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Advanced Computational Methods for System Voltage Stability Enhancement

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Abstract

Power system stability has been recognised as a crucial requirement for the reliable and secure operation of electricity power systems for almost one century. Because of this, power engineers and researchers have developed various techniques to manage instability and to maintain power system stability and reliability. Especially in modern power systems, problems occur in the form of voltage instability, frequency instability and inter-area oscillations, particularly cascading failures leading to system blackout. Voltage stability analysis plays a vital role in predicting potential voltage instability. During the planning and operation of a power system, voltage problems have become a great concern, because a considerably large number of failures are believed to have been caused by voltage instability. In recent years, much research has been undertaken to investigate this phenomenon.

This thesis explores various techniques for power system stability enhancement focusing on voltage stability. There are two main areas of investigation in this project. Firstly, this dissertation proposes a new technique for the optimal placement of distributed generations (DGs) at the distribution network to improve voltage stability. Secondly, this thesis develops a new method for under voltage load shedding (UVLS) to provide protection for unusual disturbances that are outside the planning and operating criteria when a power system is being perturbed.

The integration of distributed generations at the distribution system can improve power system reliability and voltage stability. However, these benefits depend on the size and location of the distributed generations. Therefore, it is important to determine the proper location of DGs in order to maximise their benefits. Currently, the optimal allocations of DG units are one of the major challenges for power system engineers. How to plan DGs to best utilise renewable energy sources while maintaining system security is an important problem. This project investigates the optimal placement of multiple DG units to obtain the most stable system and the highest network loss reduction. The proposed method in this project is based on two advanced voltage stability analysis methods: the reformulated Voltage-Active Power Modal Analysis (VPMA) and the Continuation Power Flow (CPF) methodologies or combined VPMA-CPF method. In this work, the initial modal analysis is modified to evaluate the system voltage stability by considering the incremental

relationship between V and P instead of between V and Q. The VPMA method involves eigenvalue techniques and the associated eigenvectors of the reduced Jacobian matrix. The eigenvectors of the reduced Jacobian matrix are calculated to determine the Voltage-Active Power Modal Participation Factor (VPMPF). On the other hand, the CPF method employs the predictor-corrector steps scheme to achieve a solution path and then calculates the Tangent Vector Sensitivity Index (TVSI). Both the VPMPF and TVSI provide an indication of the weakest bus in the system. Furthermore, an objective function based on loss reduction and eigenvalue is formulated to determine the most appropriate bus location for DG placement.

Power systems are subjected to variety of disturbances. Failure to protect the system may lead to equipment damage and structural changes that trigger cascading failures and blackouts. One of the mitigation actions for voltage instability is under voltage load shedding (UVLS). Research and experience have provided evidence that UVLS is a powerful counter-measure action to preclude voltage instability. This research develops an under voltage load shedding scheme based on dynamic voltage stability analysis using trajectory sensitivity to alleviate voltage collapse in a large heavily stressed power system. This works presents a method to determine the minimum amount and the most appropriate location of load shedding considering dynamic load motor. The power system investigated in this study has quite a large amount of air conditioning and water pumping. The system load is modelled in detail as a composite load model that consists of static and dynamic motor loads. This work investigates the impact of composite load after a large disturbance causing the loss of a transmission line. The proposed technique used in this research involves an iterative algorithm based on trajectory sensitivity analysis to solve the load shedding problem. The amount of load to be shed for each iteration is set at a low level; approximately 1 % of the total load. Furthermore, a voltage-active power trajectory sensitivity index (VPTSI) at all load buses is calculated to provide information about the bus that has the most prevalent influence in enhancing the system stability. The bus with the highest VPTSI is then selected as the location of load shedding. This process is reiterated until the voltages at all buses are stable.

High penetration levels of DGs have made the problem of load shedding in this modern power system become more challenging. Therefore, more DGs in the power system will change the distribution system’s structure and will establish more nuisances to the load shedding. Hence, this thesis also assesses the load shedding design in power systems in regard to DGs. The proposed method of UVLS based on trajectory sensitivity is further improved to include the dynamic DG performance assessment. The DG evaluated in this study is a wind turbine driven doubly fed induction generator.