Comparison of UPFC Based Stabilizer and PSS Performances on Damping of Power System Oscillations

Kh.Javani   M.Sadeghierad   H.Lesani
Master of Since   PhD Student   professor
electrical & computer engineering faculty
University of Tehran

Abstract:

This paper establises the linearized Philips–Heffron model of a power sysem equipped with UPFC and demontrates the application of the model in analyzing the damping effect of the UPFC, and designing UPFC based stabilizer to improve power system oscillation stability. A comprehensive approach to the design of UPFC based stabilizer (power flow control, DC-voltage regulator and damping controller) is presented.

In this case, the multi-machine power system with UPFC is studied and an example of power system is presented. It is shown that the DC voltage contributes negative damping to power system oscillations, which is confirmed by both eigenvalue computation and nonlinear simulation. To counterattack the negative damping effect due to the DC voltage regulator, UPFC based stabilizer is designed and its effectiveness is demonstrated by both eigenvalue computaion and nonlinear simulation. Then the effects of UPFC and PSS on power systems are compared. Simulation results show that the performance of UPFC based stabilizer on damping of power syetem is better than PSS.

Key Words: Phillips- Heffron model, UPFC, Stabilizer , PSS

1- Introduction

The Unified Powr Flow Controller (UPFC) is a FACTS device which can control power system parameters such as terminal voltage , line impedance and phase angle [1-3]. The primary function of the UPFC is to control power flow on a given and voltage at the UPFC bus. This is achieved by regulating the controllable parameters of the systemes, line impedance, phase angle and voltag magnitude. The UPFC can also be utilised for damping power system oscillations by judiciously applying damping controller. For a UPFC based stabilizer, we wish for extract an input signal for damping controller from the locally measurable quantities at the UPFC location. The electrical power flow can be easily measuredat the UPFC location and hence may be used as an input signal for the damping controller. Recently , steady state and dynamic models of UPFC have been developed by several researchers [4-6]. In [7,8], unfiled Phillips-Heffron model of a power system is established for several types of FACTS devices installed in the system.

This paper establishes the linearized Philips–Heffron model of a power sysem equiped with UPFC and demontrates the application of the model in analyzing the damping effect of the UPFC, and also designing UPFC based stabilizer to improve power system oscillation stability. A comprehensive approach to the design of UPFC based stabilizer (power flow control, DC-voltage regulator and damping controller) is presented.

In this case, the multi- machine power system with UPFC is studied and an example of power systems is presented. It has shown that the DC voltage contributes negative damping to power system oscillations, which is confirmed by both eigenvalue computation and nonlinear simulation. To counterattack the negative damping effect due to the DC voltage regulator, UPFC based stabilizer is designed and its effectiveness is demonstrated by both eigenvalue computaion and nonlinear simulation. Then we compare the effect of UPFC and PSS on power systems. Simulation results show that the performance of UPFC based stabilizer on damping of power syetem is better than PSS.

2- Unified Power Flow Controller

The UPFC is a device deviced for the real- time control and dynamic compensation of AC transmission system, providing the multifunctional flexiblity required to solve many of the problems facing the power supply industry. The UPFC is a combination of a STATtic synchronous

COMpensator (STATCOM) and a Static Synchronous Series compensator (SSSC) which is via a common DC voltage link. It is capable of controlling, simultaneously or selectively, all the parameters affecting the power flow in a transmission line (voltage, impedance and phase angle). Alternatively it can control both the real and the reactive power flow in the line independently[9,10] . The UPFC may also provide an independent, controllable, shunt reactive compensation.

