A METAHEURISTIC APPROACH FOR POWER SYSTEM STABILITY ENHANCEMENT

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REZUMAT. Această lucrare propune o abordare metaeuristică pentru setarea optimală a stabilizatoarelor de putere în scopul îmbunătăţirii stabilităţii sistemelor electroenergetice prin amortizarea suplimentară a oscilaţiilor de putere. Pentru asigurarea unui grad suficient de stabilitate, se utilizează o funcţie obiectiv care are la bază analiza modală. De asemenea, este prezentată şi o metodă de comunicare automată între Matlab şi DigSILENT pentru rezolvarea problemei de optimizare studiate.

Cuvinte cheie: DPL, DigSILENT, valori proprii, stabilizator de putere, stabilitatea sistemelor electroenergetice.

ABSTRACT. This paper proposes a metaheuristic approach for optimal setting of power system stabilizers (PSS) in order to increase the power system stability by supplementary damping of the system oscillations. To ensure a sufficient degree of relative stability, an eigenvalue-based objective function is employed. Also, a technique for automatic data exchange between Matlab and DigSILENT for solving the optimization problem is presented.

Keywords: DPL, DigSILENT, eigenvalues, power system stabilizer, power system stability.

1. POWER SYSTEM STABILITY

Power system stability has been an important concern for secure system operation even from the early beginnings of the first power systems. Over the years, the power systems were forced to operate more and more close to their operating limits because of the steady increase in network and electric power demand [1-3]. Hence, power system stability became a vital problem not only for the operation of existent power systems, but also for the safe operation, and for the development of the Smart Grid concept.

The basic concept of power system stability is described in [4] as the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. This definition offers a simple and sufficient understanding of the concept.

One of the most simple and economical way of enhancing power system stability is the use of PSS as a suplimentary control device for the generator excitation system. The literature mentions different techniques of optimal power system stabilizer (PSS) setting and placement such as pole placement, robust control or sensitivity analyse [5]. Because these approaches have major drawbacks, recent studies present new optimization techniques for PSS design. Such an approach is found in [6], where a metaheuristic approach in terms of Particle Swarm Optimization (PSO) is applied in order to find the optimal PSS parameters. For damping electromechanical modes, a two eigenvalue-based objective function is considered. To demonstrate the robustness of the proposed approach, the multi-machine system was subjected to different loading levels and to a 6 cycle three-phase short circuit. The test network and the objective function used in this approach are also used in this paper. Another similar approach is found in [5], where an artificial bee colony optimization technique was used for PSS optimal setting. The proposed technique is compared with Genetic Algorithm (GA) and Non Dominated Ranked Genetic Algorithm (NRGA) approach demonstrating its superiority regarding overshooting and settling time.

This paper presents a method of optimal setting of PSS employing GA, which combines the Matlab programming environment and the use of power flow and modal analysis toolbox from the PowerFactory software developed by DigSILENT Gmbh. To the best knowledge of the autors this approach has never been mentioned in the literature.

2. POWER SYSTEM STABILIZERS

A common way to ensure the stability of a power system is the appropriate choice of the excitation control system. In early 1960s, with the growth of the power systems, engineers used Automatic Voltage Regulators (AVRs) as close-loop feedback control in order to improve the power system stability. Over the years, for achieving a reliable and economically viable way of operating the power systems, new controllers were developed. Such a device is the PSS, which is used to add damping to electromechanical oscillations. This is achieved by generating an electric torque component through the excitation system, proportional to the speed change [7, 8]. The common input signals used for the PSS are generator shaft speed, electrical power, accelerating power or terminal bus frequency [9], but the choice of a stabilizing signal is influenced by many factors such as its availability and the fact that certain signals have different advantages and disadvantages over the others [10].

The main problem of PSS design is to determine the optimal parameters (gain, time constants) such as to damp system's electromechanical modes, but this must be done without adverse effects on other oscillatory modes. Figure 1 describes the basic structure of a PSS which has as input signal the generator shaft speed.

The PSS has a washout block which allows the high frequency signal of interest to pass, two phase compensation blocks which compensate the phase lag between the exciter input and the generator electrical torque, and a limiter. The PSS output is used as a supplementary control loop for the AVR.

