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A discussion about optimum time step size and maximum simulation time in EMTP-based programs

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ABSTRACT

This paper presents a discussion about the optimum time step size and maximum simulation time in EMTP-based programs. This is of particular importance for new users of EMTP-based programs, since the user is responsible for setting up these parameters before running a simulation case. The selection of the time step size affects the precision of the simulation. The time step size depends on the maximum frequency expected in the phenomena, which is normally unknown, a priori. The calculation of eigenvalues from the state space matrix obtained from the EMTP conductance matrix and history terms algorithm formulation allows the exact ideal values for the optimal time step size and a maximum simulation time. In comparison, a general and robust algorithm is also presented here based on all the input data given for the circuit under simulation. The proposed calculation process is based on single- or multi-phase uncoupled or coupled circuits, with lumped or distributed parameters. Simulations are given demonstrating the effectiveness of the proposed rules.

Introduction

The existing versions of the EMTP software [1–9] do not provide the user with an optimal estimate of the time step size (Δt) to be used for a given simulation case. It is up to the user to choose and adjust it properly. The same situation happens for the maximum simulation time (t_{max}).

Even though there is a close relationship between the time step size, the time constants, the propagation time, and the oscillations periods of voltages and currents in a simple circuit, this relationship is difficult to verify for large systems, because usually there is no prior knowledge of the analytical solution.

Programs like SPICE [10] change the time step continuously during the simulation, according the slope of change of the circuit variables. This strategy, however, can result in increased solution times and in some cases in non-convergence [11], or numerical instability conditions. Variable step size ODE solvers are discussed in [12] and are beyond the scope of this paper.

The methods described in this paper, follow the traditional EMTP approach of using a constant time step calculated according to the maximum frequencies that need to be simulated accurately. The trapezoidal integration rule is used in EMTP-based software, "because it is simple, numerically stable, and accurate enough for practical purposes" [1]. The effective suppression of numerical oscillations in the EMTP, which are not solved by just reducing the time step size, is well discussed in [13,14], with the Critical Damping Adjustment (CDA) method. The evaluation of accuracy and stability of different integration rules (integration solvers) as functions of the time step size (or of the sampling frequency, or of the per unit of the Nyquist frequency) is clearly discussed in [13]. For an overall accurate and stable simulation, CDA takes advantage of the accuracy of the trapezoidal integration rule and the stability of the Backward Euler integration rule, for a given and fixed time step size.

Unless the circuit equations are solved analytically (or the eigenvalues are somehow calculated for linear systems or for linearized parts of nonlinear systems [15,16]), the time simulation parameters are not known by inspection. It is possible, however, to establish "ranges" in which the time step size and the maximum simulation time must be contained, as presented in [17,18]. This approach may help new and experienced EMTP-based program

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users to minimize the simulation time without compromising the accuracy of the results. In this case, the main focus of the study can remain on the analysis of the transient system response, rather than on a trial and error approach to adjust the time step size and the maximum simulation time by running multiple simulations. Moreover, when multiple simulations cases are run through script-based files, and performed considering the variance of network or control parameters, this technique seems to be promising and particularly useful to capture the overall phenomena.

In principle, it is well known for EMTP-based simulation that the maximum frequency expected to be present in the simulation (2) should be at least five times less than the Nyquist frequency (1). This provides a reasonable accuracy (error in the order of 3.31%) in the modeling of the discretized lumped electrical components (inductor and capacitor) using the trapezoidal rule of integration [1,2]. This academic and well known rule (included here for completeness) results in (3) for the calculation of a reasonable time step size Δt.

$$f_{Ny} = \frac{1}{2\Delta t} \tag{1}$$

$$f_{max} = \frac{1}{5} * f_{Ny} = \frac{1}{5} * \frac{1}{2\Delta t} = \frac{1}{10\Delta t} \tag{2}$$

$$\Delta t = \frac{1}{10 f_{max}} = \frac{T_{min}}{10} \tag{3}$$

In terms of frequency content, Fig. 1 [3,19] illustrates the wide speed of phenomena in electrical power systems.

