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A grid computing based approach for the power system dynamic security assessment

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ABSTRACT

This paper addresses the problem of parallel dynamic security assessment applications from static homogeneous cluster environment to dynamic heterogeneous grid environment. Functional parallelism and data parallelism are supported by each of the message passing interface model and TCP/IP model. To consider the differences in heterogeneous computing resources and complexity of large-scale power system communities, a kernel-based multilevel algorithm is proposed for network partitioning. Since the bottleneck in distributed computation is low speed network communication, a bi-level latency exploitation technique is introduced for numerically solving system differential equations. The proposed grid-based implementation includes the core simulation engine, grid computing middleware, a Python interface and Python front-end utilities. Tests for a 39-bus network, a 4000-bus network and a 10,000-bus network are reported, and the results of these experiments demonstrate that the proposed scheme is able to execute the distributed simulations on computational grid infrastructure and provide efficient parallelism.

1. Introduction

The simulation of a complex power system for stability analysis is difficult due to the large number of components that need to be considered such as governors, exciters, loads, electronic converters, etc., thus increasing the number of the state variables and consequently the complexity of the dynamic model [1]. In order to develop a practicable approach utilizing limited computational and technical resources, it is often necessary to use the parallel and distributed computing technologies [2–5].

During the last decades, a number of power system simulators implementing dynamic security assessment with parallel computing have been developed. One of the most common schemes is the data parallelism [6–8]. While these low-level infrastructures are extremely powerful, they are not compatible with each other, nor are they readily accessible to an average computational electrical engineer. On the other hand, higher-level parallelization systems with a Web-based user interface may help computer neophytes, but these systems lack programming flexibility to implement a user's analysis algorithm for various research purposes [9–11].

In this paper, a grid computing based architecture was developed to produce higher-level application program interfaces (APIs) to provide users with a scripting environment and to distribute dynamic security assessment on grid environments. Functional parallelism and data parallelism are supported by each of the message passing interface (MPI) model and TCP/IP model.

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The standard approach for data parallelism has been to divide the vertices of a power gird into approximately equal-weight partitions and minimize the number of cut edges between partitions. It is proved that minimizing edge-cut may not reduce the parallel execution time of a dynamic security assessment application [12–14]. This paper presents a weighted form of stochastic-based objective to directly optimize various weighted power grid cuts. This makes the proposed algorithm scalable to irregular tasks and heterogeneous resources than standard partitioning methods.

During the dynamic security assessment, there exist both very fast and very slow dynamic devices. An important concern arises here is how to consider the contribution of the slow-varying subsystem when solving for the fast one throughout a complete interval. The initial attempts to exploit latency were made in very large-scale integration circuit simulation in connection with the waveform relaxation method. In the early 1990s, the waveform relaxation method was used for the time domain simulation of power systems in transient stability studies. In the latency technique proposed in this paper, boundary subsystem uses the self and neighboring historical iterate parameters as guesses for the current state of subsystems.

The remainder of this paper is organized as follows. Section 2 briefly introduces the power system dynamic security analysis algorithm. In Section 3, kernel-based complex power grid community finding algorithm, bordered block diagonal form class data parallelism and latency exploitation technique to speed up simulations are described. Section 4 presents a grid computing based architecture for distributed dynamic security assessment. In Section 5, three different scale power system networks are used to test the effectiveness of the proposed approach. Finally, conclusions are drawn in Section 6.

2. Power system dynamic security analysis

2.1. Electromechanical transient stability problem

A power system can be modeled as a set of generators and a set of loads interconnected via a transmission network. The electromechanical stability analysis of a power system is a simulation in the time domain, lasting several seconds or minutes. First the power system is simulated in its operating state, then large disturbances and protective actions are simulated and finally the simulation is continued for a few more seconds or minutes. Different components of the power system have their greatest influence on the stability of the system at different points in time of the response simulation. The electromechanical stability analysis of an electrical power system emphasizes the rapidly responding electrical components of the system, for instance voltage and currents at the loads.

The complete system model of a power network can be described by a set of following nonlinear differential and algebraic equations:

$$\dot{\mathbf{X}}_g = f(\mathbf{X}_g, \mathbf{V}_b), \tag{1}$$

$$\mathbf{I}_b(\mathbf{X}_{\mathbf{g}}, \mathbf{V}_{\mathbf{b}}) = \mathbf{Y}_{\mathbf{b}}\mathbf{V}_{\mathbf{b}}, \tag{2}$$

where $\mathbf{X_g}$ are the generator variables describing the dynamics of the system and $\mathbf{V_b}$ are the bus voltages of the network.Using the implicit trapezoidal integration rule for improved numerical stability, Eq. (1) can be discretized and rearranged as follows:

$$\begin{aligned}&\mathbf{X}_{g(t)} - \mathbf{X}_{g(t-1)},\\ &-\tfrac{h}{2}\{f(\mathbf{X}_{g(t)}, \mathbf{V}_{b(t)}) + f(\mathbf{X}_{g(t-1)}, \mathbf{V}_{b(t-1)})\} = \mathbf{0},\end{aligned} \tag{3}$$

where $t = 1, 2, \ldots, T$ denotes time steps, and h represents time step duration. The linearized form of Eqs. (2) and (3) for iterations at each time step is given by

$$\begin{bmatrix} [\mathbf{A}_g] & [\mathbf{B}_g] \\ [\mathbf{C}_g] & \mathbf{Y}_b \end{bmatrix} \begin{bmatrix} \mathbf{X}_g \\ \mathbf{V}_b \end{bmatrix} = \begin{bmatrix} \mathbf{R}_g \\ \mathbf{R}_b \end{bmatrix}. \tag{4}$$

Eq. (4) may also be written as

$$\mathbf{X}_g = -[\mathbf{A}_g]^{-1}[\mathbf{B}_g]\mathbf{V}_b + [\mathbf{A}_g]^{-1}\mathbf{R}_g \tag{5}$$

and, in a decoupled form

$$[\mathbf{Y}_b + \mathbf{Y}_g]\mathbf{V}_b = \mathbf{R}_b - [\mathbf{C}_g][\mathbf{A}_g]^{-1}\mathbf{R}_g, \tag{6}$$

where $[\mathbf{Y}_g]$ is the generator equivalent admittance matrix defined as

$$[\mathbf{Y}_g] = -[\mathbf{C}_g][\mathbf{A}_g]^{-1}[\mathbf{B}_g]. \tag{7}$$

The electromechanical transient stability problem can now be solved using a Newton method, obtaining $\mathbf{X}_g$ and $\mathbf{V}_b$ iteratively from Eqs. (5) and (6) at each time step.

2.2. An algorithm for performing dynamic security assessment

The dynamic security assessment can be divided into three sequential activities: (1) contingency screening; (2) dynamic contingencies analysis; and (3) preventive and corrective control. In this paper, the second activity is mainly analyzed since it