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A parallel computing approach for integrated security assessment of power system

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ABSTRACT

Fast and accurate assessment of integrated security of present day complex and highly interconnected power system within time frame is a challenging task. The traditional methods used for integrated security assessment are fast but approximate. On the other hand, full simulation methods provide more accurate security assessment, but require large computation time. This paper proposes the use of parallel computing for fast and accurate assessment of integrated security of power system by running full Newton Raphson (NR) load flow program with sparsity technique to compute real power flow or MW performance index (*MWPI*), and voltage performance index (*VPI*), and continuation power flow program with sparsity technique to compute voltage stability index (*VSI*) for all possible single line outage contingencies.

The proposed work has been carried out using the Matlab Parallel Computing Toolbox Software (PCTS). To implement parallel computing, the job scheduler, a part of PCTS, divides a computationally intensive job into various tasks and distributes these tasks to its assigned workers for evaluation. Effectiveness of the proposed approach has been demonstrated on IEEE 30-bus system and a practical NREB 246-bus Indian power system. As the proposed method utilizes NR load flow and continuation load flow programs, the accurate post contingency operating status of a power system is also available, which can be used for appropriate corrective actions planning to bring the power system back into secure state. The proposed approach is quite accurate and fast and hence can be implemented for integrated security assessment of practical power systems in smart grid environment also.

Introduction

Restructuring of power industry and the present changes in generation sources have increased many times, the complexity and uncertainty of power system operation and control. Consequently, power systems have to be operated under stressed conditions and sometimes this may lead transmission systems to work closer to their voltage and line loading limits [1]. Due to this, power system security assessment has become more challenging in emerging power system.

Power system security assessment is the process of detecting any violation of the operating limits (line loading limit and bus voltage magnitude limits) following a contingency. Severity of a contingency in power system is usually evaluated by considering two performance indices, the line flow or MW performance index (*MWPI*) and the voltage performance index (*VPI*). *MWPI* evaluates the severity of a contingency on the basis of the real power flow limit violation in various lines of a power system, while *VPI* evaluates the severity of a contingency from the viewpoint of voltage limit violation at various buses [2–5]. Due to stressed operation of most of the modern power system networks, the voltage instability has become one of the major concerns nowadays. Hence, in this paper, voltage stability index (*VSI*) has also been considered along with *MWPI* and *VPI* for integrated security assessment. The margin (in terms of load increase) between the current operating point and the voltage collapse point for a particular contingency is a commonly used index for voltage stability assessment [6,7].

On the basis of the three indices, namely, *MWPI*, *VPI* and *VSI*, the screening and ranking of all possible single line outage contingencies occurring in a power system have been carried out. For the given operating condition of a power system, a contingency having the highest value of *MWPI*/*VPI* is considered to be the most severe contingency, while the contingency providing least value of *VSI* is considered as the most severe contingency from the view point of voltage stability.

Voltage stability is concerned with the ability of a power system to maintain steady voltages at all the load buses in a system under normal operating conditions, and after being subjected to a

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disturbance. Voltage instability problem normally occurs in highly stressed power systems. The main cause of occurrence of voltage instability is deficiency of reactive power in a power system, which has direct impact on voltage profile of power system [7,8]. The most common methods for voltage stability assessment are the point of collapse method, continuation power flow [9,10], the energy function method [11] and sensitivity analysis [12], etc.

In general, security assessment results should be received within a few minutes (up to five to ten minutes) in order to be considered reliable for corrective action planning. Slower security assessment response would most likely provide the results unreliable due to changes that may have occurred in the power system model simulating the real-time conditions [14]. Integrated security assessment for all the possible contingencies using Newton Raphson (NR) load flow and continuation load flow program within acceptable time frame is extremely difficult. The application of parallel computing may be very useful for such problems of practical power system comprising of huge number of buses and transmission lines. In the literature survey, [13–22] discusses parallel and distributed processing applications in power systems.

The approximate methods used for assessing the power system security include techniques such as sensitivity methods and DC power flow [3–6]. Full simulation methods for voltage stability assessment include continuation load flow solution. Though, the approximate methods provide some computational advantages, full simulation methods offer a more accurate assessment. Another advantage of full simulation methods is that they provide detailed knowledge of post contingency state of each system variable, which can be used for appropriate corrective action planning to bring the system back into the secure state. When an approximate method is used, some assumptions are made which must be verified in order to confirm the applicability when the system conditions change. This verification is not necessary when full simulation methods are used, a fact that is regarded as an additional advantage of these methods. The main disadvantage of the full simulation techniques is the large cpu time requirement, particularly for practical power systems [16].

