POWER PLANT MODEL DESIGN USING MATLAB/SIMSCAPE

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Abstract

Design and verification of voltage and electric power controllers of synchronous generator are complex tasks, which should be often realized by simulation because of the technical and economic difficulties, but the simulation model usually not represents the higher dynamics and nonlinearities of synchronous generator, exciter and network. Therefore it is necessary to implement the proposed new forms of controller (e.g. adaptive, predictive, and robust) on real model instead of simulation model to improve the educational and research process, but the verification of such controllers is not available within the Slovak power system. Because of that it is necessary to create the realistic model of power plant unit. The basic design of the proposed power plant model has to be verified first by simulations using the Matlab physical modeling toolboxes SimScape and SimPowerSystems. The aim of this paper is to show the design process of the proposed power plant model with help of Matlab simulation.

1 Introduction

Real power plant model contains nonlinearities, which are mainly caused by characteristics of its components and grid connection, e.g. electric power of synchronous generator; synchronous generator excitation saturation, torque characteristics of the drive, grid influences etc. Many studies were done to show the nonlinear character of the synchronous generator connected to infinite bus e.g. [1], [2], [3] and [4]. During the power system operation arise a lot of fast changes, which can cause a disproportion between production and consumption of electricity what also means big changes of rotor angles [5]. Fast changes in power system consist for example of switching operations, source or load outages, but the most frequently the short circuits, what is associated with step change of impedance of power system. Synchronous generators respond to fast changes in electromechanical swings and during these swings generators could get into a situation when the rotor angle stabilizes at a new value or the rotor angle will grow to a loss of synchronism. [6]

The nonlinearities could cause some design problems and therefore the design of the proposed power plant model should be first verified by simulation. The educational and research purposes require that the model have to satisfy the following criteria:

- The power of synchronous generator implemented in the model has to be between 0.75 and 1.5kW.
- The terminal voltage of the synchronous generator has to be controlled with the excitation; the generator should not be self-excited.
- The electric power and speed of the synchronous generator has to be controlled through the coupled motor.
- The 400V grid connection has to be implemented through reactor, power line model and three phase transformer.
- The power plant model has to simulate the nonlinear behavior of the large system power plants voltage control abilities

The basic block diagram of the whole model is shown in figure 1. The block diagram consists of the blocks according to the above requirements:

- SG – Synchronous generator with excitation
- SM – Servo motor with servo drive
- Grid connection through the synchronism check, three phase transformer, 2 400kV power line models and reactor

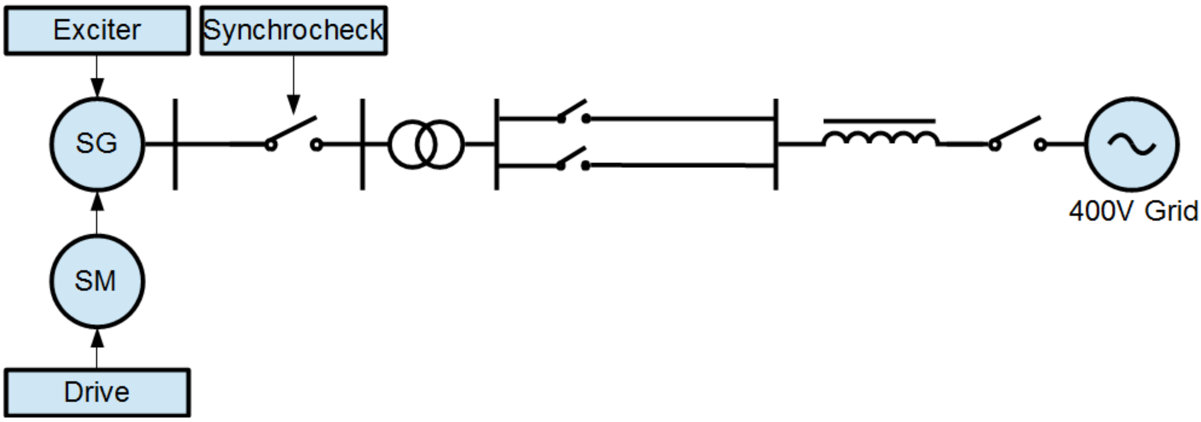

Figure 1: The basic block diagram of the proposed power plant model

2 Design of the proposed power plant model in Matlab/Simulink

Design of proposed power plant model, shown in figure 2, was developed with help of Matlab/Simulink and its toolboxes SimScape and SimPowerSystems. MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming [7]. Matlab features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology [8]. For this work have been chosen SimPowerSystem toolbox and SimScape toolbox. The SimPowerSystems has been used for modeling of synchronous generator and grid connection part of the model. The SimScape has been used for modeling Drive and Exciter. The mechanical input power of synchronous generator was modeled by mechanical connection instead of standard Simulink input and the generator was coupled with this connection to the servo motor. The advantage of this coupling is that the mechanical variables: speed and torque are common for both machines. The major task of this study was to analyze the influence of the following parts on the voltage control abilities of the synchronous generator:

