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A coordinated control scheme of PSS and comparison of FACTS devices for improving power system stability

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ABSTRACT

Nowadays, the continuous growth in power demand leads to expansion of the Power System network which makes the existing system more sensitive and prone to instability. An important issue associated with the stability of multi-area power system is low-frequency electromechanical oscillations from the multi-machine system. Generally, Power System Stabilizer (PSS) is used to compensate low-frequency electromechanical oscillation of Interconnected Power System, but local PSS does not have global observance and controllability of inter-area low-frequency oscillation because of the control signal of local PSS and generated a local signal. So next resolution is Flexible AC Transmission System (FACTS) device with a supplementary controller that are used for effective damping of low-frequency electromechanical oscillations of interconnected Power System and to improve Power System stability. This paper presents Coordination control of PSS and FACTS Devices to damp out low-frequency electromechanical oscillation. In this research study, we use different FACTS Devices like Static VAR Compensator (SVC), Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), and Unified Power Flow Compensator (UPFC) to damp out low frequency electromechanical oscillation from a Multi-machine Power System and improve the stability of Interconnected Power System. Analyzing result of all FACTS devices on simulation, we found that UPFC gives a better response. Due to reactiveness, FACTS device like UPFC are considered and assessed for their damping controller design. In this research, we studied the implementation of supplementary Power Oscillation Damping (POD) Controller to control UPFC. POD Controller is designed to improve the dynamic performance of interconnected Power System under the transient condition to stabilize Power System. Some simulation results are carried out on Kundur Two area Four Machine systems under small disturbances. From simulation result, it reveals that the proposed controller damp-out low-frequency electromechanical oscillations effectively to improve Power System stability under small disturbance.

Keywords— *Stability, low frequency electromechanical oscillation, Power System Stabilizer, SVC, SSSC, UPFC, POD*

1. INTRODUCTION

At present time load demand is increasing continuously day by day and complexity of load connected to the increase in a drastic manner. This results in frequent grid instability problem, power swing, load generation unbalance and the past few years, the angel instability, caused by small signal low frequency electromechanical oscillations, has been occurs in the interconnected power systems under certain conditions, such as transmission of a large amount of power over long distance through weak tie lines and the use of high gain exciters. These conditions introduce low-frequency oscillations [0.1 Hz-1.0 Hz] in inter-connected power system and loss of synchronism which may cause a large-scale blackout of the whole power system [1]. The low-frequency oscillation inherent to the large inter-connected power system becomes more dangerous to system security and quality of power supply under transient condition. Therefore low-frequency electromechanical oscillations put limited on the operation of the power system.

At Present time, damp out these oscillations, many different traditional approaches have been introduced, such as the application of Automatic Voltage Regulator (AVR) equipped with Power System Stabilizer (PSS) [2] while PSS control local mode of low-frequency oscillation effectively. But in the case of inter-area oscillation mode, it's not global controllability and observability because control signal is its own generator signal or local signal. PSS stabilize Power System under transient condition only.

So next resolution is power electronic based technologies have been developed. They are more effective in a large amount of transmitted power with increase the dynamic performance and more precise to control the power flow. These technologies are referred to use Flexible AC Transmission System (FACTS) in power systems. FACTS devices are installed in the transmission line to control the Power System parameters (voltage magnitude, voltage phase angle, active power reactive power) due to this increase the transmission line capacities and improve controllability. There are two main reasons that should be install FACTS controllers: The first region is the flexible Power System operation according to the power flow control capability of FACTS controllers. The other reason to improve Power System stability [3]

At recent time, FACTS Device and Wide-Area Measurement System (WAMS) technologies are used together, they can improve Power Systems stability, power quality, Power System performance, controllability, observability under global level. In this study, to implement Coordinated Control of PSS and FACTS Devices to improve Power System performance, so compare the simulation result of different FACTS Devices we get UPFC gives better results in terms of Power System stability and due to this Reactive FACTS devices, such as UPFC are considered and assessed for their damping controller design. Unified Power Flow Controller (UPFC) which is a series-shunt connected FACTS controller based on Voltage Source Converter (VSC) is used to control the tie-line power flow between two areas of a study Power System. However, in order to obtain better performance, Supplementary POD Controller along with UPFC are installed so damp out low-frequency electromechanical oscillation more effectively and improve the stability of Interconnected Power System. The control signal obtained by POD is used as the control input of the UPFC damping controller.

