Optimal tuning of power system stabilizer using genetic algorithm to improve power system stability

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***Abstract*— In the few past decades, power system stabilizers play an important role in power systems by ensuring the stability of the single machine infinite bus power system. In this context, several researchers have devoted their work to design the structure of the PSS and to optimize its parameters. In this paper, the structure of the integrated PSS is described. In order to optimize the PSS parameters, the genetic algorithm approach is proposed, developed and used. The performance of the proposed optimization method was evaluated by applying a short circuit default on a single machine infinite bus power system. Different results demonstrated that the genetic algorithm is able to find the optimal parameters of the PSS ensuring the stability of the power system.**

Keywords—Single machine infinite bus, power system stabilizers, parameter optimization, genetic algorithm

I. INTRODUCTION

In the last few decades, the stability of Synchronous Generators (SG) in power systems is considered one of the most important subjects in research area [1].

In this context, Power System Stabilizers (PSSs) are very known and commonly used in electrical networks [1, 2].

Thanks to its advantages in terms of economic cost and efficiency, PSSs are the best means that eliminate the negative effects of automatic voltage regulators (AVR) in the one hand and damp electromechanical oscillations and ensure the overall stability of the system in the other hand [1,2,3,4].

Many researches have been done to evaluate the effect of PSS on the stability of the power system, the PSS input signals, the best locations of PSS and PSS optimization techniques.

In order to increase the damping of the system oscillations and also to ensure a robust stabilization Optimal setting of the power system stabilizer parameters is one of the major important research area of single machine infinite bus (SMIB) power systems stability [5].

Numerous methods are proposed in the literature for the adjustment of PSS parameters [6,7]. These methods are classified into two categories. Classical ones are very used in the literature such as [7]:

- ✓ Phase compensation method,
- ✓ Residue method,
- ✓ Pole placement method.

These methods are linear approaches which are based on analyzing the linear model of the system by examining these eigenvalues. In this way, the stability of the system can be identified (stable or unstable system). In this cases, dimensioned controller provides a damping only around the determined operating point.

However, in case of undesirable perturbation, the integrated controller is not longer valid. Therefore, the later must be re-dimensioned around another operating point to ensure good performance.

Heuristic techniques and artificial intelligence are considered as intelligent methods of optimization. Those methods have been proposed and successfully implemented to improve the power system stability [5, 6] such as genetic algorithm (GA) and practical swarm optimization (PSO).

In [10], PSS parameters are adjusted by mean of fuzzy logic method based parameter tuner according to on-line measurements. In [11], the genetic algorithm has been applied to determine the optimal parameters for the “neurofuzzy PSS” of SMIB power system. The fitness function is based on the rotor speed variations. In [12] genetic algorithm has been proposed in order to optimize the fuzzy logic based PSS for the multimachine power system. The objective function used in this paper is a “root mean squared deviation” (RMSD).

The multi-machine power systems stabilizers (PSSs) design using the optimization approach named “cultural algorithm” (CA) has been given in [14]. A new robust power system stabilizer (PSS) design using Quantitative Feedback Theory (QFT) to enhance multi-machine power system stability is proposed in [15].

The objective of this paper is to find optimal parameters of PSS by genetic algorithm method to ensure a satisfactory damping of the rotor oscillations and to guarantee the stability of the system whatever the perturbation that appears on the system.

The implementation of the genetic algorithm in the Matlab/Simulink environment is done. A simulation analysis while applying a short circuit perturbation is presented and discussed.

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The remainder of this paper is organized as follows. Section 2 presents the power system modelling which include the generator model and the structure of power system stabilizer.

The genetic algorithm is chosen as a suitable optimization method which is applied in section 3 of this paper in order to generate the most optimal results of each PSS parameters. In section 4, simulation results are presented, discussed and compared. Finally, conclusions are presented in Section 5.

II. POWER SYSTEM MODELLING

A. Generator model

Fig.1 presents the single-machine-infinite-bus (SMIB) power system. The hole system consists of a synchronous generator connected to the network through transmission lines.

