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ORIGINAL ARTICLE

Combination of PSS and LFC for Improving the Power System Stability in Deregulated Environment Using HBMO

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ABSTRACT*:* This paper presents the robust design of a Power System Stabilizer (PSS) to improve the stability in the composed two-area Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) using Honey Bee Mating Optimization (HBMO) in a restructured environment. The coupling effects of the LFC and AVR loops are studied by extending the linearized Automatic Generation Control (AGC) system to include the excitation system. The proposed method is tested on the two-area power system. The simulation results show that adding a coordinative PSS on this model can improve the dynamic stability of the power system and effectively suppresses the low frequency oscillation. The effectiveness of the proposed method is compared with two-area system in a deregulated environment without AVR using Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) techniques.

Keywords; PSS, Load Frequency Control, HBMO, Two-Area Power System.

Introduction

The objective of the control strategy in a power system is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the frequency and voltage within permissible limits. The power system control has a hierarchical structure. The low-frequency oscillation of interconnected systems is one of the most important stability problems arising from large-scale electric power system interconnections [1].

Actually the complete model of a system in low-frequency oscillation study should consist of mechanical and electrical loops. There is no doubt that these oscillations can be controlled by adjusting exciter and speed-governor control parameters. Moreover, it has been shown that the load-voltage characteristic of the power system has a significant effect on its dynamic responses, and suggestions have been made for the proper representation of this characteristic in simulation studies [2]. On the other hand, Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) are two main control loops of a generation.

There are lots of papers studying LFC [3-5], however these researches didn't have any attention to the mutual effects between AVR and LFC. Also, these researches are based on the assumption that there is no interaction between power/frequency and the reactive-power/voltage control loops. However, there are some interactions between these two control channels in practical system during dynamic oscillations.

In [2] a PSS is added to combine with the LFC for more dynamic improvement but, the method of choosing appropriate PSS parameters have some problems. Over the years, several techniques have been developed for designing PSSs. Conventionally a lead-lag controller has been widely used in power system control to damp the low frequency oscillations. In order to determine the coefficient of the lead-lag controller, several control algorithms based on the conventional methods are proposed [6].

$H\infty$ optimization techniques [7-8] have been applied to the robust PSS design problem. However, the additive and/or multiplicative uncertainty representation cannot treat situations where a nominal stable system becomes unstable after being perturbed. On the other hand, the order of the $H\infty$ based stabilizer is as high as that of the plant. This gives rise to the complex structure of such stabilizers and reduces their applicability.

Particle Swarm Optimization (PSO) is one of the modern heuristic algorithms. It was developed through the simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [9]. The PSO technique can generate a high quality solution within shorter calculation time and has a stable convergence characteristic than other stochastic methods [10]. Generally, PSO is characterized as a simple concept, easy to implement, and computationally efficient. Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities. However, it is possible to observe that the PSO converges in local global. It is obvious that the conventional controllers which are optimized by PSO or GA have a suitable reaction in wide range systems. However, these optimizations of PSSs are valid [9] in a particular work point, whereas, this is not appropriate for various operating points.

In this paper, to overcome these problems, Honey Bee Mating Optimization (HBMO) is proposed for the solution of tuning the PSS parameters. The HBMO algorithm is a typical swarm-based approach to optimization, in which the search algorithm is inspired by the intelligent foraging behavior of a honey bee mating process [11] and has emerged as a useful tool for the engineering optimization. It incorporates a flexible and well-balanced mechanism to adapt to the global and local exploration and exploitation abilities within a short computation time. Hence, this method is efficient in handling large and complex search spaces [12].

The effectiveness of the proposed method is tested on a two-area deregulated power system. The result of the proposed controller is compared with a GA Fuzzy (GAF) [13] and PSO Fuzzy (PSOF) [14] approaches in a restructured system through nonlinear time simulation and some performance indices. Evaluation results show that by using this model higher accuracy will be reached in the dynamic and steady state responses.

Model of Power System

Load frequency Control (LFC)

Actually, the aim of the LFC is to maintain real power balance in the system through control of system frequency. Also, as the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to the turbine governor. The governor operates to restore the balance between the output and input by changing the turbine output. This strategy is also referred to as megawatt frequency or power-frequency (P-f) control [15].

Automatic Voltage Regulator (AVR)

The aim of this control is to maintain the system voltage between limits by adjusting the excitation of the machines. The AVR senses the difference between a rectified voltage derived from the stator voltage and a reference voltage. This error signal is amplified and fed to the excitation circuit. The change of excitation maintains the VAR balance in the network.

Structure of Combined LFC and AVR System

Deregulated power system consists of GENCOs, TRANSCOs and DISCOs with an open access policy. This is obvious that all transactions have to be cleared via Independent System Operator (ISO) or other responsible infrastructure. In this latter environment, it is appropriate that a new model for LFC scheme is improved to account for the effects of possible load following contracts on the system's dynamics [13].

According to the proposed idea in [4], the significant of an 'Augmented Generation Participation Matrix' (AGPM) to express the possible contracts following is presented here. The AGPM shows the communion factor of a GENCO in the load following contract with a DISCO. The dimension of the AGPM matrix in terms of rows and column is equal the total number of GENCOs and DISCOs in the overall power system, respectively. Consider the number of GENCOs and DISCOs in area i be ni and mi in a large scale power system with N control areas. The structure of the AGPM is given by:

$$AGPM = \begin{bmatrix} AGPM_{11} & \cdots & AGPM_{1N} \\ \vdots & \ddots & \vdots \\ AGPM_{N1} & \cdots & AGPM_{NN} \end{bmatrix}$$

$$AGPM_{ij} = \begin{bmatrix} gpf_{(s_i+1)(z_j+1)} & \cdots & gpf_{(s_i+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ gpf_{(s_i+n_i)(z_j+1)} & \cdots & gpf_{(s_i+n_i)(z_j+m_j)} \end{bmatrix}$$

$$s_i = \sum_{k=1}^{i-1} n_i , z_j = \sum_{k=1}^{j-1} m_j , i, j = 2,..., N \ \& \ s_1 = z_1 = 0$$

Where, n_i and m_i define the number of GENCOs and DISCOs in area i and gpf_{ij} refers to the 'generation participation factor' and displays the participation factor of GENCO i in total load following requirement of DISCO j based on the possible contracts. The sum of all inputs in each column of AGPM is univalent. The block diagram of a generalized LFC model with AVR loop in a deregulated power system to control area i is presented in Fig.1. These new information signals are considered as disturbance channels for the decentralized LFC design. As there are many GENCOs in each area, ACE signal has to be distributed among them due to their ACE participation factor in the LFC task and $\sum_{j=1}^{ni} apf_{ij} = 1$. It can be written that [5]:

$$d_i = \Delta P_{Loc,j} + \Delta P_{di} \quad , \quad \Delta P_{Loc,j} = \sum_{j=1}^{m_i} (\Delta P_{Lj-i} + \Delta P_{ULj-i}) .$$

$$\eta_i = \sum_{j=1 \& j \neq i}^{N} T_{ij} \Delta f_j , \quad \zeta_i = \sum_{k=1 \& k \neq i}^{N} \Delta P_{tie,ik,sch}$$

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{n_i} \sum_{t=1}^{m_k} apf_{(s_l+j)(z_k+t)} \Delta P_{L(z_k+t)-k} - \sum_{t=1}^{n_k} \sum_{j=1}^{m_i} apf_{(s_k+t)(z_i+j)} \Delta P_{L(z_i+j)-i}$$

$$\Delta P_{tie,i-error} = \Delta P_{tie,i-actual} - \zeta_i$$

$$\rho_i = [\rho_{1i} \ \cdots \ \rho_{ki} \ \cdots \ \rho_{n_i i}] \quad , \quad \rho_{ki} = \Delta P_{m,k-i}$$

$$\Delta P_{m,k-i} = \sum_{j=1}^{z_{N+1}} gpf_{(s_i+k)j} \Delta P_{Lj-i} + apf_{ki} \sum_{j=1}^{m_i} \Delta P_{ULj-i} , k = 1,2,..., n_i$$

Where, $\Delta P_{m,ki}$ is the desired total power generation of a GENCO k in area i and must track the demand of the DISCOs in contract with it in the steady state. Two GENCOs and DISCOs are assumed to each control an area for which the system parameters are given in [3].