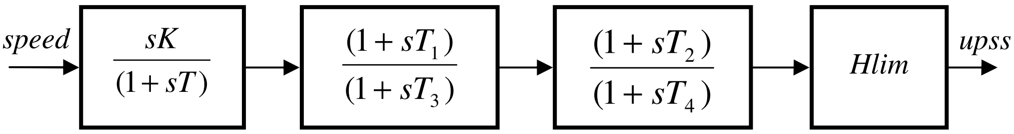


Fig. 1 The basic structure of a PSS

3. GENETIC ALGORITHMS

The genetic algorithms are a subclass of evolutionary algorithms which mimics the natural process of evolution. The origins of GA date from mid-1950s, when computer scientist Fraser and biologist Barricelli started to apply computer-aided simulations in order to better understand the genetic processes and the natural evolution. But the one who introduced GA as an optimization algorithm is John Henry Holland in his book "Adaptation in Natural and Artificial Systems" [11]. GAs have been introduced to overcome the computational drawbacks of numerical algorithms which are characterized by complex derivatives and high sensitivity to imput data. These algorithms solve the optimization problems using natural evolution inspired techniques. They imitate the replication mechanisms of the biological genome and use the power of randomness to search the optimal or near-optimal solution in the search domain [10]. GAs have been used in science and engineering as adaptive algorithms for solving various practical problems such as communication, data analysis, economy or engineering.

A particularity of GAs is that the parameters which must be optimized are coded and concatenated in strings called chromosomes. The actual structure of a chromosome depends on the nature of the solved problem.

First, a population of such chromosomes is formed and then evaluated according to an objective function to assign a degree of performance to each chromosome. The chromosomes with higher values of their fitness function are selected for crossover and mutation.

The crossover operator combines pairs of parent chromosomes to find new and potentially better solutions.

The mutation operator is used to avoid getting stuck in a local minimum by diversifying the population. The iterative process of selection, crossover and mutation continues over a number of generations until an user defined stopping criterion is met.

4. THE TEST SYSTEM AND PSS DESIGN

The aim of this paper is the optimal design of PSS using a metaheuristic approach in order to increase the stability of the power system by additional damping of system oscillations. To the autors knowledge, the analysis approach used in this paper is novel, combining two software tools which work together for finding the optimal PSS parameters. The GA is implemented in Matlab and the test system is simulated in DigSILENT PowerFactory v14. Also, for evaluating the chromosomes, eigenvalues are computed by DigSILENT PowerFactory and transferred into the Matlab environment, as presented in Section 5 of the paper.

The system used for analysis is the 9-bus WSCC test system (Figure 2), which has 3 generators and 9 nodes. In Table 1 are presented the rated apparent power and voltage of the generators as well as the active and reactive power of the loads. The generators used in the simulation use the six order model and their state vector is:

$$X = [speed\ phi\ psiD\ psiQ\ psie\ psix] \quad (1)$$

where

speed Rotor speed
phi Rotor angle
psiD Stator Flux, d – axis
psiQ Stator Flux, q – axis
psie Excitation Flux
psix Flux in damper – winding

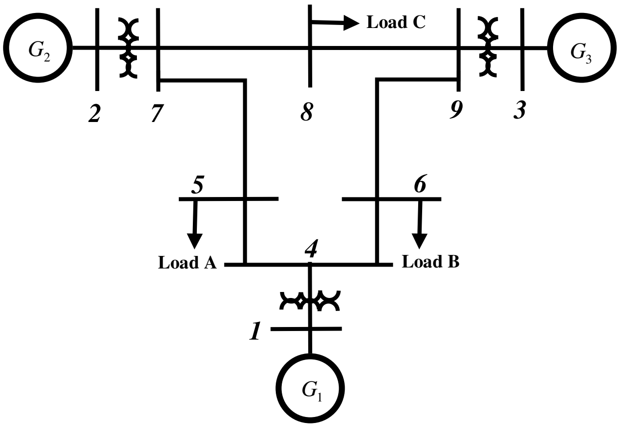


Fig. 2 WSCC Test System

The PSS used for enhancing the stability of the above mentioned test system is a common power system stabilizer (CPSS) as the one described in Section 2. It can be found in DigSILENT PowerFactory library as 'pss_STAB1'. The transfer function of the PSS is:

$$upss = K\frac{s}{(1+sT)}\frac{(1+sT_1)}{(1+sT_3)}\frac{(1+sT_2)}{(1+sT_4)}speed \quad (2)$$

where

K Stabilizer Gain [p.u.]
T Washout integrate time constant [s]
T_1 First Lead/lag derivative time constant [s]
T_3 First Lead/Lag delay time constant [s]
T_2 Second Lead/Lag derivative time constant [s]
T_4 Second Lead/Lag delay time constant [s]

For constructing the GA search space, the limits of the parameters which must be optimized are chosen around their typical values [12, 13], as follows:

$$0.001 \le K \le 90$$
$$1 \le T \le 20$$
$$0.05 \le T_1 \le 2$$
$$0.01 \le T_3 \le 0.5$$
$$0.05 \le T_3 \le 2$$
$$0.01 \le T_4 \le 0.5$$

The chromosome of the GA consists of values for the above parameters. The values from each chromosome are exported to DigSilent PowerFactory which, using modal analysis computes the eigenvalues which are returned to Matlab to compute the objective function (3), used to increase the damping of the system modes, and therefore to increase the stability of the system.