3- Dynamic model of the multimachine power system with UPFC

Whitout loss of generality, assume that a UPFC is to be installed in an n-machine power system between node 1 and 2 as shown by fig. 1. The UPFC consists of an ExcitationT ransformer (ET), a Boostng Transformer (BT), a pair of three- plase GTO based Voltage Surce Converters (VSCs) and a DC link capacitor. In fig. 1, m_E, m_B and δ_E, δ_B are the amplitude modulation ratio and phase angles of the control singnals to the UPFC [7,8 1].
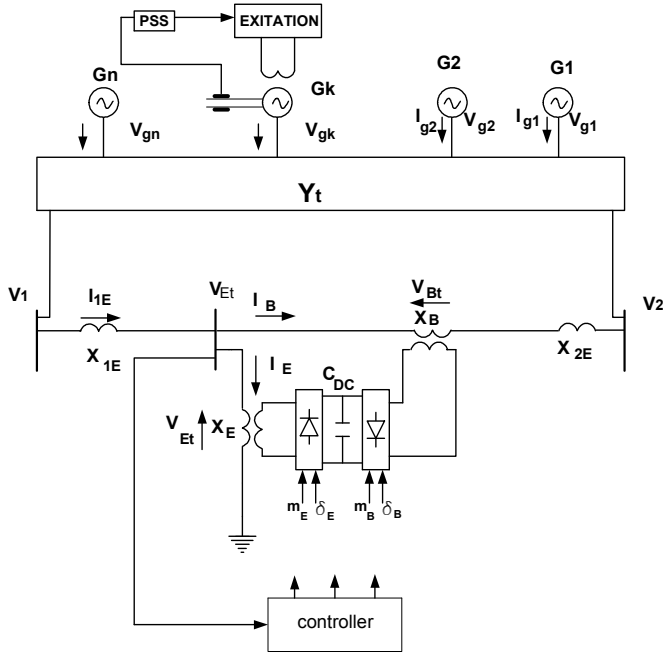

Fig. (1): n machine power system with UPFC

3.1 Non linear dynamic model

A nonlinear dynamic model of the system is derived by disregarding the resistances of the system components (genrator, transframer, transmission lines, shunt and series converter transformers) and the transients of the

transmission lines and transformer of the UPFC. The nonlinear dynamic model of the system using UPFC is given below.

It can also be assumed that, before the UPFC is installed in the power system, the network admittance matrix $\overline{Y}_t$ is formed whereonly n generator nodes plus node 1 and 2 are kept. By the instalation of the UPFC between node 1 and 2, the circuit equation of the network are as fellow:

$$\overline{Y}'_{11}\overline{V}_1 + \overline{I}_{1E} + \overline{Y}_{13}\overline{V}_g = 0$$

$$\overline{Y}'_{22}\overline{V}_2 + \overline{I}_{E2} + \overline{Y}_{23}\overline{V}_g = 0$$

$$\overline{Y}_{31}\overline{V}_1 + \overline{Y}_{32}\overline{V}_2 + \overline{Y}_{33}\overline{V}_g = \overline{I}_g$$

where

$$\mathbf{I}_g = \left[I_{g1}I_{g2}....I_{gn}\right]^T , \overline{\mathbf{V}}_g = \left[V_{g1}V_{g2}....V_{gn}\right]^T$$

$\overline{Y}'_{11}$ and $\overline{Y}'_{22}$ are obtained from $\overline{Y}_{11}$ and $\overline{Y}_{22}$ by excluding $x_{12} = x_{1E} + x_{E2}$,from fig.1.

$$\overline{V}_1 = jx_{1E}\overline{I}_{1E} + \overline{V}_{Et}$$

$$\overline{V}_{Et} = jx_{E2}\overline{I}_{E2} + \overline{V}_{Et} + \overline{V}_2$$

$$\overline{I}_E = \overline{I}_{1E} - \overline{I}_{E2}$$

$$\begin{bmatrix} \overline{I}_{1E} \\ \overline{I}_{E2} \end{bmatrix} = \frac{1}{x_{\sum}} \begin{bmatrix} -j(x_E + x_{E2} + x_B) & jx_E \\ -jx & j(x_{1E} + x_E) \end{bmatrix} \begin{bmatrix} \overline{V}_1 \\ \overline{V}_2 \end{bmatrix}$$

$$+ \frac{1}{x_{\sum}} \begin{bmatrix} j(x_{E2} + x_B) & jx_E \\ -jx_E & j(x_{1E} + x_E) \end{bmatrix} \begin{bmatrix} \overline{V}_E \\ \overline{V}_B \end{bmatrix} \quad (3)$$

where

$$x_{\sum} = (x_{1E} + x_E)(x_E + x_{2E} + x_B) - x_E^2$$

By substituting eq.1 in eq . 2 .

