

# Modified Artificial Bee Colony based on Multi-Stage Fuzzy Load Frequency Control in Deregulated Environment

Oveis Abedinia<sup>\*1</sup>, Roza Poursoleyman<sup>2</sup>, Ali Ghasemi<sup>3</sup>

Technical Engineering Dept., University of Mohaghegh Ardabili, Ardabil, Iran

<sup>\*1</sup>oveis.abedinia@gmail.com; <sup>2</sup>roza.poursoleyman@gmail.com; <sup>3</sup>ghasemi.agm@gmail.com

## Abstract

A Modified Artificial Bee Colony is presents this paper to solve the Load Frequency Control (LFC) problem of power systems in deregulated environment, which called Interactive Artificial Bee Colony (IABC). In this paper a new strategy of controller is proposed which is named Multi-stage Fuzzy (MSF) controller based. LFC problem are caused by small load perturbations, which continuously disturb the normal operation of power system. The objectives of LFC are to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zero. In the proposed controller, the signal is tuned online using the knowledge base and fuzzy inference. Also, to reduce the design effort and optimize the fuzzy control system, membership functions are designed automatically by the proposed IABC method. Obtained results from the proposed controller are compared with the results of several other LFC controllers. These comparisons demonstrate the superiority and robustness of the proposed strategy.

## Keywords

LFC, Multi-Stage Controller, IABC, Deregulated Environment

## Introduction

Power systems are used to convert natural energy into electric power. For correct operation of a power system active power balance and reactive power balance must be maintained between the generators and loads [1-2]. Accordingly, these two balances correspond to two equilibrium points: frequency and voltage. When these two balances are broken and reset at a new level, the equilibrium points will float, while it is clear that these are required for a good quality of the electric power system during operation. Hence, control systems should be provided to cancel the effects of random load changes and keep the frequency and voltage at the standard levels [3-5].

Actually, the frequency is highly dependent on the active power and the voltage is highly dependent on the reactive power. Hence, frequency control based on the active power and voltage control based on reactive power are implemented. The former is referred to as Load Frequency Control (LFC) [6-8].

In the industry, Proportional Integral (PI) controllers have been widely used for decades as the load frequency controllers. Actually, several techniques have been proposed to design the PI controller [9], where the controller parameters of the PI controller are tuned using trial-and-error approach. However, it gives poor performance in the

system transient response [9]. Proportional Integral Derivative (PID) method has been proposed to improve the performance of the PI controller [10]. However, the mentioned technique needs to a more complex design process.

To overcome the mentioned backwards, new Multi-stage fuzzy PID controller is proposed in this paper to solve LFC problem. Actually, the proposed technique has two dimensional rules and needs fewer resources to operate. Effective designs of the fuzzy controllers depend on choosing appropriate membership function, rule base inference mechanism and defuzzification [11-12]. Among these factors, tuning of the membership functions is really important for the performance of the fuzzy PID controller. Maybe, tuning of the membership functions by human experts is appropriate; however such experts may not be available. To remedy this problem intelligent techniques, such as particle swarm optimization (PSO) and Genetic Algorithm (GA), have been proposed for optimal tuning of the fuzzy LFC controller [13-14, 8]. However, these techniques have low search ability for finding optimal solutions of complex nonlinear problems.

In this paper, an Interactive Artificial Bee Colony (IABC) is proposed for optimal tuning of the membership functions of the fuzzy LFC controller. This technique is a new search algorithm that has been proven efficient in solving many problems. However, the author propose higher order objective functions for (a) better curve fitting of its running, (b) less approximation, (c) more practical, accurate and reliable results, and modified Interactive Artificial Bee Colony (IABC) is introduced to calculate the LFC problem of the proposed higher order function polynomials. Constraint management is incorporated in the IABC and no extra concentration is needed for the higher order objective functions.

The main advantages of the proposed technique are that it is not sensitive to initial parameter values and also not affected by increasing the dimension of problem. Also this technique is strong robustness, fast convergence and high flexibility, fewer setting parameters. ABC algorithm can be used for solving multidimensional and multimodal optimization problems. However, this technique has the disadvantages premature convergence in the later search period and the accuracy of the optimal value which cannot meet the requirements sometimes. For this purpose the Interactive ABC is proposed to preventing of this problem.

