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Parallelization methods for implementation of discharge simulation along resin insulator surfaces ☆

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ABSTRACT

In this paper, we will investigate the implementation of the parallelization approaches used in the program of discharge simulation along resin insulator surfaces in SF_6/N_2 gas mixture which initially consumes a great deal of computational time. In a general way, this simulation program spent 10 days of execution to achieve satisfactory research results. For this reason, the goal of our paper is to reduce the execution time by parallelizing this program. Three parallelization approaches were used in our simulation: (i) splitting by different types of the charged particles using a distributed-memory approach, (ii) splitting by physical domain using a distributed-memory approach, and (iii) splitting by both domain and charged particles using multi-level distributed and shared memory approach. At last, the three approaches are tested on a Linux cluster composed of six dual-core PCs, and the experimental results show that all the parallelization approaches achieve the goal of reducing the execution time to a certain extent. In addition, among these approaches, the multi-level approach offers the most effective parallelization method for implementing this simulation on symmetrical multi-processing (SMP) clusters.

1. Introduction

SF_6 has recently been recognized globally as an environmentally unfriendly gas [6], which many manufactures have to bear pressures world-wide. One of the proposed solutions is to replace SF_6 by SF_6 gas mixtures, this solution discussed in [14] indicates that SF_6/N_2 gas mixtures will be the most possible replacement for SF_6. Researchers have studied the discharge phenomena along insulator surfaces in the SF_6/N_2 gas mixtures by means of the numerical simulation technique [12,13,19,17].

In the past, a lot of models have been proposed. For instance, particle-in-cell (PIC) models [7,3] were first applied by Boswell and Morey [4] to simulate discharge plasmas. Recently, a combined particle-in-cell and Monte Carlo approach (PIC-MCC) scheme [16,17] is used and the elastic, exciting, ionizing and attaching collisions between electrons and neutral gas molecules are simulated on the basis of the available experimental data. However, this PIC-MCC simulation is huge and complicated, it needs extensive CPU usage and a great deal of time to complete. Usually, these huge programs can be split into several subroutines to limit the computational expense, while one subroutine executes on one crunode of a cluster. As a consequence, the efficient performance will be obtained when the operating load is distributed.

High performance computing (HPC) based on parallel computation appears to be very suitable for implementing such algorithms and symmetrical multi-processing (SMP) clusters are currently the most commonly used parallel architecture.

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In the following sections, we present the implementation of parallel algorithms using the distributed-memory approach with MPI [1,8,5,9] (Message Passing Interface) library and the hybrid distributed and shared memory approach with MPI/OpenMP [11,2,15,10,18] model. In addition, the detailed procedures of each parallel algorithm are illustrated with a flow diagram respectively. Moreover, the basic formulations of the processes are given to explain these computational algorithms in details. At last, the approaches were experimented on a Linux cluster composed of six dual-core PC computers. The experimental results show that the parallelization approaches are efficient to reduce the whole executing time.

The remainder of this paper is organized as follows. In Section 2, we describe the simulation model and the MCC collision model adopted in this simulation program. Then, Section 3 presents the three parallel algorithms in details. And Section 4 introduces the experimental environment and initial situations for our simulation. In addition, Section 4 also compares the simulation results among the parallelization algorithms under the specified environment. At last, Section 5 concludes the whole paper.

2. Methodology

2.1. The simulation model

A PIC-MCC model is applied to this simulation, it is an intricate phenomenon involving variety of physical processes. However, because of the complexity, simulating all these physical processes is nearly impossible. Generally, it is sufficient to focus on the most important physical processes which occupy dominant positions during the streamer induced discharge. Owing to the extensive CPU usage during the simulation, the discharge model is simplified to simulate several tens of nanoseconds. The detailed simulation model is described in a single processor form in [12,13,17].

The general procedure of the PIC-MCC approach is shown in Fig. 1. At the beginning, the charged particles exist in a continuous space and have certain positions and velocities, the electric field is defined in the discrete position of grid. And, the continuous particle positions are calculated from the discrete grid points, the velocities and positions could be obtained by using Newton–Lorentz equation which is applied to describe the motion of the particles using a leap-frog scheme [12,13]. The next time step is to consider the boundary conditions, particle absorption, particle diffusion at the boundary and other things applied in the simulation. Afterward, the MCC approach is used to consider the collision process between electrons and neutral gas molecules in the simulation. In the end, we complete the electric field calculation to finish the simulation in one time step. These calculation procedures are composed of five blocks which will be executed repeatedly until obtaining the sufficient simulation result or completing the predefined simulation time.

In the MCC module, the time step Δt determines the frequency of checking the collision. The module allows only one collision per particle in a time step. In this research, the time step is chosen as 1ps ($1\ \text{ps} = 10^{-12}$ s). Thus, in order to obtain sev-

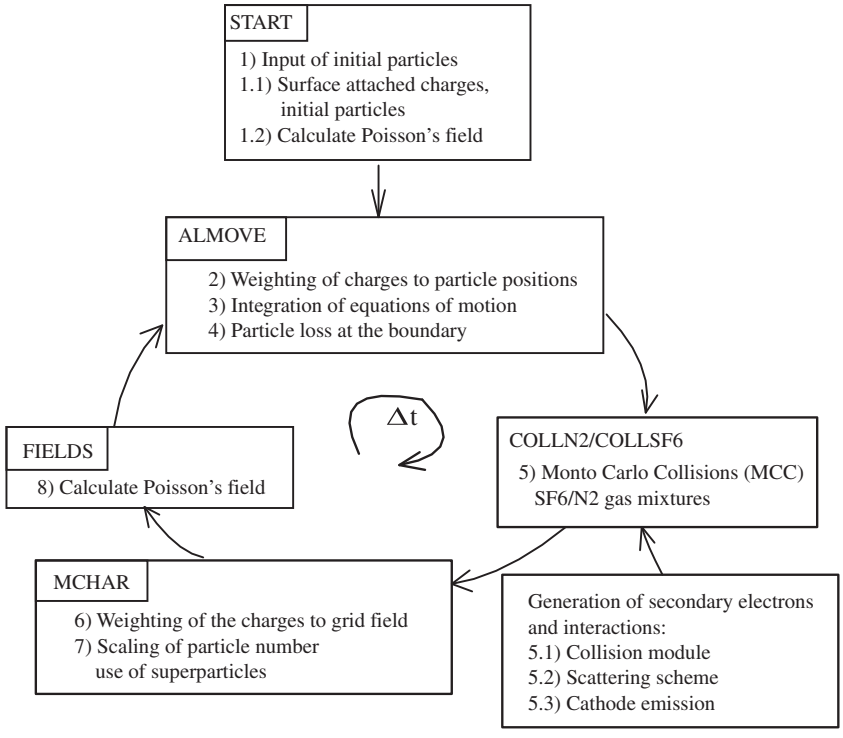

Fig. 1. Flow diagram for the PCI–MCC scheme [12,13].