$$\overline{I}_g = \overline{C}\overline{V}_g + \overline{F}_E\overline{V}_E + \overline{F}_B\overline{V}_B$$

where:

$$\overline{C} = \overline{Y}_{33} - \left[\overline{Y}_{31}\overline{Y}_{31}\right]\overline{Y}'^{-1}_t \begin{bmatrix} \overline{Y}_{13} \\ \overline{Y}_{23} \end{bmatrix}$$

2

$$\overline{F}_E = -\left[\overline{Y}_{31}\overline{Y}_{31}\right]\overline{Y'}_t^{-1}\begin{bmatrix} \dfrac{j(x_{E2}+x_B)}{x_\Sigma} \\[2ex] \dfrac{jx_{E1}}{x_\Sigma} \end{bmatrix}$$

$$\overline{F}_B = -\left[\overline{Y}_{31}\overline{Y}_{31}\right]\overline{Y'}_t^{-1}\begin{bmatrix} \dfrac{jx_E}{x_\Sigma} \\[2ex] \dfrac{-j(x_{1E}+x_E)}{x_\Sigma} \end{bmatrix}$$

$$\overline{Y'}_t = \begin{bmatrix} \overline{Y'}_{11} - \dfrac{j(x_E+x_{E2}+x_B)}{x_\Sigma} & \dfrac{jx_E}{x_\Sigma} \\[2ex] \dfrac{jx_E}{x_\Sigma} & \overline{Y'}_{22} - \dfrac{j(x_{1E}+x_E)}{x_\Sigma} \end{bmatrix}$$

The expression of eq. 4 in terms of d-q coordination:

$$\overline{V}_g = \overline{E'}_q - jX'_D\overline{I}_g = j(X_Q - X'_D)\overline{I}_Q$$

$$I_g =$$
$$\overline{C}_d\left[\overline{E'}_q - j(X_Q - X'_D)\overline{I}_Q + \overline{C}_E\overline{V}_E + \overline{C}_B\overline{V}_B\right]$$

$$\overline{C}_d = (\overline{C}^{-1} + jX'_D)^{-1}$$

$$\overline{C}_E = \overline{C}^{-1}\overline{F}_E$$

$$\overline{C}_B = \overline{C}^{-1}\overline{F}_B$$

$$\overline{I}_{Gi} = \overline{I}_{gi}e^{j\delta_i}$$

$$= \sum_{k=1}^{n}\overline{C}_{dik}\begin{bmatrix} E'_{qk}e^{j(90°+\delta_k-\delta_i)} + (x_{qk}-x'_{dk})e^{j(\delta_k-\delta_i)}I_{qk} \\ +\overline{C}_{Ek}\overline{V}_E e^{j\delta_i} + \overline{C}_{Bk}\overline{V}_B e^{j\delta_i} \end{bmatrix}$$

$$I_{di} = \sum_{k=1}^{n} C_{dik}\begin{Bmatrix} -E'_{qk}\sin\delta_{ikg} + (x_{qk}-x'_{dk})I_{qk}\cos\delta_{ikg} \\ +C_{Ek}V_E\cos\delta_{Ek} + C_{Bk}V_B\cos\delta_{Bk} \end{Bmatrix}$$

$$I_{qi} = \sum_{k=1}^{n} C_{dik}\begin{Bmatrix} E'_{qk}\cos\delta_{ikg} + (x_{qk}-x'_{dk})I_{qk}\cos\delta_{ikg} \\ +C_{Ek}V_E\sin\delta_{Ek} + C_{Bk}V_B\sin\delta_{Bk} \end{Bmatrix}$$

3.2 Modified Phllips- Heffron model of an multimachine power system including UPFC

The linearised model of power system has been successfully adopted for the analysis of power sysytems oscillation stability and design of power system damping controllers. The linearised model of n-machine power system installed with UPFC can be obtained by linearising eq.1 and 7 around an operating point of power system. This will produce a generic linearised model of the power system oscillation stability, a simplified model of generators can be used by neglecting the interanl resistance and sub-transient process of the gerators.

