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Sssc Based Time Delay Compensator Design for Interconnected Power System

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Abstract – In this paper, researcher designed a delay-dependent wide-area damping controller based on Static Synchronous Series Compensator (SSSC) to enhance the power system stability by using remote signal obtained from Wide-Area Measurement System (WAMS). This remote signals introduces a time delay in the feedback signal, as a result, degrade the system damping performance and even causes instability of close loop power system. To find out various controller parameters, use of Genetic Algorithm (GA) is adopted. The performance of Multi-Machines system is evaluated with proposed controller including signal delay and Conventional PSS(CPSS) in MATLAB simulation. Various results show that SSSC based controller damp-out the inter-area oscillations under small disturbance more effectively as compare to LPSS.

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

I.INTRODUCTION

Nowadays, electrical power demand increases continuously, but in that ratio there is no change in infrastructure of power system network to fulfill the demand in different geographical area. Existing power system network should be interconnected so that it can proficiently use separate power resources in separate fields and optimize energy resource distribution. Also, under operating condition if fault or disruption occurs, it can provide additional supporting power of each area of interconnected grids which can make the generation, transmission and distribution system more reliable.The main drawback of an interconnected power system is that, when we interconnect different area of power system network by a tie line which is weak then under some conditions of its operation it developed a inter-area oscillations of low frequency [0.1 Hz – 1 Hz] [1]. If the damping coefficient of the system is not sufficient, then these oscillation leads to loss the system synchronism.

For this, the traditional approach in industry to damp out or diminish inter-area oscillations use CPSS. The fundamental role of LPSS is to increase damping to the oscillation of rotor of the generator by controlling its excitation using Automatic Voltage Regulator (AVR) with auxiliary stabilizing signal [2]. The CPSS use local signal as an input but this type of controller not always able to damp out the inter-area oscillations because local signal based controller do not have global observation [3].

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In latest years, the development of new wide-area damping controllers to control inter-area oscillations has become a interesting topic with fast advances in synchronized phasor measurement technologies[4-7]. The WPSS has been known to be one of the most efficient solutions to damp out or diminish inter-area oscillations.

Results measured by phasor measuring units (PMUs) are transferred via communication channels to the remote control center in wide-area damping control. Network time delay is therefore inevitable. Such delays vary between tens and several hundred milliseconds. Several studies were conducted to assess the time limit reported in[8-10].Since even a very minute delay can result in the stability loss of the power system[11], input delay in controller design can not be overlooked. To control damping in wide-area, the route and mode of transmitted signal will also be corrected as soon as the place to be controlled and signal for feedback is chosen. Usually, in the short term, this transmission path will not alter, so that the delay in WPSS input will be stable. The signal delay given can therefore be designed as a steady delay in the layout of the controller. Smith predictor[25] and Pade approximation[22] are two efficient approaches to addressing this type of issue of constant time delay. This document is about the approximation of Pade. A dedicated communication channel generally offers in any transmission condition no more than 50 ms delay[18].

However, electronic energy systems are currently being created. With improved dynamic efficiency, they are more efficient in raising the quantity of transmitted energy and more accurate in controlling the power flow path. The implementation of FACTS in power systems is used in these techniques. Engineer's recently used FACTS controllers for the applications in the power system. The primary goal of the FACTS device used is to regulate parameter of the system at a very fast pace so that the stability of the system is improved [15].The SSSC is regarded a FACTS family member. One of distinctive ability to switch from capacitive characteristic to inductive is shown by SSSC [16]. This uses an additional signal that stabilizes and can considerably improve the system's stability. Basically, the SSSC control function is done by this auxiliary signal [17]. The implementation of SSSC is addressed in[19–23] to enhance stability and dampen system oscillation. Normally, from signals like voltage, current, active power flow, frequency etc., the SSSC input control signal can be acquired locally. However, two PMUs are mounted in distinct areas to detect the inter-area oscillation more clearly in order to achieve better efficiency. The control signal from PMUs is used as the SSSC damping controller control input.

