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MULTI-OBJECTIVE FUNCTION GA FOR MODAL OPTIMAL CONTROL DESIGN IN PSS AND UPFC POWER OSCILLATION DAMPING COORDINATION

[1]SASONGKO PRAMONO HADI, [1]RIAN FATAH MOCHAMAD, [1]HATTA IMADUDDIEN WIENNETOU

[1]The Department of Electrical Engineering and Information Technology, Gadjah Mada University,

Yogyakarta, Indonesia

E-mail: sasongko@te.ugm.ac.id , rianfatah_m@te.gadjahmada.edu , hattaimaduddien@gmail.com

ABSTRACT

This paper presents the design and simulation of controllers in power system equipped with UPFC. Each controller produce different supplementary signals, the power system stabilizer PSS signal for machine and the power oscillation damping POD signal for UPFC. A two stage lead lag compensator scheme was considered in the PSS structure. A new controller design, linear optimal control LOC associated with modal control scheme MO, is proposed in both PSS and POD design. The multi-objective GA method was used to determine the parameter controllers for both PSS and POD. The controller performances were investigated by using small disturbance to power system. The simulation results show that the presence of UPFC non POD leads to get less stability system. Appropriate PSS parameters have been determined and could enhance dynamic responses performance. Using Bryson method for weighting matrix Q, proposed LOC POD could improve system stability. The simulation results also show that system with PSS and MO POD has the best oscillation damping. The dominant eigenvalues shift and approach their real part threshold. POD controllers could give a better rotor angle response, up to 81.33% and 93.9% reduction in overshoot and settling time respectively. Both PSS and UPFC POD controller simultaneously present a positive interaction.

Keywords: *Genetics Algorithm (GA) , Modal Optimal (MO) control, power system stability, Unified Power Flow Controller (UPFC)*

1. INTRODUCTION

Unified Power Flow Controller (UPFC) is one of the latest Flexible AC Transmission System (FACTS) device that has been implemented in power system [1]. UPFC is a FACTS device that combine Static Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). Because of that combinantion, UPFC acquire both advantages of STATCOM and SSSC, and able to perform many function: voltage control, transient stability improvement, and oscillation damping [2]. UPFC consists of two dc/ac inverters, one, defined as STATCOM, connected in shunt with the line through a transformer and the other one, defined as SSSC, connected in series with the transmission line through a series insertion transformer. The dc terminals of the two inverters are connected together and their common dc voltage is supported by a capacitor bank [3].

The UPFC can simultaneously modify all three parameters of power flow (voltage magnitude, line impedance and phase angle), so it can control independently both real and reactive power flows on a transmission corridor [4]. Several studies have been carried out and reported in some literature shows that UPFC, due to their rapid response, might be able to play a significant role in transient and oscillatory stability improvement. Some supplementary or additional control signals for UPFC can be developed and applied to existing device, these supplementary controls are referred to Power Oscillation Damping (POD) control [5,6].

UPFC is generally installed in long transmission line of a power system. Some roles of a UPFC are scheduling power flow, providing voltage support, limiting short-circuit currents, damping the power oscillation and enhancing transient stability through Power System Stabilizer (PSS) and POD [7,8,9]. Different methods have been applied to PSS and POD design. Methods such as lead-lag compensation and PID controller have been studied

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and reported in several papers. Panda, et al and Qjiang [10,11] compare lead-lag compensation and PID controller method at different disturbances. Simulation results show that lead-lag compensation is an effective method. Another studies also represent that lead lag compensation method gives better oscillations damping and system stability in power system [8,9,13,14]. The problem to devise PSS and UPFC controller parameter is a complex exercise. Some paper used conventional techniques such as eigenvalue assignment, mathematical programming, gradient procedure for optimization, and modern control theory to devise PSS and UPFC controller. The problem is conventional techniques requires heavy computation burden and time consuming for large power system [9].

Recently, heuristic method, especially Genetic Algorithm (GA), is very popular to design PSS and UPFC controller [10,11,13,14]. The reason behind the popularity of GA is its advantages. The robustness of GA in finding optimal solution and ability to provide a near optimal solution close to a global minimum is one of the advantage of GA. GA uses multiple point instead of single point to search optimal solution, so it convergence faster. Previous studies show the effectiveness of GA to design the controller. The investigation result an improvement of oscillation damping and power system stability. Another heuristic methods such as particle swarm optimization, fuzzy logic, simulated annealing, etc. have been investigated to get better performance [15,16]. These previous studies show that designing UPFC controller is always interesting and needed to improve power system stability.

