PSS parameters setting using genetic algorithms

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Abstract
Optimal settings of the power system stabilizers (PSS) in the power system synchronous generators can assure the sufficient oscillation damping of the active powers supplied to the power system. It is a very complex optimization problem having more local extremes and it is not simple to find a global extreme. In the paper a strong tool for finding a global extreme is used in the form of genetic algorithms.

Keywords: optimization, PSS, genetic algorithm, power system.

Introduction

At present the power system stabilizers (PSS) are mostly used for the damping of local oscillations. The PSS's have been designed having different structures and their development has followed new trends in automatic control. The development of power systems (PS) tends to a creation of larger ensembles by interconnection of the national power systems. Large interconnected power systems can use various operating modes that are generally inadmissible in small PS. The interconnection of power systems to larger ensembles ensures the stable operation of national power systems also in the presence of large disturbances. On the other hand the variety of operating modes of large power systems causes new problems, such as for instance the low-frequency local oscillations that have to be damped. One of the possible ways to ensure their damping is to use the PSS that represents an auxiliary feedback of derivative nature in the control structure of the synchronous generator excitation system.

In the area of PSS implementation into the excitation systems only few simple power system stabilizers have been applied. In the Slovak power system it is the PSS3B structure, which is implemented in all excitation systems of the nuclear power plant generators. In the power plant Nováky, the PSS of the 2A structure has been implemented.

When selected PSS structure for the particular excitation system is implemented, it is necessary to optimize also the voltage controller parameters so as the active power oscillation damping is maximal.

To prevent the local oscillations in the Slovak power system, the conditions for connecting the source units above 50 MW have been issued where the obligation to install the PSS during the change of generator excitation systems has been stated. As for the PSS efficiency, conditions for the oscillation damping effectiveness have been determined.

During last ten years the excitation systems in all EBO and EMO generators have been changed. New excitation systems can be classed as the static excitation systems. In the EBO and EMO generators the 3B PSS's have been implemented. When the PSS3B is properly set up, it is able to damp very effectively the oscillations of the active power that the synchronous generator produces to the power system.

The following abbreviations have been used throughout the text:

- EMO –power plant Mochovce,
- EBO – power plant Jaslovské Bohunice,
- PS – power system,
- SG – synchronous generator,
- PSS – power system stabilizer.

1. Possibilities for oscillation damping in power systems

The low frequency inter-area oscillations in interconnected power systems still represent a topical problem in the power system control. One of possible ways to ensure their damping is using the power system stabilizers that are most often configured to the synchronous generator excitation controller.

General analysis of possibilities for oscillation damping in the Slovak power system

Damping of local and inter-area oscillations can be increased by various ways:

- The first one is a proper adjustment of the synchronous generator excitation control parameters. It means to shape the turbogenerator frequency characteristics by a suitable choice of the controller structure and parameters (optionally also by an introduction of additional controllers) in such a manner that its resonance peak is lowered so as the oscillations induced by a disturbance are not amplified, but conversely they are damped.
- The power system stabilizers in synchronous generator excitation controllers and in turbine power controllers represent important devices for the oscillation damping in the power system. They allow shaping suitably the frequency characteristics of the corresponding turbogenerators.
- Recently the possibilities of using the heavy current electronic devices known as UPFC (United Power and Flow Controller) or FACTS (Flexible A.C. Transmission Systems) have been rapidly propagated. These devices allow controlling active and reactive powers flowing through the lines. Using the suitable control algorithms it is possible to ensure also the high damping properties of PS.

Another important tool for increasing the resistance of PS against the inter-area oscillations is the turbogenerator speed controller and the possibility to choose its frequency characteristics so as in the low-frequency range the sufficient damping of inter-area oscillations is obtained.

2. Analysis of oscillation damping of important sources in the Slovak power system

To prevent the local oscillations in the Slovak power system, the conditions for connecting source units above 50 MW have been issued where the obligation to install the PSS during the change of generator excitation systems has been stated. As for the PSS efficiency, conditions for the oscillation damping effectiveness have been determined.

