Analysis of Inter-Area Oscillations and A Case Study of Two Area System

Kumar Kartikeya, Manish Kumar Singh, Devesh Singh

Abstract*— *The inter-area oscillations are highly non-linear and complex in nature. They are not easily damped by the conventional Power System Stabilizers. They cause the interruptions in the flow of bulk power in between two areas and sometimes they may cause the breaking of power system, if not damped sufficiently. Inter-Area oscillations contribute significant importance because they involve various units belonging to different areas in power system. They may cause greater oscillations in the tie line connecting various units. To analyse these inter-area oscillations, the entire power system has to be represented in detail. The analysis has also be done on how the certain quantity of power is transferred from one area to another which are interconnected by tie- line.

Index Terms*— *Inter-Area Oscillations, Oscilltions, Power System Stabilizer (PSS), Static Var Compensator (SVC), Unified Power Flow Controller (UPFC).

I. INTRODUCTION

The oscillations that are generated in one or more generators in a same area with respect to the rest of the system are called as local mode oscillations. These local mode oscillations can be sufficiently mitigated by using conventional power system stabilizers. These local mode oscillations have the frequency range from 0.7 Hz to 2.0 Hz. While the oscillations which are occurred in groups of generators in different areas that are oscillating against each other are known as inter-area oscillations. The stability of electro-mechanical oscillations is vital for the secure functioning of power system network [1]. Local modes can be suitably determined and influenced by local area states. Satisfactory solutions for the problems based on stability can be made easily. But the analysis of inter-area modes is quite complex because they require a detailed representation of the whole interconnected power network [2]. These inter-area modes are influenced by global states of huge areas of power systems [3]. They have the frequency range from 0.1 Hz to 0.8 Hz. The inter-area modes produce larger oscillations in tie-lines [4]. Therefore, it can influence the exchange of bulk power in between two areas and hence, it is considered as of greater significance [5], especially in the deregulated atmosphere where operators are forced to execute maximum utilization of transmitted power.

Minimum damping coefficient under acceptable limit with respect to any mode depends upon various factors such as the system to be studied [5], operating conditions of a utility, past observations and studies executed on the system. The magnitude of damping under acceptance is from 0.03 to 0.05 [4]. The analysis of inter-area oscillations for inter-connected power systems is vital for correcting the day to day contingencies as well as for natural increment in the quantity of power transferred in the required areas. Recently, various events of unstable oscillations, including the inter-area modes in large power systems, have been experienced [3], [6], [7]. These oscillations are increasingly become a major issue of concern and consequently lead to the analysis of these kind of modes.

Both the small signal stability analysis and transient stability analysis can be used for studying the inter-area oscillations. But using modal techniques, small signal stability analysis is superior for determining the nature of inter-area oscillations in power systems [8].

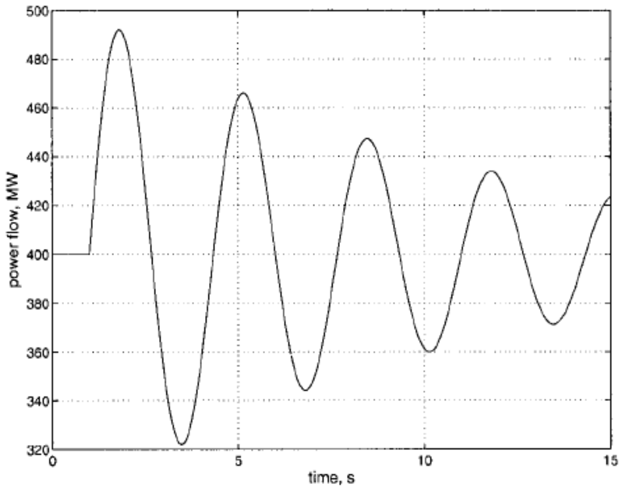

Fig 1: An example of Inter-Area Oscillation

II. DEVICES USED FOR INTER-AREA OSCILLATIONS DAMPING

For the purpose of maximum amount of power transfer, several devices are proposed for successful transmission of electrical power in power systems. These devices are not only applicable for inter-area oscillation damping but also ensure the stability of the system and the loads during the procedure of transmission. A theoretical analysis of these devices has done in the following sections.

