Investigation of Transient Stability of Multi Machine Power Systems with Multiple UPFC

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Abstract

This study examines the impact of multiple UPFC on transient stability of a power system. A real based multi machine-65 bus system is modeled and analyzed with Unified Power Flow Controller (UPFC). The placement of the compensators is determined based on the transmission lines with highest voltage drop in the system. Transient stability effects are analyzed for three system cases, one without compensators, one with one compensator at a time and the last one with multiple compensators. Angle, angular speed of rotors and voltage of each bus is observed. The simulation results showed that the system with multiple compensators can damp oscillations more effectively, which makes the system in a more reliable operation.

1. Introduction

Transmission networks of modern power systems have been causing problems because of growing demand and restrictions on building new lines. One of the consequences of such a system is the threat of losing stability following a disturbance. Flexible AC Transmission System (FACTS) devices are found to be every effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin [1]. There are various forms of FACTS devices, some of which are connected in series with a line and the others are connected in shunt or a combination of series and shunt. A unified power flow controller (UPFC) is a member of FACTS family which is connected to a system in a combination of series and shunt. It has two voltage source converters coupled through a common dc link [2]. When the literature about UPFC has been reviewed it can be seen that; PSS analysis was conducted in a multi machine power system on DC capacitor, power and voltage according to nonlinear dynamic model[3]. UPFC has been effective in the improvement of power flow which depends on serial and parallel compensators [4]. In the transient stability condition, UPFC is effective on damping oscillation which occurs on DC link capacitor voltage by converter. [5]. In the power systems, for damping interarea oscillation using UPFC and extra capacitor, the system works safer. [6-7]. In determining optimum parameters of power systems like bus voltage, line flow, UPFC has been alterative due to case based. [8]. In regulation stability and transformer settings, UPFC provides relief and more reliable working in complex power systems. [9]. In steady state and transient conditions, depending on double converter use, UPFC supports the line and the bus 10]. In multi machine power system, first swing stability of UPFC in a multi-machine power system have been investigated and it is seen its effectiveness in angle stability [11]. In different controller modeling, UPFC provides better results than traditional methods. [12]. In the present study, a real based multi-machine 65 bus system is used to evaluate the impact of UPFC under transient conditions. It has been shown that using one UPFC results in late time response. The use of multi UPFC improves the time response and effectively damps oscillations.

2. n-Machines Power Systems Modeling

Consider an n bus system with multi machines showed by a classical model. The swing equations are given as i=1,2…ng.

$$\frac{d\theta_i}{dt} = w_s \Delta wr_i \tag{1}$$

$$2H_i \frac{d\Delta wr_i}{dt} = Pm_i - \sum_{j=1}^{n+m} |V_i| \times |V_j| \times \left[G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right] - KD_i \Delta wr_i \tag{2}$$

where, Δwr is the per unit speed deviation, H is the inertia constant, w_s is the synchronous generator speed, ng is the number of machines, P_m is the mechanical power input in per unit, $V_i(i=1......n)$ is the bus voltages in per unit, $\theta_i(i=1......n)$ is the phase angles in radians, δ_i is the angular positions of the rotors.

The power flow equations for a bus in transmission network are given by a set of algebraic equations, i=1……n.

$$PL_i = \sum_{j=1}^{n} |V_i| \times |V_j| \times |Y_{ij}| \times \cos(\delta_i - \delta_j - \theta_{ij}) \tag{3}$$

$$QL_i = \sum_{j=1}^{n-ng} |V_i| \times |V_j| \times |Y_{ij}| \times \sin(\delta_i - \delta_j - \theta_{ij}) \tag{4}$$

where $Y_{ij} = |Y_{ij}| \underline{/\theta_{ij}}$ obtained from the augmented Y_{BUS} matrix where the admittance corresponding to the transient reactance of the machines are included along with normal. PL_i

and QL_i are the real and reactive power loads, respectively, at the i[th] bus [13].

3. Unified Power Flow Controller (UPFC)

Circuit modeling of a UPFC connected transmission line is shown in Fig. 1.