Linear optimal control (LOC) is a method of control where the system controlled is described in linear state equations. The control is designed by minimizing a function of both state deviations and control effort. The main characteristic of the application of optimal control is the determination of weighting matrix Q and R [17,18]. Supposed R is relatively constant, the objective function should be formulated by selection of matrix Q. The element of matrix Q represent the weight of certain state variable, when the weights of state variable are known, the optimal control can be determined. The optimal control will modify the system dynamic characteristic. The selection of Q could be taken by considering the eigenvalues loci, this technique namely modal optimal (MO) control [14,17,18].

The main objective of this study is to investigate the effectiveness of damping function of UPFC in single machine infinite bus (SMIB) power system, by applying: lead-lag compensation Power System Stabilizer (lead-lag PSS), LOC based POD (LOC POD) and a new controller design scheme modal optimal control POD (MO POD). GA is used to determine PSS controller parameter and weighting matrix Q of LOC and MO.

2. POWER SYSTEM MODEL AND CONTROLLER DESIGN

2.1. System Configuration

Consider the proposed power system in this study is a single machine infinite bus power with UPFC [5] as shown in Figure 1. The UPFC consists of an excitation transformer (ET), a boosting transformer (BT), two three-phases GTO based voltage source converters VSC-E and VSC-B, and a DC link capacitor C_{DC}. In Figure 1, m_E, m_B, δ_E, and δ_B are the amplitude modulation ratios and phase angles of the control signal of each VSC respectively, which are the control signals to the UPFC.

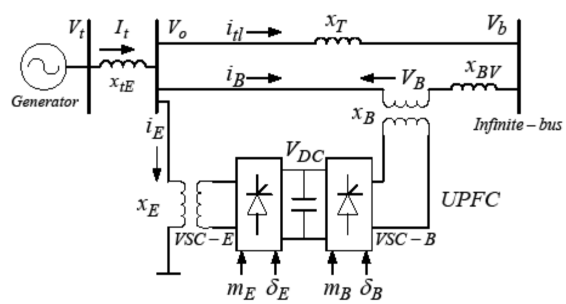

Figure 1: SMIB power system with UPFC

2.2. Dynamic Model

The power system dynamic model could be obtained by formulating the non-linear equations of the SMIB with UPFC first; and than these equations are linearised to get power system model required.

2.2.1. The non-linear equations

The UPFC model can be expressed in the following equations:

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$$\begin{bmatrix} v_{Etd} \\ v_{Etq} \end{bmatrix} = \begin{bmatrix} 0 & -x_E \\ x_E & 0 \end{bmatrix} \begin{bmatrix} i_{Ed} \\ i_{Eq} \end{bmatrix} + \begin{bmatrix} \frac{m_E cos\delta_E v_{dc}}{2} \\ \frac{m_E sin\delta_E v_{dc}}{2} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} v_{Btd} \\ v_{Btq} \end{bmatrix} = \begin{bmatrix} 0 & -x_B \\ x_B & 0 \end{bmatrix} \begin{bmatrix} i_{Bd} \\ i_{Bq} \end{bmatrix} + \begin{bmatrix} \frac{m_B cos\delta_B v_{dc}}{2} \\ \frac{m_B sin\delta_B v_{dc}}{2} \end{bmatrix} \quad (2)$$

$$\frac{dv_{dc}}{dt} = \frac{3m_E}{4C_{dc}} [cos\delta_E \quad sin\delta_E] \begin{bmatrix} i_{Ed} \\ i_{Eq} \end{bmatrix} + \frac{3m_B}{4C_{dc}} [cos\delta_B \quad sin\delta_B] \begin{bmatrix} i_{Bd} \\ i_{Bq} \end{bmatrix} \quad (3)$$