By linearising the equation 7 we will have :

$$\Delta\mathbf{I}_q = \mathbf{Y}_q\Delta\delta + \mathbf{F}_q\Delta E'_q + \mathbf{G}_q\Delta V_{DC}$$
$$+ \mathbf{H}_{Eq}\Delta m_E + \mathbf{H}_{Bq}\Delta\delta_E + \mathbf{R}_{Eq}\Delta m_B + \mathbf{R}_{Bq}\Delta\delta_B$$
$$\Delta\mathbf{I}_d = \mathbf{Y}_d\Delta\delta + \mathbf{F}_d\Delta E'_d + \mathbf{G}_d\Delta V_{DC}$$
$$+ \mathbf{H}_{Ed}\Delta m_E + \mathbf{H}_{Bd}\Delta\delta_E + \mathbf{R}_{Ed}\Delta m_B + \mathbf{R}_{Bd}\Delta\delta_B$$

Substituting eq.8 into the linearised equation of the n machine power system, we can obtain the modified Philips-Heffron model of multimachine power system with UPFC.
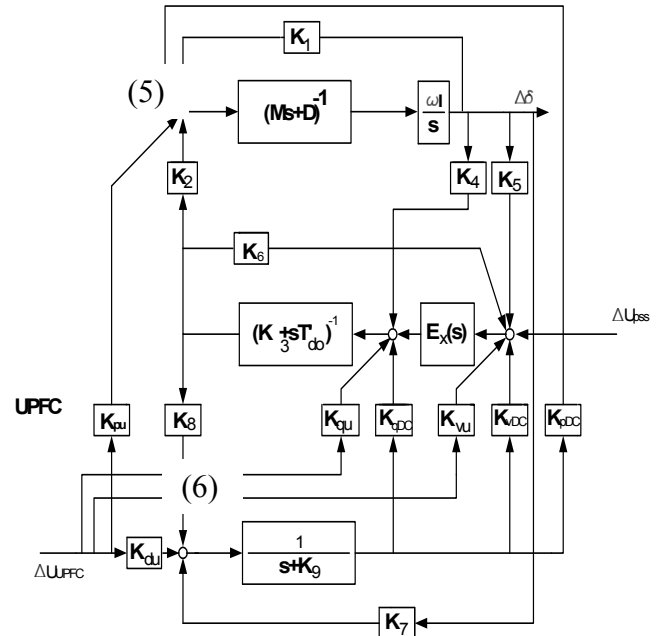

$$(5)$$

$$(6)$$

$$(7)$$

Fig. (2): Modified Heffron-Philips model of multimachine power system with UPFC

3.3 Dynamic in state – space form

The dynamic model of the system in state space form is obtained from the transfer function model as

$$\dot{X} = AX + Bu$$

3

$$
\begin{bmatrix} \Delta\dot\delta \\ \Delta\dot\omega \\ \Delta\dot E_q \\ \Delta\dot E_{fd} \\ \Delta\dot V_{DC} \end{bmatrix} = \begin{bmatrix} \mathbf{0} & \omega_b\mathbf{I} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ -\mathbf{M}^{-1}\mathbf{K}_1 & -\mathbf{M}^{-1}\mathbf{D} & -\mathbf{M}^{-1}\mathbf{K}_2 & \mathbf{0} & -\mathbf{M}^{-1}\mathbf{K}_{pDC} \\ -\mathbf{T'}_{do}^{-1}\mathbf{K}_4 & \mathbf{0} & -\mathbf{T'}_{do}^{-1}\mathbf{K}_3 & -\mathbf{T'}_{do}^{-1} & -\mathbf{T'}_{do}^{-1}\mathbf{K}_{qDC} \\ -\mathbf{T}_A^{-1}\mathbf{K}_A\mathbf{K}_5 & \mathbf{0} & -\mathbf{T}_A^{-1}\mathbf{K}_A\mathbf{K}_6 & -\mathbf{T}_A^{-1} & -\mathbf{T}_A^{-1}\mathbf{K}_A\mathbf{K}_{vDC} \\ \mathbf{K}_7 & \mathbf{0} & \mathbf{K}_8 & \mathbf{0} & K_9 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \\ \Delta V_{DC} \end{bmatrix}
$$

$$
+ \begin{bmatrix} 0 \\ -\mathbf{M}^{-1}\mathbf{K}_p I_n \\ -\mathbf{T'}_{do}^{-1}\mathbf{K}_q I_n \\ -\mathbf{T}_A^{-1}\mathbf{K}_A\mathbf{K}_u I_n \\ K_c I_n \end{bmatrix} \times \Delta U_{UPFC} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ -\mathbf{K}_A\mathbf{T}^{-1}_A I_0 \\ 0 \end{bmatrix} \times \Delta U_{PSS}
$$

