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PARALLEL IN TIME SOLUTION OF ORDINARY DIFFERENTIAL EQUATION FOR NEAR REAL-TIME TRANSIENT STABILITY ANALYSIS

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ABSTRACT

Power system stability is one of the major concerns raised as the power grid is modernized with the recent technological advancements to achieve a smarter and more resilient grid. With the increase in the size of the grid, the requirement of maintaining synchronism among the various components and controllability is a major challenge. Recent research in time-parallel algorithms has paved enormous opportunities for real-time power system analysis. Transient Stability Analysis (TSA) of a power grid involves solving a large set of time-dependent Ordinary Differential Equations (ODEs) and algebraic equations which makes it infeasible for a real-time solution. This poster discusses an approach for feasible near real-time solution of ODEs using Parareal Algorithm (PA). PA implementation using general purpose graphical processing units (GPGPU) based high-performance computing (HPC) is demonstrated for a Single Machine Infinite Bus (SMIB) power system model achieving a speedup of 73x substantiates the potential for near real-time TSA.

1 INTRODUCTION

Transient stability is an ability of the power grid to reach a stable operating equilibrium or synchronism when the grid is subjected to large external disturbances and the disturbance is mitigated in a short period of time. TSA involves time domain solutions of generator ODEs requiring the solutions to be computed in near real-time for the grid's reliability and operation. In recent years, with extensive research in temporal domain decomposition technique has resulted in several time parallel algorithms like PA, Parallel Implicit Time-integration Algorithm (PITA), and Parallel Full Approximation Scheme in Space and Time (PFASST) for solving differential equations parallel in time. The temporal domain decomposition technique primarily involves dividing numerical integration time into several sub-intervals and solving these sub-intervals in parallel by distributing them across GPU cores.

2 SWING EQUATION

The stability analysis of a particular synchronous machine in the grid is performed assuming the rest of the grid network is not affected by the disturbance which is modeled as an infinite bus resulting in a single machine connected to the infinite bus through transmission lines known as SMIB model as shown in Fig 1. The rotor angle dynamics of the synchronous generator in the SMIB model can be characterized by a nonlinear differential equation known as the swing equation shown in Equation 1.

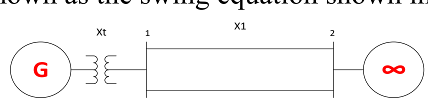

Fig 1. SMIB model.

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2} = P_m - P_e = P_a \tag{1}$$

where: H is the inertia constant (MJ/MVA), P_m is the mechanical input power, P_e is the electrical output power, P_a is the accelerating power, f_o is the nominal frequency

State variable representation of the 2[nd] order swing equation yields a set of two 1[st] order time-dependent ODEs which can be solved in parallel using PA. PA based on temporal domain decomposition technique is an iterative algorithm involving three stages namely, the Coarse Propagator ***(CP)***, Fine Propagator ***(FP)*** and Predictor-Corrector ***(PC)***. ***CP*** is computationally inexpensive, less accurate solution is solved sequentially to obtain the initial states for ***FP*** which is computationally expensive, more accurate solution is solved in parallel.

3 IMPLEMENTATION AND RESULTS

SMIB is assumed to be delivering a constant power and a 3φ fault or disturbance occurs at the middle of one of the lines at time, t = 0.5 secs and the fault is cleared at the time, t = 0.8 secs by isolating the faulted line from the system where the system attains the new steady state once isolated. The swing equation is solved numerically by implementing the PA on GPUs. The time domain solution of swing equation using numerical integration method is shown in Fig 2. Compute Unified Device Architecture (CUDA) and OpenACC parallel directives with C++ was implemented on NVIDIA's Tesla K40c along with OpenMP directives for solving the ODEs using the PA on CPUs. Fig 3 demonstrates the speedup achieved. The execution time of the GPU used in the speedup calculations is the sum of the memory latency from host to device, the computation time on the GPU and the memory latency from device to host.

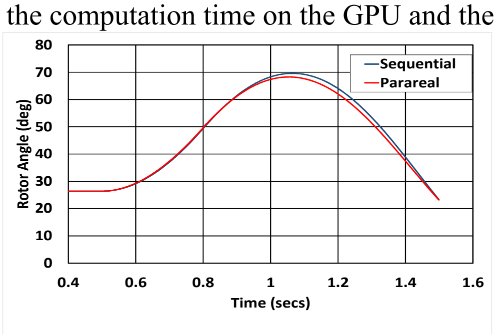

Fig 2. Time-domain solution.

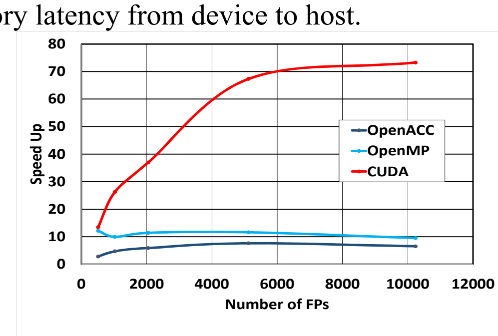

Fig 3. Speedup.

4 CONCLUSION

The implementation of the PA using GPGPU HPC approach computes the solution of an ODE with a smaller computational time in comparison to the implementing of PA using traditional HPC approach and sequential approach to compute the numerical solution of the ODE. We can observe that CUDA-C implementation provides the highest speedup in comparison to the other three approaches. Solving the ODEs using the PA, it was possible to achieve a speedup of 73x.This significant speedup demonstrates the potential of performing near real-time TSA.

REFERENCES

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