is usually accomplished with PT100/PT1000 sensors adhered to the rear side of the modules, with a measurement uncertainty ≤2 °C.

- Relative humidity, and rain gauge sensors
- Datalogger

The configuration of a weather station in a PV plant is not defined independently but as part of a broader IEC standard meant to regulate the monitorization of a PV plant (IEC 61724:1-3 [20]). There, the recommended accuracy, orientation, location, data sampling and recording intervals, recalibration and maintenance of the main sensors has been defined. Additionally, some other standards are defined for the devices of the weather station individually.

Additionally, any device devoted to the measurement or characterization of the irradiance should follow the best practices defined in the technical report "*Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy*" by the NREL [37]. Moreover, the ISO 9060 is devoted to the specification and classification of instruments for measuring hemispherical solar and direct solar radiation approved by the WMO which specifies three classes of sensors:

- **Class A**: Scientific quality and highest accuracy, Applications: Meteorology (BSRN Network); Testing in PV, CPV and CSP
- **Class B**: Good quality, Applications: Measurements for hydrology networks and greenhouse climate control
- **Class C**: Medium quality, Applications: Economic solution for routine measurements in weather stations and field testing

Where it is clear that any sensor used for PV applications must fulfilled with the requirements for spectrally Class A pyranometer devices which fulfils the requirements defined in older norm ISO 9060:1990 specifying secondary standard pyranometers with individual directional and temperature test reports.

Some other ISOs, such as the 9846 and 9847 are devoted to the calibration of pyranometers using a pyrheliometer and, more importantly for the purpose of this document, how to calibrate a pyranometers in field by comparison to a reference pyranometer.

The ambient temperatures are also standardized according to the ISO 17714, which specifies the following requirements:

- Representative height (height above ground at which the air temperature is supposed to be measured)
- Radiation screening (shield or shelter used to protect the thermometer from radiation, precipitation and accidental damage)
- Screen reference point (location of the thermometer within the screen)
- Solar radiation errors (overheating error of the measured air temperature, generated by solar radiation)
- System response time (time needed for the temperature recorded by the thermometer within the screen to reach 63% of a step change in the external temperature, with a given external wind speed of 1 $m \cdot s^{-1}$).

The solar cell references can be qualified according to what has been mentioned in Section 2.1.2 for PV modules.

However, a clear and precise procedure to validate the correct installation of all the sensors of a weather station in a PV plant should be further defined beyond the general guidelines set on the aforementioned 61724 IEC standard. Nevertheless, there is a set of common practices regarding calibration and routine maintenance within the industry to carry out this duty:

- Pyranometer:
  - Cleaning of glass with a soft cloth and alcohol (several times a week)
  - Weekly check of external appearance (cracks/scratches)
  - Weekly check of leveling (position of inner bubble)
  - Weekly check of cable and fixing system
  - Yearly recalibration, as recommended by the standard
- Anemometer
  - Monthly check of external appearance at low wind speeds.
  - Replacement of internal bearing: Check the condition of the bearing by hanging an ordinary paper clip (0.5 gm) on the outer edge of the anemometer while the instrument is kept in a horizontal position.
  - Replacement of the potentiometer after 50M of cycles.
- Reference PV cell
  - The calibrated cell needs hardly any maintenance. It suffices with guaranteeing that no dirt is accumulated on the cell glass and that the cables are in good condition. This is usually achieved with a weekly clean of the glass to guarantee its transparency.
  - The provider recommends recalibrating the cells once a year to guarantee their correct operation.
- Temperature and relative humidity sensors
  - Once every three months, clean the temperature / relative humidity (radiation) screen with a soft, clean, damp cloth. The inside of the filter must be checked to verify that no dirt is present.
  - The sensor must be recalibrated every 12/18 months according to most vendors
- Rain gauge
  - The rain gauge should be inspected regularly. Any accumulated dirt should be cleaned from the funnel and screen. The electrical connections should also be inspected and cleaned on a similar basis. Finally, the leveling screws can be readjusted at this time if needed.
  - A periodic recalibration is desirable to ensure accuracy of measurement
- Datalogger
  - Periodically (at least once a year) check for corrosion, stress cracks, frayed cables, loose cable clamps, damaged cables, etc. and take corrective actions.
  - Periodically (at least once a year) check the electrical ground connections.
  - The provider recommends recalibration of your dataloggers every 3 years.

2.7 PV plant

The PV plant as a whole must be evaluated as well in order to validate the proper construction or installation of all the elements, but also to evaluate its performance according to the design expectations. The proper evaluation of the yield is crucial as most contracts between the EPC and the plant owner will be mainly based on that value. The following tests verify and qualify the quality of the PV plant and its performance. Generally, when an EPC contractor is involved, the quality control tests described below are usually carried out at 3 different times (depending on contract) obtaining the following certificates correspondingly:

- Provisional acceptance certificate (PAC) - After one week at least of the PV connexion to the network (commissioning)
- Intermediate acceptance certificate (IAC) - After one year of operation
- Final acceptance certificate (FAC) – After two years of operation. Then, the owner takes over the PV plant

2.7.1 Inspection

Before energizing the installation, several visual inspections shall be carried out to make sure that the power plant has been built according to design best practices and safety rules and standards. Among them, the most important ones are:

- **Electric shock risks**: it must be verified that the DC side is protected by a class II or equivalent insulation, and that the DC cables are protected by a reinforced insultation (labelled H1Z2Z2-K according to EN 50618 [38]).
- **Insulation faults risks**: A PV array earth insulation resistance detection and alarm should be installed (generally inside inverters) with its corresponding monitoring system to detect any residual current.
- When functional earthing of any DC conductor is in place, it must be verified that a **galvanic separation** is installed between the DC and AC parts. This separation can be part of the inverter.
- **Overcurrent risks**: the possible reverse current has been calculated and all PV arrays are protected against it (fuses should be added if relevant or blocking diodes if allowed).
- **Earthing and bonding arrangements**: a functional earth fault interrupter should be provided where the PV system has a direct connection to earth on the DC side. The DC cables must be installed in parallel and bundled with the protective earthing and/or the equipotential bonding conductors when possible.
- **Lightning and overvoltage risks**: it must be verified that the area of all wiring loops has been kept as small as possible to minimize voltages induced by lightning as well as long cables protection (e.g. use of surge protective devices, SPDs) and that SPDs are fitted.
- **Equipment Selection**: All DC system components (PV modules, switches, fuses, terminal blocks, DC cables, etc.) are rated for continuous operation and for the maximum possible DC system voltage (usually 1000 or 1500 V). Verify that plug and socket connectors mated together are of the same type and from de same manufacturer.
- **Labelling**: ensures that all DC system components are properly labelled with the DC cables correctly identified and the *Shutdown & Emergency* procedures are displayed on site.
- **Mechanical protection**: Ensure that the DC connectors are correctly connected, and DC cables are correctly attached.

2.7.2 Performance

The performance of a PV plant is evaluated at two different moments. During the commissioning tests, at the provisional acceptance of the installation (*PAC*) and, generally, after two years of operation, as a part of the final acceptance of the PV plant (*FAC*). The most common index used in this performance tests is the Performance Ratio (PR), defined as a relation, during a certain period, between the output energy delivered by the system and the input energy received by it or, in other words, between the final yield of the installation, Y_F, and a reference yield, Y_R, obtained from the effective in-plane irradiation (G^{ef}). More in detail, this index is defined in IEC-61724 as:

$$PR_t = \frac{Y_F}{Y_R} = \frac{E_t \times G^*}{P^* \times G_t^{ef}}$$

where E_t is the energy delivered to the grid during the period t, G^* is the irradiance at Standard Test Conditions (*STC*), P^* is the nominal power of the PV generator, calculated as the sum of the *STC* power of the modules, and G_t^{ef} is the irradiation effectively received at the PV system.

The PR presents the advantage of being simple: it can be calculated directly without any kind of modelling, just from the data of the energy meters, the PV manufacturer datasheet and an irradiance sensor. In fact, the choice of the reference sensor for the measurement of irradiation becomes one of the few issues to face. In this respect, the standards of the sector have been evolving, depending on whether they considered:

- The **Global Horizontal Irradiation**, GHI. It was the reference that was initially used and corresponds to the irradiation received by a pyranometer in the horizontal plane. However, this source was soon disregarded, due to the non-linear behavior between it and the output energy, mainly derived from the pass from the horizontal to the tilted plane.
- The **Global Tilted Irradiation**, GTI. A first modification to avoid those non-linearities was to consider the global irradiance in the plane of array as a reference, as seen by a pyranometer. However, this irradiance presents the disadvantage of not corresponding to the one that actually reaches the generator, since it does not take into account the angular and spectral responses of the PV modules.
- The **effective in-plane irradiation**, G^{ef}. The most advanced procedures establish as reference the irradiance received by a PV device in the plane of array. This measurement can be provided by a reference module or cell and represents the real input of the system.

Whichever the case, for a given PV plant and site, PR tends to be constant through the years, as much as the climatic conditions tend to repeat themselves, what makes it be suitable for technical qualification when considering yearly periods (as for the FAC tests). This way, the contractual management of the PR only requires an agreement on the guaranteed value (derived from the initial yield assessment with a safety margin agreed among the parties involved in the project), on the solar radiation measuring device and on the long-term degradation effects.

Nevertheless, PR has some significant disadvantages as an evaluation index. On the one hand, it does not differentiate between avoidable and unavoidable losses in each phase, which makes difficult to preserve the chain of responsibility. For example, it does not allow distinguishing between high temperature losses (inherent of the site climatic conditions), shadowing losses (derived from the design phase), low equipment efficiency (accountable to the equipment manufacturers) or poor maintenance (accountable to the O&M contractor). Another disadvantage is its large variability in short periods of time as it does not consider the efficiency variation with temperature and irradiance, as can be seen in Figure 2.1.

In that regards, the so called PR_{25} has been proposed, which corrects the PR to 25 °C. Nevertheless, the influence of the irradiance on the solar cell efficiency (or voltage) is not considered by this PR_{25} either. Consequently, a parameter with corrects with both operating conditions (temperature and irradiance) is required, which could be considered as a PR_{STC}.