The non linear equations of the SMIB with UPFC are [5]:

$$\dot{\delta} = \omega_b \omega \quad (4)$$

$$\dot{\omega} = (P_m - P_E - D\omega)\frac{1}{M} \quad (5)$$

$$\dot{E}'_q = \left(-E_q + E_{fd}\right)\frac{1}{T'_{d0}} \quad (6)$$

$$\dot{E}_{fd} = -\frac{1}{T_A} - E_{fd} + \frac{K_A}{T_A}(V_{t0} - V_t) \quad (7)$$

where

$$P_e = v_{qt} i_{qt} + v_{dt} i_{dt}$$

$$E_q = E'_q + (x_d - x'_d) i_{dt}$$

$$v_{qt} = E'_q - x'_d i_t$$

$$v_{dt} = x_q i_{qt}$$

$$v_t = \sqrt{\left(v_{dt}^2 + v_{qt}^2\right)}$$

$$i_{dt} = i_{Ed} + i_{Bd}$$

$$i_{qt} = i_{Eq} + i_{Bq}$$

2.2.2. Linearised model

Linearising the model of SMIB with UPFC represented by equations (4-7) around an operating point of the power system will produce a linearised model of power system. The design of power system controller, such as PSS and POD, will be carried out using this linearised model. By neglecting the internal resistance and sub-transient process of the generator, and when the function of governor is neglected ($\Delta T_M = 0$), linearizing equations (4-7) gives the system equation [5]:

$$\Delta\dot{\delta} = \omega_b \Delta\omega \quad (8)$$

$$\Delta\dot{\omega} = (-\Delta P_E - D\Delta\omega)\frac{1}{M} \quad (9)$$

$$\Delta\dot{E}'_q = \left(-\Delta E_q + \Delta E_{fd}\right)\frac{1}{T'_{d0}} \quad (10)$$

$$\Delta\dot{E}_{fd} = -\frac{1}{T_A}\Delta E_{fd} + \frac{K_A}{T_A}\Delta V_t \quad (11)$$

where

$$\Delta P_e = K_{u1}\Delta\delta + K_{u2}\Delta E'_q + K_{pd}\Delta v_{dc} + K_{pe}\Delta m_E + K_{p\delta e}\Delta\delta_E + K_{pb}\Delta m_B + K_{p\delta b}\Delta\delta_B$$

$$\Delta E_q = K_{u4}\Delta\delta + K_{u3}\Delta E'_q + K_{qd}\Delta v_{dc} + K_{qe}\Delta m_E + K_{q\delta e}\Delta\delta_E + K_{qb}\Delta m_B + K_{q\delta b}\Delta\delta_B$$

$$\Delta V_t = K_{u5}\Delta\delta + K_{u6}\Delta E'_q + K_{vd}\Delta v_{dc} + K_{ve}\Delta m_E + K_{v\delta e}\Delta\delta_E + K_{vb}\Delta m_B + K_{v\delta b}\Delta\delta_B$$

$$\Delta\dot{v}_{dc} = K_{u7}\Delta\delta + K_{u8}\Delta E'_q - K_{u9}\Delta v_{dc} + K_{ce}\Delta m_E + K_{c\delta e}\Delta\delta_E + K_{cb}\Delta m_B + K_{c\delta b}\Delta\delta_B$$

The set of equation above can be represented in the form of state equation, supposed that the state variable vector **x** and the input variable vector **u** are containing respectively $\Delta\delta$, $\Delta\omega$, $\Delta E'_q$, ΔE_{fd} , Δv_{dc}, and Δm_E, $\Delta\delta_E$, Δm_B, $\Delta\delta_B$ signals , the state variable equation:

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu} \quad (12)$$

The matrix **A** is:

$$\begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 \\ -M^{-1}K_{u1} & -M^{-1}D & -M^{-1}K_{u2} & 0 & -M^{-1}K_{pd} \\ -T'^{-1}_{d0}K_{u4} & 0 & -T'^{-1}_{d0}K_{u3} & T'^{-1}_{d0} & -T'^{-1}_{d0}K_{qd} \\ -T_A^{-1}K_AK_{u5} & 0 & -T_A^{-1}K_AK_{u6} & -T_A^{-1} & -T_A^{-1}K_AK_{vd} \\ K_{u7} & 0 & K_{u8} & 0 & -K_{u9} \end{bmatrix}$$

And matrix **B** is:

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ -M^{-1}K_{pe} & -M^{-1}K_{p\delta e} & -M^{-1}K_{pb} & -M^{-1}K_{p\delta b} \\ -T'^{-1}_{d0}K_{qe} & -T'^{-1}_{d0}K_{q\delta e} & -T'^{-1}_{d0}K_{qb} & -T'^{-1}_{d0}K_{q\delta b} \\ -T_A^{-1}K_AK_{ve} & -T_A^{-1}K_AK_{v\delta e} & -T_A^{-1}K_AK_{vb} & -T_A^{-1}K_AK_{v\delta b} \\ K_{ce} & K_{c\delta e} & K_{cb} & K_{c\delta b} \end{bmatrix}$$

The block diagram of the system can be presented in Figure 2.

