OPTIMIZATION OF POWER SYSTEM STABILIZER BY GENETIC ALGORITHM

Ján Murgaš, Ivan Sekaj, Martin Foltin and Eva Miklovičová

Department of Automatic Control Systems, Faculty of Electrical Engineering
and Information Technology,
Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, Slovak Republic
tel.: 02 602 91 781, fax.: 02 654 29 734,
e-mail: jan.murgas@stuba.sk

Abstract: Power system stabilizers (PSS) play an important role in damping of power system oscillations. An intensive research activity has been devoted to design of their structure and optimal setting of their parameters. In this paper the simultaneous optimization of multiloop PSS and automatic voltage regulator parameters (AVR) by means of genetic algorithm is proposed. Using an example of the 259 MVA turbogenerator excitation system in the nuclear power plant Mochovce (Slovak Republic) it is shown that the genetic algorithms are able to find the optimal parameters of excitation system so that the requirements on terminal voltage performances as well as on damping of active power oscillations are satisfied.

Keywords: power system stabilizers, parameter optimization, genetic algorithm, power system simulation, performance index

1. INTRODUCTION

Optimal setting of the power system stabilizer parameters is of major importance in multimachine power systems, such as the European power system. The European power system represents one of the most complex large-scale technical systems. The interconnection of the national power systems ensuring considerable increase of transient stability measure is essential. Comparing the operation of the national power system within the European power system to its island operation shows higher transient stability measure when even large active power outages (800 MW and more) do not lead to disconnection of the power system into smaller islands. The benefits of the power system operation within the large system have to be compensated by implementing measures aiming to ensure damping of oscillations caused by large disturbances.

In recent literature several applications of genetic algorithms (GA) to optimize the PSS parameters have been reported. The proposed approaches differ in the considered PSS structure as well as in the form of objective function and in the way of its evaluation.

Simultaneous stabilization of the power system over a wide range of operating conditions via a single set of PSS parameters using genetic algorithms has been developed in (Abdel-Magid, *et al*., 1999). The conventional lead-lag PSS structure has been considered. Two eigenvalue-based objective functions have been investigated, allowing shifting all or some of the system eigenvalues to the left-hand side of a vertical line in the complex s-plane, or to the prescribed region in the left-half of the complex s-plane, thus ensuring some degree of relative stability as well as the desired time-domain performance specifications.

Simultaneous tuning of multiple conventional lead-lag damping controllers using GA has been reported in (Do Bomfim, *et al*., 2000). The method uses the maximization of the sum of the spectrum damping ratios as the objective function in order to guarantee system stabilization over a prespecified set of operating conditions.

GA-based simultaneous tuning of lead-lag or derivative PSS using the classical integral of squared error performance index and involving the solution of a Lyapunov equation within a genetic search process has been proposed in (Andreoiu and Bhattacharya, 2002a). To obtain the globally optimal PSS parameter settings the average performance index that quantifies the mean performance over the whole operating region has been used.

Optimum tuning of PSS with PID structure realized in discrete-time domain using the classical ISE optimization criterion over the whole operating horizon has been presented in (Andreoiu and Bhattacharya, 2002b).

A self-tuning PSS with lead-lag structure whose parameters are adjusted by a fuzzy logic based parameter tuner according to on-line measurements has been presented in (Lu, *et al.*, 2001). The fuzzy tuner rules and the shape of membership functions are obtained through a GA based optimization method to maximize the damping ratio over a wide range of operating conditions.

In (Afzalian and Linkens, 2000) the genetic algorithm with objective function based on the rotor speed changes has been applied to determine the optimal parameters for the neurofuzzy power system stabilizer of a single machine connected to an infinite bus bar through a transmission line.

Tuning of the fuzzy logic based PSS for the multimachine power system through genetic algorithms has been proposed in (Lakshmi and Abdullah Khan, 2000). The fitness function used in this paper is a root mean squared deviation (RMSD) index evaluated for the state variables in which the critical rotor swing modes are dominant.

In (Menniti, *et al.*, 2002). the coordinated tuning of a fuzzy logic power system stabilizers in the multi-machine power system has been formulated as an optimization problem to minimize dynamic performance index quantifying the deviation of the machine speed form its nominal value and has been solved by the GA search procedures.

2. PROBLEM FORMULATION

The aim of this paper is to find the optimal setting of the turbogenerator excitation system parameters so as some given requirements on the synchronous generator performances are satisfied.