Moreover, in this paper, a simple SSSC based controller designed based on change in speed deviation as a input signal.
The key factor for control system design is its robustness. In order to design robust controller to damped out inter area oscillations parametrs of controller are optimized by Genetic Algorithm (GA) based on Time Error Integral(ITE).
This paper is broken down into five parts. The first chapter is the introduction to the issue because of inter-area oscillations and signal delay. Section II represents the configuration of the study power system with SSSC and PSS. Section III presents the design of the proposed controller. In addition, the PSS optimization process parameters for achieving better GA-based efficiency and robustness. Section IV demonstrates the controller's simulation outcomes and the outcomes of the comparison. Finally, the conclusions in chapter V are finished.

II.STUDY POWER SYSTEM

System under this research work is shown in figure-1. It consists of two similar symmetrical areas inter linked by two parallel tie-line of length 220 Km and 230 kV. Each area has two generators of rating 20 kV/900 MVA both having identical round rotor. 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 [2].

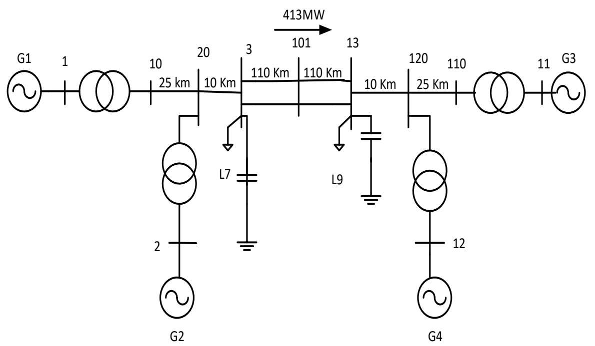

Fig. 1. Kundur 2-area 4-machine system

III.THE PROPOSED CONTROL METHOD

(a) Controller design considering time delay with SSSC and LPSS

Figure-2 demonstrates the damping controller design that is used by the SSSC to regulate the voltage input (Vq). The variation in G-2 and G-4 speed deviation (availability) is regarded as the controller's input and Vq is regarded the controller's output. Four blocks are considered here in the damping controller design[22], namely signal delay block with pade approximation, gain block with Kstab gain, determines how much damping the PSS has introduced. A high-pass washout filter with moment constant parameter TW, eliminating the low frequencies current in the speed signal and the PSS is allowed to react only to speed changes else no reaction and in Figure. 2 a 2-stage block of phase compensation is shown. The washout block will work as a filter which allows only high frequencies to pass and the phase compensation block will provide the appropriate phase-leading characteristics with time constants T1, T2, T3 and T4.

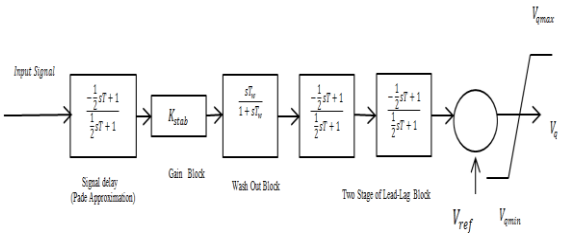

Fig2. Block diagram of SSSC based damping controller

(b) Pade Approximation

The wide-area controller's feedback signal delay the control impact is affected by the delay will introduce input signal phase deviation. In f frequency oscillation mode, the phase lag (φ) which is introduced by delay(T) can be obtained by :

$$\varphi = 360fT$$

For instance, if a WPSS ' dominant frequency is 0.6 Hz, a 100 ms delay will introduce a [23] phase lag.

$$360^0 \times 0.6 \times 0.05 = 10.8^0 \text{ (Phase lag)}$$

From above, it can be observed that both the frequency of oscillation and the delay itself determine the phase lag introduced by delay. The associated phase lag with the greater frequency is bigger for the same delay, and vice versa.
In MATLAB, the exponential shape (e^{-sT}) of the Laplace domain expresses time-delays. It can be substituted by a Pade approximation of first order[24].

