

Large systems real-time transient calculation by means of simultaneous simulation of multiple equivalents

W. C. Boaventura

Abstract — This paper deals with the real-time transient calculation for large systems simulation using multiple network equivalents. A mixed simulation involving a study system and three network equivalents is carried out in Matlab to demonstrate the simultaneous simulation. The transient calculation for the study system and each network equivalent used different time steps. A comparison between the results from the simulation carried out in Matlab and those from PSCAD, where the complete system was simulated, is presented. The main goal is to analyse the feasibility and suitability, by means of simulation, of using multiple sparse network equivalents for the purpose of large system transient simulation.

Keywords: real-time digital simulation, network equivalents, sparse representation, transmission line, simultaneous simulation.

I. INTRODUCTION

Following the wide spread use of digital computer for scientific simulation, power systems simulation has since benefited from use of digital electromagnetic transient simulation. Such transient studies have been applied for the design of systems in several areas. Among them, statistical overvoltage evaluation for the purpose of insulation coordination, relay settings and fault protection studies, temporary overvoltage due to resonance, and others. Power systems components, in general, have models for the purpose of digital transient simulation. Recently, the use real-time digital simulation has increased thanks to the advances in both hardware for signal acquisition and available computational power. This field is dominated by DSPs and FPGA [1] platforms, which are usually the chosen hardware. Several issues regarding the real-time simulation, including HIL-hardware in the loop devices, are presented and discussed in [2]. The computational efficiency and accuracy in the context of digital simulation has always been an important issue, while in the case of statistical studies, non real-time, or for the case of real-time simulation, for which it is mandatory [1]-[14]. In [3], a technique to derive network equivalents, which are both

accurate and demand little computational effort, was discussed and validated. Such equivalents, which resemble the structure of digital filters, are naturally fitted for the purpose of real-time implementation. Beyond that, the polynomials characterizing the network equivalent transfer function present a sparse structure, with several coefficients equal to zero providing computational efficiency. The integration and implementation of the derived equivalent proposed in [3] in the context of real-time digital simulation is presented in [4]. The interfacing of the derived model with analog circuits (in a form of Thévenin equivalent) is firstly validated using simulations in Matlab-Simulink environment, which provided accurate results. Then, the derived model was implemented in a hardware consisting of a data acquisition card installed in an ordinary personal computer. The analog input/output of the DAQ card are connected to analog circuits consisting of signal generators and passive circuits where several transient simulation studies were performed, validating the implementation.

Considering the real-time transient calculation for large systems, one can face several limitations, reducing the maximum number of nodes/components to be included in the study. The use of clusters, where each one represents a part of the system, is the usual solution for this issue. This paper evaluates the performance of the equivalents proposed in [4] in of the context of cluster applications. For this purpose, a mixed simulation, analog and digital, environment was prepared in Matlab/Simulink, using multiple time steps. Part of the system, the study zone (which is represented explicitly) is implemented using the Simulink toolbox for power systems simulation while the network equivalents are implemented using signal processing toolbox, which intrinsically discrete in time. The study is validated by comparisons between simulations carried out in PSCAD and those obtained from the mixed simulation in Matlab. The aim is to use computational simulation to analyse the feasibility and suitability of using multiple sparse network equivalents for the purpose of large system transient simulation, as a test of concept.

The paper is organized as follows. Section II shows the methodology for the study, presenting and discussing: *i*) network under study; *ii*) network equivalents calculation and *iii*) mixed simulation approach adopted. The results consisting of comparisons between simulations using PSCAD, for the whole network, and the mixed simulation in Matlab, using network equivalents, are presented in Section III. Finally, the

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W. C. Boaventura is with the Electrical Engineering Department of UFMG – Federal University of Minas Gerais, Brazil. (wventura@ufmg.br).

