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SSSC Based Wide-Area PSS for Stability Enhancement of Interconnected Power System under Small Disturbance

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Abstract: ***In this paper, design a Wide-area Power System Stabilizer (WPSS) to damp-out the inter-area oscillations in a large scale power system by using Static Synchronous Series Composator (SSSC). 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 Power System Stabilizer (WPSS), Static Synchronous Series Composator (SSSC), Genetic Algorithm (GA), Phasor Measurement Units (PMUs), Integral of Time Error (ITE)

1. Introduction

Recently, with the increasing of electric power demand, modern power system requires networks to be interconnected more flexibly and efficiently and thus make power system control becomes more complicated.

The main reason for interconnection of electric grids 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.

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] 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. 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)[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. [9]

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 Voltage 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) based on Integral of Time Error (ITE).

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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 II describes the configuration of the study power system with SSSC. Section III 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. Section IV shows the simulation results of the proposed controller and the comparison results. Finally, it ends with the conclusions in section V.

2. Study Power System

Fig. 1 shows the configuration of the study power system. This system consists of two areas connected by aweak tie-line. The 6th order generator model is used for each generator and is equipped with a 1st order AVR without PSS. The governor is a simple 1st order model.

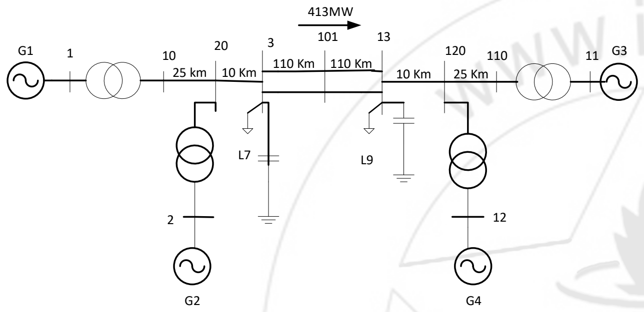

Figure 1: Kundur two-area four-machine system

3. The Proposed Control Method

Structure of PSS and SSSC

Fig. 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 [13], namely gain block with gain K_{stab}, determines the amount of damping introduced by the PSS. A washout high-pass filter with time constant TW, 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 Fig. 2. The signal was h_{out} 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.

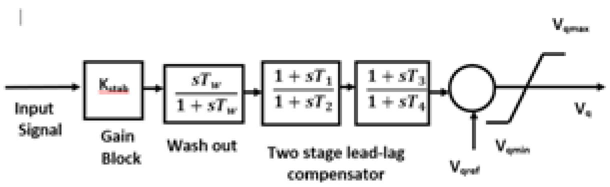

Figure 2: Structure of SSSC based damping controller

4. 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, 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. Fig. (3) shows the flow chart for the Genetic algorithm [15].

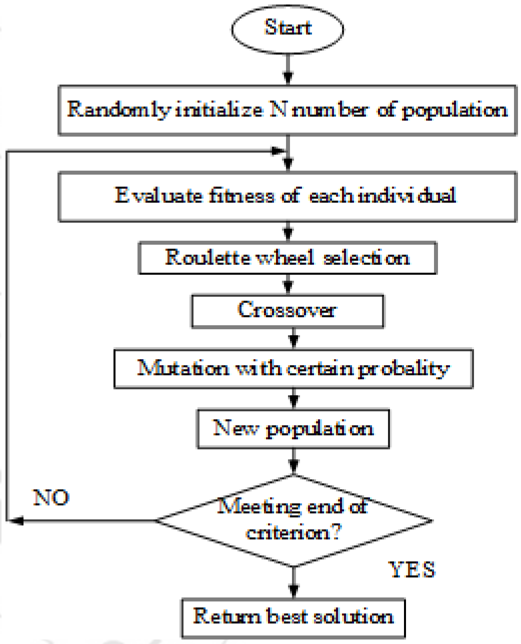

Figure 3: Flow Chat for GA

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-4taken as a objective function (J).

where

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

where

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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:

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

where T_{ji}^{min} and T_{ji}^{max} are the lower and upper bound of time constant for the controllers.

Simulation Results of Proposed Controller

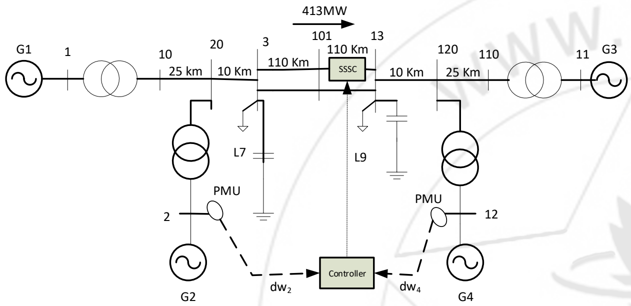

Figure 4: Two-area four-machine interconnected power system with a SSSC installed in series with the transmission line

The structure of study power system with proposed controller as shown in fig. 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 control system for proposed control system structure does not include the 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 [13] and other parameters of proposed controller after GA optimization based on ITE criterion tabulated in Table –I.

Table 1: Optimized Controller Parameters Using GA

	K_T	T_1 (S)	T_2 (S)	T_3 (S)	T_4(S)
Damping Controller	101.0779	0.9067	0.9142	0.1066	0.5514

4.1 Small Signal Stability Assessment

To perform the dynamic analysis of the closed loop test system for Kundur two area four machine system as shown in fig.4, a small pulse with magnitude of 5% as a disturbance was applied to the generator G1 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, rotor speed deviation , rotor angle deviation are examined by considering the test system with proposed controller.

