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Article

Advanced Control Strategies for UPFC in Power System to Enhance Control and Stability

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Abstract: The power system network is currently extremely overloaded as a result of the ongoing rise in power consumption. Additionally, due to financial and other constraints, new electricity lines cannot be installed in place of the current ones. Only with the cooperation of the power system community can the control system community run and manage the power system's network using the current lines. To improve the power system's performance in terms of stability and control, the control system community has been investing in and applying novel control techniques to the power system network over the past fifty years. This study proposes a hybrid control approach for the power system network installed with the Unified Power Flow Controller (UPFC) employing switching and non-switching control strategies, following the works of the control system community. MATLAB/SIMULINK platforms are used to test the suggested controllers, and the results are compared to get the relevant conclusion.

Keywords: PSS, UPFC, Switching Control, FACTS

1. Introduction

It is now very difficult for the power system and control system community to stabilize power system oscillations and minimize overshoots of state variables such as rotor angle and rotor speed deviations. Electrical experts have been studying this area in great detail during the last few decades. Because of this, the power system sector has been using tools like flexible AC transmission control (FACTS) based on Power System Stabilizers (PSS) and unified power flow controllers (UPFC). For the Power system network, hybrid control techniques like coordinating and switching between UPFC control inputs are used to address the aforementioned issues. The outcomes are compared to determine which control strategies perform best. Ban H. Alajrash & Mohamed Salem et al. [1], explain the effective utilization of power electronics, control strategies, and artificial intelligence integration to enhance the performance of FACTS devices. The authors Alok Kumar Mohanty & Amar Kumar Barik et al. in [2] have justified that the power system stability can be improved using FACTS devices. The power system network can be controlled effectively using FACTS devices, as the paper informs [3]. M. P. Donsion &, J.A. Gufemes et al. [4], detailed the benefits of utilizing FACTS devices in electrical power systems to improve the power quality. J.G. Singh & S.N. Singh et al. [5] informed that placing FACTS controllers is important in improving the power system stability.

A switched system is a dynamical system that consists of a finite number of subsystems and a logical rule that orchestrates switching between these subsystems. These subsystems are usually described mathematically by a collection of indexed differential or difference equations. Hybrid or switching systems, commonly found in control theory which are characterized by a combination of both continuous and discrete systems have created an enormous growth of interest in dynamic systems. The performance of these systems can be realized by switching between relatively two simple linear time invariant (LTI) systems with different control techniques.

In summary, the above literature survey indicates that utilizing the FACTS devices has been the best option for improving and controlling power system stability. Further to choose the FACTS device, the following literature survey is conducted:

D. Murali & Dr. M. Rajaram et al., [6] compared all the FACTS devices concerning the power system stability enhancement with and without the presence of UPFC in the system in the event of a major disturbance and the experimental results conclude that the performance of UPFC for power system stability improvement is compared with the other FACTS devices such as SVC, TCSC, and SSSC respectively. To evaluate the power quality problems, various FACTS controllers are compared by Budi Srinivasa rao and G. Sreenivasan et. al, [7]. Arthit Sode Yome & Nadarajah Mithulanantha et al,.[8] compared various FACTS devices for exclusive loadability enhancement for the appropriate choice of FACTS device, and the results show that the UPFC FACTS provides better performance compared to all other FACTS devices to all loading conditions.

One of the FACTS devices that may regulate power sys- tem parameters, including phase angle, line impedance, and terminal voltage, is the UPFC. As a result, it can be applied to both power system stabilizing control and power flow management. A linearized Phillips Heffron model with UPFC installed for single machine infinite bus (SMIB) in a power system was presented by Wang et al. [9]. Recently, researchers have been using various control strategies to select UPFC control inputs for a wide range of loading situations, including modulating indices, phase angles of series and shunt inverters (mB, mE, δB, and δE), and more. The particle swarm optimization (PSO) technique was proposed by H. Shayeghi et al. [10], who concluded that the most robust controller could be obtained for δE. Tambey et al. [11] showed that control inputs δE and δB offer strong performance in comparison to the other damping controllers by using the phase compensation control technique. After using a real-coded genetic algorithm optimization technique, A. K. Baliarsingh et al. [12] found that, out of the four options, damping control mB performs marginally better. The robust TCSC (thyristor-controlled series compensator) controller for power system oscillation damping enhancement was designed by Kwang et al. [13] using the LQG technique, and their simulation results demonstrated the controller’s efficacy in damping power system oscillations. Amir et al. [14] developed a UPFC auxiliary stabilizer employing the LQG control approach, and many simulations were used to assess the method’s efficacy and validity. The power system oscillation damping under disturbances has improved, according to the results. Uncoordinated PSS and FACTS device control, however, could result in unstable interactions. Numerous studies have attempted to coordinate PSSs and FACTS damping controllers to enhance overall system performance, yielding results that outperform those of uncoordinated PSS and FACTS-based damping controllers [15-17]. While the linearized power system model serves as the foundation for some of these techniques, others are based on complicated nonlinear simulation [18]. Generally speaking, decentralized output feedback control with feedback signals accessible at the site of each controlled device is the most advantageous for the ease of practical controller installation.

An overall summary of the above literature review suggests that any single optimized controller may not provide better performance in today’s complex power system due to its dynamic range of operation. Hence, in this paper, hybrid control methods are proposed for UPFC in the power system to improve the performance in terms of control and stability.

2. Linearized Power System Model Installed with UPFC

In 1995, Westinghouse’s L. Gyugyi introduced the UPFC concept in a power system network. One of the most complete FACTS devices is the UPFC, which allows for separate management of both active and reactive power as well as controlled bus voltage. For the current studies, a single machine infinite bus (SMIB) system is taken into consideration. Thevenin’s equivalent of the transmission network outside the machine can be used to reduce a machine that is connected to a large system via a transmission line to an SMIB system. The synchronous machine in the LTI model of the power system under study is connected to an infinite bus bar via a transmission line, and it is depicted as a Its state space formulation can be expressed as follows [19-24]: Its state space formulation can be expressed as follows [20]:

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ -\frac{k_1}{M} & -\frac{D}{M} & -\frac{k_2}{M} & 0 \\ -\frac{k_1}{T'do} & 0 & -\frac{kqe}{T'do} & \frac{1}{T'do} \\ -\frac{k_A k_5}{T_A} & 0 & -\frac{k_A k_6}{T_A} & \frac{1}{T_A} \end{bmatrix}$$

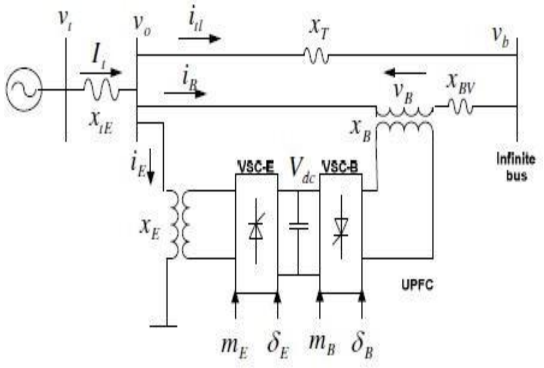


Figure. 1. Block Diagram of SMIB installed with UPFC

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -\frac{kpb}{M} & -\frac{kp\delta b}{M} & -\frac{kpe}{M} & -\frac{kp\delta e}{M} \\ -\frac{kqb}{T'do} & -\frac{kq\delta b}{T'do} & -\frac{kqe}{T'do} & -\frac{kq\delta e}{T'do} \\ -\frac{k_A k_{vb}}{T_A} & -\frac{k_A k_{v\delta b}}{T_A} & -\frac{k_A k_{ve}}{T_A} & -\frac{k_A k_{v\delta e}}{T_A} \end{bmatrix}$$

3. Proposed Hybrid Control Techniques

This section explains the design of hybrid control techniques in the following cases: Case I: Optimized feedback Linear Quadratic Regulator (LQR) control techniques are designed for the individual UPFC control Inputs of modulating index and phase angle of series and shunt inverter (mE, δE, mB & δB). Table 1 shows the control techniques:

TABLE I

CASE 1: CONTROL TECHNIQUES

UPFC Control Inputs	Gain Matrix K
mE	*KmE*
δE	*KδE*
mB	*KmB*
δB	*KδB*

Case 2: Individual UPFC control inputs of case 1 are coordinated with Power System Stabilizer (PSS), and the results are compared between coordinated & uncoordinated UPFC control inputs. Table 2 shows the control techniques:

TABLE II

CASE 2: CONTROL TECHNIQUES

UPFC Control Inputs	Gain Matrix K

PSS+*mE*	*KPSS* +*KmE*
PSS+*δE*	*KPSS* +*KδE*
PSS+*mB*	*KPSS* +*KmB*
PSS+*δB*	*KPSS* +*KδB*

Case 3: Switching between individual UPFC control inputs with coordinated and uncoordinated PSS control inputs are experimented with modified switching control algorithms. Table 3, shows the control techniques:

TABLE III

CASE 3: CONTROL TECHNIQUES

UPFC Control Inputs	Gain Matrix K
Switch *mE* /*mB*	Switch *KmE* /*KmB*
Switch *δE* /*mB*	Switch *KδE* /*KmB*
Switch *δE* /*δB*	Switch *KδE* /*KδB*
Switch *δE* /*mE*	Switch *KδE* /*KmE*
Switch *δB*/*mB*	Switch *KδB* /*KmB*

The switching model is represented by,

$$\dot{x} = A_{\sigma(t)}x(t) \qquad (1)$$

Where, the switching signal $\sigma(t)$ indicates: If, $\sigma(t) = 1$, then $\dot{x} = A_1x(t)$;

Or else, $\dot{x} = A_2x(t)$;

4. Simulation Results and Discussions

In addition to providing a thorough discussion, this part summarizes the research findings. Figures, graphs, tables, and other easily comprehensible formats can be used to convey results.

The following displays the different controller gains (K) of UPFC control inputs with and without coordinated PSS and switching matrices (S) for each of the three scenarios:

$$K_{mB} = [\ -0.8668 \quad 71.2779 \quad -8.7704 \quad -0.9770\ ]$$

$$K_{\delta B} = [\ 2.3957 \quad 110.9214 \quad -9.9935 \quad -0.0023\ ]$$

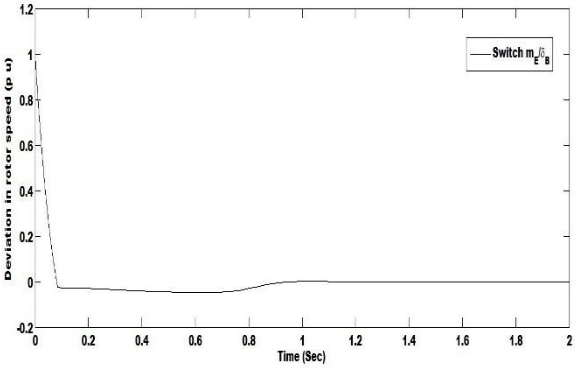
$$K_{mE} = [\ 0.9062 \quad 337.1713 \quad -14.3254 \quad -0.4622]$$

$$K_{\delta B} = [-0.711 \quad 1142.92 \quad -37.911 \quad -0.4622]$$

$$K_{PSS+m_B} = \begin{bmatrix} -0.2501 & -61.8383 & 2.3494 & 0.8588 \\ -0.5956 & -92.0354 & 2.3032 & -0.4786 \end{bmatrix}$$

$$K_{PSS+m_B} = \begin{bmatrix} \mathbf{0.0560} & \mathbf{-1.6193} & \mathbf{0.2104} & \mathbf{0.9802} \\ \mathbf{0.9079} & \mathbf{63.4799} & \mathbf{-0.9812} & \mathbf{0.0003} \end{bmatrix}$$

