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Real-Time Phasor-EMT Hybrid Simulation for Transient Stability Studies

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Abstract— **Analyzing slow dynamics of large scale power systems requires the development of phasor based tools. This paper demonstrates the use of real time transient stability phasor solver required for analyzing slow electromechanical oscillations of large power systems. Some real time scenarios of power system networks have been analyzed by combining dynamic phasor model and EMT model simulation techniques. Implementation of hybrid simulation for a balanced power transmission network and an unbalanced power distribution network has been shown.**

Keywords — ePHASORsim; eMEGAsim (SimPowerSystems); Large scale power system; Phasor domain simulation;

I. INTRODUCTION

The complexities in power transmission and distribution networks has been increasing due to the advent of distributed energy resources, smart grids. This has also linked to transmission systems. In this perspective, real time system monitoring through transient stability analysis plays a key role [1]. Various commercially available software packages such as CYMEDIST, EMTP-RV, PSS/e, ETAP, Dig SILENT are used for evaluating system's transient stability behavior [2].

The power distribution networks were considered to be passive networks as they comprised only end users and loads. This restricted the use of simulation tools, for power distribution analysis, to load flow and short circuit studies. However, with the increasing use of distributed generation, the dynamics of distributed generation has changed drastically [3]. This has led to various concerns to dynamic security of power system networks. In this paper, real-time hybrid simulation has been reported. There is a wide range of applications in power system studies ranging from balanced transmission level networks to unbalanced distribution level power system network which requires such hybrid simulations to improve dynamic security of power systems.

II. PHASOR DOMAIN SIMULATION

A. ePHASORsim Solver

ePHASORsim is a real-time transient stability solver used for simulating slow dynamics of large scale power systems. The fundamental principle of the tool is based on phasor domain solutions of power system. The application of this tool for balanced transmission networks has been introduced in [4] where the transient stability phenomena is analyzed with the positive sequence modelling of the transmission network.

ePHASORsim solver finds its application in dynamic security assessment and testing the functionality of hardware. This tool is interfaced with MATLAB/SIMULINK. It is also compatible with different operating systems like Linux and Windows. In addition to this, PTI's load flow and dynamic data files from PSS/e are also compatible [4]. The built-in library comprises of common elements of power system such as synchronous machines, excitation systems, power system stabilizers, and different loads, transformers, buses, transmission lines among others. The ePHASORsim solver can be represented by a set of differential-algebraic equations as given below:

$$\dot{x}(t) = f(x, V) \quad \text{............} \quad (1)$$

$$YV = I(x, V) \quad \text{............} \quad (2)$$

$$x(t_0) = x_0 \quad \text{............} \quad (3)$$

Where,
x is the state variables vector,
V and I are the vector of bus voltages and currents,
Y is the nodal admittance matrix of the network, and
x_0 is the initial values of state variables.

For dynamic simulation, the modelling of the power system needs to be done in the main frequency phasor domain. The dynamics of the system depends mainly on rotating machines and control devices such as excitation systems, power system stabilizers, turbines and governors. The dynamic behavior of the system is represented by (1), while (2) describes the network constraints on (1).

With the help of partitioned and simultaneous approach, the solution to the above equations are obtained that discretize equation (1). The partitioned approach computes both equation 1 and 2 to obtain state variables and algebraic variables and then alter the results. In simultaneous approach, a set algebraic equations are obtained from (1) using an implicit integration method and then this set is lumped into (2) to get a larger set of algebraic equations considering all the variables. In ePHASORsim, the Modified Euler integration method is used along with partitioned approach.

B. *RT Simulator*

The software architecture of phasor tool is based on parallel and distributed computation on multi-core processors. The phasor tool is a PC-based simulator which comprises target nodes and host nodes. Target nodes are the computational cores that perform the simulation and each of them is driven by the modern high-performance distributed supercomputer technology found in Off-the-shelf INTEL or AMD multi-core processors [5]. The host computer is utilized to develop, design and evaluate a model in offline mode. Host computer also acts as an interface between user and the target nodes. External hardware can also be attached to the simulator through FPGA-based (Field-Programmable Gate Array) A/D input/outputs.

III. EXPERIMENTAL RESULTS

A. *Network Configuration and Measurements*

The topology of the network considered in this paper is a standard IEEE 3 Generator 9 Bus network. The AC grid is built in MATLAB Simulink with the ePHASORsim tool where the main user interface is Excel workbook in which all the power system components and their specifications are defined. With ePHASORsim, this power system network can be operated as it happens in real life. The control commands can be send to the solver directly or through communication protocols such as DNP3(Distributed Network Protocol) [6].

