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Coordinated Design of PSS and SSSC Damping Controller using PSO & GA -based Optimization Algorithm

Yaminee Verma[1], Kumar Prabhakar[2]

[1, 2]IES College of Technology, Bhopal, Kalkheda, Ratibad Main Road, Bhopal-462044, Madhya Pradesh, India

Abstract: ***In this paper, a coordinated design of PSS and SSSC controller to improve the damping of low frequency oscillations is shown. The design problem has been considered an optimization problem based on Genetic Algorithm & Particle Swarm Optimization (PSO) is used for searching the optimal controller parameters. The proposed controller is employed for a Kundur two area four machines systems. The results are displayed under small disturbance, to present the efficiency of the proposed method. The proposed controller provides sufficient damping for power system oscillations, under small disturbances. Results analysis shows that the use of PSO-based optimization algorithm has a higher efficiency in damping oscillations of the power system, compared with the GA, and increases the dynamic stability more.***

Keywords: Power system stabilizer, SSSC, Low frequency oscillations, Genetic Algorithm (GA), Particle Swarm Optimization (PSO).

1. Introduction

Due to increasing electric power demand, power systems operate close to their stability limit. In this case modern power systems can reach the stressed conditions more easily than past era. In this situations occurrence of any contingency or disturbance may lead to instability or poorly damped oscillations [1]. With growing electric power demand, the inter-area low frequency oscillations become a biggest problem for power system engineers and often suffer from poor system damping [2]-[4]. Many power systems has been affected by such type of inter-area oscillations whose frequency lie between 0.1 Hz to 1 Hz and sometimes these inter-area oscillations causes blackout [5]-[6].

The conventional method to damp out such type of inter-area oscillations generally we installed Power System Stabilizer (PSS) at each generator which uses local signal such as rotor speed, accelerating power as a feedback signal. However, these controllers usually employ local signals as inputs and may not always be effective to damp out the inter area mode of oscillations, generally due to lack of global observation.

The Synchrophasor technology based Wide Area Monitoring and Control System (WAMCS) forms an important part of the smart grid to enhance the system security. This employs PMUs, which provide synchronized and time stamped voltage and current phasor in real time from various substations. These measurements have better observability of the inter-area oscillations than the local signals, and can be effectively utilized to design Wide Area Damping Controllers (WADC) [6]-[9].

To damp out such type of interarea oscillations, conventional PSS used whose design normally uses classical control theory and is based on linearized model of power system at one operating point [10]. Such PSS cannot provide optimal or guaranteed stable performance over a wide range of operating conditions [11]-[12]. So, robust PSSs are put under observation to provide satisfactory results over a wide range of operating points [13]-[14].

However, at present, power electronic technologies have been developed. They are more effective in increasing the amount of transmitted power with improving the dynamic performance and more precise to control the route of the power flow. These technologies are referred to use Flexible AC Transmission System (FACTS) in power systems.

Modern utilities are beginning to install FACTS devices in their transmission networks to increase the transmission capacities and enhance controllability. In view of their advantages, there is a growing interest in the use of FACTS devices in the operation and control of power systems. There are two main aspects that should be considered while using FACTS controllers: The first aspect is the flexible power system operation according to the power flow control capability of FACTS controllers. The other aspect is the improvement of stability of power systems [15].

Due to the technology advancements in power electronics, the trend of using FACTS devices in power systems both transmission and distribution levels is increasing. If FACTS and wide-area power system monitoring and control system (WAMS) technologies are used together, they can help improve the stability performance of power systems. In this study, the Static Synchronous Series Composator (SSSC) which is a series connected FACTS controller based on Votage Source Conveter (VSC) is used to control the tie-line power flow between two areas of a study power system.

Normally, the input control signal of SSSC can be obtained locally from these signals, such as voltage, current, active power flow, frequency, etc. However, in order to obtain better performance, two Phasor Measurement Units (PMUs) are installed in different areas so as to detect the inter-area oscillation more obviously. The control signal obtained by PMUs is used as the control input of SSSC damping controller.

Moreover, in this paper, a simple SSSC based controller designed based on change in speed deviation as a input signal. Then the other parameters of controller are optimized by Genetic Algorithm (GA) and Partical Swarm Optimization (PSO).

This paper is divided into five sections. The first section is the introduction mentioning about the problem of power oscillations and the adoption of a SSSC to solve the power oscillation issues. Section 2 describes the configuration of the study power system with SSSC. Section 3 presents the design of the proposed controller for a SSSC. Furthermore, the parameters of the PSS optimization method to obtain better performance and robustness based on GA & PSO. Section 4 shows the simulation results of the proposed controller and the comparison results. Finally, it ends with the conclusions in section 5.

