Journal of Information Systems Engineering and Management
2025, 10(2)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Coordinated & Uncoordinated Control Techniques for PSS & UPFC to Enhance Power System Stability & Control

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ARTICLE INFO

Received: 20 Oct 2024

Revised: 19 Dec 2024

Accepted: 05 Jan 2025

ABSTRACT

One of the main issues in today's power system network is the improvement of power system dynamics and stability. To reduce the power system network's instability, this research employs several control strategies, including coordinating and un-coordinating the UPFC and PSS control inputs. The MATLAB/SIMULINK platform is used to test the optimized feedback controllers that are created for each of the different control approaches. The suggested approaches are contrasted in terms of key control characteristics like peak overshoots, settling time, and Performance Index.

Keywords: PSS, SSSC, LQR, SMIB, Phillips-Heffron Model

1. INTRODUCTION

Compared to prior times, the network of the electricity system is currently overloaded. As a result, the power system network's stability changed. Additionally, the cost, time, and other considerations make it hard to replace the power system network with a new one. Novel controllers are therefore required to function with the highly loaded network. The power and control system communities are putting in a lot of effort and coming up with fresh concepts for controller design in their daily operations. This work proposes a new controller architecture that minimizes power system instability both with and without disturbances, in accordance with the control system community. By reducing generator rotor angle swings throughout a wide frequency range in the power system, power system stabilizer (PSS) management makes a beneficial contribution. A common DC voltage link connects the UPFC, one of the Flexible AC Transmission System (FACTS) devices, to a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC). The state feedback Linear Quadratic Regulator (LQR) feedback controller for the PSS was devised by A. Venkateswara Reddy et al. [1].

The performance of the suggested controller has been assessed on a single machine infinite bus system under a variety of operating situations and systems. It has been noted that the suggested controller performs far better than the traditional PSS. In the research study [2], a methodical approach to developing the power system stabilizers employing H∞ robust control was provided. The simulation results demonstrate the efficacy of the suggested approach for a SMIB-based power system utilizing the robustness H∞ control concept. Rahmat-Allah and Mohammad Ataei et al. [3] proposed a resilient PSS architecture that uses the feedback gain matrix as a controller and is based on the positioning of the power system pole. Regarding certain operational areas, the suggested approach offers benefits over traditional PSS. The power system stabilizer (PSS) is exposed to the switching concept to switch between two feedback controllers using Heffron Phillip's model in [4], and the outcomes demonstrate better performance than without switching. Particle swarm optimization and the Taguchi algorithm were used by Kumara K. et al. [5] to build the controller for PSS while taking light loading conditions into account. The results show that the suggested hybrid controller offers improved performance with regard to settling time and peak overshoot of the system. To attain perfect control in a linear system, a state-feedback controller is a control system architecture that feeds back all of a plant's state variables via a continuous feedback gain matrix.

A state feedback damping controller design for a unified power flow controller (UPFC) based on particle swarm optimization (PSO) is presented by Saied Jalilzadeh et al. [6]. The effectiveness of the suggested approach shows that the PSO-based damping controller for UPFC has a great ability to reduce low-frequency oscillations in the power system. In order to switch between two ideal controllers for the Phillips heffron model, Yathisha L et al. suggested the switching control strategy method to UPFC [7]. When compared to the individual ideal controllers (without switching), the results of the suggested control show solid performance. M. Reza Safari Tirtashi et al. suggested a coordinated design of UPFC controllers in [8] using the output feedback control technique, and the findings demonstrate overall improvements in oscillation damping. In the multimachine power system, Mahdiyeh Eslam et al. [9] suggested modified particle swarm optimization for the coordinated design of the unified power flow controller and power system stabilizer. These research findings demonstrate that the suggested coordinated controllers significantly improve the power system's dynamic stability and are highly effective at reducing inter-area oscillations. Rasool Kazemzadeh et al. and Yashar Hashemi collaborated to construct controllers that can improve power system swing dampening [10]. Three distinct kinds of power system stabilizers (PSSs) have been studied in light of the existence of flexible AC transmission systems (FACTS) such as unified power flow controllers (UPFC). Three types of power system stabilizers are available: the conventional power system stabilizer (CPSS), the dual-input PSS, and the accelerating power PSS model (PSS2B). According to the results, the PSS2B & UPFC and dual-input PSS & UPFC coordination function better than the traditional single-input PSS & UPFC coordination. Additionally, the PSS2B & UPFC coordination performs the best

