Scientific Research and Essays Vol. 6(1), pp. 136-145, 4 January, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE10.848
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Impact of UPFC-based damping controller on dynamic stability of Iraqi power network

Lokman H. Hassan[1]*, M. Moghavvemi[1] and Haider A. F. Mohamed[2]

[1]Centre for Research in Applied Electronics (CRAE), University of Malaya, 50603 Kuala Lumpur, Malaysia.
[2]Department of Electrical and Electronic Engineering, University of Nottingham Malaysia Campus, 43500 Semenyih, Selangorr, Malaysia.

Accepted 25 November, 2010

The work of this paper is a hopeful attempt to rectify poor damping issue of the Iraqi National Super Grid System (INSGS). Without proper damping control these oscillations drive the system toward instability following severe disturbances. In this paper, a Unified Power Flow Controller (UPFC)-based damping controller was proposed to improve the dynamic stability of the INSGS. The system with UPFC installed in different sectors was represented by the linearized Phillips-Heffron generator model. The excitation phase angle was used as input control signal to the UPFC. PI controller was applied to the design of the damping controller. The power system with the UPFC was tested in different sectors under different loading conditions and disturbances using the MATLAB Simulink program. Simulation results demonstrated that the UPFC can work successfully with INSGS in damping low-frequency oscillations and improving the dynamic stability and voltage profiles. In addition, the proposed approach provided higher performance when compared to a conventional PSS.

Key words: UPFC, power system oscillations, power system modeling, control strategy.

INTRODUCTION

The power demand in Iraq has grown at a rate faster than the development of infrastructure. The main problem with the Iraqi network before 2003 was the power generation capacity, not the transmission lines capacity. After 2003, however, the amount of electrical power demand increased rapidly. During the last six years, new generation stations have been constructed across the country and there are plans to construct new ones in the near future (Hassan et al., 2009; Reda et al., 2006). All efforts are put into increasing the amount of power generation but not in constructing new transmission lines, especially in the Iraqi National Super Grid System (INSGS). This may lead to some transmission lines reaching their thermal limits and may increase the probability of the system facing low-frequency oscillations which may cause instability. Moreover, among the ten generating stations, two are hydropower stations, which can produce low-frequency oscillations. In addition, undesirable oscillations produced at negative damping torques introduced by Automatic Voltage Regulators (AVRs) impair the damping process operated by the damper and field winding (Machowiski, Bialek, and Bumby, 1997).

A Power System Stabilizer (PSS) is usually used as a simple and cost-effective approach to dampen out local and inter-area modes of oscillations (Aldeen and Lin, 1999; Bhattacharya et al., 1998; Castellanos et al., 2006; Chuanjiang et al., 2003). However, researchers have shown that the conventional practices of the PSS method could produce a leading power factor and may not be able to dampen the oscillations resulting from a three-phase fault at the generator terminals (Machowiski et al., 1997). The past three decades have seen a rapid growth in the development of solid state power electronics and advanced digital controllers; the present deregulated electrical market offers Flexible Alternating Current Transmission Systems (FACTS) devices working at high speed. These new devices perform well at controlling power systems (Gerbex et al., 2001; Khan et al., 2004; Paserba, 2004). The most prominent device among FACTS is Unified Power Flow Control (UPFC), which can

---

*Corresponding author. Email: lokmanhadi@gmail.com. Tel: +603-7967-5370. Fax: +603-7967-5316.

control independently and simultaneously both the real and reactive power flows in the transmission line (Ma, 2007; YH and AT., 1999). UPFC can be used to increase the power transfer capability of transmission lines and to relocate power flows on a real-time basis. Furthermore, UPFC can improve the dynamic stability of a power system.

A systematic configuration model that can be used easily to study power system oscillation stability with FACTS-based stabilizers is the Phillips-Heffron model. This model has been used by many researchers to study low frequency oscillation stability (Abdel-Magid and Abido, 2004; Al-Awami et al., 2007; Tambey and Kothari, 2003; Wang et al., 1998). In this paper, the INSGS with an installed UPFC-based damping controller was represented by the Phillips-Heffron generator model. The UPFC has been installed individually in a number of different weak areas and its activities were computed using simulation. The results showed the capability of the proposed approach in damping low-frequency oscillations over a wide range of load conditions and disturbances. In addition, the results showed that the proposed UPFC provided better performance than a conventional PIPSS, as expected. In general, this paper presented in its following sections important data about the INSGS and a thorough study on the many wars surviving old grid system.