- Total inertia of synchronous generator, servo motor and flywheel
- Excitation voltage limit with nonlinear characteristics depending on excitation current
- Reactor inductance

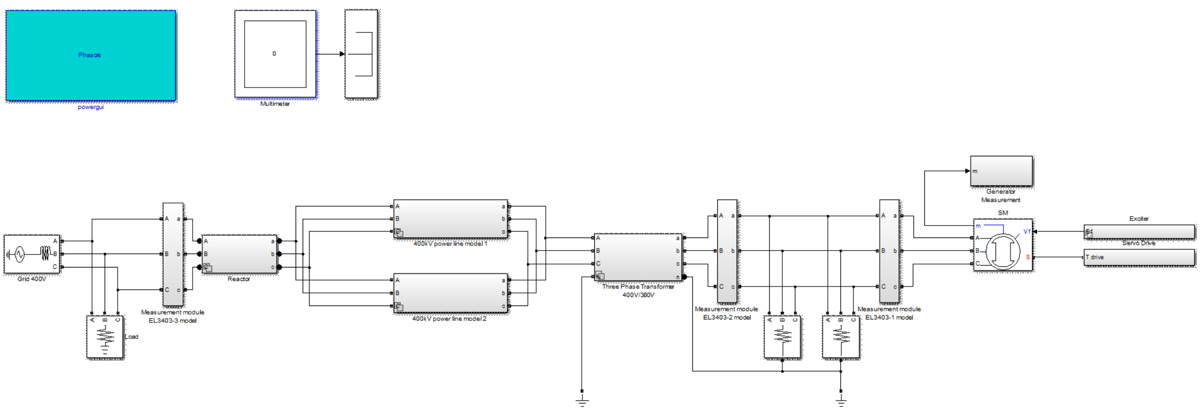

Figure 2: The power plant simulation model

The main part of the whole proposed power plant model is the synchronous generator and it had to be chosen first. The supplier data for the chosen synchronous generator are shown in table 1.

Table 1: SYNCHRONOUS GENERATOR DATA

Parameter	*Value*
Power	1180 VA
Voltage	380 V
Excitation voltage	250V
Excitation current	0.95A
Nominal speed	3000 rpm
Weight	16 kg
Excitation resistance	180 Ohm

It is commonly known that the excitation voltage step response of the synchronous generator cause the electric power to oscillate. The amplitude and the frequency of the oscillations depend on the inertia of the synchronous generator and the turbine. The total inertia of the model is very small if we compare it to the inertia of large generation units used in power system. Therefore we have to include the flywheel to the machine coupling. The servo drive design in Matlab/Simulink is shown in figure 3.

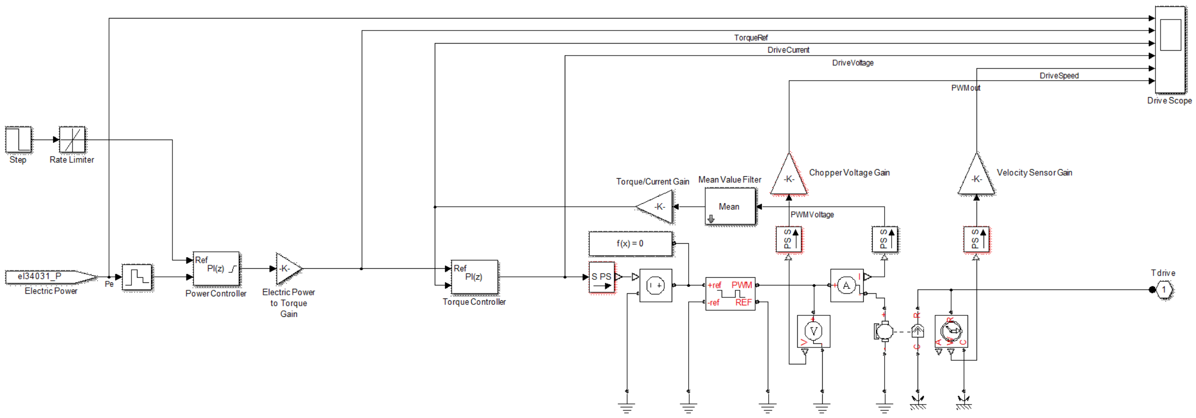

Figure 3: The servo drive of the power plant model

The exciter is usually modeled as a first order transfer function in power system studies with excitation voltage limits. The limits of excitation voltage are usually nonlinear because the excitation current has to be limited also. The excitation current is limited by simple transistor current limiter at the excitation voltage source part of this model. The nonlinear characteristics of the excitation current and voltage are shown in Figure 4 according to the supplier data.

