# An Improved Genetic Algorithm based Power System Stabilizer for power system stabilization

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*Abstract*—**This paper considers the damping of the local-mode power system oscillation using Lead-Lag power system stabilizer (PSS). Thus, a simple single-machine infinite-bus power system is used. The Lead-Lag PSS parameters are tuned using Genetic Algorithm Optimization (GAs). Simulation results are presented with and without the proposed controller. Also, a comparison study is presented when using the conventional Lead-Lag PSS, Simple Genetic Algorithm Optimization-based PSS, and when using the Improved Genetic Algorithm Optimization-based PSS. The results obtained show the significance of using improved Genetic Algorithm Optimization as compared to using conventional PSS and Simple Genetic Algorithm based PSS.**

*Keywords—Power system oscillation, Genetic Algorithm Optimization, Improved Genetic Algorithm Optimization, Lead-Lag Power System Stabilizer (PSS)*

## I. INTRODUCTION

The electrical energy is a prerequisite for economic growth. Due to the deregulation of the electric power system and an increase in demand, the modern power system operates under different stressed conditions. The stressed causes many problems regarding the operation and control of power system. Consequently, the economics of power generation has significant concern for the utilities. Therefore, the power utilities always need new technology to solve its problems [1]

An interconnected power system consists of several essential components. They are the generating units, the transmission lines and the loads. During operations, there may be disturbances such as fault on the lines, periodic variations in the torque that is applied to the generator or changes in lighting loads. These disturbances can be referred to as faults. These faults may result in voltage or frequency fluctuation and rotor angle instability. When a fault occurs, it causes the generator to lose synchronism. With this in mind, the essential condition for a stable power system is synchronism. Other necessary conditions include steady-state stability, the collapse of voltage and loss of reactive power [2].

The stability of a system is the ability of the power system to develop restoring force equal to or greater than the disturbing force to maintain the state of equilibrium [3]. There are several major blackouts caused by the instability of a power system that proved the importance of this phenomenon [4]. Therefore, stability has been recognized as an essential problem for reliable and secure system operation since the 1920s [5].

Damping of power system oscillation is essential for ensuring reliable and secure system operation. The continuous persistence of these power system oscillations (0.2-2.0Hz) also called power swings hinders the transfer of bulk power across weak transmission lines [6]. The mathematical model presented for small signal stability analysis is a set of linear time-invariant differential equations [7]. The stability under the condition of small load changes has been called steady-state stability [8]. The synchronous machine stability as a result of excitation and the phenomenon of stability of synchronous machines under small perturbations in the case of the single machine infinite bus connected through external reactance is presented in F.P. Demello and C. Concordia [9]. In the early 1960s, the fast-acting high-gain automatic voltage regulators (AVR) were used in the generator excitation system which in-turn invites the problem of low-frequency electromechanical oscillations in the power system by decreasing the damping torque. To reduce the low-frequency oscillations, the PSS adds a stabilizing signal to the automatic voltage regulator to modulate the generator excitation system. This resolves the oscillatory stability problem and enhances power system damping. The commonly used type of PSS is known as conventional PSS (CPSS) [10], which consists of the lead-lag type components. The control and power engineers made a significant contribution to CPSS design after the pioneering work of demello and Concordia [11]. After that, most designs were developed using modern control theory, like eigenvalue (pole) assignment and optimal control [12], adaptive control [13]. These methods require extensive knowledge of power system dynamics and long processing time.

In recent years, artificial intelligence-based learning and tuning techniques have been used to design PSSs. These include artificial neural networks (ANNs) [14], fuzzy logic [15], adaptive fuzzy [16] and neuro-fuzzy [17]. While for complex and multi-dimensional power system problems, heuristic optimization techniques such as Particle Swarm Optimization (PSO) [18], Tabu Search Algorithm [19], Simulated Annealing (SA) [20], Bacteria Forging Algorithm (BFA) [21] and genetic algorithm (GAs) [22, 23] were deployed.

This paper focus on the design and evaluation of an improved PSS method for the stability enhancement of a single machine infinite bus power system using Lead-Lag PSS whose parameters are tuned using Genetic Algorithm. The paper is presented as follows: Synchronous machine model is presented in section II, a brief of PSS is given in section III, section III.F discusses the Genetic Algorithm (GAs), and the improved GA is discussed. Section IV presents simulation and discussion of results. Concluding remarks are highlighted in section V.

## II. TEST SYSTEM MODEL

The system under consideration consists of a single machine connected to an infinite bus system (SMIB) through transmission lines, as shown in Fig. 1.

