

Frequency Domain Simulation of Networks Including Electronic Devices

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Abstract—Previously, a hybrid time/frequency domain method was proposed for calculating either the transient or the periodic steady state of an electrical network including nonlinear reactors. That method handles the linear part in the frequency domain whilst the nonlinear part is solved in the time domain. This letter proposes the extension of such technique to include time-periodic elements, such as electronic devices.

Index terms—Electronic devices, frequency domain analysis.

I. INTRODUCTION

The time domain (TD) and the harmonic domain (HD) techniques are widely used to simulate electrical networks, the latter especially in cases when harmonics play an important role [1]-[3]. Alternatively, frequency domain (FD) methods have been successfully applied to the simulation of electromagnetic transients [4]. In the FD, electrical elements whose behavior highly depends on frequency (for instance transmission lines) can be handled in a straightforward manner. However, it is not a trivial task to include in an FD program time-periodic elements such as electronic devices.

In this work a hybrid FD-TD methodology, previously proposed for a network including nonlinear reactors [5], is now extended to include electronic devices. The underlying idea is that the linear part of the network is fully treated in the FD whilst the electronic device variables (current, voltage, and switching functions) are treated separately in the TD. The interfacing between the time-periodic and the linear parts is made through the numerical Laplace transform (NLT) [4]. The current mismatch at the point of coupling is included into a Newton-type solution scheme.

II. NETWORK FORMULATION AND SOLUTION

Consider the complete network separated into linear and time-periodic (switching) parts, as shown in Fig. 1.

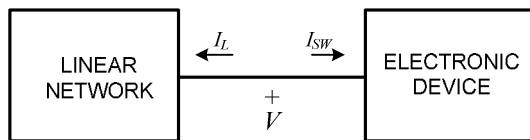


Fig. 1. Representation of the total network

The iterative process described in the following is applied to calculate the steady state of the complete network or, with minor modifications to the algorithm, its transient state.

- Assume an initial voltage, V_{old} , at the bus joining the two sub-networks.

- Calculate the currents entering the linear and the switching parts, I_L and I_{SW} , respectively.

a) I_L is calculated (in the FD) from the nodal representation of the linear network.

b) I_{SW} is calculated in the TD for the electronic device and its companion parameters, generally as a function of the input voltage and the firing angle [3]. The interfacing between TD and FD variables is made through NLT operations [4].

Note that the calculation of the currents above can be made separately, thus allowing the use of parallel processing.

- Calculate the Jacobians J_L and J_{SW} where:

a) J_L corresponds to an equivalent network admittance matrix and it is constant along the iterative process.

b) J_{SW} is obtained numerically via voltage perturbations [5], being the switching device's current the output.

- In theory, it is expected that I_{SW} be equal to $-I_L$.

However, a mismatch $\Delta I = I_{SW} + I_L$ will result. Use this mismatch into (1) to calculate a new voltage, V_{new} .

$$V_{new} = -(J_L + J_{SW})^{-1} \Delta I + V_{old}. \quad (1)$$

- Repeat the process above until a predefined error tolerance between V_{new} and V_{old} is reached.

For transient analysis the NLT, which converts an FD variable (X) into its TD counterpart (x), can be expressed as (further details can be seen in [4])

$$x = \frac{1}{\Delta t} e^{ct} \text{fft}(X \sigma), \quad (2)$$

where t is the discrete array of time, σ corresponds to a function window used for decreasing Gibbs' oscillations, and c is a damping constant that diminishes truncation errors [4].

For steady state calculations, the algorithm outlined above is modified by taking a small number for c in (2). In the author's experience a good choice is $10^{-6} \leq c \leq 10^{-4}$. Additionally, the $1/\Delta t$ coefficient in (2) should be taken equal to one.

III. EXAMPLE: TRANSMISSION NETWORK

For illustration purposes, consider the transmission network shown in Fig. 2. The three transmission lines are considered here as single-phase frequency dependent lines, 10 km long each with height, conductor radius, and ground resistivity equal to 15m, 0.0254m, and 100Ω-m, respectively.

The rest of the parameters are: $\omega_o = 377$ rad/s, $R_o = 1\text{m}\Omega$, $L_o = 1\text{mH}$, $R = 100\Omega$, $L = 0.1\text{H}$, and for the SVC [6]: $L_{\text{cr}} = 0.1\text{H}$, $C = 0.44\mu\text{F}$. The source in Fig. 2 has been arbitrarily chosen as (notice the presence of an interharmonic)

$$u = \sin(\omega_o t) + 0.3\sin(2.5\omega_o t) + 0.01\sin(3\omega_o t)$$

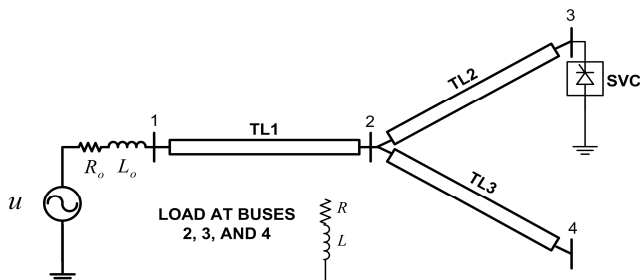


Fig. 2. Single-phase transmission network with SVC

For the described network, a transient computation (assuming zero initial conditions) has been made using the extended methodology. The source voltage, the voltage at bus 3, and the current (magnified 50 times) entering the SVC are shown in Fig. 3 (note that steady state is quickly reached for this specific example). These results were obtained in six iterations with an error criterion set equal to 10^{-8} and using 512 samples. The computational time to obtain the results in Fig. 3 is 10s, using a 2GB RAM, 3GHz processor, Matlab[®] v.7.

