SOLAR MODULE SOILING

WHITE PAPER | By Charles Thurston, Marc Korevaar, Donald van Velsen, Clive Lee

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Introduction

Environmental factors such as wind, rain and module temperature all affect photovoltaic plant performance but, in many environments, PV module soiling has the greatest impact on performance. Soiling results in a reduced level of energy production, often up to 20 % over a year, due to the accumulation of sand, dust, other particles that obscure the glass surface of a PV module and prevent solar radiation from reaching the cells.

Soiling is a complex solar industry problem that increases plant monitoring and performance uncertainty and drives up LCOE through lost energy production, increased O&M costs, and higher finance rates, according to analysis by the U.S. National Renewable Energy Laboratory [1].

Driven by location, soiling is worst in arid and semi-arid environments, in the presence of air-borne pollution, and on modules with shallow tilt angles. In such conditions soiling that builds up when modules are not cleaned regularly can result in 25 % yield loss in a month as shown in figure 1. Longer term cumulative soiling, particularly cementation, can result in a 100 % loss of yield [2]. This loss in power generation is reported as the Soiling Ratio (SR), which is the ratio of the power output measured with a soiled PV module compared to a clean module of the same type [3].

Tilt angles as low as 5 ° can cause an increased deposition of dust. An expected energy loss of between 3 % to 5 % from soiling is often assumed, resulting in unnecessary over-design [4].