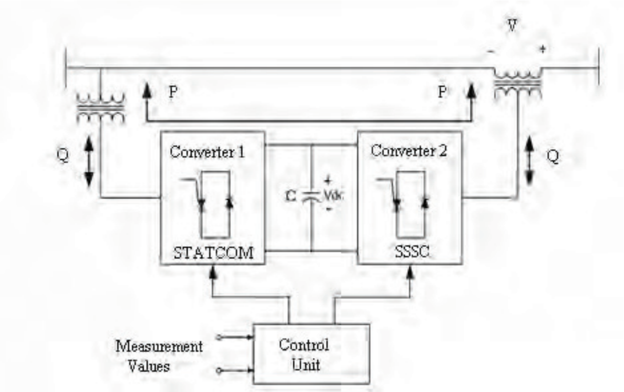

Fig. 1. UPFC circuit modeling

An UPFC consists of a parallel and series branches, each one contain of a transformer, power-electronic converter with turn-off capable semiconductor devices and dc circuit. Converter 2 is connected in series with the transmission line by series transformer. The real and reactive power flows in the transmission line can be quickly regulated by changing the magnitude and phase angle of the injected voltage produced by converter 2. The basic function of converter 1 is to supply the real power demanded by converter 2 through the common dc link. converter 1 can also generate or absorb controllable reactive power [14]. The system load flow equations can be rewritten

$$P_k = P_{km} + \sum_{j=1}^{N} [V_k] \times [V_j] \times [Y_{kj}] \times \cos(\delta_k - \delta_j - \theta_{kj}) \quad (5)$$

$$Q_k = Q_{km} + [V_j] \times [Y_{kj}] \times \sin(\delta_k - \delta_j - \theta_{kj}) \quad (6)$$

with FACTS devices added k bus load flow equations,

$$P_k = P_{km} + \sum_{j=1}^{N} [V_k] \times [V_j] \times [Y_{kj}] \times \cos(\delta_k - \delta_j - \theta_{kj}) + P_{kUPFC} \quad (7)$$

$$Q_k = Q_{km} + \sum_{j=1}^{N} [V_k] \times [V_j] \times [Y_{kj}] \times \sin(\delta_k - \delta_j - \theta_{kj} + Q_{kUPFC}) \quad (8)$$

Load flow equations for the m[th] bus with FACTS devices

$$P_m = P_{mk} + \sum_{j=1}^{N} [V_m] \times [V_k] \times [Y_{mk}] \times \cos(\delta_m - \delta_k - \theta_{mk}) + P_{mUPFC} \quad (9)$$

$$Q_m = Q_{mk} + \sum_{j=1}^{N} [V_m] \times [V_k] \times [Y_{mk}] \times \sin(\delta_m - \delta_k - \theta_{mk}) + Q_{mUPFC} \quad (10)$$

Figure 2 shows schematically how multiple UPFCs can be integrated into the system admittance matrix.

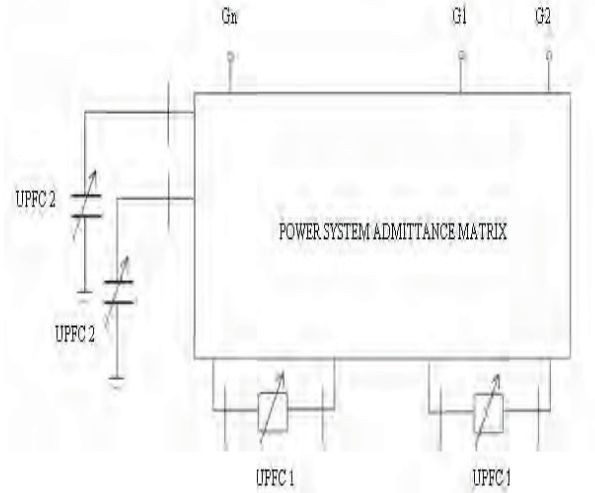

Fig.2. Schematic Representation of a Power System with Multiple UPFC

By adding multi UPFC into the system, the admittance matrix has been re-established in UPFC 1. Besides this, in UPFC 2 according to the new established admittance matrix, flow value has been re-calculated depending on the converters. [15].