A common practice for EMTP-based simulation is to always adopt a time step size of

$$\Delta t = 50\ \mu s \tag{4}$$

which then implies that:

$$f_{Ny} = \frac{1}{2 * 50\ \mu s} = \frac{1MHz}{100} = 10\ \text{kHz} \tag{5}$$

$$f_{max} = \frac{1}{5} * f_{Ny} = \frac{1}{5} * \frac{1}{2\Delta t} = \frac{1}{10 * 50\ \mu s} = 2\ \text{kHz} = 2 * 10^3\ \text{Hz} \tag{6}$$

If one chooses, for example a Δt of 1 microsecond, even though very small, it might not be adequate for example, when simulating very high frequency transients in SF_6 gas insulated substations. For the very common Δt of 50 microseconds, only transients up to 2 kHz will be properly simulated.

Ranges of time constants

This paper develops an algorithm to estimate an adequate Δt automatically from the circuit. In a first simple approach, we will assume that we have no knowledge of the way the circuit components are connected.

Here we "estimate" a minimum and maximum value for all the R's combined into a single parallel (minimum) or series branch (maximum); similarly for all the L's and all the C's, according to (7)–(12). For n R's, L's, or C's we have:

$$R_{MIN} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}} \tag{7}$$

$$L_{MIN} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}} \tag{8}$$

$$C_{MIN} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}} \tag{9}$$

$$R_{MAX} = R_1 + R_2 + \cdots R_n \tag{10}$$

$$L_{MAX} = L_1 + L_2 + \cdots L_n \tag{11}$$

$$C_{MAX} = C_1 + C_2 + \cdots C_n \tag{12}$$

Eqs. (7), (8) and (12) assume that each type of circuit component is all connected in parallel whereas (9)–(11) assume that each type of circuit component is all connected in series.

Correspondingly, we can estimate the maximum and minimum values for inductive or capacitive time constants (i.e., $(T_L)_{MAX}$, $(T_L)_{MIN}$, $(T_C)_{MAX}$, $(T_C)_{MIN}$) and for the system natural modes of oscillations (i.e., $(T_N)_{MAX}$, $(T_N)_{MIN}$).

For a circuit composed by a resistance and an inductance, its time constant can be calculated using the expression (13),

$$T_L = \frac{L}{R} \tag{13}$$

For a circuit composed of a resistance and a capacitance, the time constant can be calculated using the expression (14),

$$T_C = R.C \tag{14}$$

For a circuit composed of an inductance and a capacitance, its natural oscillation time period is given by:

$$T_N = 2\pi\sqrt{LC} \tag{15}$$

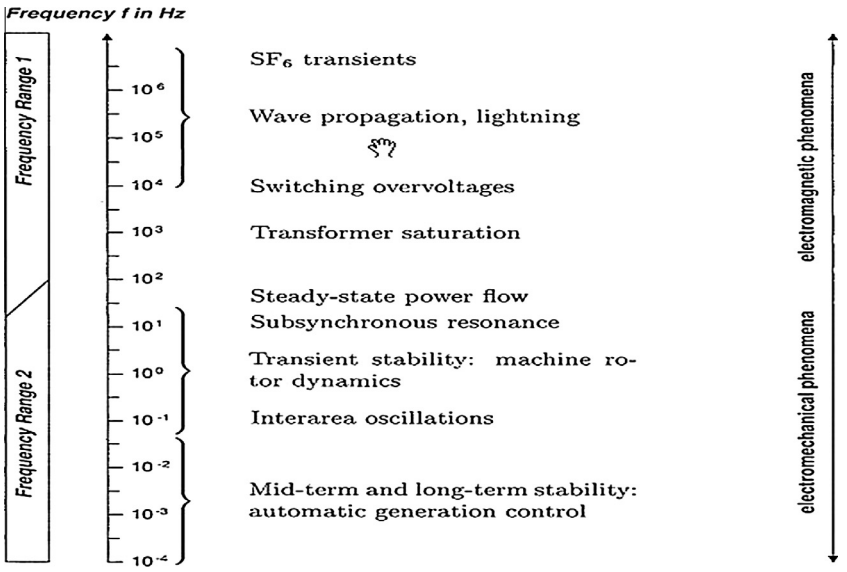

Fig. 1. Typical frequency ranges for electromagnetic and electromechanical transient phenomena [3,19].