Various real-time situations have been monitored by giving simultaneous signals such as

- Bus Faults
- Line faults with varying distance of faults
- Connect/Disconnect commands for Capacitor banks, loads
- Transformer tap position adjustment commands
- Breaker opening and reclosing

In ePHASORsim tool, the results are obtained by defining the measurement pins in the excel workbook, such as

- Bus Voltages (RMS and degree)
- Line Currents (RMS and degree)
- Frequency deviation of synchronous machine and rotor angle
- Status of transformer taps

B. *Instantaneous Outputs*

The outputs of the solver being phasor values, it has been represented as sinusoidal waveforms (i.e. in EMT domain). The sinusoidal signal is generated in a different CPU core with a quicker time-step of 50us, in parallel with the ePHASORsim solver running at a slower time-step of 10ms simultaneously.

The sinusoidal voltage can be represented as

$$v(t) = \sqrt{2}V_{rms}\sin(2\pi f t + \emptyset_V) \quad .... \quad (4)$$

Where,
f is the standard frequency of the power system (i.e. 50 Hz),
V_{rms} is the respective bus voltage magnitude in RMS and
$\emptyset_V$ is the voltage angle

C. *Hybrid simulation*

System Validation

The objective behind this work is to demonstrate Phasor based and EMT based simulation on one standard model with the eMEGAsim(SimPowerSystems) simulator. The model was built both in phasor domain using ePHASORsim tool with a time-step of 10ms, fig-2. and in EMT domain using eMEGAsim with a time step of 50us, fig-3, and was run in real-time.

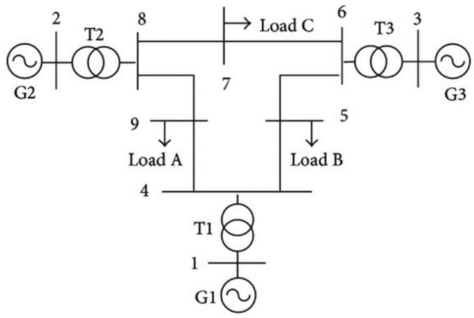


Fig - 1 - Schematic of a 9-bus network

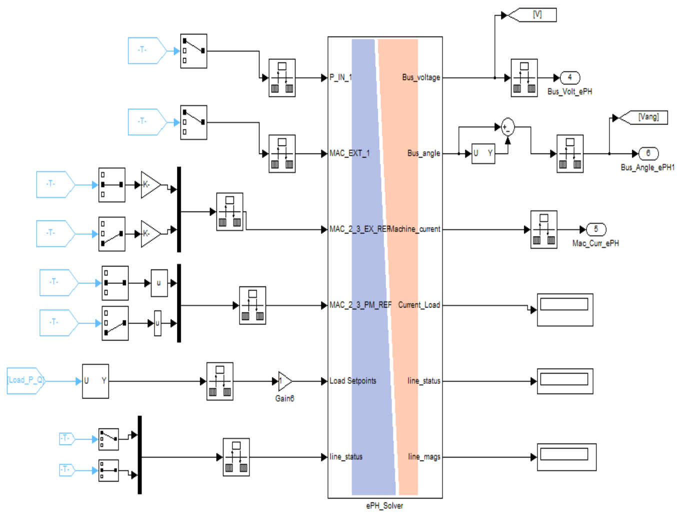


Fig - 2 - 9bus network modelled using ePHASORsim

To validate the model, the results obtained from phasor model was compared with the results obtained from eMEGAsim model. The values that are taken into consideration are the bus voltages and their phase angles and the machine currents, as shown in fig-4.

