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A Comparative Analysis of Facts Devices for Damping of Inter Area Oscillation

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Abstract:
A Unified Power Flow Controller (UPFC) is a typical FACTS device capable of instantaneous control of three system parameters. Unified Power Flow Controller (UPFC) is able to control both the transmitted real power and the reactive power flows at the sending- and the receiving-end, at the midpoint of the transmission line. This paper discusses a novel approach for damping interarea oscillations in a bulk power network using multiple unified power flow controllers (UPFCs). An additional power oscillation damping (POD) controller is used along with the UPFC main controller for this purpose. The simulation is carried out in MATLAB simulink which shows promising results. STATCOM is reactive power compensator based upon a voltage source converter which uses power electronic devices with turn-off capability as switching devices. Its main function is to support bus voltage of which it is connected to the system by providing quick response to supply or absorb reactive power. For damping power oscillations purpose, it is required to employ power oscillation damping (POD) function wherein its output is summed to voltage reference as input of STATCOM. This paper focuses on implementing POD function in STATCOM control to damp interarea oscillations mode. Kundur's two area system with 11 buses and four generating units is used. Each generating unit uses fast exciter and the system presents three modes of oscillations, that is, local mode area 1, local mode area 2 and interarea mode. The power oscillations can then be damped by STATCOM Controller which is equipped with the POD function. This paper investigates the effect of Interline Power Flow Controller (IPFC), an advanced Flexible AC Transmission System (FACTS) controller, in damping low frequency oscillations via supplementary control. For this purpose, a modified linearised Phillips-Heffron model for a Single machine Infinite Bus (SMIB) system installed with IPFC is established, and the power oscillation damping controller is designed.

Keywords: UPFC, IPFC, STATCOM, Power oscillator damping controller, inter area oscillations

1. INTRODUCTION

Unified power flow controller (UPFC) is a series shunt FACTS device. It consists of a combination of SSSC in series and STATCOM in shunt with the transmission line. These two voltage source converters are connected by a common d.c. link capacitor. The series part injects the voltage of controllable magnitude in the transmission line to control the real and reactive power of the power system. The shunt part is used to maintain the voltage across the d.c. link capacitor and the bus voltage where it is connected by injecting the current of controllable magnitude in the system. Each voltage source converter can control the magnitude and phase angle of the output voltages of series and shunt converters by controlling the amplitude of modulation index. UPFC main control consists of series and shunt controller. These controllers do not provide adequate damping. Hence, an additional damping controller known as power oscillations damping (POD) controller is used in conjunction with the main controller of UPFC for this purpose. The IPFC allows to simultaneously and independently inject, over each transmission line, a controllable series voltage which enables to equalize both real and reactive power flow between the lines; transfer power demand from overload to under loaded lines; compensate against resistive line voltage drops and the corresponding reactive power demand; increase the effectiveness of the overall compensating system for dynamic disturbances. Though the primary function of the IPFC is to control power flow on a given line, it can also be utilized for damping power oscillations. ST ATCOM Controller is used to perform inter-area oscillations damping. It should be noted that the main objective of STATCOMs is to enhance voltage stability and increase power flow transfer capability, and hence a POD function shall be incorporated in the ST ATCOM Controller to perform power oscillation damping. Kundur's two area system, with static exciter in all generators, is used as study case, because it clearly shows both local modes and inter-area modes of oscillation. The effect of IPFC on damping inter-area oscillations with a PI damping controller, with electrical power as input.

2. SYSTEM MODEL AND BLOCK DIAGRAMS

2.1 Unified Power flow controller (UPFC) Model:

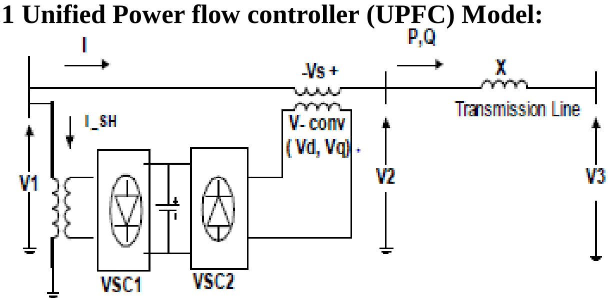

Figure.1. UPFC MODEL

2.1.1 POD CONTROLLER:

The construction of POD controller is shown below.. Fig. shows the block diagram of POD controller. 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.