In the national power systems the qualitative requirements on the terminal voltage control performances as well as on the active power oscillation damping are defined. For example, in the Slovak power system these requirements are determined as follows:

- The terminal voltage settling time t_{set} must be less than 15 s.
- The terminal voltage maximal overshoot Δ_{max} must be less than 5 %.
- The damping index $\gamma \leq 0.5$.

The damping index γ is defined using the first two peak magnitudes of the active power transient response as follows:

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

where $\Delta P_1, \Delta P_2, \Delta P_3$ are the first three consecutive peak magnitudes of the active power transient response after the terminal voltage reference step change. An example of the active power and the terminal voltage time responses is in Fig. 1.

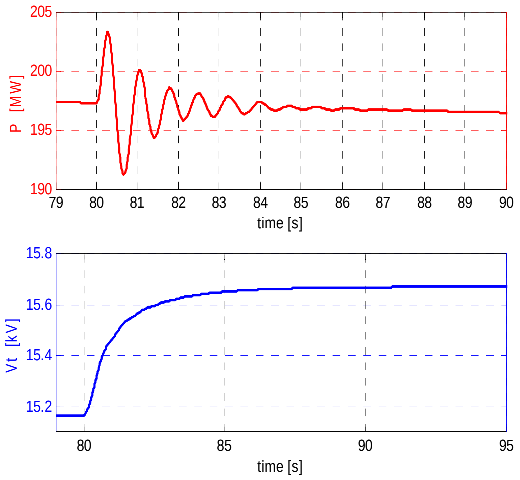


Fig. 1 Active power and terminal voltage time response

The aim is to design the excitation system (ES) parameters so as the power system response to disturbances is damped as soon as possible. The satisfaction of the above mentioned requirements on the transient processes can be ensured by optimisation of the PSS and the excitation system parameters so that the sum of the integral of active power absolute error and the integral of terminal voltage absolute error is minimised:

$$J = \alpha_1 \int_0^t |(P(t) - P_d(t))| dt + \alpha_2 \int_0^t |(V_t(t) - V_{td}(t))| dt \rightarrow \min \qquad (2)$$

where P denotes the active power and P_d is its desired value; V_t and V_{td} 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.

Another possible integral objective function can be expressed in the form

$$J = \alpha_1 \int_0^t \left| \left(P(t) - P_d(t) \right) \right| dt + \alpha_2 \eta_{Vt} + + (1 - \alpha_2) T_{sVt} \rightarrow \min \tag{3}$$

where η is the terminal voltage maximal overshoot, T_{sVt} is the terminal voltage settling time and α_1 and $0 \le \alpha_2 \le 1$ are weighting constants. The minimisation of (2) or (3) for complex power system models is a complex optimisation problem requiring effective tools. For that reason genetic algorithms have been used.

3. GENETIC ALGORITHMS IN OPTIMIZATION PROBLEMS

Genetic algorithms (GA) represent a universal search or optimization method that is able to find or at least to approach the global optimum in the bounded region of admissible solutions. In genetic algorithms, the evolution principle observed from nature is employed – surviving of strongest or most adaptable individuals and necessity of death of those, who are the weakest and not adapted. GA's are sufficiently described in literature e.g. (Goldberg, 1898, Michalewicz, 1996, and other). The general scheme of the GA is as follows:

1. initialisation of the population of individuals (potential solutions, strings),
2. objective function (fitness) calculation,
3. test of terminating conditions,
4. selection of parents and their modification using crossover and mutation,
5. completion of a new population and jump to the step 2.

Each string is represented by a sequenced set of parameters characterizing its properties. In order to use the genetic algorithm-based search/optimisation of PSS parameters it is necessary to define the string format. Each string of the population comprises a sequence of the PSS parameters $s = \{p_1, p_2, \dots, p_n\}$.

The objective function evaluation consists of two steps (Fig. 2) (Sekaj, 1998). The first one is the control loop simulation using the appropriate dynamic model. In our case the simulation model should include a turbogenerator model with corresponding control loops and a model of the surrounding power system.

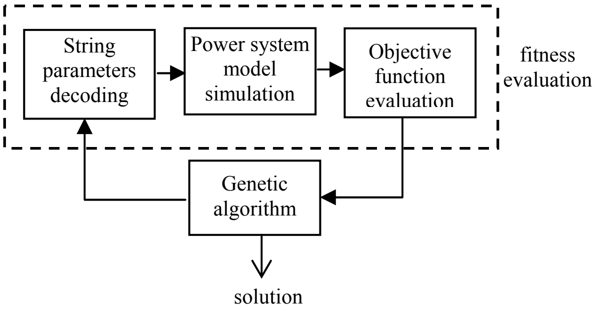


Fig. 2 Fitness evaluation

The simultaneous optimization of the AVR and PSS parameters is important for obtaining the desired performances in the stator voltage control as well as for the active power oscillation damping. For the ES parameter optimization it is convenient to use the terminal voltage and active power transient responses after a step change of the terminal voltage desired value.