A reliable condition for achieving the desired damping of characteristic oscillations of the synchronous generator active power is to ensure the frequency characteristics modulus with the value lower than one. In Figure 1 the synchronous generator frequency characteristics where the above stated conditions have been satisfied after the PSS installation are shown [2].

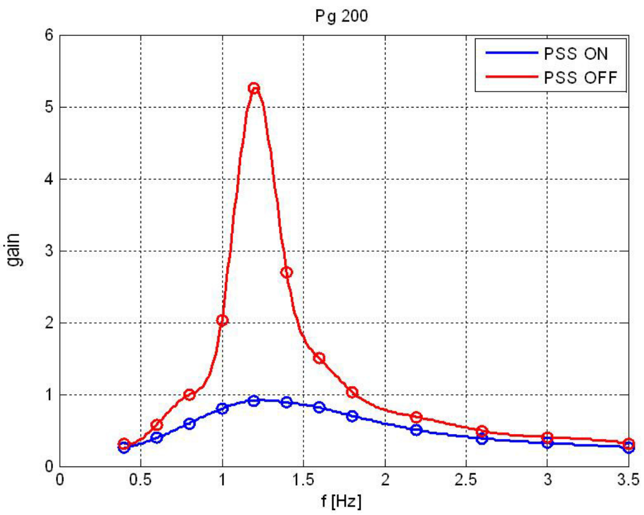


Figure 1. Comparison of amplitude frequency characteristics of the EMO 12 active power when the PSS has been switched on (PSS on) and switched off (PSS off)

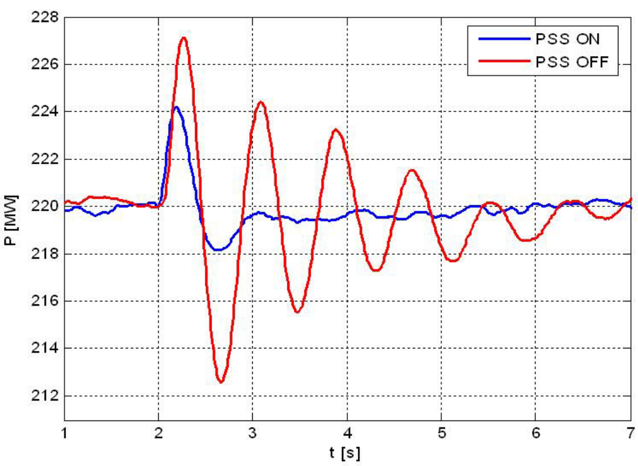


Figure 2. Step responses of the EMO 21 active power

Direct measurement of the frequency characteristics is not simple and is usually classed as a risk test. The evaluation of the PSS efficiency is also possible from step responses by introduction of a damping coefficient that can be defined as follows:

$$\gamma = \frac{|\Delta P_2| + |\Delta P_3|}{|\Delta P_1| + |\Delta P_2|} < 0.5 \qquad (1)$$

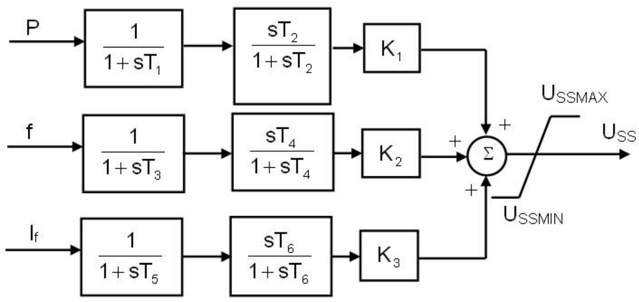
where $\Delta P_1, \Delta P_2, \Delta P_3$ are the first three consecutive peak magnitudes of the active power transient response. The damping coefficients for results in Figure 2 are the following:

- PSS switched off: $\gamma = 0.8$,
- PSS switched on: $\gamma = 0.36$,

what means that the PSS efficiency is by 28% greater than the required value.

Optimization of PSS/AVR parameters during the change of excitation system in EBO, EMO

During last ten years the excitation systems of all machines in EBO and EMO have been changed. New excitation systems can be classed as the static excitation systems. Based on the requirements of EBO and EMO new excitation systems include the PSS with the PSS 3B structure in modified form according to the Figure 3.



