TUNING OF UNIFIED POWER FLOW CONTROLLER (UPFC) USING PSO AND NSGA-II INVESTIGATIONS

G.Kannayeram*   P.S.Manoharan
*Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India
kannayeramnec@rediffmail.com
Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, India

M.Willjuice Iruthayarajan   T.Sivakumar
Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India

Abstract: This paper describes, tuning of Unified Power Flow Controller (UPFC) using evolutionary algorithm to reduce the electro-mechanical oscillations in power systems. This UPFC tuning is formulated as single and multi-objective optimization problem, to minimize the objective function considered by modulating the control parameters. The objective function considered for this work is Integral Squared Error (ISE) of change in speed deviation and Integral Squared Error (ISE) of control signal (u) under different operating conditions. Time domain simulation and Eigen value analysis are carried out to show the effectiveness of the proposed method. The optimal parameters and objective function values obtained with single and multi-objective algorithms (PSO and NSGA-II) are evaluated and the benefits of multi-objective optimization in FACTS controller tuning is explained. Simulation result reveals that the Non-dominated Sorting Genetic Algorithm-II based damping controller damp out oscillations quickly with minimum control input as compared with Particle Swarm Optimization based controller without compromising the stability of system.

Key words: *UPFC, ISE, Optimal Tuning, PSO, NSGA-II*

1. Introduction

Stable and reliable operation of power systems can be improved by power electronic based controllers termed as FACTS devices (Flexible AC Transmission Systems). Flexible AC Transmission systems incorporating power electronic based and static controllers to enhance controllability and increase power transfer capability [7,9]. Steady state and dynamic models of UPFC have been developed by many researchers [3,10,17]. H.F.Wang developed linear dynamic model named Modified Heffron-Phillips model for single machine system including UPFC [6,21]. N.Tambey et al. have proposed a complete approach for designing UPFC based damping controller using conventional phase compensation technique. The UPFC (m_B, m_E, δ_B , δ_E) control parameters are modulated to achieve required damping [19, 20]. Sidhartha Panda et al. has been compared PSO and GA for the design of FACTS based controllers with speed deviation as objective [14]. Many researchers has been developed PSO based UPFC for damping power system Oscillations [1,16]. Hybrid GA-GSA algorithm is also used for tuning UPFC damping controller [13]. In literature, single objective optimization algorithm is used to regulate UPFC damping controller with objective function as change in speed deviation when the system subjected to disturbances. NSGA has high computational difficulty of non-dominated sorting, lack of elitism[4,18]. To overcome all the above issues Deb et al. [5] proposed a better version of NSGA, called NSGA-II a superior sorting algorithm. It encompasses advanced concepts like elitism, fast non-dominated sorting approach and diversity maintenance along the Pareto-optimal front. Non-dominated sorting genetic algorithm-II (NSGA-II) was successfully applied to many engineering problems with conflicting objectives [2,8,11,12,15,22,23]. Multi-objective algorithm NSGA-II is used for tuning of TCSC based damping controller considering speed abnormality and control signal as objective [11].In this proposed work, NSGA-II has been taken for the optimal design of UPFC damping controller by minimizing Integral Squared Error of change in input control signal(Δu) and change in speed deviation ($\Delta\omega$) to obtain optimum performance under nominal, light and heavy operating conditions. For the purpose of understanding the benefits of multi-objective algorithms the UPFC damping controller is also tuned with single objective algorithm PSO with Integral Squared Error of Speed deviation as objective. For comparison, conventional phase compensation method [20] is also considered. Eigen value analysis is also carried out to evaluate the stability of the proposed method. The remaining part of the paper is organized as follows: Section 2 consists of SMIB power system equipped with UPFC is explained. Section 3 explains the transfer function model and state space model of power system installed with UPFC. In Section 4, Problem formulation for the proposed UPFC damping controller is described. In section 5, an overview of PSO and NSGA-II algorithm is described in detail. In Sections 6 and 7 the results obtained in simulation and conclusions are discussed respectively.

2. SMIB Installed with UPFC

Figure.1 shows the single machine infinite bus system (SMIB) installed with UPFC damping controller. IEEE-ST1A type excitation system is considered. m_B, m_E, δ_B , δ_E are the input control signals of the UPFC damping controller.