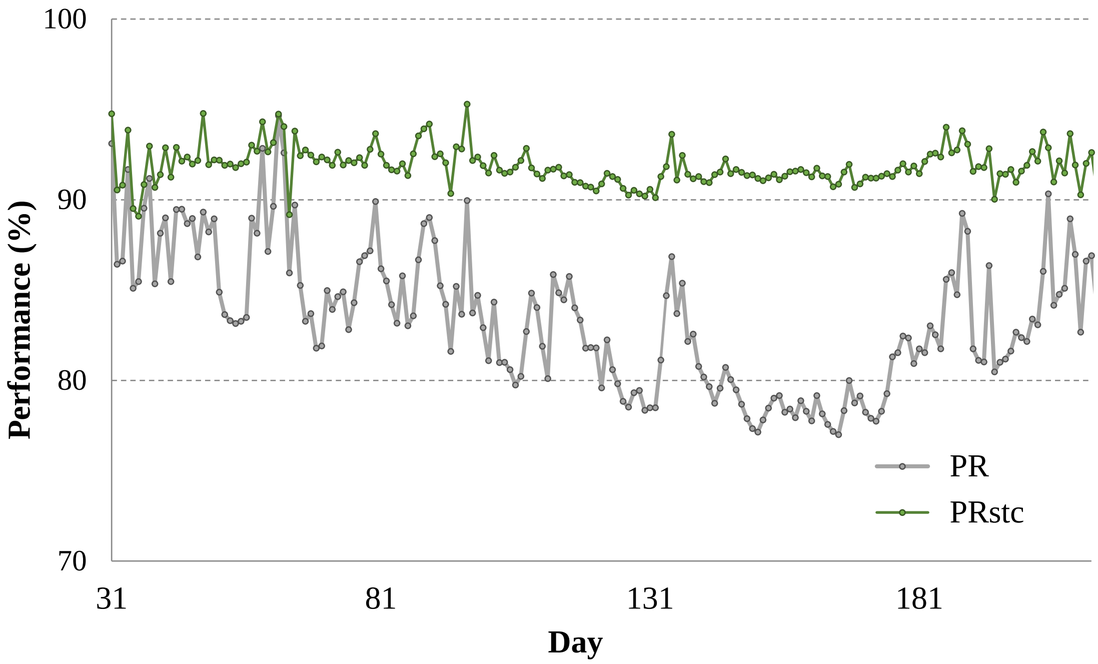

Figure 2.1: Variation of the PR and PR_{STC} along the year.

The outstanding benefit for the rather low added complexity of measuring the cell operating temperature is that PR_{STC} is neither time nor site dependent, allowing more precise qualification of the technical quality of PV installations and to detailed intercomparisons between PV plants in different climate regions.

2.7.3 Testing

Before energizing the installation, it is advisable to:

1) Make electrical continuity tests on all bonding conductors.
2) Check the polarity of all DC cables using a suitable voltmeter.
3) Make open circuit voltage tests on PV strings using a suitable voltmeter.
4) Measure short circuit current: make short circuit tests on PV strings using a short circuit switch test box.

After energizing the installation carry out the following tests and verifications:

5) Current measurement: measure the current from each PV string or HSA (Harness Sub Array = group of PV strings) using a suitable clip-on ammeter (up to 2kV) or by using the ammeters integrated into inverters. PV string measures may be compared to note maximal current gap (%) upstream of the inverter.
6) Power measurement: DC input powers at the MPPTs can be measured and compared. The same goes for AC output powers of inverters. The basis of comparison shall be the specific powers, as the rated power can differ from one MPPT (or inverter) to another.
7) Insulation resistance test on every PV string (as a minimum, for each PV array) using a suitable insulation controller.
8) String I-V curve measurement using device suitably rated for the voltage and current of the circuit test. An I-V curve test is an acceptable alternative method to derive the string open circuit voltage and short circuit current (tests 3, 4 & 5). Annex D of IEC 62446-1 describes how to interpret I-V curve shapes.

9) Infrared thermography test on every electrical component (switches, fuses, terminal blocks, etc.). Classification of abnormalities will depend on the component.

10) If applicable, make open circuit voltage and short circuit current tests on every blocking diode.

These tests shall be performed at stable irradiance conditions of at least 400W/m² as measured in the plane of the array. For non-stable irradiance conditions, it is highly recommended to delay the tests until they can be carried out under more suitable conditions. For safety reasons it is also encouraged to perform the measurements with suitable equipment (rated for 2000 V DC) and that the operator wear adequate Personal Protective Equipment.

3 QCP NEEDS FOR FUTURE PV PROJECTS

Once the QCPs, or best practices, currently applied to the different elements of a PV plant have been reviewed, the new QCPs required for the proper evaluation of PV plants or projects are assessed. In order to carry out such an evaluation, three different approaches have been followed:

- **Needs identified by the task partners** – Based on the expertise of each partner involved in Task 4.1 the QCP requirements for future PV projects have been developed. All the partners have been involved in the revision and definition of the QCP needs, although each area has been led by the corresponding expert within the partners.
- **QCPs Survey** – With the final aim to obtain a comprehensive view of the QCP requirements, a survey has been distributed among the SERENDI-PV consortium and the PV community. This survey, which is based on the needs defined by the partners in the previous point, is meant to obtain further feedback from different roles in the PV community, broadening the perspectives and points of view included in the assessment.
- **Publications and media review** – the scientific publications and news, published in scientific journals and in the media, have been reviewed to try and identify trends in the scientific community or the PV industry.

