Theis Title: IMPACT ANALYSIS OF SOLAR PHOTOVOLTAIC ARRAY FAULTS ON POWER NETWORK

Abstract: Solar photovoltaic (SPV) arrays can experience electrical issues like line-to-line (LL), open circuit (OC), and line-to-ground (LG) faults, leading to reduced efficiency, output power drops, voltage instability, and potential fire risks. To maintain stability in power distribution networks, particularly in the face of high impedance faults and low solar insolation, it is crucial to accurately pinpoint and identify these faults. Quantifying the power injection during high impedance array faults and faults under low insolation is challenging due to the maximum power point tracking control and the associated blocking and bypass diodes. Hence, this thesis focuses on elucidating the impact of these SPV array faults to develop efficient control, operation, and planning strategies for a renewable-integrated power system. In the initial phase, the work introduces an innovative approach using data-driven multi-modal transformation (MMT) to detect and classify such events. It also presents an MMT-aided support vector machine that uses only voltage magnitude data to identify SPV array faults and load variations. It incorporates a multi-class classification scheme for distinguishing between different types of SPV array faults. Additionally, a co-analysis method is outlined for precise fault location within a distribution system, along with a strategy for assessing the impact of SPV faults at various points across the network. The proposed method is efficient in terms of data usage. It has been validated through simulations on the modified IEEE 33-bus and CIGRE low-voltage benchmarks using PSCAD/EMTDC, demonstrating an enhanced accuracy and scalability compared to existing methods.

Later, the research extends to the panel-level diagnosis of SPV array faults. Changes in environmental conditions and nonlinear characteristics of solar cells make it challenging to identify faults by conventional protection schemes. Existing learning-based fault diagnosis approaches require voluminous data and sensors, making them costly and challenging to integrate with existing SPV systems. Moreover, the lack of panel-level monitoring in existing approaches renders them incapable of pinpointing the precise location of the faulty panel. To address these issues, this work proposes a methodology for detecting faults, localizing the exact faulty panel, and accurately classifying faults in SPV arrays. The methodology involves a sensorless electronic circuit using a bipolar junction transistor and Zener diode for fault detection, an IoT-based web application for monitoring individual solar panels for fault localization, and a deep autoencoder-based semi-supervised learning module followed by a hybrid support vector machine and logistic regression for fault classification. The proposed methodology is a low-cost and less data-intensive solution that results in precise fault detection, exact faulty panel localization, and fault classification with an overall accuracy of 99.67%. The methodology is validated in a laboratory-scale, real-time setup of a grid-connected SPV system under varying electrical and environmental conditions.

Further, the thesis proposes a global sensitivity analysis (GSA) of output power to random SPV array faults to study the impact of the aforementioned SPV array faults. A data-driven approach based on the polynomial chaos Kriging method is proposed for the GSA. Four different state-of-the-art topologies of SPV array, namely, series-parallel, total-cross-tied, honey-comb, and bridge-linked, have been analyzed to determine power sensitivity to various electrical faults at different fault resistances. A sparse set of orthonormal polynomials approximate the global behavior, whereas analysis of variance kernel-based Kriging analyzes the local variability of the system output. This creates a hybrid metamodel that reflects the global relationship between the output power and random SPV array faults. With the developed metamodel, Sobol indices are calculated analytically to assess the sensitivity of outputs to the input variations, thus determining the severity of faults for array topology.