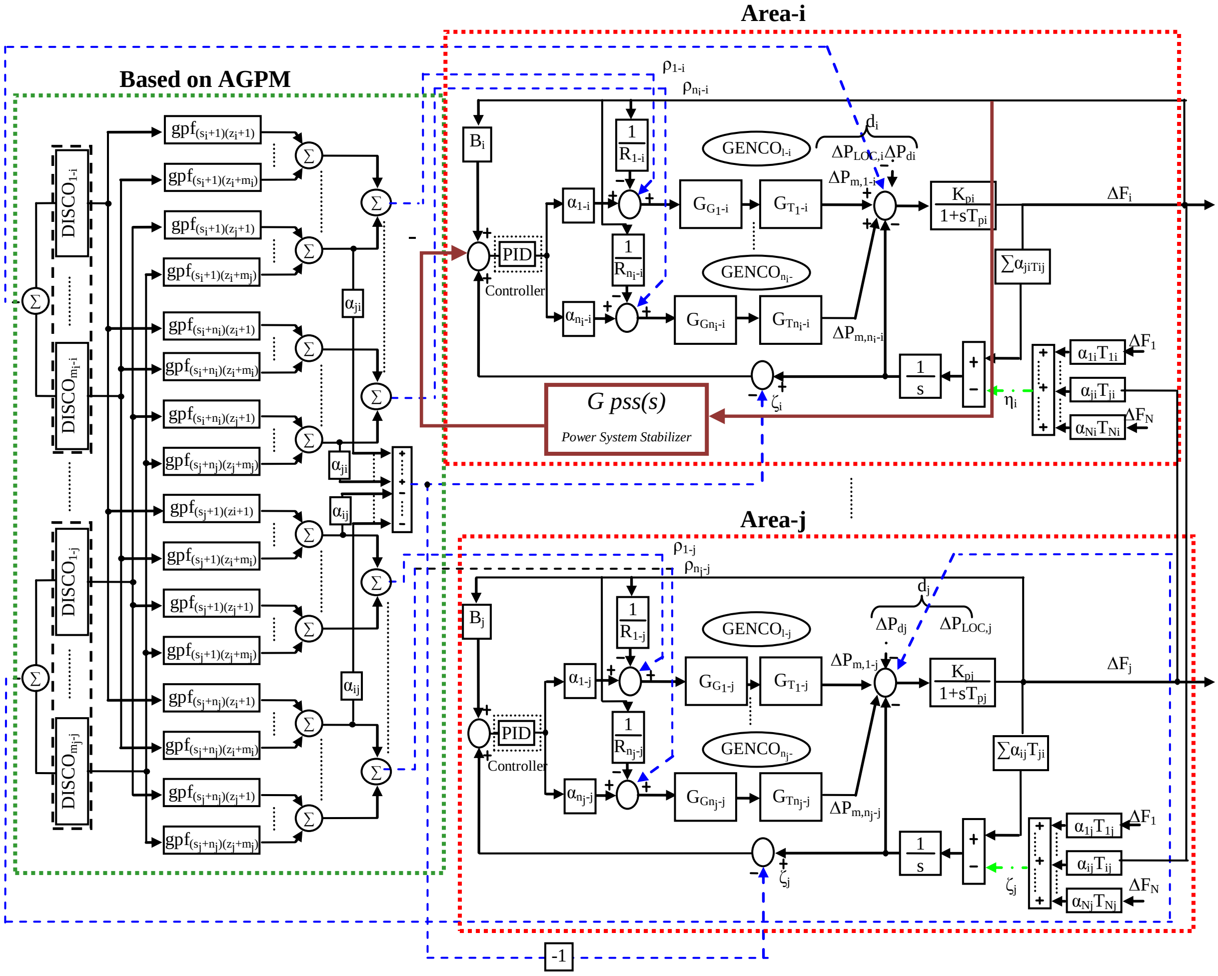

figure 1 Generalized LFC model in the restructured system

To make the visualization of contracts easier, the concept of a "DISCO Participation Matrix" (DPM) will be used. Essentially, DPM gives the participation of a DISCO in contract with a GENCO. In DPM, the number of rows has to be equal to the number of GENCOs and the number of columns has to the number of DISCOs in the system. Any entry of this matrix is a function of the total load power contracted by a DISCO toward a GENCO.