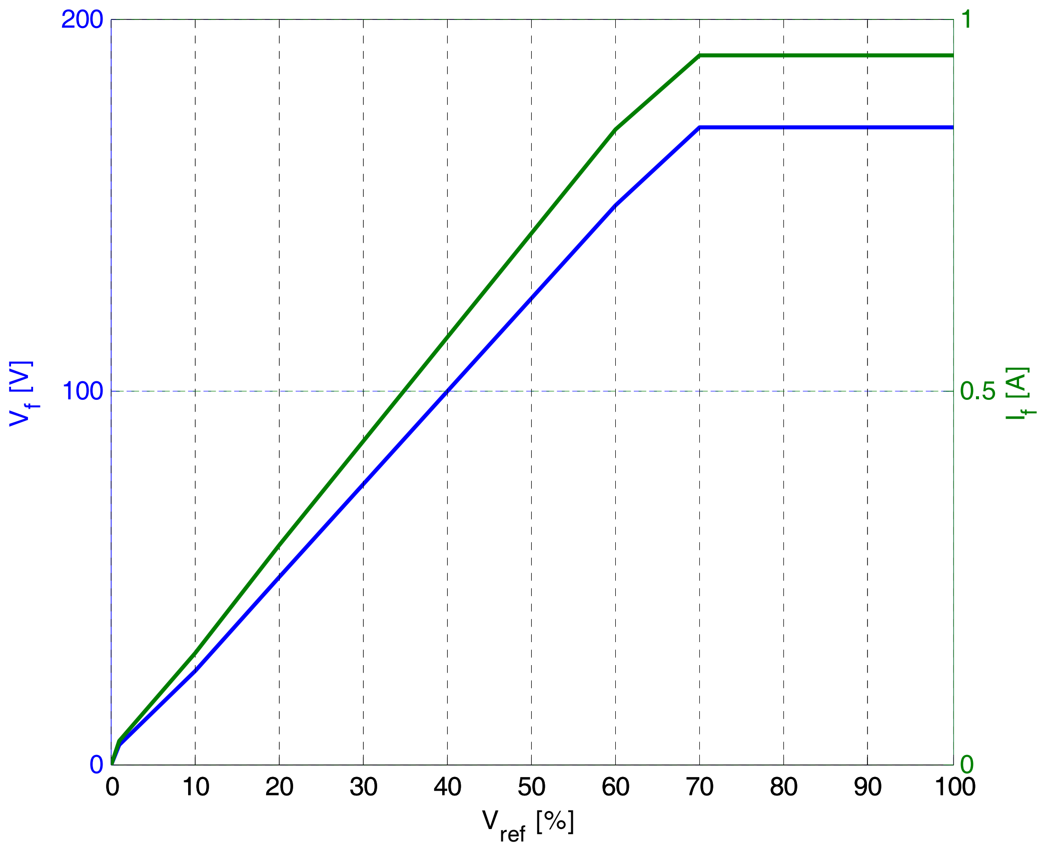

Figure 4: The excitation current and excitation voltage limit

The synchronous generator is connected to the grid through small inductances: power line models and three phase transformer. The grid voltage had large negative influence on the synchronous generator voltage operational limits. Because of that the new series inductance, the reactor, with the grid had to be introduced. The reactor function is to lower the grid voltage influence on the synchronous generator terminal voltage. The part of the model grid connection through the reactor is shown in Figure 5.