The second step of the fitness evaluation is the control performance evaluation that can be based on norms valid for the national power system in close coordination with the interconnected power system requirements. In our case the objective functions (2) and (3) have been used.

4. OPTIMIZATION OF THE MULTILOOP PSS PARAMETERS SETTING

In order to ensure the robustness with respect to various disturbances occurring in the power system the PSS structure has been enlarged to the multi loop form using the suitable measurable generator signals (Murgaš, *et al.*, 2004) An example of such a solution is the excitation system with PSS depicted in Fig. 3.

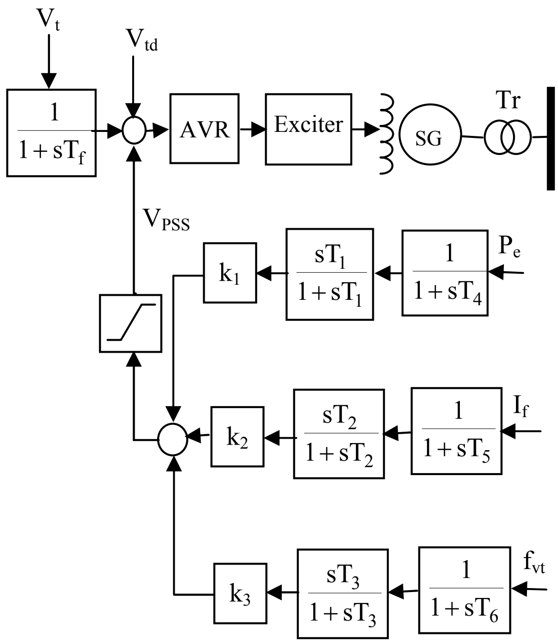
The AVR is a PI controller with transfer function in the form

$$G(s) = K_p \left(1 + \frac{1}{sT_i} \right) = r_0 + \frac{r_{-1}}{s} \tag{4}$$

where K_p is a proportional gain
T_i is an integral time constant.

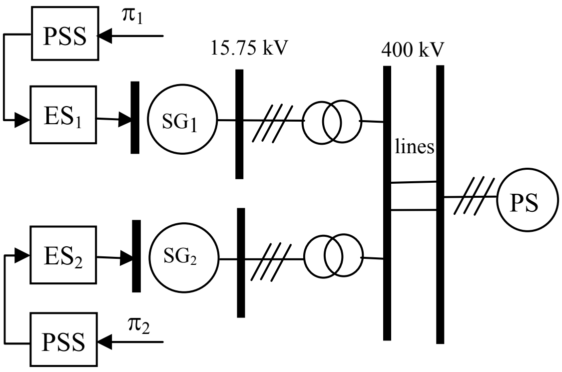
The PSS in Fig. 3 is a three-loop compensator. The low pass and the high pass filters are inserted in each branch in order to filter off the parasitic signals out of the considered frequency range (0.1 ÷ 3.5 Hz). The PSS output signal is limited into apriori-defined range, e.g. <-0.2 ÷ 0.2 p.u.>.

For the purpose of the GA-based excitation system parameters optimization the simulation model in Matlab Power System Blockset has been used, where only a segment of the Slovak power system comprising relevant blocks of the nuclear power plant Mochovce (Slovak republic) has been considered (Fig. 4). The stabilizing signal π contains three measured signals P_e, I_f, f_{vt}, as shown in Fig. 3.



k_1, k_2, k_3 – PSS loop gains
T_1, T_2, T_3 – washout time constants
T_4, T_5, T_6 – low-pass filter time constants

Fig. 3 Excitation system with PSS



PS – power system
SG_i – i-th synchronous generator
ES_i – i-th excitation system
π_i – i-th stabilizing signal

Fig. 4 Power system simulation model

Optimization of the automatic voltage regulator and the power system stabilizer parameters for the TG21 turbogenerator of the nuclear power plant Mochovce (Slovak republic) has resulted in the higher oscillations damping level (Fig. 7) and the satisfaction of conditions required for the terminal voltage performances. Using the simultaneous optimization of the PSS and AVR parameters the similar good performances can be obtained as when the PSS with special structure is used (Murgaš and Miklovičová, 1999).