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

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

(c) Optimization Method - Genetic Algorithm (GA)

A search algorithm which applies genetic legislation and natural selection law fundamentally is genetic algorithm. An original population comprising a group of chromosomes is assessed To fix any issue with optimization (using GA). At first a random population is generated, then the fitness value of each chromosome is calculated from this population. This could be discovered through the encoding method calculating the objective function. A set of chromosomes called parents will be evaluated, called offspring generation, produced from the original population. The present population is substituted by its recent or updated descendants, that can be acquired by bringing some approach of replacement. Figure-3 demonstrates the Genetic algorithm flow chart[24].

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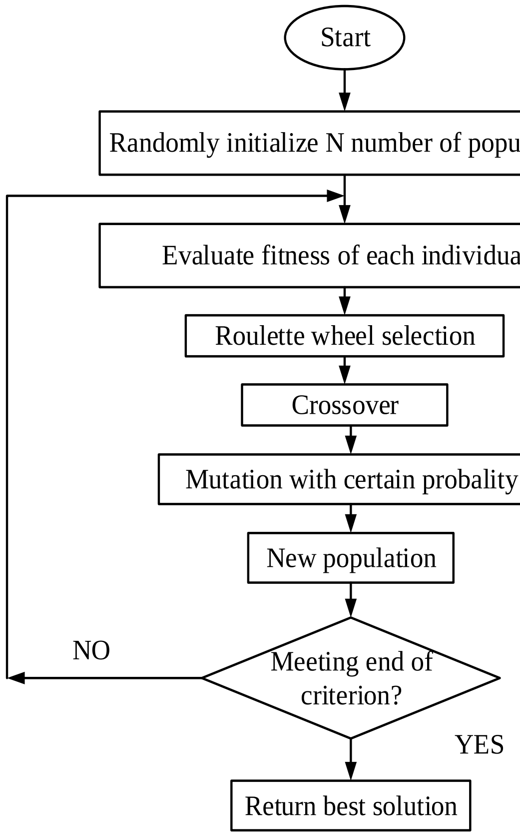

Figure 3. Flow Chat for GA

A set of alternatives called the population (represented by chromosomes) begins the genetic algorithm. results are drawn from one population and outcomes are used to create a fresh population. This motive is due to the likelihood of bettering the fresh population compared to old. Solutions are selected to form fresh solutions (offspring) as per their fitness; they are high/more appropriate, there is high/more likely to reproduce. This process is continously repeated until some condition (e.g improvement of the best solution) is satisfied.

Oscillation of a system can be seen through the active power deviation tie-line or rotor speed deviation. Research is aimed at minimizing the oscillation of any deviation. The integral of time error of speed deviation forG-2and G-4 is taken as an objective function (J) for kundur's 2-area 4- machine scheme.

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

where

t_{sim} = simulation time range.

The simulation of the time domain of the above power system is performed for a specified period of time and the calculation for the the objective function of the simulation is done. The PSS and damping controller prescribed range is restricted within a border. From the above design approach, the following optimization problem is formulated.

Minimize J

Subject to :

$$T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max}$$
$$T_{2i}^{min} \leq T_{2i} \leq T_{2i}^{max}$$
$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max}$$
$$T_{4i}^{min} \leq T_{4i} \leq T_{4i}^{max}$$

where T_{ji}^{min} and T_{ji}^{max} are the min and max 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

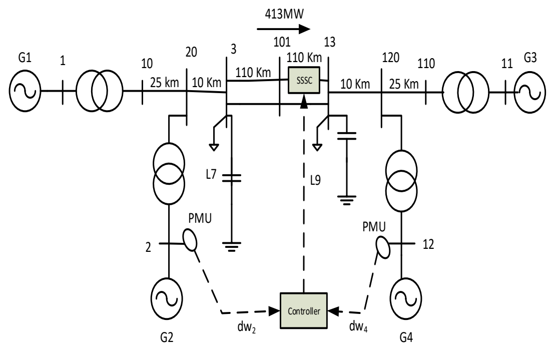

Fig 4. 2-area 4-machine interconnected power system with a SSSC connected in series with the transmission line

The structure of a power system with the proposed controller used in this research is shown in Figure 4. SSSC is mounted between B-101and B-13 in series with the transmission line. To assess the difference in speed between two inter-area oscillation generators, two PMUs are installed at G-2andG-4 respectively for wide-area control. The control system for the proposed design includes 50 ms delay time owing to wide-area control communication system.