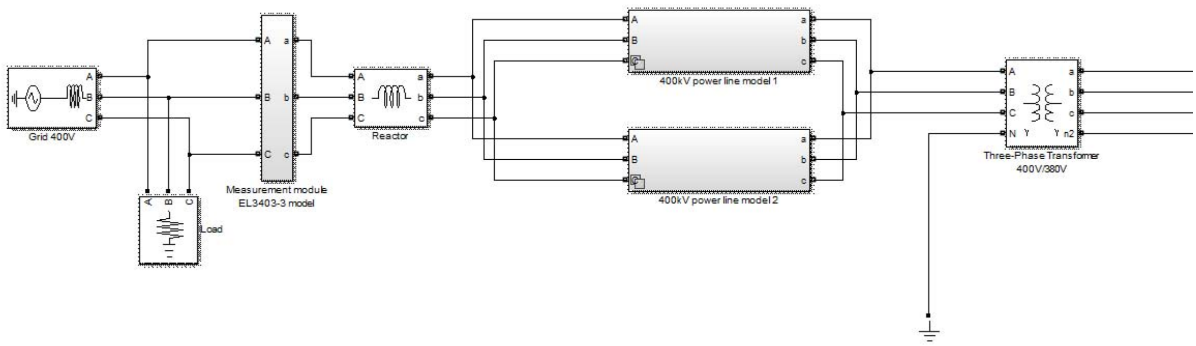

Figure 5: The model grid connection

3 Simulation analysis of the proposed power plant model

After the simulation model in Simulink has been developed, the steady state of the model had to be calculated. The terminal voltage steady state of synchronous generator has been 380V and the steady state of electric power has been 800W. The simulation analysis of the proposed power plant model has been done to obtain the results from the two main experiments:

1. Response of terminal voltage of synchronous generator on reactor inductance variation
2. Response of active power to variation of total inertia of synchronous generator, servo motor and flywheel

The first analysis has been made on reactor inductance variation and the terminal voltage of synchronous generator was observed. The terminal voltage was changed by 10% step response of excitation voltage. The reactor inductance influence analysis was done in 3 cases:

a) Reactor inductance 10mH
b) Reactor inductance 50mH
c) Reactor inductance 100mH

The simulation results for the first experiment are shown in figure 6. As expected the highest reactor inductance gives the largest voltage response. Increase of the reactor inductance value does not only increase the terminal voltage of synchronous generator capability but also increases the time constant of the step response. The uncontrolled response of terminal voltage rise time was about 16.8 s in this case and was above 9 seconds larger when compared to the case a. The largest reactor decrease the excitation field voltage value to maintain the steady state of terminal voltage 380V by 30% compared to the case a.

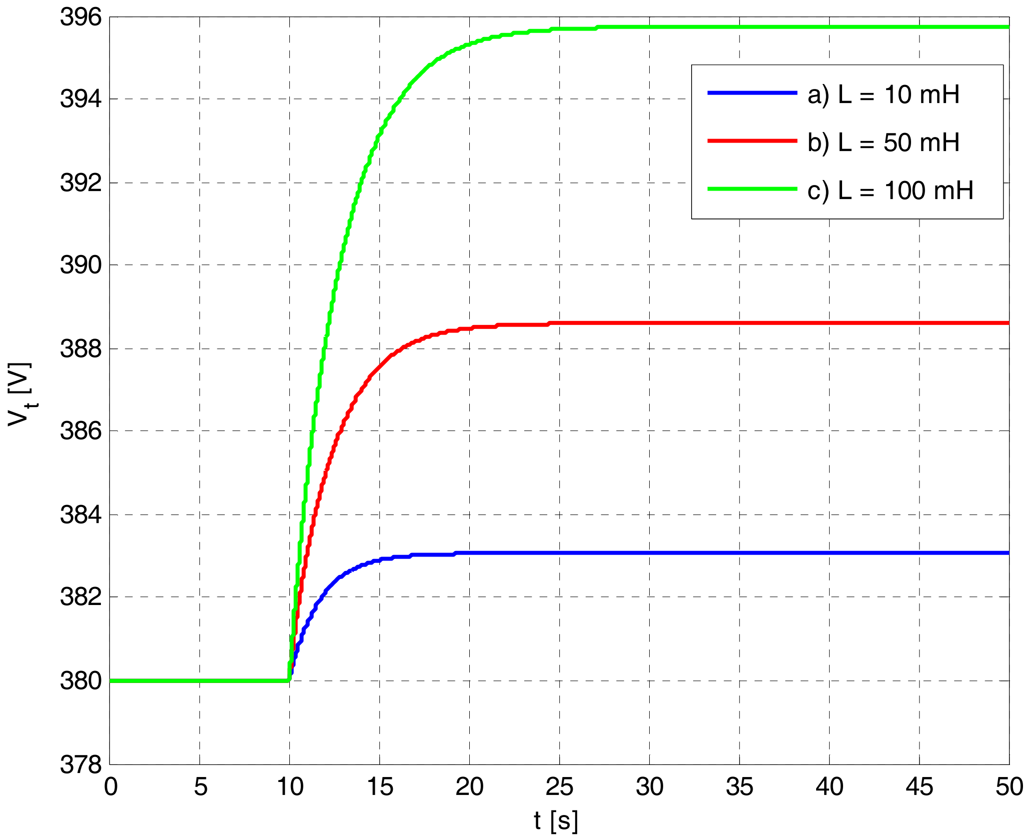

Figure 6: The terminal voltage of synchronous generator response to the step change of excitation voltage