4. Description of the System

A modeling and simulation study has been carried out on a real based multi generator-65 bus system shown in Fig.3 . The system has 35 load buses (buses 2-36) and 29 generator buses (buses 37-65) [16]. system shown in Fig.3 . The system has 35 load buses (buses 2-36) and 29 generator buses (buses 37-65) [16].

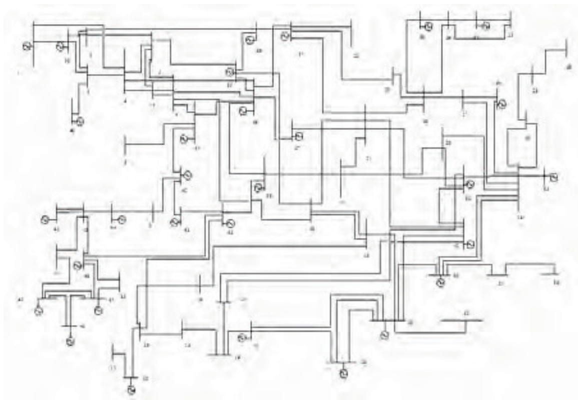

Fig.3. 65 buses real system

A load flow analysis is performed to determine the bus with the lowest voltage and the line with highest voltage drop. While Bus 21 has the lowest voltage, the lines between buses 37-54 and busses 33-59 are found to have the highest two voltage drops. Later, a three phase short circuit between the period of 0.1s and 0.25s is applied to the lowest bus voltage. Circuit breakers located at between buses 21 and 65 has the opening time of 100ms.

Single and multiple shunt and series connections of FACTS devices in the faulted system are simulated and effects are analyzed through observing rotor angle. The following scenarios are simulated.

A series and shunt FACTS, A 100MVA UPFC between bus 18 and 20, Multiple series and shunt FACTS, A 100MVA UPFC between bus 37 and bus 54 and UPFC between bus 33 and bus 59.

5. Simulation Results

When the 3 phase fault occurs, it is seen that; generator angle speed, angle, bus voltage have been instable. The results of the 3 phase fault without a UPFC in the system have been given in Figures 4, 5, and 6.

