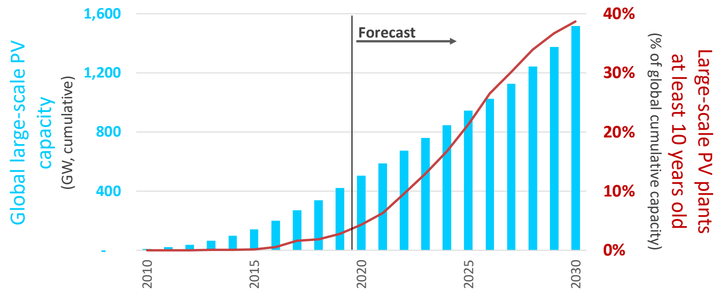
Large-Scale Solar Photovoltaic Plant Performance and Degradation Benchmarking

Background and Motivation

Large-scale solar photovoltaic (PV) plants have been rapidly deployed globally over the past decade, growing from approximately 10 GW cumulatively in 2010 to over 500 GW cumulatively forecasted by the end of 2020. This means 95% of existing large-scale PV plants have been operational for less than 10 years and over half of the global capacity has been operational for less than 3 years. The underlying technology components are relatively mature, but operating and maintaining them as a large-scale system is new.



Less than 5% of large-scale PV plants have been operational for more than 10 years. There is a knowledge gap between the expected 20+ years plant lifetime and actual experience.[1]

Given that PV plants are designed to operate for 20+ years and the nascency of the fleet, there is a knowledge gap between actual operational experience in the field and predicted/expected plant performance. Extensive analyses on large-scale plants are just now becoming possible as enough fielded systems collect data over a significant operating span to compare actual and expected performance and degradation. Quickly learning from this genesis fleet is important to inform the additional order of magnitude of large-scale PV plant deployments anticipated globally in the coming decades.

> *Long-term field data that proves today's PV modules will perform reliably for decades does not exist*
>
> — PVEL: 2019 PV Module Reliability Scorecard

Projecting system performance is of great importance for both existing and future systems. Economic models are sensitive to factors like module degradation and system lifetime, for which there are few comprehensive studies to confirm that fielded modules perform as expected in large-scale installations. The majority of focus to date has been on research-grade and small-scale systems.

EPRI is addressing this industry-wide knowledge gap by developing a large-scale PV plant performance and reliability benchmarking database. An analytical tool is also being developed to facilitate data intake from PV plant owners/operators, conduct rigorous data analysis, and visualize information through an interactive tool showing how plants perform against their peer group in an anonymized fashion. The benchmarking tool is part of the newly launched Solar Owners League (SOL), a user group for owners, operators, maintainers, and organizations purchasing power from large-scale PV plants that focuses on reducing lifetime costs, increasing energy production and reliability, and adding operational capabilities.

Through fleet-scale benchmarking, owners/operators find answers to such questions as:

- How does my fleet perform relative to others? How are individual plants performing within the fleet?
- How is performance changing over time against initial predictions? What factors may be causing underperformance or degradation over time?
- What are the opportunities to do more (or less) maintenance? Should maintenance strategies or type and frequency of activities be tailored for a specific plant?
- What are the impacts of plant design decisions? And location-specific factors influencing performance and reliability, such as snow or soiling?

