A Hierarchical Markov Chain Model for Probabilistic Reliability Assessment of a Stand-Alone Building-Integrated Photovoltaic System Based on Experimental BMS Data

Gabriela Mantescu
Institute of Scientific Research for Science and Technology, Valahia University of Targoviste, Targoviste, Dambovita

Let Dorin
Institute of Scientific Research for Science and Technology, Valahia University of Targoviste, Targoviste, Dambovita

Nicolae Olariu
Faculty of Electrical Engineering, Electronics and Information Technology, Valahia University of Targoviste, Targoviste, Dambovita

Paul Ciprian Patic
Faculty of Electrical Engineering, Electronics and Information Technology, Valahia University of Targoviste, Targoviste, Dambovita

Abstract

The stochastic variability of solar irradiance represents one of the main challenges affecting the reliability and operational performance of stand-alone Building-Integrated Photovoltaic systems. This paper proposes a hierarchical Markov chain model for the probabilistic reliability assessment of a stand-alone installation integrated into the Institute of Scientific Research for Science and Technology from Valahia University of Targoviste, Romania. The proposed methodology consists of two coupled stochastic processes. The first-level Markov chain models the temporal evolution of solar irradiance using high-resolution experimental measurements, while the second-level chain describes the battery energy state conditioned by photovoltaic power generation and building load demand. Both transition probability matrices are identified directly from synchronized operational data acquired by the Building Management System, including solar irradiance, photovoltaic power, battery voltage and current, State of Charge, inverter operating parameters, and electrical load profiles, recorded during the experimental campaign conducted on 6 June 2026. The stationary probability distributions obtained from the hierarchical model are employed to evaluate the long-term reliability of the stand-alone system through the Probability of Energy Deficit, Probability of Energy Surplus, Battery Availability Factor, and Loss of Power Supply Probability. Experimental validation demonstrates that the proposed framework accurately captures the stochastic interaction between solar resource variability and battery energy dynamics. The developed methodology provides an efficient decision-support tool for reliability assessment, battery sizing, and operational optimization of stand-alone BIPV systems operating under highly variable environmental conditions.

Keywords

Battery energy storage, building-integrated photovoltaics, hierarchical Markov chain, stand-alone photovoltaic systems, probabilistic reliability assessment.