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Design of Robust PSS to Improve Stability of Composed LFC and AVR Using ABC in Deregulated Environment

O. Abedinia
Islamic Azad University, Young Researcher Club,
Ardabil Branch, Ardabil, Iran
E-mail: oveis.abedinia@hotmail.com

H. A. Shayanfar *
Electrical Eng. Department, Islamic Azad University,
South Tehran Branch, Tehran, Iran
E-mail: hashayanfar@yahoo.com

B. Wyns
Department of Electrical Energy, Systems and
Automation, Ghent, Belgium
E-mail: bart.wyns@ugent.be

A. Ghasemi
Technical Eng. Department, University of
Mohaghegh Ardabili, Ardabil, Iran
E-mail: ghasemi.agm@gmail.com

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 Artificial Bee Colony (ABC) 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; Artificial Bee Colony, PSS, Load Frequency Control, AVR, Two-Area Power System.

I. 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

* Correspanding Author. E-Mail Address: hashayanfar@yahoo.com (H. A. Shayanfar)

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, an Artificial Bee Colony (ABC) is proposed for the solution of tuning the PSS parameters. The ABC 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 swarm 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.

II. MODEL OF POWER SYSTEM

A. 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].

B. 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.

C. 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

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

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

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:

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

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]:

$$d_i = \Delta P_{Locj} + \Delta P_{di} \quad , \quad \Delta P_{Locj} = \sum_{j=1}^{m_i} (\Delta P_{Lj-i} + \Delta P_{ULj-i}) \tag{2}$$

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

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

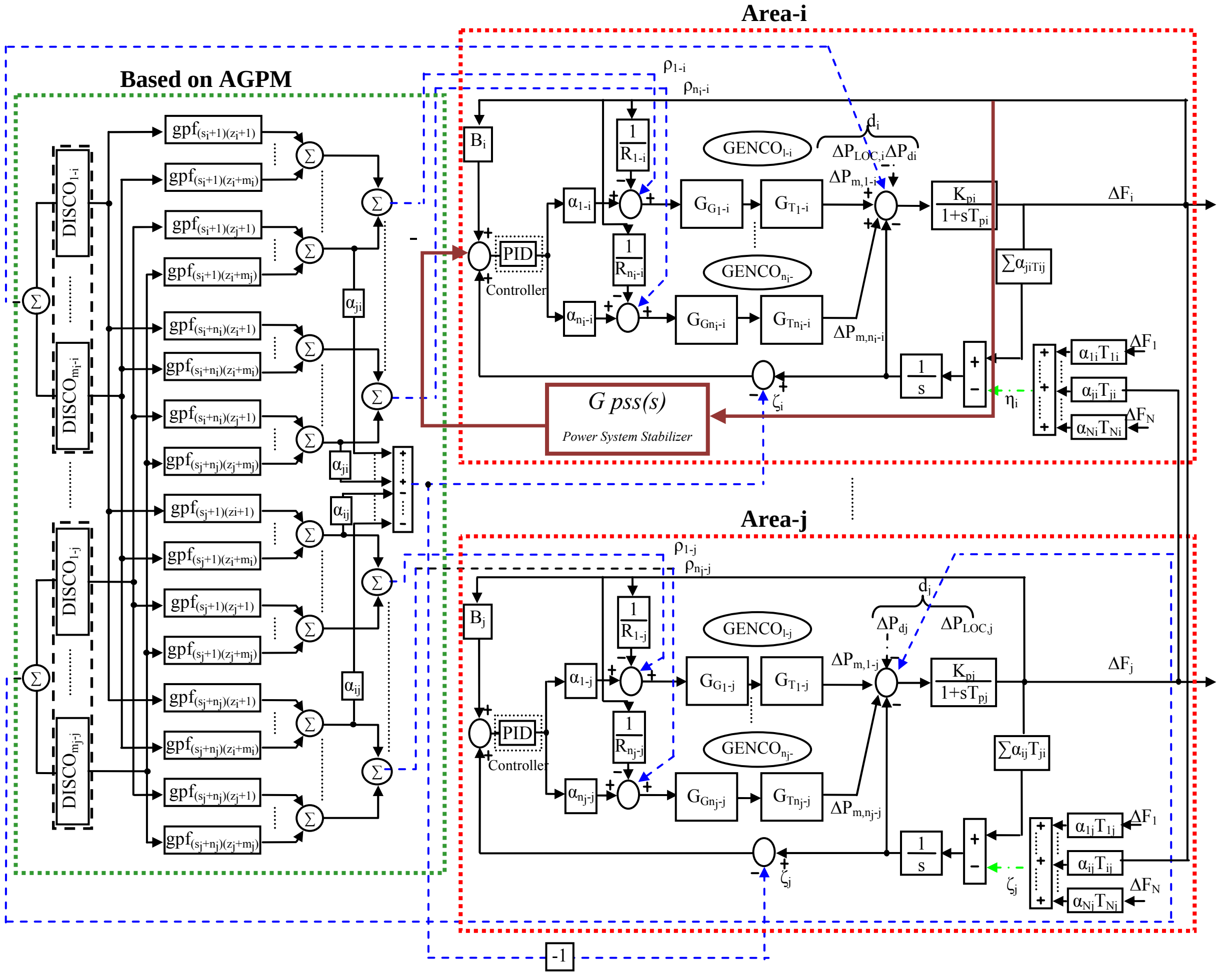

Figure 1. Generalized LFC model in the restructured system

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

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

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

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].

