MODELLING OF SYNCHRONOUS MACHINE FOR STABILITY STUDIES IN PSCAD

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Abstract: The paper deals with synchronous machine modelling for transient stability studies. Classical synchronous machine model (constant internal voltage after reactance) is described. This model was built in PSCAD using components from standard libraries and its setup and initialization is described. Comparison of simulation results on dynamic model for PSCAD and MODES software is done.

Keywords: synchronous generator, transient stability, PSCAD

1 INTRODUCTION

Synchronous generators are the principal sources of electricity in power grids, even though the number of non-synchronous sources (typically renewables like photovoltaics) connected to power grids is increasing. Therefore, behaviour of the synchronous machine strongly influences the overall behaviour of the grid. The accurate modelling of synchronous machine performance is important for performing reliable computational studies, mainly in case of stability studies and assessment of other transients (e.g. short circuits). This paper is focused mainly on transient stability studies.

Stability studies are performed in simulation tools for power grids such as PSS-E, PowerFactory, PSCAD or EUROSTAG. In these tools, users can benefit from already built models available in standard libraries. However, these models need not suit user’s needs and specific applications could require building user’s own model, which can be a difficult task.

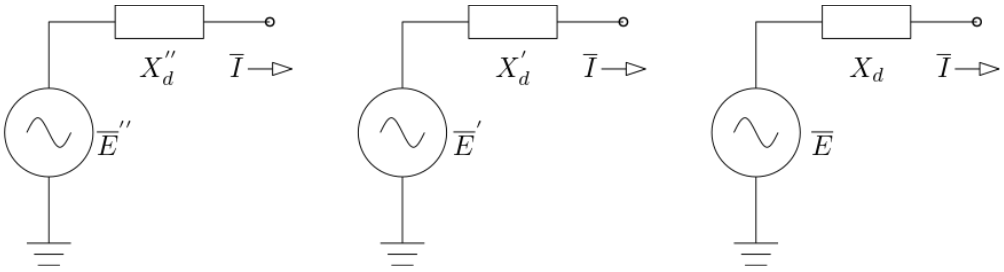
This paper deals with building so called classical model of synchronous machine for transient stability studies in PSCAD software. Building and setup of the model is described in the third section. The built model is used for dynamic simulation done in PSCAD and MODES simulation tool, results are compared in the fourth section.

2 SYNCHRONOUS MACHINE MODELLING

Synchronous machine modelling is an issue, which was extensively researched and can be found in many books, e.g. [1] in or [2]. Mathematical representation of synchronous machine is based on Park’s transformation (machine variables are represented in a d q reference frame fixed to the rotor). Respecting different effects in machine windings, a system of multiple differential equations can be written. In simulation tool, this system of equations for each machine is solved numerically to simulate machine dynamics in performed studies.

To simulate machines close-to-disturbance, 6th order model of the machine in Park’s transformation is usually required. This model is built in PSCAD standard library and its setting is described in a detail in [3]. However, for simulating machines far-from-disturbance or e.g. overall behaviour of the system (this could be also applied for machines representing interconnection), this model is not suitable. In that case, it is better to use so called classical model of the synchronous machine. As [1] says, it is *“the simplest of all the synchronous machine models, but it is the hardest to justify*”.

Classical model of synchronous machine is available in three forms (depending on which phenomenon is assessed) – subtransient model, transient model and steady-state model [2]. The representation is always the same – synchronous machine is represented by constant voltage source (of induced voltage) behind reactance, resistance of the machine is neglected. This is shown in the following Figure 1. Important is that only induced voltage magnitude is constant, voltage angle can vary.



a) Subtransient model. b) Transient model. c) Steady-state model.

Figure 1: Classical synchronous machine models.

For transient stability studies (when simulation time is smaller than transient time constant T_{d0}'), transient model is used, which means constant induced voltage *E’* (magnitude) behind transient reactance X_d'. Nevertheless, internal angle, which means angle of induced voltage, is changing during the oscillations. To use classical model in simulations, it is required to implement the swing equation (1), which is the second order differential equation of motion of rotor. In this equation, T_m is a mechanical time constant of the machine, $S_{r,G}$ is the machine rated power, ω_0 is the synchronous angular speed, δ is the internal load angle, B is the damping coefficient, P_m is the mechanical power of primary mover (considered to be constant) and P_e is electrical real power supplied from generator to the grid.

$$\frac{T_m \cdot S_{r,G}}{\omega_0}\frac{\mathrm{d}^2\delta}{\mathrm{d}t^2} + B \cdot \frac{\mathrm{d}\delta}{\mathrm{d}t} = P_m - P_e \tag{1}$$

The issue is how to determine the damping coefficient B. In [4], for small rotor speed deviation, the following equation (2) is suggested. In this equation, U_g is machine terminal voltage line-to-ground, X_d', T_d' are machine transient reactance and time constant, X_d is machine steady-state reactance.

$$B = U_g^2\left(\frac{1}{X_d'} - \frac{1}{X_d}\right)T_d' \tag{2}$$

3 CLASSICAL MODEL IN PSCAD

PSCAD standard library does not contain already built classical model. This model has to be built by user using externally controlled voltage source. Overview of a such model is shown in the Figure 2.

