Solar operations in extreme conditions

AUTHOR

Kim Clark

Senior project engineer

kimc@naturalpower.com

Introduction

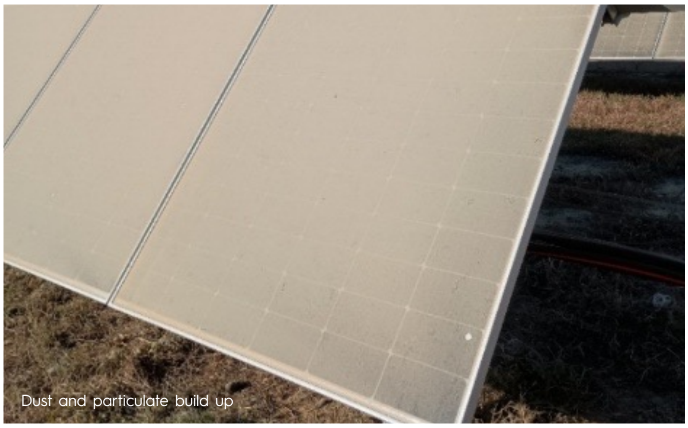
Photovoltaic power plants are complex generation facilities and are installed and operated in highly variable environmental conditions. In this article we explore the environmental stresses imposed on PV Facilities and their associated risks and mitigations.

Dust and particulates

Different climates and locations present specific issues that negatively affect both operation and maintenance as well as production. Dryer climates can experience dust storms and wildfires, and generally lead to higher levels of airborne particulate matter. More humid climates experience high levels of pollen of various types throughout the year.

Particulates in the ambient air can decrease production by refracting and reflecting direct sunlight and through soiling of module surfaces. [1]Research done in collaboration between the SRM Institute of Science and Technology in India and Woosong University in Korea investigated the influence dust had on both mono-crystalline and poly-crystalline PV modules. Results showed that both types of modules experienced current and power losses due to dust accumulation and that such losses were more pronounced on poly-crystalline modules due to their surface characteristics. [2]Research carried out in 2012 at the Libyan Center for Solar Energy Research and Studies showed dust accumulation on module surfaces reduced both short circuit current and power output.

Inverters are the most common source of faults, downtime, and parts consumption on most PV projects, and particulates can clog air filtration, increase the viscosity of bearing grease in cooling fans causing them to fail, and accumulate on electronics which can exacerbate corrosion if there is any moisture ingress. Not only can high particulate levels drive higher failure rates in bearings and electronics but can also drive higher labor costs if more frequent cabinet cleaning and filter changes are required. Protecting inverters from particulates can be achieved through a number of best practices in both equipment selection and maintenance. Some simple steps include monitoring the effectiveness and cleanliness of filters and exchanging or cleaning them as frequently as necessary, replacing weather sealing on cabinet doors before they become ineffective, and frequent cleaning of cabinet enclosures. Procuring inverters with NEMA 4 rated electronics enclosures, internal heat exchangers between its electronics enclosures and main cabinet, and actively monitored air-flow data are highly effective design features that can protect against the negative effects of airborne particulate matter.



Dust and particulate build up

Trackers rely on drives, springs, and dampers for normal operation and withstanding high winds. Heavy airborne particulates can cause maintenance issues on all components of typical trackers systems, including increasing the viscosity of grease in drives, gears, and dampers, reducing the effectiveness of cooling on drive motors, and increasing strain on components. Though there are minimal actions that can be taken to reduce these issues, effective monitoring and having an adequate spare parts inventory can greatly reduce downtime and tracker error caused by contamination.

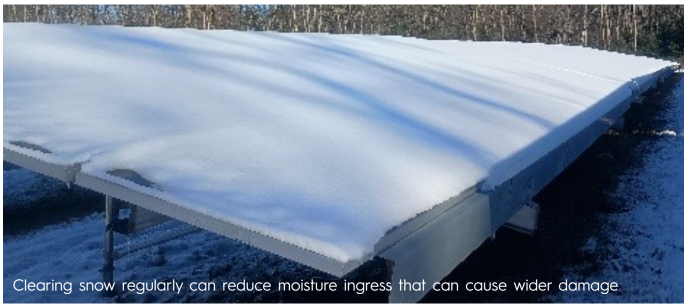
Precipitation

Aside from the well-known effects on performance of snow cover and effects on operation from hail and snow load, the less obvious issues caused by heavy precipitation are what can prove most costly. The National Renewable Energy Laboratory has published multiple [3,4]papers on the control of moisture ingress on PV Modules.