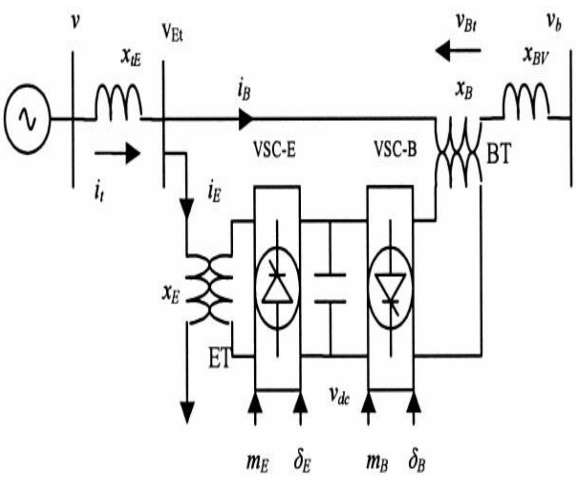


Figure .1. UPFC controller installed in SMIB

3. UPFC Transfer function model

The linearized modified Heffron-Phillips model taken is displayed in Figure.2. The state-space expression of the proposed system is as follows.

$$\dot{x} = Ax + Bu \tag{1}$$

where

$$x = \left[\Delta\delta \quad \Delta\omega \quad \Delta E_q^{'} \quad \Delta E_{fd} \quad \Delta V_{dc}\right]^T$$

$$u = [\Delta m_E \quad \Delta\delta_E \quad \Delta m_B \quad \Delta\delta_B \ ]^T$$

$$A = \begin{bmatrix} 0 & \omega_b & 0 & 0 & 0 \\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{K_{pd}}{M} \\ -\frac{K_4}{T_{do}^{'}} & 0 & -\frac{K_3}{T_{do}^{'}} & \frac{1}{T_{do}^{'}} & -\frac{K_{qd}}{T_{dp}^{'}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{vd}}{T_A} \\ K_7 & 0 & K_8 & 0 & -K_9 \end{bmatrix}$$

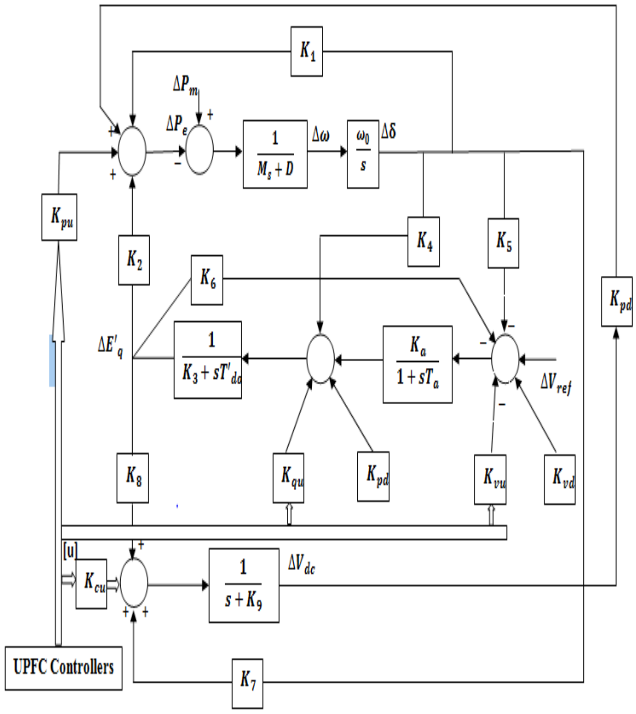


Figure .2. Linearized heffron-phillips model installed of UPFC

4. Proposed UPFC damping controller

UPFC control parameter is adjusted in order to produce the electrical torque required to compensate the deviations in speed. The controller parameters are tuned by using single and multi-objective optimization algorithm such as Particle Swarm Optimization (PSO) and Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) respectively. The objective considered for minimization using single objective optimization is Integral Squared Error (ISE) of speed deviation. For multi-objective optimization, ISE of speed deviation and ISE of control signal are the two differing objectives considered. Figure.3 shows the UPFC damping controller structure with washout filter block.