3.1 Needs identified by the task partners

The QCPs identified as the main ones to be developed or improved future PV projects can be split into: a) PV modules and strings; b) bifacial PV; c) floating PV; d) solar trackers; e) weather station; f) inverters; g) batteries; and h) PV plant. For each of these topics the list of required QCP is depicted providing an explanation about what is actually pursued by each of them and why it is needed.

3.1.1 PV modules and strings

- Temperature coefficients determination in field

  The determination of the module temperature coefficients should be further specified, determining the range of operating conditions under which the results are valid for the eventual performance extrapolation to STC (whether for a PV module or a complete PV plant). Additionally, how this evaluation should be carried out in field, and what is the expectable or acceptable module-to-module variation must be defined.

- PV module and string ageing

  The assessment of the degradation in field for PV modules is not define accurately enough to achieve reliable results in a short period of time (within the frame of reliability issues, where one year is a “short” period of time) as the yearly degradation rate falls within the measure uncertainty. Therefore, a solid methodology must be defined specifying the required procedures to decrease the uncertainty and allow for an accurate determination of the degradation rate on a yearly basis. In this regard, some possibilities to explore would be multiple measurement of a PV module, or the combination of multiple modules to work with averages. Additionally, it should also be defined how to evaluate the degradation at a string level. This is of utmost importance as it could be larger than the one estimated on a module basis due to the current limitation imposed by the series connection of the modules [39].

- IRT measurements

  Based on the aforementioned best practices and reported experiences in field, some efforts should be devoted to further validate the proposed correlations between the results of IRT campaigns and the expected PV module performance by the:
  - Validation of fault type with (ground) visual and/or IR inspection on-site
  - Validation of fault type with electrical/optical characterization (I-V, EL) off-site
  - Validation of estimated power/current/voltage loss with module-level I-V tracing on-site
  - Validation of estimated power/current/voltage loss from inverter/monitoring output data
  - Validation at two different times in the year, to assess the impact of seasonality

  The KPIs to define the success of these assessment could be based on the:
  - Accuracy in power loss estimation %
  - Total number of different failure modes successfully diagnosed/classified
  - % of underperformance issues (e.g. failures) with root-cause identified.

  There are also no clear standards about what are the acceptable temperature ranges, or limits, when qualifying a PV module by means of ITR. This should be clearly stated, at least under a defined range of operating conditions, to allow the acceptance or rejection of PV modules based on its temperature management performance.

3.1.2 Bifacial PV

- Albedo in large PV projects with variable surfaces

  Currently there is no standard nor widely accepted procedure to evaluate the albedo for large PV projects. In such scenario, it is expectable that the albedo will not be homogeneous throughout the whole surface of the PV plant (which can take up several square kilometres). This variability will affect the energy generation, mostly in bifacial PV plants. Therefore, a valid procedure to characterize the albedo in large surfaces is required, providing that the accuracy is low enough to detect any variation of the albedo and consider it correspondingly.

- Impact of the array structure on the rear side irradiance (Structure Shading Factor)

  A valid procedure to characterize the shading caused by the supporting structure and its influence on the albedo must developed, as it directly affects the energy generation. This shading will be dependent on the structure used (whether it is fixed or is a solar tracker, and even on its particular design) the PV plant pitch and even on the time of the day, or the period of the year. Furthermore, its impact on the energy generation will be a convolution of the energy shading with the albedo.

- Bifaciality characterization

  A univocal methodology to determine the bifaciality of a bifacial PV module must be proposed. In particular, the characterization of the temperature coefficients of the rear side as well as how to deal with nonlinearities must be addressed. The coefficients dispersion will have a direct impact on the energy generation and therefore it must be addressed.

- Mismatch losses due to inhomogeneity in rear irradiance, temperature, and electrical characteristics (mismatch factor).

  A procedure to evaluate the losses in bifacial PV caused by inhomogeneities due to the aforementioned points (i.e. albedo and electrical characteristics inhomogeneities) must be proposed. This procedure should integrate all the losses taking into consideration the particular boundary conditions (albedo, shading, etc.) of the PV system under study.

- Assessment of soiling impact on various bifacial tilt configurations

  The soiling effect in the rear face of bifacial PV plants must be studied to evaluate its impact and whether it can be mitigated with any tilt strategy. Additionally, whether the rear face needs cleaning as often as the front one must be studied considering that rain will not clean the rear surface as effectively as the front one.

- Assessment of performance ratio in bifacial PV plants

  A process to extrapolate the performance of a bifacial PV module under real conditions to STC must be developed considering the nuances involved in the performance of bifacial PV modules. This should be integrated with the previous points to develop a methodology to properly calculate the PR of bifacial PV plants obtaining a more meaningful comparison with the estimated PR during pre-commissioning phases (PV plant design). Although this could be done at a module level, it is strongly recommended that together with this procedure, a reasonable simplification to properly evaluate the impact of variable albedos, shadings, bifacialities, etc. is proposed, simplifying the calculation of the PR for a PV plant and allowing to determine the PR without requiring the characterization of each module in the PV plant.