MATERIALS AND METHODS

Phillips-Heffron model of INSGS with a UPFC

The INSGS comprises twenty-two bus bars and thirty five 400 kV overhead transmission lines. Ten generating stations with different kinds of generating units are connected to the grid such as thermal non-reheat, thermal single reheat, gas turbine, and hydro-turbine. The configuration of the network is shown in Figure 1. Loads are represented by static admittance and transmission lines by nominal π sections. All network data are expressed per unit referred to a common base power of 100 MVA. Data for the transmission lines are given in Appendix A. In the load flow study, the BAJP station is selected as the slack bus. The power flow results are given in Appendix B. Machines and excitation data are given in Table 1. To install a UPFC in the INSGS, the linearized Phillips-Heffron model proposed in (Hassan et al., 2010; Wang, 1999) was used.

The linearized model can be represented in state-space form:

$$\dot{x}=Ax+Bu \qquad (1)$$

where the state matrix (A), input matrix (B), control vector (u) and state vector (x). The linearized Philips-Heffron dynamic model of the state-space representation is shown in Figure 2.

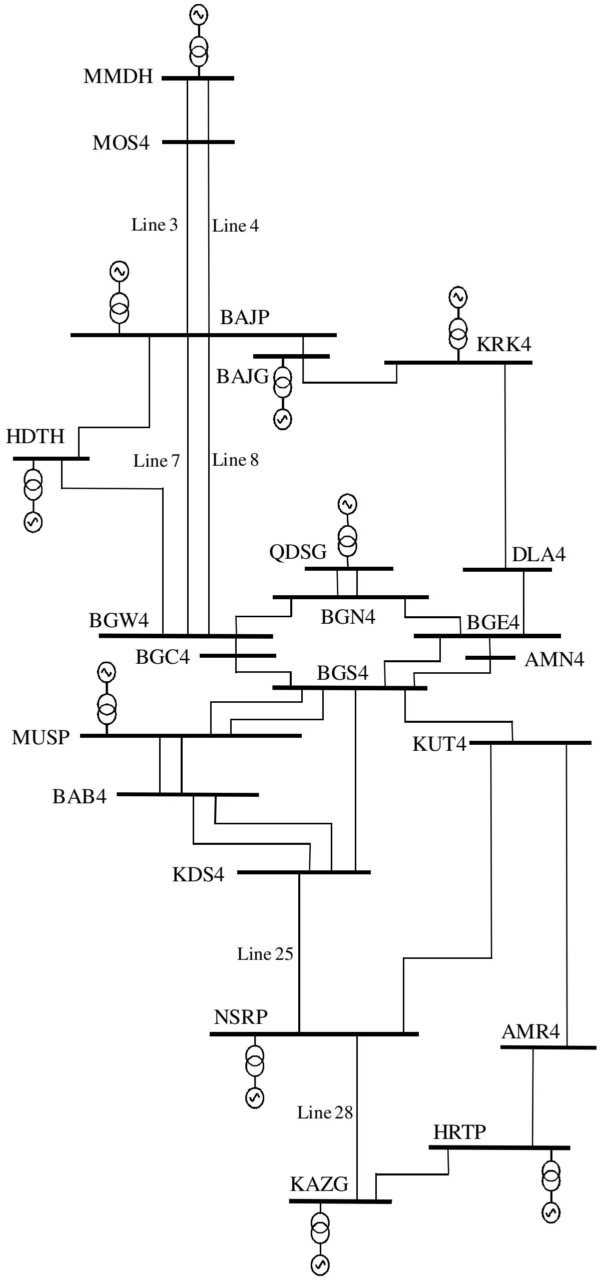

Figure 1. Configuration of INSGS.

The control strategy

Proper structures were considered in this work for designing UPFC damping controller. The more efficient method of using input control signal of UPFC was applied in this paper; the excitation phase angle (δ_E) (Al-Awami et al., 2007). PI controller was applied to design the damping controller. The voltage across the DC link capacitor was controlled by a PI controller during δ_E as:

$$\delta_E = \left\{ \left(K_{dp} + \frac{K_{dI}}{s} \right) \Delta\omega + \left(K_{dcp} + \frac{K_{dcI}}{s} \right) \left(v_{dcrf} - v_{dc} \right) \right\} \left(\frac{K_s}{(1 + sT_s)} \right) \quad (2)$$

For this design, the data of the UPFC and controller are given as the following:

x_E = 0.1, x_B = 0.1, C_{dc} = 3, V_{dc}=2, K_{dcp} = -5, K_{dcI} = 0, K_{dp} = -5, K_{dI} = -60, K_s=1, T_s=0.05.

Table 1. Machines data.