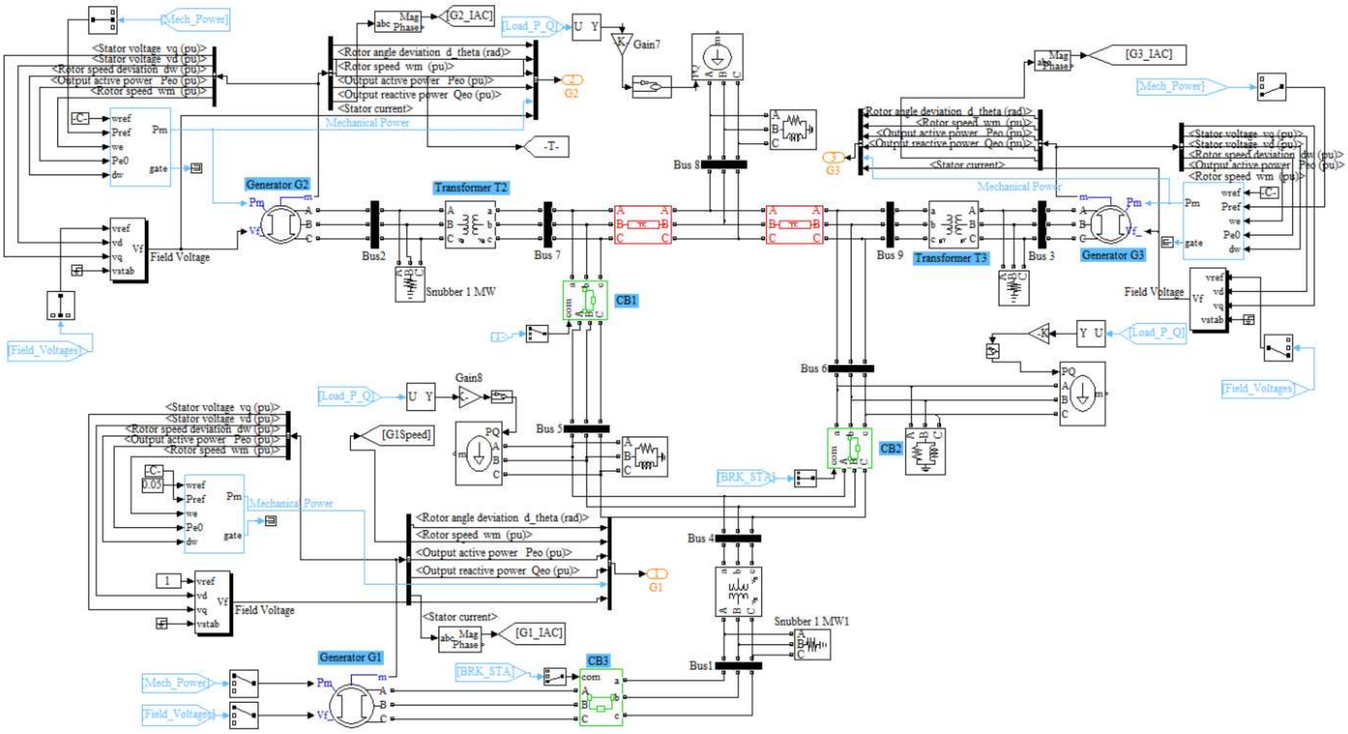
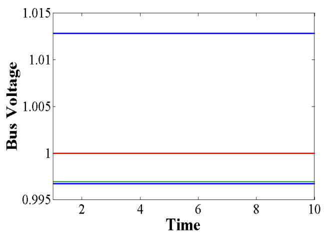
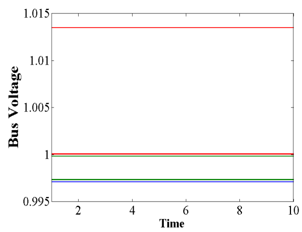


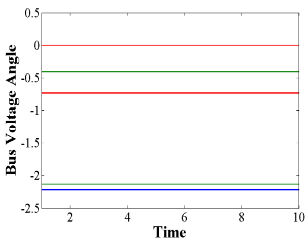
Fig - 3 - 9bus network modelled using eMEGAsim



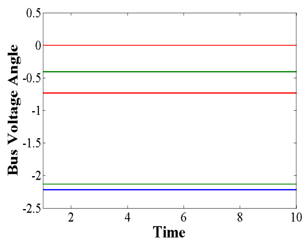
Bus Voltages_eMEG



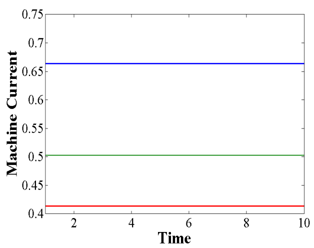
Bus Voltages_ePH



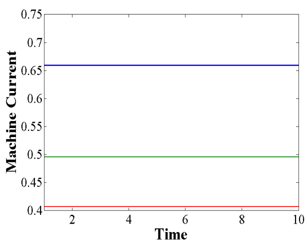
Bus Angle_eMEG



Bus Angle_ePH



Machine Curr_eMEG



Machine Curr_ePH

Fig - 4 - Results from eMEGAsim and ePHASORsim

Current Injection and Fault Occurence

A distribution network is considered. This network includes two feeders with 55 3-phase buses along with loads, shunt capacitors, transformers with variable tap positions and etc. This Simulink model of the distribution network was built using ePHASORsim tool, and was run in real time. For demonstration purpose, load current injection, at a time-step of 50us is shown. The current flow is three phase unbalanced. The load connected to one of buses was deleted from the .xls file and was connected external to the phasor solver at the same bus. Initially the voltage and angle was measured at that bus. This voltage was converted to its equivalent sinusoidal quantities using (4), as shown in fig-5.