This paper is divided into six sections. The first section is the introduction mentioning about the problem of low-frequency electromechanical oscillation and Power System instability and the implementation of FACTS Controller to solve the low-frequency oscillation issues and improve the stability of large-scale Power System. Section II describes the configuration of the study power system. Section III presents technology implemented in this research study and analysis of small signal stability under small disturbance condition. Section V shows the simulation results of the proposed controller and the comparison of results. Finally, it ends with the conclusions in section VI.

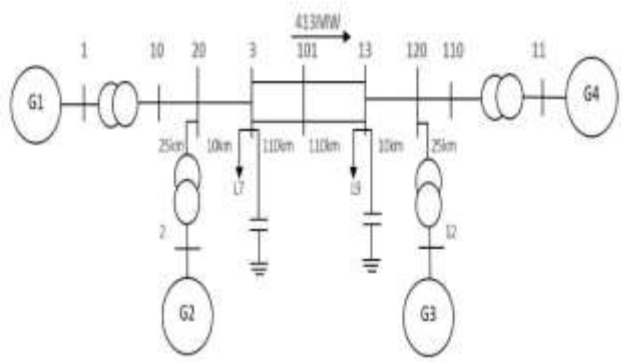

Fig. 1: Kundur two-area four-machine system

2. STUDY POWER SYSTEM

Fig-1 shows the single line Diagram of the study Power System. This system consists of two symmetrical areas connected by two parallel tie-lines 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=6.175 s for Gen-3 and Gen-4 in area-2.

3. TECHNOLOGY IMPLEMENTED

3.1 Power System Stabilizer (PSS)

Power System Stabilizers (PSS) is supplementary control block of excitation system of machine unit to provide the efficient damping ratio to suppress the low-frequency electromechanical oscillation. The main function of PSS is to add damping to the generator rotor oscillations by controlling its excitation by using auxiliary stabilizing signal E_{pss} [4]. So that it can increase low-frequency oscillation damping and enhance the dynamic stability of Power System.

PSS is consisting of different control block design by us to improve the dynamic performance of the power system under transient condition. It is consist of different control blocks are, Washout block, and Lead-Lag compensator, Gain of PSS, Limiter, respectively. Fig-2 shows the block diagram of PSS.

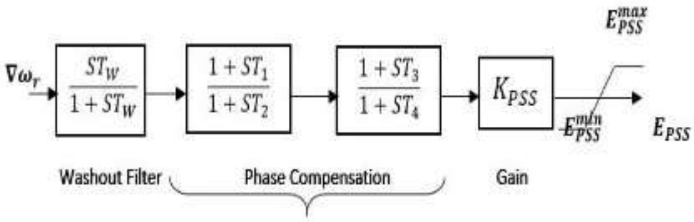

Fig. 2: Block diagram of PSS

The parameters of PSS are used in this research study are tabulated in Table 1.

Table 1: **Parameters of PSS**

Param eters	K_{pss}	T_w (s)	T_1 (s)	T_2 (s)	T_3 (s)	T_4 (s)	E_{pss}^{max}	E_{pss}^{min}
PSS	60	10	0.05	0.02	3	5.4	0.15	-0.15

3.2 FACTS Device

The FACTS devices are generally utilized in Power System to supply fast continuous control of power flow in the transmission system by controlling the Power System parameters, voltage magnitude, voltage phase angle, Active power, Reactive power respectively.

3.2.1 Static VAR Compensator (SVC): The Static VAR Compensator (SVC) is a shunt connected device whose main functionality is to regulate the voltage at a chosen bus by suitable control of its equivalent reactance. A basic topology consists of a series capacitor bank, C, in parallel with a thyristor controlled reactor, L, as shown in Fig-3 In practice, the SVC can be seen as an adjustable reactance that can perform both inductive and capacitive compensation. The details about the modelling of the SVC can be found in [5].

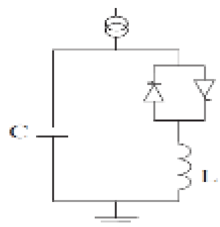

Fig. 3: Block diagram of PSS

3.2.2 Static Synchronous Series Compensator (SSSC): The Static Synchronous Series Compensator (SSSC) is a series connected FACTS Device based on Voltage Source Converter (VSC).it is connected series with the transmission line to compensate line reactance and improve power transferred through the transmission system.

3.2.3 Static Synchronous Compensator (STATCOM): A STATCOM is a shunt connected Voltage Source Converter (VSC) based FACTS Devices. It is a Voltage regulating device based on regulating of reactive current to maintain bus voltage constant.it is a reactive power compensator device either source of reactive power or sink of reactive power [6]. The STATCOM is made up of a coupling transformer, a VSC, and a dc energy storage device. The energy storage device is a relatively small dc capacitor, and hence the STATCOM is capable of only reactive power exchange with the transmission system. If a dc storage battery or other dc voltage source were used to replace the dc capacitor, the controller can exchange real and reactive power with the transmission system. figure 4 shows the circuit diagram of STATCOM.