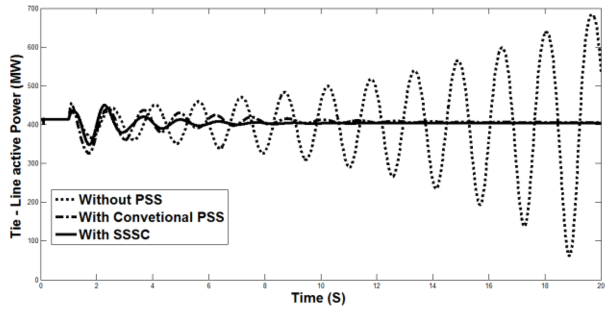

Figure 5: Tie-Line Active Power Flow

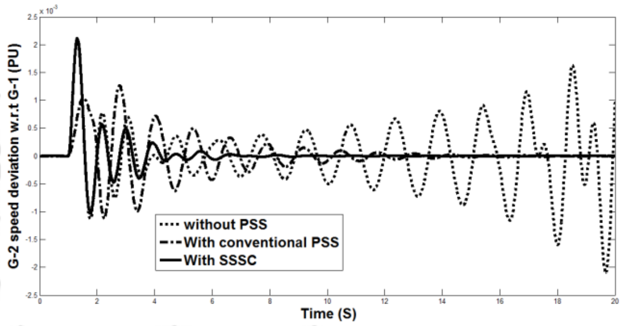

Figure 6: Speed deviation of G-2 w.r.t. G-1

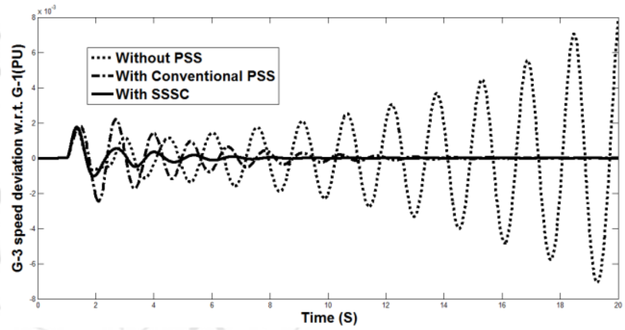

Figure 7: Speed deviation of G-3w.r.t. G-1

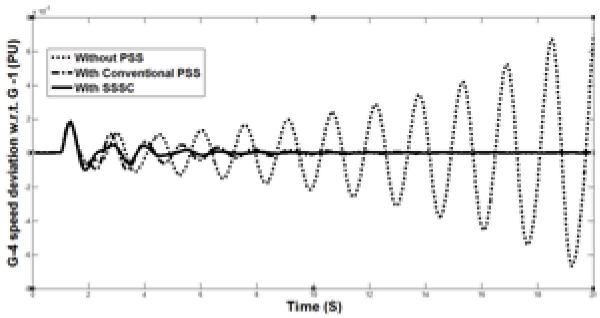

Figure 8: Speed deviation of G-3 w.r.t. G-1

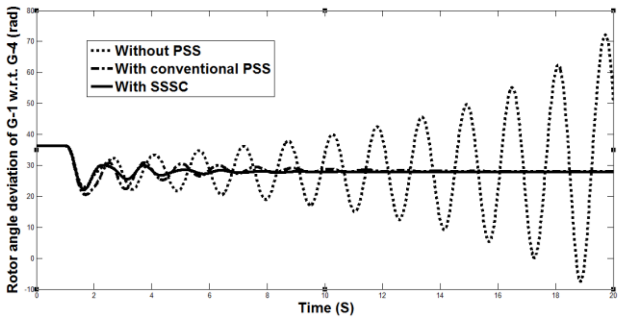

Figure 9: Rotor angle deviation of G-1 w.r.t. G-4

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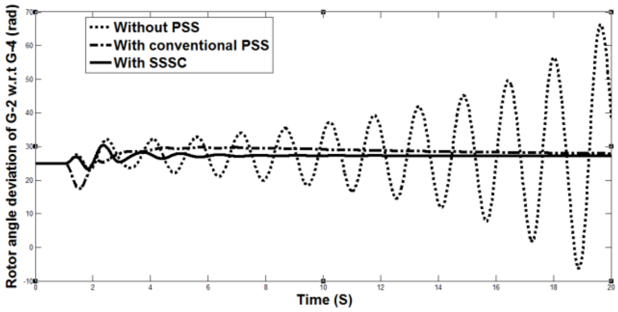

Figure 10: Rotor angle deviation of G-2 w.r.t G-4

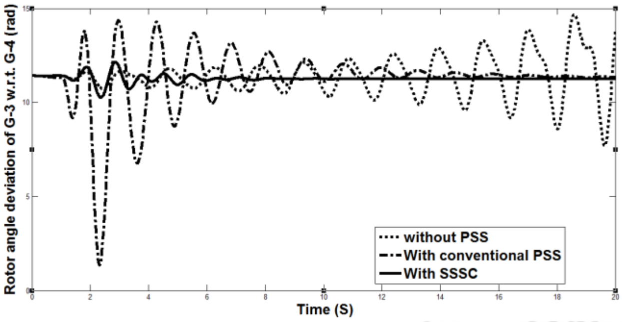

Figure 11: Rotor angle deviation of G-3 w.r.t G-4

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 SSSC. 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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