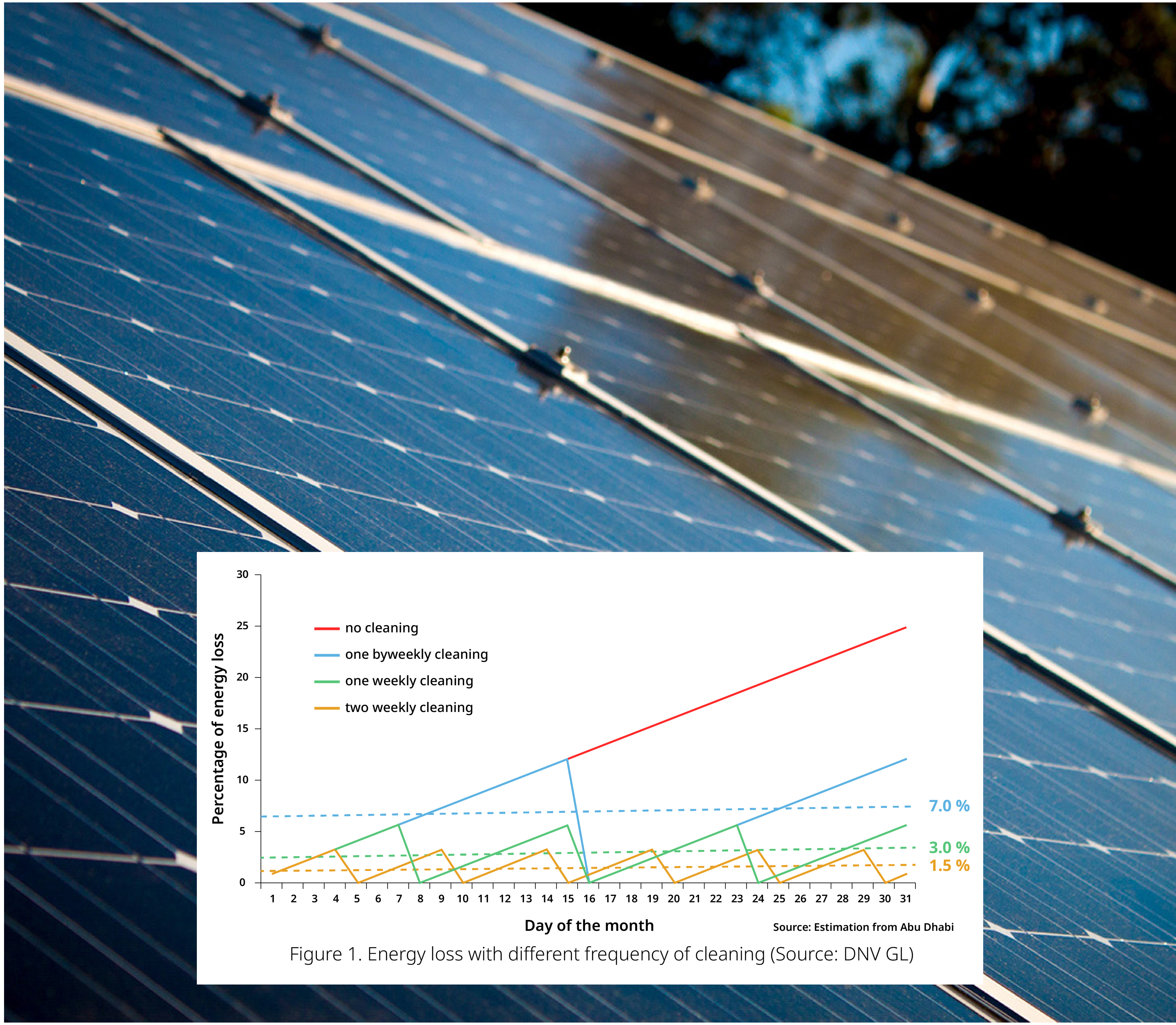


Figure 1. Energy loss with different frequency of cleaning (Source: DNV GL)

1. www.researchgate.net/figure/voltage-current-characteristics-of-a-PV-module-for-soft-and-hard-shading_fig6_292275071
2. https://www.nrel.gov/pv/assets/pdfs/2015_pvmrw_105_weber.pdf https://www.nrel.gov/pv/assets/pdfs/2015_pvmrw_105_weber.pdf
3. International norm IEC 61724-1 (Photovoltaic System Performance – Part 1: Monitoring)
4. The current standard for soiling testing is IEC 60068 -2-68

What is Soiling?

Soiling is a thin layer of dust that covers the surface of a solar module, typically with particles that are less than 25 µm in diameter and depending upon the specific location and its environment [5]. Dust that is on the ground becomes airborne by many means; such as wind, people and animals, vehicular movements, agriculture, and volcanic eruptions. Over time, particularly with humid conditions or dew, the dust can form a hard layer like cement that is opaque and hard to remove.

Not surprisingly, the amount of accumulated dust on the surface of a PV module that affects the overall energy delivered can be measured on an hourly, daily, monthly, seasonal and annual basis. Sanaz Ghazi in 2014 investigated the pattern of dust distribution in different parts of the world and found that the Middle East and North Africa have the worst dust accumulation zones in the world [6].

Soiling is generally associated with dust, however there are many environmental and natural factors that can result in reduced energy yield; sand and soil, salt deposits near the coast, bird droppings, pollen, snow or frost, and other materials falling on the module surface.

Studies by Zaki Ahmad, et al. on dust variants, also in 2014, found 15 types; including red soil, cement, ash, carbon, limestone, silica, calcium carbonate, sand, clay, soil, mud, coarse air-born dust, and Harmattan or Saharan dust [7]. Six of these types have the most significant effect on PV modules; ash, calcium, limestone, soil, sand and silica.

These materials can be present in the air and on the module in different combinations and forms; such that the type of shading that occurs can be considered either 'soft' or 'hard' shading.

Soft shading takes place when haze particles such as smog or light dust on the module reduces the overall intensity of the solar irradiance which reaches the solar cells. Hard shading occurs when a more solid type of dust or material blocks the sunlight in a clear and definable shape [8].

These two types of shading have different effects. Soft shading affects the current generated by the PV module, while the voltage remains the same. With hard shading, the performance of the module depends on how many cells are shaded, and where they are in the module, and can affect both current and voltage produced.

5. www.chegg.com/homework-help/questions-and-answers/thickness-dust-solar-cells-performance-solar-cell-deteriorate-atmospheric-dust-accumulates-q22797203

6. www.researchgate.net/publication/278177273_dust_effect_on_flat_surfaces_-_A_review_paper

7. Z.A. Darwish, H.A. Kazem, K. Sopian, M. Al-Goul, H. Alawadhi Effect of dust pollutant type on photovoltaic performance Renew Sustain Energy Rev, 41 (2015), pp. 735-744.