The results of parameters setting optimisation for the 259 MVA turbogenerator excitation system in the nuclear power plant can be illustrated by transient processes in Fig. 5, where the active power response to 4% step change of the terminal voltage desired value is shown. The damping factor values are in Table1, where PSS1 denotes the original parameter settings and PSS2 stands for the optimised parameter settings.

Table 1 Damping factors

	without PSS	PSS1	PSS2
γ	0.82	0.52	0.41

The qualitative requirements on the terminal voltage control performances are also satisfied, as can be seen from Fig. 6:

$$t_{set} = 10 \text{ s} < 15 \text{ s}, \qquad \Delta_{max} = 0 < 5\%$$

The real machine active power time responses without PSS and with PSS2 are in Fig. 7.

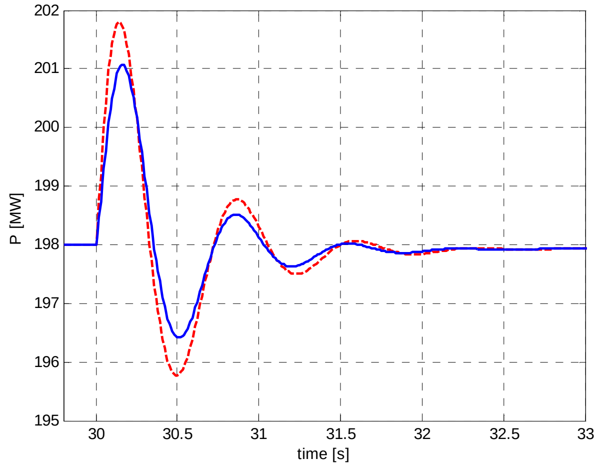


Fig. 5 Active power time response
···· PSS1, —— PSS2

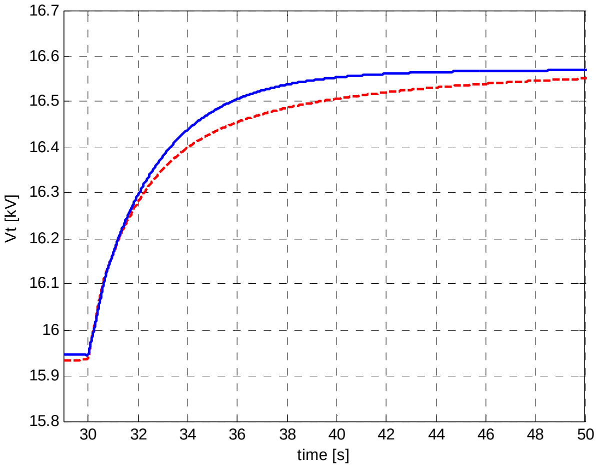


Fig. 6 Terminal voltage time reponse
···· PSS1, —— PSS2

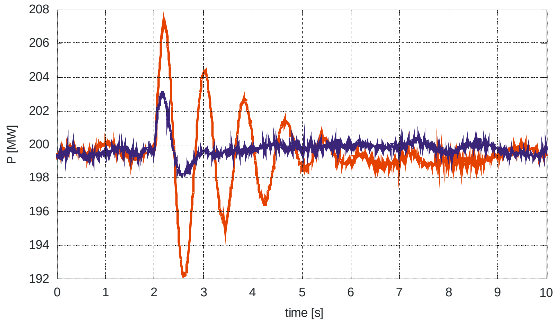


Fig. 7 Real machine active power time response
— without PSS, — with PSS2

5. CONCLUSION

The aim of the paper has been to design and verify the tool for parameter optimization of the synchronous generator excitation system with given structure. The genetic algorithm-based approach has been used to solve the problem. This approach is able to design/optimise the parameters of such complex dynamic systems as the power systems taking into account the synchronous generator models with their surroundings and considering different types of disturbances. As the optimised objective function, various integral or other performance indices can be used. The essential part of each objective function evaluation is the power system dynamic model simulation. The proposed approach is powerful, robust and leads to good results. On the other hand, in comparison to other design approaches, the simulation-based approach using genetic algorithms requires a relatively high computational effort or high computational time, respectively.

The proposed approach effectiveness has been illustrated by excitation system parameters optimisation for synchronous generators of 259 MVAr in nuclear power plant Mochovce. In all cases the excitation system parameters have been optimised so that given qualitative requirements on the terminal voltage performances as well as on damping of the active power oscillations were satisfied.

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