2. Study Power System

The test system for this research work is shown in figure-1 [2]. The system consists of two symmetrical areas linked by two parallel tie-line of length 220 Km and 230 kV. Each area is equipped with two identical round rotor generators rated 20 kV/900 MVA. All four generators have identical parameters, except inertia coefficient (H), which are H = 6.5s for Gen-1 and Gen-2 in area-1 and H = 6.175s for Gen-3 and Gen-4 in area-2.

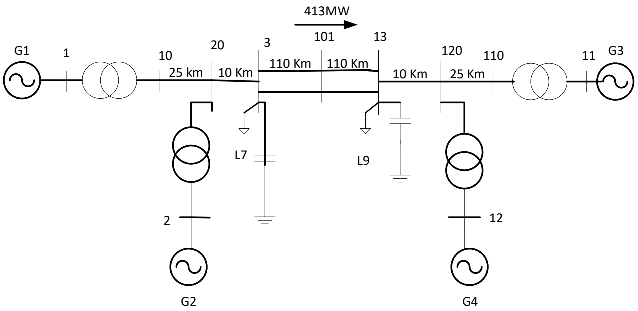

Figure 1: Kundur two-area four-machine system

3. The Proposed Control Method

3.1 Structure of PSS and SSSC

Figure -2 shows a damping controller structure which is basically used to control the voltage injected (V_q) by the SSSC. The change in speed deviation ($\Delta\omega$) of G-2 and G-4 is considered to be the input of the controllers and V_q is considered to be the output of the controller. The damping structure considered here consists of three blocks [16], namely gain block with gain K_{stab}, determines the amount of damping introduced by the PSS. A washout high-pass filter with time constant T_W, which eliminates the low frequencies that are present in the speed signal and allows the PSS to respond only to speed changes and two-stage phase compensation block as shown in figure-2. The signal washout block will serve as a high-pass filter and the appropriate phase-lead characteristics will be provided by the phase compensation block, with time constants T_1, T_2, T_3 and T_4.

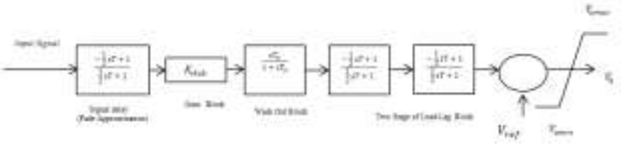

Figure 2: Structure of SSSC based damping controller

3.2 Optimization Method

3.2.1 Genetic Algorithm (GA)

The GA is basically a search algorithm in which the laws of genetics and the law of natural selection are applied. For the solution of any optimization problem (using GA), an initial population is evaluated which comprises a group of chromosomes. Initially, a random population is generated, then from this population fitness value of each chromosome is calculated. This can be found out by calculating the objective function by the process of encoding. Then a set of chromosomes termed as parents are evaluated which are known as offspring generation, which are generated from the initial population. The current population is replaced by their updated offspring that can be obtained by considering some replacement strategy. Figure-3 shows the flow chart for the Genetic algorithm [17].

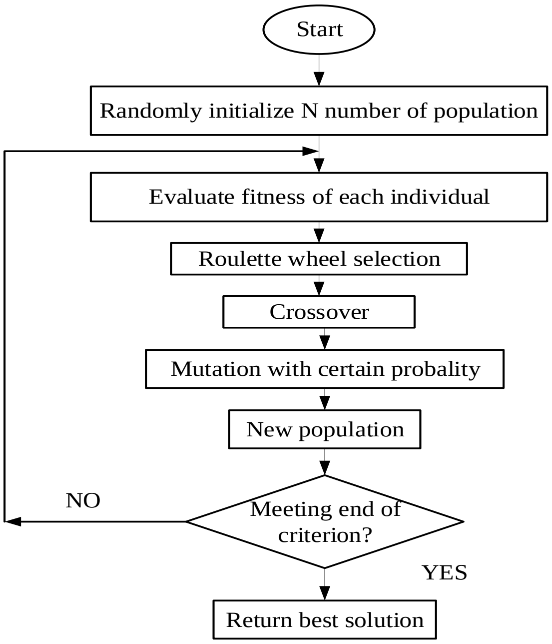

Figure 3: Flow Chat for GA

The genetic algorithm begins with a set of solutions (represented by chromosomes) called the population. Solutions from one population are taken and used to form a new population. This is motivated by the possibility that the new population will be better than the old one. Solutions are selected according to their fitness to form new solutions (offspring); more suitable they are, more chances they have to reproduce. This is repeated until some condition (e.g. number of populations or improvement of the best solution) is satisfied.