To be able to perform simulations with the classical model, a specific initialization has to be done. The initialization procedure is done as follows. When the simulation is started, dynamic of machine is not considered and the machine is replaced by simple internally controlled voltage source with internal reactance equal to the transient reactance X_d' of the machine ①. The internal controllers of this voltage source are set to ensure desired power flow at the terminal. After short period of time (approx. 2 s), steady-state is reached, values of internal voltage and angle of the source ① are held, i.e. their values are kept constant and set to the other source ② representing the machine (with the same internal reactance equal to X_d'). Now, the source ② is connected to the rest of the grid, whereas, source ① is disconnected by operation of breakers ③. Constant internal voltage and angle are kept for a while till the steady state is reached again (there are some transients as the source ② had no load before). Finally, the controller ④ is switched, so voltage source ② angle is no more kept constant, but it is changing according to the swing equation (1).

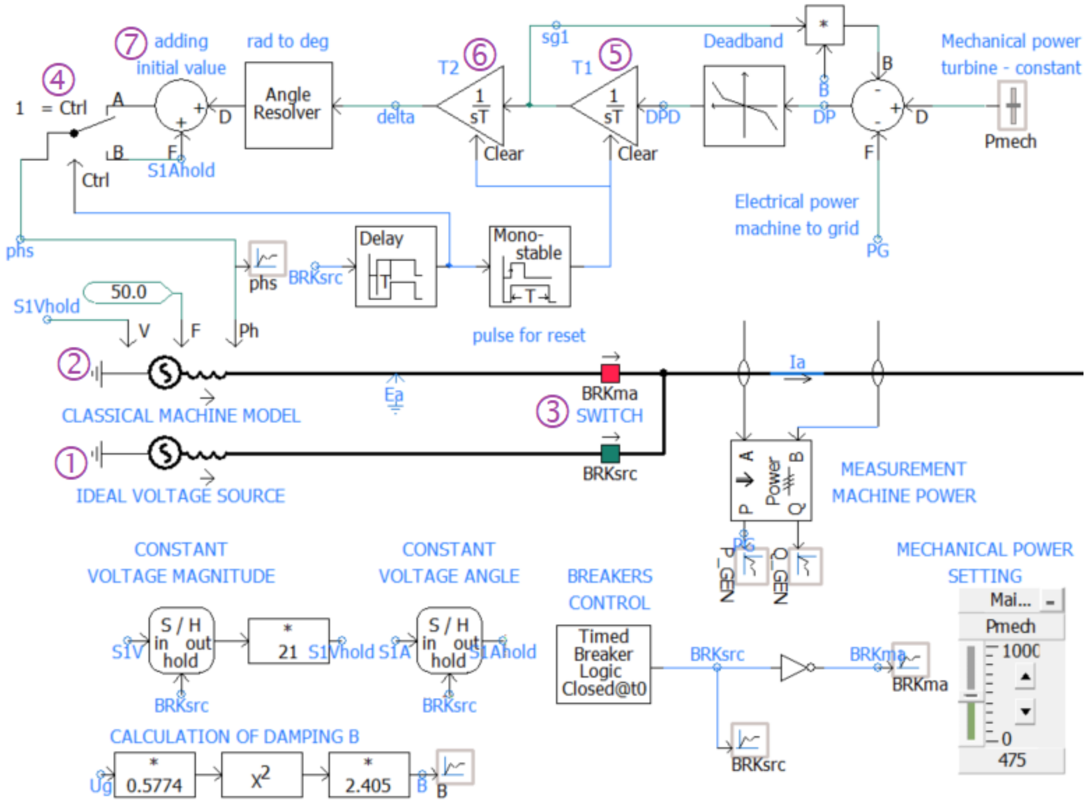


Figure 2: Overview of the classical model in PSCAD.

Values of integrators' time constants are set to $T_1 = \frac{T_m \cdot S_{r,G}}{\omega_0}$ for integrator ⑤ and $T_2 = 1$ for integrator ⑥. After the machine reaches the steady-state, integrators have to be reset to their initial value (0 for both ⑤ and ⑥) – initial value of load angle is set externally by adder ⑦.

4 DYNAMIC SIMULATION IN PSCAD AND MODES

To test the behaviour of the machine model, simple test system according to [5] was used. The test system is a single machine – infinite bus system proposed by ENTSO-E. Single-line diagram of this system is depicted in the following Figure 3, where also basic grid parameters are stated (all parameters in a greater detail can be found in [5]).