4. UPFC Controllers

The UPFC control system comprises four controllers:

(i)   DC voltage cegulator ,
(ii)   AC voltage regulaor,
(iii)   Power – flow controller,
(iv)   Power – system oscillation – domping controllers,

4.1 DC voltage regulator

The DC voltage regulator controls the DC voltage across the DC capacitor of the UPFC. The DC voltage regulator functions by exchanging active power between the UPFC and the power system. Hence its influence on power sysem oscillation damping should be expected and can be investigated based on the phillips-heffron model.

4.2 AC voltage regulator

It has been decided that support UPC bus voltage VE on one of the two transmission lines connecting nodes 1 and 3 [7-8,1].

4.3 Power Flow Controller   [8]

The UPFC is installed in an n-machine power system between node 1 and node 2 [10].

4.3 Power System Osillation Damping Controller

A damping controller is provided to improve the damping of power system osillation. The damping controller may be considered as comparing two cascade connected blocks.

5. Case Study

we consider a three machine power system with UPFC shown by fig. 3, parameters of which are given in the Appendix.
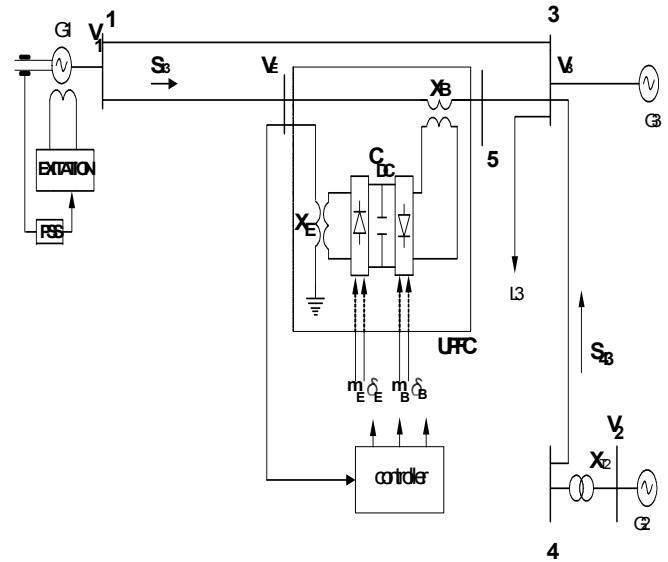

Fig. (3): Example of three machine power system

Table 1 gives the results of computing the oscillation modes of power system from the system linearized model in investing the impact UPFC control on system oscillation stability . we can see that|:

(i)   The influence on system oscillation stability of power flow control and voltage control of the UPFC is small (compare the result in the third and fourth rows in table 1); it can be seen that the UPFC power flow and voltage control have a little effect on the damping of system oscillation modes.

(ii)   The addition of the basic voltage control of the DC link capacitor in the UPFC interacts with the PSS on G1, which was desigend to damp the inter-area oscillation made ,because the inter-area oscillation occurs again after the installation of the UPFC the results in the last row of table 1 demonstrate the sharp reduction of the damping of the inter-area oscillation mode.

