Models of synchronous generator and transformers for Dispatch Training Simulators and Real Time Digital Simulators

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Abstract: This paper is aimed firstly to own-made dynamic models of synchronous generators (SG) for Dispatcher Training Simulators (DTS). The basic requirements are contending claims from mathematical physical description and the numerical solution point of view on the other side. From this fact yields necessity of „engineering intuition“ and experiences. Secondly the model of power transformers (PT) is evaluated for Real Time Digital Simulators (RTDS), which are aimed to design and verification of digital protections and local automatics. It is most important especially in analysis of intersystems swings, abnormal and warning state, near critical state, blackout and restoration of power systems.

Keywords: modeling and simulation, synchronous machines, transformers, MATLAB-SIMULINK, Dispatch Training Simulators, Real Time Digital Simulators, bifurcations, deterministic chaos.

1. INTRODUCTION

The collapses during 2006 show that Czech Transmission Power System (e.g., during 25th July, 2006) is also in danger by critical operation states of European Interconnected Power System – UCTE (global collapse during at 4th November, 2006). Therefore the new methods and equipments must be used for analysis and control of the Transmission and Distribution Power Systems. These equipments are especially the DTS (Neuman et al., 2006a) and RTDS (Mäki et al., 2006), (Mäki et al., 2007), (RTDS website). The basis for development of these simulators are the realistic complex nonlinear dynamic models of the Power Systems. In connection with occurrence of the critical operation regimes in Power Systems we must suggest also the occurrence of the nonlinear bifurcations and chaotic phenomena because these systems could be categorized into „huge cybernetic systems“. From these reasons we need not only to monitore and to analyse of the power systems but also to find a better method of modeling and simulation of its. It is necessary for realization of the best practicable control of power systems.

2. MODELS OF SYNCHRONOUS GENERATOR

2.1 *The complex models of SG*

We consider the complex mathematical model of synchronous machine with three reactor windings, one excitation winding and two attenuation winding. Instantaneous value of voltages in any windings is generally.

$$u = \pm\sum ri \pm \sum \frac{d\psi}{dt} \qquad (1)$$

where ψ is linkage magnetic flux , r winding resistance and i winding current.

The Park's transformation make a more simple the mathematical model of synchronous machines. The advantage is that electrical parameters (especially mutual inductances) are not functions of time after transformation (Arrillaga et al., 1994). The voltage equations must be completed about two equations of motion.

Park´s three-phase model, which is obtained by synthesis of 6 electrical a 2 mechanical equations, then the finally equation is 7^{th} **order**. The result is nonlinear state model in general form $\dot{x} = f(x, u, t)$, where the state variables are $i_d, i_q, i_D, i_Q, i_F, \omega, \delta$ and input variables are $u_d, u_q, u_D, u_Q, u_F, M_m$ (in our case the next variable is changing frequency of network).

Electromagnetic transients go with the changes and disturbances in systems and its express oneself above all in synchronous generators by high changes of currents and moments. The time of its is very short (practically milliseconds). However the greate inertia torque of spinning mass (turbines, rotors) is dumping of all important change of speed, therefore it is put down as stationary during electromagnetic transients. When we need to simulate also electromagnetic transients the voltage equation could be enlarged. In this cases both transients are modeled by the same way. The complex Park´s model of synchronous machines could described both electromechanical and electromagnetical transients. It depends on volume of simplification of following general equation of stator (reactor).

$$u = \pm\sum ri \pm \sum \frac{dE}{dt} \pm \sum xi \pm \sum X\frac{di}{dt} \qquad (2)$$

The first equation includes the attenuation windings and differentiation of variables with respect to time and therefore describes also electromagnetic transients.

$$-u_d = Ri_d + \frac{1}{\omega_0}\frac{d(E + E_{rq})}{dt} + (1+s)E_{rd} + (1+s)x_q i_q + \frac{x_d}{\omega_0}\frac{di_d}{dt}$$

The similar equation is valid for voltage u_q. (3)

2.2 The more Simple Models of Synchronous Generator

Firstly we consider so called ***E" – model***, which is respecting the attenuation electrical network and thus also the subtransients. Nevertheless the transients in attenuation winding are consider as symmetrical, i.e. $x''_d = x''_q = x''$.

