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Power System Oscillations Damping Using Unified Power Flow Controller-Based Stabilizer

[1]Lokman H. Hassan, [1]M. Moghavvemi and [2]Haider A.F. Mohamed
[1]Department of Electrical Engineering, University of Malaya,
50603 Kuala Lumpur, Malaysia
[2]Department of Electrical and Electronic Engineering,
University of Nottingham Malaysia Campus, 43500 Semenyih, Malaysia

Abstract: Problem statement: The Phillips-Heffron model of a power system with UPFC published by AJAS, demonstrates the effect of the UPFC in improving power system oscillation stability. Unfortunately, some of the equations have not been correctly derived and so working with this model in its existing form is misleading. **Approach:** In this study, the model is revisited and the equations are re-derived obtaining correct results. Three-machine power system installed with a UPFC is used to investigate the validity of these equations. **Results:** The simulation results demonstrated that the corrected model with an effective controller is active on damping of the low-frequency oscillations under different operating conditions. **Conclusion:** The corrected model works properly with power system networks for enhancing power system stability.

Key words: Phillips-Heffron model, UPFC, low-frequency oscillations

INTRODUCTION

Simplicity and ease of application of Phillips-Heffron model has encouraged many researchers to use this model in representing the power system with FACTS devices (Song and Johns, 2000; Paserba, 2004; Al-Awami *et al*., 2007).

The Phillips-Heffron linear model is presented by (Meshkatoddini *et al*., 2009) to develop the non-linear dynamic model of multi-machine power system with UPFC. However, in its current form this model cannot properly represent power system networks installed with a UPFC and need to be corrected.

In this study, the model proposed by (Meshkatoddini *et al*., 2009) is corrected and tested on a three-machine power system installed with a UPFC. The effect of efficient control of UPFC on damping of the low-frequency oscillations is demonstrated by using the corrected model and the results are compared with model presented by (Meshkatoddini *et al*., 2009).

MATERIALS AND MATHODS

Dynamic model of multi-machine power system with a UPFC: The dynamic model of an n-generator installed with a UPFC is derived in reference (Meshkatoddini *et al*., 2009). The $\bar{I}_{1E}$ and $\bar{I}_{E2}$ are derived and listed in matrix form as:

$$\begin{bmatrix}\bar{I}_{1E}\\ \bar{I}_{E2}\end{bmatrix}=\frac{1}{x_\Sigma}\begin{bmatrix}-j(x_E+x_{E2}+x_B) & jx_E\\ -jx_E & j(x_{1E}+x_E)\end{bmatrix}\begin{bmatrix}\bar{V}_1\\ \bar{V}_2\end{bmatrix}+\frac{1}{x_\Sigma}\begin{bmatrix}j(x_{E2}+x_B) & jx_E\\ -jx_E & j(x_{1E}+x_E)\end{bmatrix}\begin{bmatrix}\bar{V}_E\\ \bar{V}_B\end{bmatrix} \quad (1)$$

where, $x_\Sigma=(x_{1E}+x_E)(x_E+x_{E2}+x_B)-x_E{}^2$.

However, the actual value of the $\bar{V}_E$ coefficient of the matrix second row is $(-jx_{1E})$ and not $(-jx_E)$ as claimed by (Meshkatoddini *et al*., 2009). Also derived equation for generator current is stated as:

$$\bar{I}_g=\bar{C}\bar{V}_g+\bar{F}_E\bar{V}_E+\bar{F}_B\bar{V}_B \quad (2)$$

Where:

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

$$\bar{F}_E=-[\bar{Y}_{31}\quad \bar{Y}_{31}]\bar{Y}'^{-1}_t\begin{bmatrix}\dfrac{j(x_{E2}+x_B)}{x_\Sigma}\\ \dfrac{jx_{1E}}{x_\Sigma}\end{bmatrix}$$

Corresponding Author: Lokman H. Hassan, Centre for Research in Applied Electronics, University of Malaya, 50603 Kuala Lumpur, Malaysia

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

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

This result is not correct. The $[\overline{Y}_{31}\ \overline{Y}_{31}]$ in $\overline{C}$, $\overline{F}_E$ and $\overline{F}_B$ must be changed to $[\overline{Y}_{31}\ \overline{Y}_{32}]$ in order to correspond with actual value.

RESULTS

A UFPC has been installed with a controller between bus 4 and 5 in Fig. 1. The data of the system generators and excitation are given by (Anderson and Fouad, 2002). The voltage across the DC link capacitor is controlled by δ_E which is the more efficient input control signal of the UPFC control (Al-Awami *et al*., 2007):

$$\delta_E = ((K_{dp} + \frac{K_{dI}}{s})\Delta\omega + K(v_{dcrf} - v_{dc}))(\frac{K_s}{(1+sT_s)}) \qquad (3)$$

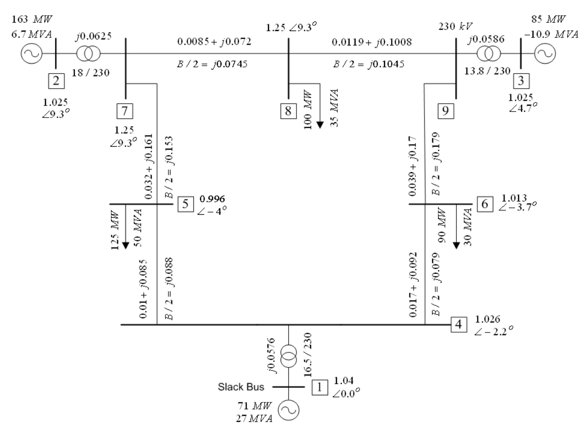

Fig. 1: Three machine power system (Anderson and Fouad, 2002)

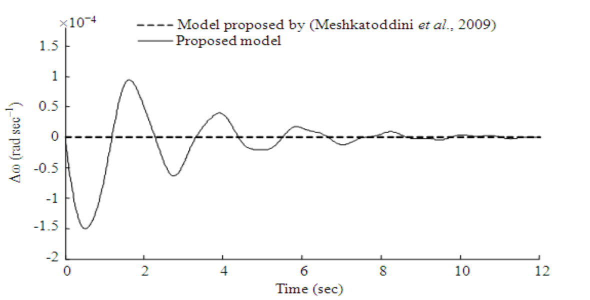

Fig. 2: Frequency response for G1 at torque angle change

The data of UPFC and the controller are:
$x_E = 0.075$, $x_B = 0.075$, $C_{dc} = 1$, $K = 10$, $K_{dP} = -120$, $K_{dI} = -0.5$, $K_s = 1$, $T_s = 0.05$, $v_{dc} = 1$.

The controller is applied to the system using corrected model and the model proposed by (Meshkatoddini *et al*., 2009). The models constants are computed. The results demonstrate that the $K_{1.1j}, K_{4.1j}, K_{5.1j}, K_{7.1j}$, $K_{pd,1j}, K_{qd,1j}, K_{vd,1j}, K_{pu,1j}, K_{qu,1j}, K_{vu,1j}$ constants are equal to zero just by using model proposed by (Meshkatoddini *et al*., 2009). However these results are not acceptable.

The simulation is implemented by using MATLAB Simulink program to demonstrate the effect of UPFC on the power system.

Case 1: In this case the system is subjected to 0.1 torque angle change at generator 1. The system time domain responses under DC link capacitor controller for both models are shown in Fig. 2.

Case 2: In another test case, the system is subjected to a 3 cycle three phase fault near bus 6 at the end of line 4-6. The initial torque angle is assumed to be 0.1. The system responses for both models are shown in Fig. 3 and 4, respectively.

DISCUSSION

It is clear from the Case 1 that the generator 1 in model proposed by (Meshkatoddini *et al*., 2009) is not affected by δ change as shown in Fig. 2. By contrast, the corrected model gives real response. In case 2, Fig. 3 shows that the generator 1 in the model proposed by (Meshkatoddini *et al*., 2009) is not affected by the fault. This is not the real result. Figure 4 shows the actual response for all generators by using the corrected model.

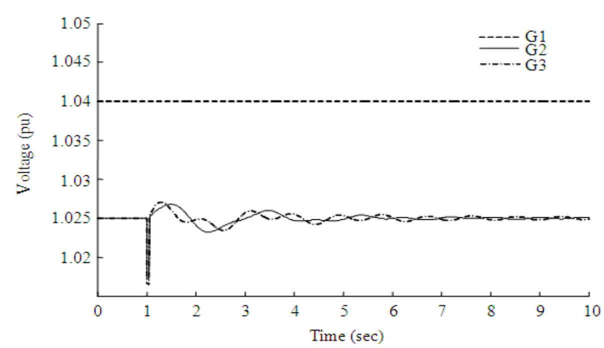

Fig. 3: Terminal voltage response for the model proposed by (Meshkatoddini *et al*., 2009)

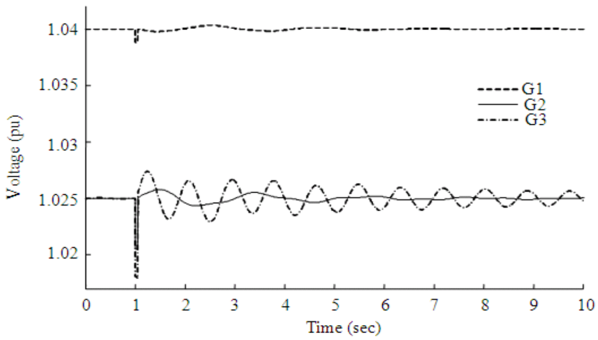

Fig. 4: Terminal voltage response for the corrected model

CONCLUSION

In this study, The Phillips-Heffron linear model is presented to develop the non-linear dynamic model of multi-machine power system installed with a unified power flow control UPFC. The model presented in reference (Meshkatoddini *et al*., 2009) corrected to work properly with power system networks. The correct model was tested on three-machine power system installed with a UPFC.

The efficient controller for UPFC was implemented by controlling the DC link capacitor voltage and applied to corrected model. The results show the effectiveness of the controller in damping of the low-frequency oscillations.

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