Title	発電量が不規則変動する再生可能エネルギー源の電力配電システムへの最適導入
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Abstract

The significance of renewable energy sources, such as solar and wind power, has experienced a remarkable surge in the modern world. Advancements in solar panel technology, along with decreasing costs and the integration of solar power and energy storage, have significantly enhanced the efficiency and cost-effectiveness of solar energy. Similarly, wind energy has made notable strides through the development of larger and more efficient wind turbines, including offshore and floating wind farms. As a result, renewable energy has become an increasingly vital component of power systems.

However, the integration of renewable energy sources presents challenges concerning voltage stability, power loss, and unpredictable reactive power consumption. Voltage instability and power loss in power distribution networks are influenced by the reactive power compensation of renewable distributed generators (RDGs). Consequently, it is important to allocate and determine the optimal placement of RDGs while considering their unpredictable reactive power consumption and the system's capacity for reactive support. This dissertation presents novel methods for the location, sizing, and allocation of RDGs, considering the uncontrolled and reactive power consumption of the generators.

The study begins by addressing voltage instability caused by uncontrolled loads, generators, and the reactive power compensation of RDGs. A methodology is proposed to quantify the system's reactive support capacity and improve voltage stability through the Reactive Power Compensation Support Margin for Voltage Stability Improvement (QSVS). Key functions derived from the complex power formula are utilized to calculate voltage stability and identify the bus most susceptible to voltage collapse. Consequently, the Load-Disabling Nodal Analysis (LDNA) method is introduced for identifying the optimal location and size of RDGs. A methodology is then presented that determines the placement of RDGs using LDNA, which consists of two parts that leverage the QSVS concept. The first part utilizes QSVS as the objective function to maximize the reactive support capacity and determine the optimal location for RDGs. This process of locating RDGs using the QSVS as the objective function to be maximized is called LDNA-QSVS. Subsequently, the loss minimization is conducted to determine the optimal sizing of RDGs. By considering reactive compensation and incorporating safety margins using LDNA-QSVS, the proposed methodology of achieves improved power loss reduction and enhances voltage stability. This emphasizes the significance of compensating reactive power in achieving improved reduction in power losses and ensuring resilient voltage stability.

Next, the Normalized Voltage Stability index (Λ) is introduced for identifying RDG locations that address both voltage stability and power loss. Then, the LDNA for Robust Voltage Stability (LDNA-RVS) method is employed to locate RDGs by maximizing Λ as the objective function. This approach improves robust voltage stability and efficiency in reducing power losses during the integration of RDGs. Consequently, the LDNA-RVS method effectively enhances voltage stability and optimizes power loss reduction in RDG allocation. Comparative analyses conducted on the IEEE 33-bus and IEEE 69-bus test distribution systems demonstrate the superior performance of LDNA-RVS over other techniques, particularly in terms of robust voltage stability and power loss reduction.

Lastly, this dissertation presents an innovative allocation approach that addresses the system's robustness against power fluctuations. By incorporating lower and upper power level bounds, the approach ensures a balanced and stable system operation. The robustness conditions, inspired by the perfect matching concept from Graph Theory, are employed to establish a solid theoretical framework for the proposed approach. To further validate its effectiveness, simulations are conducted using a simplified model of a real power system, demonstrating the successful application of the proposed approach in maintaining system stability and optimizing power allocation under various operating conditions.

This dissertation investigates novel methods for the precise placement, optimal sizing, and efficient allocation of RDGs within power distribution networks. The research addresses the challenges related to power delivery efficiency, particularly in weather-dependent reactance fluctuations. By introducing innovative approaches, this study contributes significantly to various aspects of power distribution networks, including the seamless integration of renewable energy sources, enhancement of voltage stability, reduction of power losses, improvement of safety measures, reinforcement of system resilience, and the facilitation of practical implementation. These contributions collectively advance the field and pave the way for more sustainable and reliable power infrastructure.

Keywords: renewable energy, voltage stability, reactive compensation, system robustness, loss reduction efficiency