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Delay Dependent Coordinated Controller Design for SSSC & PSS to Improvement Power System Stability

Vikash Kumar[1], Kumar Prabhakar[2]

PG Student [Power System], Dept. of EX, IES College of Technology, Bhopal, Madhya Pradesh, India[1]

Assistant Professor, Dept. of EX, IES College of Technology, Bhopal, Madhya Pradesh, India[2]

ABSTRACT:The usage of remote signals obtained from a Wide-Area Measurement System (WAMS) introduces time delays, which would degrade system damping and even cause instability. In this work, design a delay dependent coordinated strucutre of Power System Stabilizer (PSS) and Static Synchronous Series Composator (SSSC) to improve the power system stability. Genetic Algorithm (GA) is used in order to find the controller parameters. Some simulations results on Kundur Two-Area Four Machine system show that the proposed controller effectively damp-out the inter-area oscillations.

KEYWORDS: Wide-Area Measurement System (WAMS), Power System Stabilizer (PSS), Static Synchronous Series Composator (SSSC), Genetic Algorithm (GA), Signal delay, Integral of Time Error (ITE).

I.INTRODUCTION

Recently, with the increasing of electric power demand, either existing power system network should be interconnected or we add new lines in existing network. The main reason for interconnection of power system network is that it can efficiently utilize various power resources distributed in different areas and achieve the optimal allocation of energy resources. This also optimizes the economic dispatch of power and gets relatively cheaper power, which implies that decrease of system installed capacity and the investment. Moreover, in case of fault or disturbance in operating condition, it can provide additional supporting power of each area of interconnected grids which can increase the reliability of generation, transmission and distribution system.

But with the expansion of new power system network, lot of restrictions like environmental factors, cost factors etc. occurs. The major problem associated with an interconnected power system when connected by a weak line is the low frequency oscillations [0.1 Hz - 1 Hz] [18] are developed. If the damping of the system is not adequate, then these oscillation leads to system separation. The inter area oscillations inherent to the large inter connected grid becomes more dangerous to the system's security and the quality of the supply during transient situation. Hence it can be said that the low frequency oscillations put limitations on operation of the power system and network's control security. The increased interconnected network of power system carries out heavy inter change of electrical energy which invokes such poorly damped low frequency oscillations that the system stability becomes major concern.

For this, the traditional approach to damp out the inter-area oscillations by using Conventional Power System Stabilizer (CPSS). The basic function of PSS is to add damping to the generator rotor oscillation by controlling its excitation using auxiliary stabilizing signal. These controllers use local signals as an input signal and it may not always be able to damp out inter-area oscillations, because, the design of CPSS used local signals as input and local signal based controller do not have global observation and may does not be effectively damp out the inter-area oscillations [22].

The effective damping mechanism is that the damping torque of synchronous generator is enhanced through proper field excitation. The application of remote signal for damping controller has become successful due to the recent

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development of Phasor Measurement Units (PMUs). PMUs have very useful contribution in newly developed Wide Area Measurement System (WAMS) technology. The initial development of PMU based WAMS was introduced by Electric Power Research of Institute (EPRI) in 1990. It is found that if remote signals come from one or more distant location of power system are used as a controller input then, the system dynamics performance can be improved in terms of better damping of inter-area oscillations [23]. The signals obtained from PMUs or remote signals contain information about overall network dynamics whereas local control signals lack adequate observability with regard to some of the significant inter-area mode. The real time information of synchronous phasor and sending the control signal to major control device (e.g. PSSs, HVDC controllers, FACTS based controllers) at high speed has now become easier due to the use of PMU [23].