A. Static Var Compensator (SVC)

The Static Var Compensator (SVC) is a static reactive power compensation component which is connected in shunt arrangement. It is actually prepared [9] to ensure that the magnitude of bus voltage lie very closer to a set value. It involves a shunt capacitor bank and thyristor controlled shunt reactors.

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An SVC can be shown in figure 2 for the study of power flow and study of power system. This is an ideal model of a SVC. It consists of a fixed capacitor which is connected in parallel arrangement to a variable reactor. The SVC evolves or absorbs reactive power to keep the voltage in an acceptable limit, when the value of reactance is controlled.

Figure 3 shows the block diagram arrangement of SVC control. In steady state, the SVC controller employs the magnitude between the reference voltage and the measured voltage to determine the adjustment of reactive power, Q, of the output of SVC. These adjustments enable to hold the local voltage that is close to the reference voltage. If the parameters of controller are set properly, then SVC can also be used for improvement in small signal stability of the system.

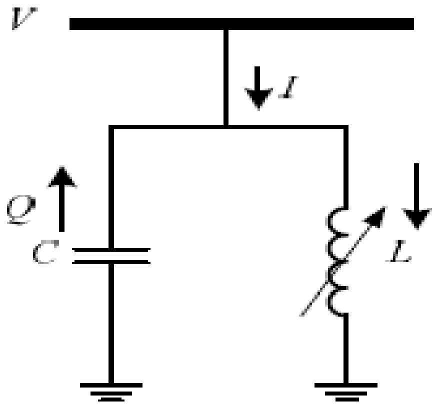

Fig 2: Model of a SVC

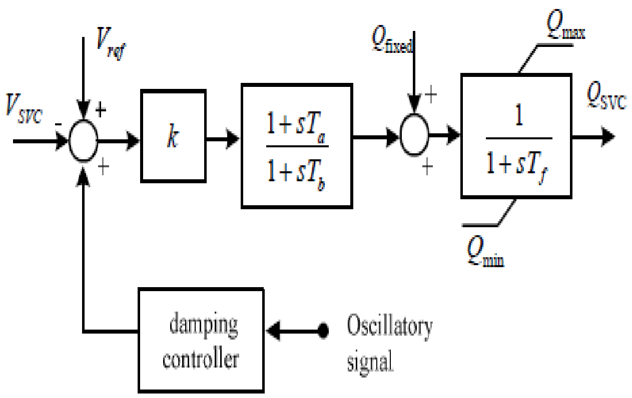

Fig 3: Block diagram representation of SVC

B. Unified Power Flow Controller (UPFC)

Unified Power Flow Controller (UPFC) is a series-shunt FACTS instrument. It involves the combination of SSSC, which is connected in series and STATCOM, that is connected in parallel with the transmission line [10]. These two voltage source converters are connected by a common dc. link capacitor. Fig 4 is the circuit diagram of UPFC.

The series part injects the voltage of controllable value in the transmission line for regulating the real and reactive power of the power system. The shunt part maintains the voltage across the d.c. link capacitor and the bus voltage where it is connected by injecting the current of controlled value in the system. Each voltage source converter is able to control the magnitude and phase angle of the output voltages of series and shunt converters by controlling the amplitude of modulation index and phase-angle of series and shunt respectively [11].

For damping of oscillations, the design of UPFC consists of series and shunt controller. But these controllers are