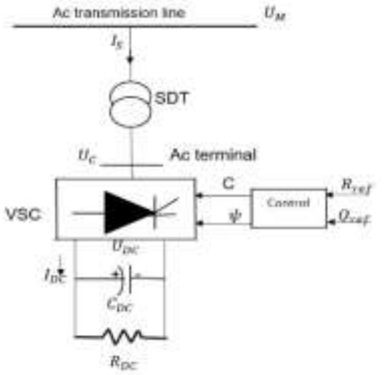

Fig. 4: Circuit diagram of SVC

3.2.4 Unified Power Flow Controller (UPFC): The UPFC is a series-shunt connected FACTS devices, can provide simultaneous control of all Power System parameters (voltage magnitude, voltage phase angle, active power, reactive power). The controller can fulfill functions of reactive shunt compensation, series compensation, and phase shifting, meeting different control objectives [7]. From a functional perspective, the objectives are met by applying a DC capacitor, shunt connected transformer and voltage source converter in parallel branch and dc capacitor, voltage source convertor and series injected transformer in the series branch.

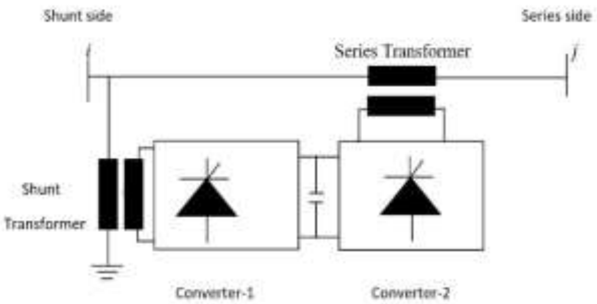

Fig. 5: Implementation of the UPFC by back-to-back voltage source converter

The two voltage source converters are a so called "back to back" AC to DC voltage source converters operated from a common DC link capacitor, figure 5 the shunt converter is primarily used to provide active power demand of the series converter through the common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provides independent shunt reactive compensation for the line. Converter 2 provides the main Function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line.

3.3 FACTS POD Controller Design

Supplementary controller is applied to FACTS devices to increase the system damping is called Power Oscillation Damping (POD) to improve the performance of the power system under transient condition. Generally FACTS controllers are located in transmission systems, local input signals are always preferred, usually the active or reactive power flow through FACTS device or FACTS terminal voltages. Fig-6 shows the considered closed-loop system where G(s) represents the power system including FACTS devices and H(s) FACTS POD controller.

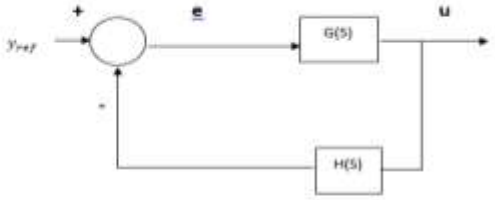

Fig. 6: Closed Loop System with POD Control

The POD controller provides additional damping to system to improve dynamic performance of Power System under transient conditions.it is consist of several control block design by us to stabilize the Power System, control blocks are, Gain of POD Controller, Low pass filter, Washout block, Phase Compensation Lead-Lag block respectively are as shown in figure 7.

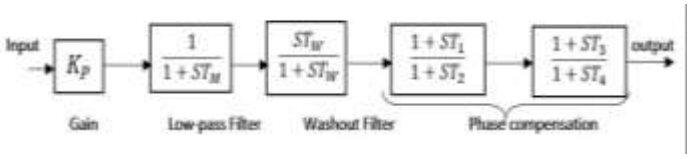

Fig. 7: Block diagram of POD Controller

The transfer function, H(s), of the POD controller is given by

$$H(S) = K_P \left(\frac{1}{1+ST_M}\right)\left(\frac{ST_W}{1+ST_W}\right)\left(\frac{1+ST_1}{1+ST_2}\right)\left(\frac{1+ST_3}{1+ST_4}\right) \quad (1)$$

The Parameters of Power Oscillation Damping Controller (POD) are set-up by Hit and Trial Method are tabulated in table 2.