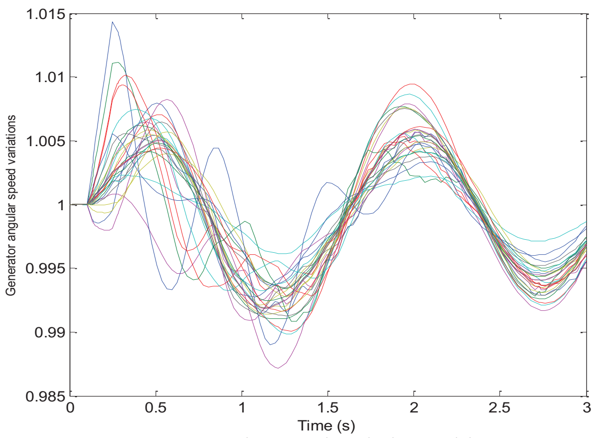

Fig. 4. Generators angular speed variations without UPFC

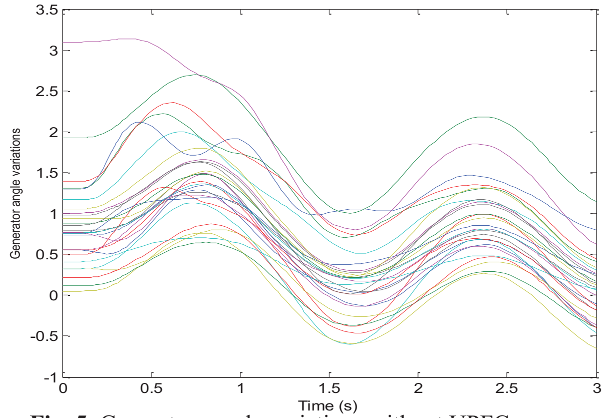

Fig. 5. Generators angle variations without UPFC

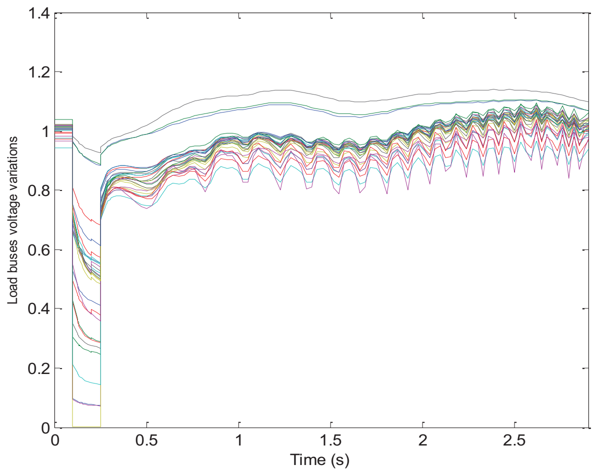

Fig. 6. Load buses voltage variations without UPFC

The results of the 21 number bus 3 phase fault with a single UPFC in the system have been given in Figures 7, 8 and 9.

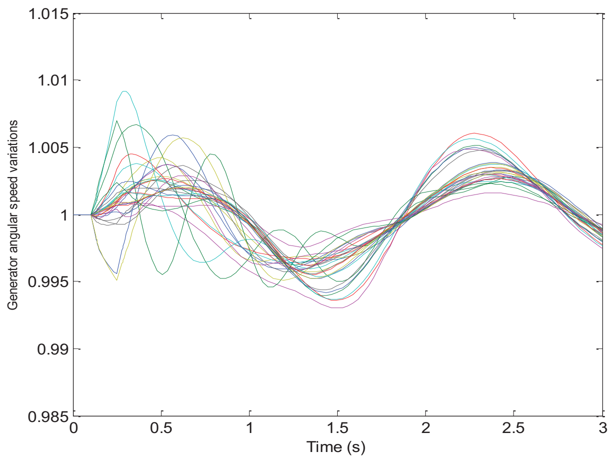

Fig. 7. Generators angular speed variations with UPFC

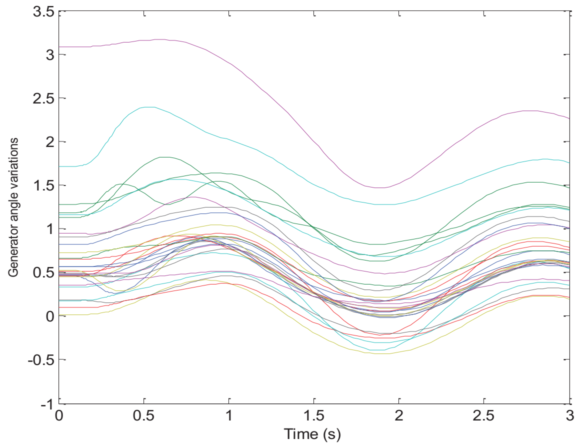

Fig. 8. Generators angle variations with UPFC

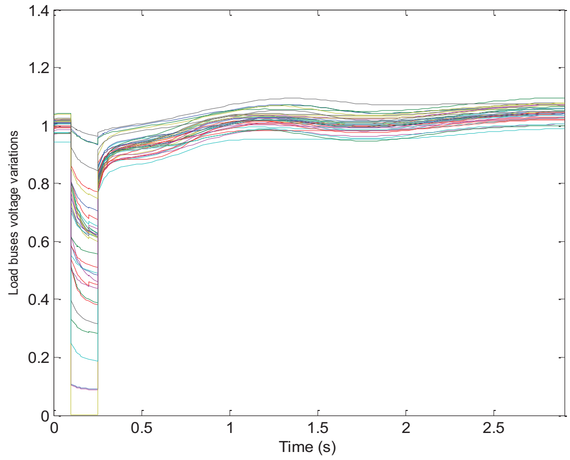

Fig. 9. Load buses voltage variations with UPFC

When the 3 phase fault occurs, it is seen that generator angle speed, angle and bus voltage have been instable. For this situation, the results between 18-20 buses and between 33-59 buses including 21 number bus 3 phase fault with multi UPFC have been given in Figures 10, 11 and 12.