Generator	x_d	x'_d	x_q	T'_{do}	**H**	T_A	K_A
MMDH	0.5	0.05	0.27	6	43	0.06	25
BAJP	0.5	0.07	0.33	6	83	0.40	25
BAJG	1.0	0.09	0.33	6	46	0.05	30
KRK4	2.0	0.11	0.38	6	41	0.06	30
QDSG	0.4	0.15	0.48	6	52	0.20	30
HDTH	0.5	0.15	0.63	6	23	0.02	50
MUSP	0.29	0.17	0.95	6	110	0.02	100
NSRP	0.67	0.17	0.95	6	50	0.40	245
KAZG	1.0	0.17	0.95	6	50	0.40	275
HRTP	1.0	0.34	1.90	6	17	0.20	400

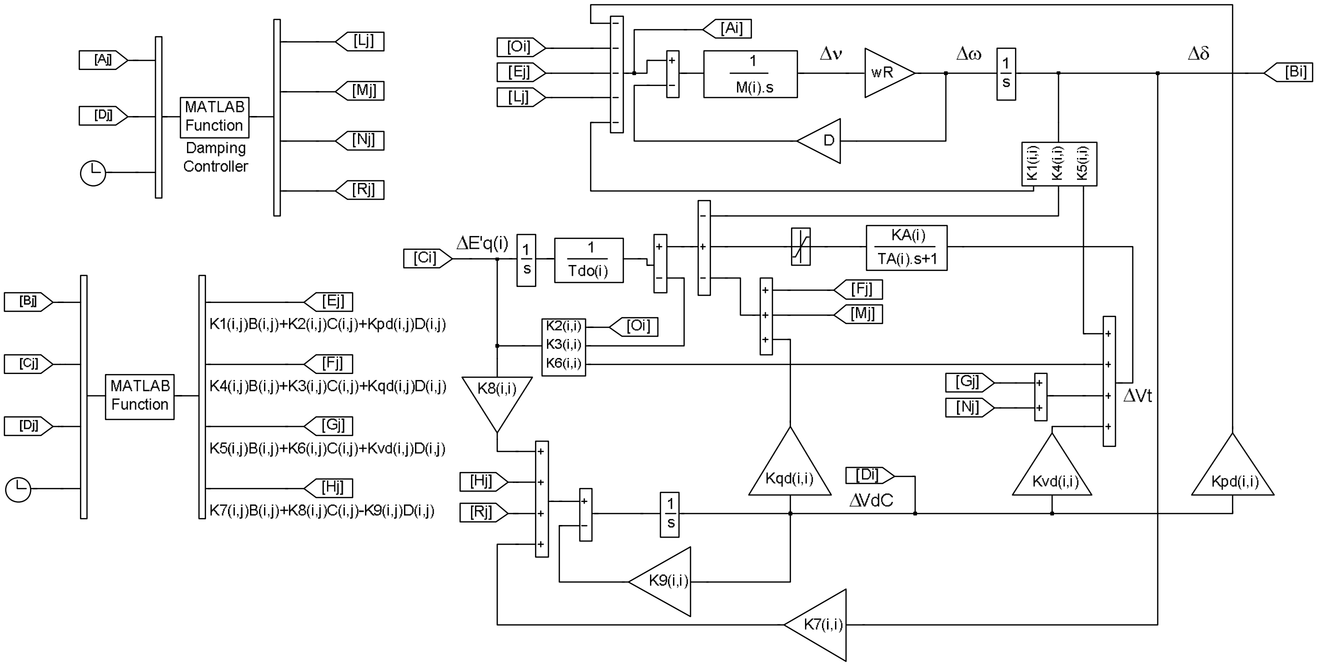

Figure 2. Philips-Heffron linearized model of the INSGS installed with a UPFC-based damping controller.

The linearized model of the INSGS installed with a UPFC-based damping controller was depicted in Figure 2.

RESULTS AND DISCUSSION

Simulation studies have been carried out using the MATLAB Simulink program. The eigenvalues and damping factors of the system with nominal parameters were computed for the case when the damping

Table 2. Eigenvalues of the INSGS.

Mode no.	**Eigenvalue**	**Damping factor (%)**
16, 17	-0.0105 ± 2.2222i	0.472
22, 23	-0.0376 ± 1.4747i	2.55
30, 31	-0.0835 ± 0.9332i	8.91

coefficients are equal to zero for all generators. As shown in Table 2, the INSGS is a poor damping system. Note here that only those eigenvalues that have very small negative real parts were listed in Table 2. To install the UPFC, The VCPI index (Moghavvemi and Faruque, 1998) based on the concept of maximum possible power transfer that is permissible through a line under loaded condition was proposed to detect the stress conditions of the lines and reveal weak areas. According to (Hassan et al., 2008), five transmission lines in different sectors are most affected by load changes.