2.1.2 BLOCK DIAGRAM OF POD CONTROLLER

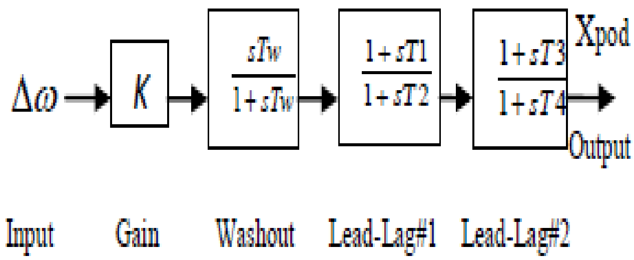

Figure.2. Block Diagram of Pod Controller

2.1.3. The Study System

Fig.3 shows a single line diagram of the study system i.e. two area power system which is used to investigate the effect of UPFC for damping the power system oscillations. The system consists of two areas namely area-1 and area-2 connected with a tie line of 230kV and 220km length. Each area is equipped with two generators. The rating of the parameters are same except the inertia constant, H= 6.5s for area-1 and H=6.175s for area-2. Area-1 transmits 400kW power to area-2.

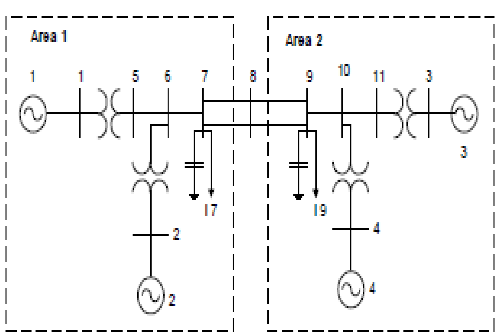

Figure.3. Two area power system

2.2 IPFC MODEL

A single machine infinite bus system installed with IPFC as shown in Fig. 4 is considered. The IPFC is installed on the two parallel transmission lines. The IPFC is assumed to be based on pulse width modulation (PWM) converter

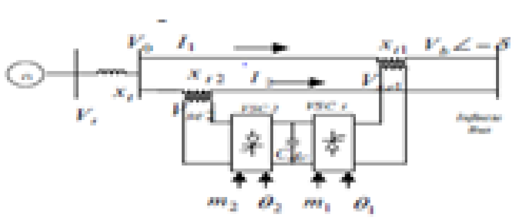

Figure.4. IPFC installed in a SMIB system

2.2.1 Linear dynamic model (Modified Heffron –Phillips Model): Here, the modified Phillips-Heffron model of the system incorporating IPFC.

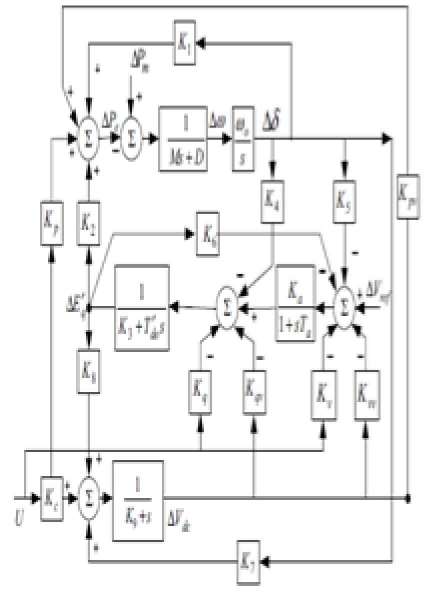

Figure.5. Modified Heffron-Phillips model of SMIB system with IPFC

2.2.2 Design of damping controllers:

The damping controllers are designed to provide an additional electrical torque in phase with the speed deviation. The speed deviation is considered as the input to the damping controller whose output is used to modulate the controlled parameters which controls the series voltage injected in line. It is assumed that, for the series converter in line, the active power flow control constraint is used while the reactive power flow constraint is relaxed. The structure of IPFC based damping controller is shown in Fig. 6. It consists of gain, signal washout and phase compensation blocks.