- Annual degradation assessment

  The manufacture of bifacial modules involves a noticeable change in the encapsulation of the cells as glass-glass or other technologies using synthetic transparent backsheets are required. Therefore, different degradation processes are expected for this type of encapsulation. Moreover, the fact that the light enters the solar cell from the rear side as well makes it more sensitive to the degradation of the rear surface in opposition to the bulk or front surface degradation. Accordingly, the long-term degradation of this type of solar cells should be accurately studied to provide a reasonable degradation rate to be considered in the design stage of bifacial PV Projects. Although these tests have already been developed for monofacial PV modules (for instance the assessment of LID or PID degradation), they should be adapted to the nuances present in the design and operation of bifacial PV modules. Beyond that, a standard to assess the LeTID degradation process must be developed as well. As a side note it should be noted that, due to scale-economy, bifacial solar cells might be used in monofacial modules. Even if the light does not enter from the rear side in this approach, the degradation mechanisms ruling the solar behaviour might be different as well from those modules employing monofacial solar cells. In order to obtain valuable results, it will be required to compare the outdoor degradation with indoor tests to understand the underlying mechanisms ruling the module degradation.

3.1.3 Floating PV

- Impact of high humidity and salt environment on the PV Module reliability (corrosion…)

  High humidity weathers can damage PV modules. Therefore, extended IEC tests in thermal chambers need to be undertaken in order to evaluate which bills of materials are the most resistant to this stressor. Similarly, the potential presence of salt in marine environments is a hazardous thread to every metallic component of the installation. Accordingly, the PV modules resistance to these aggressive environments must be evaluated.

- Operating temperature and wind influence

  Proximity with water will surely generates convective movements between the water surface and the PV module heated up by the irradiance. One can even expect conductive cooling if waves are present (marine environment for example). Similarly, wind is well known to be present on the shore due to the temperature gradient between the shore and water (sea/lake…). Thus, these two factors head towards lower operating temperatures compared to terrestrial installations. Therefore, an accurate analysis of the operating temperatures in floating PV must be carried out.

- Mechanical stress for the supporting structure and the PV module

  In the presence of waves, the supporting structure of PV modules will not be stable. The continuous movement of the structure can cause mechanical stresses on the modules. If expected stronger wind gusts are considered as well, the demands on the mechanical resistance of the modules need to be more stringent than for terrestrial installations. Accordingly, a procedure to ensure that the mechanical resistance is high enough, as well as a methodology to evaluate the mechanical stress that caused by each source (waves and wind) in a location in particular prior to the PV plant installation must be developed.

- Procedures for the characterization of power degradation

  The degradation suffered by floating PV modules need to be assessed as specific failures modes can be promoted or developed as a consequence of the surrounding environment. In order to evaluate it, outdoor degradations could be compared with indoor testing to understand and identify the root cause of each failure mode. The ultimate result would be the guidelines required to discriminate those PV modules unsuitable for floating PV plants. The most important stressors to be evaluated for floating PV plants are: damp heat, PID, salt mist, dynamic mechanical load and UV degradation. Additionally, in a similar manner to what has been previously pointed out for bifacial PV modules the LID and LeTID degradations should also be assessed. Finally, this should be adapted to evaluate the annual degradation and compare it with the predictions from accelerated degradation tests.

- Procedures for the characterization of isolation degradation

  Wet leakage measurements need to be carried out in order to ensure the proper security of the installation and to evaluate the PV module performance. This should be cross-check with indoor testing for the different stressors listed in the previous point.

3.1.4 Trackers

- Tracker battery assessment

  As pointed out one of the key aspects to improve is the energy supply to the tracker to maintain it working properly without any misalignments. Therefore, and similarly to what is described in the battery section for energy storage, procedures to properly evaluate the state of charge and state of health of trackers' batteries must be developed. This will allow to detect any malfunctioning of the battery in advanced and carry out the corresponding maintenance task to avoid the solar tracker from falling in an idle state. Additionally, the continuous assessment of trackers' batteries will provide the required information to pin down what is the optimum battery size.

- Tracking and backtracking strategy

  A standard methodology to evaluate the tracking and backtracking strategies should be defined. This is especially important in non-completely flat PV plants, where the z component (the height of the ground) needs to be considered for the aforementioned strategies. This can impact the energy generation due to an inexact tracking or an ineffective backtracking. Therefore, a methodology to evaluate the tracking and backtracking strategies at a PV plant level needs to be developed.

3.1.5 Weather station

- Standard procedure to carry out the quality control in field

  A procedure to qualify the weather station of a PV plant in field is yet to be defined. Currently, the only applicable control procedure that can be carried out are the cross-check validation of the data acquisition as well as visual inspection of each of the elements (cleanliness, inclination and orientation, location, etc.) and whether it suffices for the monitoring system declared according to the IEC 61724. However, an accurate and detailed list of procedures to check and validate the correct installation of each sensor in the weather station of a PV plant is required.

3.1.6 Inverters

- Efficiency measurement in the field, including the influence of DC/AC voltage and operation temperature

  Currently, the inverter's efficiency is simply calculated as the ratio between AC and DC power. Given the high efficiency values –near 99%– and the proximity of them among different models, it is necessary to enhance the precision of the instrumentation and to analyse the factors with an effect on the converter's losses. The input voltage is already taken into account in the current quality control procedures in factory so, similarly, output voltage and components operation temperature should also be considered. The output voltage directly influences the output current, and so the efficiency through both semiconductors as well as resistive components as wiring, chokes, etc. In a similar manner, temperature monitorization of those components needs to be included in the procedures so as its effect on the value of efficiency is counted. Finally, this should converge on a valid procedure that allows to compare the efficiency measured in field to the results obtain in factory tests (once the effect of input/output voltage and temperature can be corrected).