1. *New Energy Outlook 2019*. Bloomberg NEF. 2019

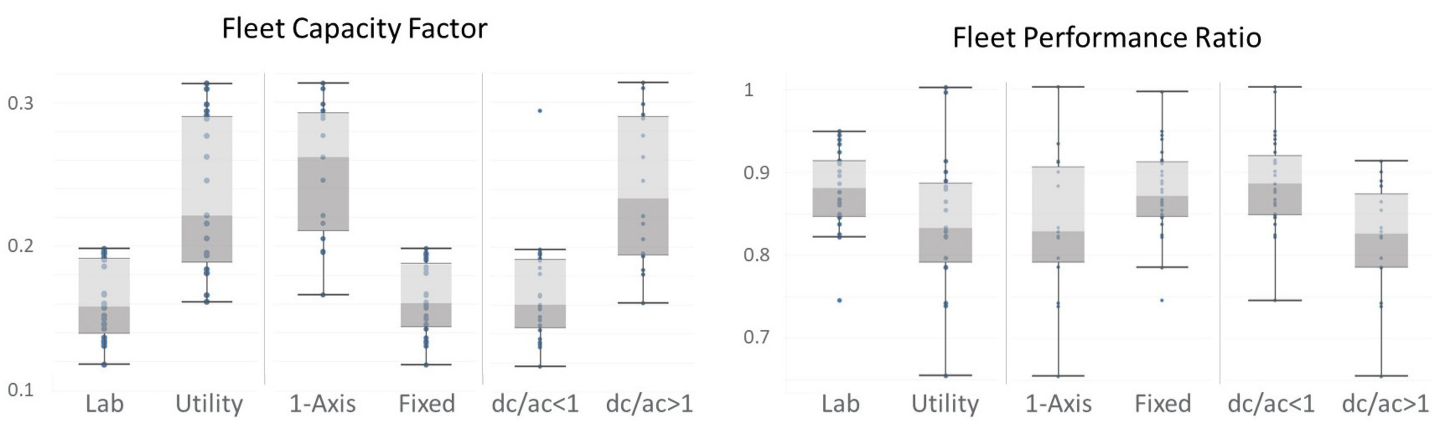
Approach and Key Findings

EPRI has collected and analyzed the performance of PV arrays – of all sizes – for the past decade. The data used in this study includes minute-level meteorological (e.g., irradiance, ambient temp., wind speed) and performance (e.g., power at inverter and point-of-interconnect) collected from on-site sensors and instrumentation.

This paper includes analysis from over a dozen large-scale plants (collective nameplate of 256 MW) and four small-scale research systems with multiple technologies under evaluation (collective nameplate of 160 kW) to provide an illustrative example of lessons learned thus far from a subset of data. The average operational life of systems evaluated is 4 years. A consistent and transparent methodology is applied to all systems to allow users to make likewise comparisons. Details about the methodology can be found elsewhere.[2-4]

Traditional Metrics: Capacity Factor and Performance Ratio

Traditional performance metrics, such as capacity factor and performance ratio, do well to describe a system's real energy production and efficiency. Capacity factor normalizes the energy production to the size of the plant, given by its ac nameplate, against a period of time, in this study the operational lifetime of each plant. Temperature-corrected performance ratio normalizes actual plant production against expected production based on solar irradiance and temperature. The capacity factor and performance ratio of the 19 large-scale and 4 laboratory systems, with 24 configurations, are shown in the charts below, broken down by various system characteristics.



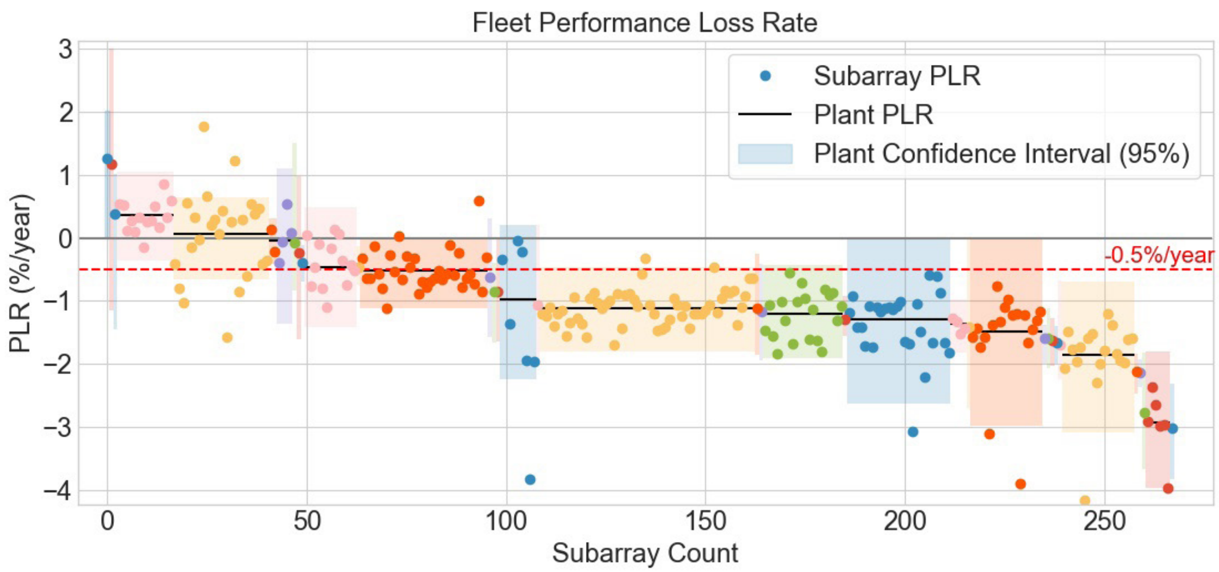
Comparison of various plant sizes and design choices and their impact on capacity factor and performance ratio metrics.

