RTDS/PSCAD STUDY ON THE OPERATION OF A POWER SYSTEM STABILIZER APPLIED IN A SMALL GAS POWER PLANT

Anna KULMALA, Sami REPO, Pertti JÄRVENTAUSTA
Tampere University of Technology – Finland
anna.kulmala@tut.fi

ABSTRACT

In this paper, the operation of a power system stabilizer (PSS) applied in a small gas power plant is studied using time domain simulations. The objectives of the study are to determine how the PSS affects the oscillation modes of the power system and to examine its other possible effects on the operation of the excitation system. Simulations are performed in PSCAD and Real Time Digital Simulator (RTDS) simulation environments. In RTDS simulations, a real automatic voltage regulator (AVR) and especially a PSS, which is a part of it, is tested.

INTRODUCTION

Power system stabilizers (PSSs) are used to add damping to electromechanical oscillations in power systems through supplementary control of generator's excitation. They have been applied in large centralized generating units for many years but have not been used in distributed power plants because the local mode oscillations of these smaller plants are usually sufficiently damped without the added stabilization and, on the other hand, network operators have not demanded PSSs to be installed. However, the penetration level of distributed generation (DG) is constantly growing and, on the other hand, the damping of the low frequency inter-area oscillations is decreasing as more power is transferred through relatively weak interconnections. Hence, in some transmission systems a PSS is nowadays obligatory also in relatively small generators (even for all power plants with rated power over 20 MW [1]) and might be demanded of ever smaller ones in future. These small generators have quite different characteristics to the large centralized power stations which has to be taken into account when selecting and tuning the stabilizers. [2], [3]

Although PSSs have been a target of extensive research for years the operation of PSSs applied in small generating units has been addressed, to our knowledge, only in few publications. In [4] and [5] the operation of a PSS installed in a microturbine power plant is studied. The study is restricted to the distribution system and the transmission system is modeled simply as a Thevenin equivalent.

In this paper, the operation of a PSS applied in a small gas power plant is examined using time domain simulations. Simulations are performed in PSCAD and Real Time Digital Simulator (RTDS) simulation environments. In PSCAD studies the whole study system is represented by a model. In RTDS simulations, a real automatic voltage regulator (AVR) and especially a PSS, which is a part of it, is tested. The objectives of the study are to determine if the studied PSS is able to enhance the damping of both the inter-area and local mode oscillations in an example power system and to examine if it has any adverse effects on other operations of the excitation system. Closed-loop testing of the real AVR is an important part of the study.

CLOSED-LOOP TESTING OF A REAL AVR IN RTDS SIMULATION ENVIRONMENT

RTDS is a digital power system simulator for real-time studies. The simulation environment consists of a rack (or multiple racks) and a computer which controls the simulation. An amplifier is also often needed when external devices are connected to the simulation. The rack contains processor cards, I/O-cards and other necessary hardware like a power supply. The actual simulation is carried out by the processor cards and the I/O-cards are used to transfer data between the processor cards, the controlling computer and possible external devices. [6]

The connection used in RTDS simulations

In RTDS simulations, a real AVR is used instead of a modeled one and the interactions between the modeled power system and the external controller are examined. The basic structure of the model of a gas power plant is depicted in Fig. 1. The parts inside the dashed line are represented by a model in PSCAD simulations and replaced with a real regulator in RTDS studies.

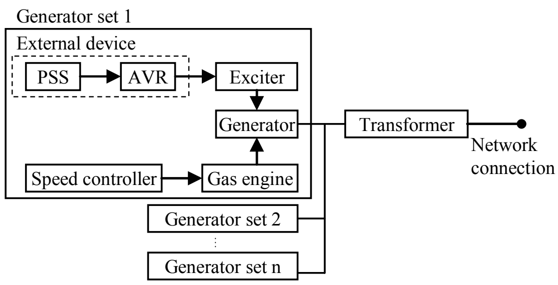

Fig. 1. The basic structure of the model of a gas power plant. The power plant consists of paralleled generator sets that are connected to the network through the same transformer.

To be able to examine the interactions between the real AVR and the modeled power system, measurement data has to be extracted from the simulation and a control signal has to be fed back to the simulation. The connection used in RTDS simulations is depicted in Fig. 2. The test arrangement consists of two computers, an RTDS rack, an amplifier and the studied AVR. One computer is used to construct the network model and to control the simulation and the other is used to alter the settings of the voltage regulator. The processor cards located in the RTDS rack solve the equations needed in the simulation and the amplifier is used to amplify the voltage signals obtained from the simulation to appropriate voltage and current signals. Only one amplifier is needed because the control signal fed back to the simulation is obtained from an analog output of the AVR that has an output range similar to the input range of the OADC analog input card.