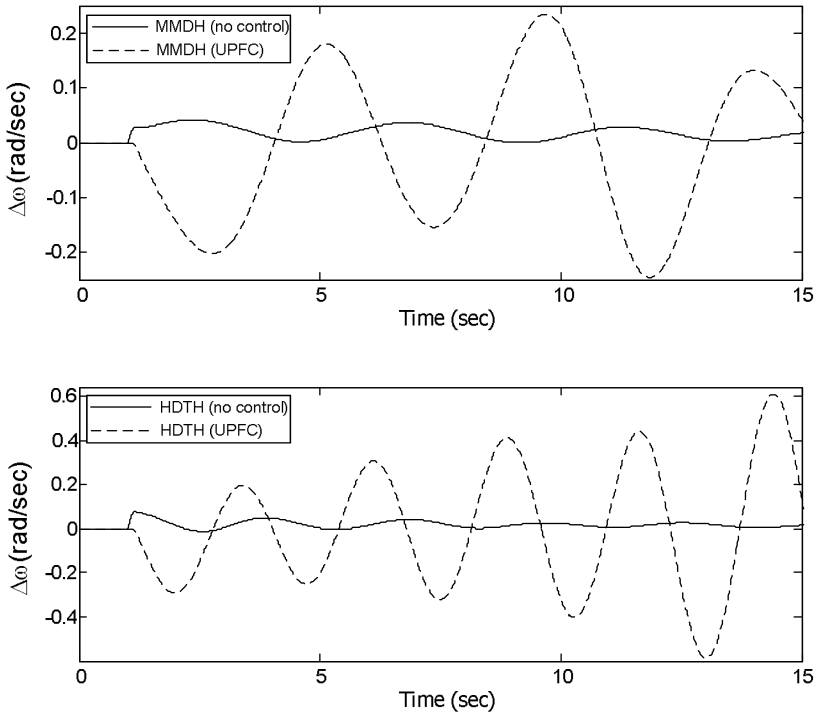

Figure 3. Speed deviation responses of the generators MMDH and HDTH at transmission line 4 subjected to a 6-cycle three-phase fault under nominal load condition.

These critical lines are: transmission lines 3 and 4 in the North, transmissions line 7, 10 and 8 in the centre and transmission line 25 in the South of Iraq. In this paper, transmission lines 3, 7, 10 and 25 were selected to be fitted with UPFC. To verify our choice, the performance of the proposed UPFC was compared to a conventional PI PSS. In order to assess the ability of the UPFC to dampen power oscillations, the system was subjected to a 6-cycle three-phase fault at different locations with different loading conditions. The initial torque angle was considered to be 0.1.

Nominal load condition

For testing, the network was divided into three regions; North, Central and South sectors

Northern sector

In the first case, the UPFC was placed on transmission line 3 connecting the MOS4 bus and PAJP bus in the North of Iraq. The system was subjected to a fault in the middle of transmission line 4 in parallel with line 3. Figure 3 showed the speed deviation response of MMDH and HDTH generators in the two different cases; with no control and with a UPFC. The results demonstrated that the system without active control was facing an unstable condition. Also, the results showed that the effective damping can be achieved using the UPFC. The speed of those generators most affected by the fault, and the rotor angle difference between generator BAJG and several other generators were depicted in Figure 4.

Central sector

In the central sector, the UPFC was installed on transmission line 7 linking the PAJP bus and BGW4 bus. The fault was applied in the middle of transmission line 8 which is in parallel with line 7. The system time domain responses with connection of the UPFC were shown in Figure 5. In order to compare the UPFC with another damping device, a conventional PSS was suggested to be installed in the system. Based on Table 2, the smallest real part eigenvalues were -0.0105 ± 2.2222i. Participation factors associated with the eigenvalues were computed and the results revealed that these eigenvalues were most related to state variables of

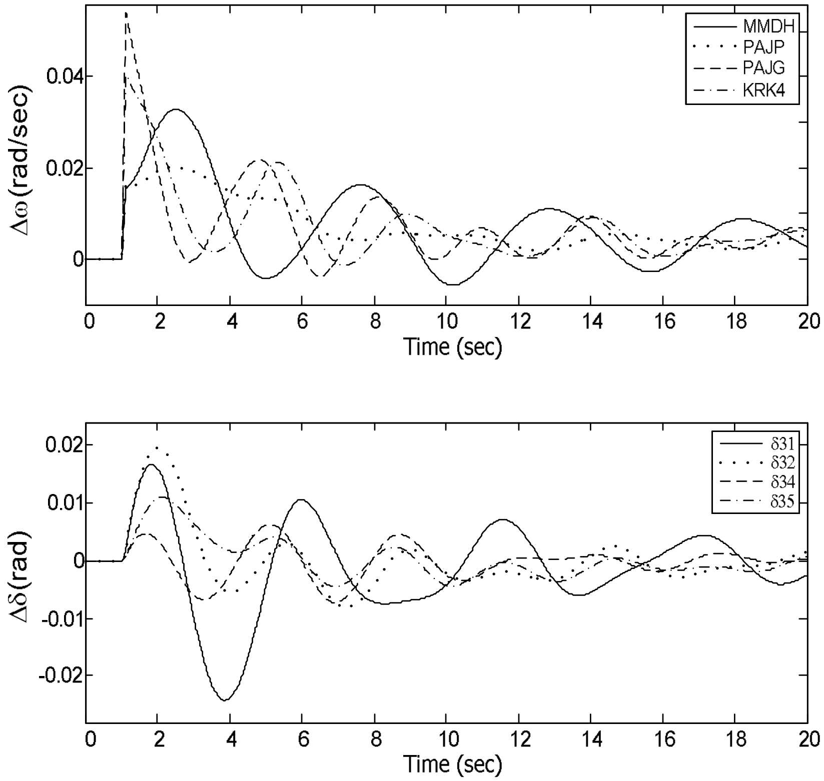

Figure 4. Speed and rotor angle deviation responses at transmission line 4 subjected to a 6-cycle three-phase fault under nominal load condition.