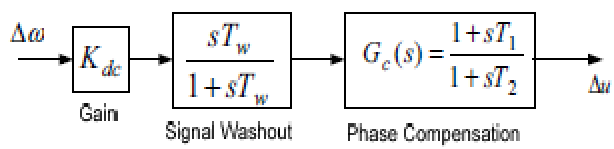

Figure.6. Structure of IPFC based damping controller

2.3 STATCOM MODEL

ST ATCOM is defined as a static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage .it acts as the synchronous condenser, but without inertia. Rotational inertia as a STATCOM can provide synthetic inertia from the energy stored in the DC capacitor. STATCOMs can utilize a new generation of power semiconductors such as IGBT/IGCT that lead to a high speed response in enhancing voltage, transient stability as well as power oscillation damping.

2.3.1 Basic structure of a STATCOM

A STATCOM primarily comprises a voltage source converter, a coupling transformer and controls. It is employed to supply or absorb reactive power to the ac power system to which it is connected for maintaining voltage profile. A dc capacitor acts as the dc power source and thus the converter produces a set of controllable three phase output voltages at fundamental frequency.

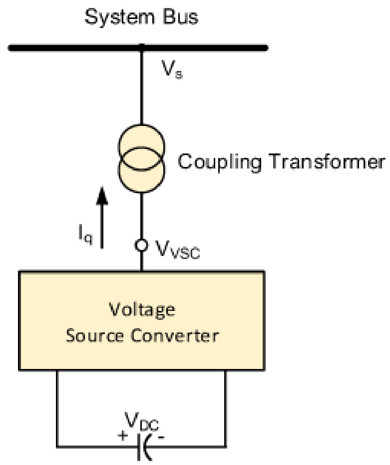

Figure.7. Schematic of the STATCOM.