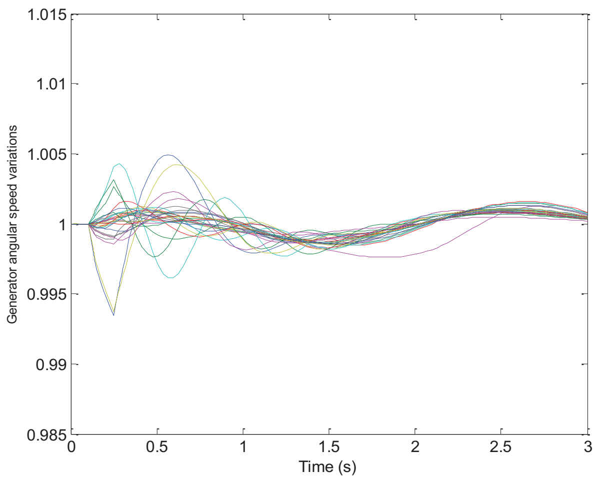

Fig. 10. Generators angular speed variation with multiple UPFC

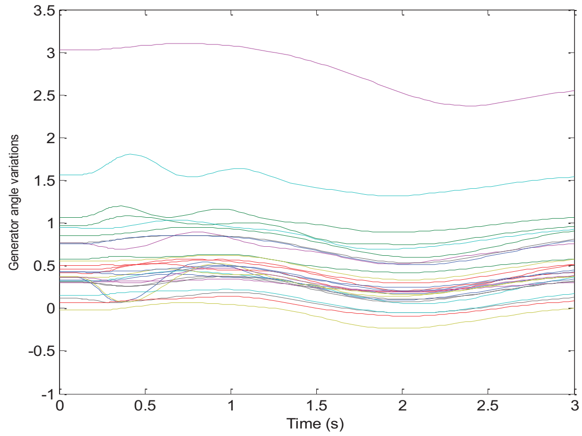

Fig. 11. Generators angle variations with multiple UPFC

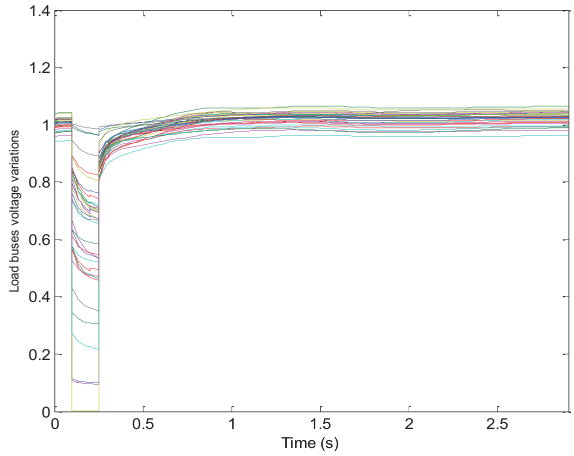

Fig. 12. Load buses voltage variations with multiple UPFC

According to the results; the system time responses have been given in table 2 respectively as; without UPFC, with a single UPFC and with multi UPFC.

Table 1. System time response values

Time response (s)			
Variables	Without UPFC	With UPFC	With multiple UPFC
Generator angular speed	4.5 s	3.75 s	3.0 s
Generator angle	4.25 s	3.50 s	2.75 s
Load bus voltage	5.0 s	1.3 s	0.9 s

If the system parameters in Table1 are investigated for time response, it is clear that when multi UPFC is used the system is stable in a short time.

6. Conclusion

When the transient stability effects of UPFC in a multi-machine 65 bus systems have been investigated in this study. The system with no UPFC shows an oscillatory behavior under transient conditions. A single UPFC can partly improve the transient stability of the system while multi UPFC can provide more damping and quick response leading to a more stable and reliable operation of the system.

7. References

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