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# Modeling and Performance Evaluation of Distributed Photovoltaic Systems under Complex Operating Conditions

Distributed photovoltaic (PV) systems have become an essential component of modern power systems due to their flexibility, scalability, and proximity to end users. Unlike centralized solar power plants, distributed PV installations are often deployed on rooftops, building facades, parking structures, and other non-uniform locations. While these characteristics enhance land-use efficiency and reduce transmission losses, they also expose distributed PV systems to complex and highly variable operating conditions, which pose significant challenges to accurate performance assessment and system optimization.

Complex operating conditions of distributed PV systems typically arise from a combination of environmental, electrical, and structural factors. These include partial shading caused by surrounding buildings or vegetation, non-uniform irradiance distribution, temperature gradients across PV modules, irregular installation angles, and dynamic load interactions within distribution networks. Such conditions lead to nonlinear power output behavior and increase the uncertainty in energy yield prediction. Conventional performance evaluation methods, which often assume uniform irradiance and steady operating states, are therefore insufficient for accurately characterizing the real-world behavior of distributed PV systems.

To address these challenges, advanced modeling approaches are required to capture the coupled effects of environmental variability and system-level interactions. Electrical models based on equivalent circuits have been widely used to describe PV module characteristics; however, their effectiveness under complex operating conditions depends heavily on the incorporation of shading effects, temperature dependence, and mismatch losses. In recent years, hybrid modeling strategies that integrate physical models with data-driven techniques have gained attention, as they offer improved adaptability to changing operating environments. Nevertheless, the applicability and accuracy of these models for distributed PV systems operating under diverse and transient conditions remain an open research question.

Performance evaluation of distributed PV systems under complex conditions is not limited to power output analysis. It also involves assessing voltage regulation impacts, power quality issues, and operational reliability within distribution networks. Fluctuating PV generation can introduce voltage deviations and increase the stress on power electronic interfaces, particularly in areas with high penetration of distributed generation. Therefore, a comprehensive evaluation framework should consider both energy performance indicators, such as conversion efficiency and energy yield, and system-level indicators, including voltage stability and operational robustness.

This study focuses on the modeling and performance evaluation of distributed photovoltaic systems operating under complex and non-ideal conditions. A system-level modeling framework is developed to incorporate environmental variability, electrical characteristics of PV modules, and interactions with the local power network. The proposed approach enables the analysis of PV system behavior under scenarios such as partial shading, temperature variation, and fluctuating load demand. Key performance metrics are evaluated to quantify the impact of complex operating conditions on system efficiency and operational stability.

The results of this study aim to provide engineering insights into the performance limitations of distributed PV systems and identify critical factors influencing their operational effectiveness. By improving the accuracy of modeling and evaluation methods, this work contributes to the design, operation, and optimization of distributed photovoltaic systems in real-world deployment environments. The findings are expected to support more reliable integration of distributed solar energy into modern power systems and enhance the overall performance of renewable energy infrastructures.