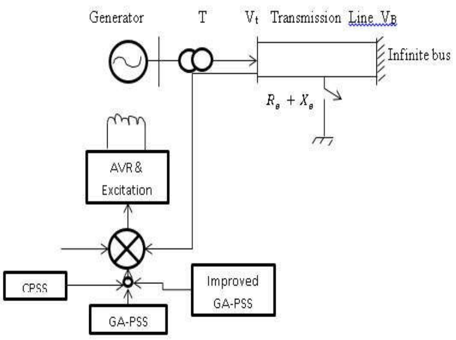

Fig. 1. Schematic line diagram of a single machine infinite- bus power system

In this work, the model equations described by the Heffron-Phillips model is used to represent the power system as shown in the block diagram-Figure 2. In this model, the synchronous machine is described by a 4th-order model. The relation in the block diagram applies to a two-axis machine representation with a field circuit in the direct axis without damper windings. The interaction between the speed and the voltage control equations of the machine is given in terms of the six constants K1-K6 which depend on the real and reactive power loading of the machine except for k3. The linearized equations describing the system are shown in the relations (1) to (4).

$$\Delta\dot{\omega} = \frac{1}{2H}(-K_D\Delta\omega - K_1\Delta\delta - K_2\Delta\psi_{fd} + \Delta T_m) \tag{1}$$

$$\Delta\dot{\delta} = \omega_o\Delta\delta \tag{2}$$

$$\Delta\dot{\psi}_{fd} = -\omega_o R_{fd}\left(\frac{m_1 l'_{lads}}{l_{fd}}\right)\Delta\delta + \ldots \tag{3}$$
$$\left[\frac{1}{l_{fd}} - \frac{l'_{ads}}{l^2_{fd}} + \frac{m_2 l'_{lads}}{l_{fd}}\right]\Delta\psi_{fd} + \frac{K_A}{l_{adu}}\Delta v_1$$

$$\Delta\dot{V}_1 = \frac{1}{T_R}(K_5\Delta\delta + K_6\Delta\psi_{fd} - \Delta v_1) \tag{4}$$

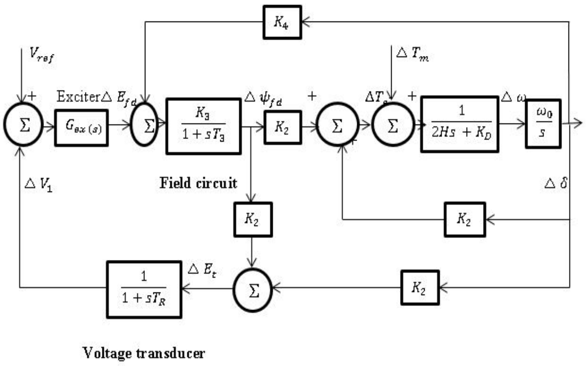

Fig. 2. Heffron-Phillips model for SMIB

## III. THE IMPROVED POWER SYSTEM STABILIZER

Power system stabilizers (PSS) are designed to aid in damping the oscillations via modulations of the excitation system of generators. The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. The change in rotor speed is taken as input to the PSS, as shown in Fig. 3. To provide damping, stabilizers must produce a component of electrical torque on the rotor which is in phase with speed variations. However, the conventional PSS is tuned around a steady-state operating point; their damping effect is only valid for small excursions around this operating point. To overcome this drawback, this paper considers tuning of PSS using the intelligence of genetic algorithms. The sections that follow explains the approach used in this work.

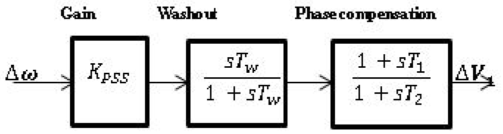

Fig. 3. Structure of power system stabilizer

### A. Gain block

The stabilizer gain, K_PSS determines the amount of damping introduced by the PSS. Ideally, the gain should be set at a value corresponding to maximum damping, however, it is often limited by other system considerations. Therefore, in this work, it is set to a value which provides satisfactory damping of the critical mode(s) of the system. And without compromising the stability of other modes or transient stability so as not cause excessive amplification of stabilizer input signal noise [24].

### B. Washout Circuit

The signal washout block serves as a high-pass filter, with the time constant Tw high enough to allow signals associated with oscillations in $\omega_r$ to pass unchanged. Without the washout circuit, steady changes in speed would modify the terminal voltage. It allows the PSS to respond only to changes in speed. From the viewpoint of the washout function, the value of Tw is not critical and may be in the range of 1 to 20 seconds. The main consideration is that it be long enough to pass stabilizing signals at the frequencies of interest unchanged, but not so long that it leads to undesirable generator voltage excursions during system islanding conditions.

