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A reliable and efficient method for assessing voltage stability in transmission and distribution networks

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ABSTRACT

Voltage collapse has been the topic of an increasing body of research during the past few years. In this paper a new method is presented for assessing static voltage stability in transmission and distribution networks. The proposed method (PM) is fast, accurate and robust. The expanded Newton–Raphson–Seydel (NRS) and Down-Hill (DH) algorithms are employed in PM. In addition, the elimination of the trigonometric terms in power flow equations and Jacobian matrix, can improve the convergence of PM algorithm. Standard CPF, CPF–GMRES and expanded NRS methods are compared to PM. These algorithms are tested on 420 bus transmission and 4438 bus distribution networks.

1. Introduction

In the present study, the power system model's saddle node bifurcation phenomenon was identified which characterized the static point of voltage collapse of the power network [1,2]. In order to locate the saddle node bifurcation point, the continuation method and the Newton–Raphson–Seydel (or point of collapse) method have been originally developed and consequently applied to conventional AC system analysis [3,4].

The determinant of Jacobian matrix might display large discontinuities which makes the Jacobian determinant method inadequate when it is aimed to predict the critical point. In [5], the Estimation of the Determinant of Jacobian matrix (EDOJ) is utilized for computing Voltage Stability Analysis (VSA) index. Voltage stability constraint is used in EDOJ method as the upper limit of transient stability; in other words, static Available Transfer Capability (ATC) is used as upper limit of dynamic ATC [5].

The comparison method used in this paper is Generalized minimum residual (GMRES [6]) method, one of the Krylov subspace methods for solving a set of linear equations with a nonsymmetrical coefficient matrix. It performs efficiently on the convergence characteristics compare to other iterative methods and is appropriate for the continuation power flow (CPF) method. Hizam [7] investigates and improves the time taken by the CPF method through enforcing the GMRES method to the initial point at the start up. In order to enhance the time, the robustness of the standard CPF method is improved by means of the new CPF–GMRES method.

It was demonstrated in [3,4] that the NRS method is computationally feasible as a means of determining the saddle node bifurcation point in AC/DC systems. In [3,4] an expanded NRS method is presented. This method is not only accurate but is also faster than NRS method and converges all the system. The expanded NRS [3,4] is employed in this paper.

The NRS method is sometimes inappropriate for the distribution networks. This paper takes Down-Hill (DH) algorithm in order to extend its convergence region [8]. This effective improvement of the expanded NRS method causes less calculation time to be consumed. Besides, it is more robust for distribution networks. Furthermore, Broyden method [9] is a functional method for distribution networks. In this method, Jacobian matrix is used only in initial value. Therefore, this method is not appropriate for voltage stability [9].

Distribution networks might be numerically ill-conditioned as a result of the wide ranging r/x ratios and the inherent radial structure. Therefore, many power flow algorithms specifically suited for distribution system have been produced and well documented [10–12]. A fast decoupled G-matrix method for power flow (FDGPF) [10], a fast decoupled distribution power flow (FDDPF) [11] and branch-to-node matrix based power flow (BNPF) [12] are among the most effective methods. Based on loop analysis method, a theoretical formulation of the forward/backward sweep with compensation power flow method has been presented in [13]. Ref. [14] presented a local voltage stability index that considers the dynamic model of induction motors and is based on WAMS measurements. Ref. [15] proposed index includes different parameters which affect the steady state voltage stability of distribution systems, therefore it gives accurate results.

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