Table1: result of computing oscillation modes

Case study	Local oscillati on mode	Inter- area Oscillati on mode

4

Three machine whithout stabilizer	$-1.099 \pm j$ 5.500	$0.001 \pm j$ 4.400
PSS on G1 installed	$-1.380 \pm j$ 5.600	$0.495 \pm j$ 4.310
UPFC installd with power flow and voltage control function and PSS on G1 installed	$-1.001 \pm j$ 5.610	$0.490 \pm j$ 4.300
UPFC installd with power flow, voltage control function, UPFC DC voltage control function and PSS installd on G1	$-1.001 \pm j$ 5.60	$0.110 \pm j$ 3.910

In table 1 the result in the third row that obtained whithout UPFC DC capacitor voltage control. This is just a demonstrative case to show that the UPFC power flow and voltage control have no effect on system oscillation be stability. In practive these two functions must be appled at the same time as that of UPFC DC capacitor voltage contol.

Fig. 4 -9 compare the effect of UPFC and PSS on power systems. Simulation results show that the performance of UPFC based stabilizer on damping of power syetem is better than PSS.

Fig 5 persents the nonlinear simulation based on the system dynamic model of eqs. 1 and 7. The oscillation is triggered by a three-phase short circuit occurring on the transmission line between node 3 and 5 in example power system at 1.0 second of he simulation and cleared after 100 ms. It abviously confirms the results in table 1, the influence of the DC capacitor voltage control is great.

Measures therefore are needed to tackle the inter-area oscillation. One option is simply to readjust parameters of the PSS on G1. By adjusting the parameters of the PSS, the inter-area oscillation maode is moved to $-0.440 \pm j$ 3.810 and the oscillation is will damped again as confirmed by the non linear simulation of fig.6.

Another measure is to introduce damping controller into the UPFC. And the feedback signal of the damping controller, y_c, is taken to be the active power delivered a long the transmission line from node 3 to 4. By using the eginvalue assignment methd[12,13], the parameters of damping controller are set.

The inter-area oscillation modes are assigned to $-0.590 \pm j$ 4.001 and oscillation is well suppressed as shown by the nonlinear simulation at Fig.8.
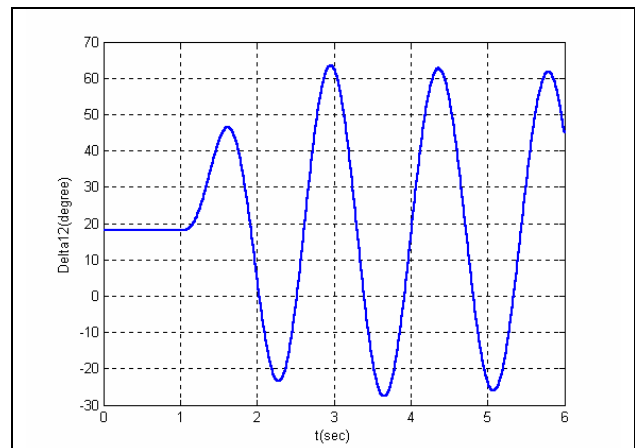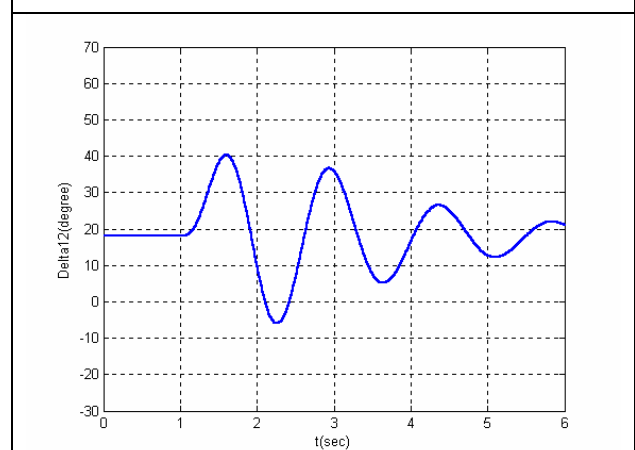