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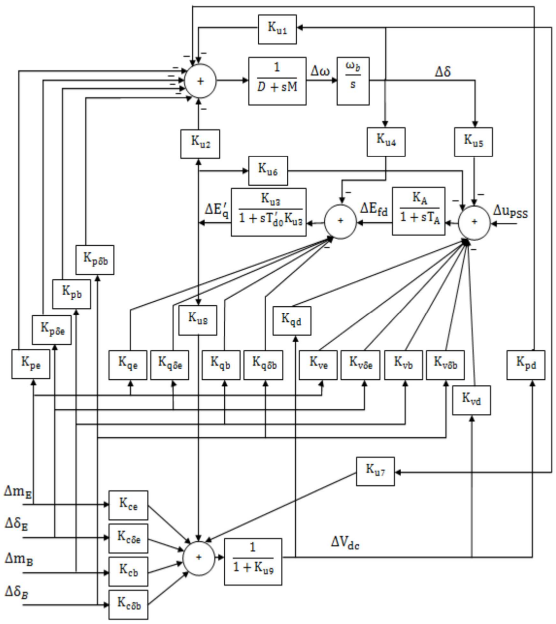

Figure 2: Linearised Phillips-Heffron of single-machines power system with the UPFC installed

K_7, K_8, K_9 are new parameters in addition of DC link installed in UPFC.

2.3. Controller Design

To improve the system stability, 2 controllers will be proposed : PSS and POD. The control signal PSS is designed using speed deviation signal Δω as feedback of PSS to produce supplementary signal as control signal. This supplementary signal is fed into excitation system (for electrical loop in machine model). The control signals POD are designed by LOC and MO based methods using state variable, namely deviation of: rotor angle, angular speed, internal voltage, armature voltage, and dc link voltage to produce supplementary signals Δm_E, $\Delta\delta_E$, Δm_B, $\Delta\delta_B$. These supplementary signals are fed into UPFC. The control parameter for both PSS and POD are calculated using GA.

2.3.1. Lead-lag PSS design

Lead-lag compensation as a common PSS design scheme [13], is proposed in this study. It consists of a gain, a washout, and a two stage phase compensation block as shown in Figure 3. Δω is used as the input of this controller, and the output will give an additional signal to excitation system.

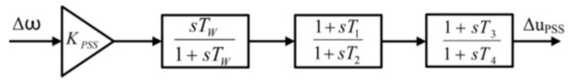

Figure 3: Power System Stabilizer structure

Following reference [19], the common parameter value used for two stage of lead-lag compensator are: K_{PSS} = 0.1 – 50, T_1 and T_3 = 0.2 – 1.5 s, T_2 and T_4 = 0.02 – 0.15 s and the wash out parameter T_w is taken at 10 s. Gain of PSS (K_{PSS}) will multiply the amplitude of Δω. Washout block has a function as a high pass filter that will eliminate steady state bias at output signal. Washout parameter, T_W, is chosen at 10 s [13,14]. Two stage phase compensation block is used to compensate lead or lag phase of the transmission. However, most of transmission system has a lag phase because the inductive reactance is more dominant than the resistance and hence, the compensation is lead compensation.

2.3.2. LOC POD design

Based on linear equation expressed in (12), control design of POD could be designed using LOC scheme to produce a supplementary control signal [17,18].