The PMU can provide wide area measurement signals. The signals can be used to enhance the wide area damping characteristics of a power system. Generally a FACTS device is installed far away from the generator. On the other hand PSS is installed near to the generator. Thus a transmission delay is observed due to various signal transmission [24]. These delays should be included when designing a FACT/PSS based damping controller. Such kind of delay varies from ten to several hundred milliseconds. [25]–[27]. Generally a dedicated communication channel provides not more than 50 ms delay in any condition during transmission [28]. Pade approximation [29-30] is the effective approach to deal with this kind of constant time delay problem. Presently, in industries to damp out these oscillations, many different techniques have been introduced, such as application of Automatic Voltage Regulator (AVR) equipped with Power System Stabilizer (PSS) [13].

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 [8].

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 coordinated with PSS 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. The key factor for coordinated control system design is its robustness. In order to design robust controller to damp out inter area oscillations parametrs of controller are optimized by Genetic Algorithm (GA) based on Integral of Time Error (ITE).

This paper is divided into five sections. The first section is the introduction mentioning about the problem due to inter-area oscillations and signal delay. Section II describes the configuration of the study power system with conrdination control of SSSC and PSS. Section III presents the design of the proposed controller. Furthermore, the parameters of the PSS optimization method to obtain better performance and robustness based on GA. Section IV shows the simulation results of the proposed controller and the comparison results. Finally, it ends with the conclusions in section V.

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II. STUDY POWER SYSTEM

The test system under this research work is shown in figure-1[13]. 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 = 6.5 s for Gen-1 and Gen-2 in area-1 and H = 6.175 s for Gen-3 and Gen-4 in area-2.

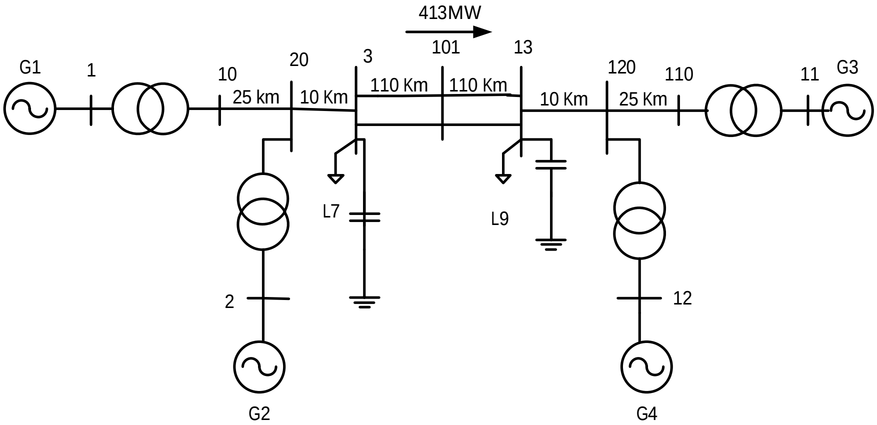

Fig. 1. Kundur two-area four-machine system

III. THE PROPOSED CONTROL METHOD

(a) Controller design considering time delay with coordinated 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 four blocks, namely signal delay block with Pade approximation, 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.

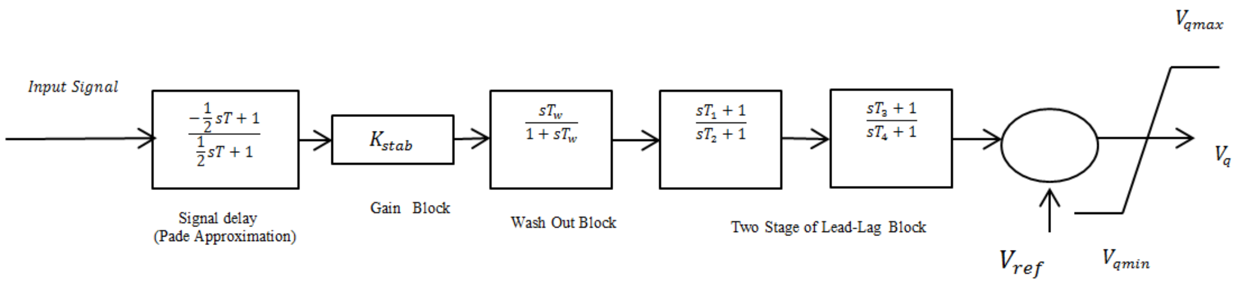

Fig.2. Structure of SSSC based damping controller

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(b) Pade Approximation

The feedback signal delay of wide-area controller affects the control effect is because the delay will introduce phase deviation at the input signal. Usually, for an oscillation mode with frequency off, the phase lag φ introduced by delay T can be obtained by

$$\varphi = 360fT$$

For example, when the dominant frequency of a WPSS is 0.5 Hz, a delay of 100 ms will introduce a phase lag of