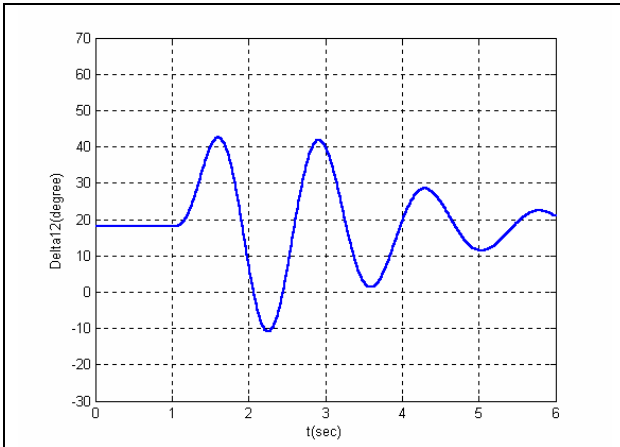Fig. (4): whithout stabilizer

Fig. (5): PSS on G1 installed

Fig. (6): UPFC installd with power flow and voltage control function and PSS on G1 installed
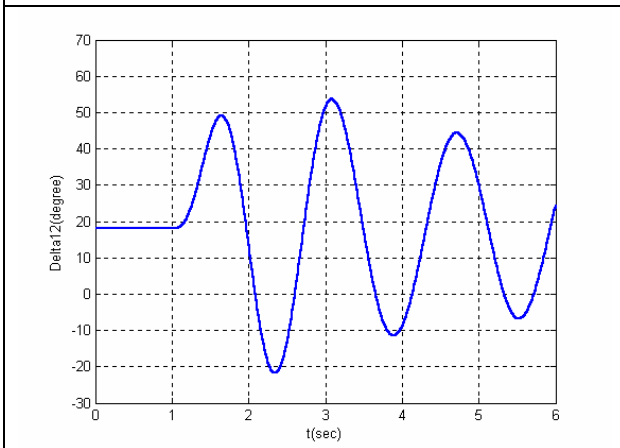

Fig. (7): UPFC installd with power flow, voltage control function, UPFC DC voltage control function and PSS installd on G1
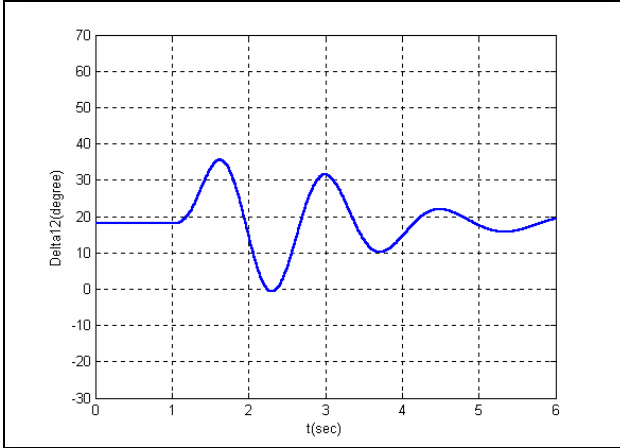

Fig. (8): UPFC installd with power flow, voltage control function, UPFC DC voltage control function and UPFC based stabilizer
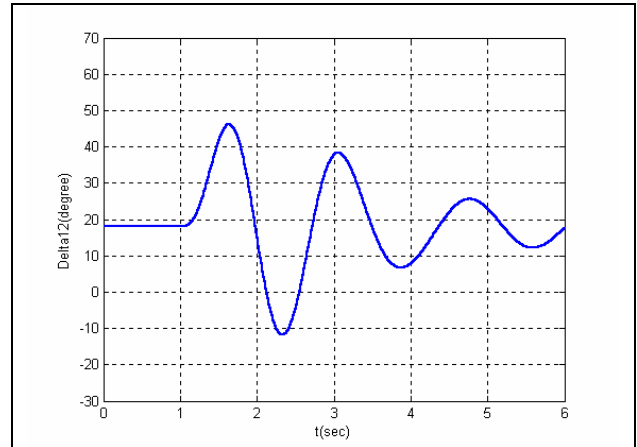

Fig. (9): UPFC installd with power flow, voltage control function, UPFC DC voltage control function and Readjusting PSS installd on G1

6. Conclusion

This paper establishes the linearized Heffron-Philips model of a power system equipped with UPFC and demonstrated the application of the model in analysing the damping effect of the UPFC, It also designed UPFC based stabilizer to improve power system oscillation stability. The multi-machine power system with UPFC is studied and an example was presented. It has shown that the DC voltage contributes negative damping to power system oscillations, which was confirmed by both eigenvalue computation and nonlinear simulation. Then we compared the effect of UPFC and PSS on power systems. Simulation results were demonestrated that the performance of UPFC based stabilizer on damping of power syetem is better than PSS.