For this study, value of the controller gain is taken as K=101.0779[25] and other parameters of the suggested controller after optimizing GA based on the ITE criteria set out in Table – I.

Table – 1 Optimized Controller Parameters Using GA

	T_1 (S)	T_2 (S)	T_3 (S)	T_4 (S)
Damping Controller (with out 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

A short pulse with a magnitude of 5 percent as a distortion was introduced to generator G-1 for 12 cycles to conduct the dynamic assessment of the closed loop test system for Kundur two area four machine scheme as shown in figure-4. The time for simulation was 20 seconds. The response flow from area-1taken to area-2 of the tie-line active power, rotor angle(mechanical) deviation, rotor speed deviation, and bus voltage is then detected by taking into account the effect of signal delay with and without the test scheme..

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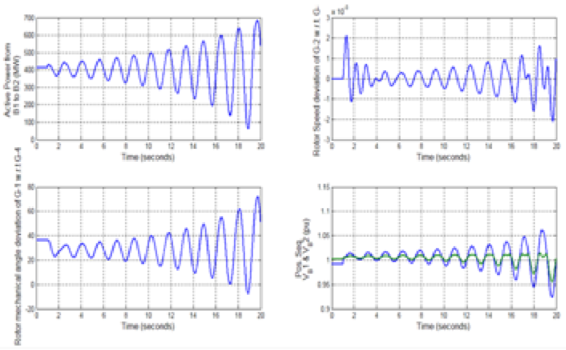