2.3.2 Operating characteristics of the STATCOM

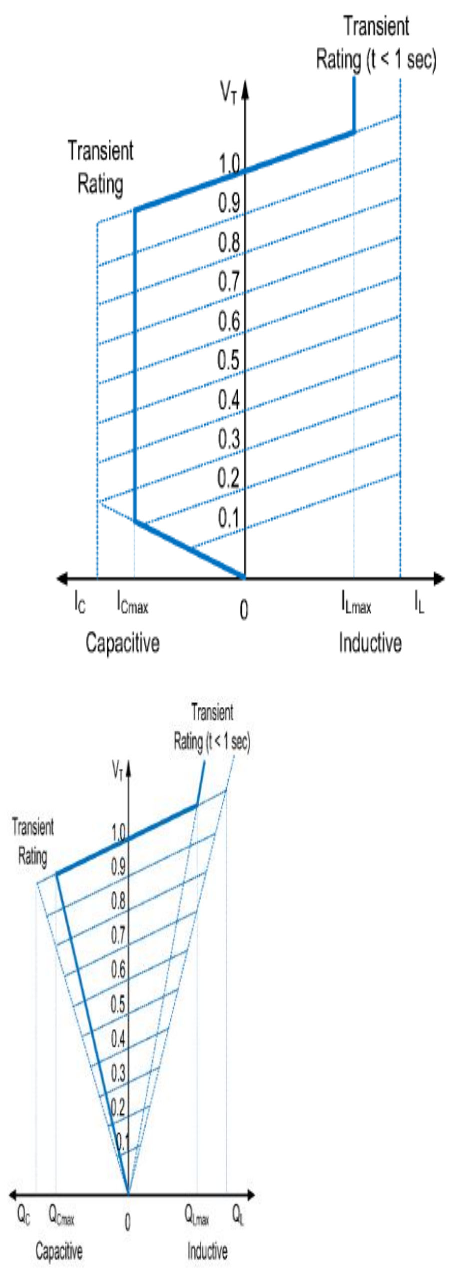

Figure.8. Operating characteristics of the STATCOM

2.3.3 Kundur's Two Area System

The system comprises two similar areas connected by a weak tie. Each area consists of two generators, and each generator has a rating of 900 MV A and 20 kV. The system contains eleven buses wherein two loads and two shunt capacitors are applied to the system at bus 7and 9. The fundamental frequency 60 Hz is applied in the system. The Kundur's two area system is shown in Fig.9.

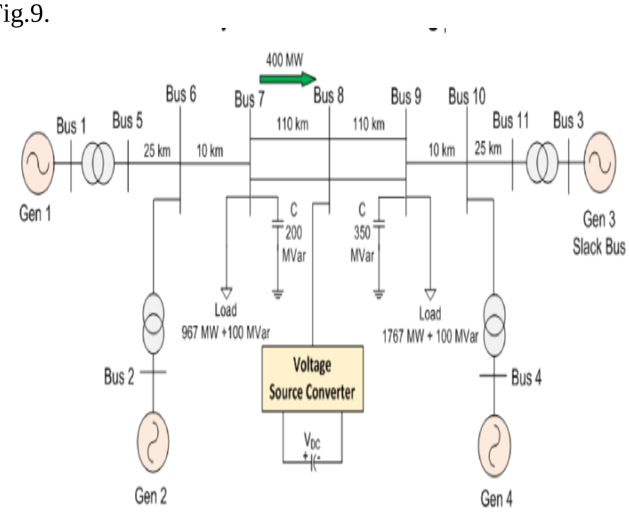

Figure.9. Kundur's two area system.

3. RESULTS AND DISCUSSION

3.1 RESULTS FROM UPFC CONTROL

This section presents the analysis of the two area power system during disturbance with UPFC, its POD controller. The simulation is carried out for 12s on MATLAB/simulink platform. The disturbance is created by a three phase fault of 0.1s near bus-B7.The fault occurs at 2.5s and clears after 2.6s. The UPFC is connected near bus-B8. The figures 10.1, 10.2, 10.3,10,4 shows the simulation results for active power in MW from area-1 to area-2 without any controller and with combination of UPFC, POD, whereas fig. 10.5 shows the result for rotor angle of generator-1 i.e. G1 relative to G4 with the same operating conditions.