Mathematical expression of LOC can be written as follows [17]:

Given a linear system state equation as (12), determine the control signal u:

$$\mathbf{u = - Kx} \qquad (13)$$

where **K** is state variable feedback control matrix, by minimizing the performance index J, representing cost function in the quadratic form:

$$J_1 = \frac{1}{2}\int_0^{\infty} (\mathbf{x}^T \mathbf{Q}\, \mathbf{x} + \mathbf{u}^T \mathbf{R}\, \mathbf{u})\, dt \qquad (14)$$

Q is the weighting matrix of the state variable deviations and R that of the control effort. Both Q and R, in the most cases are chosen as diagonal matrices. The matrices Q and R are usually chosen considering the contribution of state variable and control to performance index. By minimizing Hamiltonian H related to the Lagrangian, the optimal control can be expressed as follows:

$$\mathbf{u} = -(\mathbf{R}^{-1}\mathbf{B}^T\mathbf{P})\,\mathbf{x} \qquad (15)$$

in which **P** must satisfy the Riccati equation:

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$$A^T P + P A - P B R^{-1} B^T P + Q = 0 \quad (16)$$

The LOC design selects the weighting matrices Q and R such that the performances of the closed loop system can satisfy the desired requirements. One practical method is to set Q and R to be diagonal matrix. Following Bryson method, in this simulation we considered that the diagonal elements of Q and R selected as :

$$q_i = (1/(x_{i\,max})^2) \quad (17)$$

$$r_i = (1/(u_{i\,max})^2) \quad (18)$$

where $x_{i\ max}$ and $u_{i\ max}$ are the permissible maximum value of state variable and control deviations, for i = 1,2, ….. n,.

According to the system dimension as indicate in equation (12), the feedback gain K is a (4X5) matrix, the feedback variables are rotor angular deviation ($\Delta\delta$), rotor speed deviation ($\Delta\omega$), armature voltage ($\Delta E'_q$), internal voltage (ΔE_{fd}) and dc link voltage v_{dc}.

2.3.3. MO POD Design

The important problem in the application of LOC is the selection of Q (R supposed to be constant). A method based on modal analysis could be applied, the selection of Q is taken incorporate with the desired eigenvalue locus. By shifting the dominant eigenvalue to left side of s plane in certain damping ratio, variations of Q required to comply this eigenvalue movement, could be accomplished that guarantee the better control by Riccati matrix equation solution. In other words, modal optimal control algorithm can be used to the selection of Q in order to get a control that will make the system more stable by shifting the dominant eigenvalues (approach the threshold).

The formulation of modal optimal control design become:
Find the control u = -Kx, , that minimize the objective function J_1 as formulated in (14), by selecting Q in order to minimize objective functions [8,10,15]:

$$J_2 = \Sigma\,(\sigma_0 - \sigma_i)^2 \quad (19)$$

$$J_3 = \Sigma\,(\xi_0 - \xi_i)^2 \quad (20)$$

Subject to:

a. System dynamics constraint

$$\dot{x} = Ax + Bu$$

b. Eigenvalue locus constraint [15]:

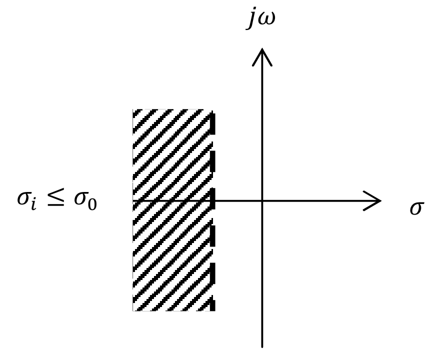

Figure 4: Region of eigenvalue for J_2

c. Damping ratio constraint

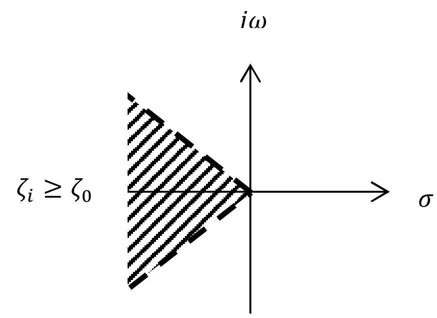

Figure 5: Region of eigenvalue for J_3

σ_i and ξ_i are the real part and the damping ratio of the i-th eigenvalue and σ_0 is a chosen threshold.