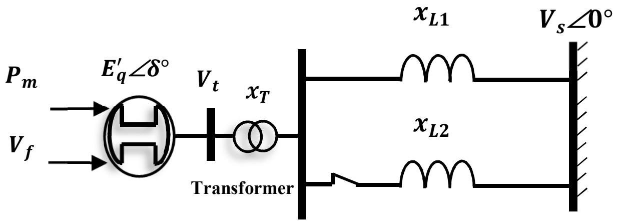

Fig. 1. Single-machine infinite-bus power system.

The third order dynamic generator model presents a simplification of the real generator. Although, it is widely used while developing the excitation controllers thanks to its capability to maintain different characteristics of the power system dynamics [8, 9]. The third order dynamic generator model can be written as follows (Eq.1):0

$$\begin{cases} \dot{\delta} = \omega \\ \dot{\omega} = -\frac{D}{H}\omega + \frac{\omega_s}{H}(P_m - P_e) \\ \dot{E}'_q = \frac{1}{T'_{do}}(E_f - E_q) \end{cases} \quad (1)$$

Where

δ : The power angle of the generator.
ω_s: The synchronous machine speed.
ω : The relative rotor speed of the generator ($\omega = \omega_g - \omega_s$) were ω_g being the generator angular speed).
H : The inertia constant.
D : The damping constant.
P_e : The active electrical power.
P_m : The mechanical power input.
T'_{d0} : The direct axis transient open-circuit time-constant.
E_f : The equivalent EMF in the excitation coil of the generator.
E_q : The EMF in the quadrature axis.
The active electrical power equation is given by (Eq.2).

$$P_e(t) = \frac{V_s E_q}{x_{ds}} \sin\delta(t) \quad (2)$$

The EMF in the quadrature axis is given by (Eq.3).

$$E_q(t) = \frac{x_{ds}}{x'_{ds}} E'_q(t) - \frac{x'_d - x_d}{x'_{ds}} V_s \cos\delta(t) \quad (3)$$

Where
$x_{ds} = x_d + x_T + x_L$: is the total reactance which takes into account the generator direct axis reactance x_d.
$x'_{ds} = x'_d + x_T + x_L$: is the total reactance which takes into account the direct axis transient reactance of the generator x'_d.
$x_L = \frac{x_{L1}x_2}{x_{L1}+x_{L2}}$ the transmission line reactance.
x_T is the reactance of the transformer.

The equivalent EMF in the excitation coil of the generator can be expressed by (Eq.4).

$$E_f = k_c v_f \quad (4)$$

where
k_c : The gain of the excitation amplifier;
u_f : The input to the SCR amplifier of the generator.
The terminal voltage of the generator is expressed as (Eq.5).

$$V_t = \frac{1}{x_{ds}}\sqrt{x_s^2 E_q^2 + V_s^2 x_d^2 + 2x_s x_d V_s E_q \cos\delta} \quad (5)$$

$$x_s = x_T + 0.5x_L \quad (6)$$

B. Structure of Power system stabilizer (PSS)

The PSS is a device used to improve the stability of power systems by adding an auxiliary control signal, noted V_{PSS}, to the input of the automatic voltage regulator AVR.

The main role of the PSS is to extend the stability limits of a power system by reducing the oscillations of the generator rotor speed.

The PSS must produce an electric torque component in phase with the rotor speed variation ($\Delta\omega$) which can be used directly as an input signal.

Fig.2 shows the structure of PSS used in the present study.

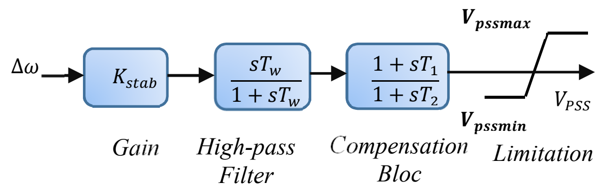

Fig.2. Structure of power system stabilizer.