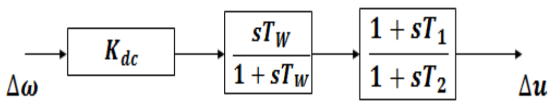


Figure 3. Structure of UPFC damping controller

For Single objective Particle Swarm Optimization,

$$F = \int_{0}^{t1} e_1^2(t)dt \qquad (2)$$

And for multi-objective NSGA-II, the objective functions are formulated as follows

$$\overset{\min}{F} = \{F_1, F_2\} \qquad (3)$$

Where,

$$F_1 = \int_{0}^{t1} e_1^2(t)dt \qquad (4)$$

$$F_2 = \int_{0}^{t1} e_2^2(t)dt \qquad (5)$$

The constraints considered for both PSO and NSGA-II are gain and time constants are expressed as

$$K_{dc}^{\min} \le K_{dc} \le K_{dc}^{\max} \qquad (6)$$

$$T_2^{\min} \le T_2 \le T_2^{\max} \qquad (7)$$

$$T_1^{\min} \le T_1 \le T_1^{\max} \qquad (8)$$

e_1 is the small change in speed deviation $(\Delta\omega)$ and e_2 is the small change in control input signal

5. Overview of PSO and NSGA-II algorithms

The UPFC damping controller tuning is carried out by single objective optimization algorithm Particle swarm optimization and also multi-objective optimization algorithm such as Non-dominated sorting genetic algorithm-II (NSGA-II). The overview of these optimization algorithms are explained as follows.

A. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is a strong stochastic optimization algorithm based on the movement and cooperation of swarms. Social interaction to problem solving principle is involved. It uses a number of particles that comprise a swarm moving around in the search space observing for the best solution. Each particle is taken as a point in an N- dimensional space which controls its mounting according to its own elevated experience as well as the soaring experience of other particles. Each particle keeps track of its co-ordinates in the solution space which are associated with the best solution has achieved for by that particle.

First best value is called personal best, ‘pbest’. Second best value obtained so far by any particle in the neighborhood of that particle. This second value is called global best, ‘gbest’. The concept of Particle Swarm Optimization lies in accelerating each particle towards its ‘pbest’ and the ‘gbest’ locations, with an unsystematic weighted acceleration at each time step. Each particle tries to change its position using the information such as the present positions, the present velocities, the distance between the contemporary positions are called as ‘pbest’ and ‘gbest’.

B. Non-dominated Sorting Genetic Algorithm-II (NSGA-II)

NSGA-II incorporates elitism, fast non-dominated sorting strategy and the crowding distance operator maintains the diversity along the Pareto optimal front. The problems in NSGA such as, computational complexity and lack of diversity are overcome by NSGA-II. Elitism preserves the knowledge acquired during the algorithm implementation by conserving the individuals with best fitness in the population. Initially, a random parent population P^o is created. The population is sorted based on the non-domination. Each solution is having fitness equal to its non-domination level. Best level is 1.Thus, minimization of fitness is assumed. Tournament selection, recombination, and mutation operators are used to generate offspring population O^{Ok} of size N.

6. Results and Discussion

In this study, optimal parameters of UPFC damping controller is determined by subjecting the system to disturbance. The optimal parameters are obtained using evolutionary algorithms like PSO and NSGA-II by considering Integral squared error of speed deviation and control signal as objectives. The performance of single and Multi-objective evolutionary algorithms in tuning of UPFC based damping controller installed in SMIB system is analyzed. The results obtained in proposed method are compared with conventional phase compensation method. The simulations are performed using MATLAB 10a software on Intel core duo processor, 2.93GHz, 1.96 GB RAM. The population size is taken as 200 and the functional evaluation is taken as 20000. The performance of the proposed controller is evaluated by applying disturbance at different operating conditions. The operating conditions considered are shown in Table 1.

Table .1. Load operating conditions

Operating Condition	P (p.u)	Q (p.u)
Nominal Load	0.8	0.167
Light Load	0.2	0.01
Heavy Load	1.2	0.4

A. Nominal Load Operating Condition

In this operating condition, the damping controller performance is valued by giving a mechanical disturbance of Pm=0.01 p.u. The optimal values of the lead-lag compensator gain and time constants obtained for this operating condition is reported in Table 2.