- Heat dissipation characterization and evolution

  Verification of the correct performance of the inverter over time, which may or may not be the consequence of a poor maintenance, can be determined by monitoring the thermal layout of the inverter components and their temperature increases with respect to the ambient. These temperature increases may not be constant over time, which could point out a potential problem whose causes are to be analysed: components inherent degradation, deficient maintenance, wear and tear, etc. Therefore, it is required to develop a valid procedure to register the temperature of the devices and a methodology to estimate whether a significant degradation of the components is taken place.

- MPP tracking

  MPPT efficiency is currently measured on lab following EN-50530. However, there is no standard procedure to carry out in field measurements and confirm that the inverter does operate at the array's MPP. New procedures have to be proposed to improve this situation such as analysing the operation point or determining the I-V curve using the inverter's own instrumentation and checking that the operation point is correct. Internal knowing of the array's I-V curve will also allow to check that the MPP falls into the inverter's range. This is important because sometimes sizing mistakes bring to this unwanted situation.

- THD characterization at different electrical points

  In field measurements of harmonic distortion is not currently usual due to the lack of methodical procedures for it. Nonetheless, it is important to measure the THD at different power levels to prove that the inverter itself is behaving as expected and that it exhibits no resonance with other devices on field. Resonance effects may even remain unnoticed or may imply overheating and/or early damage of components. The inverter level measurements (by an internal grid analyser) as well as plant level measurements are both valuable approaches to study in order to check if harmonics of different devices compensate each other or if they reach the grid.

- P-Q and power factor analysis

  It will be important to validate in field those power capacities determined on lab. There are external factors like the impedance of transformers in the PV plant and the grid connection point which modify the voltage perceived by the inverter at its terminals. This forces the inverter to limit its capacity of injecting the active and/or reactive power with respect to the ones provided by the lab tests.

3.1.7 Batteries

- Evaluation of the quality of the charging/discharging strategies

  Existing type-approval tests are based on the behavior of cells and batteries under laboratory conditions. It would be advisable to use tests adapted to their management in charging and discharging conditions extrapolated from reality. Something similar to what is used in the automotive industry to certify the kilometers travelled by an electric car.

- Battery charge/discharge efficiency

  The efficiency of the battery once integrated in the PV system has to be checked using real parameters.

- Battery charge cycle lifetime

  The current homologation is using a limited number of cycles because operational issues. More extended test of cyclability has to be performed to get the real degradation of the batteries with battery life.

- SOH characterization

  Related to the previous point, the SOH of the battery has to be obtained using “in situ” technics to update the lifetime of the battery in real operation. The knowledge of this parameter allows us to adapt the use of the battery to extend its life.

3.1.8 PV Plant

- PR_{STC} implementation

  The use of a corrected PR with both, temperature and irradiance should become the standard in the industry in order to guarantee reliable and consistent PR values.

3.2 Survey

In order to broad the points of view considered in the deliverable a survey has been developed based on the previous requirements identified for future QCPs. The survey, which can be found at https://forms.gle/tit7aNBJALJD3rZX7, has been disseminated across the SERENDI-PV consortium, in the WIP newsletter and further disseminated in social media (such as LinkedIn) by QPV, WIP, and other partners of the consortium. Additionally, all the partners have been asked to disseminate the survey among their contacts within the PV community to take advantage of the dissemination potential of the SERENDI-PV consortium. Among the participants there has been Large PV plant owners, R&D laboratories, EPCs and consultancy services companies, which ensures a reasonable variety of points of view in the answers obtained.

The survey conclusions are presented below, although it will be open for the duration of the project to gather as much answers as possible. The main conclusions from the interview, which follows the same lines defined in the previous points by the task partners, are:

- Bifacial and floating PV seems to be one step ahead of inverters or batteries regarding the importance to develop new QCPs or to adapt the current ones to the new requirements.
- Regarding bifacial PV, the topic perceived as the most important one was the PV module degradation, closely followed by the albedo assessment. Another interesting conclusion is that it was also highlighted the requirement of an advanced quality control procedure for the bifaciality of PV modules. In an intermediate point was the assessment of soiling, paying particular attention to the rear face soiling. Finally, the influence of the module design (for instance the cell pitch) or the impact of the horizon line were perceived as topics with a modest importance on the future of bifacial PV.
- In respect to floating PV the most important concerns are those related to the durability or reliability of the PV system, such as the impact of the high humidity or the salt environment, the mechanical stress subjected to the supporting structure, the isolation of the devices or the annual degradation evaluation. On a second step were those procedures related to the soiling and its cleaning as well as the assessment of the operating conditions in such environments (irradiance and temperature).
- The most valued quality control procedures for inverters were those related to the comparison of the inverter efficiency between factory test and in field test such as the influence of the operating temperature (as well as how to properly determine the inverters temperatures and its dissipation efficiency) and the MPPT tracking. On a second line appears the component degradation, the evaluation of the harmonics, the P-Q and power factor analysis and the sensitivity to the trigger threshold.
- The answers about the required quality control procedures pointed towards an indeterminate area, as most of the proposed quality control procedures obtained a similar recognition of its importance for future PV projects. Taking into account that most of the PV plants nowadays do not incorporate energy storage, it seems reasonable that the needs are still to be defined and that there is not a clear opinion on what needs to be developed. This fits with a still unmatured market, which in any case, points towards the necessity of developing a whole new palette of quality control procedures for PV plants incorporating energy storage which allows to identify what is actually needed for future PV projects.
- Finally, regarding the bankability of a PV project, the key point identified as crucial for future QCPs is to determine the uncertainty in the energy generation of a PV plant and break it down to the different uncertainty sources and how it will evolve with time. Then, the other factors perceived as potential points to study are the technical uncertainties against economic ones (financial structure, energy price in the long term, etc.) as well as the direct impact of better QCPs on the levelized cost of electricity (LCOE).