8. www.researchgate.net/figure/Voltage-current-characteristics-of-a-PV-module-for-soft-and-hard-shading_fig6_292275071

Soiling Type and Color Affects Transmission Loss

As soiling can be caused by a wide range of materials (such as dust, sand, and pollen) the color of the soiling can also vary by location and this has different effects on the transmission loss caused.

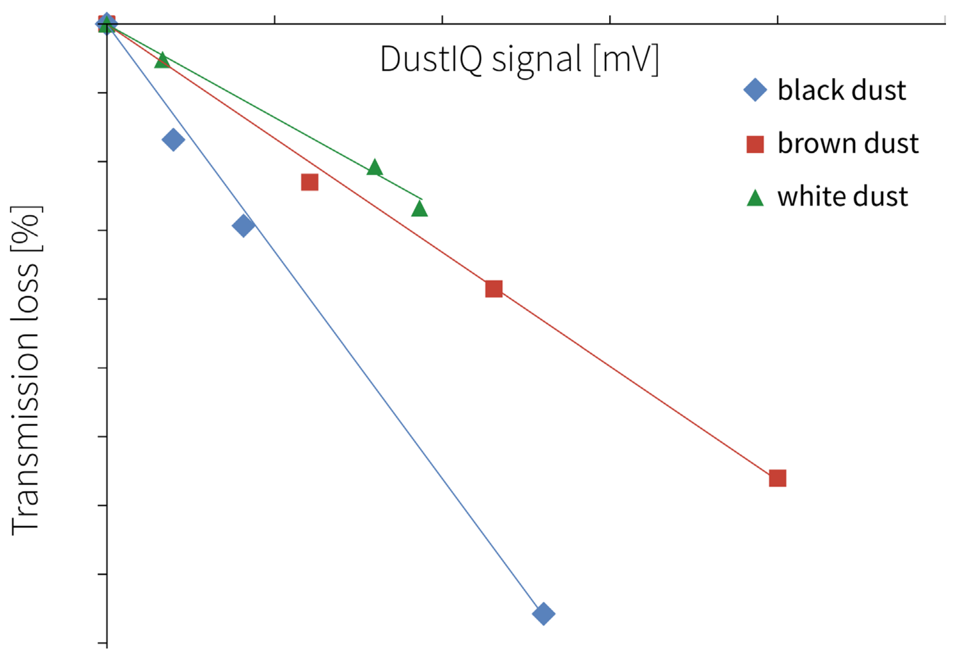


Figure 2: Soiling losses, highest for black, lowest for white dust

Since the color (figure 4) of the soiling material varies by specific location, soiling monitoring equipment needs to be sensitive to the local dust characteristics. The factory calibration of the Kipp & Zonen DustIQ, is for standard Arizona test dust, but it can be simply recalibrated in the field to suit the site dust color.

The loss of energy that results from soiling also changes over the course of a day as a function of the angle of the radiation directly from the sun.