### C. Phase Compensation Block

The phase compensation block provides the appropriate phase – lead characteristic to compensate for the phase lag between the exciter input and the generator electrical (air-gap) torque. The figure shows a single first-order block. In practice, two or more first-order blocks may be used to achieve the desired phase compensation. Normally the frequency range of interest is 0.1 to 2.0 Hz, and the phase lead network should provide compensation over this entire frequency range. The phase characteristic to be compensated changes with system conditions. Therefore, a compromise is made, and a characteristic acceptable for different system conditions is selected.

### D. Input Signals

The input signals that have been identified as valuable include deviations in the rotor speed ($\Delta\omega$), the frequency ($\Delta f$), the electrical power ($\Delta Pe$) and the accelerating power ($\Delta Pa$). Since the main action of the PSS is to control the rotor oscillations, the input signal of rotor speed has been the most frequently considered in the literature. Therefore, a speed signal is used as an input signal. The output is the stabilizing signal $V_1$ which is added to the reference excitation system voltage. The transfer function of PSS is given by equation (5) as obtained from Fig. 3.

$$G_{PSS} = \frac{ST_W}{1+ST_W}\frac{(1+ST_1)}{(1+ST_2)} \quad (5)$$

### E. Phase Compensation Design Technique

In the phase compensation technique, the design of the PSS should set the phase of the PSS, $\angle G_{pss}(j\omega_s)$, to be equal to the negative phase of the forward path, $\angle F_{pss}(j\omega_s)$. This implies that the PSS is such that it compensates for the phase Lag of the forward path through the generator excitation system. Therefore, the torque changes in phase with speed and it produces a pure positive damping torque. This is a simpler approach and easy to implement. The phase lag depends on the operating point and the system parameters.

To increase the system damping over a wide range of operating conditions and configuration of the power system, a more robust tuning must be incorporated. This is so because, the power system oscillations which the proposed controller is designed to minimize are reflected in the deviations in power angle, rotor speed and line power. Thus, minimizing any one or all of the above deviations can be chosen as the objective function. The PSS design formulated in this study is an integral time absolute error of the speed deviation based objective function. The objective function is described by equation (6).

$$J = \int_{t=0}^{t=t_{sim}} (|\Delta\omega| \cdot t \cdot dt) \quad (6)$$

Where $\Delta\omega$ is the speed deviation, and $t_{sim}$ is the time range of simulation. The optimization constraints are the bounds/limits on the parameters to be optimized, such as time constants and the gain. Thus, the optimization problem is subjected to equations (7) to (9).

$$K^{\min} \le K \le K^{\max} \quad (7)$$

$$T_1^{\min} \le T_1 \le T_1^{\max} \quad (8)$$

$$T_2^{\min} \le T_2 \le T_2^{\max} \quad (9)$$

Typical values of the optimized parameters are taken as [0.1-1.5] for T_1, [0.02-0.15] for T_2 and [0.1-20] for K. the time constant is considered as 1.4

### F. Genetic Algorithm

Genetic algorithms (GAs) were first introduced by John Holland in the 1970s (Holland 1975) as a result of investigations into the possibility of computer programs undergoing evolution in the Darwinian sense. GAs are robust search and optimization techniques which were developed based on the ideas and techniques from genetic and evolutionary theory [25]. They attempt to find an optimal solution through the process analogous to the biological process. Starting with a random population of chromosomes, a genetic algorithm chooses parent from which to reproduce offspring by applying operations analogous to biological processes, usually crossover and mutation. All chromosomes are evaluated using a fitness function known as an objective function to determine their “fitness”. These fitness values are then used to decide whether the chromosomes are eliminated or retained.

According to the principle of the survival of the fittest, the fitter chromosomes are kept, and the less fit chromosomes are discarded in the course of generating a new population. The new population replaces the old one, thereby reducing the search space for GA. The whole process is repeated until a stopping criterion is met. The stopping criterion could be a maximum number of generations, population convergence criterion, lack of improvement of the best solution over a specific number of generations, or target value for the objective function. GA researchers focus on enhancing the performance of GA by solving the problem of poor convergence, [26]. Researchers look for optimal control parameters such as the mutation rate, crossover rate, or population size to enhance the performance of the GA. The optimal control parameters are determined for tuning the PSS. The computational flowchart of the GA optimization process employed in this study is given in Fig.4.