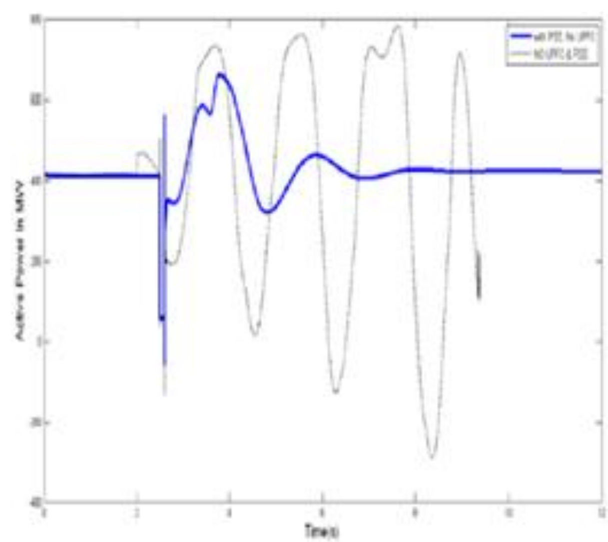

Figure.10. 1 Active power in MW with PSS alone and without PSS and UPFC

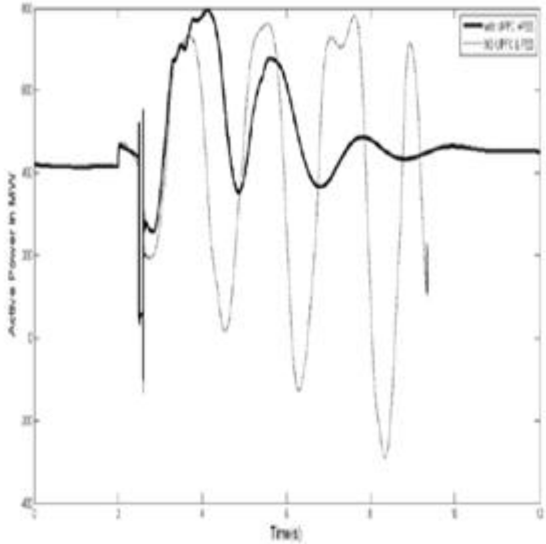

Figure.10. 2: Active power in MW with and without PSS and UPFC

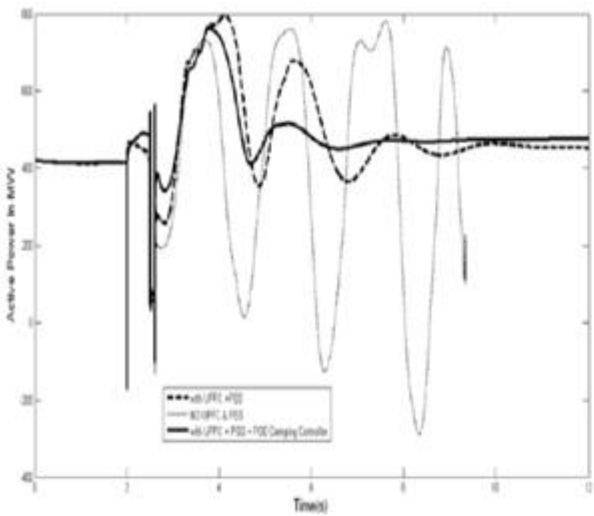

Figure.10. 3: Active power in MW with UPFC+POD+PSS and without PSS and UPFC

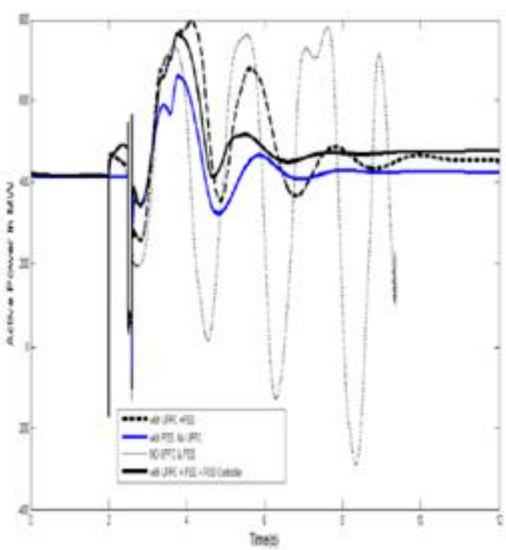

Figure.10. 4: Comparison between simulation response for UPFC+POD+PSS, UPFC+PSS+ No POD and only PSS for Active power in MW