The remaining parts of the paper are organized as follows. In section 2, the LFC model is described. The proposed IABC algorithm is introduced in section 3. The suggested fuzzy PID controller for LFC and application of the IABC for its optimal tuning are presented in section 4. The proposed controller is tested on three area deregulated power system and its obtained results are compared with the results of several other LFC controllers in section 5. These comparisons reveal the effectiveness of the proposed controller for LFC. Section 6 concludes the paper.

### LFC Model Description

Traditionally, electric industry is vertically integrated with all the transmission, generation and distribution under its control with interconnecting with the neighboring areas. Whereas, in deregulated power systems, the Vertically Integrated Utility (VIU) no longer exists [15]. However, the usual LFC objectives, i.e. reconstruction the frequency and the net interchanges to their ideal values for each control area, still remain. For the purpose of evaluating the performance of such a system, a flexible technique has been developed and implemented. The method assumes that LFC is performed by an Independent System Operator (ISO) based on parameters defined by the participating generating units [16]. The participant units comprise beneficial generators and independent power producers. The utilities describe the units, which will be under LFC, while the independent power producers may or may not participate in the load frequency control [17, 8].

The LFC is a technical requirement for the proper operation of an interconnected power system. The capability of the system to control and balance the load-generation-and-frequency is measured with the area control error of Automatic Generation Control (AGC). In a deregulated and open competition environment, LFC becomes a commodity that can be traded [18].

Generating units participating in the LFC provide a service for which they must be compensated. Alternatively, a generating unit utility or independent producer, may elect not to participate in the LFC in which case it must be penalized or compensate the rest of the system for the service it receives. Conceptually, load-frequency control may be offered or received by any generating unit in the system. Units may make the choice in real time [19]. Accordingly, the total generating capacity participating in LFC may vary in real time. In this situation, it may be expected that the frequency deviations may be large at times when the portion of generating capacity on load-frequency control is low compared to the total load [20, 8].

In the restructured power system, Generation Companies (GENCOs) may or may not participate in the AGC task. Also, Distribution Companies (DISCOs) have the liberty to contract with any available GENCOs in their own or other areas. Therefore, there can be various combinations of the possible contracted scenarios between DISCOs and GENCOs [25]. The Augmented Generation Participation

Matrix (AGPM) is defined to express these possible contracts in the generalized model. The rows and columns of AGPM is identical with the total number of GENCOs and DISCOs in the overall power system, respectively [21, 8]. The AGPM structure for a large scale power system with  $N$  control area is given by:

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

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

$$s_i = \sum_{k=1}^{i-1} n_k, z_j = \sum_{k=1}^{j-1} m_k, i, j = 2, \dots, N \text{ \& } s_1 = z_1 = 0$$

Where,

$n_i$  = number of GENCOs in area  $i$

$m_i$  = number of DISCOs in area  $i$

$gpf_{ij}$  = 'generation participation factor' and display the participation factor GENCO $_i$  in total load following requirement of DISCO $_j$  based on the possible contracts. The block diagram of LFC model in a deregulated environment is presented in Fig. 1. According to this fact that, there are many GENCOs for each area, ACE signal should be distributed among them due to their ACE participation

$$\sum_{j=1}^{n_i} apf_{ij} = 1$$

factor in the LFC task and

Also it can be written [7];

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

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

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{n_i} \sum_{t=1}^{m_k} apf_{(s_i+j)(z_k+t)} \Delta P_{L(z_k+t)-k} -$$

$$\sum_{t=1}^{n_k} \sum_{j=1}^{m_i} apf_{(s_k+t)(z_i+j)} \Delta P_{L(z_i+j)-i}$$

$$\Delta P_{tie,i-error} = \Delta P_{tie,i-actual} - \zeta_i \quad (3)$$

$$\rho_i = [\rho_{i1} \cdots \rho_{i2} \cdots \rho_{in_i}] \quad , \quad \rho_{ki} = \Delta P_{m,k-i}$$

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

Where,  $\Delta P_{m,ki}$  = desired total power generation of a GENCO $_k$  in area  $i$