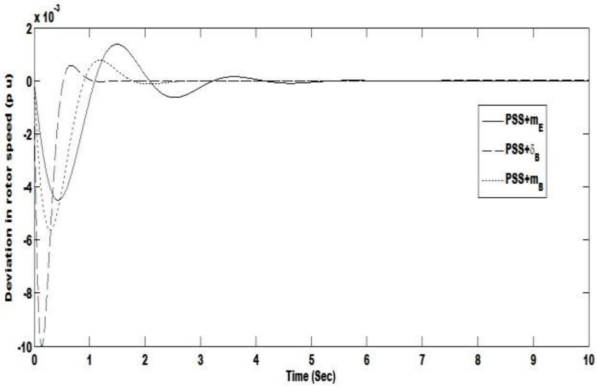
$$K_{PSS+m_B}=\begin{bmatrix}0.2460 & -76.6973 & 8.4305 & 0.9816\\ & 110.6368 & -4.0838 & -0.0212\end{bmatrix}$$



$$\begin{matrix}0056 & 0.0001 & 0.0000\\ .5449 & 0.1256 & 0.0101\\ 1256 & -0.0026 & -0.0001\\ 0101 & -0.0001 & 0.0000\end{matrix}\Bigg]$$

$$\begin{matrix}.0747 & -0.0012 & 0.0000\\ .5413 & -0.3084 & 0.0010\\ 0.3084 & 0.0064 & -0.000\\ .0010 & -0.0000 & 0.0000\end{matrix}\Bigg]$$

The dynamic response of the state variable deviation in rotor speed $\Delta\omega$ for the Case I & Case II are shown in Figures 2-3, and the Plots for Case III is depicted in Figures 3-4 (switching between two UPFC control inputs along with opti- mized feedback controller gains). Figure 5 represents the better visibility of the switching between *mE*/*δB* with the individual controllers of *mE* & *δB*. Table 4 shows the comparison of the proposed controllers with respect to the control system prominent parameters Peak Overshoot (*MP*) & Settling Time (*Ts*).



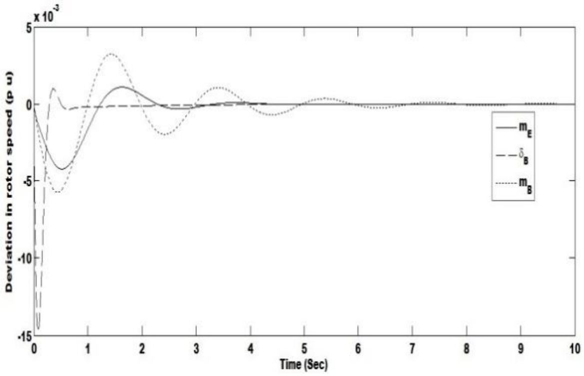
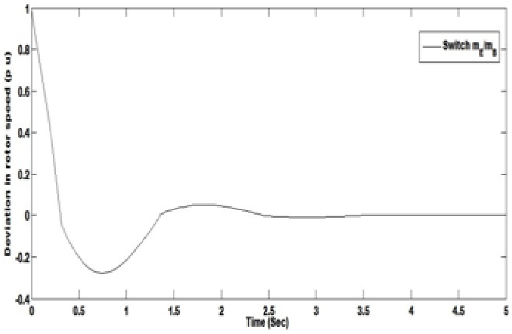