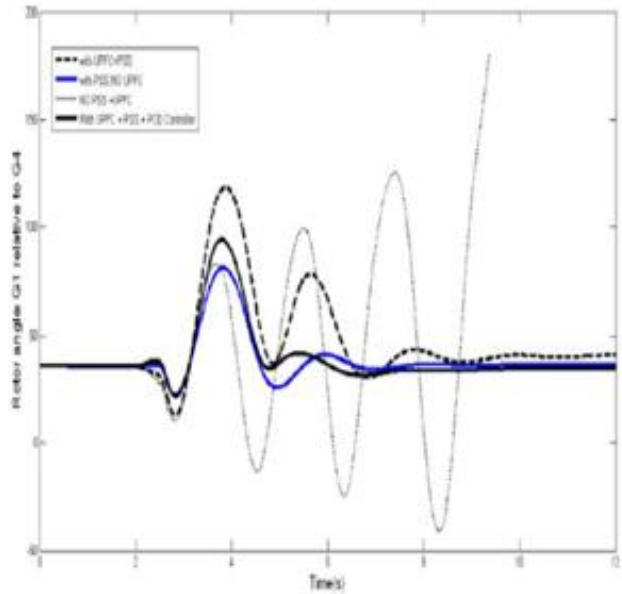

Figure.10. 5: Rotor angle G1 relative to G4 in degrees.

3.2 RESULTS FROM IPFC CONTROL

To examine the effect of IPFC based damping controller on the system, simulations are performed using Matlab simulink on the system, first without IPFC and then, with IPFC and damping controller. Using these values the Phillips-Heffron linear model of the single machine infinite bus without IPFC is simulated in Matlab. The response of change in speed for the system when there is no IPFC is given in Fig 11.1. Which indicates the system is unstable and requires additional damping to sustain the oscillation.

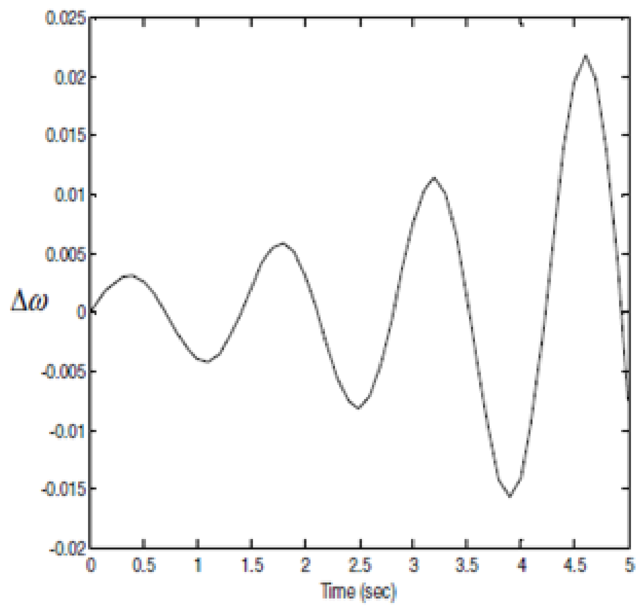

Figure.11. 1: Dynamic response for dw without IPFC

Fig 11.2 shows the damping controller provides satisfactory performance at the nominal operating condition. The robustness of the damping controller designed at the nominal operating point is examined by varying the loading conditions of the system. The load condition of the system is varied from *Pe* = 0.1 to *Pe* = 1.0. The dynamic responses of the system are obtained for each loading condition.

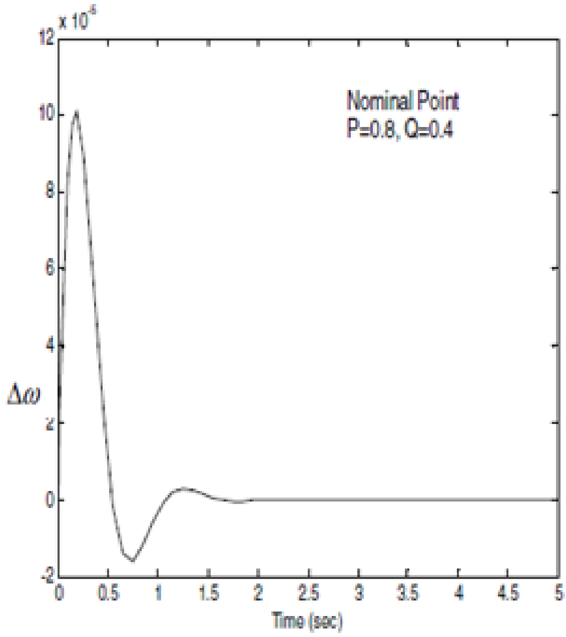

Figure.11. 2: Dynamic response for DW with the IPFC based damping controller

Fig 11.3 , shows the dynamic responses of dw for *Pe* = 0.2 (light loading), *Pe* = 0.8 (nominal loading)and *Pe* = 1.0 (heavy loading) It can be seen that the responses are similar in terms of settling time which indicates that the damping controller provides satisfactory performance under wide variation in loading conditions.