$360^0 \times 0.5 \times 0.05 = 9^0$ (Phase lag)

It can be seen from above that the phase lag introduced by delay is determined by both the delay itself and the oscillation frequency[33]. For the same delay, the corresponding phase lag is larger with the higher frequency, and vice versa.In MATLAB, time-delays are expressed in the exponential form (e^{-sT}) in the Laplace domain. It can be replaced by a first-order Pade Approximation [32]:

$$e^{-sT} \approx \frac{-\frac{1}{2}sT + 1}{\frac{1}{2}sT + 1}$$

In this work, 50ms time-delay is taken only

(c) Optimization Method - 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, and 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 [14].

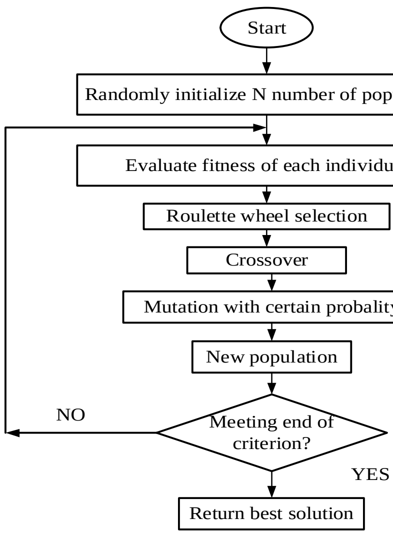

Fig. 3. Flow Chat for GA

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

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(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 oscillationof 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)

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

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.

IV. SIMULATION RESULTS OF PROPOSED CONTROLLER

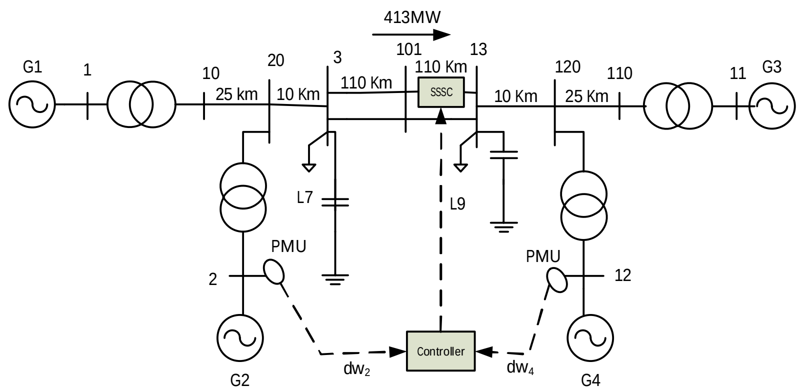

Fig.4. Two-area four-machine interconnected power system with a SSSC installed in series with the transmission line

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. The proposed control system structure includes the 50 ms delay time due to the communication system of the wide-area control.
For this research work the value of controller gain taken as K =101.0779 [12] and other parameters of proposed controller after GA optimization based on ITE criterion tabulated in Table – I.

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Table – 1 Optimized Controller Parameters Using GA

	T_1 (S)	T_2 (S)	T_3 (S)	T_4 (S)
Damping Controller (without delay)	0.9067	0.9142	0.1066	0.5514
Damping Controller (50ms delay)	0.1706	0.1156	0.8545	0.7824

V. 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 are examined by considering the test system with proposed controller with considered the effect of signal delay.

