# Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates

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The Technical Report will be available for download from the IEA-PVPS website www.iea-pvps.org.

## Executive Summary

The increasing adoption of PV systems in different climate zones and conditions worldwide has indicated that stress factors such as temperature, humidity, exposure to UV light, rain, and wind could contribute to the occurrence of module failures. Knowing this fact, operation & maintenance (O&M) operators have looked to customize O&M services to the climate zone where particular plants are located.

At present, comprehensive guidelines for climate-specific O&M programs have yet to be developed. With this gap in mind, this report aims to provide comprehensive guidance for customized O&M service in seven different climate zones. The first four are for conditions which broadly prevail in large parts of the world (moderate, hot and dry, hot and humid, desert at high elevation), while the latter three are for extreme conditions (flood-prone regions, cyclonic regions, snowy regions). These guidelines can assist PV plant engineers and de-signers, financing parties, and investors in designing and maintaining PV plants, as well as in determining operational risk related to investment decisions.

The report presents these guidelines according to the following topics: O&M performance indicators and standard O&M operator services, guidelines for monitoring, forecasting, and analysis of PV plant performance and safety, the different types of maintenance services and advanced inspections, and finally the recommendations for climate-specific O&M along with field experiences encountered that affected reliability, performance and safety.

The key highlights from this report are the following:

- An O&M contract should clearly describe the scope of the services and responsibilities of the operator to prevent any ambiguities in their respective responsibilities, as well as acceptable compensation if operators fail to fulfil their obligations. Key to this is including at least one of the O&M operator KPIs (key performance indicators) such as Guaranteed Performance Ratio, Guaranteed Plant Availability, and Response Time in the contract to allow for straight-forward standards in measuring contract compliance. The choice of which of these KPIs to select is based on negotiations in the O&M contracting phase. Finally, O&M contracts should take into account regional differences, such as national or local legislation that affects the availability of staff on-site, as well as variations in the capabilities of key stakeholders that affect project cost.

- Performance monitoring systems should allow for a ´follow-up´ of the energy flows within a PV system. The scale and complexity of plants determine the level of monitoring: the larger and more complex the plant, the more intensive the monitoring. Minimum requirements are detailed in international standards such as IEC61724-1, as well as best practice guidelines such as the SunSpec Alliance. To gather insights on specific failures and underperformances, predictive maintenance services with data collection devices on-site should be put in place to create an "intelligent" monitoring system. O&M operators need to be ready to comply with applicable grid codes and regulations, allowing for the re-evaluation of the scope of operations for contracts if grid codes change, especially in contexts where more RE plants replace thermal sources of power.

- This could particularly apply to PV power forecasting services, which are increasingly critical but could be offered either by O&M contractors or by external service providers. Asset owners may find it convenient to choose a PV forecasting service s/he is already working with, as these may impact con-tract agreements with other partners who may depend on the performance of the plant, such as trading service providers. Finally, to ensure safety, O&M operators must guarantee plant and worker safety by ensuring that staff is well-trained and qualified to implement safety procedures, equip them with PPE, tools and consumables, and take into account site-specific risks such as heights, presence of water, increased fire risks, or weather conditions.

- Preventive maintenance (PM) action plans that exclude redundant activities can bring costs down. The preventive maintenance plan should seek to optimize the overall PV plant and O&M budget-ing, depending on the plant´s size, design, complexity, and environment. The most important actions here include periodic sampling of individual electrical measurements at module level, soiling and snow mitigation, site and vegetation management, and keeping balance of systems and SCADA (supervision control and data acquisition) monitoring systems operational.

- Aerial infrared (IR) and visual imagery are powerful tools for diagnosing faults, especially for power losses. As of present, turnkey solutions for aerial imagery diagnostic solutions for large-scale PV does not yet exist, as current wireless communication and camera control technology limit the operational range. Typical costs for base O&M scope from the years 2021/2022, including soiling mitigation, range from 6.5 up to 16.5 €/kWp*year. Additional costs for advanced diagnostics/analytics based on aerial IR scans (on bi-annual basis), range from 0.5 to 3 € per PV module or array. In corrective maintenance/spare parts action plans, maintenance reserve accounts are recommended to be set aside by the plant owner, to foresee possible replacement costs.