In a power system, this has been observed that some contingencies are severe (critical) due to line overloading, some are severe due to voltage limit violation, and some are critical from the viewpoint of voltage stability while some are critical from the viewpoint of more than one. Some contingencies are non-critical for all the operating conditions, while some are critical for some of the operating conditions but not for other operating conditions of a power system. Also, the ranking order of critical contingencies is not fixed, and depending upon operating condition of a power system, ranking order may change a lot. For secure operation of a power system, real power flow security, voltage security and voltage stability are to be assessed simultaneously.

Hence, the contingency ranking of a power system from the viewpoint of these three indices (*MWPI*, *VPI* and *VSI*) for all the possible single line outage contingencies has been considered in this paper. For integrated security assessment, NR load flow method has been used for evaluating *MWPI* and *VPI*, and continuation load flow program for evaluating *VSI*. However, to overcome the problem of large cpu time requirement, parallel computing has been applied using Parallel Computing toolbox software [23].

For contingency ranking, the simulation of the contingencies occurring in a power system is independent of one another; therefore, this job can be performed using parallel/distributed computing in an efficient manner. The parallel computing speeds up the execution process of computationally intensive program (job), by dividing the job into segments (tasks) and assigning different tasks to various workers of a multi-core computer. These tasks are executed simultaneously, by the workers and the results are submitted to the job scheduler.

In addition to this, to reduce the computational time further, sparsity technique [24] is employed to the NR load flow and continuation load flow programs. Since Y_{BUS} matrix is highly sparse, it is necessary to conserve sparsity structure of the Y_{BUS} matrix so as to optimize computer memory and also to decrease computational time in order to decrease the cost of computation [24]. The proposed method also provides detailed contingency analysis from the view point of overloading of lines, voltage limit violation at load buses and voltage stability margin. These results can be directly used for corrective action planning, if required.

This paper is structured as follows. Section 'Problem formulation' presents the problem formulation, while implementation of parallel computing is discussed in Section 'Implementation of parallel computing'. In Section 'Results and discussion', the effectiveness of the proposed approach has been demonstrated on IEEE 30-bus system [25] and Practical NREB 246-bus Indian system [26,27] and Section 'Conclusion' concludes the paper.

Problem formulation

In this paper, for integrated security assessment of a power system, three performance indices are used namely power flow performance index, voltage performance index and voltage stability index. For power system security assessment, *MWPI*, *VPI* and *VSI* are defined and used in different manner [1–3].

Real power flow performance index

The real power flow performance index used for power flow security assessment [1] is:

$$MWPI = \sum_{\substack{\text{branches}\\ l}} \frac{w}{2n}\left(\frac{P_l^{flow}}{P_l^{\max}}\right)^{2n} \tag{1}$$

where P_i^{flow} is the real power flow in transmission line l and $P_i^{\max}$ is maximum real power flow (MW) rating of the transmission line l. In this paper, *MWPI* has been used for identification of line overloading. Here $w = 1$ and $n = 2$.

Voltage performance index

For voltage security assessment, the voltage performance index [1] used in this paper is:

$$VPI = \sum_{\substack{\text{buses}\\ i}} \left(\frac{\Delta|V_i|}{\Delta|V^{\max}|}\right)^{2m} \tag{2}$$

where $\Delta|V_i|$ is the difference between the voltage magnitude at bus i for the line outage condition and the base case voltage magnitude and $\Delta|V^{\max}|$ is a value decided by the utility engineers indicating how much they wish to limit a bus voltage from changing on one outage case.

Voltage stability index

The behavior of a power system can be described by differential equations in the form of (3)

$$\dot{x} = f(x, \lambda) \tag{3}$$

where x be the n-vector of state variables (voltage magnitudes and angles at all the buses), and λ represents the change in load at all the buses in the power system. For slow variation of the parameter, the power system can be modeled by a series of steady state solutions to (3) obtained for different values of λ. These solutions are obtained