The PSS is composed mainly of:

- A gain K_{Stab} which determines the amount of required damping provided by the PSS in order to attenuate the power oscillations without risk of degrading the stability.
- A signal washout block (High-pass Filter) which eliminates very low frequency oscillations and acts only during variations in speed. The time constant T_w

of this block is generally in the range of 1 to 20 seconds.

- A phase compensation bloc which is designed to move the unstable oscillation mode to the left part of the complex plane in order to ensure the system stability. The time constants of this block are generally within the range 0.01 to 6 seconds.
- The PSS must be fitted with a limiter in order to reduce its undesirable influence during the transient phases. The minimum and maximum values of the limiter range from ± 0.02 to 0.1 per-unit.

In the following section, we propose to introduce the genetic algorithm to optimize different PSS parameters in order to improve its performances. This approach is called nonlinear because it takes into account the nonlinear nature of the power system already ignored by the other methods. The influence of the adaptation of the parameters of the PSS is described in the following paragraph.

III. DESIGN OF GAPSS

The genetic algorithm (GA) evolves a population of genes using the mechanisms of natural selection and the genetics of evolution. It uses a cost function based on a performance criterion to calculate a "suitability" [13].

The genetic algorithm is considered one of the most known optimization methods. It derives its name from the biological evolution of living beings in the real world. This algorithm is seeking to simulate the process of natural selection in an environment

Unfavorable, drawing inspiration from the theory of evolution proposed by C. Darwin. Such that the most suitable "individuals" tend to live long enough to reproduce while the weaker ones tend to disappear.

Moreover, this approach is called nonlinear because it takes into account the nonlinear nature of the power system already ignored by the other methods. The influence of the adaptation of PSS parameters is described in this paragraph where we can summarize the main stages of GA as follows:

1. Initialization of the population of individuals.
2. Parameter selection: allows to specify the choice of parent selection for the new generation in the genetic algorithm.
3. Reproduction: The "strongest" individuals will be able to reproduce and have more descendants than the others. Each chromosome consists of a set of elements called characteristics or genes. The goal is to find the optimal combination of these elements that gives a maximum "fitness". At each iteration (generation of population), a new population is created from the previous population.
   Parameter crossing: demonstrates the combination of two parent individuals in order to form the children's individuals for the new generation in the genetic algorithm.
   Parameter mutation: specifies the random change of an individual's chromosome in a population to form the new generation mutated child individual.
4. Calculate the objective function (fitness) and verify the stop criterion.
5. Complete with a new population and return to the second step.

The necessary steps of the genetic algorithm can be summarized in the flowchart shown in Fig.3.

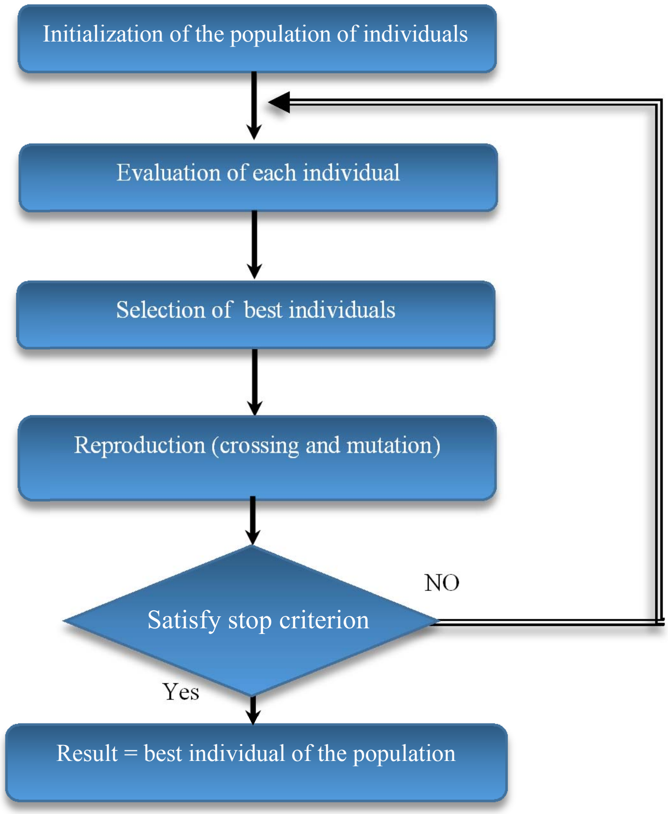

Fig.3. Genetic Algorithm flowchart.