- The essential practical guidelines for the climate zones studied are:
  - **Temperate** – An on-site evaluation of vegetation, wildlife and farm animals should be conducted. Grass cutting should be combined with an inspection of the status of solar PV modules to decide if cleaning and/or corrective maintenance actions are required. In industrial environments, solar PV modules can develop unexpected deterioration. Special attention must be paid to selecting cleaning products. It is advised to follow expert recommendations on suitable products.

  - **Hot and Dry** – Assessments must be made of wildlife risks, appropriate planning for visits to typically remote sites (hydration, anti-venom procedures, PPE, travel to and from sites). Wildlife risks cover poisonous animals and insects that can harm humans directly, whereas nesting insects and animals can cause short-circuits or arc flashes. The typically remote nature of PV sites in hot and dry climates entails significant travel and preparation requirements, due to logistical risks in terms of supplying these facilities as well as access to emergency medical care. Temperature extremes and salt exposure also increase material degradation in modules, frames, junction boxes and transmission cables.

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- **Hot and Humid** – Wildlife intrusion in ground-mounted systems, particularly from rodents, snakes, and termites can cause failures in PV components and electrical systems. Rapidly growing plants can also have a soiling impact (dust accumulation). Cleaning schemes can decrease production losses of PV modules by as much as 6-8% during summer months. Fire risks can also be posed by agricultural activities such as field clearing. Adequate ventilation during hot months is crucial for good operating conditions of inverters.

- **Flood-prone** – It is important to note that PV systems are not typically designed with flood endurance in mind. However, climate change and extreme weather events, combined with limited availability of land in certain parts of the world, mean that some plants are built in areas that flood 2-3 times a year. Actions to prevent damage include switching off the plant in anticipation of flooding and only switching it back on after technical inspection. Floods can damage module mounting clips, PV modules, the lamination on panels, and even uproot foundations. Soiling damage is particularly difficult to repair when water has been standing on the PV modules for a long time. Submerged inverters can also short circuit and cause burn/fire risks. Fast flowing water can also cause debris impact because most PV mounting systems present a high resistance to flowing water.

- **Cyclonic Regions** – Damage from typhoons and cyclones typically affect PV modules and mounting racks. Glass breakage is also a particular issue in cyclonic regions. The breakage of fixing parts was also observed due to uplifts in air pressure. Cell cracks caused by deflection with strong wind load can also occur. While national standards for wind loads are present in the USA, Japan, and the EU, non-uniform mechanical load testing has not yet been launched due to a lack of experts and countries which are needed to form a project team. It is thus recommended to estimate the effects of winds using wind tunnel tests, ensuring that structural connectors are of sufficient strength and that PV modules have sufficient uplift resistance. It is also recommended to assess the compliance with standards during construction, to conduct periodic maintenance of all bolted connections, to store sufficient repair parts, and to remove loose debris around the plant.

- **Snowy Regions** – Snow accumulation affects PV performance, as heavy snow loads hinder the transmission of light to the cells and could damage modules. A suggested limit for snow accumulation on panels is 0.7m. PV racking systems can also be damaged by extremes between winter and summer temperatures. In this case steel racking is preferred over aluminium racking. If active cleaning measures are implemented, such as brushing, care must be taken not to scratch the glass as well. Experiments have been conducted to heat PV modules by applying a controlled forward voltage to melt the snow. This would require careful load control and the use of weather forecasts.

In conclusion, a combination of well-designed O&M specifications, proactive monitoring systems and a flexible and tailored O&M regime that considers both climactic impact on systems as well as possible changes to grid requirements are good practices to ensure that PV systems reach or even exceed the expected lifetime. Reducing risks by ensuring that personnel are trained and equipped for O&M operations, as well as using PV forecasting to reduce possible downtimes, also helps to maintain PV plant performance to specifications.

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