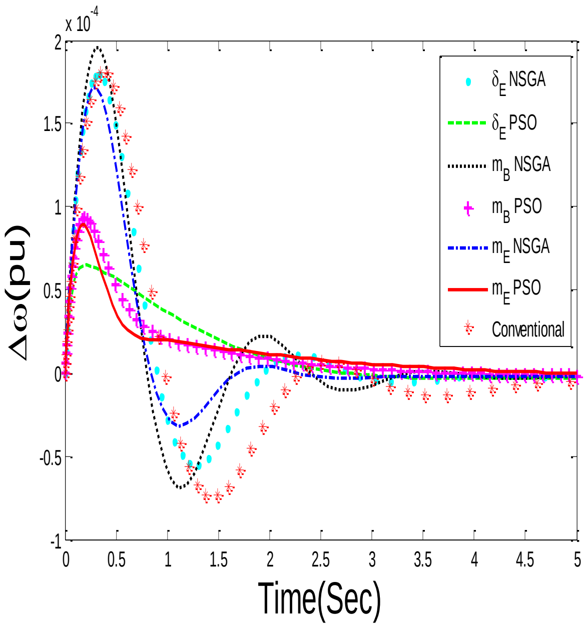


Figure 4(a) Variation in Speed deviation

Table .2. Optimal parameters of Nominal loading condition (Pm=0.01p.u)

Controller Algorithm	δ_E		m_B		m_E		**Conventional method**
	PSO	**NSGA II**	**PSO**	**NSGA II**	**PSO**	**NSGA II**	
K	99.8959	13.8664	98.9826	22.2646	99.8908	9.6312	18.0960
T_1	0.4990	0.2581	0.4927	0.3186	0.4987	0.4536	0.2296
T_2	0.2012	0.2109	0.2109	0.2030	0.2100	0.2199	0.2516
F_1	2.458e-8	3.6537e-7	6.779e-8	4.306e-7	2.144e-8	3.3525e-7	3.4983e-5
F_2	7.646e-4	8.0615e-5	0.0023	3.263e-4	6.001e-4	6.983e-5	0.0102

In PSO, the objective function considered (Speed deviation) is having minimum value with higher control input whereas NSGA-II provides better damping performance with minimum control energy. The AC voltage regulator (m_E) type damping controller provides outstanding performance with minimum objective function values thereby damp out oscillations quickly while tuning with NSGA-II. In single objective tuning using PSO, δ_E controller provides better performance as compared with other controller. Figure 4 shows the speed deviation, control input and rotor angle curves obtained for different controllers at nominal operating condition.