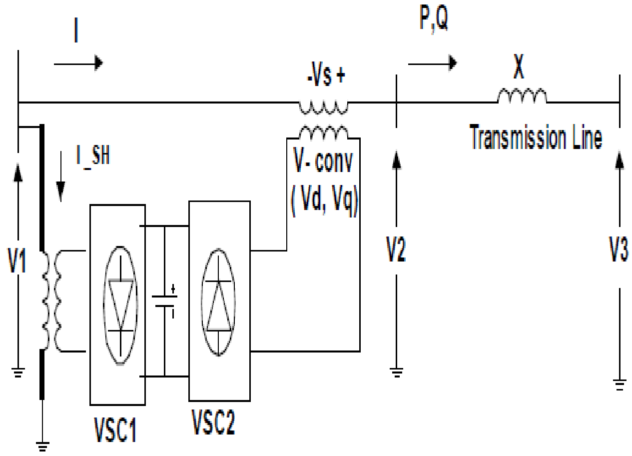

Fig 4: Circuit diagram of UPFC

unable to provide adequate damping. Therefore, an additional damping controller called Power Oscillations Damping (POD) Controller is employed with the main controller of UPFC for the desired purpose. Fig 5 is the block diagram of POD controller [10]. It consists of a gain block, washout block and two lead-lag blocks. The input to the POD is the change in speed or change in real power and output is the damping signal Xpod.

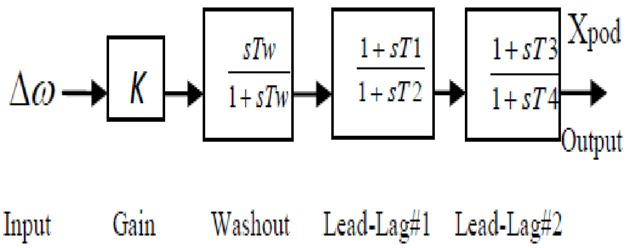

Fig 5: Block diagram representation of UPFC

C. Power System Stabilizers (PSS)

Power system stabilizers are the generator controlled equipments which are used in feedback to provide stabilizing signals to increase the damping of oscillations caused by the signal disturbance. This disturbance may be caused by the small change in the reference voltage of Automatic Voltage Regulator that results increase in oscillations. The conventional power system stabilizers [12] apply the local signals like rotor speed or frequency, active power for input signals in order to add damping torque in phase with the speed deviation to damp local and inter-area oscillations. The block diagram representation of Power System Stabilizer is shown in Fig 6. The PSS consists of three blocks: a phase compensation block, a signal washout block and a gain block [13]. The phase compensation block provides compensation by proper phase-lead characteristic due to the phase lag between the exciter input and the generator electrical (air-gap) torque. The signal washout block acts like a high-pass filter, having time constant T_{W}.

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It allows the signals which are associated with oscillations ω_r to pass without any variation. It allows the PSS to respond towards the variations in speed. The magnitude of T_w lies in the range of 1 to 20 seconds. The stabilizer gain K_{STAB} is employed to determine the amount of damping provided by the PSS. Ideally, the gain should be set at a value corresponding to maximum damping; but, it is often limited by the other considerations. When a PSS is employed, care should be taken that the overall system stability should be enhanced, not only the small signal stability.

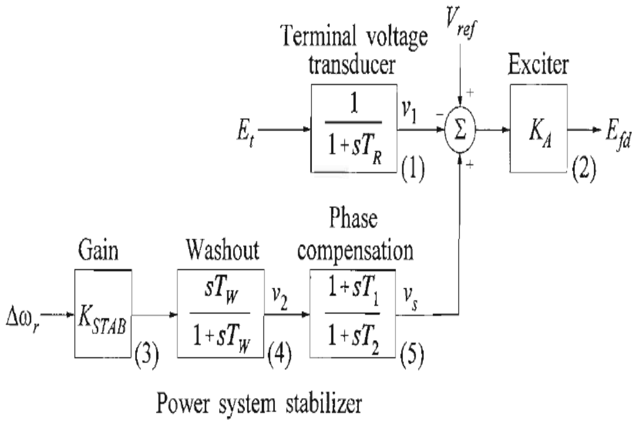

Fig 6: Block diagram representation of Power System Stabilizer

III. Experimental Study

The nature of inter-area oscillations in large power systems is quite complex. There are various number of modes, each of having a large number of generators. In this analysis of a specific two area case as shown in Fig. 7 [13], the small signal stability analysis for local and inter-area oscillation has been done to find the eigenvalues and corresponding damping frequency and damping ratio of various modes.