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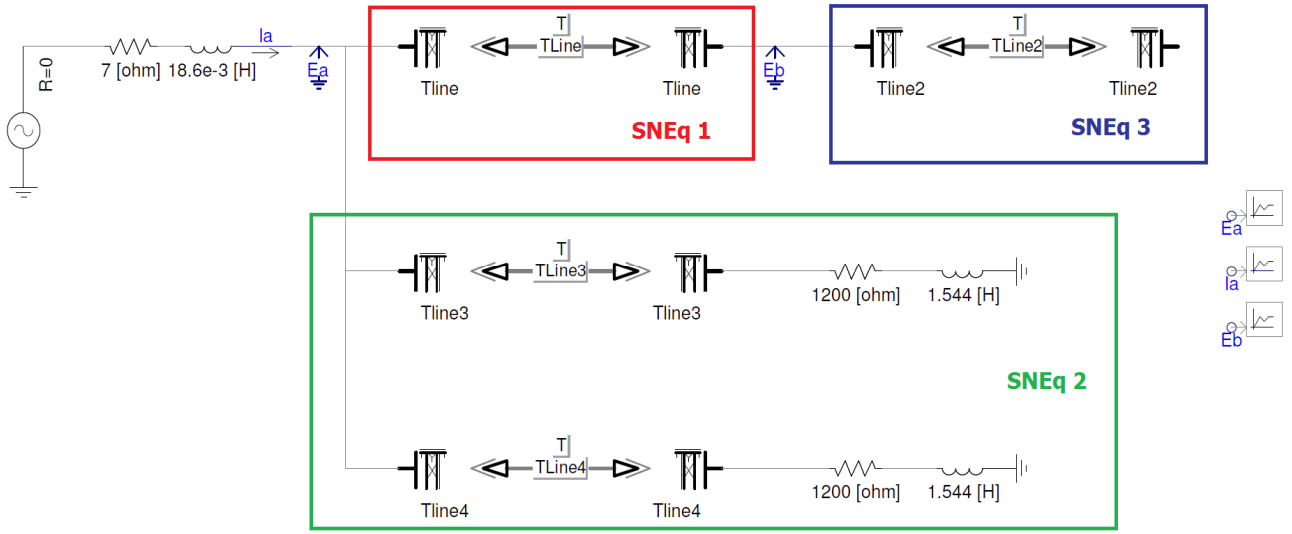


Fig. 1. The complete network implemented in PSCAD. The portions to be equivalence are identified by the color rectangles.

conclusions are stated in Section IV.

II. METHODOLOGY

The main objective of this paper is to evaluate the performance of the network equivalent derived according to [3]-[8] in the context of cluster application for the real-time transient simulation of large systems. Before going to actual real-time simulations, an investigation is done in a computer simulation environment to gather a first insight about the performance of such equivalents, which is reported in this paper. For this purpose, a system comprised of a study system (basically an AC Thévenin equivalent) and three network equivalents are simulated together in Matlab/Simulink environment [15]. The study system is to be considered the analog portion of the network while the equivalents are the digital portion. The analog portion of the system, represented in the SimPowerSystems toolbox, uses a smaller, variable, time step, while the digital portion, the network equivalents, uses larger time steps, typical of real-time transient studies. Obviously, this is an approximation since the analog portion of a network has an intrinsically infinitesimal time step. Despite this limitation, the performed evaluation is useful to show if multiple network equivalents, using different time steps, can be simulated altogether without the delays due to the equivalent using the large time step posing constraints on the stability of the simulation. The bulk simulation is done using the smaller time step. Then, the digital network equivalents have their outputs interpolated (upsampled) to simulate analog signals and then interact with the other portions of the system. The details are given below.

A. The complete network

A network comprised of three buses, loads, interconnected

by four transmission lines, fed by an AC Thévenin equivalent source, is used to demonstrate the concept. The whole system was implemented in PSCAD [16], whose transient calculation is used later for comparison. Figure 1 shows the implemented system.

The transmission lines used are single phase with characteristics of either line mode or ground mode of propagation, typical of three-phase transmission lines. They have a single conductor (*chukar*), 20m height, different lengths and soil resistivities, as the following:

- . TLine: 100 km, 0.01 Ω m soil (in SNEq1).
- . TLine2: 150 km, 0.01 Ω m soil (in SNEq3).
- . TLine3: 200 km, 1000 Ω m soil (in SNEq2).
- . TLine4: 200 km, 0.01 Ω m soil (in SNEq2).

The AC source represents a 345 kV (L-L), 600 MVA, with a series impedance of 5%. The simulated transient consists of the energization of the network, from rest condition, using a time step of 4 μ s. The current flowing to the network (I_a , as shown in Fig.1), the voltage at its entrance port (E_a) and the voltage at a middle point (E_b) are the transient curves recorded for comparisons. Figure 1 also shows the portions of the network used to derive the network equivalents. These are delimited by the color rectangles and discussed below.