7. References

[1] Gyuguyi.L, "Unified power–flow control: Concept for flexible AC transmission systems " IEE Proc.C, no .4 1992

[2] Gyugyi.L , Rietman.T.R , Edris.A , Schauder .C.D,Torgerson.D.R , and Williams.S.L, "The unified power flow controller : A new approach to power transmission control " IEEE Trans .on PWRS , no .2 ,1995

[3] Nabavi–Niaki.A and Iravani.M.R , " Steady–stated and dynamic models of unified power flow controller (UPFC) for power system studies" IEEE Trans. On PWRS, no.4,1996

[4] Arabi.A and Kundur.P , "Aversatile FACTS deviece model for power flow and stability simulation" IEEE Trans , on PWRS , no . 4 ,1996

[5] Noroozian.M and Andersson.G , "Damping of power system oscillation by use of controllable components " IEEE Trans. on PWRD , no.4 ,1994

[6] Heffron.W.G and Phillips.R.A, "Effect of a modern amplidyne Voltage regulatior on under excited operation of large turbine generator" AIEE Trans .,1952

[7] LIMYINGCHAROEN, S. ANNAKAGE , U.D. , and PAHALAWATHTHA , N.C. "Effects of unified power flow controllers on transient stability", IEE Proc.C. 2002.2(145). pp182 188

[8] WANG.H.F. , and SWIFT.F.J. "A nunified model for the analysis of FACTS devices in damping power system oscillations. Part 1 : Single –machine infinited – bus POWER systems" . IEEE trans 1997,PD -2 (12) , pp. 941 964

[9] GYUGYO. I. "A unified power flow control conccept for flexible AC transmission systems" IEE Proc.C.1992, 4 , (139) , pp. 323 331

[10] PAPIC.1. ZUNKO. P. POVH.D. and WEINIIONI.D.M. "Basiec control of unified power flow controller" , IEEE trans . 1997 PWRS 4,(12) , pp1734 1739

[11] SMITH, K.S. RAN, L.and PENMAN, J.Dynamic modeling of a unified power flow controller, IEE provc.C .2000,(144) PP.7-12

[12] Schoder , K., Hasanovic A.Feliachi,A. " Power System Damping Using Fuzzy Controlled unified power flow Controller " IEEE Trans Power Delivery 2001 pp617 622

[13] Chen.C.T and Hsu.Y. Y. " Design of UPFC controlers and Supplementary damping controller for power transmission control and stability enhancement of longitudial power system " IEE Proc. Gener. Transm. Distrib. Vol. 149,no . 4,2002

7. Appendix

generators:

$H_1 = H_2 = 20$,$H_3 = 11.8$s,

$D_1 = 0.0$,$D_2 = 0.0$,$D_3 = 0.0$,

$T'_{do1} = 7.5$s ,$T'_{do2} = 7.5$,$T'_{do3} = 4.7$,

$x_{d1} = 0.19$,$x_{d2} = 0.19$,$x_{d3} = 0.41$,

$x_{q1} = 0.163$,$x_{q2} = 0.163$,$x_{q3} = 0.33$,

$x'_{d1} = 0.0765$,$x'_{d2} = 0.0765$,$x'_{d3} = 0.173$

exation:

$K_{A1} = K_{A3} = 20.0$, $K_{A2} = 100$,

$T_{A1} = T_{A3} = 0.05$s, $T_{A2} = 0.01$ s

Network and UPFC:

$Z_{13} = j1.2$, $Z_{23} = j0.2$, $Z_{1E} = j0.2$, $Z_{E3} = j0.2$,

$V_{1t} = 1 < 9$, $V_{2t} = 1 < 5$, $V_{3t} = 1 < 0$,$L_3 = 1.5 + j 0.5$

$Z_{T2} = j0.03$,

$P_{53} = 0.6$p.u.,$P_{43} = 0.8$p.u.

$C_{DC} = 1.0$, $V_{DC0} = 1.0$, ,$K_P = 10.0$,$K_V = 40$