The state variables are the voltages in axis *d,* and *q*,

e' – electromotive transit phenomenon,

e" – electromotive impulse phenomenon.

The equation of machine armature yields from Park's transformation.

$$\begin{aligned}
T'_{d0}.\dot{e}'_q &= e_{FD} + (x_d - x'_d).i_d - e'_q \\
T'_{q0}.\dot{e}'_d &= -(x_q - x'_q)i_q - e'_d \\
T''_{d0}.\dot{e}''_q &= (x'_d - x'').i_d + e'_q - e''_q \\
T''_{q0}.\dot{e}''_d &= -(x'_q - x'')i_q + e'_d - e''_d
\end{aligned} \tag{4}$$

After that the equations (4) are enlarged about 2 equations of motion. By this way we obtain the system of **5th order**. These equations give the very reliable results.

Secondly we consider so called ***E'$_q$* – *model***, which is totally neglecting the attenuation winding. The equation of machine armature is described by following relation.

$$\begin{aligned}
T_{d0}.\dot{e}'_q &= e_{FD} + (x_d - x'_d).i_d - e'_q \\
T_{q0}.\dot{e}'_d &= -(x_q - x'_q)i_q - e'_d
\end{aligned} \tag{5}$$

By this way we obtain the system of **3th order**. This model is suitable for medium-term dynamics, because for short-circuit transients is not enough accurate. It is rather suitable for dynamic stability calculation.

Usually the approximation for modeling and simulation made in the derivation are as follows:

- the very fast electromagnetic transients are not considered, e.g. the higher harmonics, the transients component of short-circuit current;

- the rotor speed is always sufficiently near 1.0 p.u. that it may be considered a constant;

- the effects due to nonlinaer saturation of iron are neglected;

- the effects due to network inductances are also neglected, only the generators inductances are calculated.

In MATLAB Toolbox SimPowerSystems there are two types of synchronous machine models. The first is generic module „Simplified Synchronous Machine“ (the number of parameters is 8), which is similar as simple ***E'$_q$* – *model.*** This model could be used for slow electromechanical transients in the models of large Power Distribution and Transmission Systems. The second is also generic module called „Synchronous Machine“, which is modeling the dynamics of three-phase generators (the number of parameters is 27). This module is described by system of Park's equations. Unfortunately these SimPowerSystems modules require the numeric method with variable steps only. This is unacceptable for constantly real-time simulation in the scope of DTS (Neuman, 2007), where in addition the connection between MATLAB complex model and real specific SCADA is realized through the DDE or OPC programme and PC I/O cards. Therefore more suitable model of SG was developed in SIMULINK.

2.3 The Parameters of Synchronous Generator

The synchronous machines are described by following parameters, some of them could be calculated from parameter cards. The some parameters of generators used in Czech Power Plants are in Table 1.

According to way of measurements is usually declared the reactance of the saturation machines (x_{qs}), sometimes also the reactance of the unsaturated machines (x_{qn}), it depends on goal of the projects.

Table 1. The Basic Parameters of selected Czech Generators

Parameters	235 MVA (EPOC)	137.5 MVA (ELE 1)	62.5 MVA (EPO)	588 MVA (EME 3)
x_{ds} x_{dn}	1.65	2.18	2.23	2.44 2.66
x_{qs} x_{qn}	1.59	2.06	2.10	- 2.41
x_{ds}' x_{dn}'	0.23	0.25	0.25	0.276 0.325
x_{qs}' x_{qn}'	0.38	0.42	0.42	- -
x_{ds}'' x_{dn}''	0.17	0.15	0.15	0.226 0.266
x_{qs}'' x_{qs}''	0.18	0.16	0.16	(0.286)
T_{ds}' (s) T_{dn}' (s)	0.83	0.70	0.85	1.10 0.85
T_{qs}' (s) T_{qn}' (s)	0.42	0.35	0.42	- -
T_{ds}'' (s) T_{dn}'' (s)	0.03	0.025	0.02	0.038 0.022
T_{qs}'' (s) T_{qs}'' (s)	0.02	0.015	0.013	- -

x_d	series reactance
x_q	cross reactance
x'_d	series reactance transient
x'_q	cross reactance transient