Table 2: Parameters of POD Controller

Parameters	K_p	$T_M(s)$	$T_w(s)$	$T_1(s)$	$T_2(s)$	$T_3(s)$	$T_4(s)$
POD	50	0.1	10	0.259	0.225	0.259	0.225

3.4 Small Signal Analysis

In small signal stability studies under small disturbance, the nonlinear power system is required to be linearized around a certain equilibrium point and reorganized as a set of Differential and Algebraic equations (DAE). State-space representation is shown in the following equation.

$$\Delta\dot{x} = A\Delta x + B\Delta U \quad (2)$$

A series of linearized system models are integrated together to form the multi-model system:

$$\Delta\dot{x} = A_i\Delta x + B_i\Delta L$$
$$\Delta Y = C_i\Delta x + D_i\Delta L \quad (3)$$
$$i = 1,2,3, \ldots L$$

Where i represents equilibrium point number, L is the total number of operating points and Δy is the selected system output used as the controller feedback signal.

4. SIMULATION RESULTS OF PROPOSED CONTROLLER

The single line diagram of study power system with the proposed controller is shown in figure 8. In this research study A Coordinated Control Scheme of PSS and Comparison of FACTS Devices, SVC, SSSC, STATCOM, and UPFC, respectively, to improve Power System stability. So Compare of all facts device on simulation result we get UPFC is a better response, and due to this Reactive FACTS device, such as UPFC are considered and assessed for their damping controller design. In this research study to implement the supplementary Power Oscillation Damping (POD) Controller to control the UPFC, and POD Controller is design to improve the dynamic performance of inter-connected power system under the transient condition to stabilize power system. The Proposed UPFC-POD controller is installed in Series with the transmission line B-101 and B-13. This system consists of two symmetrical areas connected by two parallel tie-lines of length 220 km and 230 km. Each area is equipped with two identical round rotor generators rated 20kv/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=6.175 s for Gen-3 and Gen-4 in area-2.

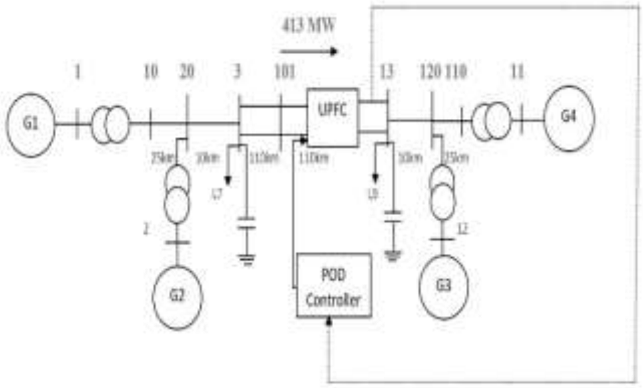

Fig. 8: **Two-area four-machine interconnected power system with UPFC-POD Controller**

5. SYSTEM PERFORMANCE WITH COMPARISON OF FACTS DEVICES

To perform the transient analysis of the closed-loop test system for Kundur two area four machine system as shown in fig-8, a small pulse with a magnitude of 5% as a disturbance was applied to the generator G1 for 12 cycles. The simulation time was of 30 seconds. Then the response of tie-line active power flow from area-1 to area-2, rotor speed, rotor speed deviation, is examined by considering the test system with PSS and Comparison of FACTS Devices.