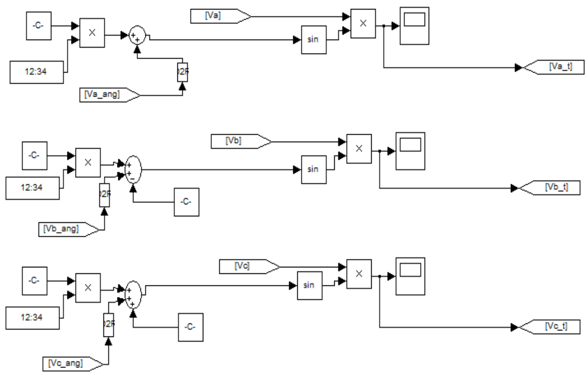
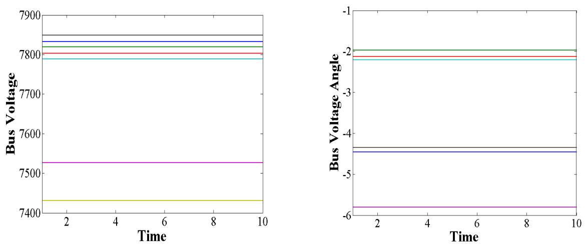
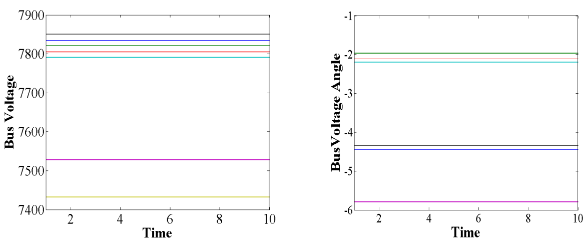


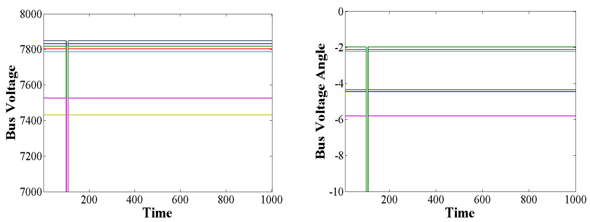
Fig - 5 - Conversion from phasor to sinusoidal quantities



(a) Without Current Injection



(b)With Current Injection



(c)With bus fault

Fig - 6 - Line Voltage magnitude and Phase Angle

The voltages were then fed to controlled voltage sources followed by equivalent load impedance (R+jX). The current flowing through the load was measured. The model which is built external to the phasor solver is operating at a time step of 50us. The load current was measured and were converted to their corresponding phasor values using abc to dq0 transformation, using the equations 5-8. These load currents were injected to the ePHASORsim model which is running at a time step of 10ms.

$$Id = \frac{2}{3}(Ia * \sin wt + Ib * \sin(wt - \frac{2\pi}{3}) + Ic * \sin(wt \ldots \quad (5)$$

$$Iq = \frac{2}{3}(Ia * \cos wt + Ib * \cos(wt - \frac{2\pi}{3}) + Ic * \cos(wt \ldots \quad (6)$$

……………………..... (7)

and …. (8)

To validate the response of the current injection, some of the network parameters such as the bus voltages and angles were measured with the load connected externally (at 50us time step). And it was compared to the actual values when same load was connected internally in ePHASORsim solver. Another real time scenario has been considered. A three phase to ground fault was introduced at one of the buses for 80ms and its effect on the bus voltages and their phase angle was monitored, as shown in fig-6.

IV. CONCLUSION

The requirements for testing of power grid is huge due to increasing network interconnection and renewable energy integration. The research is aimed to study two different parallelization techniques for EMT-type simulations. The goal was to show interfacing of two different domain simulations, both EMT and phasor, in one working model and analyze different working conditions for improving power system performance.

In real time we come across situations where we may have to perform various contingency analysis, transient stability studies which may include both time domain and phasor domain calculations. This work shows hybrid simulation for such conditions. Although the test system was simple the output was promising to examine other proposed strategies to link phasor and EMT solutions.

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