Applied PSS for Proposed System

The problem of setting the parameters of the PSSs that assure maximum damping performance is solved using an HBMO algorithm. A widely used conventional lead-lag PSS is considered in this study which is shown in Fig. 2. Also a gain of K_s and four time constants T_1, T_2, T_3 and T_4 are considered for this controller.

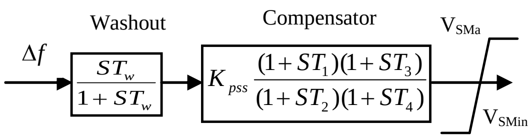

Figure 2. Power system stabilizer

HBMO

The honey bee is a social insect that can survive only as a member of a community, or colony. This means that they tend to live in colonies while all the individuals are the same family. In the more highly organized societies there is a division of labor in which individuals carry out particular duties. In fact, a colony consists of a queen and several hundred drones, 30,000 to 80,000 workers and broods in the active season. Each bee undertakes sequences of actions which unfold according to genetic, ecological and social condition of the colony [12]. The queen is the most important member of the hive because she is the one that keeps the hive going by producing new queen and worker bees and any colony maybe contain one or much queen in it life's. Drones' role is to mate with the queen. In the marriage process, the queen(s) mate during their mating flights far from the nest [16]. In each mating, sperm reaches the spermatheca and accumulates there to form the genetic pool of the colony. The queen's size of spermatheca number equals to the maximum number of mating of the queen in a single mating flight is determined. When the mate be successful, the genotype of the drone is stored. In start the flight, the queen is initialized with some energy content and returns to her nest when her energy is within some threshold from zero or when her spermatheca is full. A drone's mate probabilistically is [12]:

$P_{rob}(Q,D) = e^{-(\Delta f)/(S(t))}$

Where,

Prob (Q, D) = The probability of adding the sperm of drone D to the spermatheca of queen Q

Δ(f) = The absolute difference between the fitness of D and the fitness of Q (i.e., f (Q))

S(t) = The speed of the queen at time t

After each transition in space, the queen's speed, and energy, decay using the following equations:

$S(t+1) = \alpha \times S(t)(2), \quad \alpha \in [0,1]$

$E(t+1) = E(t) - \gamma$

γ = The amount of energy reduction after each transition. The flowchart of Classic HBMO is presented in "Fig. 3", [16].

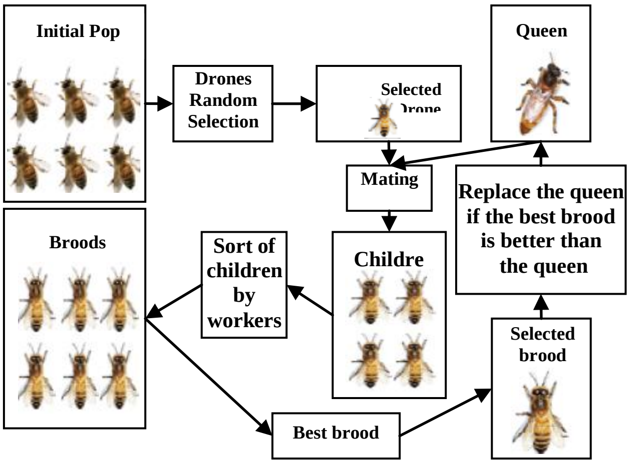

Figure 3. The Classic HBMO technique

Proposed HBMO-PSS in LFC

The proposed controller was applied for one area in a two-area LFC power system in the deregulated environment. Also, the proposed algorithm optimizes the parameters of the LFC power system as K_{Pi}, K_{Ii} and K_{Di} for i=1, 2… N. For both of the PSS and LFC optimization these "Time multiplied Absolute value of the Error" ITAE (Δf) and ITAE (ΔP) are calculated for the objective functions which are defined as:

$$ITAE(\Delta f) = 150 \times \int_0^{tsim} |dF1| dt$$

$$ITAE(\Delta P) = 150 \times \int_0^{tsim} |dp12| dt$$

Where, the constraints of the PID controller parameter bounds which are considered with PSS parameters consist of:

$$\text{Minimizeu subject to:} \quad \begin{matrix} K_{Pi}^{min} \le K_{Pi} \le K_{Pi}^{max} \\ K_{Ii}^{min} \le K_{Ii} \le K_{Ii}^{max} \\ K_{Di}^{min} \le K_{Di} \le K_{Di}^{max} \end{matrix}$$