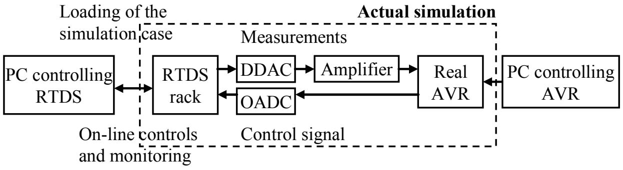

Fig. 2. The connection used in RTDS simulations. DDAC card is an analog output card which performs D/A conversion and OADC card is an analog input card which performs A/D conversion.

DETERMINATION OF THE DAMPING FACTOR FROM TIME DOMAIN SIMULATION RESULTS

The operation of PSSs is usually studied using modal analysis as PSSs are intended to enhance the small-signal stability of the power system [3]. In this study, time domain simulations are used instead of modal analysis because testing the real AVR is an important part of the study. Logarithmic decrement γ or damping factor ζ could be used as a measure of oscillation mode's damping. Logarithmic decrement is calculated as follows using the peak values of oscillation.

$$\gamma = \frac{1}{m}\ln\frac{y_n}{y_{n+m}}, \qquad (1)$$

where y_n is the n:th and y_{n+m} is the (n+m):th peak value of the oscillation. Damping factor can be determined using the logarithmic decrement γ as follows. [7]

$$\zeta = \frac{\gamma}{\sqrt{4\pi^2 + \gamma^2}} \qquad (2)$$

Damping factor was chosen as the measure of performance in this study because it is a familiar concept to many people. In this paper, damping factor is considered to be merely a measure of damping of a sine wave of a certain frequency and not a characteristic related to an eigenvalue of the linearized power system.

A Matlab script was written to determine the damping factor of the interesting oscillation modes. The script filters selected quantities, finds the peak values and determines the damping factor according to (2). The method does not give precise results as the filtering can not fully remove other oscillation modes from the studied quantities and the number of peak values used in the calculation is low especially when the damping is good. However, even if the numerical values calculated are not fully accurate the results of different simulations can be compared and the effect of the PSS on oscillation modes assessed.

DESCRIPTION OF THE STUDY SYSTEM

The operation of a PSS applied in a small gas power plant is studied in an example power system. The study system comprises the gas power plant, a 69 kV subtransmission network and a 230 kV transmission network.

The power plant

The power plant consists of one or four generator sets and a generator transformer (see Fig. 1). The model of a generator set comprises a generator, a gas engine, a speed controller, an exciter and an AVR possibly including a PSS.

The generator is a salient pole syncronous machine with brushless excitation. The rated power of the generator is approximately 10 MVA, nominal voltage 13.8 kV and nominal frequency 60 Hz. The exciter model is similar to the one used in IEEE AC5A excitation system model [8].

The excitation voltage applied to the field of the AC exciter is produced by ABB's Unitrol 1000-15 AVR. The AVR consists of a control system which determines the magnitude of the excitation voltage and a chopper which creates the desired voltage. Also the PSS is a part of the regulator. The basic structure of the studied AVR is depicted in Fig. 3.

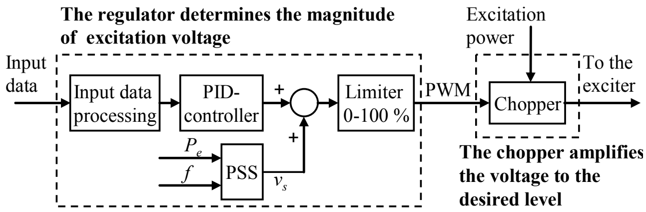

Fig. 3. The basic structure of the studied AVR.

In this paper, the operation of the AVR is studied both in voltage control (auto) and in power factor control (pf) modes. In auto mode the input data processing block in Fig. 3 is used to implement reactive current droop and in pf mode it calculates the set point of reactive current. The error signal obtained from the block is fed to the PID controller which has different parameters depending on the control mode.