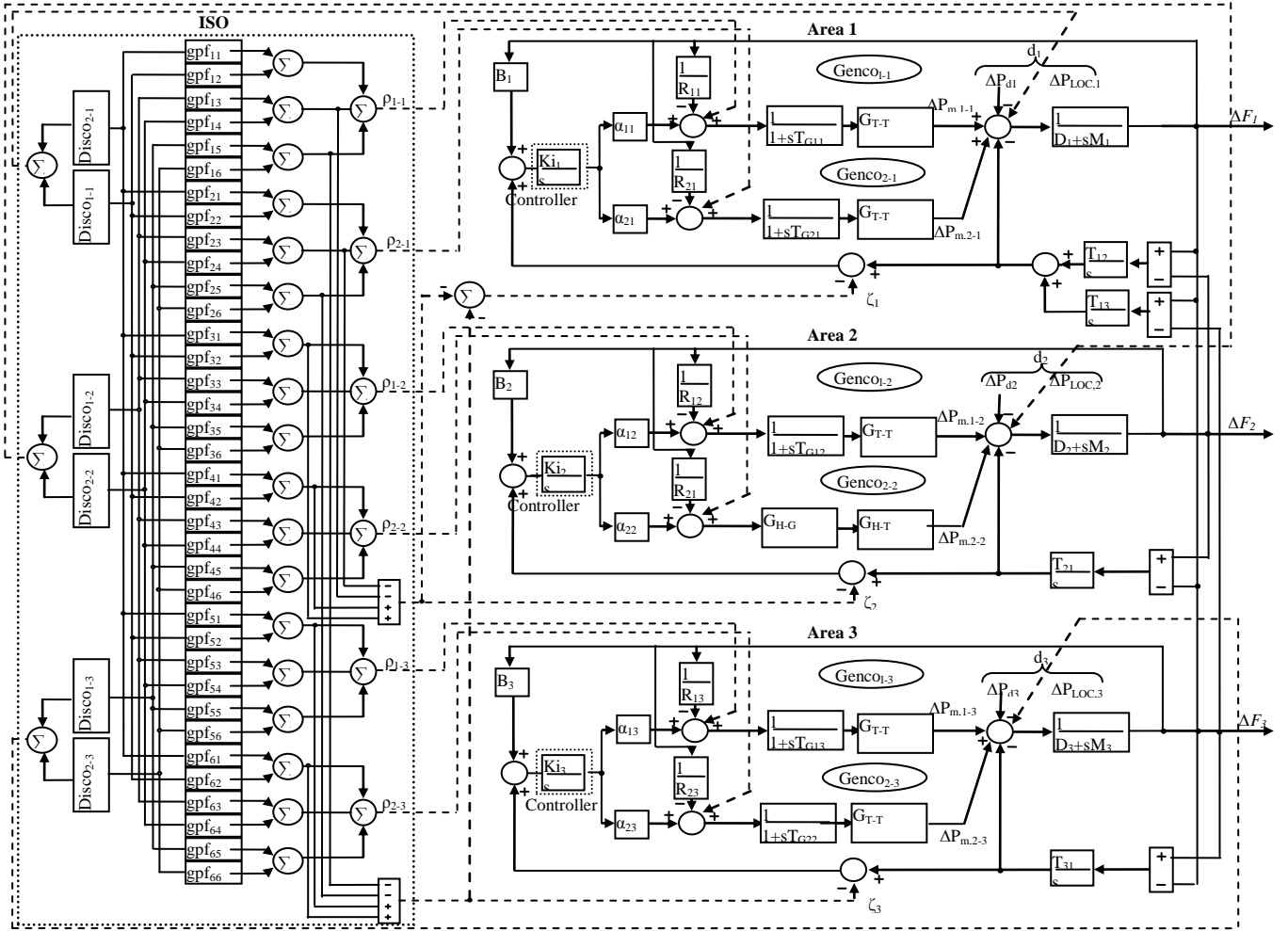


Figure 1. Generalized LFC model in the restructured system

$\Delta P_{m,ki}$  must track the demand of the DISCOs in contract with it in the steady state. For each control area two GENCOs and DISCOs are considered [8]. The parameters of proposed power system are presented in Tables 1 and 2.

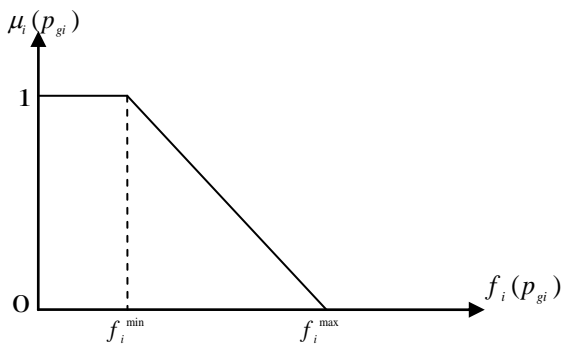


Figure 2. Membership function of fuzzy function.