Capacity factors are higher for the large-scale plants analyzed because they include a majority of systems with single-axis tracking and dc/ac ratios greater than 1, which leads to increased energy production for a given ac nameplate rating. Performance ratios, on the other hand, fall slightly with tracking and high dc/ac ratios because those system experience higher clipping. The lab-scale systems analyzed experienced less clipping and were well-maintained, resulting in higher production efficiency. SOL's benchmarking tool allows members to interact with the data to filter and compare how various systems and configurations perform to their own plants.

2. *Solar Photovoltaic (PV) Degradation and Performance Loss Rate (PLR) Analysis.* EPRI. Palo Alto, CA: 2020. 3002019363.
3. Multi-site Performance Evaluation and Comparison. EPRI. Palo Alto, CA: 2019. Webcast.
4. *PV System Degradation: Review and Application of Analysis Methods.* EPRI. Palo Alto, CA: 2018. 3002013669

Performance Loss Rate

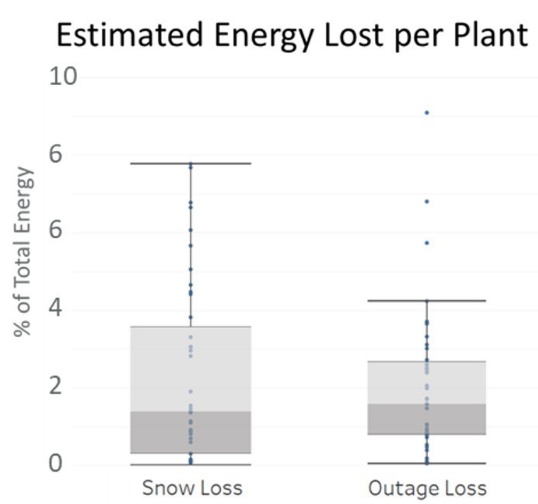
Performance loss rate (PLR) is a metric that comprehensively measures all factors that reduce the nameplate capacity of a plant over time, including module degradation. For this study, PLR is calculated using RdTools' year-on-year methodology and with careful data filtering and quality control. The loss rate for each system is represented in the chart below by a range including the estimated median value and a 95% confidence interval. The systems are color coded and the dots represent the PLR of the individual subarrays or inverters that comprise the system. Negative PLR values indicate a system losing power over time. Many systems fall below the oft assumed -0.5% per year nameplate reduction per year due to module degradation alone. A positive PLR value is usually a mathematical phenomenon caused, for example, by a plant losing a large amount of nameplate capacity and then having it repaired over time. Performance loss rates are influenced by site specific factors in addition to module degradation, like soiling. Variations among subarrays within a plant are may be due to localized faults and failures. More research and consensus are needed within the solar industry about analyzing and reporting PLR, which is a topic discussed in SOL.



The performance loss rate (PLR) metric encompasses module degradation and other factors that reduce the nameplate capacity of a PV plant over time. A negative PLR indicates that median rate at which a PV plant is losing capacity over time. The colors represent plants and the dots represent individual subarrays (inverters) in each plant.

Specific loss factors

Filters and algorithms are applied to to disaggregate the mechanisms of production loss to achieve greater insight. Loss estimates due to system outages and snow cover are shown here. There are many additional loss factors not shown herein that impact plant performance to varying degrees. Each of these will be analyzed and reported in detail through the SOL performance benchmarking initiative.



System outages and snow cover are two prominent mechanisms of production loss in the systems analyzed.

Further Information and Opportunity to Join SOL

Additional objective and data-driven analysis and insights can be gained through active participation in EPRI's Solar Owners League (SOL). The key offerings of SOL include:

- **Workshop.** An annual workshop provides a multi-day meeting, with scheduled technical presentations and round-table discussions, and opportunities for in-person exchanges. The focus is on operations and maintenance topics, resulting in a report summarizing findings.
- **Performance Analysis and Benchmarking.** SOL provides the opportunity for EPRI to intake, analyze, and integrate individual member data into the benchmarking database. This capability enables SOL members to visualize and compare the performance of their own plants to the broader fleet of plants.
- **Website.** A website provides access to workshop proceedings and reports as well as a data portal for benchmarking the performance and reliability of PV plants. A public-facing version allows very high-level information, and a members-only section allows access to more detailed benchmarking analysis.
- **Webcasts.** EPRI also conducts periodic webcasts for all SOL members on selected topics, and less formal meetings may be scheduled.
- **Published Materials.** Conference proceedings and slide decks are available from annual workshops and webcasts for all SOL members.

Joining SOL can provide many benefits, including the opportunity to share lessons learned with a continually expanding network of colleagues and experts. This opportunity means PV companies have access to objective, expert, and peer insights on operations and maintenance best practices, reducing lifetime costs, increasing energy production and reliability, and adding operational capabilities.

For more information about this analysis or how to join EPRI's Solar Owners League, please contact Michael Bolen (mbolen@epri.com).

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