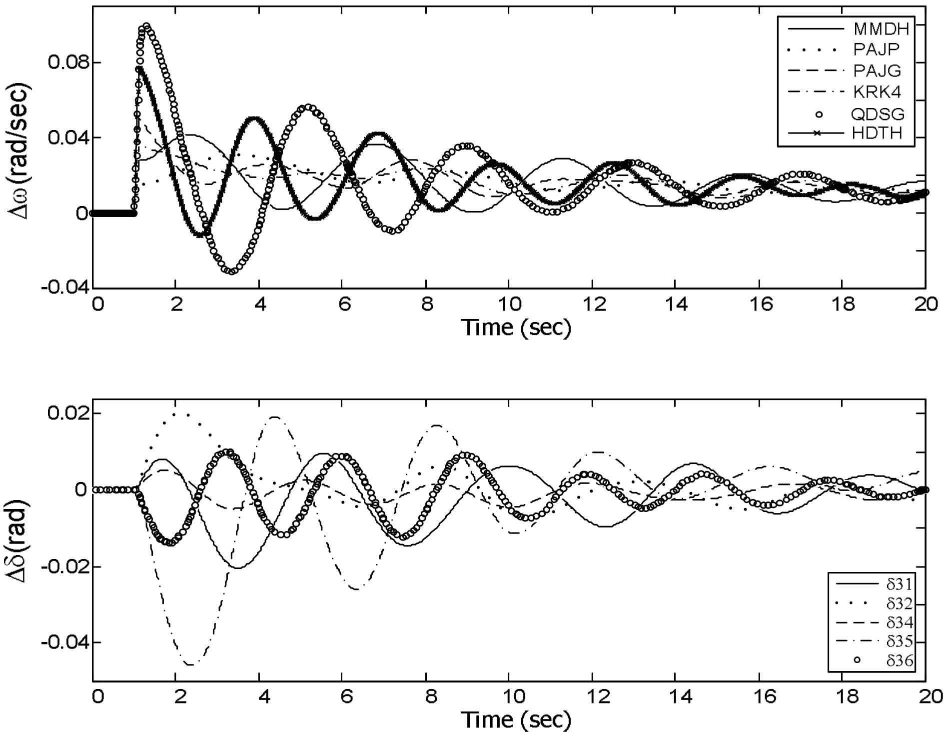

Figure 5. Speed and rotor angle deviation responses at transmission line 8 subjected to a 6-cycle three-phase fault under nominal load condition.

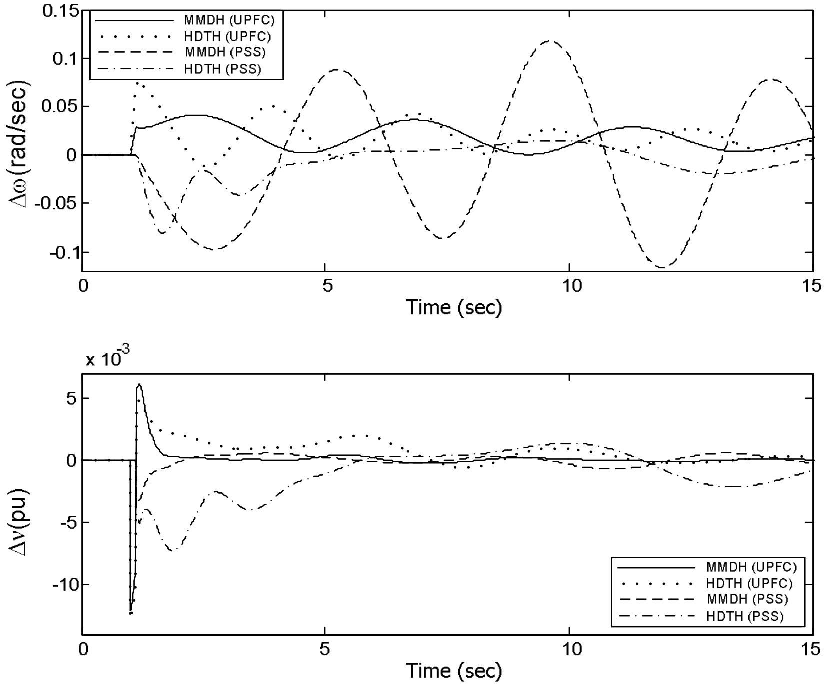

Figure 6. Speed and terminal voltage deviation responses of the generators MMDH and HDTH at transmission line 8 subjected to a 6-cycle three-phase fault under nominal load condition.