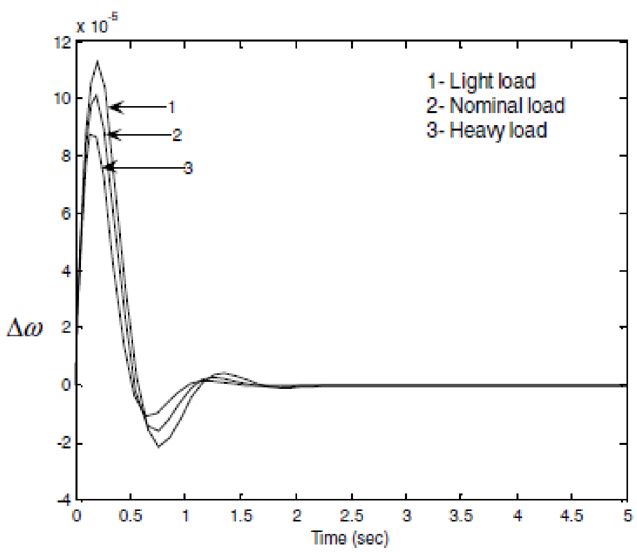

Figure.11. 3 Dynamic response for w with the IPFC based damping controller for different loading conditions.

3.3 RESULTS FROM STATCOM CONTROL

3.3.1 The System without the STATCOM (The Base System):

In order to know the base condition of the response system, the simulation of the system without the STATCOM applied is conducted. The normal condition which is no fault applied and some different contingencies condition for the system without the STATCOM connected are simulated. The simulation results of the system without STATCOM are as shown in Fig 12.1.

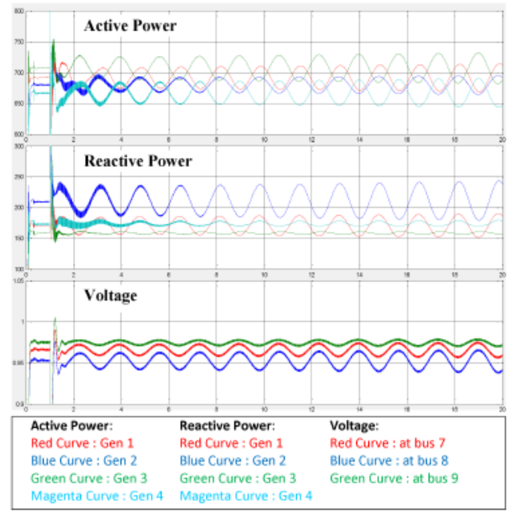

Figure.12.1: The system without STATCOM (the base system) when a three phase to ground fault applied at t = I s and fault clearing time 0.05 s .3.3.2 The System with the STATCOM without the POD Function: The ST ATCOM was connected to the power system with three different bus connected i.e. , bus 7, bus 8, and bus 9. The selected bus is based on the simulation result of the system without the STATCOM which shows three of those buses have the lowest voltage level. Moreover, the voltage level of others buses such as bus 1, bus 2, bus 3, and bus 4 were supported by generation units in each area.