The uncoordinated control inputs of UPFC, such as modulating index and phase angle of series and shunt inverters, as well as the PSS control input, are originally discussed in the current work for the power system model equipped with UPFC and PSS. To choose the best-coordinated control input, a coordinated design of all UPFC and PSS control inputs in different combinations is also suggested, and the outcomes are evaluated. Lastly, for additional assessment, the best-coordinated design that was selected is disturbed for further evaluation.

The paper is organized as follows. Section II provides an explanation of the linearized Phillips-Heffron model implemented with PSS & UPFC. The design of optimal feedback controllers are described in Section III along with the suggested control strategies with and without coordination. Section IV provides an explanation of the simulation findings obtained using the suggested method. The discussions and conclusion are included in the following sections.

2. SMIB POWER SYSTEM MODEL

With the help of UPFC, one of the most complete FACTS devices, active and reactive power may be independently controlled. Bus voltage can also be controlled. 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 a SMIB system. The LTI model of the power system under study is depicted by a block diagram in Figure 1 and comprises a synchronous machine coupled to an infinite bus bar via a transmission line.

Its state space formulation can be expressed as follows [11,12]:

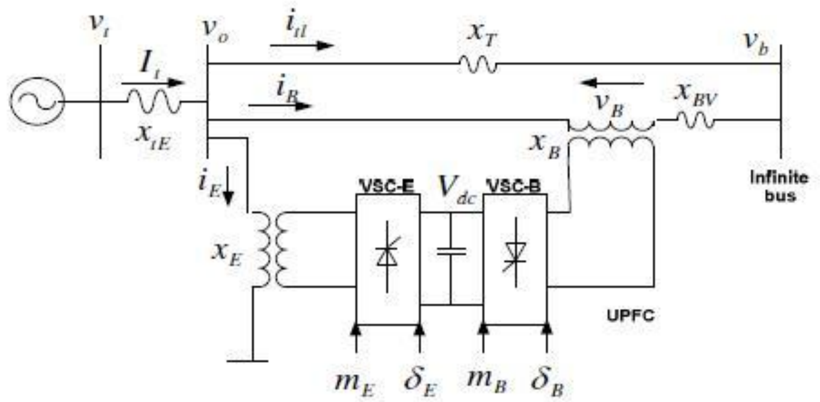

Figure 1: Block Diagram of SMIB installed with UPFC

$$A = \begin{bmatrix} 0 & w_0 & 0 & 0 \\ -\frac{k_1}{M} & -\frac{D}{M} & -\frac{k_2}{M} & 0 \\ -\frac{k_1}{T'_{d0}} & 0 & -\frac{k_3}{T'_{d0}} & \frac{1}{T'_{d0}} \\ -\frac{k_A k_5}{T_A} & 0 & -\frac{k_A k_6}{T_A} & \frac{1}{-T_A} \end{bmatrix} \qquad B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -\frac{k_{PB}}{M} & -\frac{k_{\delta B}}{M} & -\frac{k_{PE}}{M} & -\frac{k_{\delta B}}{M} \\ -\frac{k_{qb}}{T'_{d0}} & -\frac{k_{q\delta b}}{T'_{d0}} & -\frac{k_{qE}}{T'_{d0}} & -\frac{k_{q\delta E}}{T'_{d0}} \\ -\frac{k_A k_{vB}}{T_A} & -\frac{k_A k_{V\delta B}}{T_A} & -\frac{k_A k_{VE}}{T_A} & \frac{k_A k_{V\delta E}}{T_A} \end{bmatrix}$$

The appendix at the conclusion of the paper contains descriptions of all the pertinent variables and k-constants utilized in the experiment, together with their values.