P – signal from active power,
f_E – signal from stator voltage frequency,
I_F – signal from field current,
U_{SS} – PSS output signal,
T_1, T_3, T_5 – time constants of low-pass filters,
T_2, T_4, T_6 – time constants of high-pass filters,
K_1, K_2, K_3 – gains of stabilizing feedbacks

Figure 3. PSS3B structure implemented in the Slovak power system

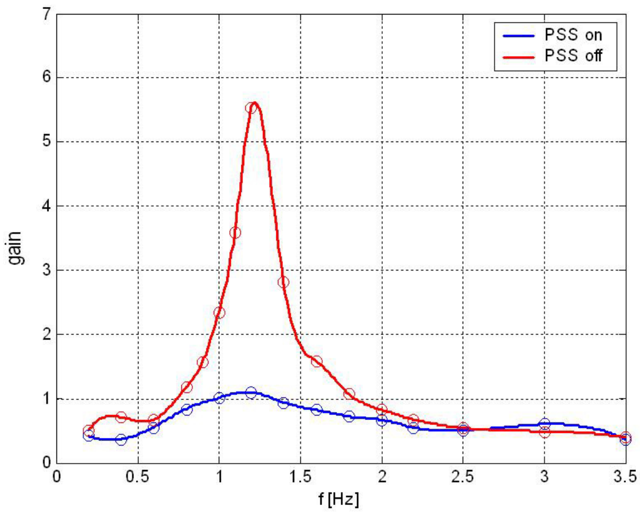


Figure 4. Amplitude frequency characteristics of active power under nominal loading

When the PSS3B is properly set up, it is able to damp very effectively the oscillations of active power that the synchronous generator produces to the power system.

As the first example the damping of oscillations arising after the terminal voltage step change of EBO generator will be presented. In this case the standard PSS and AVR setting does not assure the satisfaction of condition where the gain should be lower than one for all range of transferred frequencies. As shown in Figure 4, at the frequency 1.2 Hz the gain is greater than one even when the PSS is switched on.

Using the step responses in Figure 5 for the PSS efficiency evaluation, the damping coefficient is as follows:

- PSS switched off: $\gamma = 0.71$,
- PSS switched on: $\gamma = 0.56$.

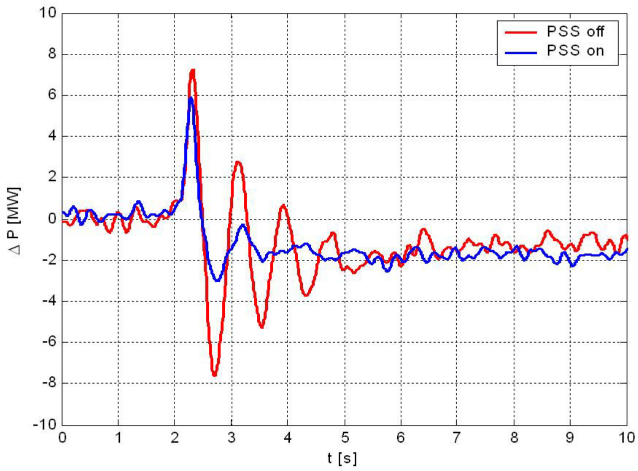


Figure 5. EBO active power step responses

The efficiency of oscillation damping after the PSS implementation can also be observed on network devices of the Slovak power system. To illustrate this statement we will present two experiments realized using the model of the Slovak power system. The first experiment documents the oscillation damping in the power system if the oscillations arise locally on one of the power system sources, more specifically these oscillations have been induced by a step change of the EMO 21 stator voltage desired value.

Figures 6 to 8 show the currents on lines:
V492: Veľký Ďúr – Horná Ždaňa,
V439: Križovany – P. Biskupice,
V408: Lemešany – Kapušany – distant line from the place of short-circuit.