The proposed modal optimal control algorithm can be presented in the following flowchart:

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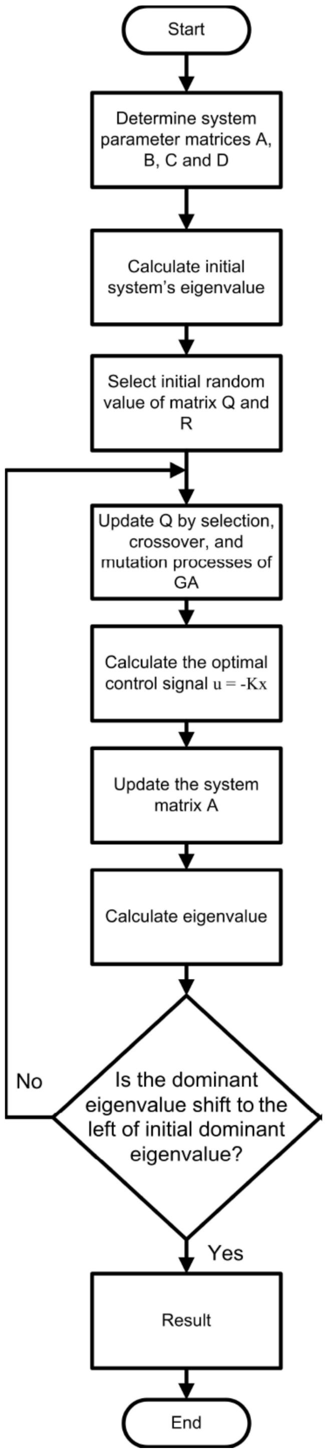

Figure 6: Modal optimal flowchart

3. NUMERICAL SIMULATIONS

3.1. System under Study

The system parameters that were used in this study presented in Table 1 as follows:

Table 1: Machine Parameters

Parameter	Value
H	4.0 s
x_d	1.0 pu
x'_d	0.3 pu
D	0
x_q	0.6 pu
T'_{d0}	5.044 s
K_A	100
T_A	0.01 s

DC link: C_{dc} = 9.09e+02 pu, V_{dc} = 0.49 pu. Transformer: X_E = 0.2 pu, X_B = 0.133 pu and X_{TE} = 0.1 pu. Transmission line: X_{BV} = 0.3 pu. Operating condition: P_e = 0.8 pu and V_t = 1.0 pu.

3.2. Simulation Result and Discussion

The damping function of PSS and POD were investigated based on eigenvalue analysis and the system dynamic response against small disturbances, following these four system scenarios:

1. neither UPFC and nor PSS
2. no PSS with UPFC non POD
3. with PSS and UPFC non POD
4. with PSS and LOC POD
5. with PSS and MO POD

These scenarios were made in order to show the effect of UPFC and the synergy of both PSS and POD. The tuning mechanism for coordinating PSS and POD was conducted by applying procedure as follows

1. Select optimal PSS parameter using lead lag compensation controller scheme (K_{PSS} , T_1 , T_2 , T_3 , T_4, K_w and T_w) by using GA, apply these parameter to system with no UPFC and with UPFC non POD
2. Determine the POD parameter for UPFC, based on the design of LOC for system with PSS installed, by selecting the weighting matrix Q using Bryson method
3. Determine the POD parameter for UPFC, based on the design of MO for system with PSS installed, by selecting the weighting matrix Q in conjunction with the eigenvalue locus using GA

3.2.1. PSS controller performance

Using increment of P_e (0.2 pu) as disturbance, the performance of system is investigated by

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presenting: rotor angle (δ) and speed deviation ($\Delta\omega$) responses. Three operation conditions are: system with neither UPFC nor PSS, system with no PSS and UPFC non POD, and system with PSS and with UPFC non POD. The system responses are presented in Figure 7 and Figure 8 below:

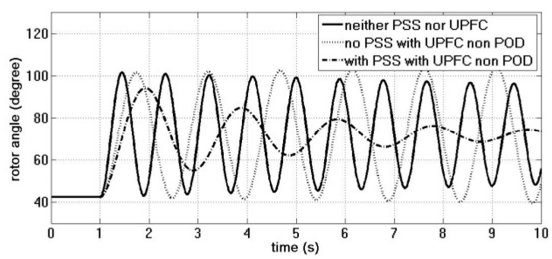

Figure 7: Rotor angle with PSS

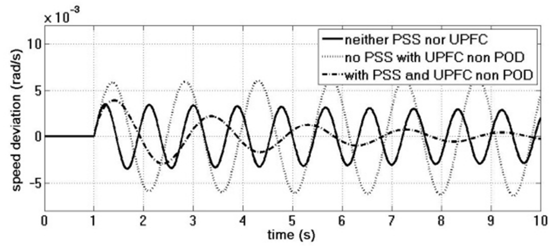

Figure 8: Speed deviation with PSS

Each figure consists of three system responses with different operating conditions. The first condition is a condition where there is neither PSS nor UPFC installed, it's response damps very slowly, it signify the nature of this machine, a disturbance (small signal) makes the rotor oscillate at 1.17 hertz with 59° amplitude (very-very slow damping). The second curve represents the response of system with UPFC non POD, the oscillations tend to slightly un-damped. The presence of UPFC non POD leads to get less stability system. The third one is the system with PSS only, where the UPFC non POD is installed in the power system. Figure 7 and Fig 8 show the rotor angle and speed deviation damp considerably (15.21s settling time each), although the first swing of speed deviation (0.0044 rad/sec) greater than before PSS installed (0.0039 rad/sec). This good damping in rotor angle is produced by the presence of an appropriate PSS (as shown in Table 2). PSS parameters are needed to ensure that PSS will enhance dynamic responses performance.

Table 2: PSS Parameters

K_{PSS}	T_1(s)	T_2(s)	T_3(s)	T_4(s)
15.502	1.7024	0.1913	0.4404	0.1801

3.2.2. PSS and POD synergy

LOC POD control performance

Based on the result presented in Figure 7 and Figure 8, we want to enhance the stability of the system by using LOC method to process input signal for POD. The weighting matrix Q in LOC formula is selected based on Bryson method, equation (17), there are 3 additional states belonging to PSS:

Table 3: Weighting Matrix Q

Q_1	6.2500e+000
Q_2	6.2500e+004
Q_3	2.5000e+001
Q_4	3.9063e-003
Q_5	1.0000e+002
Q_6	4.4444e+001
Q_7	2.5000e+001
Q_8	3.9063e+001

Using the weighting matrix as shown in Table 3, a simulation then conducted. The result depicted in Figure 9 and Figure 10 show that a better stability has been achieved.

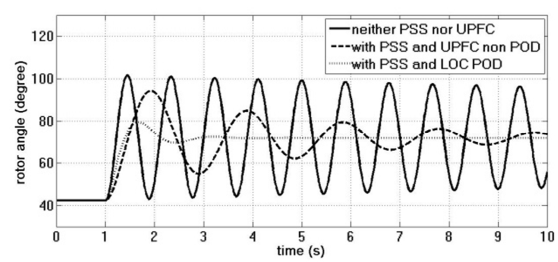

Figure. 9: Rotor angle with LOC POD

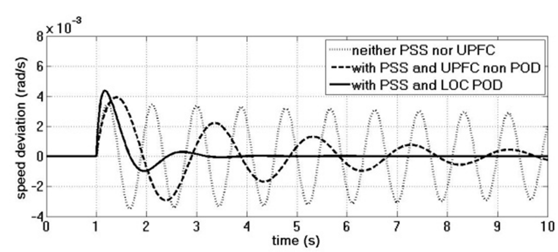

Figure. 10: Speed deviation with LOC POD

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Figure 9 and Figure 10 illustrate the response of the three types of condition: system with neither UPFC nor PSS, system with PSS and UPFC non POD and system with PSS and LOC POD. The rotor angle as depicted in Figure 9 shows that damping function LOC POD (first swing has 7.86° overshoot, settling time attaint in only 2.17s) is more significant than the PSS's one. The first swing of speed deviation of system equipped with LOC POD is greater than that's of system with PSS, however, we get a shorter damping (2.17s), presented in Figure 10. It is also shown that the synergy between PSS and POD has been achieved; the system responses (with both PSS and LOC POD) have better damping, and are more effective than PSS only.

MO POD control performance

This sub section aims to show the role of proposed MO POD in damping the oscillation of system dynamic response following a disturbance, where the weighting matrix Q in LOC formula are selected based on modal control. According to the result as presented in Table 4 where the eigenvalue locus of system with LOC POD shown, we want to shift more, in order to increase the stability of the system. The eigenvalue shifting approach to a predetermined locus, will be accomplished by selecting weighting matrix Q.