Actively clearing snow from modules eliminates soiling and overloading of racking and tracker components but may also reduce the likelihood of moisture ingress between top glass and backplane. This is especially true on thin film products that rely on the integrity of an encapsulant that degrades over time. Water ingress leads to shorter operational life of the module as well as electric short circuit of cells. Melting snow causing water ingress indicates that the temperature is likely to drop below freezing which can lead to catastrophic mechanical failure of the module.

Heavy precipitation and storms can lead to water ingress in electrical enclosures as well. Combiner boxes, load break disconnects, recombiners, junction boxes, switchgears, and inverter enclosures must be inspected regularly to ensure that weather sealing remains effective. Water ingress in electrical enclosures most commonly leads to electrical failure and corrosion.

It is best to install equipment with proper environmental ratings but also purchase the correct equipment and design the installation to avoid this specific issue. Examples of some instances where this was not properly thought out include an intake vent between the inverter and MV transformer that regularly pulled snow into both components causing electrical failures and ground faults, and inverters with large vent


Clearing snow regularly can reduce moisture ingress that can cause wider damage

openings on the enclosure doors without filtering leading to standing water inside the enclosure causing corrosion.

Precipitation always finds the low spots on a PV project. Most apparent are large puddles and mud making travel over interior roads difficult. Less obvious is slow erosion within an array as water finds the path of least resistance to its nearest low spot of accumulation. Specifically, when there is moving water close to piles it can erode them to the point where the structural integrity of the racking is weakened. This erosion can cause pile twist, pile settling, and pile leaning, all of which puts unknown stresses on the modules and trackers. If left to progress, this near pile erosion may even cause strings to collapse. Severe wind conditions may accelerate this possibility.

Extreme temperatures

High ambient temperatures are notorious for driving derated operations of inverters and converters on solar and wind projects. Early utility scale solar projects built in regions where summer temperatures regularly rise above 100°F (38°C), like those built in the American Southwest between 2010 and 2015, included full enclosures to house their central inverters and control cabinets. These enclosures would include external filtering and separate HVAC to keep the internal temperatures below a defined maximum.

The current development model of minimizing capital costs in order to provide the lowest dollar per watt of construction means that including this type of enclosure is a non-starter, despite the obvious benefits to operations. Inverter OEMs have instead relied on convective cooling with multiple fans as well as employing multi-level IGBT architecture. Some inverter OEMs are working on solutions to remove heat from systems by other methods, which will eliminate some of these issues. In 2012, General Electric introduced the [5]ProSolar central inverter with liquid cooling systems. The GE design, however, required technicians maintaining these units to be trained to maintain hydraulic systems. In 2019, [6]Huawei announced the development of inverters with external heat sinks. Huawei, however, is legally not permitted to sell its products in the United States.

Cold ambient temperatures can also cause issues with PV operations. Low temperature will cause string open circuit voltages (Voc) to increase which may lead to inverter failure if the maximum allowable input voltage is exceeded. Extremely low temperatures also greatly reduce inverter efficiency, for most, around 15°F (-10°C). Additionally, cold starts of electrical equipment can be difficult or impossible if the ambient temperature is below the operating range of the equipment. Some equipment is operated from the auxiliary circuit which can enable preheating in cold temperatures if needed. One small benefit is that modules operate slightly more efficiently in colder temperatures.

Proper siting and equipment specifications can be implemented to minimize the effects of extreme temperatures. New designs from OEMs to mitigate temperature-induced failure and increase the operating temperature range may also be available in the not-so-distant future.


Progressed corrosion in load break disconnect

How Natural Power can help

Issues driven by extreme weather and temperature can be mitigated, if not eliminated, with a combination of proper planning, equipment specification and selection, installation, operation, and maintenance. Natural Power has a team of engineers with experience and expertise in these areas and more. Reach out if you would like more information on how we can help you.

If you have any queries related to the content of this paper, please contact:

Kim Clark, Senior project engineer
kimc@naturalpower.com

Notes and source material

1: https://www.aimspress.com/article/doi/10.3934/energy.2025019?viewType=HTML

2: https://ieeexplore.ieee.org/document/10449762

3: https://docs.nrel.gov/docs/fy05osti/37390.pdf

4: https://research-hub.nrel.gov/en/publications/evaluation-of-moisture-ingress-from-the-perimeter-of-photovoltaic-2

5: https://www.ge.com/news/press-releases/ges-latest-central-inverter-technology-clears-path-utilities-boost-solar-energy

6: https://www.pv-magazine.com/magazine-archive/a-tale-of-dust-and-heat/