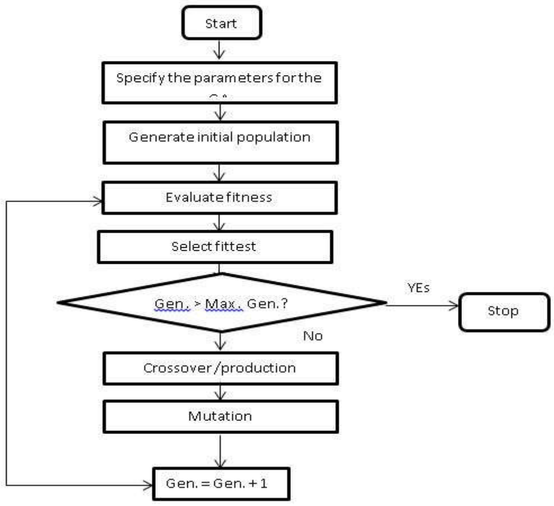

Fig. 4. The computational flowchart of the GA optimization process

### G. Improved Genetic Algorithm

The selection and crossover operations in GA on their own generate a large number of different strings, which causes two main problems. Firstly, inadequate diversity in the initial strings which ensure the GA’s exploration ability to search the entire problem space, and secondly, convergence of the GA on sub-optimum strings. These may be overcome by the mutation operator in the GA; the performance of GA is sensitive to the mutation rate.

Mutation operator occasionally alters a bit in a string to improve its fitness. The mutation probability is typically low in other not to destroy a fit string and degenerate the GA into random search.

Although most researches focus on finding optimal crossover or mutation rates. However, since there is a higher sensitivity of a GA performance to mutation rate than to crossover rate, this article focusses on optimal mutation rate. Researchers often use either variable or constant mutation rate. Herein, the mutation rate is constant throughout the optimization run, and the adopted range is 0.01 - 0.0.5. The mutation ratio of all the mutation operators are equal and calculated according to the equation (10) multiply by the highest mutation rate N.

$$Mutation\,ratio = \frac{1}{N} \quad (10)$$

The data and parameters of the model presented in Fig. 1 are provided as follow.

- Generator parameter in (pu)

$X_d = 1.81$pu,; $X_q = 1.76$pu; Xd^' = 0.30, Td0^' = 8.0s, KA = 200, TR = 0.002, H = 3.5, K_D = 0ω_0 = 100π

- Exciter parameters for the generator

$K_A = 200$ ; $T_R = 0.002$s

- Transmission line parameters in (pu)

$r_{L1}=0$; $X_{L1} = 0.5$; $rL_2=0$; $XL_2 = 0.93$.

- Washout filter parameter

$T_w = 1.4$s.

## IV. SIMULATIONS AND RESULTS

The response of the SMIB power system under the following scenarios is determined by simulations and compared:

- The SMIB only (i.e. generator without PSS)
- The generator is equipped with conventional PSS - CPSS
- The generator is equipped with a GA tuned conventional PSS (GACPSS).
- The generator is equipped with a GA tuned conventional PSS (IMGAPSS).

The comparison of responses is recorded in Figs. 5-8. The responses due to CPSS can stabilize the plant but with a higher settling time as compared to GACPSS and IMGAPSS. Since the oscillations are damped out much faster with IMGAPSS, it demonstrates the potential and superiority of the proposed design approach to obtain an optimal set of parameters of CPSS using Genetic Algorithm. Table I and Table II indicates the improvement of the damping ratio and settling time respectively.

TABLE I: Eigenvalue, Damping Ratio and Oscillatory Frequency of the Electro-Mechanical Modes

| Power System Model | Eigenvalue | Damping Ratio | Frequency Hz |
|---|---|---|---|
| **Without PSS** | +0.504 ± j7.23 | -0.07 | 1.15 |
| **With CPSS** | -1.005±j6.607 | 0.15 | 1.05 |
| **With GAPSS** | -8.9334 ± 3.7797 | 0.9 | 0.6 |
| **With IMGAPSS** | -10.3224 ± 2.5619 | 0.97 | 0.41 |

TABLE II: Settling time for rotor angle responses with CPSS, SGAPSS, IMGAPSS and without PSS.

| Settling time with IMGAPSS | Settling time with SGAPSS | Settling time with CPSS | Settling time without PSS | % Improvement by IMGAPSS wrt SGAPSS |
|---|---|---|---|---|
| 1.7 | 3.2 | 8.2 | oscillatory | 46.875% |

From the speed and rotor angle responses without PSS and control of Figs. 5 and 6, the amplitude of oscillation increases with time.