3. PROPOSED CONTROL TECNIQUE

This section will present the suggested various coordinated and uncoordinated control techniques using optimal LQR & LQG feedback controllers. The UPF has four control inputs such as:

1. Modulating index of shunt inverter (m_E).

2. Phase angle of shunt inverter (δ_E).

3. Modulating index of series inverter (m_B).

4. Phase angle of series inverter (δ_B).

The following cases are examined in order to examine the suggested different combinations of UPFC and PSS control inputs as well as the coordinated and uncoordinated input:

Case 1: Uncoordinated Control Inputs - The LQR-based state feedback controllers for the SMIB model are made to work with each of the PSS and UPFC's separate control inputs. The following are the values of the feedback gain matrix:

$K_{PSS} = [0.3686\ -132.6922\ 12.5499\ 0.9827]$ $\qquad K_{ME} = [0.9026\ 337.1713\ -14.3254\ -0.4622\ \mathrm{i}\ ]$

$K_{MB} = [-0.1200\ -180.9723\ 15.1770\ 0.9506$ $\qquad K_{\delta E} = [-0.0007\ 1.1429\ -0.0379\ -0.0004\ ] * 1.0e\ +\ 003$

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

Case 2: Coordinated UPFC Control Inputs - The LQR-based state feedback controllers for the SMIB model are made to work with every possible combination of UPFC control inputs. The following are the values of the feedback gain matrix:

Table 1: Combination of Coordinated Control Inputs

Case 2	Combination	Gain Matrix K
2.1	$M_E + M_B$	$K_{2.1}$
2.2	$\delta_E + M_E$	$K_{2.2}$
2.3	$\delta_B + M_E$	$K_{2.3}$
2.4	$\delta_E + M_B$	$K_{2.4}$
2.5	$\delta_B + M_B$	$K_{2.5}$
2.6	$\delta_E + \delta_B$	$K_{2.6}$

$$k2.1 = \begin{bmatrix} 0.3736\ 103.6008\ -4.7459\ -0.0276 \\ -0.0669\ -133.1704\ 12.1262\ 0.9537 \end{bmatrix} \qquad k2.2 = \begin{bmatrix} 0.0276\ 37.9020\ -1.8134\ -0.1023 \\ 0.8972\ 332.7667\ -14.1992\ -0.4577 \end{bmatrix}$$

$$k2.3 = \begin{bmatrix} 1.9877\ 99.5968\ -7.8812\ 0.0031 \\ -0.4962\ 5.8099\ 1.5455\ -0.4135 \end{bmatrix} \qquad k2.4 = \begin{bmatrix} 0.0269\ 9.9345\ -0.5455\ -0.0075 \\ -0.1195\ -180.6445\ 15.1558\ 0.9506 \end{bmatrix}$$

$$k2.5 = \begin{bmatrix} 0.9393\ 64.6812\ -1.3271\ 0.0059 \\ 0.0772\ -3.2164\ 0.3764\ 0.9645 \end{bmatrix} \qquad k2.6 = \begin{bmatrix} -0.1829\ 0.6800\ 0.5623\ -0.1117 \\ 2.3615\ 110.0430\ -9.8277\ -0.0025 \end{bmatrix}$$

Case 3: Coordinated UPFC along with PSS Control Inputs - The best optimal coordinated control inputs from case 1 & 2 and PSS are used to create the state feedback controllers using LQR for the SMIB model.

Table 2: Combination of Coordinated Control Inputs

Combination	Gain Matrix K
Best control from case 2+ PSS	$K_{UPFC} + P_{SS}$

4. SIMULATION RESULTS AND DISCUSSION

Simulations are performed for the state variable variation in rotor speed Δω of the power system fitted with PSS & UPFC, to compare the suggested control strategies.