HDTH station. Hence, the PSS was assumed to be installed on the generators of HDTH station in order to damp the oscillation corresponding to the oscillation modes 16 and 17.

The system was simulated using the PSS and UPFC independently. The results proved that the PSS is unable to control the system efficiently. By contrast, the proposed UPFC showed its ability to control the system efficiently and provides higher performance compared to the PSS, as shown in Figure 6.

Southern sector

The UPFC was installed between the NSRP bus and KDS4 bus on transmission line 25 in the South of Iraq. The fault was assumed to take place at the midpoint of transmission line 28, which links the NSRP bus and KAZG bus. Figure 7 showed the speed and rotor angle responses of the system with connection of the UPFC. The results of the three cases above demonstrated that the UPFC was able to increase the damping of power oscillations and improve the dynamic stability of the system.

Heavy load condition

To simulate a different loading condition, the system was tested with the load of the system increased by 30%. Here, the UPFC was installed on transmission line 10 linking the BGW4 bus and HRTH bus. The system was again subjected to a 6-cycle three-phase fault disturbance in the middle of transmission line 8. The time domain responses of the system were shown in Figure 8. The findings proved that the proposed UPFC achieved the best damping of oscillations and considerably improved the stability during the first swing even when the system was heavily loaded.

Conclusion

In this paper, the low-frequency oscillation problem that Iraqi National Super Grid System (INSGS) faces and the best solution for solving the problem were presented. A UPFC-based damping controller was proposed for improving the stability and damping of the low frequency oscillations of the INSGS. The linear Phillips-Heffron generator model was applied to assess the impact of the UPFC on the INSGS. Simulations of the effect of the proposed damping controller on the system show that the system performs well when subjected to load changes and faults at different locations. The proposed approach proved to be more effective in damping of oscillations than a PSS. It is envisaged that the implementation of the proposed UPFC in the INSGS would greatly improve the dynamic stability of the system and voltage profiles.

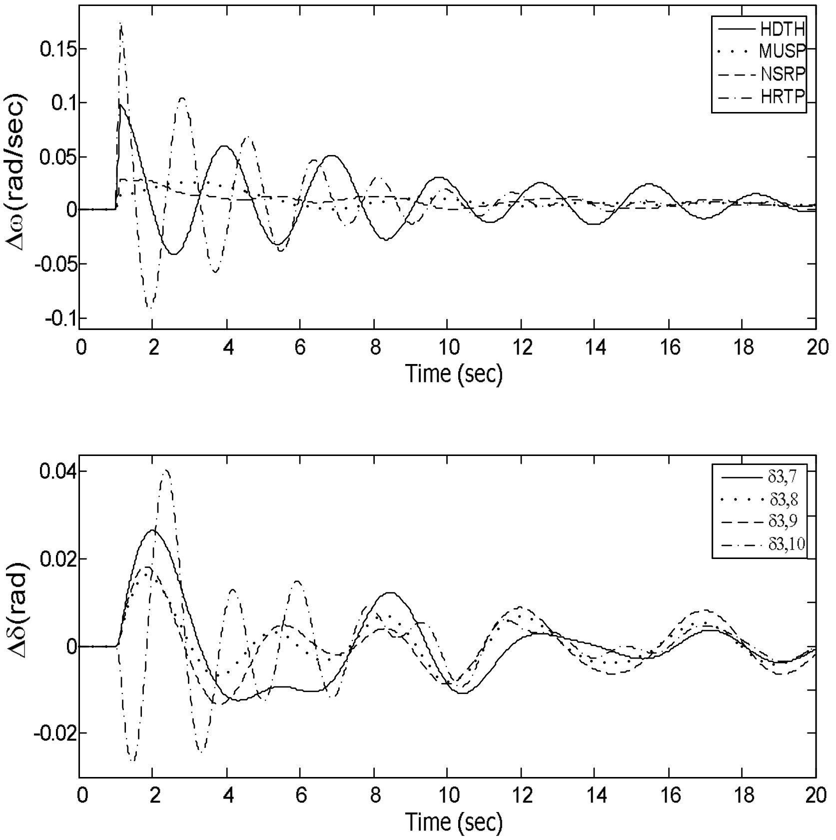

Figure 7. Speed and rotor angle deviation responses at transmission line 28

subjected to a 6-cycle three-phase fault under nominal load condition.