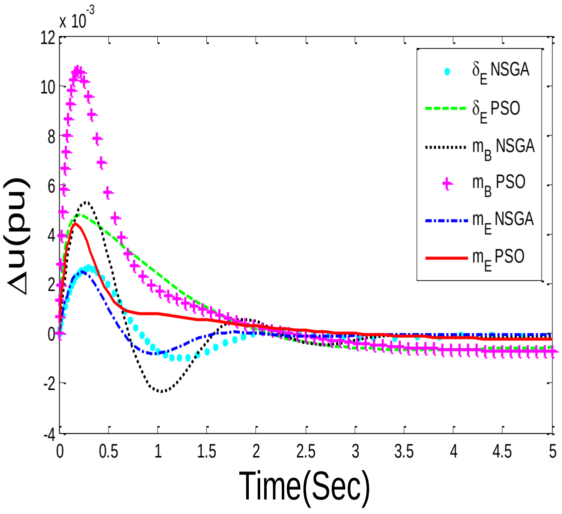


Figure 4(b) Variation in Control input

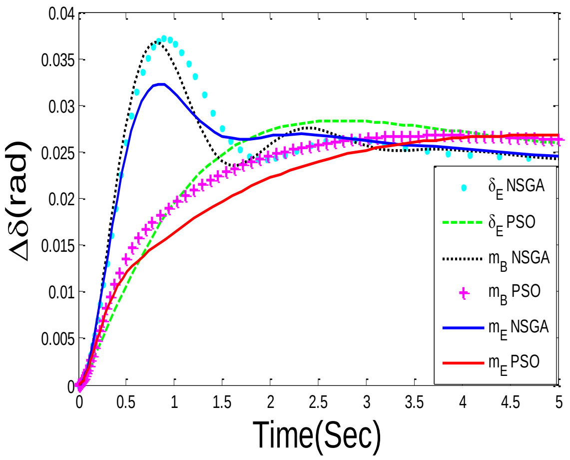
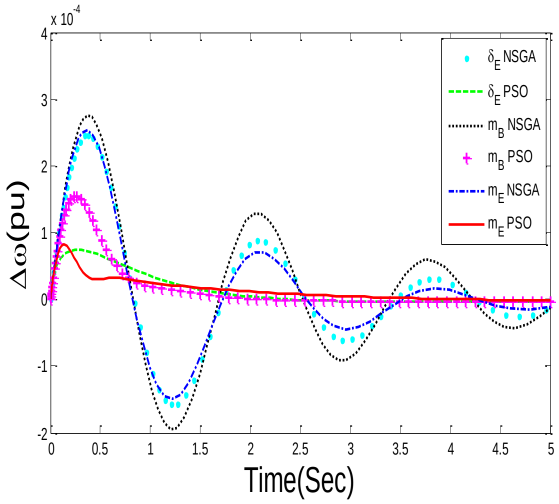


Figure 4(c) Variation in Rotor angle

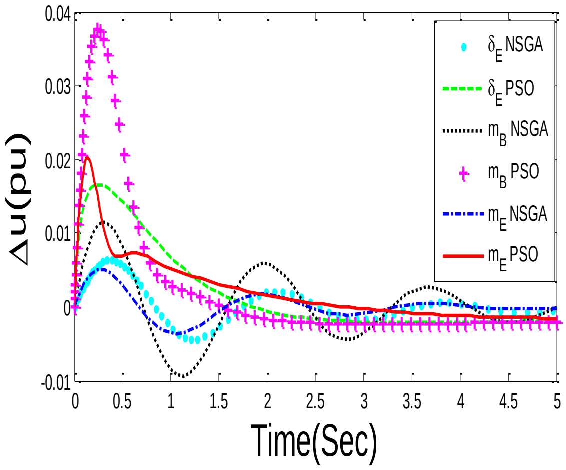
Figure 4. Responses of different UPFC controllers at Nominal load operating condition

B. Heavy Load Operating Condition

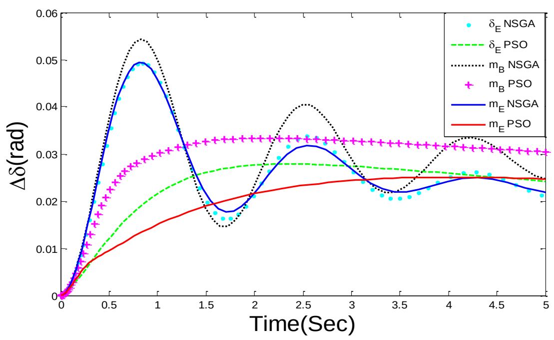
The damping controller performance is investigated by applying mechanical disturbance under heavy operating condition. It is inferred that at heavy operating condition DC voltage regulator (δ_E) based controller gives better performance with single objective optimization, whereas AC voltage regulator (m_E) controller provides enhanced performance among multi-objective optimization. Figure 5 shows the dynamic response of the system under heavy load operating condition.



