New method helps analyze changes in solar photovoltaic power generation across the globe

March 12 2024

Credit: Pixabay/CC0 Public Domain

The shift toward renewable energy sources decreases our reliance on fossil fuels, providing a cleaner, more sustainable alternative. However, with their increasing use and development, we also face new challenges. Solar photovoltaic (PV) plants, for instance, are subject to the whims of

the weather and many other environmental conditions. This variability leads to inconsistent power output from these plants.

Prof. Mahesh Bandi, head of the Nonlinear and Non-equilibrium Physics Unit at the Okinawa Institute of Science and Technology (OIST) and Prof. Golan Bel at the Ben-Gurion University of the Negev, wanted to find a way to predict changes in the amount of energy produced from solar photovoltaic systems. In their study published in *Physical Review Applied*, the researchers have developed a method to study variations in power output from solar PV plants over time, accounting for distinct power fluctuations observed across different geographical areas.

The grid integration challenge

Our electricity system relies on a mix of power sources that provide steady electricity, but demand varies throughout the day. The challenge is to balance fluctuations in power generation (input-side) with changing power demand (demand-side). Gas turbines and energy trading help stabilize supply and demand, crucial for mission-critical users like hospitals and data centers. However, electricity grids lack storage capacity, so production and consumption must match to avoid blackouts.

The "grid integration problem" arises when including variable renewable energy sources like wind and solar into the power grid. These resources pose unique challenges due to their variability and uncertainty compared to conventional energy sources.

Smart grids, with sensors monitoring supply and demand, could be part of the solution. They can reroute power where needed or subtly adjust energy usage. However, designing such a network requires understanding different energy production scenarios. Because renewable energy sources like solar and wind are unpredictable, they need to be carefully analyzed to balance supply, demand, and technology.

Solar radiation changes across different locations

Scientists use a concept known as the power spectrum to investigate changes in solar photovoltaic power output. The power spectrum helps measure these fluctuations in power generation across individual solar plants worldwide and different time scales, helping in effectively planning and operating solar PV systems. However, comparing measurements across different solar plants is challenging due to changing environmental factors like cloud coverage and dust particles, which cause intermittent and uncertain energy production.

Prof. Bandi and Prof. Bel expanded on their 2019 study, where they analyzed the clear-sky index to calculate changes in solar power generation across different locations. The clear-sky index tells us how much total solar radiation reaches the Earth's surface under clear-sky conditions. This index helps meteorologists and researchers understand deviations from ideal clear-sky conditions due to clouds, aerosols, and other atmospheric conditions.

"With wind power, we have the advantage of a theory of atmospheric turbulence to help us understand these fluctuations. This is because the power generated by a wind turbine is directly related to the cube of the wind speed. However, for solar power, no such relationship exists. This means we do not have a systematic way or a theoretical framework to forecast the changes in solar power output," Prof. Bandi said.

"In our analysis, we specifically examined the measured global radiation intensity at the Earth's surface. We wanted to understand how this intensity changes over time and how it is affected by factors that cause deviations from the predicted clear-sky conditions. Before this, there was no baseline study taking these factors into account to compare solar radiation across different geographic areas."

Solar irradiance fluctuations depend on clear-sky signals (measurements of clear-sky conditions at the location) and certain environmental factors. Clear-sky signals are predictable because they depend on where you are located (latitude) and how long daylight lasts, while environmental factors, such as those that influence air quality, are unpredictable.

Using data from two geographic locations, the Negev desert and a buoy situated at the equator in the Indian Ocean, the scientists calculated the clear sky signal and the actual measured solar radiation signal at these sites. They found that frequent changes in solar radiation were connected to unpredictable environmental changes, while intermediate changes were associated with clear-sky patterns.

In the future, scientists can use this new method to study how the size of solar photovoltaic plants and specific factors affecting energy absorption influence solar power generation at different locations. This could help us understand why energy fluctuations vary across sites. While some irregular changes in energy levels become less extreme when we consider different locations, others may persist. To get a clearer picture, researchers can collect and compare data from photovoltaic plants across many diverse locations.

More information: G. Bel et al, Spectral analysis of solar-irradiance fluctuations, *Physical Review Applied* (2024). DOI: 10.1103/PhysRevApplied.21.034019

Provided by Okinawa Institute of Science and Technology