A Power System Simulation Tool Based on Simulink

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Abstract—This paper describes the Power System Blockset (PSB) from The MathWorks, Natick, MA, which is a new software package for the simulation of electric circuits, power systems, power electronic devices, and electric drives. The PSB is developed in the graphical Simulink environment of the general-purpose Matlab software. This blockset inherits a number of advantages from its development environment, namely, an open architecture, a powerful graphical user interface, and versatile analysis and graphics tools. The user can integrate control systems implemented with Simulink blocks directly into a diagram built with the PSB. Solution of differential equations is accomplished using the state-space approach with variable-step variable-order integration algorithms. A simulation example is presented, and the results are compared with those obtained with PSPICE.

Index Terms—Power electronics, power system, simulation.

I. INTRODUCTION

Historically, simulation of transient phenomena related to power systems has been carried on using the electromagnetic transients program (EMTP) [1] or one of its variants, such as the alternative transient program (ATP) or electromagnetic transients for dc (EMTDC), which are all based on the trapezoidal integration rule and the nodal approach. These software packages use fixed-step algorithms, which yield excellent results for power systems free of any power electronics devices. However, the fixed-step algorithms do not adapt well to the presence of discontinuities which are caused by the switching devices. SPICE is a general-purpose circuit simulation program which was developed at the University of California, Berkeley [2]. It contains models for basic circuit elements ($R$, $L$, $C$, independent and controlled sources, transformer, transmission line), switches, and most common semiconductor devices: diodes, bipolar junction transistors (BJT’s), junction field-effect transistors (JFET’s), MESFET’s, and MOSFET’s. SPICE is mainly applied to simulate electronic and electrical circuits for different analyses, including dc, ac, transient, zero pole, distortion, sensitivity, and noise. SPICE uses the nodal approach with a variable-time-step integration algorithm so that it can correctly simulate switching power electronic circuits. The simulation of control systems in PSPICE A/D (a commercial version of SPICE by MicroSim) is facilitated by using the analog behavioral modeling (ABM) blocks. However, there are no specific models for power systems and drives, such as electrical machines, circuit breakers, surge arresters, thyristors, etc. To simulate a power system, the user has to build the needed models using SPICE primitives and basic elements, so the simulation setup can be highly time consuming.

In this letter, we present a new software package based on variable-step integration algorithms which allows very accurate simulation of nonlinear, stiff, and discontinuous dynamic systems. We demonstrate that this software, the Power System Blockset (PSB) [3], is a convenient tool to simulate electrical circuits containing power electronic devices, since it detects very accurately the instants at which discontinuities and switchings occur. Since this software is entirely compatible with the Matlab and Simulink software packages, the user can easily integrate control systems implemented with Simulink blocks directly in a diagram built with the PSB. The user also has access to numerous design and analysis tools provided in Matlab and its toolboxes.

II. MODELING AND STATE-SPACE REPRESENTATION OF ELECTRICAL CIRCUITS

In the PSB, the dynamics of the linear part of the electrical circuit are represented by continuous time-domain state-space equations. A multi-input multi-output (MIMO) $n$th-order linear system is resolved using $n$ integrators and the output vector is obtained through linear combinations of inputs and state variables.

In an electrical circuit, the inductor currents and capacitor voltages are chosen as the state variables. Since all the power system’s components can be constructed from these two basic elements, it is always possible to obtain a state-space representation of such a system. For example, the state variables associated to an induction machine are normally rotor and stator currents or magnetic fluxes. For a switching device such as a thyristor or a gate-turn-off thyristor (GTO), choosing the associated state variable is not so evident and depends on the macromodel used to represent the switch. Switches are represented in the PSB as a series RL circuit associated to the proper logic for the considered type of switch. In these models, the inductor current becomes the state variable for that switch. However, switches and electrical machines are nonlinear and their models appear outside the state-space representation of the linear part of the system in the form of voltage-controlled current sources. These sources inject their current as inputs to the linear part of the system.

III. BASIC COMPONENTS MODELS

The PSB was designed to simulate power systems and electric drives. To this end, seven families of models are made available to the user. These families are the electrical sources, the linear and nonlinear passive elements, the three-phase elements, the connection devices, the measurement devices, the electric machines, and the power electronics devices.

The electrical sources include ac voltage and current sources, a dc voltage source and Simulink-controlled voltage, and current sources. The passive elements include series and parallel $RLC$ branches, linear and saturable transformers, $\pi$ section and distributed parameters lines, and, finally, breaker and surge-arrester models. The three-phase elements include a number of combinations of models from the other families, assembled together to give users a basic three-phase library and to serve as examples for creation of other three-phase systems. The connections and measurement devices are utility blocks which facilitate interconnection and interfacing of various systems. The electric machines comprise several models
of synchronous and asynchronous machines. The power electronics devices are particularly important for simulation of drives and power converters and will be described next.

