A digital real-time simulation model of a power supply operating in normal or fault state by using multiple modules

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Abstract Using the multiple-module coupling algorithm, this contribution presents a model of a concrete power supply system operating in the normal state and the fault state of its module single-circuit high-voltage three-phase power transmission line. The corresponding digital real-time simulation is carried out on a PC. The real-time results of the model show that the model of the multiple-module coupling algorithm presented here is in good agreement with practical experience and suited to meet the demand of real-time simulation.

Key words Power system, Fault-handling system, Digital real-time simulation, Multiple-module coupling algorithm

1 Introduction
In 1969 Dommel developed software for the digital simulation of the electromagnetic transient phenomena in power supply systems [1]. This facilitated an efficient design of power supply systems. For about 10 years it has been possible to perform digital simulation of power supply systems in real-time due to the great progress in computer technology [2]. At the same time the digital real-time simulation software for power supply systems has become increasingly faster and better. The digital dynamic real-time simulation of power supply systems will replace traditional analog (physical) simulation because of the advantages of the digital simulation, namely high speed, simple change in simulation structures and parameters, and the possibility of reproduction. Digital dynamic real-time simulation plays an increasingly important role in planning and designing of power supply systems and in testing of control equipment, protection instrumentation, and controllers of the power supply systems. In [3] a digital real-time simulation model of power supply systems is presented by using multimodule parallel processing. This model includes the module double-circuit high-voltage three-phase power transmission line (DHTT), but no adequate module for the single-circuit line (SHTT). It should be noted that the module SHTT is an important part of the power supply system. Even in cases in which the power supply system uses only DHTT, the single circuit operation state of the module DHTT must be considered. When a fault is present in the module DHTT, this module must operate in the single-circuit state. In this contribution we present a new model and an appropriate integration method for a typical power supply system containing a SHTT, for the normal operation state of the system and fault states of the module SHTT, with the aid of the multimodule parallel processing technique. The software based on this model and its integration method can run on a PC Pentium III 500 MHz in real-time.

2 The model of a typical power supply system
The power supply system to be simulated is depicted in Fig. 1, where RL and LL are the resistance and inductance of the compensation reactors, respectively. According to the multimodule coupling model [3], this system can be separated into seven modules: module 1, synchronous generator G1; module 2, transformer T1; module 3, three-phase long-distance high-voltage symmetrical single circuit transmission line SHTT; module 4, synchronous generator G2; module 5, transformer T2; module 6, equivalent-load MO+R (motor + resistance) simulating the load group of the power supply system; module 7, transformer T3. The multimodule coupling model is shown in Fig. 2. The following voltages can be taken as independent coupling voltages between the modules of the model shown in Fig. 2 by considering that the modules G1, G2, and MO+R are three-phase threephase transmission line systems: \( u_{r1}, u_{s1}; u_{a1}, u_{b1}, u_{c1}; u_{a2}, u_{b2}, u_{c2}; u_{r2}, u_{s2}; \) and \( u_{r3}, u_{s3}. \) The coupling equations read:

\[
\begin{align*}
ir_1 &= itfr_1, \\
is_1 &= its_1, \quad (2)
\end{align*}
\]

\[
\begin{align*}
iam &= itfa_1 + itfa_3, \\
ibm &= itfb_1 + itfb_3, \quad (4)
\end{align*}
\]

\[
\begin{align*}
icm &= itfc_1 + itfc_3, \quad (5)
\end{align*}
\]

\[
\begin{align*}
ian &= itfa_2, \\
ibn &= itfb_2, \quad (7)
\end{align*}
\]

\[
\begin{align*}
icn &= itfc_2, \quad (8)
\end{align*}
\]

\[
\begin{align*}
ir_2 &= itfr_2, \quad (9)
isl &= its_2, \quad (10)
\end{align*}
\]

\[
\begin{align*}
ir_3 + itfr_3 &= 0, \quad (11)
is_3 + itfs_3 &= 0. \quad (12)
\end{align*}
\]
The coupling currents $i_1 \sim i_3$ depend on the corresponding coupling voltages $u_1 \sim u_3$. Then every coupling current can be determined via an appropriate function of corresponding coupling voltages. To simplify the system model every transformer is simulated by its linear short-circuit impedance. The magnetic saturation of the transformers is neglected. The Park differential equations are used to model the synchronous generators. The model of every generator can be formulated and evaluated in the dqo system rotating with the same velocity as the rotor. Then the results obtained in the dqo system can be transformed to the phase domain [4]. The model of the equivalent load module consists of two parts, namely the static load model and the dynamic load model. Both simulate appropriate impedance groups and asynchronous machine groups of the power supply system [5].

The model of the normal operation state of the module SHTT can be decoupled by a method described in [3], namely a similarity transformation, i.e., the three coupled phase-wave voltage equations in the phase domain can be transformed by a similarity transformation to three decoupled mode-wave voltage equations in the modal domain. The model of the $0t$ mode is depicted in Fig. 3, where $r_0t_{\theta}$ is the characteristic impedance of the $0t$ mode of the module SHTT; $u_{0t}w_1(t - \Delta t)$, $u_{0t}w_2(t - \Delta t)$, $u_{0t}w_3(t - \Delta t)$, and $u_{0t}w_4(t - \Delta t)$ are the corresponding historical equivalent voltages of the $0t$ mode; $\Delta t$ is the simulation step size. The models of the other modes, i.e., the $1t$ and $2t$ modes of the module SHTT are similar to the $0t$ mode. In the normal operation state of the module SHTT the currents occurring on the left-hand side (M side) of Fig. 3 satisfy the following equation:

$$i_{0tm} = i_{0t1} + i_{0t1}$$  \hspace{1cm} (13)

For the other modes we have a similar relation as in Eq. 13. After the state equations have been formulated for the M side circuit (Fig. 3) of the $0t$ mode and for the similar circuits of the modes $1t$ and $2t$, these equations are integrated by applying the implicit Euler method. Thus we arrive at the following relations: