International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 11 • Issue 1 pp. 125-129 Jan 2019-June 2019 www.csjournals.com

Power System Dynamic Stability Analysis using Unified Power Flow Controller (UPFC)

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Abstract: Dynamic stability problems mainly due to frequency variations in power systems are a major concern for electrical engineers around the world. Frequency oscillations problems are due to change in generation, load or fault in the system. Traditionally, Power System Stabilizer (PSS) damps these variations to an extent. Currently power electronic based FACTS can also replace to damp these frequency variations. In this paper the capabilities of UPFC FACTS device to deal with the problem are presented. The simulation outcomes shows the effectiveness of UPFC to damp the electromechanical variations in power system.
Keywords: Dynamic Stability, FACTS, Oscillation Damping, Power System Stabilizer, UPFC.

Introduction

Presently, power transmission structure is escalating gradually and is getting ever more complex.The transmission of energy is limited by angle stability (transient, small signal), frequency and voltage stability [1], [2]. These stabilities put constraints to the full utilization of the available transmission system.

A problem of current interest is to mitigate power system variations. Occurrences of these frequency variations are mostly due to change in generation, load demand and fault in power systems. These disturbances will stimulate the power system into an accepted mode of variations of order 0.1 to 2.0 Hz. To transmit bulk power in complex power system over long distances, PSS are not sufficient to damp the frequency electromechanical oscillations [3]. So need of the time is to explore more effective solution to damp these power system oscillations.

In recent times the advancement in power electronics technology such as FACTS have gained the huge interest. They are mainly used to improve the power transfer capability, controlling power flow, reactive power compensation (voltage control) and power quality enhancement. As a supplementary function of FACTS to enhance the systems dynamic stability such as damping the frequency oscillations have been studied extensively [4], [5]. The FACTS devices are mainly classified in (1) shunt devices mainly SVC, STATCOM, TCR and TSC (2) series devices mainly TCSC, SSSC and TCPST (3) combined shunt and series connected devices mainly UPFC, TCPST.

In this paper, dynamic stability problems mainly due to frequency variations in power systems using FACTS device are analyzed. Following the introduction next section, presented the mathematical model of UPFC. In next section, discussed the power system model that was used for UPFC FACTS device dynamic stability. In next sectionsimulated results and performances analysis are presented and finally in last section, conclusion and future works are presented.

UPFC Model

In this section UPFC model are presented. UPFC is a promising device in the FACTS technology. UPFC mainly controls the connected bus voltage, reactance and phase difference of the connected buses. UPFC power systems frequency damping enhancement are presented in [6]. Fig. 1 shows basic diagram of UPFC FACTS.

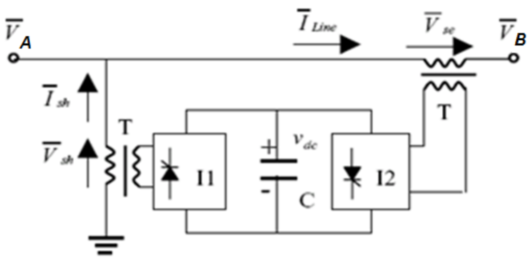

Figure1. Basic Structure of UPFC

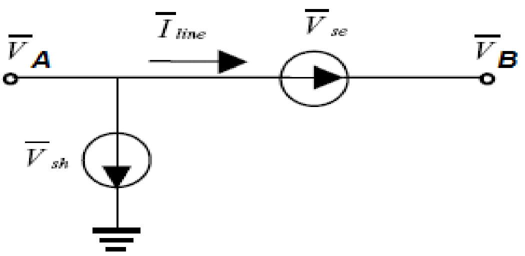

Figure 2. UPFC Dynamic model

Mainly, UPFC be made of two voltage source invertors (VSI), a DC storage capacitor, two transformers (i.e. excitation and boosting). The first VSI attached through excitation transformer, connected in parallel. The second VSI attached through boosting transformer, connected in line with the system. UPFC has several controlling modes through series control and shunt control [7], [8]. For oscillations damping the UPFC worked in voltage addition mode. UPFC dynamic simulation model are displayed in Fig.2.