Also the bounds of PSS parameters are presented in Table 1.

Table 1. PSS Limitations

Parameters	T_1	T_2	T_3	T_4	K_{pss}
Lower limit	0.01	0.01	0.01	0.01	0.01
Uper limit	3	3	3	3	3

Moreover, the trend of the objective function of the algorithm is presented in Fig. 4. Also, the optimized parameters of the PID and PSS are presented in Table. 2 and 3, respectively.

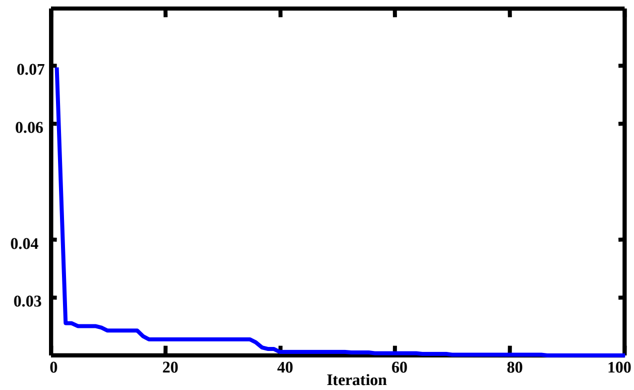

Figure 4.Variations of fitness function.

Table 2. Optimum pid controller gains found by hbmo

Algorithm	K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
HBMO	2.857	2.975	1.354	2.758	0.458	1.228

Table 3. Optimum pss controller parameters found by hbmo

Algorithm	K_{pss}	T_1	T_2	T_3	T_4
HBMO	0.1478	0.277	3.578	1.857	1.866

Simulation Results

In this part, a PSS is designed to display the dynamic improvement for a composed model of LFC and AVR. The simulation is performed for different possible operating conditions of the power system.

It is supposed that each DISCO demands 0.1 pu MW power from GENCOs. Also, it is possible that a DISCO violates a contract by demanding more power than the amount specified in the contract. This additional power must be reflected as a local load of the area but not as the contract demand and taken up by the GENCOs in the same area. Moreover, DISCOs 1, 2 each demand 0.05 puMW of additional power. According to equation (2) the total loads in areas are calculated as:

$P_{Loc,1}=\Delta P_{L,1-1}+\Delta P_{L,2-1}+\Delta P_{U,1-2}=0.1+0.1+0.05=0.25$

$P_{Loc,2}=\Delta P_{L,1-2}+\Delta P_{L,2-2}+\Delta P_{U,1-2}=0.1+0.1+0.05=0.25$

To make the visualization of contracts easier, the concept of a "DISCO Participation Matrix" (DPM) will be used. Essentially, DPM gives the participation of a DISCO in contract with a GENCO. The purpose of this scenario is to test the effectiveness of the proposed controller against uncertainties and large load disturbances in the presence of Generation Rate Constraints (GRC). For this purpose the elements of the DPM are cpf_{ij} the factor for restructured system as:

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

The results of the proposed controller are compared with the PSO-F PID [14] and GA-F PID [13]. Also, disturbances of the area are the following: dP1=0.05, dP2=0.03. Considering to this scenario the modifications of excess power as: Disco1=0.17 (equal to 0.1+0.07), Disco2=0.14 (equal to 0.1+0.04), Disco3=0.12 (equal to 0.1+0.02), Disco4=0.12 (equal to 0.1+0.02). Also, the factors of PID controller are: apf1=0.75, apf2=1-apf1, apf3=.5, apf4=1-apf3. The results for +25% and -25% changes of parameters for the LFC are shown in Fig. 5-6, respectively.