A. Power Electronics Library

This library contains macromodels for the diode, thyristor (SCR), GTO, MOSFET, and ideal switch. The diode is taken as the core model for all the semiconductor devices. The basic diode model is represented by a first-order system consisting of an \( R_{on}L_{on}V_F \) series branch. In this model, the inductor \( L_{on} \) represents the energy storage of the device and gives the state variable \( i_s \) which is the current flowing through. A typical value of \( L_{on} = 10 \mu H \) is chosen as a default value. This choice is a compromise between simulation stability and computation speed and is suitable for most applications where converters are operating at up to 20 kHz. The resistor \( R_{on} \) stands for the dynamical resistance of the semiconductor and the constant voltage source \( V_F \) represents the forward voltage drop (junction voltage drop). A finite value of \( L_{on} \) is always required to avoid the algebraic loop, whereas the choice of \( R_{on} \) and \( V_F \) are less critical for computational stability. Therefore \( R_{on} \) can be set equal to zero and \( V_F \) is automatically set to zero in the modeling of the ideal switch and MOSFET because these two devices have no junction voltage drop during the conducting state. During the blocking state, the state variable \( i_s \), and its derivative \( di_s/dt \) are forced to zero. The basic macromodel of the diode has the fundamental ON/OFF characteristics needed to build the functional behavior of the four other devices. At the macromodel level, the basic difference that characterizes a particular semiconductor device resides, indeed, only in its switching logic. Thus, the same basic electrical model associated to appropriate switching logics allows us to represent uniformly all the components of the power electronics library.

Since the semiconductor model is a highly nonlinear current source driven by the differential voltage across its terminals, it cannot be connected directly in series with another semiconductor model, or with other current-source branches. A node should be created to constitute a path for the flow of instantaneous differential current between the branches containing the current sources. Fortunately, the conventional snubber circuit (such as \( R-C \), or \( R-C-D \), or \( C \)) connected in parallel with the individual devices can be used to accomplish this additional task [4]. The choice of snubber parameter values is based on normal criteria and depends on the type of device, the topology, the power level involved, and the operating frequency. With suitable parameter selection, one can avoid internal high-frequency oscillations that can be caused due to the interaction of the \( R-I \) equivalent circuit of the device and its snubber \( R-C \) values. The high-frequency oscillations force the variable-step algorithm to reduce the computation step size considerably and, consequently, the simulation time becomes too long.

IV. VALIDATION AND ACCURACY OF THE PSB

In this section, we present a simulation example of power electronics to demonstrate the accuracy of results obtained with the PSB and to validate these results against PSPICE.

A. AC-to-DC Resonant Converter

Various power conversion schemes have been used to achieve active power-factor correction. A very popular method used in today’s industry incorporates the boost converter topology, which is chosen in this example. This topology is suitable to operate in continuous mode for medium-power applications and in discontinuous mode for lower output power applications. Resonant converters are widely used for medium- and high-power dc-to-dc conversion. The proposed series resonant converter in this example is among the most utilized converters.

To demonstrate the capability of the PSB in simulating stiff and complex power electronic circuits, an industrial 500-W ac-to-dc isolated-type converter with different time constants and different operating frequencies has been considered. The PSB diagram of the converter is shown in Fig. 1. The circuit consists of two stages connected in cascade through a dc link. The first stage is a unity-power-factor boost converter operating in discontinuous mode, and the second stage is a dc-to-dc series resonant converter operating above the resonant frequency of the LC tank. The load is represented by an RC circuit. The boost converter control circuit (Unitrode integrated circuit UC1852) is modeled using Simulink blocks. The main functions of this IC are implemented. The ac supply voltage is 170-V peak. The source impedance of 5 \( \mu H \) is taken into account. The unity power factor converter (UPFC) operates close to 10 kHz. The dc-link voltage is maintained at 400 V. The output voltage is regulated at 75 V.
rectifier inductor input current \( I_{L1} \) [Fig. 2(a)(i) and 2(b)(i)], the loop effect on the inductor current \( I_{L1} \) [Fig. 2(a)(ii) and 2(b)(ii)], and the boost output dc-bus voltage across the 200-\( \mu \)F capacitor [Fig. 2(a)(iii) and 2(b)(iii)]. Fig. 3 shows the current \( I_{Lr} \) in the resonant tank [Fig. 3(a)(i) and 3(b)(i)], the voltage \( V_{p_{in}} \) across the primary winding of the high frequency transformer [Fig. 3(a)(ii) and 3(b)(ii)], and the output voltage \( V_{out} \) across the \( R/C \) load [Fig. 3(a)(iii) and 3(b)(iii)]. It is to be mentioned that there is very good agreement between the results obtained by the PSB and PSPICE.

V. CONCLUSIONS

Because of their stiffness and nonlinearity, modern power systems require simulation tools based on performance integration methods. Graphical user interface has also become mandatory. This letter has shown that the PSB fulfills these essential requirements and is particularly well suited for the simulation of electric circuits containing switching devices because of its capability of detecting precise discontinuities. The important advantage of the PSB is that elaborate controllers can be easily and seamlessly integrated into the power system diagram thanks to Simulink, its development environment. Moreover, the PSB contains power electronics and electric machinery libraries particularly suited to simulate power systems and drives.

REFERENCES