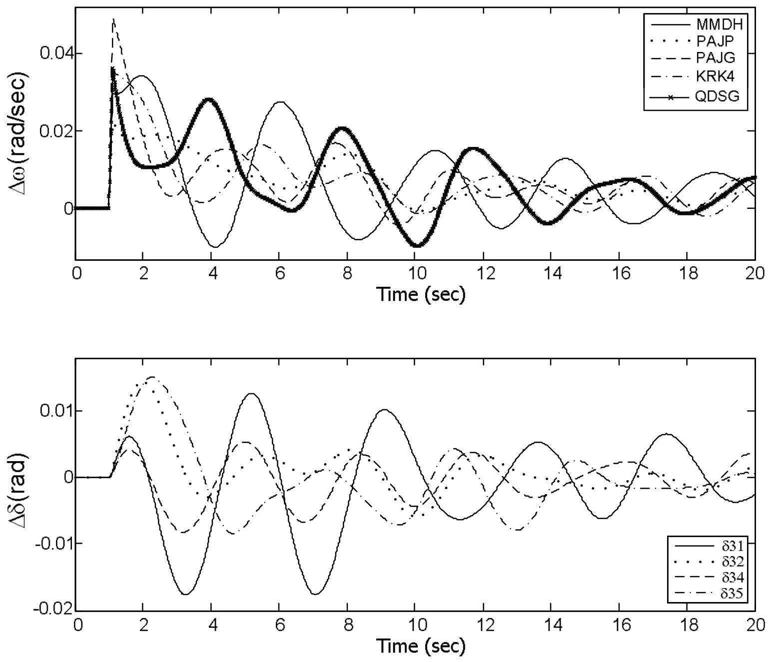

Figure 8. Speed and rotor angle deviation responses at transmission line 8 subjected to a 6-cycle three-phase fault under heavy load condition.

REFERENCES

Abdel-Magid YL, Abido MA (2004). Robust coordinated design of excitation and TCSC-based stabilizers using genetic algorithms. Electr. Power Syst. Res., 69(2-3): 129-141.

Al-Awami AT, Abdel-Magid YL, Abido MA (2007). A particle-swarm-based approach of power system stability enhancement with unified power flow controller. Electr. Power Energy Syst., 29(3): 251-259.

Aldeen M, Lin L (1999). A new reduced order multimachine power system stabilizer design. Electr. Power Syst. Res., 52(2): 97-114.

Bhattacharya K, Kothari ML, Nanda J, Aldeen M, Kalam A (1998). Tuning of power system stabilizers in multi-machine systems using ise technique. Electr. Power Syst. Res., 46(2): 119-131.

Castellanos BR, Calderón GJG, Olguin SD, Sarmiento UH, Messina AR (2006). Use of power system stabilizers for damping inter-area oscillations in the south systems of the Mexican electrical grid. Electr. Power Syst. Res., 76(4): 169-179.

Chuanjiang Z, Khammash M, Vittal V, Wenzheng Q (2003). Robust power system stabilizer design using H∞ loop shaping approach. IEEE Trans. Power Syst., 18(2): 810-818.

Gerbex S, Cherkaoui R, Germond A (2001). Optimal Location of Multi-Type FACTS Devices in a Power System by Means of Genetic Algorithms. IEEE Power Eng. Rev., 21(8): 59-60.

Hassan LH, Moghavvemi M, Mohamed HAF (2009). Dynamic stability assessment of the Iraqi power system network. Paper presented at the Technical Postgraduates (TECHPOS) International Conference. pp. 1-5.

Hassan LH, Moghavvemi M, Mohamed HAF (2010). Power System Oscillations Damping Using Unified Power Flow Controller-Based Stabilizer. Am. J. Appl. Sci., 7(10): 1393-1395.

Hassan LH, Mohamed HA, Moghavvemi M, Yang S (2008). Contingency monitoring and voltage collapse estimation for Iraqi national super grid system. Paper presented at the The 4th International Colloquium on Signal Processing and its Applications (CSPA), pp. 570-574.

Khan L, Rogers GJ, Lozano CA (2004). Intelligent control of FACTS for damping power system low frequency oscillations. Paper presented at the 8th International Multitopic Conference (INMIC), pp. 731-736.

Ma TT (2007). P-Q decoupled control schemes using Fuzzy neural networks for the unified power flow controller. Electr. Power Energy Syst., 29(10): 748-758.

Machowiski J, Bialek JW, Bumby JR (1997). Power System Dynamics and Stability: John Wiley & sons.

Moghavvemi M, Faruque O (1998). Real-time contingency evaluation and ranking technique. IEE Proc. Gener. Transm. Distrib., 145(5): 517-524.

Paserba JJ (2004). How FACTS controllers benefit AC transmission systems. Paper presented at the IEEE Power Engineering Society General Meeting, pp. 1257-1262

Reda M, Saied N, Khaldi A, Abdul-Hussain MA, Ekwue A (2006). Iraq Electrical Power Infrastructure- Past, Present and Future Developments and Expectations. Paper presented at the Power Systems Conference and Exposition, 2006. PSCE '06. IEEE PES, pp. 1792-1795.