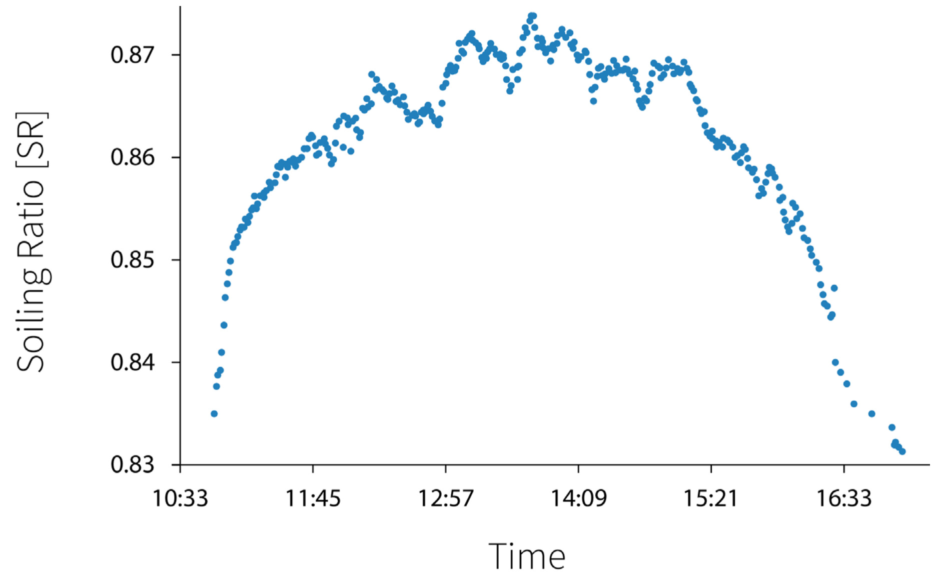


Figure 3: Soiling Ratio variation over the course of a day

With the sun lower in the sky, solar rays reach the soiled PV module at low angles, resulting in greater light reflection, which results in less energy capture. The capture loss is greatest around sunset and sunrise and the lowest around solar noon. Solar noon is when the sun is highest in the sky and often this is not local 'clock' midday due to time zones and daylight-saving time changes.

Figure 4: samples of dust colours from around the world

For a mainly clear sky, the largest power generation of a PV park will be the timeframe around solar noon. So, although the losses are larger at sunrise and sunset these are only a small proportion of the total energy generated during the day.

Soiling is also affected by the daily moisture and precipitation cycle in a given location. Studies show that at least 20 millimeters of rainfall is needed to clean the surface of PV module, or soil deposition continues. Cemented particles are often irremovable, which causes a fixed reduction of power output from the module and may damage the module glass permanently. Field studies of soiling have shown widely varying results depending on geography and local rainfall.

For example, a 2001 study in California found an average daily PV module efficiency reduction of 0.2 % on days without rainfall. Annualized soiling losses caused by a lack of rain can range from 1.5 % to 6.2 % depending on the location of the PV plant, the study found.

A more recent study by researchers at Arizona State University found that Arizona road dust (ISO 12103-1, A2 Fine Test Dust) soiling on solar arrays in the state showed annualized losses as high as 15 % during a period without rain.

A Kipp & Zonen study in 2018 in Spain and Morocco found a soiling rate of up to 0.4 % per day. The researchers were able to detect small changes in the soiling of less than 1 %, using the DustIQ monitoring system. Night data, for example, showed an accumulation of dew on the modules lasting until the early hours of the morning.

In the late spring and early summer in Morocco there is a soiling ratio increase of approximately 0.3 % to 0.4 % per day, leading to a SR of 92 %. In Spain the annualized buildup of soiling at the test site was close to 2.5 %, a Soiling Ratio of 97.5 %. For most of the year natural rainfall events clean the modules, but in the Spanish summer the lack of rain allows the loss to accumulate to over 20 %.

In Chile's Atacama Desert, a 2018 study by R. R. Cordero, et al., found that with no cleaning throughout the year, the combination of high deposition rates and infrequent rainfalls led to annual energy losses that peaked at 39 % in the northern coastal part of the desert. In contrast, annual energy losses of 3 % or less were measured at relatively high-altitude sites and at locations in the southern part of the desert.

Technologies to mitigate these losses are under development; with the emergence of dust resistant coatings, abrasion resistant coatings, and new dust removal techniques, and some of these might have affected the soiling rate, the study noted. Currently, there is no standardized way of verifying the validity of such mitigation claims, the researchers asserted.