In this work and by applicating the genetic algorithm, our objective is to find the optimal parameters (K_{stab}, T_1, T_1) of the proposed stabilizer "GAPSS".

For this purpose, we have chosen to minimize the variation of the angular speed. According to the objective function J (fitness) defined by the following criterion:

$$J = ITAE = \int t.|\Delta\omega|dt \quad (7)$$

As a general rule, the system will be better adjusted so that the criterion "the integral of the absolute error multiplied by the time" chosen will be minimized.

The parameters of the genetic algorithm such as the population size, the probability of crossing, the probability of mutation and the number of generation are given in Table 1. Moreover, the research area of the system parameters is described in this table.

Table 2 contains different system parameters. It is shown that there is a difference between optimized and non-optimized values.

Table. 1. Genetic Algorithm parameters.

The parameters of the genetic algorithm		Research Area
Type of coding	Decimal	
Population size	100	$1 \le K_{stab} \le 50$
Probability of crossing	0.9	$0.01 \le T_1 \le 0.5$
Probability of mutation	0.01	$0.01 \le T_2 \le 0.5$
Number of generation	500	

Table. 2. System parameters.

Parameters	*Optimized Values*	*Non Optimized Values*
K_{stab}	11.9498	10
T_1	0.3056	0.154
T_2	0.2530	0.154

IV. Simulation Results and Discussion

To highlight the effect of PSS parameters optimization by genetic algorithm, we propose as a three-phase fault short circuit.

The following fault sequences are simulated:

Stage 1: The system is in a pre-fault steady-state.

Stage 2: A fault occurs at $t = 0.5s$.

Stage 3: The fault is removed by opening the breaker of the faulted line at $t = 0.6s$.

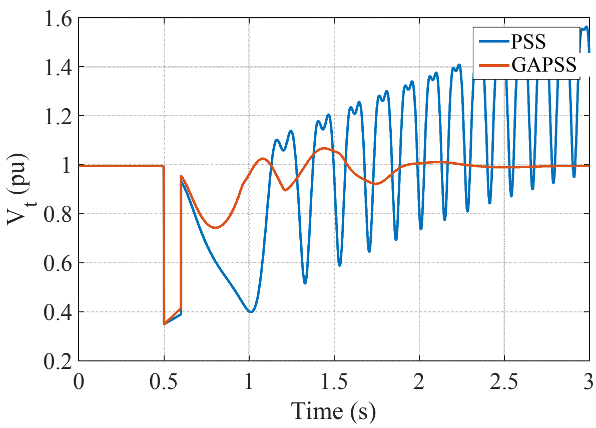

Fig. 4. Terminal voltage of generator responses.