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.

D. Applied PSS for Proposed System

The problem of setting the parameters of the PSSs that assure maximum damping performance is solved using an ABC 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.

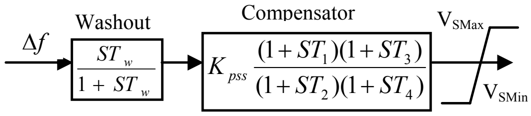

Figure 2. Power system stabilizer

E. Artificial Bee Colony Algorithm

The ABC algorithm is proposed by Karaboga [11] in 2005, and the performance of the ABC is analyzed in 2007 [16]. The foraging bees are classified into three categories; employed bees, onlookers and scout bees. All bees that are currently exploiting a food source are known as employed. The employed bees exploit the food source and they carry the information about the food source back to the hive and share this information with onlooker bees. Onlookers bees are waiting in the hive for the information to be shared by the employed bees about their discovered food sources and scout bees will always be searching for the new food sources near the hive. Employed bees share information about food sources by dancing in the designated dance area inside the hive. The nature of this dance is proportional to the nectar content of the food source just exploited by the dancing bee. Onlooker bees watch the dance and choose a food source according to the probability proportional to the quality of that food source. Therefore, good food sources attract more onlooker bees compared to the bad ones. Whenever a food source is exploited fully, all the employed bees associated with it abandon the food source, and become scout. Scout bees can be visualized as performing the job of exploration, whereas, employed and onlooker bees can be visualized as performing the job of exploitation [12].

In the ABC algorithm, the number of employed bees is equal to the number of food sources which is also equal to the number of onlooker bees. There is only one employed bee for each food source whose first position is randomly generated. Each employed bee, at each iteration of the algorithm determines a new neighboring food source of its currently associated food source by the following equation, and computes the nectar amount of this new food source:

$$v_{ij} = z_{ij} + \theta_{ij}(z_{ij} - z_{kj})$$

Where, Θ_{ij} is a random number between [-1, 1]. If the nectar amount of this new food source is higher than that of its currently associated food source, then this employed bee moves to this new food source, otherwise it continues with the old one. After all employed bees complete the search process; they share the information about their food sources with onlooker bees. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount by this equation. This method, known as roulette wheel selection method, provides better candidates to have a greater chance of being selected:

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_i}$$

Where, fit_i is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position i and SN is the number of food sources which is equal to the number of employed bees. Pseudo code for ABC algorithm:

- Initialize
- Repeat.
- Move the employed bees onto their food source and evaluate the fitness
- Move the onlookers onto the food source and evaluate their fitness
- Move the scouts for searching new food source
- Memorize the best food source found so far
- Until (termination criteria satisfied)

F. Proposed ABC-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:

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

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

TABLE I. 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. 3. Also, the optimized parameters of the PID and PSS are presented in Table. 2 and 3, respectively.

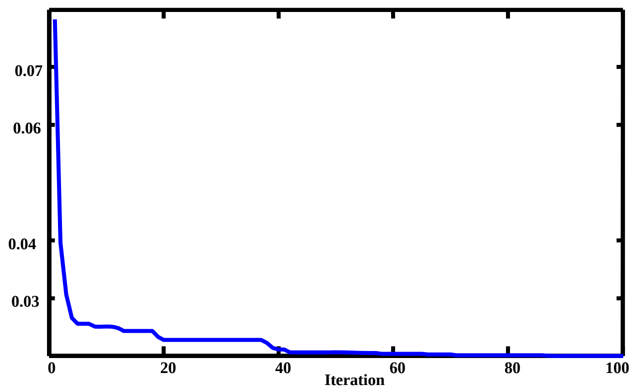

Figure 3. Variations of fitness function.