The oscillation of a system can be seen through the tie-line active power deviation or speed deviation of rotor. To minimize the oscillation of any deviation is research objective. For kundur's two area four machines system, integral of time error of speed deviation for G-2 and G-4 taken as a objective function (J).

$$J = \int_{t=0}^{t_{sim}} \left|\Delta\omega\right|.t.dt$$

where

t_{sim} = simulation time range.

For a stipulated period of time, the time domain simulation of the above power system is worked out and from the simulation the calculation for the objective function is calculated. The prescribed range of the PSS and damping controller are limited in a boundary. Thus the following optimization problem is formulated from the above design approach.

Minimize J
Subject to:

$$t_{1i}^{\min} \le t_{1i} \le t_{1i}^{\max}$$
$$t_{2i}^{\min} \le t_{2i} \le t_{2i}^{\max}$$
$$t_{3i}^{\min} \le t_{3i} \le t_{3i}^{\max}$$
$$t_{4i}^{\min} \le t_{4i} \le t_{4i}^{\max}$$

where $t_{ji}^{\min}$ and $t_{ji}^{\max}$ are the lower and upper bound of time constant for the controllers. All four time constants have same range of lower and upper limits: 0.01 to 1.

3.2.2 Particle Swarm Optimization (PSO)

Particle Swarm optimization (PSO) Particle Swarm Optimization is swarm intelligence based optimization method which was first introduced by Kennedy and Eberhart in 1995 [18]. High quality solutions within shorter calculation time and stable convergence characteristics can be obtained by the algorithm. It uses particles which represent potential solutions of the problem. Each particle fly in search space at a certain velocity which can be adjusted in light of proceeding flight experiences. The projected position of ith particle of the swarm x_i, and the velocity of this particle v_i at (t+1)th iteration are defined from the following two equations:

$$v_i^{t+1} = w.v_i^t + c_1 r_1\left(p_i^t - x_i^t\right) + c_2 r_2\left(g_i^t - x_i^t\right)$$
$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

where, i = 1, ..., n and n is the size of the swarm, w is inertia weight decreased linearly, c_1 and c_2 are positive constants, r_1 and r_2 are random numbers which are uniformly distributed in [0, 1], t determines the iteration number, p_i represents the best previous position of the ith particle and 'g' represents the best particle among all the particles in the swarm. At the end of the iterations, the best position, 'g', of the swarm will be the solution of the problem [18].

4. Simulation Results of Proposed Controller

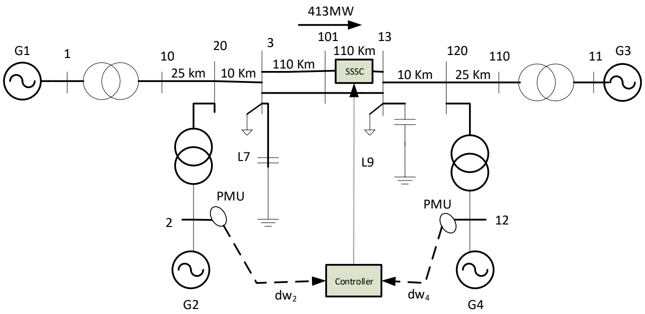

Figure 4: Two-area four-machine interconnected power system with a SSSC installed in series with the transmission line

The structure of study power system with proposed controller as shown in figure-4. The SSSC is installed in series with the transmission line between B-101 and B-13. For wide-area control, two Phasor Measurement Units (PMUs) are installed at G-2 and G-4 respectively to measure the speed difference between two generators representing the inter-area oscillation mode. For this research work the value of controller gain taken as K =101.0779 [19] and other parameters of proposed controller after GA & PSO optimization tabulated in Table – 1

Table 1: Optimized Controller Parameters Using GA & PSO

	T_1 (S)	T_2 (S)	T_3 (S)	T_4 (S)
GA	0.9067	0.9142	0.1066	0.5514
PSO	0.8147	0.4387	0.3517	0.1067

4.1 Small Signal Stability Assessment

To perform the dynamic analysis of the closed loop test system for Kundur two area four machine systems as shown in figure 4, a small pulse with magnitude of 5% as a disturbance was applied to the generator G-1 for 12 cycles.

The simulation time was of 20 seconds. Then the response of tie-line active power flow from area-1 to area-2, rotor speed deviation, rotor mechanical angle deviation and voltage at bus B-1 and B-2 are examined by considering the test system with proposed controller.