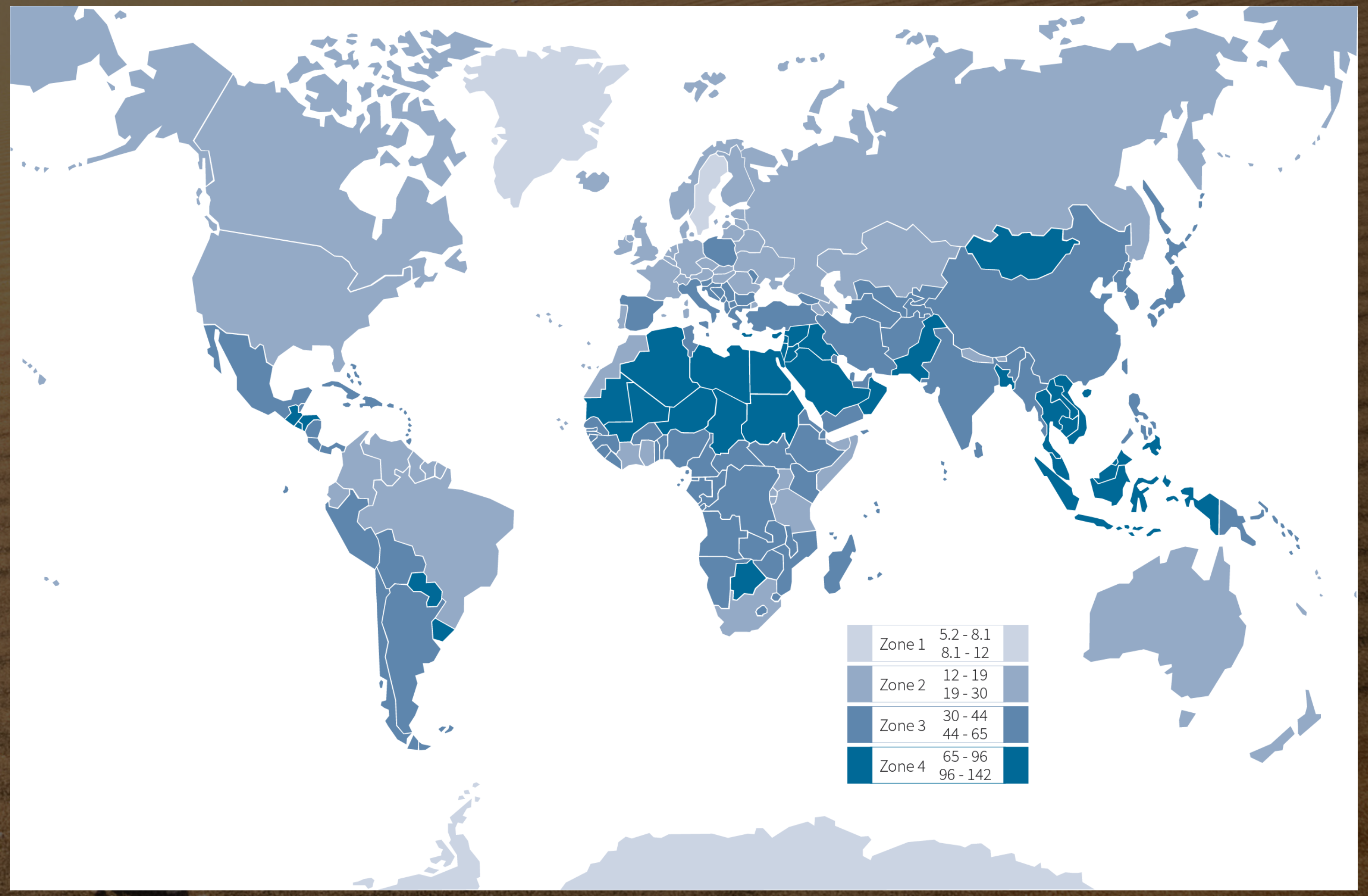


Figure 5: Dust intensity variation around the world

Effects of Dust on Different Solar Energy Technologies

Given the potentially high level of energy loss from dust accumulation, it is understandable that PV plant performance is determined by three main factors; irradiance, module temperature and soiling. Soiling is a key performance issue for both transmissive surfaces, including fixed and tracking PV modules and CPV systems; and for reflective surfaces, such as heliostats or mirrors for concentrating thermal power systems.

In a PV module, a shaded cell performs as an area of resistance to the current generated from the unsoiled cells. This causes the shaded cell to heat up, and leads to a hot spot that can eventually damage the module and cause failure

Soiling can differ between the perimeter of an array and the center of an array, because of the relative differences in wind across the array and effects from the rows of modules in front. Thus, the effect of soft shading from soiling on a single PV module is often the same as on the single string in which the module is wired. However, in a multi-string string PV array, the current imbalance from shading in one string can affect the other strings in parallel through the common inverter.