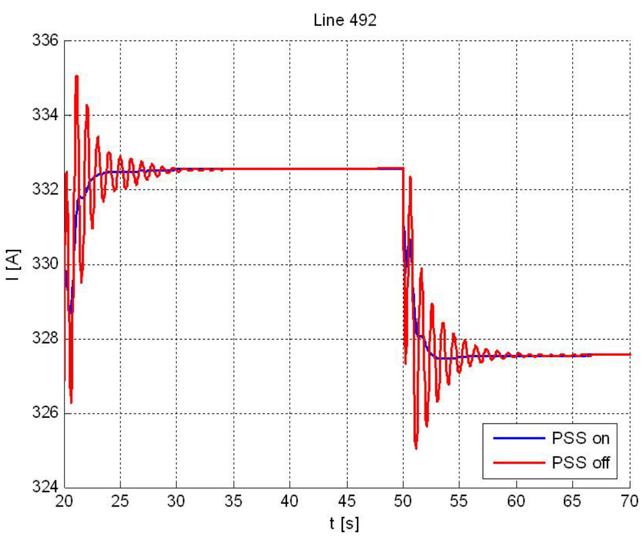


Figure 6. Currents of V492 with PSS switched on and off

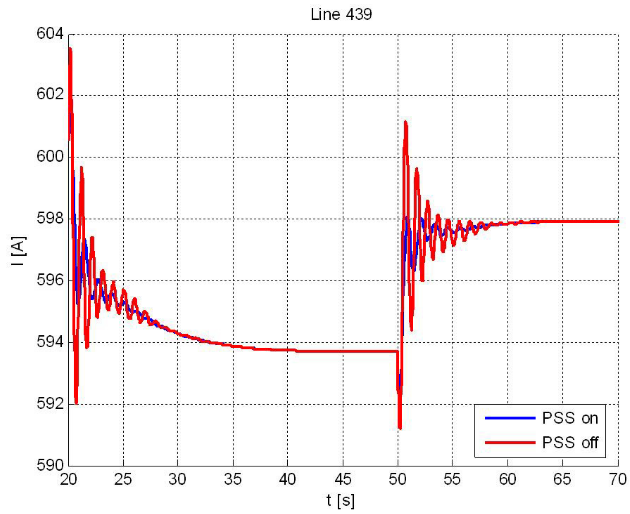


Figure 7. Currents of V439 with PSS switched on and off

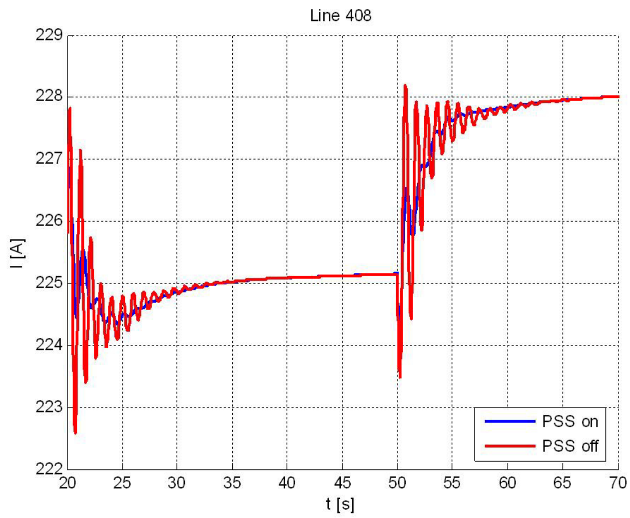


Figure 8. Currents of V408 with PSS switched on and off

The second experiment illustrates the oscillation damping if the oscillations arise after the short-circuit in the power system. In the experiment a three-phase metallic short-circuit in the substation Križovany lasting 100 ms has been realized. The Figures 9 to 11 show the currents of the following lines:
V492: Veľký Ďúr – Horná Ždaňa,
V439: Križovany – P. Biskupice,
V408: Lemešany – Kapušany.