The PSS is of type IEEE PSS2B [8]. The inputs to the stabilizer are electrical power and frequency and the PSS output signal is added to the output of the PID controller. The combined output of the regulator represents the duty ratio of the chopper and is limited between 0-100 %. The chopper is modeled as a simple gain block in the simulations. When operating in pf mode, auto mode takes over the control if the voltage falls below a set value (terminal voltage limiter). The real AVR contains also other limiters but they are not included in the model because they are not usually needed in transient and small-signal stability studies [3].

In RTDS simulations, measurements of machine voltages and one phase current are transferred to the real AVR through the DDAC card and the amplifier. Normally, the AVR would use the chopper to create the excitation voltage based on these measurements. In this study, the chopper is not used but the control signal, which determines the duty ratio of it, is obtained from an analog output of the AVR and fed back to the simulation. The chopper is included in the RTDS model as a gain block in the similar way as in PSCAD simulations.

As stated earlier, paralleled generator sets all have their own controllers. However, as only one real AVR was available for the RTDS tests, the same control signal was used in all the generator sets when a power plant containing four generator sets was studied. This should not add significant error to the simulation results as all the generator sets are connected to the same point in the network and have identical control systems and set points. In PSCAD simulations every generator set had its own controller.

The mechanical torque applied to the generator is produced by a gas engine whose output power is controlled by the speed controller. The model of these components comprises the parts illustrated in Fig. 4. The output power of the engine contains an oscillating component which is modeled as a sine wave added to the output torque of the engine. The oscillating frequency is 5 Hz and the magnitude 0.5 % of the rated power. The oscillation in the mechanical torque is visible also in electrical power because the inertia of the power plant is low.

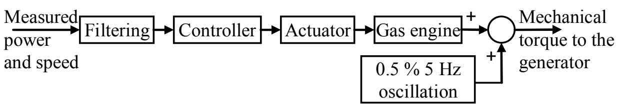

Fig. 4. The structure of the model representing the speed controller and gas engine. The output is the mechanical torque which rotates the generator.

The power system

The power plant is connected to a 69 kV subtransmission network which is a real network situated in USA Arizona. The network structure and data can be found in [9]. The power plant is connected to bus Superstition.

The transmission network is a 2-area 4-machine system introduced in [10] and used in several inter-area oscillation studies. Only one line between the areas is in operation and no power is transferred between the areas at steady state. All generators have fast excitation systems, simple speed controllers and no PSSs. Power system loads are modeled as constant impedance. The subtransmission network is connected to bus 13.

In this study, a three-phase fault located in the subtransmission network between nodes Thunder2 and Cluff is used to excite the oscillation modes of the power system. The fault duration is 0.1 s after which the line is disconnected and no reclosing occurs. After the breaker operation, the damping factors of inter-area and local oscillations are calculated from the time response of the power transfer between the areas and the output power of the gas power plant respectively.

SIMULATION RESULTS

In RTDS studies, a real AVR was connected to the simulation whereas in PSCAD simulations also the AVR was represented by a model. In Fig. 5 the control signal, which determines the duty ratio of the chopper and which is the output of the real AVR in RTDS simulations, is depicted for both the modeled and the real AVR in one simulation case. It can be seen from the figure that the modeled and the real AVR behaved quite similarly except for the first second after the fault. Some differences can also be observed in the steady state operation of the PSS.

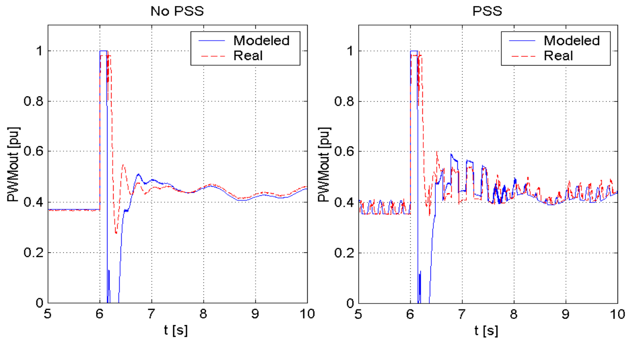

Fig. 5. AVR's output signal (PWMout) in PSCAD and RTDS simulations when a fault is applied to the system at time 6 s. The power plant comprises one generator set and the AVR is in auto mode. In the left-hand picture the PSS is not in use and in the right-hand picture it is in use.

Effect of PSS on inter-area oscillations

The most important task of a PSS applied in a small generating unit is to add damping to the inter-area oscillations as the local oscillations are usually well-damped also without the added stabilization. The studied PSS was able to fulfill this requirement as the damping factor of the inter-area mode was always improved when the PSS was taken in use. The numerical values of damping factor obtained from RTDS and PSCAD simulations were not identical but the effect of PSS on damping was in both simulation environments positive.