B. Network Equivalents

Three network equivalents were used SNEq1, SNEq2 and SNEq3, as depicted in Fig. 1 by the color rectangles. SNEq1 is a two-port network equivalent while SNEq2 and SNEq3 are single-port equivalents. The pertinent equations are, respectively, Eq.1 and Eq.2 for case of single-port and two-port equivalents [4].

$$i_1(t) = b_0 v_1(t) + \sum_{k=1}^p b_k v_1(t - k\Delta t) - a_k i_1(t - k\Delta t). \quad (1)$$

$$\begin{bmatrix} i_1(t) \\ i_2(t) \end{bmatrix} + \sum_{k=1}^p a_k \begin{bmatrix} i_1(t - k\Delta t) \\ i_2(t - k\Delta t) \end{bmatrix} = \sum_{k=0}^p \begin{bmatrix} b_{11}^k & b_{12}^k \\ b_{21}^k & b_{22}^k \end{bmatrix} \begin{bmatrix} v_1(t - k\Delta t) \\ v_2(t - k\Delta t) \end{bmatrix}. \quad (2)$$

Differently from the whole system simulation, each network equivalent was calculated for a different, larger, time step. The corresponding portion of the network was simulated in PSCAD to produce the voltages and currents needed for the equivalent calculation, which was done according to [3]-[8]. These led to various order for the corresponding polynomials (a_k and b_k) of the equivalents. The characteristics of each equivalent are as follows:

- . SNEq1: time step = 12 μ s, order for a_k and b_k = 67 (5 polynomials);
- . SNEq2: time step = 16 μ s, order for a_k and b_k = 260;
- . SNEq3: time step = 20 μ s, order for a_k and b_k = 53.

The order for SNEq2 is larger due to the presence of a transmission line representing the ground mode of propagation, which has a lower velocity, and, consequently, demands a higher value for the order [3].

C. Mixed simulation approach

The approach to simulate a mixed analog/digital environment in Matlab/Simulink was carried out by means of the adoption of different time steps for each part of the network. Obviously, the part corresponding to the analog portion used the smaller time step. The system implemented in Matlab/Simulink is shown in Fig. 2.

The analog portion of the network: AC source, voltage-controlled sources, resistances and inductance were simulated using the features of the SimPowerSystems toolbox, using a time step of 4 μ s. The digital portion of the network, the equivalents, used the features of the Signal Processing toolbox and is shown in subsystems depicted by the color rectangles in Fig. 2. Each equivalent used the same color as in Fig. 1. Within each equivalent subsystem, a special arrangement was used to accommodate the different time steps employed. In each input, the data is downsampled (on the fly, data frames were not used) to result in a time step for which the equivalent was derived. Accordingly, at each output, the data is upsampled to return to the data rate used in the analog portion simulation. With the proper data rate, the output data is fed to a voltage-controlled source, which uses a resistance (in a form of a Thevenin equivalent), to interface the network equivalent with the remaining network, the analog portion and the other network equivalents.