In voltage injection mode, the FACTS device output is in line with the V_{se}(compensated voltage). The compensated voltage and I_{Line} (line current) are in quadrature with each other. In phasor the I_{Line} leads with V_{se}. UPFC damping compensation phasor diagram is shown in Fig.3. The dynamic stability can be achieved by controlling the magnitude of compensated voltage V_{se}.

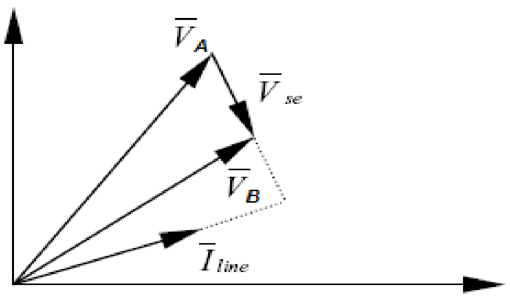

Figure 3.UPFC Damping Compensation Phasor Diagram

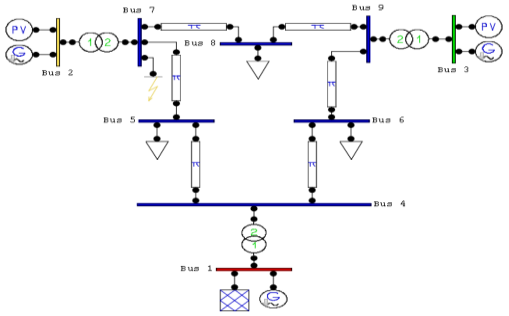

Figure 4. Power System Single Line Diagram

Power System Model

Fig. 4 shows the 9 bus, 3 machine power system model that was used for the current dynamic stability analysis. The dynamic simulations are carried out using the PSAT package 2.1.7 [9]. To study the power system dynamic behavior a 0.083 second 3-phase fault was created in the system. The complete details of power system under current analysis are presented in [9].

A UPFC FACTS connected between bus 8 and bus 9. The best location in the current system was find using Genetic Algorithm (GA) optimization based FACTS Placement Toolbox [10]. Table 1 shows GA optimization algorithm control toolbox values.

Table 1: GA Optimization Options

Sr. No.	GA Options	Value
1.	Generations	4
2.	Population Size	3000
3.	Elite Count	4
4	Crossover Fraction	0.7
5	Fitness Limit	1e-6
6	Time Limit	Inf.

Simulation Results and Discussions

Fig. 5 to Fig. 16 shows the dynamic stability analysis results. In this section the generators rotor angle, angular speed, bus voltages and active power supplied by the generators are presented. A 3-phase fault is instated at bus 7 at 1 second and cleared after 1.083 seconds.

The simulated result are compared with no control, with PSS and with PSS+UPFC. All values shows in the results are in Per Unit (P.U.). In Fig. 5 rotor angle variations at Gen. 1 w.r.t. time are presented. Fig. 6 represents the same at Gen. 2.

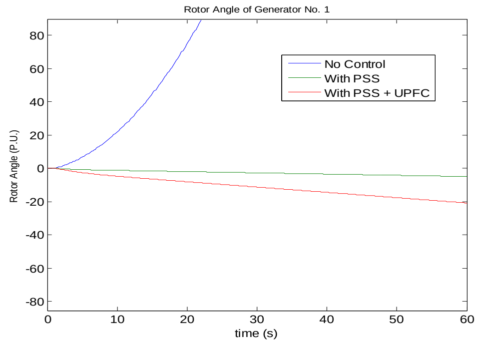

Figure 5.Rotor Angles at Generator no. 1

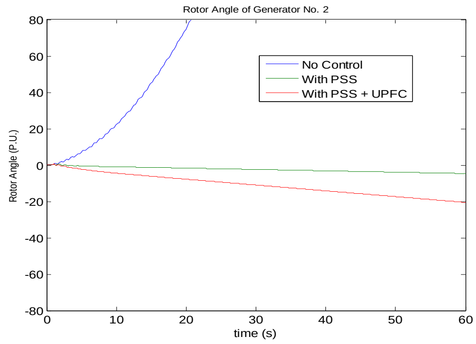

Figure 6. Rotor Angle at Generator no. 2

The above figure results shows that at no control the system became unstable after the fault and it will be in stable condition when connected with PSS and UPFC. The system shows the similar results at generator 3. Fig. 7 to Fig. 9 are shows the results of angular speed of the generators using with and without FACTS control.