Figure. 2. Deviation in rotor speed Case I

Figure. 3. Deviation in rotor speed Case II



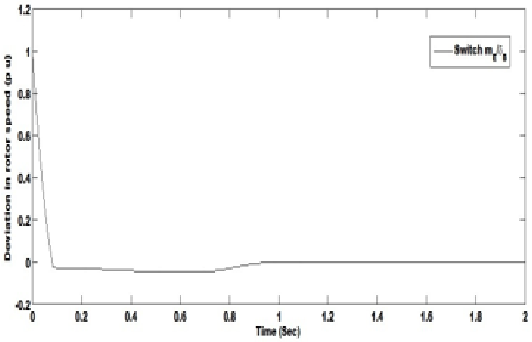


Figure. 4. Deviation in rotor speed Case III

Figure. 5. Deviation in rotor speed Case III

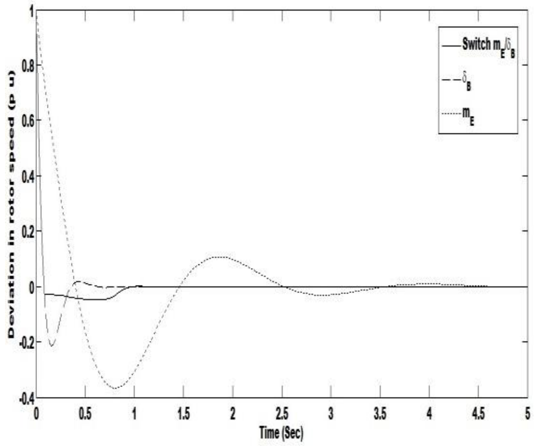


Figure. 6. Deviation in rotor speed Case III with clarity of switching response

TABLE IV

COMPARISON OF PROPOSED CONTROL TECHNIQUES

Case	Control Inputs Strategy	Peak Overshoot (*Mp*)	Settling Time (*Ts*)
I	*mE*	-4.5	8s
I	*δB*	-14.5	1s
I	*mB*	-6	8s
II	PSS+*mE*	-4.5	6s
II	PSS+*δB*	-10	1s
II	PSS+*mB*	-5	3s
III	Switch *mE* /*mB*	-0.28	2.8s
III	Switch *mE* /*δB*	0	0.9s

5. Conclusion

In this paper, hybrid control methods are proposed for power systems equipped with UPFC FACTS controllers to enhance the power system stability. The proposed controllers are experimented in three cases and the results are compared concerning Peak Overshoot (MP) & Settling time (Ts). In case 1, the controllers are designed with optimal LQR for all the individual UPFC control inputs (mE, δE, mB & δB) and the response of the state variable deviation in rotor speed (Δω) is plotted. Case II experiments depict the response of Δω using coordinated control with Power System Stabilizer (PSS+mE, PSS+δB & PSS+mB). The switching control is implemented for the UPFC control inputs mE/mB & mE/δB in case III. In Summary, the experimental results (Figure 2 - 4 & Table 4) show that the coordinated control design of PSS with UPFC control inputs has better performance to MP & Ts compared to the uncoordinated UPFC control input, and the combination of coordinated design PSS+δB provides dynamic performance compared to all other combinations of coordinated and uncoordinated control design techniques. Further, the switching between two UPFC control input designs using the well-defined switching control law has robust performance compared to without switching control design combinations of coordinated and uncoordinated control UPFC inputs with PSS. Finally, the switching control combination of mE/δE has the excellent performance with respect to all the proposed hybrid control methods.