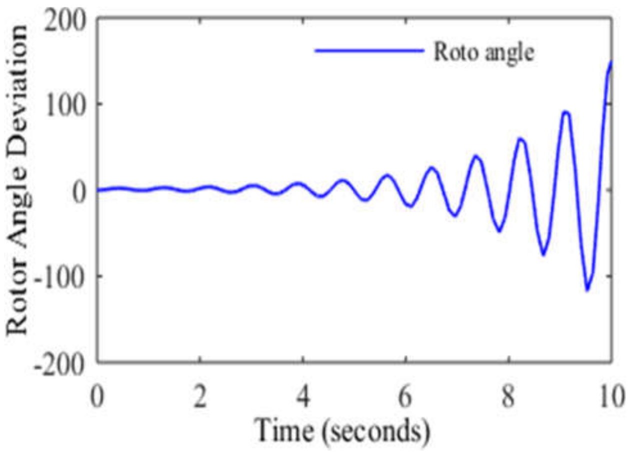

Fig. 5. Rotor Angle Response without PSS

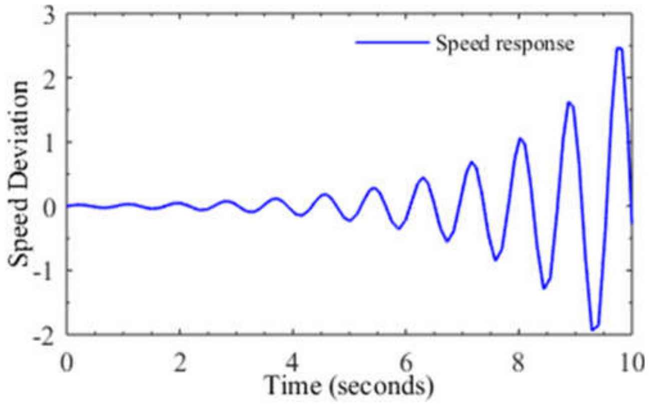

Fig. 6. Speed response without PSS

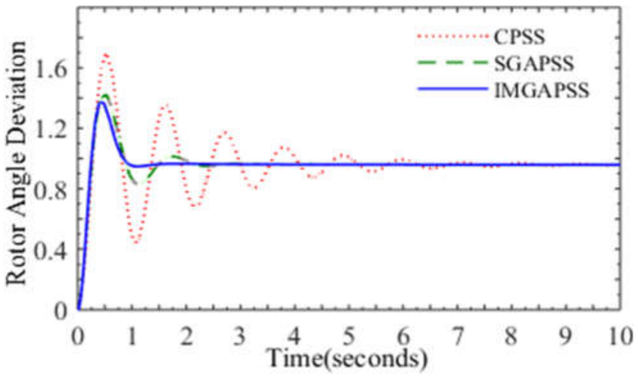

Fig. 7. Rotor angle deviation with CPSS, SGAPSS and IMGAPSS

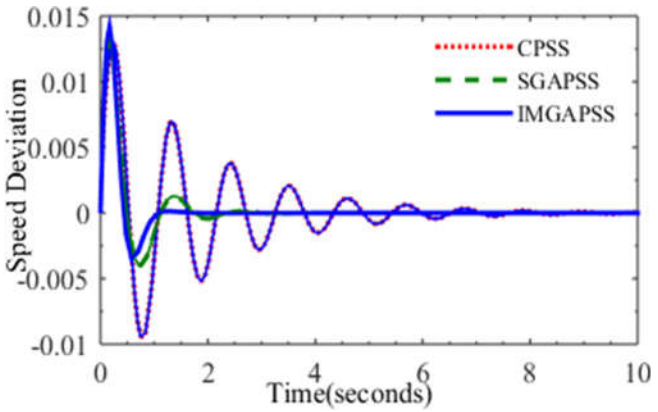

Fig. 8. Speed deviation with CPSS, GAPSS and IMGAPSS

## V. CONCLUSION

In this paper, CPSS is designed for a single-machine infinite bus power system. The gain and time constants (zeros and poles) of CPSS are optimized by using GA and improved GA. The simulation results for the deviations in the speed and the angle of the generator for SMIB power system without PSS, with CPSS, with the GAPSS and with IMGAPSS are compared. It is found that the response with CPSS has prolonged settling time as compared against reduced settling time with GACPSS and IMGAPSS. Since, the oscillations are damped out much faster with IMGAPSS as compared with the system equipped with the CPSS and SGAPSS, the superiority of the proposed design approached to obtain an optimal set of parameters of CPSS using IMGAPSS is illustrated. It is clear from Table 2 that the settling time is improved from 8.2 to 1.7 which reveals the advantage of the IMGAPSS.

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