Results calculated from RTDS simulations are represented in Table 1. The change in the damping factor due to the PSS is quite small but, nevertheless, visible. The damping is enhanced more when the power plant comprises four generator sets which is reasonable as a larger power plant naturally affects the power system more than a smaller one. Also the control mode of the AVR has a slight impact on the effectiveness of the PSS.

In time domain, the effect of the PSS on the inter-area mode can be viewed by examining the power transfer between the

Table 1. The effect of the gas power plant's PSS on the damping factor of inter-area oscillations. The simulations are conducted in RTDS simulation environment and $\Delta\zeta$ is the change in the damping factor when the PSS is taken in use. The frequency of the inter-area mode is 0.54 Hz.

Number of generator sets	AVR mode	ζ without PSS	$\Delta\zeta$
1	auto	-0.00118	1.15E-05
1	pf	-0.00098	1.91E-05
4	auto	-0.00094	6.30E-05
4	pf	-0.00040	6.53E-05

areas in the transmission system. In Fig. 6 the power transfer is depicted with and without the PSS in one simulation case. The corresponding row is coloured in Table 1 and the change in damping factor is $6.30 \cdot 10^{-5}$. The first peaks are almost equal regardless of the PSS but the 12th peak is slightly lower with the PSS. Hence, the damping is slightly better when the PSS is in use.

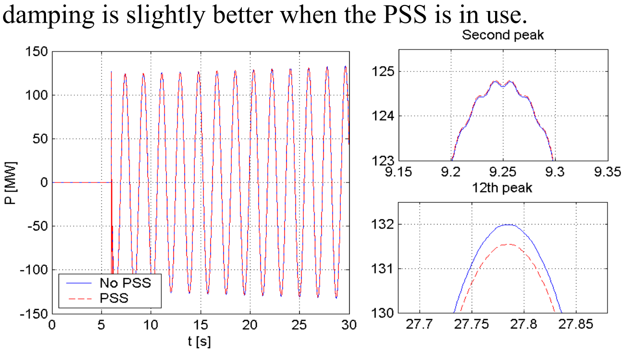

Fig. 6. The power transfer between the areas in the transmission network with and without a PSS in the gas power plant. The left-hand picture illustrates the power transfer for the whole study period. The second and the 12th peak are zoomed in at the right-hand pictures.

Effect of PSS on local oscillations

As the frequency of local oscillations is in the study system quite high (3.0-3.5 Hz) and the exciter relatively slow, the PSS can not significantly affect the local oscillations. The changes in the damping factor of the local mode due to the PSS are in the study system only of computational nature and have no real significance. On the other hand, the damping of local oscillations is originally quite good (damping factor is in the range of 0.11-0.16) and, hence, there is no need to enhance it further.

Effect of PSS on steady state operation of the AVR

PSSs are intended to enhance the damping of oscillations in the power system after a disturbance. The PSS should only be active in transient conditions and its output should be near zero when the power system is in steady state. In the study system, a 5 Hz oscillation is constantly present in the mechanical power of the gas power plant. As the inertia of the power plant is low and, on the other hand, the PSS uses electrical power as an input, the PSS introduces a significant noise component to the output of the AVR in steady state. The noise amplitude is several per cent and can be seen in Fig. 5 before the fault application at time 6 s.
The noise in the AVR output could be decreased by filtering the electrical power before the PSS or by using a PSS which does not use electrical power as an input at all.

Discussion of the simulation results

The simulation results show that a correctly tuned PSS applied in a small power plant can slightly enhance the damping of inter-area oscillations at least in the study system. Hence, if a power system is operating near its maximum capacity the requirement to install PSSs also in small generators might be justified. This requirement will, however, also complicate the design of power system's damping controllers as the number of PSSs and PSS owners will increase significantly. The power plant owners do not typically have sufficient data to tune the PSSs robustly and the added stabilizers might in some cases even deteriorate the damping of oscillation modes [11]. Hence, the question on who is responsible of tuning the PSSs has to be solved before extensive application of PSSs in the smaller generators.

CONCLUSIONS

The studied PSS was able to enhance the damping of inter-area oscillations in the study system. Its effect on local oscillations was negligible because the frequency of local oscillations was high and the excitation system relatively slow. In steady state, the PSS introduced significant noise to the AVR output. The operation of the AVR model was verified by testing a real AVR in RTDS simulation environment.

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