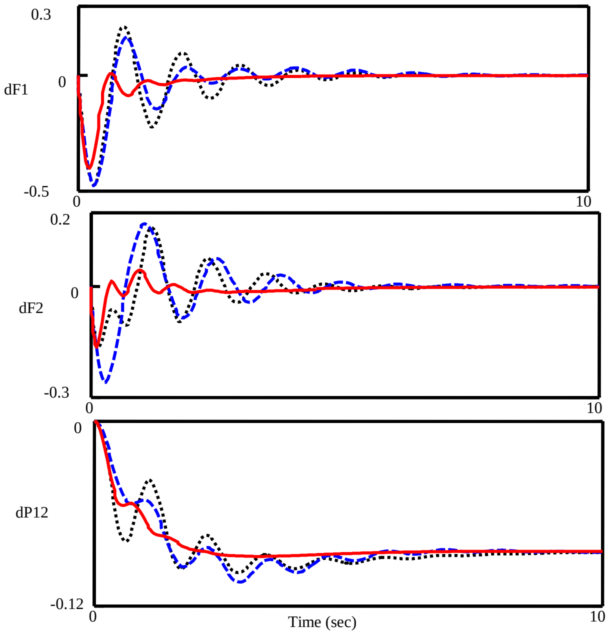

Figure 5. Deviation of frequency and tie lines power flows for +25% changes; Solid (HBMO with PSS), Dashed (PSO-F without PSS) and Dotted (GA-F without PSS).

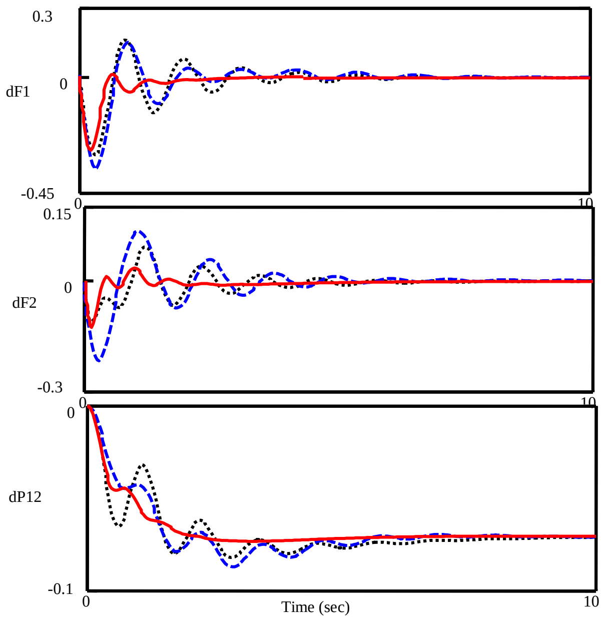

Figure 6. Deviation of frequency and tie lines power flows for -25% changes; Solid (HBMO with PSS), Dashed (PSO-F without PSS) and Dotted (GA-F without PSS).

The simulation results represent the positive effect of the AVR composed LFC on the improvement of the oscillation of frequency due to any load demands and disturbances. It can be seen that the proposed control strategy can ensure robust performance such as possible contracted scenario under modeling uncertainties in the various operating conditions.

Conclusion

In this research, a new combination of LFC and AVR based HBMO technique was introduced for improvement of stability in power system in a restructured environment. In this paper the effect of the AVR loop is considered over LFC loop which leads to an improvement in the mentioned power system. The parameters of PSS and PID controller are tuned according to some performance index based HBMO. It incorporates a flexible and well-balanced mechanism to adapt to the global and local exploration and exploitation abilities within a short computation time. It is well known that the conventional methods to tune the gains of the PID controller and PSS parameters with numerical analysis may be tedious and time consuming. This control strategy was chosen because of the increasing complexity and changing structure of the power systems. The effectiveness of the proposed method is tested on a two-area restructured power system for a wide range of load demands and disturbances under different operating conditions that is compared via PSOF, GAF controllers through some performance indicates and could be ensure the robust performance such for possible contracted scenario under modeling uncertainties in the various operating conditions.

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