TABLE II. OPTIMUM PID CONTROLLER GAINS FOUND BY ABC

Algorithm	K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
ABC	2.7634	2.9929	1.3690	2.8406	0.3751	1.5638

TABLE III. OPTIMUM PSS CONTROLLER PARAMETERS FOUND BY ABC

Algorithm	K_{pss}	T_1	T_2	T_3	T_4
ABC	0.0126	0.2293	3.4321	1.6034	1.6539

III. 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. 4-5, respectively.

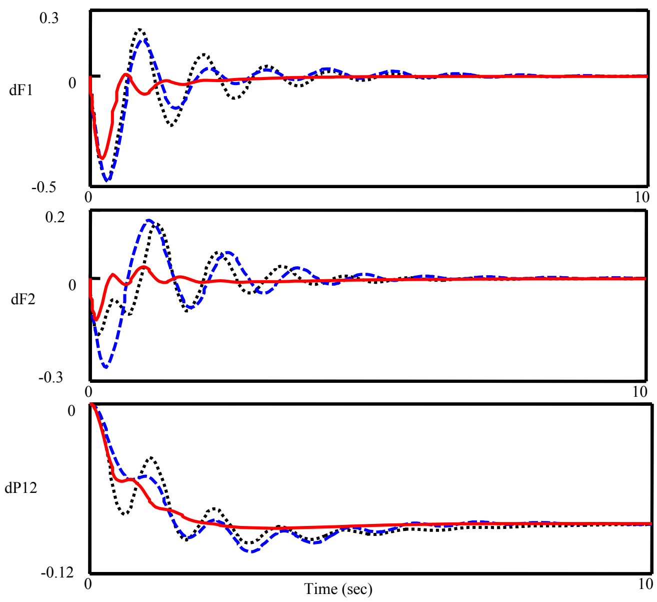

Figure 4. Deviation of frequency and tie lines power flows for +25% changes; Solid (ABC with PSS), Dashed (PSO-F without PSS) and Dotted (GA-F without PSS).

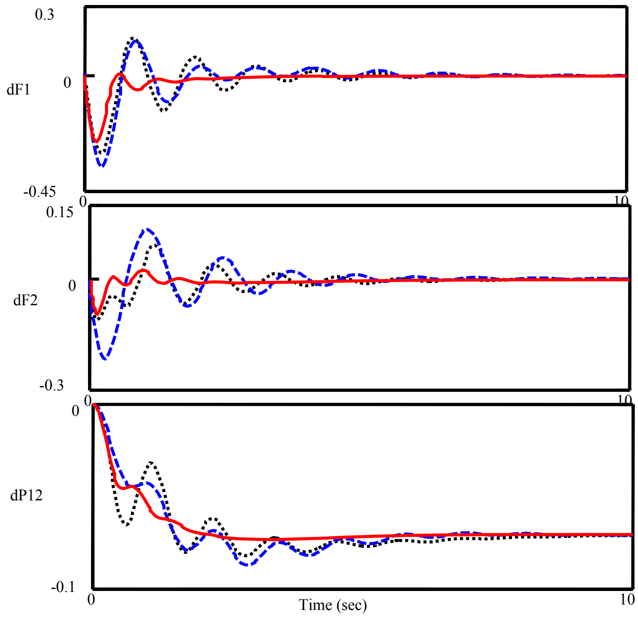

Figure 5. Deviation of frequency and tie lines power flows for -25% changes; Solid (ABC with PSS), Dashed (PSO-F without PSS) and Dotted (GA-F without PSS).

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.

IV. CONCLUSION

In this research, a new combination of LFC and AVR based ABC 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 ABC. The ABC algorithm is a search algorithm that is inspired by the intelligent foraging behavior of a honey bee swarm process and has emerged as a useful tool for 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. 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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BIOGRAPHIES

Oveis Abedinia received the B.S. and M.Sc. degrees in Electrical Engineering from Azad University, Ardabil and Science and Technology Research Branch, Tehran, Iran in 2005 and 2009, respectively. His areas of interest in research are the Application of Robust Control, Artificial Intelligence to Power System Control and restructuring, optimization in Distribution Generation and power system.

Heidarali Shayanfar received the B.S. and M.S.E. degrees in Electrical Engineering in 1973 and 1979, respectively. He received his Ph. D. degree in Electrical Engineering from Michigan State University, U.S.A., in 1981. Currently, he is a Full Professor in Electrical Engineering Department of Iran University of Science and Technology, Tehran, Iran. His research interests are in the Application of Artificial Intelligence to Power System Control Design, Dynamic Load Modeling, Power System Observability Studies, Voltage Collapse, Congestion Management in a Restructured Power System, Reliability Improvement in

Distribution Systems and Reactive Pricing in Deregulated Power Systems. He has published more than 350 technical papers in the International Journals and Conferences proceedings. He is a member of Iranian Association of Electrical and Electronic Engineers and IEEE.

Bart Wyns received the B.S. and M.Sc. degree in Computer Science in 1999 and 2001, respectively from Ghent University, Belgium. He received his Ph.D. degree in Computer Science from the same university in 2007. Currently, he is a postdoctoral research fellow in the Department of Electrical Energy, Systems and Automation. His research interests include application of artificial intelligence to mobile robotics, swarm robotics, human machine interfacing.

Ali Ghasemi received the B.S. degree in Electrical Engineering from Esfahan University of Technology, Esfahan, Iran in 2009. Currently, he is a M.S.E. student in Technical Eng. Department of the University of Mohaghegh Ardabili, Ardabil, Iran. His Areas of interest in Research are the Application of Heuristic Optimization to Power System Control.