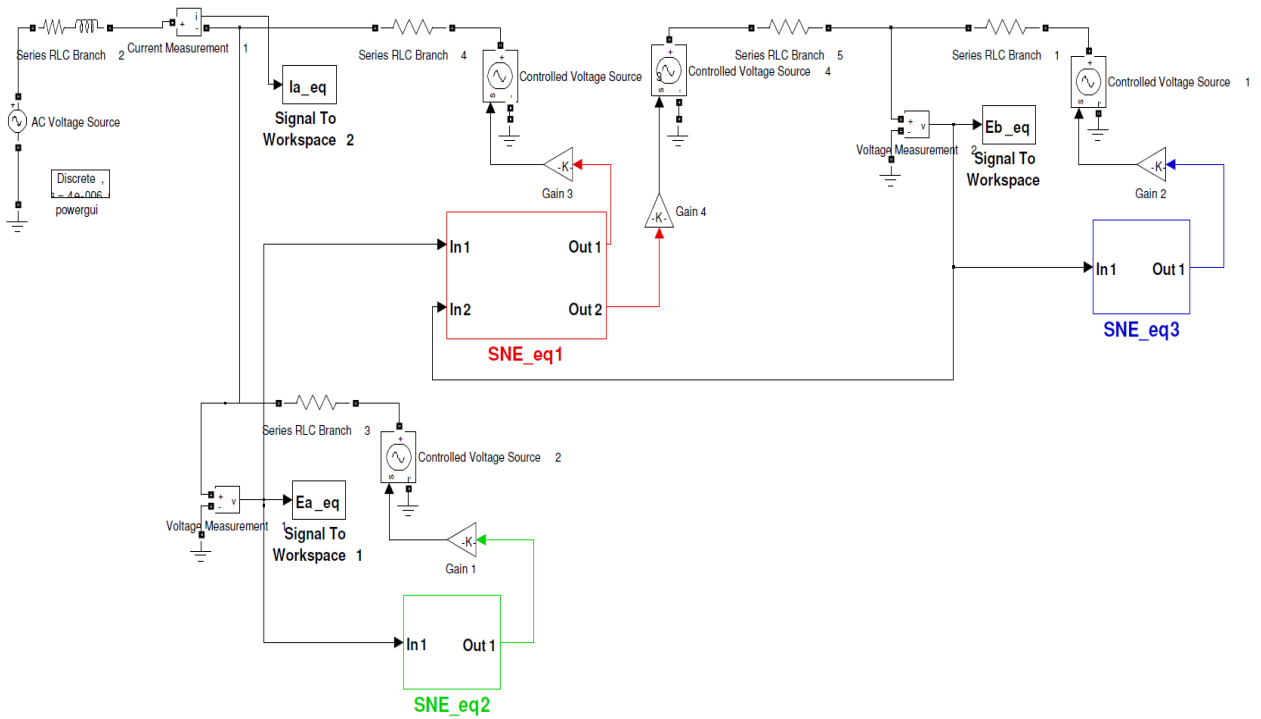


Fig. 2. The mixed simulation system implemented in Matlab/Simulink.

It is worthy to note that the time step by each network equivalent is a multiple of the time step employed in the simulation of the analog portion. While this is a limitation, it does not impede the evaluation of the possible problems posed by the used of different time steps in each part of the network. The results presented in the following permit such analysis.

III. RESULTS

The comparisons are done for the transient curves obtained from simulation using the PSCAD, whole system, and MATLAB, which used the equivalents. The PSCAD simulation used a time step of $4\mu\text{s}$ and the Matlab used $4\mu\text{s}$ for the analog portion and $12\mu\text{s}$, $16\mu\text{s}$, and $20\mu\text{s}$, for SNEq1, SNEq2 and SNEq3, respectively. Figure 3, Fig. 4 and Fig. 5 show the comparisons for the current I_a , voltage E_a and voltage E_b , respectively.

These comparisons show that, despite a small deviation for the case of the current I_a , both simulation produced practically the same results. This indicates that should be possible to use

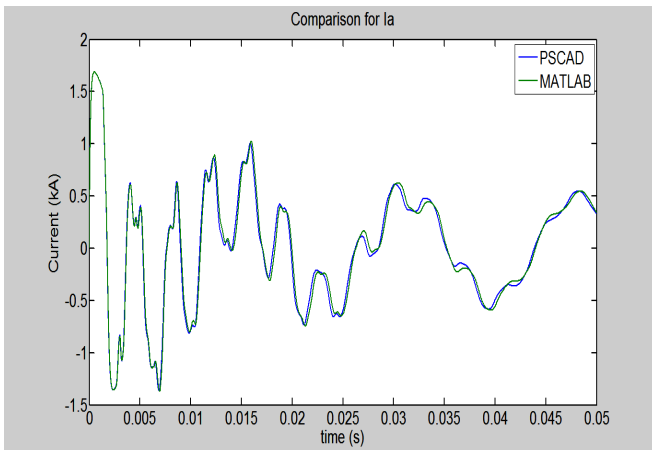


Fig. 3 – Comparison for the current I_a .

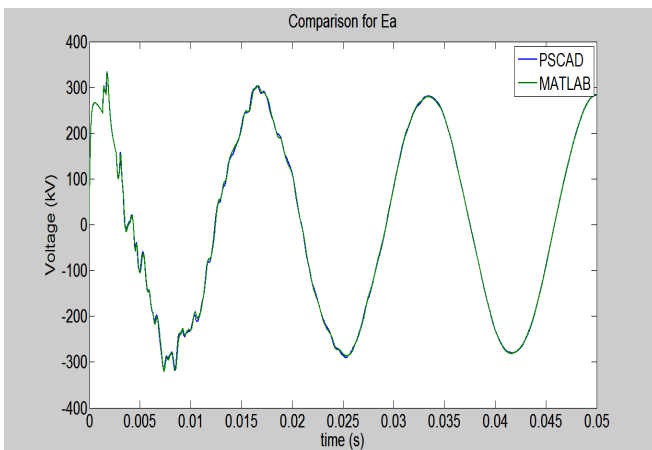


Fig. 4 – Comparison for the current E_a .