Using multi objective GA as formulated in equation (19,20), optimal parameter for weighting matrix then could be searched. The previous weighting matrix Q selected by Bryson method is taken as initial value. When we take σ_0 = -0.1 and ξ_0 = 0.2 as respectively real part and damping ratio thresholds, the final loci of eigenvalues are as follows:

Table 4: LOC and MO POD Eigenvalue Loci

With LOC POD	With MO POD
-78.753	-46.595
-23.649 +11.003i	-38.447
-23.649 -11.003i	-30.378
-5.5974 +5.1257i	-6.0626+5.6913i
-5.5974 -5.1257i	-6.0626 -5.6913i
-2.7386	-2.8046
-0.58001	-0.56911
-0.0018209	-0.018030

Table 4 shows how the dominant eigenvalues shift to the more stable area, real part of the new most dominant eigenvalue approach the threshold. This result indicates that the proposed modal optimal control has a good performance.

Figure 11 and Figure 12 illustrate the time domain responses of the all four type of condition: system with neither UPFC nor PSS, system with PSS and UPFC non POD, system with PSS and LOC POD and system with PSS and MO POD.

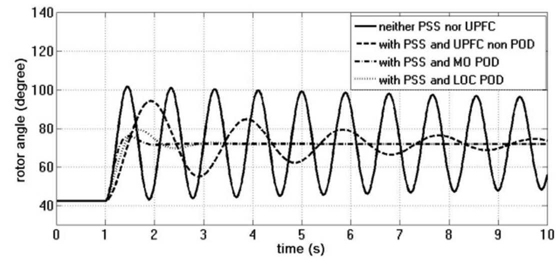

Figure 11: Rotor angle with MO POD

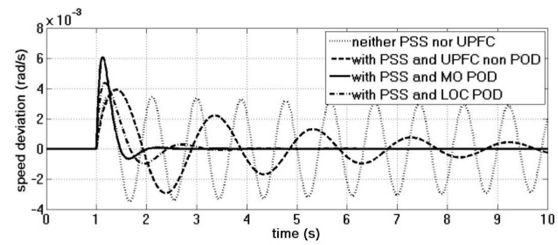

Figure 12: Speed deviation with MO POD

The rotor angle dynamics as depicted in Figure 11, show that damping function of MO POD is excellent (only 4.32° overshoot and 0.93s settling time), more significant than the LOC's one. The final weighting matrix Q, as shown in Table 6, obtained by minimization of the two objective functions can improve the eigenvalue loci. A considerable response in speed deviation is also obtained, two response characteristics: overshoot and settling time, show excellent performances. We could resume numerically the results as presented in Table 5 as follows:

Table 5 Controller performances.

	Rotor angle		Speed deviation	
	Overshoot (degree)	Settling time (s)	Overshoot (rad/sec)	Settling time (s)
PSS	23.14	15.21	0.0039	15.21
LOC	7.86	2.17	0.0044	2.17
MO	4.32	0.93	0.0061	0.93

Table 6: Final Weighting Matrix Q

Q_1	1.2845e+001
Q_2	6.9648e+004
Q_3	4.6204e+001
Q_4	1.1016e-003

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Q_5	1.1711e+002
Q_6	6.4796e+001
Q_7	3.6265e+001
Q_8	4.3416e+001

The last two tables present the comprehensive result, controllers have enhanced system stability, final weighting matrix Q has been chosen in order to get a more stable eigenvalues.

4. CONCLUSIONS

Performance of three controllers: lead-lag PSS, LOC and MO POD, have been conducted. In the design of MO controller, the weighting matrix Q of LOC could be selected in order to assign the dominant eigenvalue to the left side s plane. GA has provided an effective solution of multi-objective optimization problems.

The simulation results show that the presence of UPFC non POD leads to get less stability system. Using Bryson method for weighting matrix Q, proposed LOC POD could improve system stability. The simulation results also show that system with PSS and MO POD has the best oscillation damping and it is shown that damping function of MO POD is excellent.

POD controller could give a better rotor angle response, up to 81.33% and 93.9% reduction in overshoot and settling time respectively. The dominant eigenvalues shift and approach their real part threshold -0.1. Both PSS and UPFC POD controller simultaneously present a positive interaction.

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