The second analysis was done on total inertia variation and the electric power of synchronous generator was observed. The reactor inductance value was fixed in this experiment to 100 mH. The terminal voltage has been changed by 10% step response of excitation voltage. The total inertia influence analysis has been made for 3 cases:

a) The total inertia of synchronous generator and servo motor without flywheel influence 9.55 kg cm^2

b) The total inertia of synchronous generator and servo motor with flywheel influence 120 kg cm^2

c) The total inertia of synchronous generator and servo motor with flywheel influence 240 kg cm^2

The simulation results for the second experiment are shown in figure 7. The smallest response of active power should be observed during the case a response. If we consider the amount of inertia difference between cases b and c, the electric power amplitude value is comparable. The flywheel should then be realized by aluminum cylinder with 20cm diameter and 2.8 cm height.

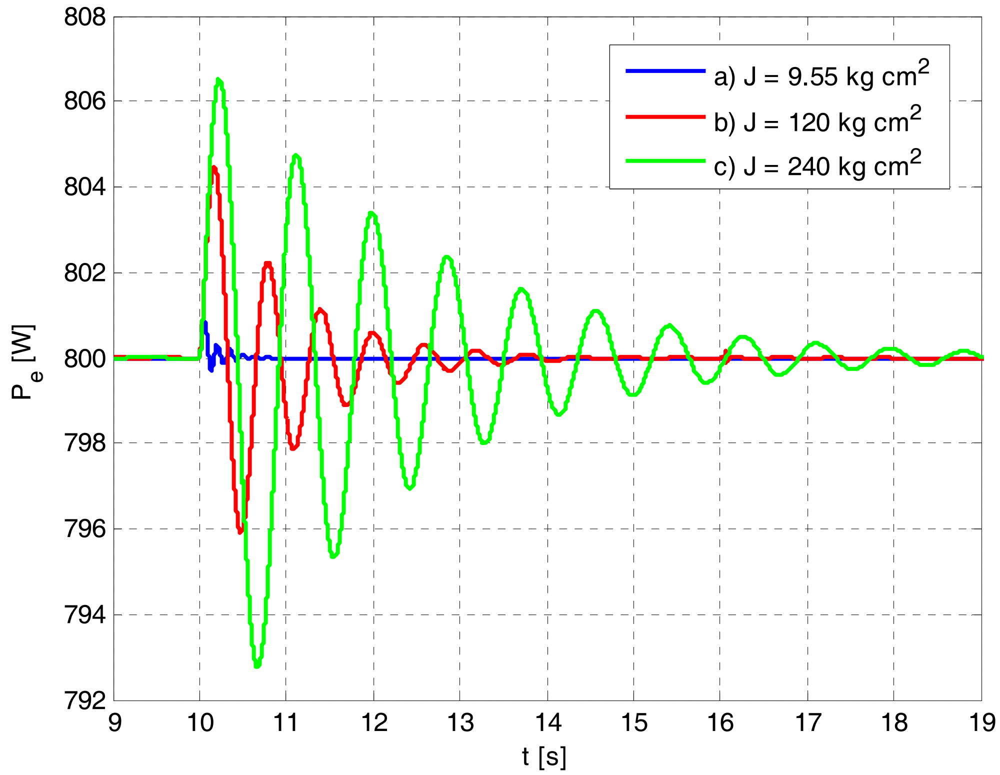

Figure 7: The electric power of synchronous generator response to the step change of excitation voltage

4 Hardware and software realization planning

The hardware and software realization plan is based on the consideration from the simulation model analysis done in Matlab/Simulink. The considerations should be made for the power plant model from the obtained simulation results. The basic inductance of the reactor caused relatively small changes in synchronous generator terminal voltage. The chosen inductance for the reactor has been 100mH for the next experiment. The proposed power plant model had to simulate the voltage control dynamic characteristics of the large power plants. The original inertia of the coupled machines caused that the active power oscillations had very small amplitude, while the exciter voltage was stepped. Therefore the flywheel had to be introduced to the model.

The considerations for the model equipment obtained from the simulation results:

- 1180VA synchronous generator coupled with servo motor and flywheel with the total inertia of 120 kg cm^2,
- Three phase transformer, 2 parallel 400kV power lines models, Reactor with 100mH inductance for grid connection

- Exciter voltage source had to control the excitation current in the limits

Acknowledgment

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