In Fig. 4, the results for the transient study obtained with PSCAD [7] are presented (using 1000 samples for better agreement with those of Fig. 3). The differences between PSCAD (Fig. 4) and the extended method (Fig. 3) are due to the use of an equidistant firing scheme for the two thyristors in the former whilst the latter handles different conduction periods for the thyristors.

Also as illustration, the steady state of the system was calculated in eight iterations (cpu time 14s) and the corresponding waveforms are shown in Fig. 5.

Interfacing of the proposed methodology with controls and electronic devices models from alternate software is possible. For instance, in this work the example above was additionally reproduced with the SVC modeled in Simulink (results not shown here) whilst the linear part handled in Matlab[®] basic code.

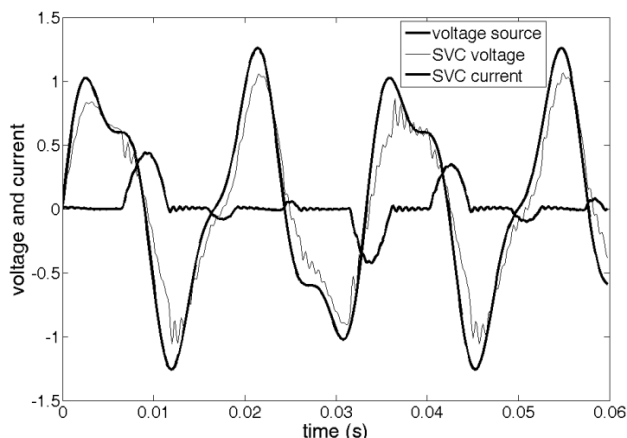


Fig. 3. Transient state waveforms

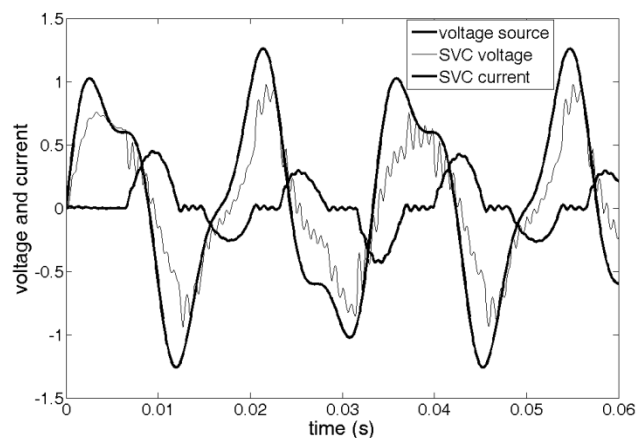


Fig. 4. Transient state waveforms from PSCAD

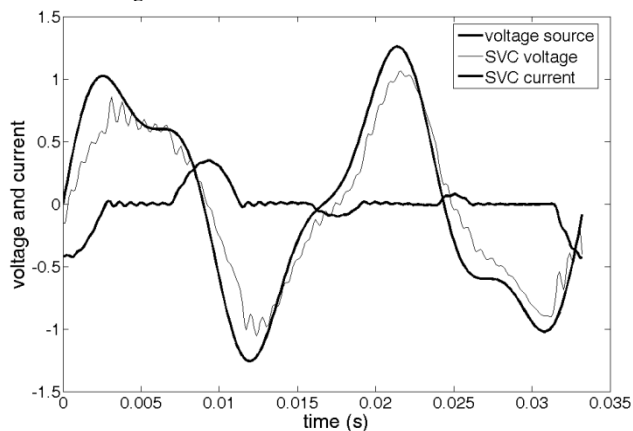


Fig. 5. Steady state waveforms

IV. CONCLUSIONS

A hybrid time/frequency domain methodology for obtaining either the transient state or the steady state of a network has been extended to include electronic devices. The proposed method, presented here as an alternative to time domain techniques, permits to highlight the flexibility of frequency domain techniques to handle time-varying network elements.

REFERENCES

- [1] H. W. Dommel, "Electromagnetic transients program reference manual (EMTP Theory Book)", Prepared for Bonneville Power Administration, P. O. Box 3621, Portland, Oregon 97208, U.S.A., 1986.
- [2] A. Semlyen, "Steady-state analysis of non-linear dynamic systems with periodic excitation based on linearization in harmonic space", *Canadian Electrical Engineering Journal*, vol. 11, no. 3, pp. 114-117, 1986.
- [3] E. Acha and M. Madrigal *Power Systems Harmonics*, England: Wiley, 2001.
- [4] P. Moreno and A. Ramirez, "Implementation of the numerical Laplace transform: a Review", *IEEE Trans. On Power Delivery*, vol. 23, no. 4, pp. 2599-2609, October 2008 (Task Force paper).
- [5] A. Ramirez, "Frequency Domain Computation of Steady and Dynamic States Including Nonlinear Elements", accepted for publication in *IEEE Trans. on Power Delivery*, paper TPWRD-00468-2008.
- [6] N. Mohan, T.M. Undeland, and W.P. Robbins, *Power electronics: converters, applications, and design*, John Wiley & Sons, 3rd Ed., 2003.
- [7] PSCAD v.4.1.0, Manitoba HVDC Research Centre Inc.