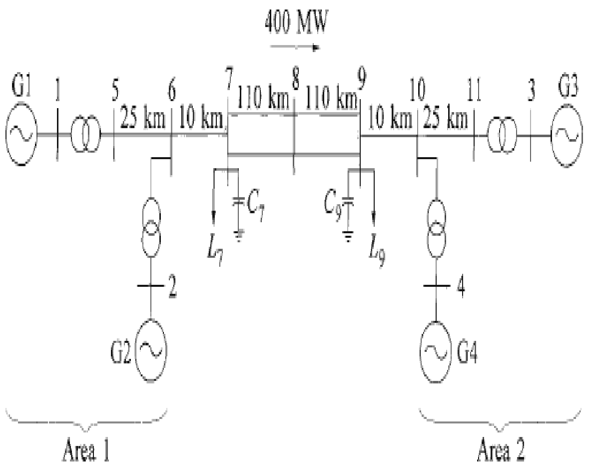

Fig 7: A general system representing two identical Areas

From the table 1, it is observed that the system is stable. There are three modes of oscillation and their mode shapes are shown in figure 8. The graph 1 shows inter-area mode with frequency, f = 0.546 Hz and damping ratio, ζ = 0.033. It shows that generators G_1 and G_2 of area 1 are swinging against generators G_3 and G_4 of area 2. The graph 2 shows the local mode of area 1 with f = 1.09 Hz and ζ = 0.074. In this case, G_1 is swinging against G_2 in area 1. In graph 3, G_3 is swinging against G_4 with f = 1.118 Hz and ζ = 0.075 with local mode of area 2.

Table I : Eigen Values with Corresponding Frequency and Damping Ratio

Eigen Values			Frequency (Hz)	Damping Ratio
No.	Real	Imaginary		
1,2	-0.74e-3	± 0.25e-2	0.0003	0.334
3	-0.97e-1	_	_	_
4,5	-0.112	± 3.45	0.546	0.033
6	-0.118	_	_	_
7	-0.267	_	_	_
8	-0.278	_	_	_
9,10	-0.490	± 6.84	1.090	0.074
11,12	-0.506	± 7.02	1.118	0.075
13	-3.430	_	_	_
14	-4.138	_	_	_
15	-5.288	_	_	_
16	-5.304	_	_	_
17	-31.06	_	_	_
18	-32.47	_	_	_
19	-34.03	_	_	_
20	-35.51	_	_	_
21,22	-37.85	± 0.144	0.021	≈1
23,24	-38.03	±0.37e-1	0.007	≈1

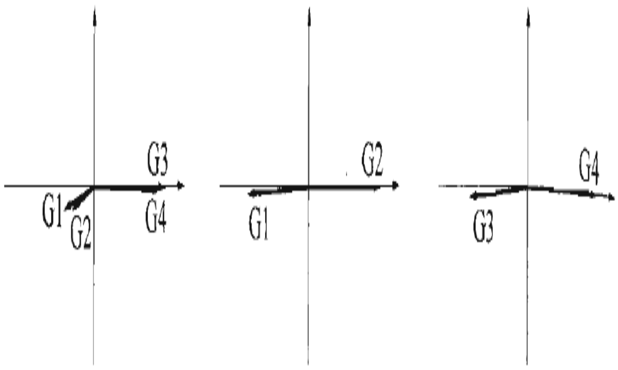

Fig 8: Shapes of Rotor Angle Modes of Two Areas with Generators G_1, G_2, G_3 and G_4

IV. Results

After designing the models and executing simulation, all the graphs are plotted with per unit at y-axis and time at x-axis.

The red line shows the performance of Multi Band-Power System Stabilizer (PSS), blue line shows the Generic PSS receiving change in speed of synchronous machine, dw and the pink line shows Generic PSS with synchronous machine acceleration power as input signal. The graphs of change in angle of rotor, dtheta (Fig 9), speed of synchronous machine, w (Fig. 10), acceleration power of synchronous machine (Fig. 11), Pa and terminal voltage Vt (Fig 12) are shown.