Tambey N, Kothari ML (2003). Unified Power Flow Controller (UPFC) Based Damping Controllers for Damping Low Frequency Oscillations in a Power System. IEI J. EL. 84:35-41.

Wang, HF (1999). Applications of modelling UPFC into multi-machine power systems. IEE Proc. Gener. Transm. Distrib., 146(3): 306-312.

Wang, HF, Swift FJ, Li M (1998). A unified model for the analysis of FACTS devices in damping power system oscillations. II. Multi-machine power systems. IEEE Trans. Power Delivery. 13(4): 1355-1362.

YH S, AT J (1999). Flexible AC Transmission Systems (FACTS): International Ltd. Padstow.

APPENDIX

Appendix A.

Line parameters of INSGS.

Line no.	From Bus	To Bus	Resistance (p.u.)	Reactance (p.u.)	Susceptance (p.u.)
1	MMDH	MOS4	0.00144	0.0118	0.3644
2	MMDH	MOS4	0.00144	0.0118	0.3644
3	MOS4	BAJP	0.0042	0.0344	1.0643
4	MOS4	BAJP	0.0042	0.0344	1.0643
5	BAJP	BAJG	0	0.0002	0.0058
6	BAJG	KRK4	0.0018	0.0164	0.4845
7	BAJP	BGW4	0.0048	0.0439	1.3017
8	BAJP	BGW4	0.005	0.0451	1.3367
9	BAJP	HDTH	0.0034	0.0313	0.9281
10	HDTH	BGW4	0.0048	0.044	1.3052
11	BGW4	BGN4	0.0009	0.0085	0.251
12	BGE4	BGN4	0.0003	0.0026	0.0776
13	BGN4	QDSG	0.0002	0.0014	0.0409
14	BGN4	QDSG	0.0002	0.0014	0.0409
15	BGE4	DLA4	0.0009	0.0079	0.2335
16	BGE4	BGS4	0.0013	0.0115	0.3397
17	BGS4	MUSP	0.0012	0.0101	0.319
18	BGS4	MUSP	0.0012	0.0101	0.319
19	BGS4	KUT4	0.0004	0.0039	0.1167
20	BGS4	KDS4	0.0031	0.028	0.8283

21	MUSP	BAB4	0.0008	0.0067	0.2117
22	MUSP	BAB4	0.0008	0.0067	0.2117
23	BAB4	KDS4	0.0023	0.0193	0.6081
24	BAB4	KDS4	0.0023	0.0193	0.6081
25	KDS4	NSRP	0.0038	0.0348	1.0326
26	KUT4	NSRP	0.0043	0.0393	1.1639
27	KUT4	AMR4	0.0048	0.0435	1.2899
28	NSRP	KAZG	0.0044	0.0399	1.1832
29	KAZG	HRTP	0.0012	0.0108	0.3187
30	HRTP	AMR4	0.0029	0.0264	0.7822
31	DLA4	KRK4	0.0042	0.0386	1.1441
32	BGS4	AMN4	0.0008	0.0075	0.2218
33	AMN4	BGE4	0.0004	0.0039	0.1167
34	BGW4	BGC4	0.0006	0.0056	0.1662
35	BGS4	BGC4	0.001	0.0088	0.2599

Appendix B

Load and generation of INSGS including bus voltages and angles.

Bus	Voltage	Angle degree	Load		Generation	
			MW	MVAr	MW	MVAr
MOS4	0.986	-33.45	322	414	0.0	0.0
MMDH	1.0	-32.56	0.0	0.0	286	169.92
BAJP	1.0	-33.17	158	133.6	351.6	-63.67
BAJG	1.0	-33.14	0.0	0.0	311	-59.03
KRK4	1.01	-33.49	39.6	165.2	240	58.047
BGW4	0.999	-38.87	420	137.2	0.0	0.0
BGS47	0.997	-39.46	189	23.9	0.0	0.0
BGE4	0.995	-39.84	410	195.2	0.0	0.0
BGN4	0.999	-39.75	412	25.6	0.0	0.0
QDSG	1.0	-39.63	0.0	0.0	311	163.67
AMN4	0.99	-39.74	40	209.6	0.0	0.0
BGC4	0.999	-39.11	0.0	0.0	0.0	0.0
DLA4	1.006	-38.8	-8.7	-101	0.0	0.0
KUT4	0.997	-39.37	184	185.2	0.0	0.0
HDTH	1.0	-32.92	172	54	420	-70.28
MUSP	1.0	-38.81	195	75.6	682	185.7
BAB4	0.995	-39.28	169	125.2	0.0	0.0
KDS4	0.986	-39.73	260	288	0.0	0.0
NSRP	1.0	-36.73	208	222.6	429	85.713
AMR4	1.028	-36.92	0.0	0.0	0.0	0.0
HRTP	1.02	-35.3	103	125.4	284	208.1

KAZG	1.0	-35.62	247	291.6	222	33.884