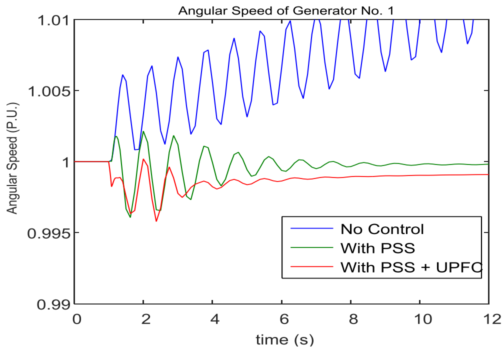

Figure 7. Angular Speed at Generator no. 1

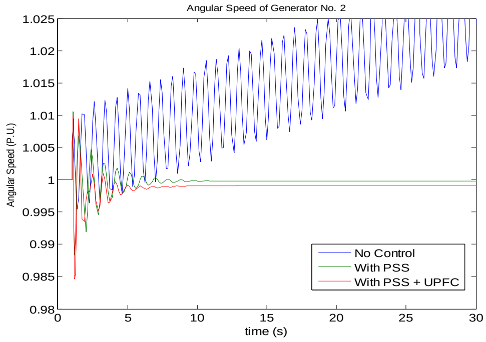

Figure 8.Angular Speed at Generator no. 2

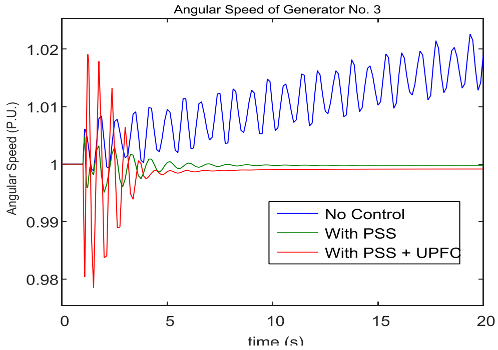

Figure 9. Angular Speed at Generator no. 3

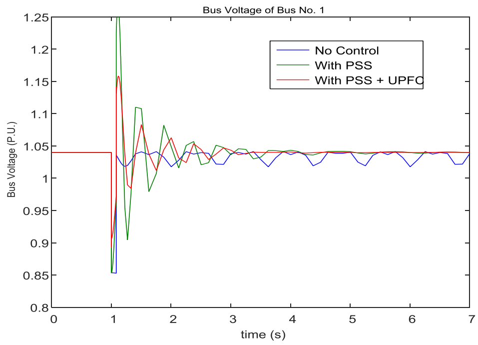

Figure 10.Bus Voltage at Bus no. 1

Fig. 10 and Fig. 11 shows the simulation results of generator bus voltages. Here also from the results with PSS+UPFC system is more stable as compared to the system with either no control or with PSS only. The settling time as well as the peck overshoot are minimum when the system connected with PSS+UPFC.

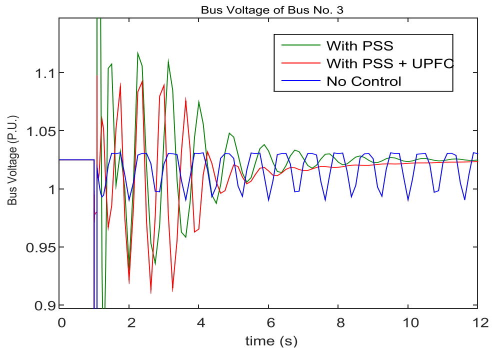

Figure 11.Bus Voltage at Bus no. 3

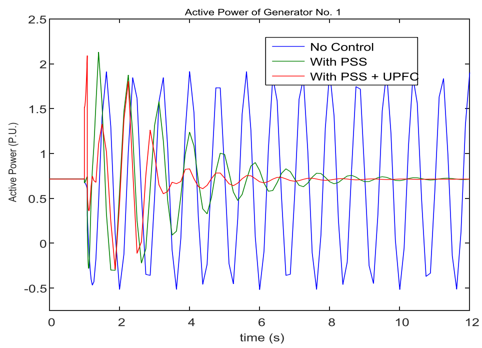

Figure 12.Active Power at Generator no. 1

Active power supplied by generator no. 1 and generator no. 2 are shows in Fig. 12 and Fig. 13 and it is verified that with UPFC FACTS device the system oscillations damps more quickly as compared to the system without control as well as with PSS.