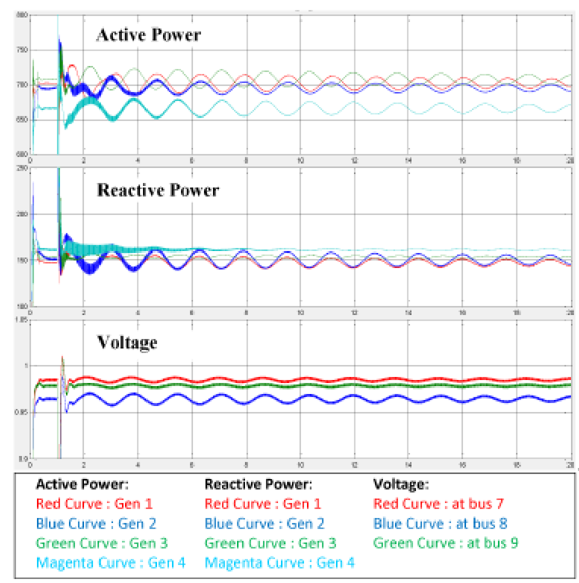

Figure.12. 2: the system with STATCOM without POD function, connected at bus 7 when a three phase to ground fault applied at t = 1s and 0.05 s.

3.3.3 The System with the STATCOM and the POD Function:

The POD function was incorporated to the STATCOM model to perform power oscillation damping. Parameters of the POD function consist of a gain, a washout filter and lead-lag constants. The washout filter is in the range 1-20 s, and therefore can be determined 10 s, whereas the gain, the lead time, and the lag time are tuned by trial and error to obtain the best performance for damping power oscillations.

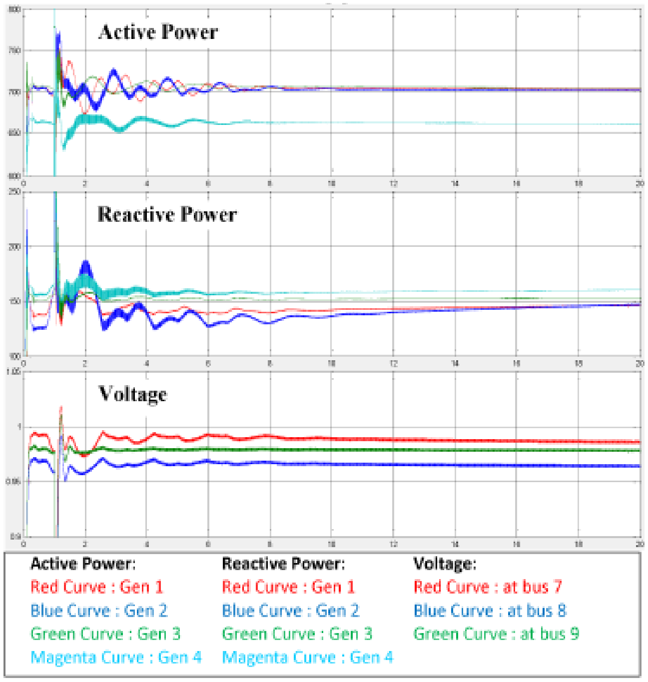

Figure12. 3: The system with STATCOM and POD function, connected at bus7 when a three phase to ground fault applied at t = I sand fct 0.05 s.

4. CONCLUSIONS

This is a review paper showcasing the application of UPFC for damping power system oscillations. The two area power system was used to analyse the role of UPFC for damping the oscillations. It was observed that the results with UPFC, POD and PSS show satisfactory performance as compared with only UPFC & PSS. Thus it can be concluded that for effective damping of power system oscillations, UPFC requires an additional power oscillations damping (POD) controller. The effectiveness of the IPFC based damping controller has been investigated in damping low frequency oscillations. Dynamic simulations results have emphasized that the damping controller which modulates the control signal provides satisfactory dynamic performance under wide variations in loading condition and system parameters. Further work will be carried on applying the controller design for a multi machine system. The POD function has been implemented in the STATCOM Controller to damp power oscillations in Kundur's two area systems. The simulation results show that with a proper placement and parameter setting of the POD function can enhance the power oscillation damping of the specific power system and contingency conditions.

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