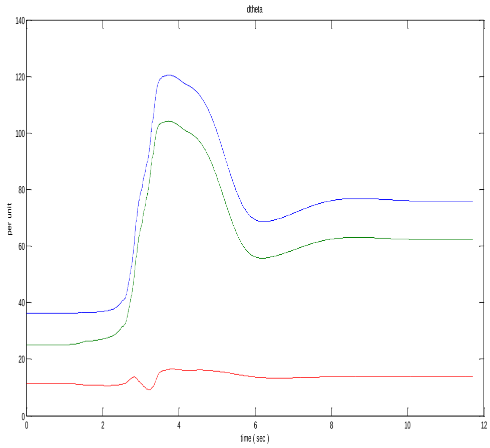

Fig 9: Graph of Change in Angle of Rotor (per unit vs time)

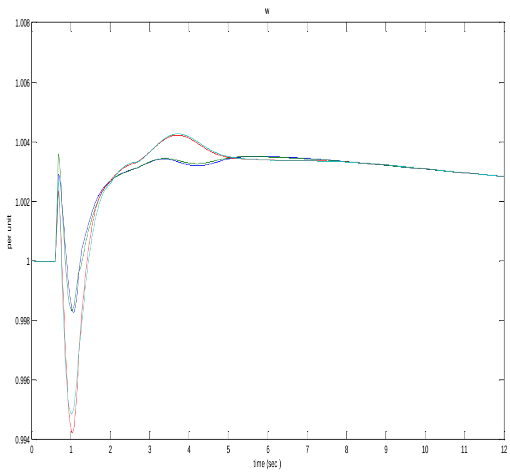

Fig 10: Graph of Speed of Synchronous Machine (per unit vs time)

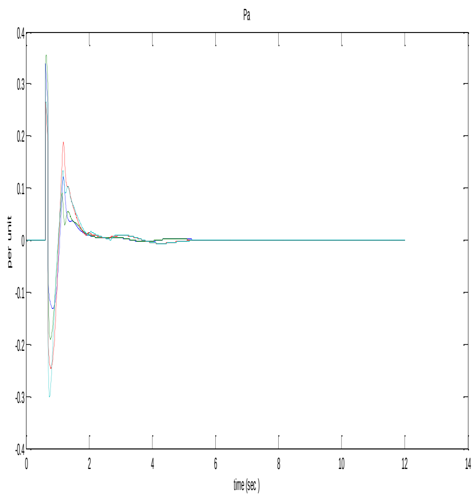

Fig 11: Graph of accelerated power (per unit vs time)

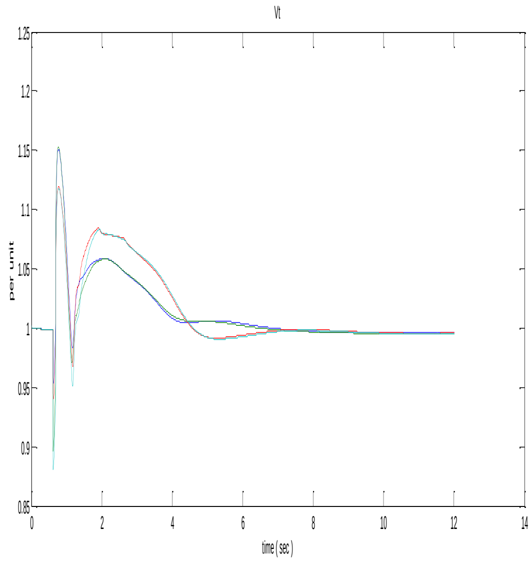

Fig 12: Graph of terminal voltage (per unit vs time)

All the Power System Stabilizers executed a fine job regarding stabilizing the unstable system. But it can be observed that Multi Band-PSS is much better as compared to the other two PSSs, especially from Generic PSS with dw as input. Although, all of them are widely applied for damping of power oscillations but for inter-area oscillations, MB-PSS is more preferred than other two as it possess various bands for damping local modes, inter-area modes and global modes.

V.CONCLUSION

A brief description of inter-area oscillations is given along with the instruments that are widely applicable for the damping of them. These are Static Var Compensator (SVC), Unified Power Flow Controller (UPFC) and Power System Stabilizer. Their block diagrams with components are provided for the better explanation regarding the damping of inter-area oscillation. An experimental study of inter-area oscillations and local oscillations for small signal stability analysis is carried out after which eigenvalues with frequency and damping ratio respectively are calculated. The simulation is executed and the consequent graphs are shown in results. It determines the performance of various PSSs about their damping abilities on various parameters which are already described.

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