Multivariable Controller Design for Unified Power Flow Controller Using Evolutionary Optimization Algorithms

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Abstract
This paper discusses the design of a multivariable control for unified power flow controller using evolutionary optimization algorithms. It utilizes two biologically inspired optimization algorithms; the particle swarm optimization algorithm and biogeography optimization algorithms, to obtain the optimal set for the controllers of the UPFC. The UPFC is to control the active power flow through the line, regulate the AC bus voltage, regulate the DC link voltage, and damp the low frequency oscillations in the network through a set of PI controllers and a two stage lead lag compensator respectively. The obtained controllers are then verified through time domain simulation for different variable control to assess the capability of this multivariable control scheme.

Keyword--- FACTS, Power System Dynamics, Power System Oscillations, PSO, BBO

1. INTRODUCTION

In the past few decades the flexible AC transmission system (FACTS) controllers have become an interesting field of research, due to the range of solutions that they offer for the transmission network problems. The introduction of the power electronics devices in the power system was initially intended to overcome the steady state limitation of the network and to increase the power transfer capability of the transmission lines through the control of system parameters. However, the functionality of the FACTS controllers was not limited to the steady state problems but it was extended to solve transient and dynamic problems of the power system, hence increasing the system stability. In [1], Abido has reviewed and compared the FACTS based damping controllers based on their performance and other technical aspects.

The unified power flow controller (UPFC), was introduced by Gyugyi in [2]. The UPFC is one of the typical FACTS devices that can provide simultaneous control of all or selectively basic parameter of the power system (transmission voltage, line impedance, and phase angle) [3]. The UPFC is able to fulfill the functions of a STATCOM, SSSC, and a phase shifter hence realizing multiple control schemes. Moreover the UPFC is reported to be able to damp system oscillations, where a UPFC stabilizer was designed in to mitigate the torsional oscillations in [4]. From this it can be seen that the UPFC is a multi-input multi-output (MIMO) system.

Several references in literature have tackled the problem of designing MIMO controller for the UPFC. In [5], [6]and [7], a study of the dynamic interaction between the UPFC control variables was presented along with a proposed method of decoupling through the design of a M IMO PI controller in order to maintain the closed loop stability of the system. Another approach has been presented in [8], where the μ- synthesis decentralized UPFC controller was designed, through decomposing the MIMO system into a multi-input single output (MISO) systems in order to reduce the interaction between the variables. Taher *et al,* in [9] has presented and compared between three decentralized control schemes, theμ synthesis, the QFT method, and H∞ loop shaping for the UPFC controller design.

Population based, cooperative and competitive stochastic search algorithms have been very popular in recent years in the field of computational intelligence[10]. These algorithms proved to be a useful tool in many studies for designing FACTS based power oscillation damping (POD) controller, that provide good response characteristics. Sidhartha *et al* ,in [11] designed a TCSC based power system stabilizer using genetic algorithm (GA). In [12], an output feedback UPFC POD controller, in which PSO was used to evaluate time based objective function in order to find the optimal parameters for

$$\begin{gathered}\min J_t \\ \mathit{Subject\ to} \\ K_{pp}^{min} \le K_{pp} \le K_{pp}^{max} \\ K_{pi}^{min} \le K_{pi} \le K_{pi}^{max} \\ K_{dp}^{min} \le K_{dp} \le K_{dp}^{max} \\ K_{di}^{min} \le K_{di} \le K_{di}^{max} \\ K_{vp}^{min} \le K_{vp} \le K_{vp}^{max} \\ K_{vi}^{min} \le K_{vi} \le K_{vi}^{max} \\ K_{p}^{min} \le K_{p} \le K_{p}^{max} \\ T^{min} \le T \le T^{max}\end{gathered} \tag{11}$$

It can be seen that the objective function is a sum of the ITEA performance index of each control output. Furthermore, each part of this objective function is weighted to give emphasis on the desired output. The weights were found through fine tuning and given as: $\alpha = 100$, $\beta = 1$, $\gamma = 50$, $\rho = 1$.

