Reliability Models of Photovoltaic System Topologies for System Adequacy Evaluation

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Abstract: Solar cell panels, power electronic converters, and high power switching are critical components of Photovoltaic system. These components collectively play an important role in shaping the reliability of PV systems. Moreover, the power output of PV systems is variable, so it cannot be controlled as easily as conventional generation due to the unpredictable nature of weather conditions. Therefore, solar power has a different influence on generating system reliability compared to conventional power sources. Recently, different PV system designs have been constructed to maximize the output power. These different designs are commonly adopted based on the scale of a PV system. Large-scale grid-connected PV systems are generally connected in a centralized or a string structure. Central and string PV schemes are different in terms of connecting the inverter to PV arrays. Micro-inverter systems are recognized as a third PV system topology. It is therefore important to evaluate the reliability contribution of PV systems under these topologies. This work utilizes a probabilistic technique to develop a power output model for a PV generation system. A reliability model is then developed for a PV integrated power system in order to assess the reliability and energy contribution of the solar system to meet overall system demand. The developed model is applied to a small isolated power unit to evaluate system adequacy and capacity level of a PV system considering the three topologies.

1. Introduction

The output power of PV systems differs from the power generated by conventional sources due to the high uncertainty of PV power output, and the availability associated with PV system components [1]-[3] and their relative configurations. Electric power utilities and customers are therefore concerned about the reliability of PV-integrated power systems. Previous studies have discussed the system reliability of adding PV systems to electric power system grids using both analytical [4], [5] and simulation techniques [6], [7]. Billinton and Karki [8], [9] discuss the adequacy benefit associated with installing renewable energy sources in electric power systems. A system well-being model is used in these works with combining deterministic and probabilistic technique to provide useful reliability indices for test system containing renewable energy. The reliability contribution of photovoltaic and wind energy sources is presented evaluated in these studies. Most reliability studies however consider PV systems as a whole component, and do not incorporate the sub-components and the design configurations of the PV topology in the evaluation.

PV power systems are composed of components that are vulnerable to failures with different probabilities. The structure of power electronic converters in PV systems can be broadly classified into centralized-inverters, string-inverters, and micro-inverters. The structures of central and string PV systems often have similar electric components, but are differently configured in terms of connecting the solar array to the inverter. A central PV system topology is composed of multi-strings topologies that are connected to only one inverter. However, one inverter is connected to each string in a string PV system topology. Micro-inverter topology, on the other hand, requires one inverter per solar panel. Previous published works do not consider all the aforementioned topologies. The quantitative assessment of reliability for an entire PV system is essential in determining the overall reliability contribution of adding solar power to electric power systems, and this has not been sufficiently addressed in the available literature.

This poster presents a comprehensive overview of the reliability models of PV systems, and presents the reliability quantification process of central, string, and micro-inverter PV systems. The developed models are embedded in the reliability evaluation methodology to obtain a discrete probability distribution in the form of a capacity outage probability table (COPT) [4] for each component group using individual component failure rates assuming exponential distribution of times to failure. The loss of load expectation (LOLE) [6] and the loss of energy expectation (LOEE) [6] indices are used in this paper to quantify the reliability of the PV-integrated systems. The capacity credit (CC) and the effective load carrying capability (ELCC) are calculated to estimate the capacity contribution by the different PV system topologies. The application of system reliability risk indices provides valuable quantitative risk measures, and is illustrated using a small isolated power system (SIPS). The main contribution of this work is the development of a detailed analytical reliability model of a PV system that accounts for PV system components and PV topologies. The benefit from the addition of a PV system using the three topologies is quantified in terms of LOLE, LOEE, ELCC, and CC.

References

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