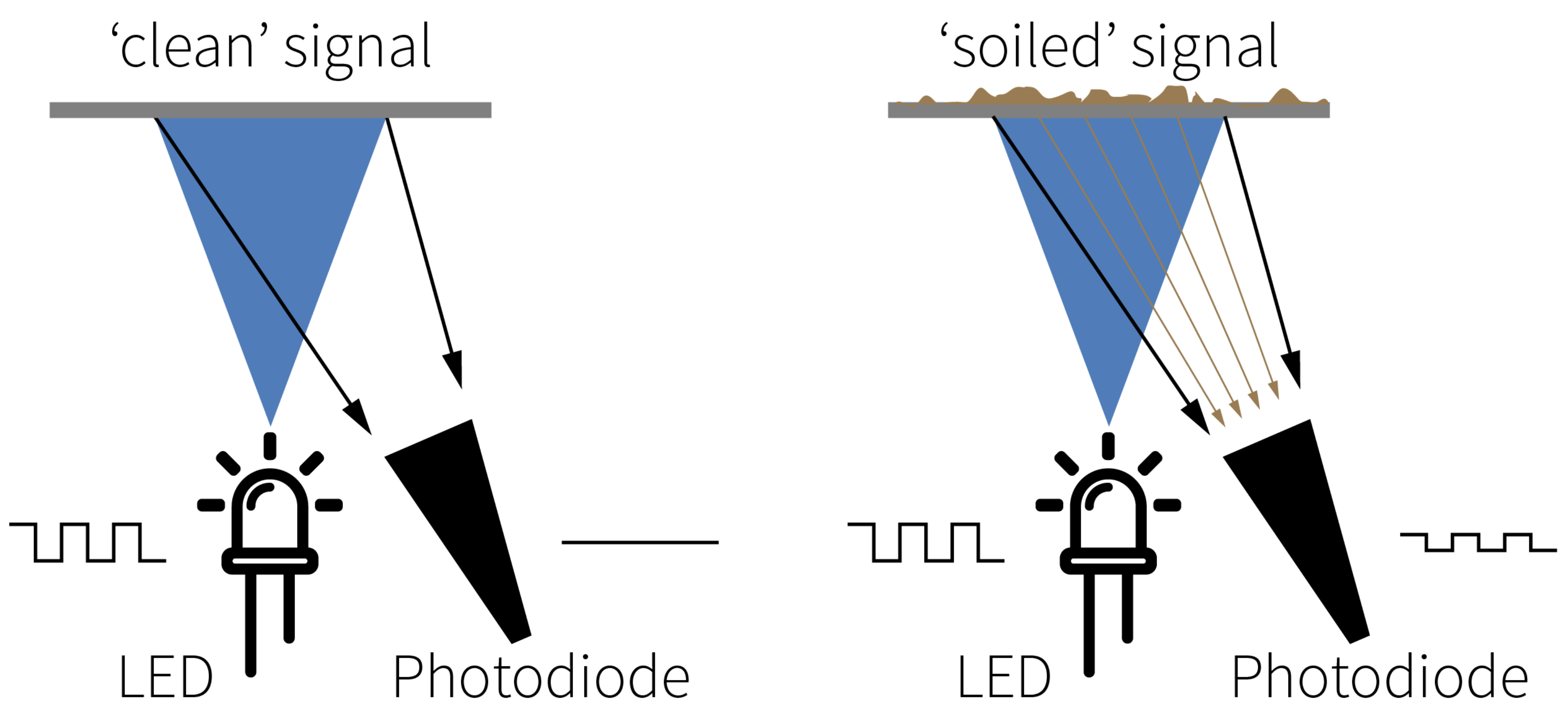
Hard shading dust on a surface of a PV array with a single string can reduce the voltage of the string, but generally, the inverter will detect this reduction and immediately regulate it. However, when there is uneven hard dust on different strings in parallel, a voltage mis-match occurs. In this condition, which is called partial shading, different parallel strings that are connected to a common inverter can deliver different voltages. This makes it difficult for the inverter to regulate the optimum voltage point at which the maximum power is delivered.