The control system design is done through optimizing the objective function in (10) under nominal loading condition, where the population size considered is 150 and total generation of 100. The BBO maximum mutation is 0.05, and for PSO the acceleration coefficients are chosen as $c_1 = c_2 = 2.05$, and ω is to decrease from 0.9 to 0.4 as a function of the generation, based on [24]. With these conditions the following results were obtained:

Table 1: Optimal Control System Parameters and Cost Function Value.

Controller Parameter	*BBO Obtained Value*	*PSO Obtained Value*
K_p	-86.1999	-81.5887
T_1	0.6406	0.85137
T_2	0.6977	0.6319
T_3	0.0726	0.0133
T_4	0.4472	0.3575
K_{pp}	-0.2228	0.2730
K_{pi}	3.1689	1.4484
K_{dp}	-3.0814	-8.0792
K_{di}	-4.6577	-4.6412
K_{vp}	2.1841	2.2523
K_{vi}	0.7192	5.5808
J_t	2.7011	2.2871

From table 1, it can be seen through the comparison of the value of objective function attained that PSO has a superior performance over BBO for the following problem.

4. SIMULATION RESULTS

For the purpose of comparison between the controllers performance there are a set of tests that are to be evaluated in order verify the superiority of a controller over the other, and these tests are:

4.1 Setpoint Variation

The UPFC is initial set to controller the power flow through the transmission line such that 50% of the generated power is carried by each of the lines. In this test the setpoint of the power flow controller is varied from its initial setting by -15% to 15% change in the setpoint. Both of the obtained multivariable controllers are tested under nominal loading condition of the generator.

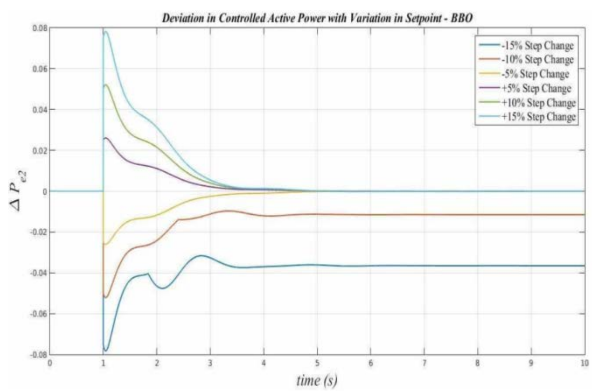

Figure 3: Deviation in line power flow ΔP_{e2} BBO tuned MIMO control system under variation of power flow setpoint.

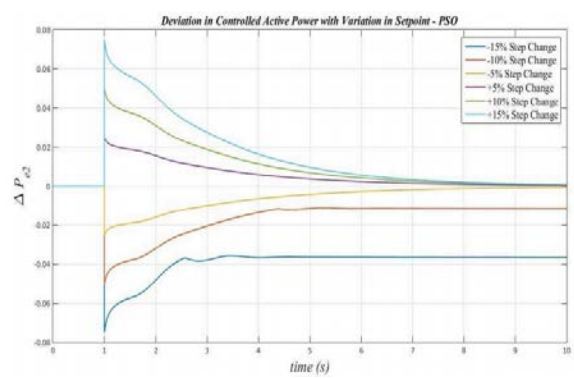

Figure 4: Deviation in line power flow ΔP_{e2} PSO tuned MIMO control system under variation of power flow setpoint.

There are two observations that can be made from figures (3) and (4), the first is that for setpoints -15% to -5% of the initial line active power flow there is a steady state error which can be seen in both control systems. Hence, this is an issue of the control system structure, and specifically the pairing of inputs and outputs. Where the active power flow P_{e2} is controlled through the amplitude modulation index of the boosting converter m_B, where $0 \leq m_B \leq 2$ p.u based on [15]. Due to this the control signal gets saturated when the value of the setpoint is varied in the negative region. The other observation that can be seen, is that the response of the BBO tuned control system for power flow control is superior to that of the PSO tuned control system when comparing the settling time of the output.