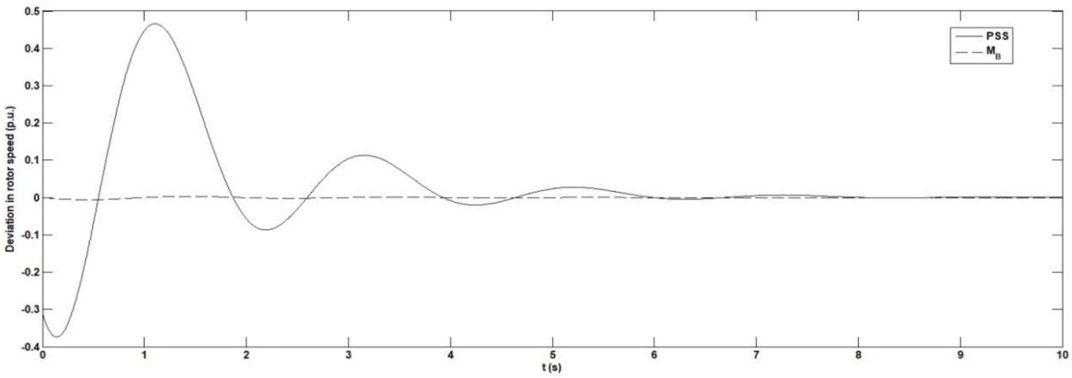

Figure 2: Case 1: Simulation

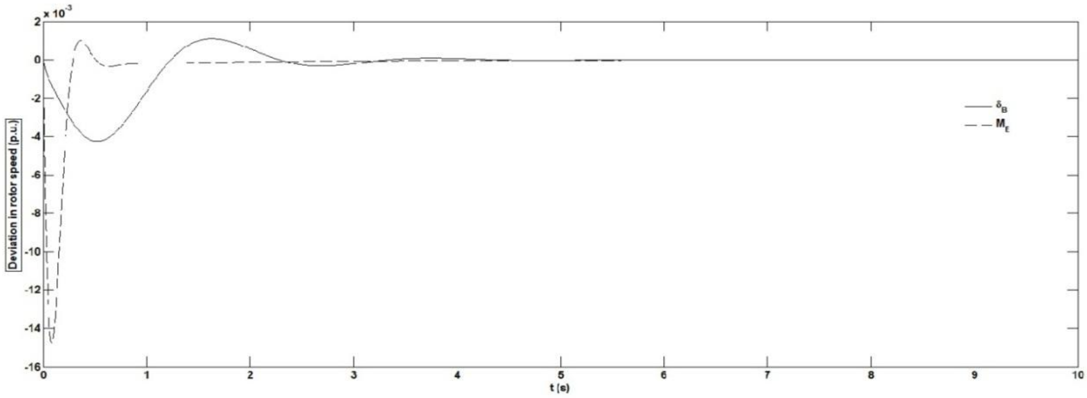

Figure 3: Case 1: Simulation

Figures 1 to 3 show the simulations for Case 1, and Figures 4 to 5 show the simulations for Case 2. To determine the optimal control of the PSS and UPFC's Uncoordinated or Coordinated Control input, the Settling Time (Ts) and Peak Overshoots (MP) are compared for all cases.