Measurement and Action

Knowing when it is most cost effective to clean solar modules is a function of the detailed monitoring of the soiling state. This information can be used by an O&M company to come to an agreement with stakeholders on an optimal cleaning schedule, and to trigger action after a specific event ranging from a micro-event to a sand storm.

Information about the soiling across a PV plant can inform on when and where to clean the modules, rather than having a fixed schedule leading to cleaning costs that may not be necessary.

Kipp & Zonen's DustIQ uses Optical Soiling Measurement (OSM) technology to determine the Transmission Loss, which can also be reported as the Soiling Ratio. It employs two sensors in which a pulsed blue LED and a photodiode measure the light scattered back by soiling on the top of the DustIQ glass cover.



The glass and the frame construction are similar to the majority of installed PV modules around the world. DustIQ also contains a small PV cell, which enables the user to calibrate the unit for the local dust characteristics. The system requires no maintenance, it is just cleaned at the same time as the adjacent modules.

A unique feature of DustIQ is that the soiling measurement does not need any external irradiance to operate, it is independent of the sun position and sky conditions. As a result, the SR is delivered by the DustIQ every minute, 24 x 7, day and night and without any corrections for the sun position being necessary.

Cleaning modules daily in an environment like Abu Dhabi, where the local climatic conditions are very dry and with dust storms, might make economic sense. In semi-arid conditions, cleaning once per week may be required; whereas in much of the U.S. market a two-weekly, or monthly, cleaning cycle is often sufficient.

The most common method employed to clean large-scale PV installations involves water being trucked to the site for a manual rinse and dry treatment. However, a 100 MW desert-sited solar plant could require more than 50 million gallons of water over its lifetime; according to one estimate. The associated long-term costs could be up to $70 million in the U.S. Southwest, considering both the cleaning costs and production losses due to soiling between cleanings.

One reduced water cleaning system designed for commercial and utility-scale solar farms is Saint-Gobain's PV Solar Clean 01, which features high-performance dispersants specifically designed to remove dust, dirt, carbon and other debris from glass surfaces. The surfactant technology cuts through and removes oily and organic residues such as petroleum pollutants and bird droppings without harming the glass.

PV Solar Clean 01 offers surface tension reduction and lubrication abilities that protect the glass from damage during contact scrubbing, such as when using sponges or water-fed poles, the company says. Its unique chemistry offers effective cleaning with all water types; deionized water, soft water, well water or municipal tap water.

Ecoppia E4 is a waterless module cleaning robot that can clean 1,200 modules per night. Using powerful yet soft microfiber brushes and controlled airflow, the E4 moves dust particles downwards and off the modules. Moving along a rigid frame, the E4 adds no load to the module surface and has been proven to be fully safe on both the modules and on anti-reflective coatings.

Another robotic solution, from SunPower, is claimed to clean modules 20 times faster than manual methods; allowing for rapid response to soiling issues. The robots are deployed at night to minimize impact on energy generation and require very little water to operate; making them a good choice for projects with limited access to water or where water is very expensive.

Nomadd, developed specifically for the MENA region, has only two direct drive motors and no exposed gears, pulleys, cables or power transmission components. The machine can 'float' over misaligned rails by automatically changing angle, and can compensate for settling of module mountings and the resultant unevenness of the rail system. The system hangs entirely off the understructure, has no load on the modules, and is designed to operate with a 600 mm module overhang.

Conclusion

Solar module shading from dust and other materials can have very substantial impacts on electrical yield, which often can be found in the field to be as high as a 30 percent loss. While geographic areas with regular rainfall do not require cleaning as frequently as those in dry environments, all PV plants should be monitored for soiling losses, and the data collected should be incorporated into a maintenance schedule that fits the goals of the owners and the operators.

For optimal PV plant monitoring and maintenance planning, dust monitoring systems such as Kipp & Zonen's DustIQ can provide a critical input for optimizing the financial balance between yield loss and cleaning costs and maintaining performance ratio goals.

Insights for Experts

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