4.2 Power System Oscillation Damping

This is to evaluate the ability of the obtained control systems to damp power system oscillations resulting from different type of disturbances that can occur in power systems. In this section the control system will be subjected to two types of disturbances:

4.2.1 Generator Load Variation:

A common occurrence disturbance in the system is the load variation that causes the input mechanical power of the generator to vary in accordance to that variation. The UPFC power oscillation damping controller of the multivariable controller is designed in order to mitigate the system oscillations that are resulting from these variations. In this test both of the controllers are subjected to a 10% step disturbance in the mechanical power P_m under light and nominal loading conditions of the generator.

Table 2: System eigenvalues and EM damping ratios for light and nominal loading condition.

	BBO	PSO
Light	EM= -1.0750±j5.1840	EM= -2.0042±j6.0193
ζ	0.2030	0.2240
Nominal	EM= -1.3237±j5.7602	EM= -2.1394±j7.1600
ζ	0.3159	0.2863

Table 2, gives the electromechanical modes and their respective damping ratio. It can be seen that the PSO tuned control system has superior damping capability when compared to the BBO tuned control system.

[Case 1: Light Loading (P_e = 0.3 p.u, Q_e = 0.015 p.u)]

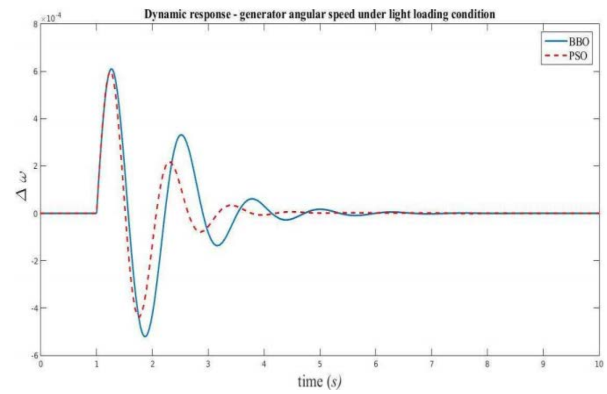

Figure 5: Deviation in rotor angular speed Δω under light loading conditions for a 10% step change in P_m.

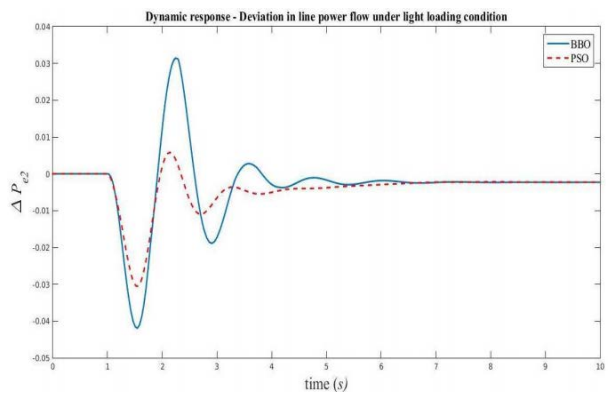

Figure 6: Deviation in active power flow ΔP_{e2} under light loading conditions for a 10% step change in P_m.

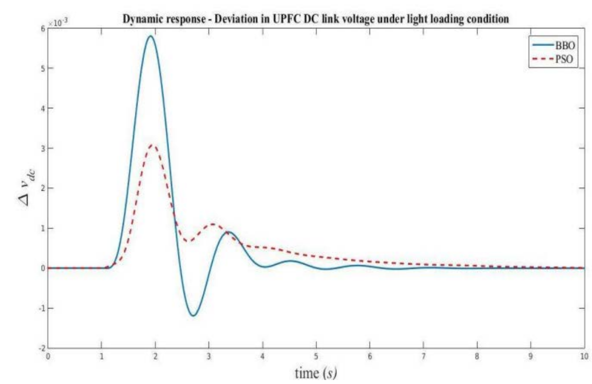

Figure 7: Deviation in UPFC DC voltage Δ v_{dc} under light loading conditions for a 10% step change in P_m.