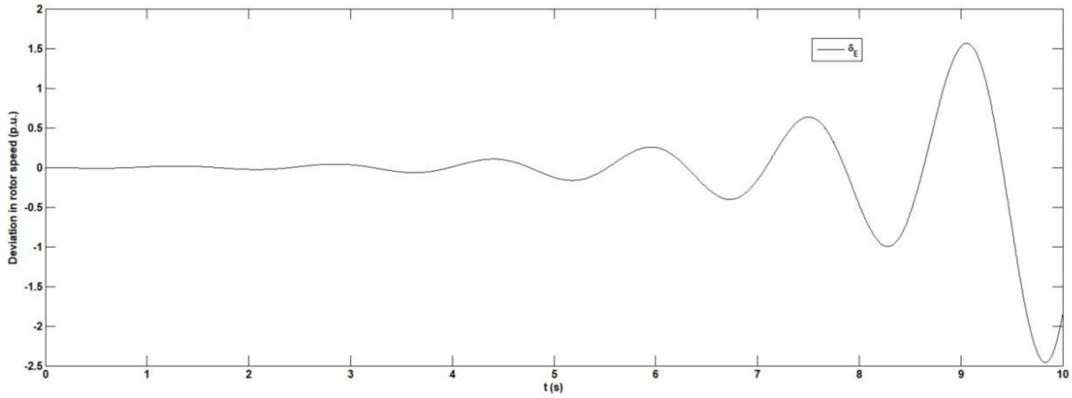

Figure 4: Case 1: Simulation

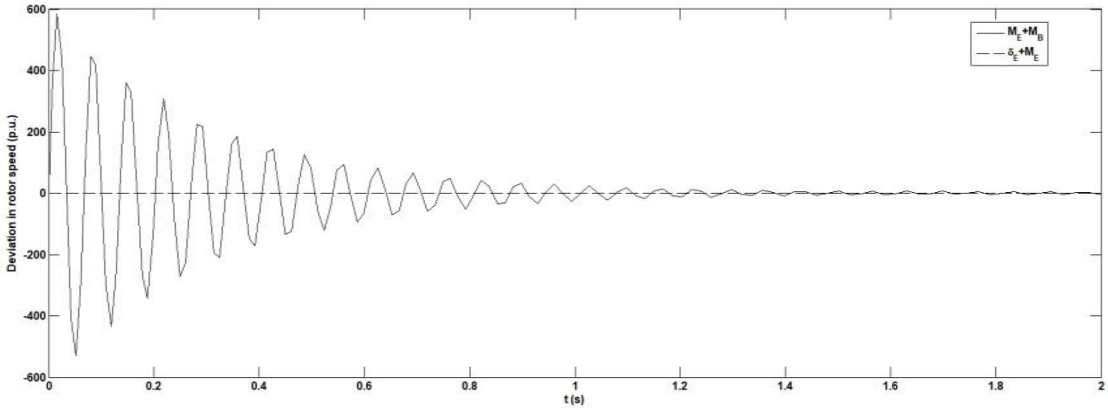

Figure 5: Case 2: Simulation

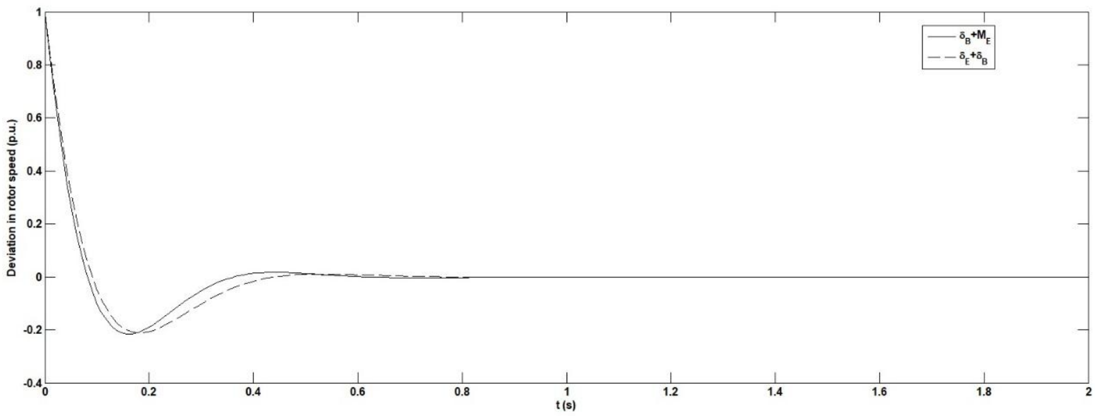

Figure 6: Case 2: Simulation

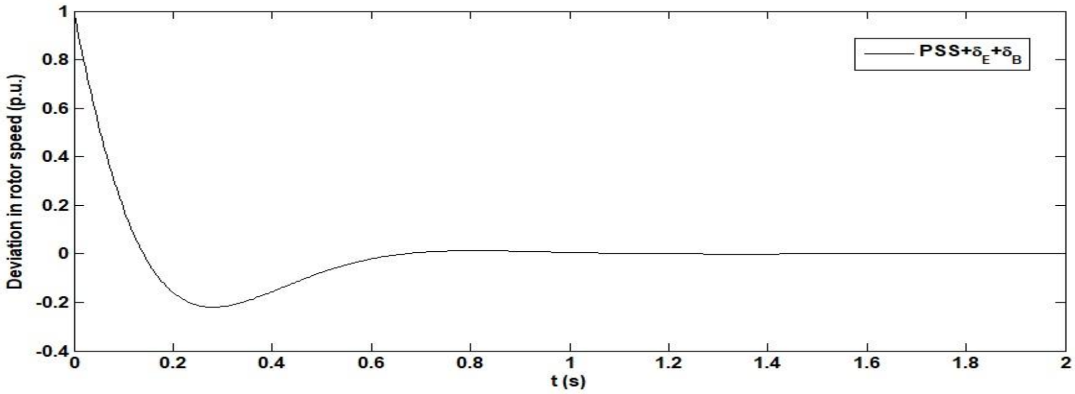

Figure 7: Case 2: Simulation

The Coordinated Control inputs of δ_B +M_E & δ_E +δ_B perform better than any other suggested uncoordinated and coordinated control inputs, according to Figures 2 to 6 and Table 1. According to case 3's statement, the PSS experiment has been conducted for the best-coordinated control inputs of UPFC δ_B +M_E & δ_E +δ_B. The simulation results show that the P_{SS}+δ_E + δ_B coordinated control input offers strong performance concerning the control system's key parameters of M_P & Ts, as illustrated in Figure 7.

Table 3: Comparison of M_P & Ts for all the proposed controllers

Case	Control Input	M_P	Ts
1	m_E + m_B	0.48	7s
1	δ_E + m_E	-5.8*1.0e-003	9s
1	δ_B + m_E	-1.5	1s
1	δ_E + m_B	-4.2*1.0e-003	5s
1	δ_B + m_B	More Damping	-
2	M_E + M_B	-500	1.6s
2	δ_E +M_B	-0.45	Above 2s
2	δ_B +M_E	-0.2	0.5s
2	δ_E +δ_B	-0.25	0.6s
3	P_{SS} + δ_E + M_E	-0.2	0.5s
3	P_{SS} + δ_E + δ_B	-0.25	0.6s

5. CONCLUSIONS

The outcomes of experiments with PSS and UPFC coordinated and uncoordinated control inputs for power systems are reported in this work. Three scenarios are used to set up the trials. Case 1 involves experimenting with the uncoordinated control inputs of individual PSS and UPF control