The optimization formula, using the objective function *J*, is:

$$\max_{gen}(J) = \max_{gen}(\min_{cz}(\zeta_i)) \quad (3)$$

where:

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \quad (4)$$

$$\lambda_i = \sigma_i + j\cdot\omega_i \quad (5)$$

λ_i - *i*-th oscillation mode (eigenvalue)
ζ_i - the damping ratio of the *i*-th oscillation mod.
cz - the *cz*-th chromosome
gen - the number of generation

Table 1

Generator and load data

Generator					Load				
	Rated Apparent Power		**Rated Voltage**			**Active Power**		**Reactive Power**	
G_1	247.5	MVA	16.5	kV	**Load A**	125	MW	50	Mvar
G_2	192	MVA	13.8	kV	**Load B**	90	MW	30	Mvar
G_3	128	MVA	18	kV	**Load C**	100	MW	35	Mvar

5. AUTOMATIC DATA EXCHANGE BETWEEN MATLAB AND DIGSILENT

This approach was developed in order to extend the capabilities of the power system analysis techniques by combining the advantages of two software tools. The Matlab's convenient and easy to debug programming language is combined with DigSILENT's modal analysis capabilities. Figure 3 presents a simple diagram which depicts the procedure used in this paper to communicate between the two programs.

The data exchange is made using three buffer *.csv* files: one for transferring the GA chromosomes from Matlab to DigSilent, one for transferring the eigenvalues of the studied system computed by DigSilent back to Matlab and one for the read/write protocol of the involved programs. The communication functions are written using Matlab and DigSilent's own programming language, DPL.

The protocol file acts like a switch and it takes two values: 1 and 0. For an efficient communication the following assumptions were considered: if the value of *Q.csv* (Figure 3) is 1, then DigSILENT reads the *Test.csv* file, computes the eigenvalues, writes the *Test2.csv* file and Matlab waits. If the value of *Q.csv* is 0, then Matlab reads the *Test2.csv*, runs the GA, writes the *Test.csv* file and DigSILENT waits.

Q.csv is constantly scanned and rewritten by both programs after each of them finishes its work.

This technique is not limited just as a solution for this paper analysis. With few alterations and improvements, it can be used for every type of problem that involves both programs working together.

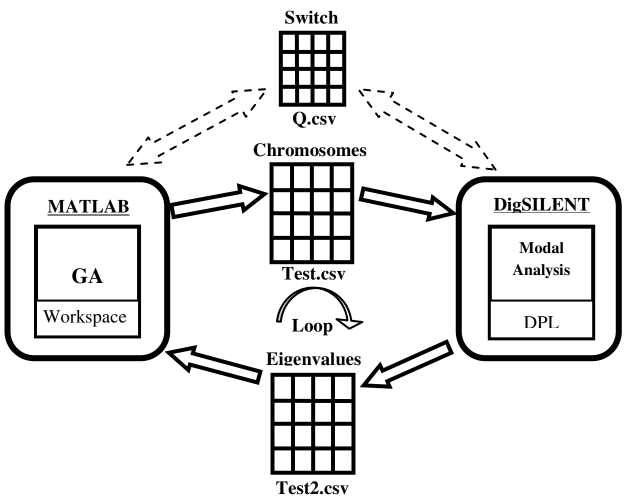


Fig. 3 Automatic data exchange between Matlab and DigSILENT

6. RESULTS AND DISSCUSIONS

The test system (WSCC) was provided with governor and automatic voltage regulator (AVR) only to the generator 3, where the PSS will be connected. Therefore, the total number of system eigenvalues is 31 (6 for every generator, 4 for AVR, 6 for governor and 3 for PSS). Must be mentioned that further are presented and discussed only the oscilation modes with lowest damping ratio.

As seen in Table 2, computing the eigenvalues for the system without PSS, it can be observed that the electromechanical mode which is associated with G_1 speed has a small damping ratio, much smaller than is considered to be satisfactory in practice (*≥0.05*) [14]. Also, the third set of complex-pair of eigenvalues has a small damping ratio near the limit of 0.05.

To assess the effectiveness of the PSS tuned using the proposed approach, the system is subjected to a three-phase fault at line 5-7, at t=1 s. The fault is cleared after 0.083 s by opening the affected line. After running the GA, the optimal PSS parameters are found and listed in Table 3.

