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Dissertation

"Fault Detection and Isolation in DC Distribution Grids"

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Abstract

Facing the growing demands of environment-friendly energy sources, e-mobility and energy-efficient buildings, DC distribution grids provide an advantageous solution of electric energy management in terms of flexibility and efficiency. However, immature protection technologies are still an obstacle to the commercialization of DC distribution grids.

In order to clear faults in DC distribution grids timely and accurately, fast and reliable fault detection and isolation (FDI) methods are needed. For this purpose, this dissertation introduces three different approaches of FDI in DC distribution grids based on signal-processing, system modeling and machine learning, respectively.

The first part presents an FDI method for DC distribution grids using the regularity of the second derivative of current (SDOC). As the major contribution of this work, the correlation between the singular feature in the SDOC and the short circuit fault in DC lines is proved and applied to DC protection. Furthermore, a singularity detection approach using stationary wavelet transform is adopted. With this FDI method, the faulty line and faulty pole can be identified based on only local current measurements. Compared with existing current derivative-based methods, this method has a distinct advantage in the robustness against operating disturbances. The effectiveness of this FDI method has been verified through the hardware tests under the real-time simulations of various fault scenarios in a 5-kV three-terminal DC distribution grid model.

In the second part, an FDI method able to isolate different types of component faults is developed based on system modeling. First, the state-space representation of a three-terminal DC distribution grid with various component faults is derived. Then, an FDI function based on H_{-}/H_{∞} observers is designed. To achieve the desired selectivity in fault isolation, the parameters of the observers are optimized using linear matrix inequalities. The performance of the proposed FDI method is verified under the real-time simulation of a three-terminal low voltage DC distribution grids and with a small-scale laboratory DC grid, respectively.

In both simulated and real-world DC grids, the proposed FDI method is proved to be effective to recognize different faults with a response time of 1 ms.

In the third part, an ensemble learning algorithm is applied to FDI in DC distribution grids using synthetic data. The ensemble learning algorithm is suited to differentiate normal data from fault data of different severity levels. Next, to remove the requirement of the data-driven FDI methods on the fault data, synthetic data are introduced as the label data in training a classification model for the FDI in DC distribution grids. Synthetic data can be obtained during the normal operation, which provide valid current features of short circuit faults in frequency domain. For feature extraction, discrete wavelet packet transform is applied. In the verification tests, the detection rates of the proposed ensemble model approach 100% while the false positive rates are below 0. 5%, which verify the effectiveness of ensemble model with synthetic data in the FDI in DC distribution grids.

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