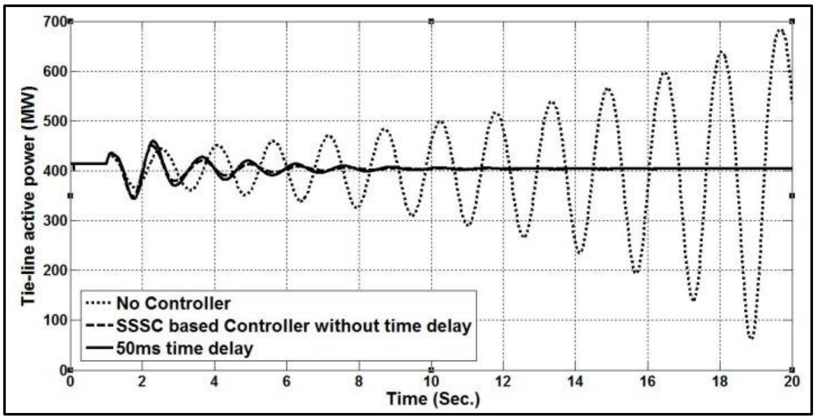

Fig. 5 - Tie-Line Active Power Flow

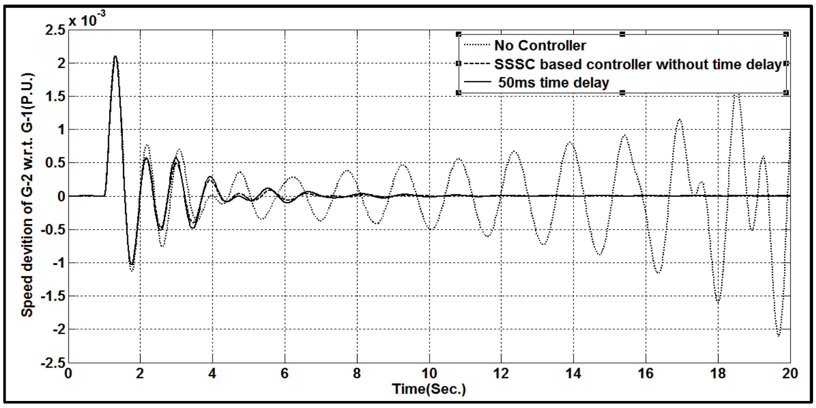

Fig. 6 - Speed deviation of G-2 w.r.t. G-1

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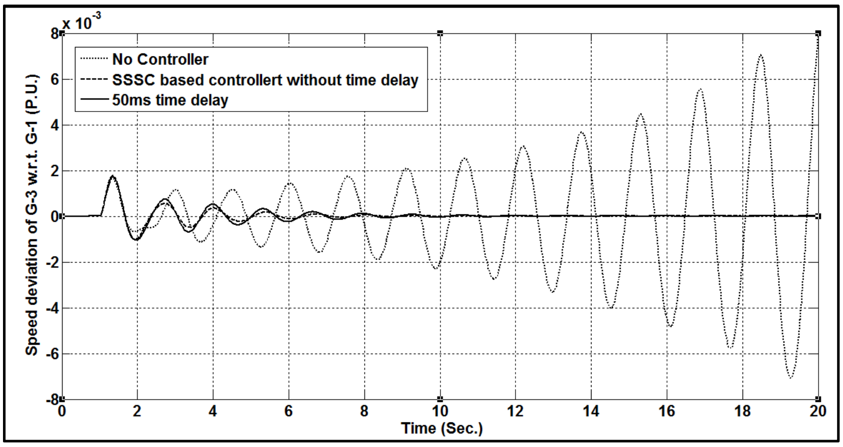