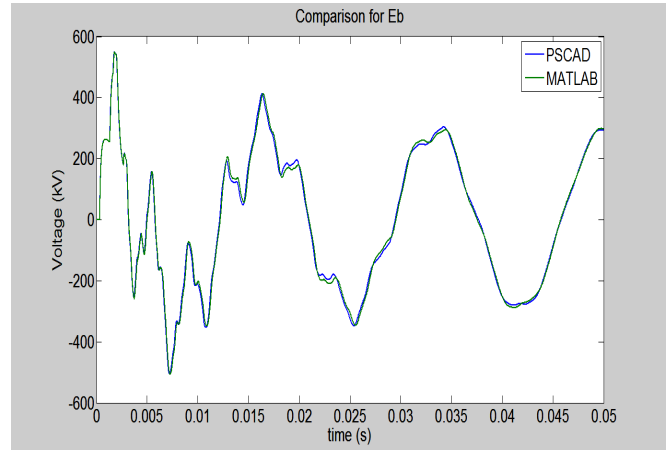


Fig. 5 – Comparison for the current E_b .

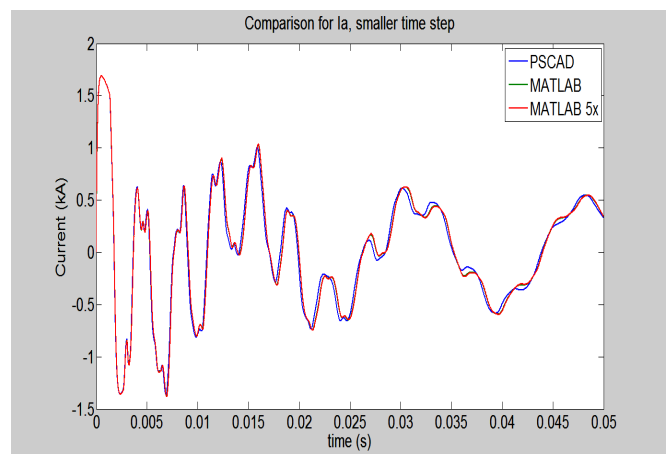


Fig. 6 – Comparison for the current I_a , using different time steps in Matlab

multiple network equivalents, each one using its own preferable time step, for purpose of large systems simulation. Naturally, the final conclusion should be driven from a actual real-time simulation, which will be carried out in near future.

In order to investigate the compromise between the time steps used in Matlab simulation, an additional comparison was made for the case of a smaller time step used in Matlab simulation of the analog portion. This time step was reduced to $0.8\mu\text{s}$ and the upsampling/downsampling factor were adjusted accordingly in each network equivalent subsystem. The comparison of the resulting transient curves is shown in Fig. 6. The same results were obtained for both Matlab simulation showing that the network equivalent methodology used can cope with different time steps used for the simulation of the analog portion of the network.

IV. CONCLUSIONS

This paper dealt with the implementation of a mixed analog/digital simulation environment integrating multiple

network equivalents for the purpose of large systems transient calculation. The system under study was divided into an analog portion (source and impedances) and digital portion, comprising the part to be simulated by digital network equivalents. The simulation was implemented in Matlab/Simulink environment and used multiple (three) network equivalents. These were derived using a technique for robust sparse network equivalent calculation, proposed in previous work. Each equivalent is interfaced with the remaining network (the analog portion and the other equivalents) by means of a Thévenin equivalent. In the overall simulation, different time steps were used, with the smaller one used for the simulation of the analog portion of the network. The resulting transient curves were compared to a simulation done in PSCAD (for the whole system) showing practically the same results. The successful comparison suggests that should be possible to use multiple network equivalents, each one using its own preferable time step, for purpose of transient calculation for the study of large systems. Furthermore, as the network equivalents used are suitable for real-time simulation, this could be an alternative for the real-time transient calculation of large systems, which is intended for a future work,

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