Figure 5. Different parameters of power system without controller

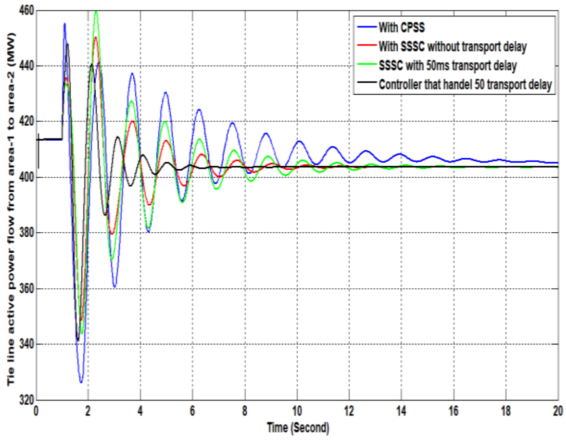

Figure 6: Tie-Line Active Power Flow

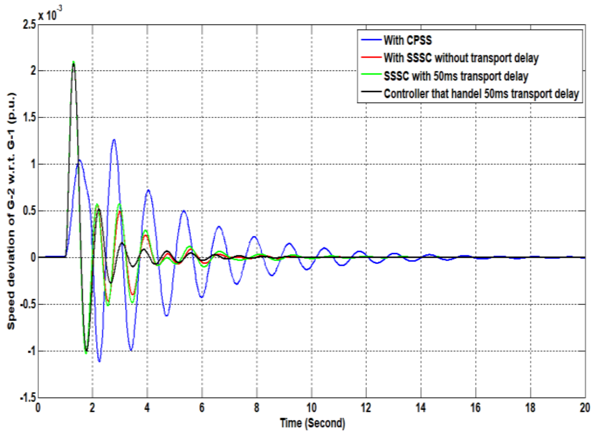

Figure 7: Speed deviation of G-2 w.r.t. G-1

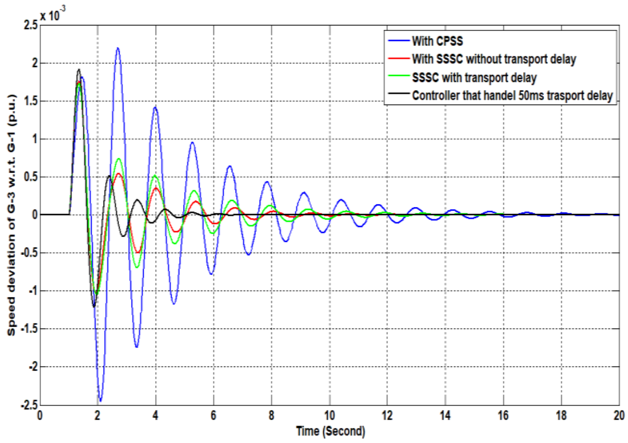

Figure 8: Speed deviation of G-3 w.r.t. G-1

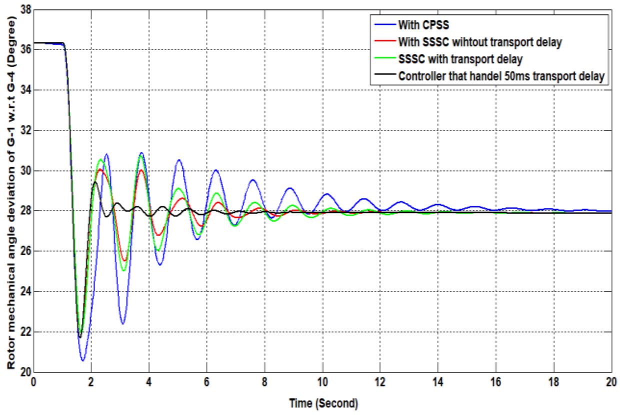

Figure 9 : Rotor mechanical angle deviation of G-1 w.r.t G-4

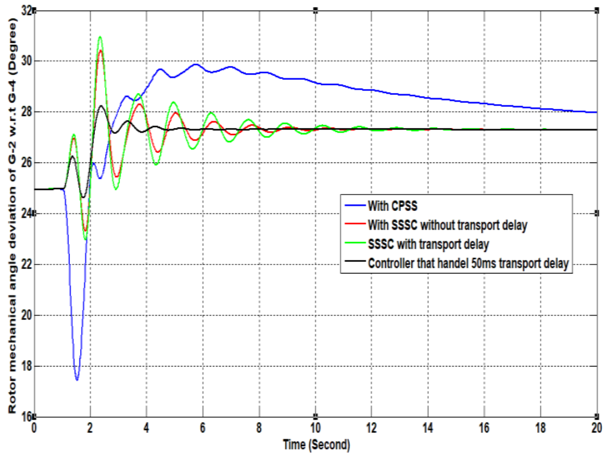

Figure 10 : Rotor mechanical angle deviation of G-2 w.r.t G-4

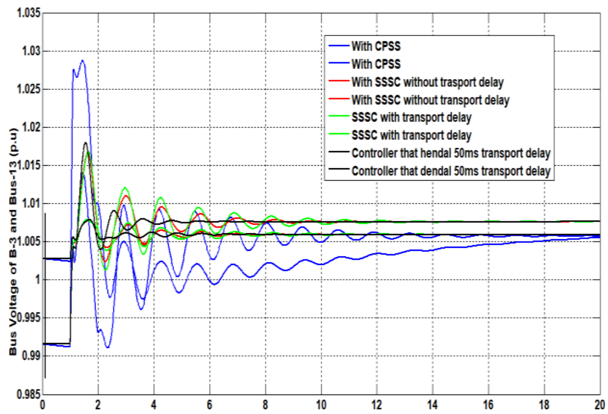

Figure 11 : Bus voltage at B-3 and B-13 (p.u)

VI. CONCLUSION

A delay-dependent (50ms) controller for wide-area damping has been intended in this paper researcher to controllarge-scale power system inter-area oscillations using SSSC and PSS. A simulation of the time domain based on minimizing the controllers ' objective function is performed using GA. Some simulation findings are performed to check the efficacy of the suggested controller in tiny disruption.Simulation results shows that under signal delay, the designed controller efficiently dampens the inter-area oscillations.

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