Performance of New Photovoltaic System Designs

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Executive Summary

The goal of this document is to provide a compendium of new performance characterization methods for new photovoltaic (PV) system designs as a reference. New methods are described and explained by laboratory tests up to case studies. While performance characterization is more than evaluating efficiency of a component or a system in certain operating points, the results account for multi-dimensional usage and benefits. These assessments are intended to provide well-founded and comparable key figures in order to enable new PV system designs to move faster into new fields of application. This report gives a short introduction into current standards and definitions regarding performance characterization of PV systems as a starting point. New PV system components and complex new systems with PV are then described with their respective performance characterization methods. Where currently no performance characterization methods for complex PV systems particularly with multiple functions exist, their design and their performance, energetically and regarding multi-dimensional usage benefits, are presented and described by means of showcases. PV systems are not only PV modules and PV inverters in an optimally oriented system which produce as much electrical energy as possible. Current PV systems may provide a dual or even a triple use. However, as varied as the use of each system and each PV installation is, as different is the approach of performance evaluation.

The market of PV system components for special applications e.g. partially shaded operating conditions, or foldable or floating PV is growing. For all kinds of these PV systems, the Performance Ratio (PR) can be calculated. This PR in the PV sector just relates the energy yield of ideal PV systems to the real energy yield of real PV systems operated at a certain place. The PR cannot rate non-energy benefits of PV systems, components or installations. Then again, the key performance indicator KPI for PV installation investment decisions often is the energy yield respecting PR only. Often, PR is used because measurement schemes are unknown or do not exist to evaluate the multiple benefits of the PV system. In the design phase of a certain PV installation the PV energy yield can only be calculated via simulation if the PV components' behaviour under different operating conditions is known. However, manufacturers of Balance of System (BOS) components often provide less meaningful performance figures in their datasheets which are not appropriate input data for a PV component or PV system simulation. Starting from this point, this report provides measurement protocols to characterize single new PV system components with the goal of providing simulation models, figures for the model parameterization and the goal of obtaining meaningful performance indicators besides the PR.

For multi-Maximum-Power-Point-Tracker (MPPT) inverters, a measurement protocol is proposed based on existing standards for the efficiency assessment of string inverters. In the new measurement protocol adjustments for the existing protocol are introduced and validated. In the case of PV Module Level Power Electronics (MLPE), their performance under different representative shaded operating conditions of their respective PV module is more meaningful than their weighted EURO or California Energy Commission (CEC) efficiency. For the PV module micro inverter, DC/DC optimizer, or in

general, MLPE equipped PV system installations and particularly shade resilient PV module designs measurement protocols and figures as a performance indicator to rate their specific beneficial operation are presented. They enable the comparison of new PV system components and designs with their advanced functions and benefits. The PV battery system characterization is discussed in four steps. At first, with a simple test showing the inertia of a PV battery storage system the need of more meaningful performance indicators besides the nominal storage capacity and maximum efficiency is demonstrated. In the second step, the efficiency guideline for PV storage systems is discussed. Here, a measurement protocol is introduced which enables to systematically assess performance relevant figures from PV battery storage systems. In a third step, a dynamic PV battery storage simulation model is introduced which can be parameterized by the performance relevant figures assessed, according to the previously introduced efficiency guideline. All of these figures enable to parameterize PV battery system simulation models in a more sufficient way than the often-found figures of the maximum efficiency or the maximum capacity in datasheets. In the fourth step, simulations with that way parameterized dynamic PV battery storage model enables for individual PV system performance assessment by means performance indicators established in the sector of PV battery storage system.

Furthermore, the concise cycle test (CCT) a measurement protocol for the performance assessment of whole energy supply systems for single family or semi-detached houses in a Hardware-in-the-Loop test bench is introduced. This CCT allows for a performance assessment in a reasonably short time of six days without any previous examinations of the devices to be tested. Finally, we introduce the new key performance indicator grid purchase ratio. It allows a system assessment even if inefficient electric applications are used in the system under test. Performance indicators for complex new systems with PV have to consider their multiple-usage benefits, e.g. additional yield or benefit, economically or regarding social acceptance.

The performance indicators are as manifold as the multiple-usage of a certain PV system installation may be. As an example, in the area of parallel agricultural and PV usage (APV) the Land Equivalent Ratio (LER) shall be mentioned here. It indicates how efficient the parallel double-usage of a field is compared to two parallel single usage fields with the same total area. For foldable PV systems, the multiple-usage performance can be rated, for example by the amount of steel and respective CO_2 emissions saved by its light weight structure, as operation during heavy wind or snow load conditions is avoided. A showcase with a foldable PV installation over wastewater treatment basins with respective performance indicators is given in the report. The variety of multiple-usage of foldable PV makes it difficult to determine a certain set of performance indicators which can be generally applied. For floating PV (FPV) systems also, the multiple-usage benefits depend on their certain environmental operating conditions (e.g. reduced algal growth). A KPI is the PV module operating temperature which, besides the irradiation, is influenced by the wind speed. However, the pure presence of a waterbody beneath the PV modules does not imply lower PV module operating temperatures compared to land-based PV systems in the same area. Currently, there is no commonly applicable use case for rating an FPV performance characterization. Therefore, further research has to be carried out to find valid use cases and performance indicators for FPV.

For all performance characterization methods and performance indicators introduced in this report no standards exist currently. Although, some are closer to an existing standard multi-MPPT inverter) or on the way to a standardization process (PV storage systems). In the case of floating PV and foldable PV research and development are just at the beginning of the way to standardized performance characterization.

The work on this report has shown, that the development of a uniform performance indicator for all kinds of new PV components or new complex systems with PV will hardly be possible. Nevertheless, a framework should be developed which allows to normalize different performance indicators to make them comparable.

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