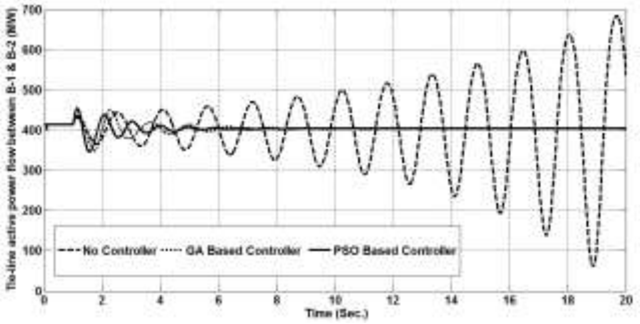

Figure 5: Tie-Line Active Power Flow

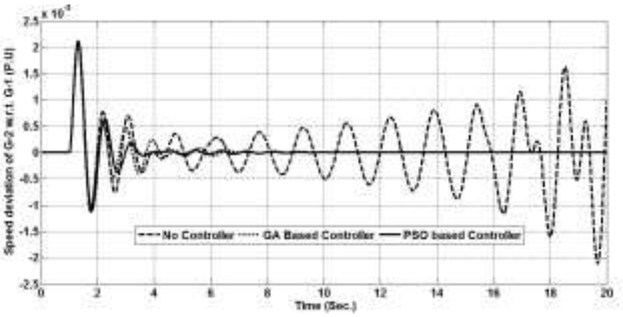

Figure 6: Speed deviation of G - 2 w.r.t. G – 1

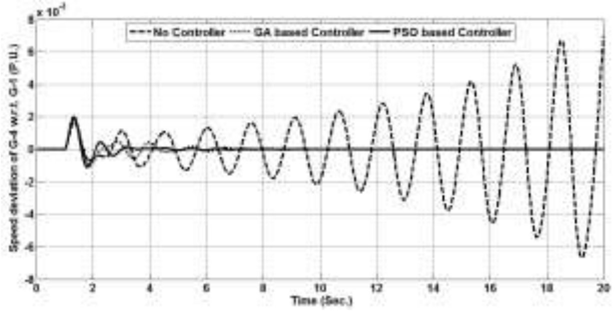

Figure 7: Speed deviation of G - 4 w.r.t. G – 1

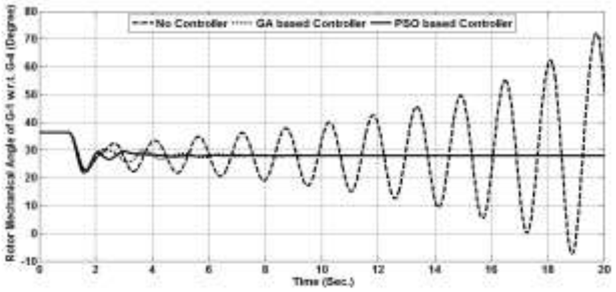

Figure 8: Rotor Mechanical Angle of G -1 w.r.t. G - 4 (Degree)

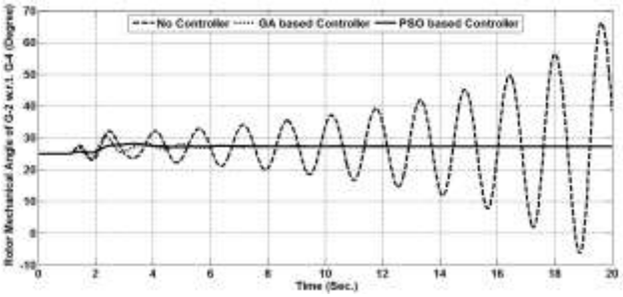

Figure 9: Rotor Mechanical Angle of G -2 w.r.t. G - 4 (Degree)

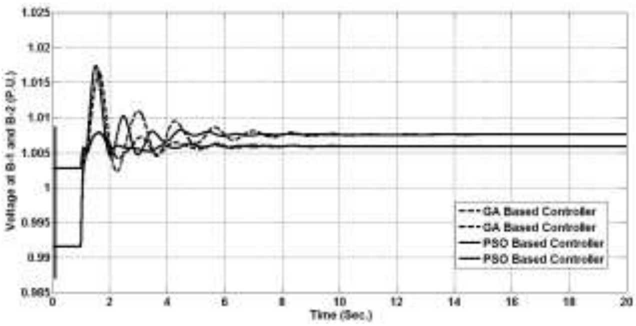

Figure 10: Voltage at B-1 and B-2 (P.U.)

5. Conclusion

In this paper researcher designed a wide-area damping controller to damp out the inter-area oscillations in a large scale power system using coordinated design of SSSC and PSS. A time domain simulation based on minimization of an objective function for the controllers is carried out by using GA and PSO. Some simulation results are carried out to verify the effectiveness of proposed controller under small disturbance. From the simulation results, it reveals that the proposed controller based on PSO damps out the inter-area oscillations more effectively as compare to GA based controller.

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