inputs (M_B, δ_B, M_E & δ_E), whereas Case 2 involves experimenting with the coordinated control inputs of UPFC in a variety of combinations. The PSS control input and the better-chosen coordinated control input from instance 2 are further coordinated in case 3. Using the MATLAB/SIMULINK platform, all of the suggested coordinated and uncoordinated control inputs are simulated and contrasted using Peak Overshoots (MP) and Settling Time (Ts).

Simulation results for cases 1 and 2 show that it is preferable to construct a controller with coordinated UPFC control inputs rather than an uncoordinated one. When compared to various uncoordinated and coordinated suggested controllers, the coordinated control inputs of UPFC δ_B +M_E & δ_E +δ_B perform admirably. As a result, in instance 3, PSS is used to further coordinate and simulate the better coordinated UPFC control inputs δ_B + M_E & δ_E + δ_B. In comparison to all other coordinated and uncoordinated control inputs of PSS and UPFC, the experimental results show and conclude that the coordinated control input of PSS & UPFC P_{SS} + δ_E + δ_B provides robust control with respect to the control system prominent parameters of Settling Time (Ts) and Peak Overshoots (M_P).

Appendix Choosing the machine parameters at nominal operating point as X_d = 1.6, Xq = 0.32, Xe = 0.4p.u. M = 10, ω0 = 377, T ′ d0 = 6 D = 0, P = 1p.u, Q = 0.25p.u KA = 25, TA = 0.06s.

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