References

1. Ban H. Alajrash and Mohamed Salem,” A comprehensive review of FACTS devices in modern power systems: Addressing power quality, optimal placement, and stability with renewable energy penetration,” Energy Reports., vol. 11, pp. 5350-5371–137, Jun. 2024, doi:10.1016/j.egyr.2024.05.0113.
2. Alok Kumar Mohanty and Amar Kumar Barik, “Power System Stability Improvement Using FACTS Devices,” International Journal of Modern Engineering Research (IJMER)., vol. 1, Issue 2, pp. 666–672, 2019, ISSN:2249-6645.
3. Sthitaprajna rath, Bishnu Prasad sahu and Prakash dash, ”Power System Operation and Control Using FACTS Devices,” International Journal of Engineering Research & Technology (IJERT)., Vol. 1, Issue 5, July 2012, ISSN: 2278-0181.
4. M.P.Donsio´n, J.A. Gufemes and J.M. Rodrıguez, “Power Quality Benefits of Utilizing FACTS Devices in Electrical Power Systems,” A International Journal., Spain.
5. J. G. Singh, S. N. Singh and S. C. Srivastava, “Placement of FACTS controllers for enhancing power system loadability,” IEEE Power India Conference, 2006, pp 7, doi: 10.1109/POWERI.2006.1632526.
6. D. Murali, Dr. M. Rajaram and N. Reka, “Comparison of FACTS Devices for Power System Stability Enhancement,” International Journal of Computer Applications., vol. 8, no. 4, 2010, ISSN: 0975–8887.
7. Budi Srinivasarao, G. Sreenivasan and Swathi Sharma, “ Comparison of Facts Controller for Power Quality Problems in Power System, “ Indian Journal of Science and Technology, vol. 8, no. 31, pp. 1–4, 2015, doi: 10.17485/ijst/2015/v8i31/76302.
8. Arthit Sode-Yome, Nadarajah Mithulananthan and Kwang Y. Lee, “Com- prehensile Comparison of FACTS Devices for Exclusive Loadability Enhancement,” IEEJ Transactions on Electrical and Electronic Engineering, vol. 8, pp. 7–18, 2013, doi: 10.1002/tee.21785.
9. H. F. Wang.,” A unified model for the analysis of FACTS devices in damping power system oscillations– Part III: Unified power flow controller”. IEEE Transactions on Power Delivery, 2000, 15(3): 978– 983.
10. H.Shayeghi, H. A., Shayanfar and S. Jalilzadeh, ”Design of output feedback UPFC controller for damping of electromechanical oscillations using PSO,” Energy Conversion and Management, 2009, Vol. 50, Issue 10, pp. 2554–2561.
11. N. Tambey and M. L. Kotharir.,” Unified power flow controller (UPFC) based damping controllers for damping low frequency oscillations in a power system”, Maturitas, 2003, Vol. 72, Issue 1, pp. 35– 41.
12. A. K. Baliarsingh, S. Panda and A. K. Mohanty,” UPFC supplementary controller design using real-coded genetic algorithm for damping low frequency oscillations in power systems”, International Journal of Electrical and Computer Engineering, 2013, Vol. 7, Issue 4, pp. 759– 761.
13. K. M. Son and J. K. Park,” On the robust LQG control of TCSC for damping power system oscillations”, IEEE Transactions on Power Systems, 2000, Vol. 15, Issue 4, pp. 1306– 1312.
14. A. Elahi, A. Gholizadeh and A. Aghae,” Linear quadratic Gaussian control for UPFC auxiliary stabilizer”, Science International, 2014, Vol.26, Issue 5, pp. 2353– 2356.
15. P. Pourbeik and M. J. Gibbard,” Simultaneous coordination of power system stabilizers and FACTS device stabilizers in a multimachine power system for enhancing dynamic performance”, IEEE Transaction on Power Systems, 1998, Vol. 13, Issue 2, pp. 473– 479.
16. L. J. Cai and I. Erlich,” Simultaneous coordinated tuning of PSS and FACTS damping controllers in large power systems”, IEEE Transaction on Power Systems, 2005, Vol. 20, Issue 1, pp. 294– 300.
17. L. Yathisha and S. S. P. Kulkarni,” Optimal switched feedback controller design for the simultaneous coordinated design of UPFC and PSS in power system”, Journal of Electrical Engineering, 2016, Vol. 16, Issue 4, pp. 414– 421.
18. A. M. Yousef and M. K. Ei-Sherbiny,” Improvement Of synchronizing and damping torque coefficients based LQR power system stabilizer”, International Conference on Electrical, Electronic and Computer Engineer- ing, Cairo, Egypt: IEEE, 2004, pp. 753– 758.
19. A. Alfi and M. Khosravi,” Optimal power system stabilizer design to reduce low frequency oscillations via an improved system optimization algorithm”, International Journal on Technical and Physical Problems of Engineering, 2012, Vol. 4, Issue 2, pp. 24– 33.
20. Al. Olimat, K. S, Farhoud and J. K. Hurtig,” Power system stabilizers with fuzzy logic switching”, Power Systems Conference and Exposition, Atlanta: IEEE, 2006, pp. 2152– 2157.
21. L. Yathisha and S. P. Kulkarni,” Optimum LQR switching approach for the improvement of STATCOM performance. Proceedings of the Third International Conference on Trends in Information, Telecommunication and Computing”, New York: Springer, 2013, pp. 259– 266.
22. L. Yathisha, K. Davoodi and S. P. Kulkarni,” Optimal switching control strategy for UPFC for wide range of operating conditions in power system”, Proceedings of 3rd Indian Control Conference, Guwahati: IEEE, 2007, pp. 225– 232.
23. L. Yathisha and S. P. Kulkarni,” Application and comparison of switch- ing control algorithms for power system stabilizer”, IEEE International Conference on Industrial Instrumentation and Control, Pune, IEEE, 2015, pp. 1300– 1305.
24. L. Yathisha and S. P. Kulkarni, “LQR and LQG based optimal switching techniques for PSS and UPFC in power systems”, Control Theory and Technology, Springer Journal, Vol. 16, Issue 1, 2018, pp. 25-37.
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