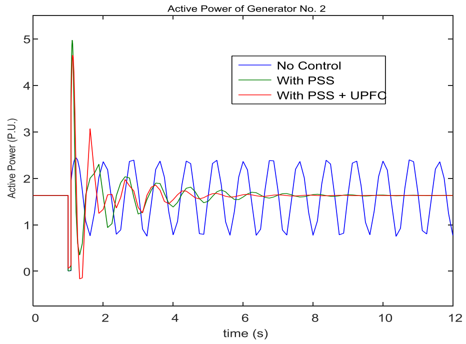

Figure 13. Active Power at Generator no. 2

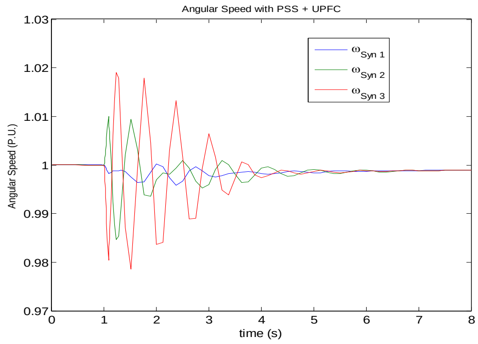

Figure 14. Angular Speed with PSS+UPFC

In Fig. 14 result of angular speed variations at Gen. 1, 2 and 3 are presented, when the system connected with PSS+UPFC.

Fig. 15 and Fig. 16 are shows bus voltage and real power variations at Gen. 1, 2 and 3 when the system connected with PSS+UPFC.

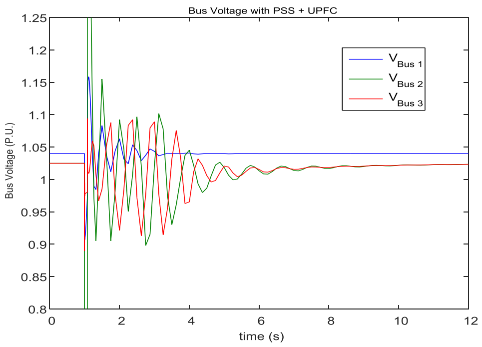

Figure 15. Bus Voltage with PSS+UPFC

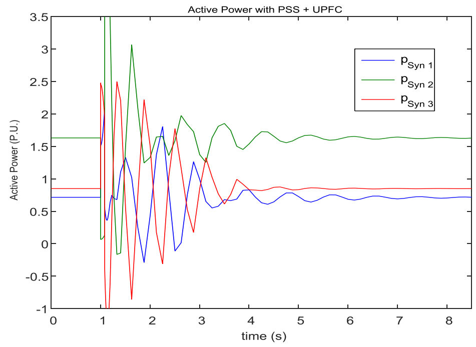

Figure 16. Active Power with PSS+UPFC

From the above simulated results it is clear that the variations are minimum at generator 1 because of connected at infinite bus. At bus 2 and bus 3 the generators oscillation dies quickly.

Finally from the above simulated results as represented power system dynamic stability are enhance using FACTS device. FACTS minimize the overshoot and the oscillations are die out quickly.

Conclusion

The dynamic stability analysis of 9 bus, 3 machine system using variations of rotor angle, angular speed, bus voltages and active power supplied by the generator are presented. From the time domain simulated results it is verified that the dynamic stability can be enhanced using FACTS device. Using the FACTS the settling time and overshoot can be reduced. In future the system will be analyzed using eigenvalue analysis for dynamic stability enhancement using FACTS devices.

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