3.3 Scientific publications

Finally, in order to get a better idea of what is driving the scientific research, a study analysing the publications about the aforementioned topics related to key words within each technology has been reviewed. The trends observed as well as the relation among the different topics allow to distinguish the importance of each of them as well as which ones are expected to drive the research in the near future.

The main topics driving the research about bifacial PV since 2010 are depicted in Figure 3.1. It is clear, that it is a fairly recent subject, as there were almost no publications before 2013. Since then, the study of the albedo for bifacial PV has steadily increase being the most important topic most of the years. It is true that there is a fall in 2020, but that happens to almost every topic (not only for bifacial PV) due to the impact of the Covid-19 pandemic situation during that year. It can also be seen that the annual generation or the mismatch in bifacial solar cells are non-negligible topics strongly related to the albedo, but they are always behind it. Regarding the solar cells, the dominant architecture has been coming back and forth between the PERC and the heterojunction ones, being slightly less publications about PERT solar cells while the IBC is the least employed of them all. Finally, the degradation processes have not been particularly studied related to bifacial PV, as this kind of publications are usually more related to the architecture of the solar cell itself rather than the module one.

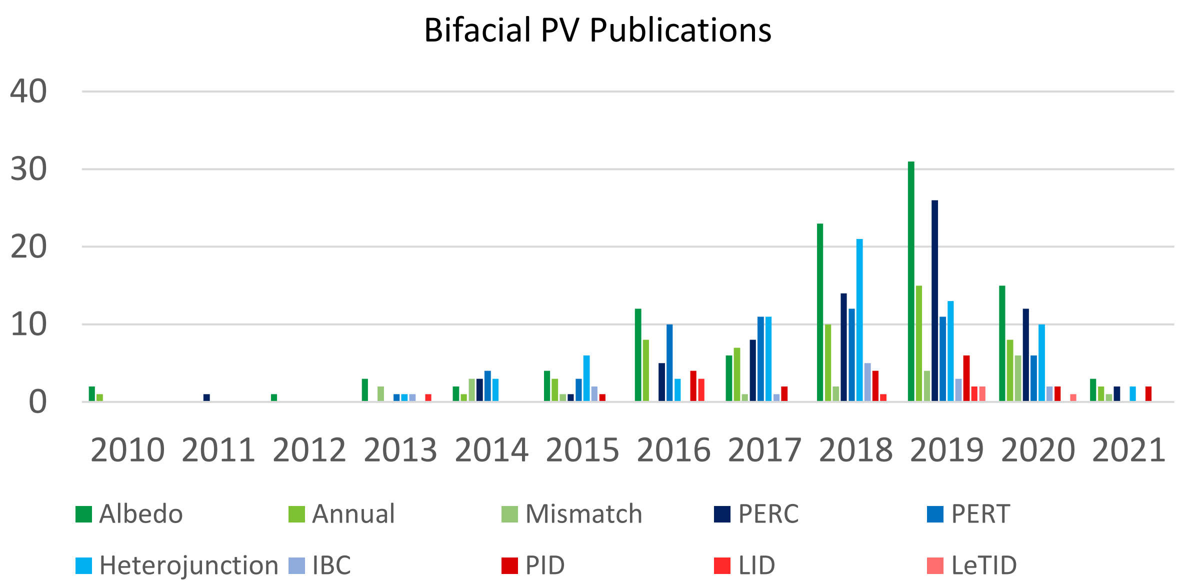

Figure 3.1: Scientific publications about bifacial PV technology related to other topics, namely: energy generation (Albedo, annual and mismatch), type of solar cell (PERC, PERT, Heterojunction and IBC) and degradation (PID, LID and LeTID).

Then, all the publications about bifacial PV has been compiled and compared to those studying floating PV. It can be seen that although bifacial has always been more studied than floating PV, the latter is getting more attention every year. Actually, it is clear that both are new topics with just a few publications before 2012, and also, both has started growing steadily since 2016, with the similar drop in 2020 observed in the previous chart.