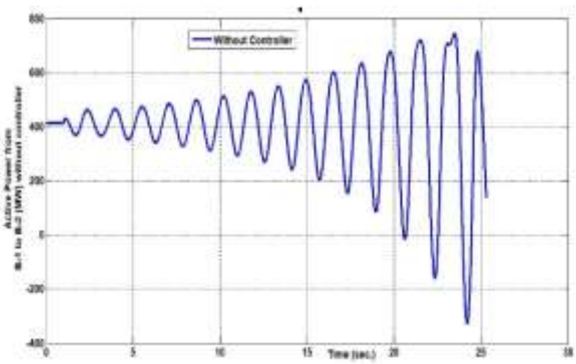

Fig. 9: Tie-line active power flow without any controller

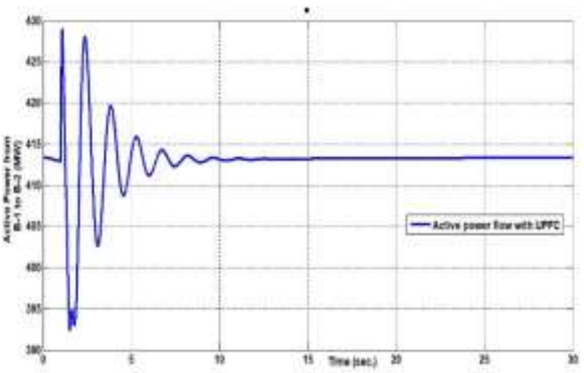

Fig. 10: Tie-line active power flow with UPFC-POD Controller

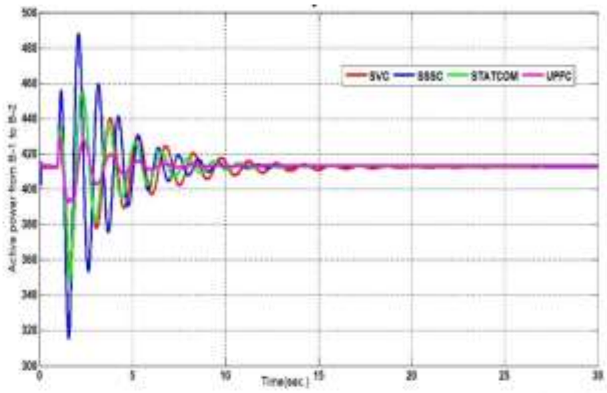

Fig. 11: Tie-line active power flow with Comparison of FACTS Devices

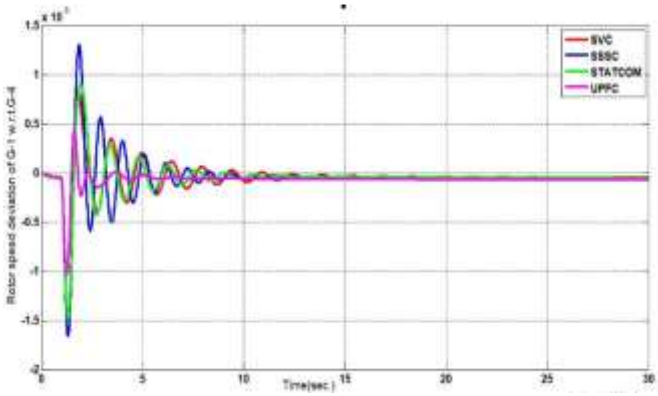

Fig. 12: Rotor Speed deviation of G-1 w.r.t G-4 with Comparison of FACTS Devices and local PSS

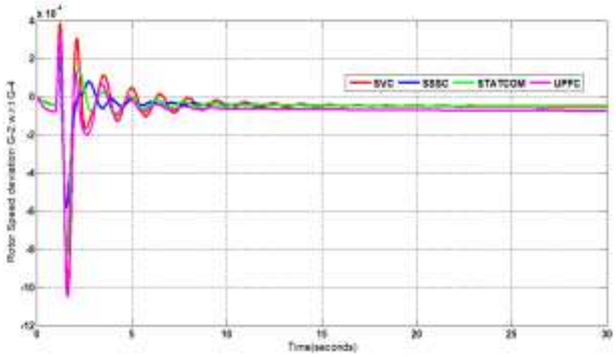

Fig. 13: Rotor Speed deviation of G-2 w.r.t G-4 with Comparison of FACTS Devices and local PSS

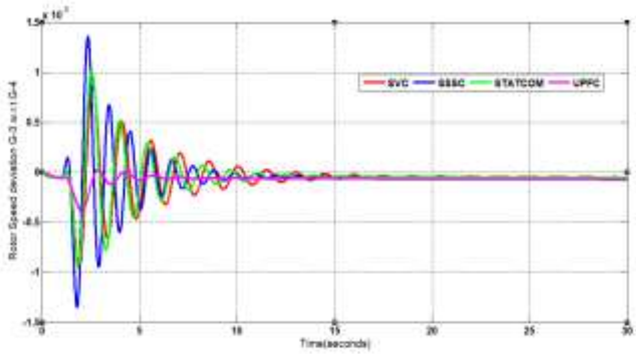

Fig. 14: Speed deviation of G-3 w.r.t G-4 with Comparison of FACTS Devices and local PSS

6. CONCLUSION

In this paper researcher designed FACTS damping controller to damp out the low-frequency electromechanical oscillations in a large-scale Power System due to this Power System stability improve by using Comparison of FACTS Devices. To observe our simulation result UPFC gives better result Compare of other FACTS Devices like SVC, SSSC, and STATCOM. Due to this Reactive FACTS device, such as UPFC are considered and assessed for their damping controller design. In this research study, we also implemented supplementary POD Controller to control the UPFC and improve the performance of Power System under transient condition. Some simulation results are carried out to verify the effectiveness of the proposed controller under small disturbance. From the simulation results, it reveals that the proposed controller damps out low-frequency electromechanical oscillations effectively and improve Power System stability.

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