The system eigenvalues with optimal PSS parameters are listed in Table 4. In Figure 4 is represented the objective function evolution through the searching process. It can be seen that the damping ratio of the oscillatory modes has been significantly improved by finding the optimal parameters for the PSS. The damping ratio of the complex-paire of eigenvalues associated to G_1 has also been improved, leading to a satisfactory degree of stability of the system. Furthermore, Figures 5 (a) and (b) show the effect of the PSS with optimal parameters determined by the Matlab-DigSilent approach, compared with the case of the system without PSS. It is obvious that the speed deviation of G_2 and G_3 with PSS describes a better evolution and has a smaller settling time (≈ 5 s) than in the case of the system without PSS.

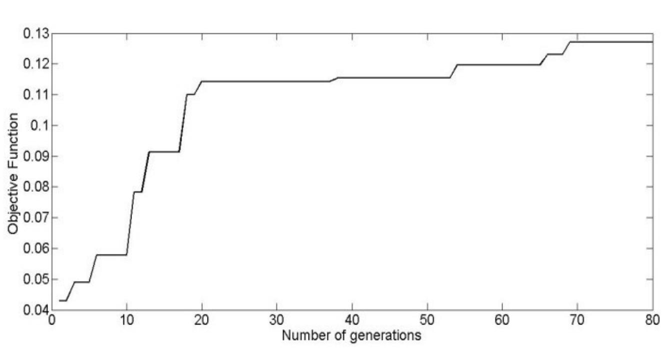


Fig. 4. GA evolution

Table 2

System eigenvalues without PSS

Eigenvalues without PSS		Damping ratio
G_1 *speed*	-0.10813 ± j·6.83056	**0.015828**
G_2 *speed*	-19.15712 ± j·37.03154	0.459477
G_3 *speed*	-1.08615 ± j·13.77224	0.07864

Table 3

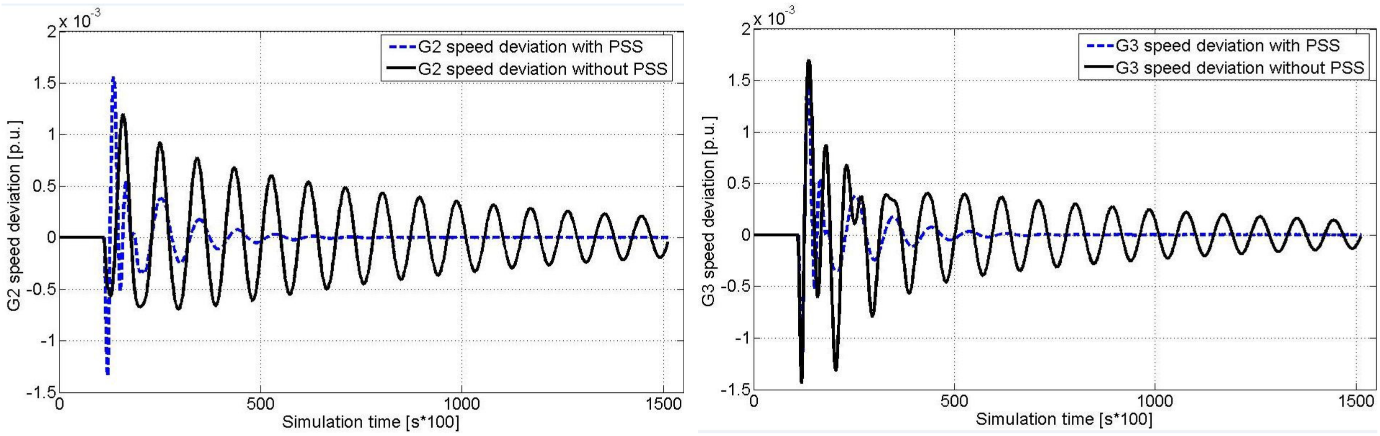
Optimal PSS parameters

K	T	T_1	T_3	T_2	T_4
2.26	*2.98*	*1.69*	*0.22*	*1.71*	*0.014*

Table 4

System eigenvalues with PSS

Eigenvalues with PSS		Damping ratio
G_1 *speed*	-0.85782 ± j·6.682	0.1273
G_2 *speed*	-43.892 ± j·11.24378	0.968
G_3 *speed*	-4.296 ± j·33.263	0.128



a) Speed deviation of G_2 with and without PSS

b) Speed deviation of G_3 with and without PSS

Fig. 5. Speed deviation of G_2 and G_3 with and without PSS

7. CONCLUSIONS

This paper presents a metaheuristic approach for finding the optimal PSS parameters in order to enhance the power system stability. This approach combines the use of Matlab and DigSILENT, taking advantage of the ease of use of Matlab and modal analysis module from DigSILENT PowerFactory. The effectiveness of PSS which use local signals as inputs is studied and confirmed. A possible further approach is the integration of remote signals from key points of the network into the PSS input.

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