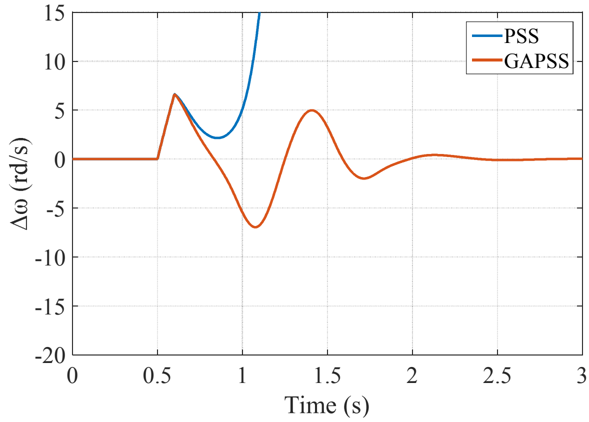

Fig. 5. Relative speed responses

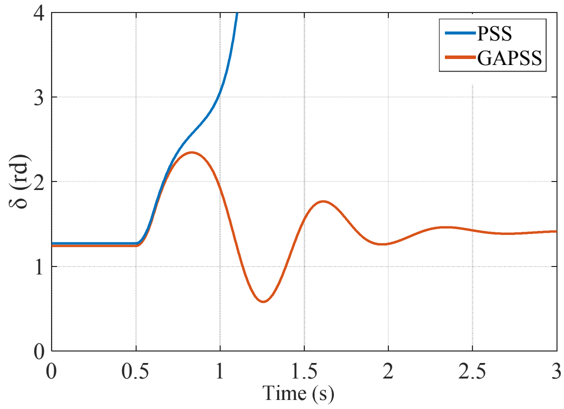

Fig. 6. Power angle responses.

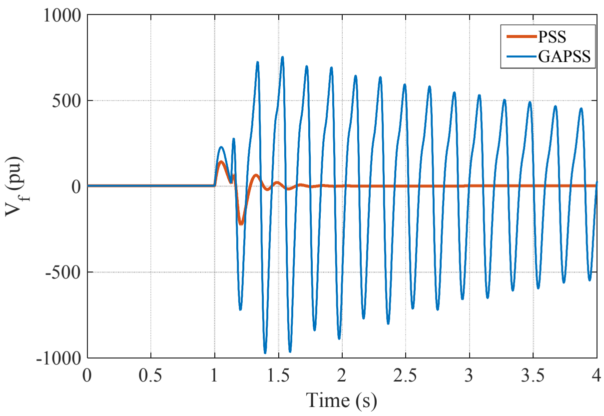

Fig. 7. Field voltage responses.

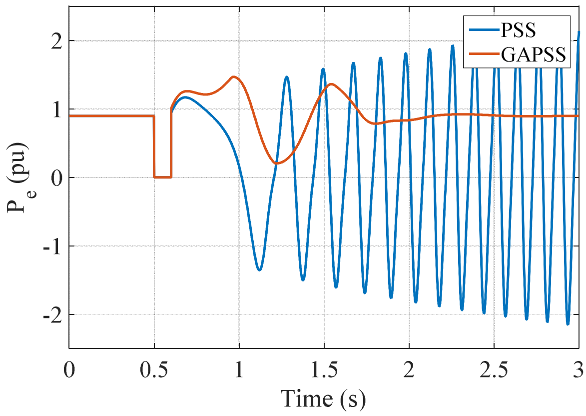

Fig.8. Active power responses.

Fig.4, Fig.5, Fig.6, Fig.7 and Fig.8 clearly demonstrate the effectiveness of Genetic Algorithm (GA) optimization, resulting in better performance results; Speed response (short response time), stable system (elimination of exceedances).
The optimal response obtained using AG is very satisfactory, comparing the results obtained before and after the optimization The results obtained, after optimization by AG show a better stability with damping the oscillations.

Different generator parameters are given in Table.3.

Table. 3. System parameters.

H	$\mathbf{x_{L1}}$	**D**	$\mathbf{x_{L2}}$	$\mathbf{x_d}$	$\mathbf{x_T}$
4	0.4853	5	0.4853	1.863	0.127
$\mathbf{E_{fmax}}$	$\mathbf{E_{fmin}}$	$\mathbf{x'_d}$	$\mathbf{T'_{d0}}$	$\boldsymbol{\omega_0}$	$\mathbf{f_0}$
$\mathbf{7pu}$	$-7pu$	0.257	6.9	314.159	$50Hz$

Network parameters are: $V_s = 1pu,\ f_0 = 50Hz$

Excitation system parameters are: $K_a = 200,\ T_a = 0.15$; $E_{fmax} = 7pu,\ E_{fmin} = -7pu;\ k_c = 1$

V. CONCLUSION

The aim of this paper is to design and apply an approach for parameter optimization of power system stabilizer with led-lag structure. The genetic algorithm approach is used to solve this problem. The integral time absolute error is chosen as the objective function to be minimized in order to evaluate the performance of the proposed controller GAPSS. The proposed approach has shown an improvement in the stability of the SMIB power system while applying a short circuit perturbation on the system.

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