Fig.7 - Speed deviation of G-3 w.r.t. G-1

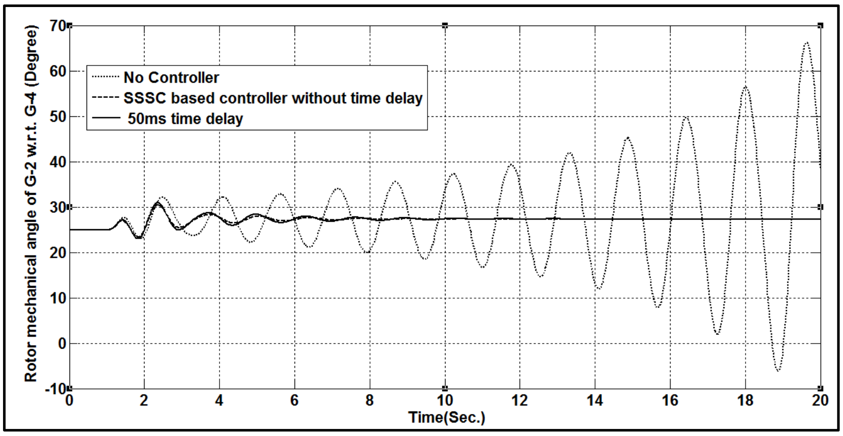

Fig. 8 - Rotor mechanical angle deviation of G-2 w.r.t G-4

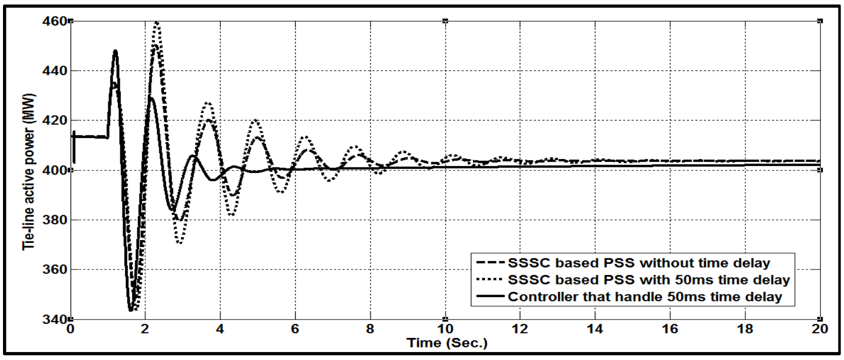

Fig. 9- Tie-Line Active Power Flow with proposed controller, 50 ms delay

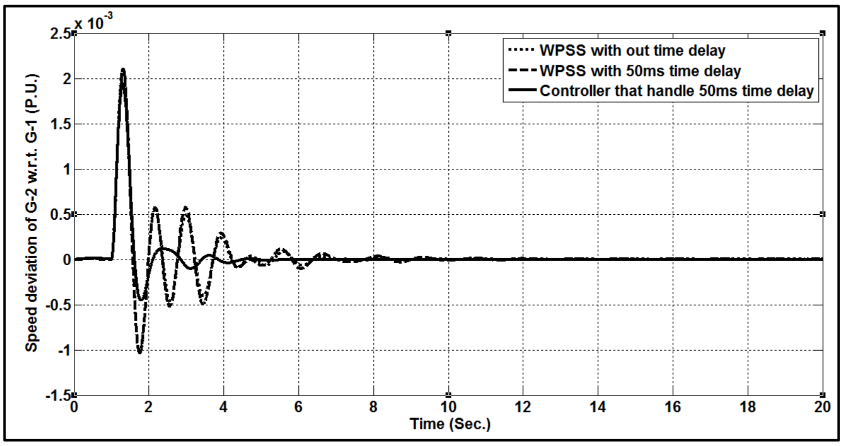

Fig. 10- Speed deviation of G-2 w.r.t. G-1 with proposed controller, 50 ms delay

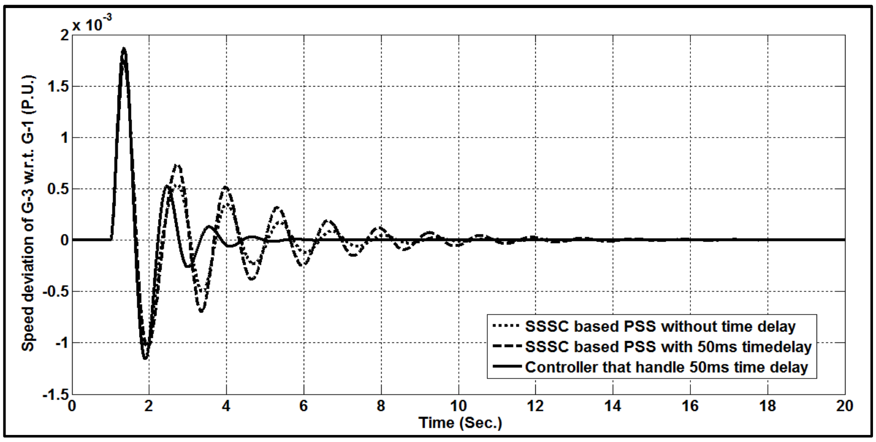

Fig. 11- Speed deviation of G-3 w.r.t. G-1 with proposed controller, 50 ms delay

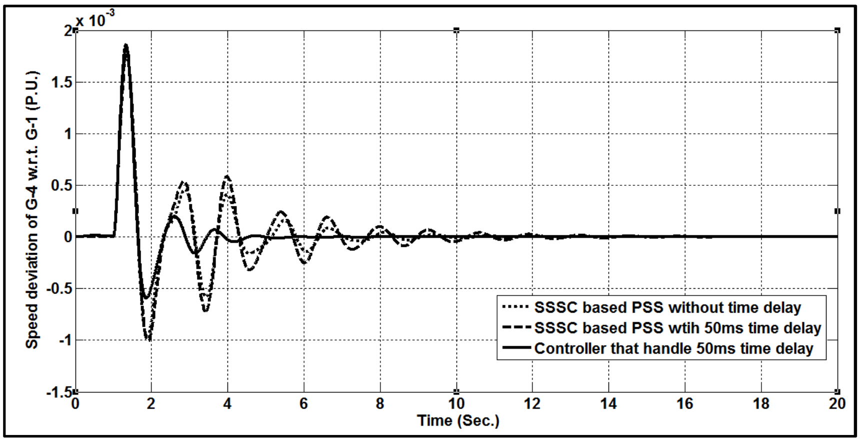