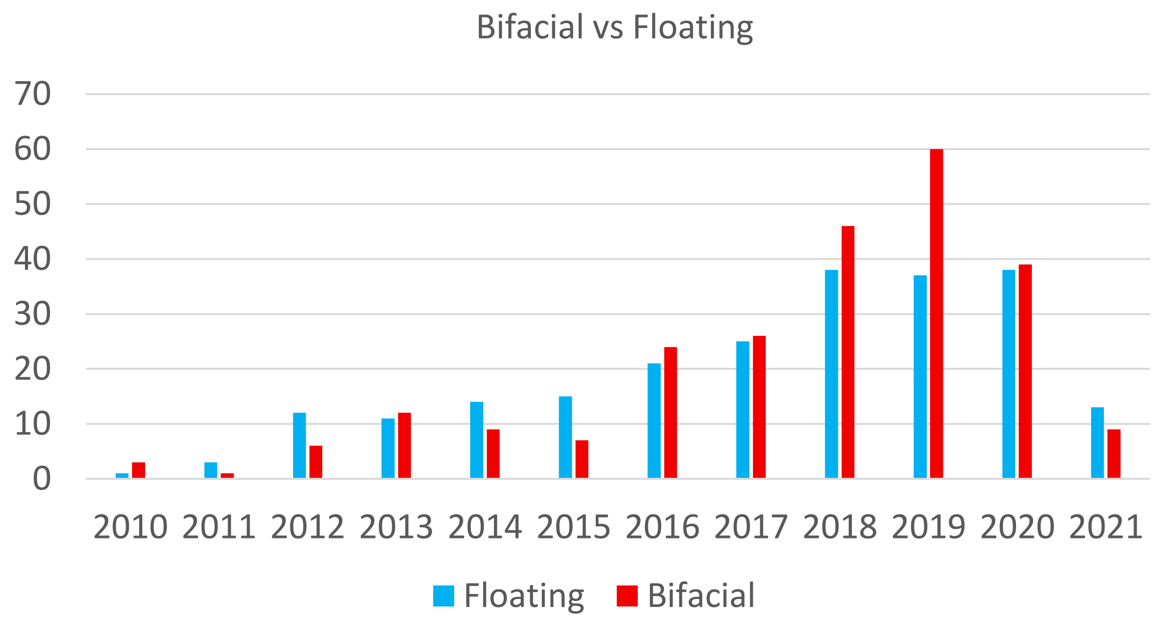

Figure 3.2: Scientific publications for floating PV and bifacial PV technologies.

A similar assessment to that shown for bifacial, was meant to be carried out for floating, inverters or batteries. However, it has been extremely difficult to find keywords that allow to filter the results coherently.

4 CONCLUSIONS

In this deliverable the QCPs and best practices currently applied to qualify or maintain the different elements of a PV plant, as well as the PV plant itself, have been reviewed. The final aim of this work is to pin down the QCPs required for future PV projects, detecting those QCPs that do not satisfy the current needs or the lack of any related QCP. The key items identified to improve or develop new QCPs are: the PV module, the solar tracker, the weather station, the inverter, and the battery. Finally, the importance of each QCP has been further validated carrying out a survey disseminated among the PV community and studying the scientific publications trends in the recent years. Taking all of this into account, has allow us to identify the following QCPs are the key ones to be developed for future PV projects:

- **PV module/string** – it is required to further develop the procedures defined to obtain the temperature coefficients of a PV module to be applicable in field. Additionally, the operating conditions required for it should also be specified. Regarding the module degradation, a procedure that allows to measure the yearly degradation in-field in short periods of time (one year) is needed. Finally, the faults detected by means of IRT measurements must be cross-checked with other characterization techniques to validate them.
- **Bifacial PV** – it is mandatory to extend the standard to characterize bifacial PV modules and their bifaciality in field as well as the temperature coefficients of the module. Then, this has to be combined with the proper assessment of the albedo (considering the shading structure) to develop a standard for characterizing the performance of bifacial PV plants. In order to obtain a valid PR for this type of plants, an extrapolation procedure that takes into account the nuances in the performance of bifacial solar cells must be developed. Finally, the degradation of bifacial PV modules needs to be properly assessed providing a standard rate to consider in the design stages.
- **Floating PV** – the corrosion and degradation suffered by floating PV plants due to the high humidity, and even salt water has to be properly evaluated together with the additional mechanical stress that the supporting structure needs to support. Additionally, the influence of the water on the temperature of operation needs to be accurately determined in order to decrease the uncertainty in the expected energy of a PV plant.
- **Trackers** – the monitoring of trackers' batteries needs to be implemented in order to developed strategies to prevent the lack of energy (and consequent tracking fault) as well as a definition of the optimum battery size depending on the PV plant location. Additionally, QCPs to evaluate the tracking and backtracking strategy needs to be develop, ensuring that the orography of the PV plant has been considered maximizing the energy generation.
- **Weather station** – a standard procedure to qualify all the elements of a weather station of a PV plant is required, to allow for a proper validation of each of its elements.
- **Inverters** – the impact of operating temperature (considering the temperature of each component or the heat dissipation), as well as the input or output voltages needs to be considered to develop future QCPs allowing for an in-field validation of the inverter efficiency. Similarly, a standard to validate the inverter's MPPT in-field is also required, together with the characterization of its THD and P-Q and power factor.
- **Batteries** – the impact on the battery SOH by the charge/discharge cycles imposed by the operation of a PV plant needs to be evaluated, developing a procedure to carry out in-field assessments of the batteries.
- **PV plant** - The use of a corrected PR (PR_{STC}) with both, temperature and irradiance should become the standard in the industry in order to guarantee reliable and consistent PR values.

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