5(a) Variation in speed deviation



5(b) Variation in control input

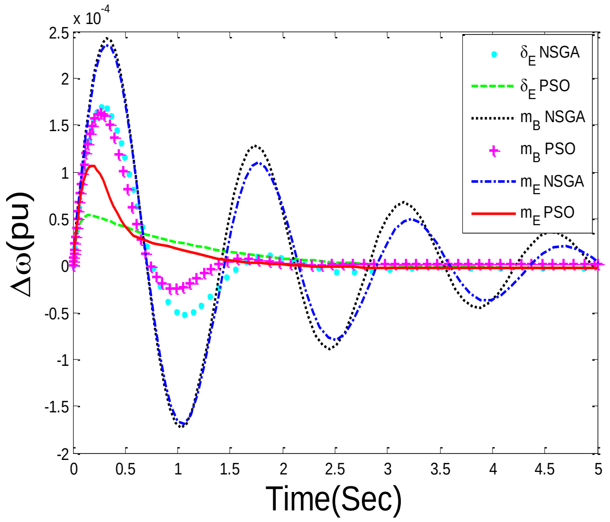


5(c) Variation in rotor angle

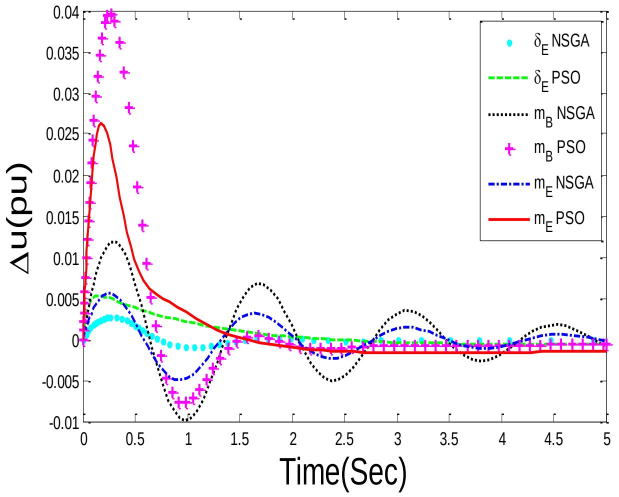
Figure 5. Responses of different UPFC controllers at heavy load operating condition

C. Light Load Operating Condition

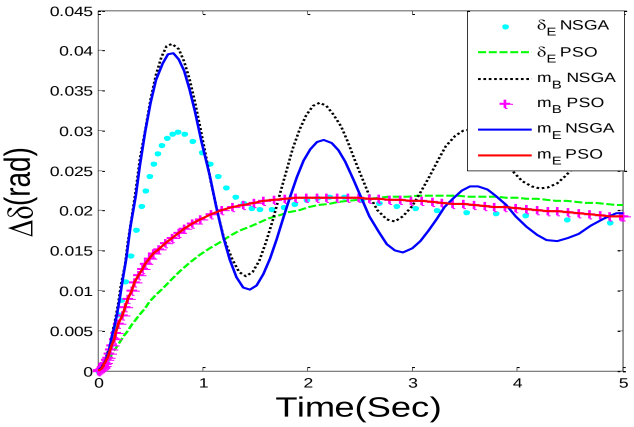
DC voltage regulator type damping controller provides better performance in light operating condition with minimum error. Figure 6 shows the dynamic responses of UPFC controllers while subjecting the system to 1% mechanical disturbance. The change in rotor angle curve indicates that evolutionary algorithm based controller improves the dynamic stability of the system.



6(a) Variation in speed deviation



6(b) Variation in control input



6(c) Variation in rotor angle

Figure 6. Responses of different UPFC controllers at light load operating condition

D. Stability Analysis

Eigen values helps to realize the stability of the system. The eigen values obtained for nominal load operating condition is given in Table 3. The eigen values obtained are in the left half of the s-plane confirms that the proposed NSGA-II based UPFC damping controller improves the small stability of the power systems.

Table 3.Eigen values of nominal load operating condition for controller δ_E

Eigen values in NSGA-II	Eigen values in PSO
-98.284	-98.3526
-5.815	-64.287
-1.377+ 3.195i	-2.0185
-1.377- 0.1952i	-0.746 + 0.7891i
-2.272	-0.746 - 0.7891i
-0.101	-0.118
-0.027	-0.027

7. Conclusion

In this work, single and multi-objective algorithm based UPFC damping controller tuning is carried out by abating the ISE of the change in speed deviation and input control. In order to assess robust performance of proposed controller, the system is subjected to different operating conditions and scrutinized. Simulation results reveal that the single objective optimization gives minimum speed deviation with higher input control signal; however multi-objective optimization provides loftier damping performance with considerable diminution in control signal. The dynamic responses obtained shows that DC voltage regulator type damping controller damp out oscillations quickly compared with other controllers in single objective optimization. In case of multi objective optimization m_E controller gives better damping performance as compared with other UPFC controllers. The Eigen value analysis proves that the proposed evolutionary algorithm based controller greatly improves the stability of the power systems.

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