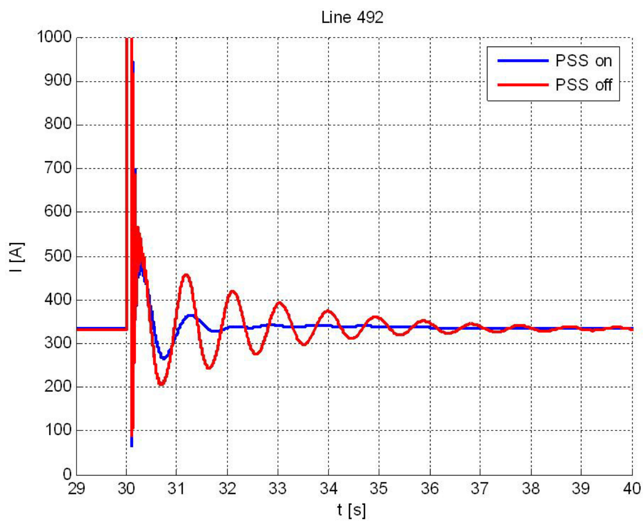


Figure 9. Currents of V492 with PSS switched on and off after the short-circuit in the power system

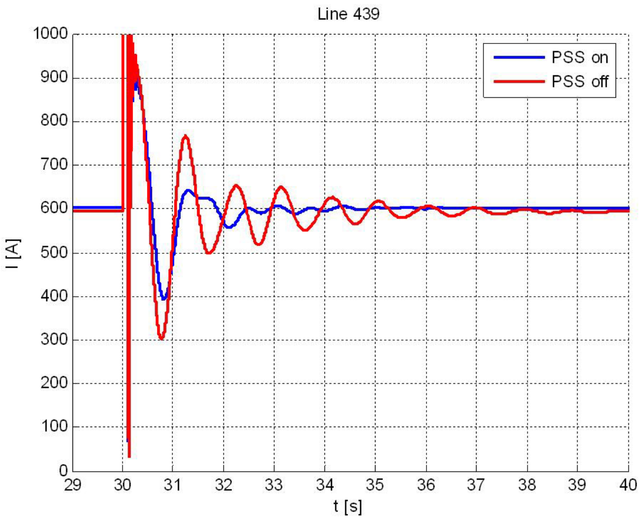


Figure 10. Currents of V439 with PSS switched on and off after the short-circuit in the power system

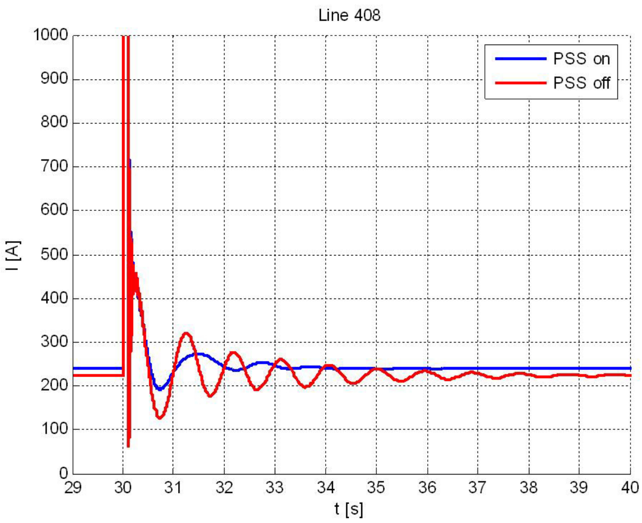


Figure 11. Currents of V408 with PSS switched on and off after the short-circuit in the power system

PSS and AVR parameter optimization using genetic algorithms

Genetic algorithms (GA) represent a universal optimization approach using stochastic effects and copying natural evolution process. They belong to the category of so called evolutionary computation methods [3]. Their basic tools are random changes in properties of individuals – objects of optimization, preferring the more successful individuals at the expense of the less successful ones and high computational effort.

Genetic algorithms can be advantageously used for the optimization of AVR and PSS parameters [1]. The objective function has been chosen so as all requirements laid on the generator voltage control are satisfied and at the same time the damping properties of active power are ensured:

$$J = \alpha_1 \int_0^t \left|(P_G(t) - P_{ref}(t))\right| dt + \alpha_2 \int_0^t \left|(V_G(t) - V_{ref}(t))\right| dt \rightarrow \min \qquad (2)$$

where P_G denotes the active power and P_{ref} is its desired value; V_G and V_{ref} are the terminal voltage and its desired value; α_1 and α_2 are weighting coefficients emphasizing the effect of the active power oscillation damping or the effect of the terminal voltage control optimization.