Fig. 12- Speed deviation of G-4 w.r.t. G-1 with proposed controller, 50 ms delay

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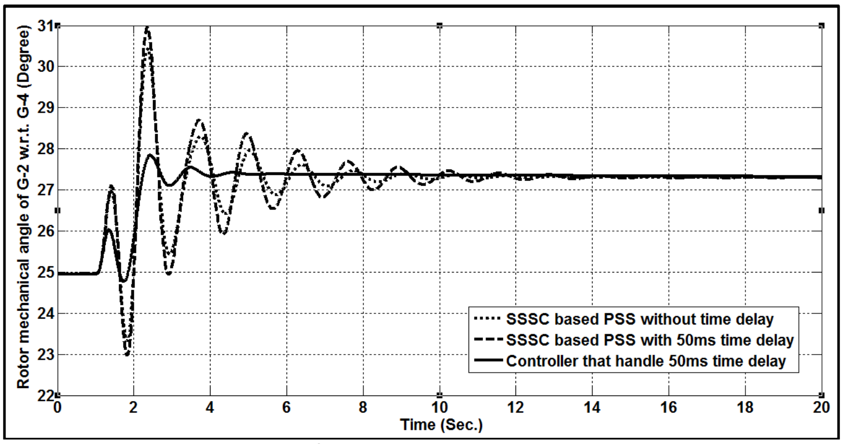

Fig. 13- Rotor mechanical angle of G-2 w.r.t. G-4 with proposed controller, 50 ms delay

VI.CONCLUSION

In this paper researcher designed a delay dependent (50ms) 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. 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 damps out the inter-area oscillations effectively.

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