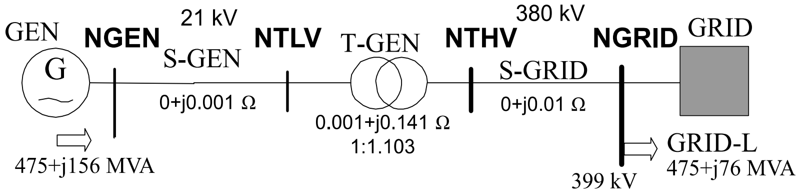


Figure 3: Single-line diagram of the test grid.

Basic parameters of the synchronous machine used in the model are summarized in the following Table 1 (as for grid parameters, detailed information can be found in [5]).

$S_{r,G}$ (MVA)	$U_{r,G}$ (kV)	x_d	x'_d	T'_d (s)	$T_M = 2H$ (s)
500	21	2	0.35	0.9	8

Table 1: Basic parameters of synchronous machine used for modelling.

For testing, Case 3 from [5] was used. In this case, a three-phase short circuit was applied at node NTHV. After 100 ms, short circuit was cleared. Assessed variable is the internal load angle δ (plotted as the difference δ-δ_0, where δ_0 is the load angle at $t = 0$). Simulation results for PSCAD and MODES are shown in the following Figure 4 and Figure 5.

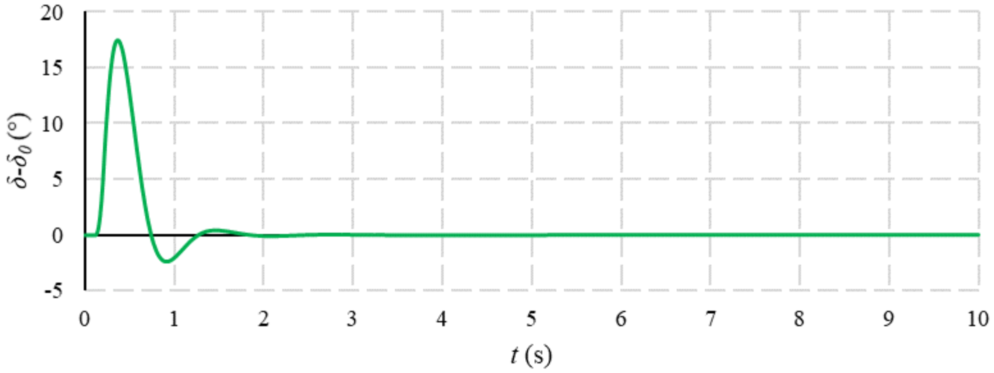


Figure 4: Waveform of internal load angle in PSCAD.

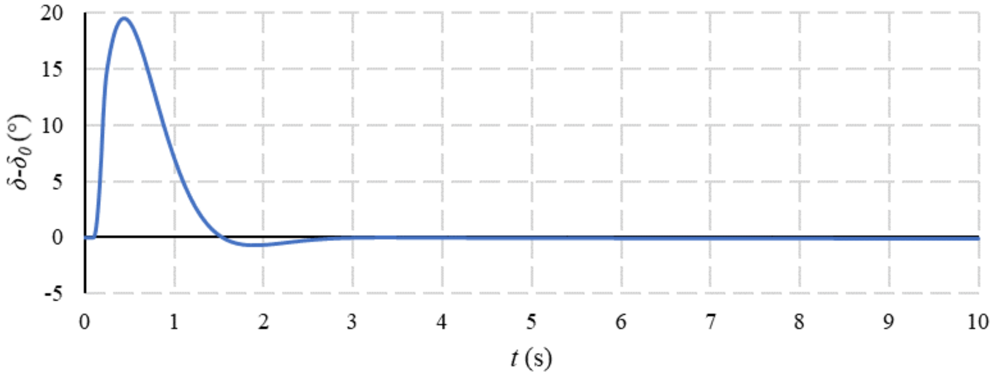


Figure 5: Waveform of internal load angle in MODES.

From Figure 4 and Figure 5 can be seen that magnitude of waveform in PSCAD (17.5°) is pretty close to MODES (19.5°). Also, the initial pitch is the same. However, in PSCAD, the swing is slightly more damped than in MODES. This can be explained by the difference of approach in damping modelling. In MODES, more complicated approach is used for damping modelling than equation (2), implemented in PSCAD, uses. Overall behaviour of the model can be considered convenient, oscillations are damped quickly (comparing to the case when full machine model is used – see [6]).

5 CONCLUSION

This paper presented the issue of synchronous machine modelling for stability studies in PSCAD. In PSCAD, classical model was built using externally controlled voltage source (setup and initialization was described in section 2). This model was used for simulation of a simple test case. Results showed that this model is suitable for representation of machine far-from-disturbance as the oscillations are damped quickly. There was a difference between waveforms in PSCAD and MODES caused probably by the damping modelling. The built model can be improved by considering more detailed damping equation, which would require study of advanced machine modelling.

ACKNOWLEDGEMENT

This research work has been carried out in the Centre for Research and Utilization of Renewable Energy (CVVOZE). Authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports of the Czech Republic under BUT specific research programme (project No. FEKT-S-20-6449).

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