Such objective function does not take into account the constraints, more specifically the maximum voltage overshoot that must be less than 5%. Therefore the constraints have been implicated into the optimization process by an introduction of penalty functions. In order to increase the active power oscillation damping, to fasten the computations and to exclude the improper individuals from the optimization, the constraint has been defined as a maximum active power magnitude. The objective function after the introduction of constraints is in the following form:

$$J = \alpha_1 \int_0^t \left|(P_G(t) - P_{ref}(t))\right| dt$$

$$+ \alpha_2 \int_0^t \left|(V_G(t) - V_{ref}(t))\right| dt \rightarrow \min \qquad \text{if } P_G, V_G \in H \qquad (3)$$

$$J = \text{penalty} \qquad \text{if } P_G, V_G \notin H$$

where H is an admissible space bounded by defined constraints. The objective function evaluation has been performed by simulation using the computer model of the Slovak power system.

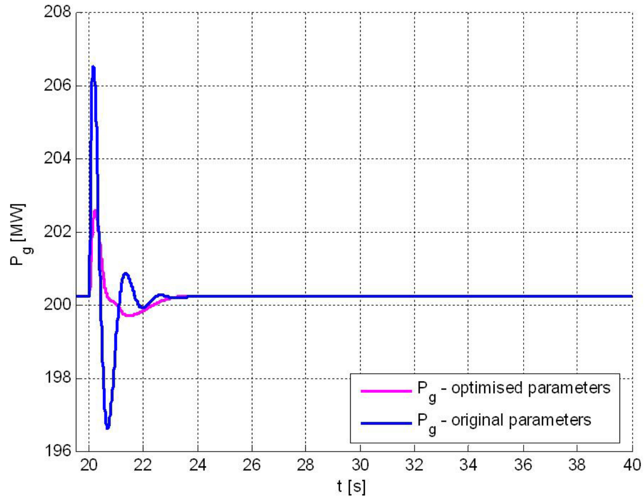


Figure 12. Comparison of the active power oscillation damping effectiveness after 3% step change of stator voltage

- **parameters optimized using genetic algorithms**
- **original parameters after new excitation system implementation**

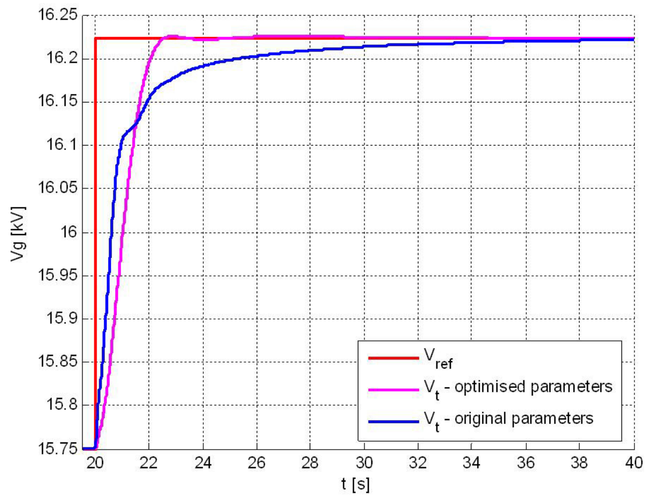


Figure 13. Comparison of the generator terminal voltage after 3% step change of stator voltage

Figure 12 shows the comparison of the active power oscillation damping effectiveness in two cases. The blue line represents the oscillation damping (in compliance with the standard) after intuitive optimization and the violet line illustrates the results of the parameter optimization using genetic algorithms. It can be seen from the Figure 13, that the parameters of voltage control are much better than required by the standard.

Conclusion

PSS represents an important tool for the local oscillations damping in the power systems. Though they are implemented in single synchronous generators, their damping properties are manifested also in the network as has been illustrated by the plots of currents of selected system lines of the Slovak power system.

Acknowledgements

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