TABLE I. THE PARAMETERS OF GENCOs

MVA <sub>base</sub> (1000MW)	GENCOs (k in area i)					
Parameter	1-1	2-1	1-2	2-2	1-3	2-3
Rate (MW)	1000	800	1100	900	1000	1020
$T_T$ (sec)	0.32	0.30	0.30	0.32	0.31	0.34
$T_G$ (sec)	0.06	0.08	0.06	0.07	0.08	0.06
$R$ (Hz/pu)	2.4	2.5	2.5	2.7	2.8	2.4
$\alpha$	0.5	0.5	0.5	0.5	0.6	0.4

TABLE II. THE PARAMETERS OF CONTROL AREA

Parameter	Area-1	Area-2	Area-3
$K_P$ (Hz/pu)	120	120	125
$T_P$ (sec)	20	25	20
$B$ (pu/Hz)	0.4250	0.3966	0.3522
$T_{ij}$ (pu/Hz)	$T_{12}=0.245$		$T_{13}=0.212$

Interactive Artificial Bee Colony

### Review of Artificial Bee Colony

Recently, an Artificial Bee Colony (ABC) algorithm based on the foraging behavior of the honey-bees is presented by Karaboga and Basturk [22] for optimization problems. The proposed technique simulates the intelligent foraging behavior of the honey bee swarms. Also, this algorithm is very simple, robust and population based stochastic optimization technique [23].

The colony of artificial bees contains three groups of bees in the proposed algorithm in literature as: employed bees, onlookers and scouts. A bee expecting on the dance section for making decision to opt a food source is called an onlooker and a bee going to the food source visited by it previously is named an employed bee. A bee executive random search is called a scouter. In the ABC algorithm, half of the colony conclude of employed artificial bees and

the other half constitutes the onlookers. The employed bee whose food source is tired by the employed and onlooker bees becomes a scout. The main stages of the algorithm are given below [22, 23]:

- *Initialize*
- *REPEAT*
- *Place the employed bees on the food sources in the memory*
- *Place the onlooker bees on the food sources in the memory*
- *Send the scouts to the search area for discovering new food sources*
- *UNTIL (requirements are met)*

In the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods; determining the scout bees and then sending them onto possible food sources. In the ABC algorithm, the location of source represents a possible solution of the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. The numeral of the employed bees or the onlooker bees is equal to the number of solutions in the population. At first, the proposed technique generates a randomly distributed initial population  $P(G=0)$  of SN solutions (food source locations), where SN explains the size of population. Each solution (food source)  $x_i$  ( $i = 1, 2, \dots, SN$ ) is a D-dimensional vector [24]. Here, D is the number of optimization parameters. After initial population, the population of the positions (solutions) is subjected to repeated cycles,  $C = 1, 2, \dots, C_{max}$ , of the search processes of the employed bees, the onlooker bees and scout bees. An artificial employed or onlooker bee probabilistic produces a correction on the position (solution) in their memory for finding a new food source and tests the nectar amount (fitness value) of the new source (new solution). The artificial bees randomly select a food source position and produce a modification on the one existing in their memory. Provided that the nectar amount of the new source is higher than that of the previous one the bee memorizes the new position and forgets the old one. Differently, she keeps the location of the previous one. After all employed bees complete the search procedure; they share the nectar information of the solutions and their location information with the onlooker bees on the dance area. An onlooker bee appraises the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. As in the case of the employed bee, she produces a modification on the position (solution) in her memory and checks the nectar amount of the candidate source (solution). Providing that its nectar is higher than that of the previous one, the bee memorizes the new position and forgets the old one [25]. An onlooker bee chooses a food source depending on the probability value associated with that food source,  $p_i$ , calculated by the following expression:

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (4)$$

Where,  $fit_i$  is the fitness value of the solution  $i$  evaluated by its employed bee, 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 (BN). In this way, the employed bees exchange their information with the onlookers.

In order to produce a candidate food position from the old one, the ABC uses the following expression:

$$v_{ij} = x_{ij} + \phi_{ij} (x_{ij} - x_{kj}) \quad (5)$$

Where,  $k \in \{1, 2, \dots, BN\}$  and  $j \in \{1, 2, \dots, D\}$  are randomly chosen indexes. Although  $k$  is determined randomly, it has to be different from  $i$ .  $\phi_{ij}$  is a random number between  $[-1, 1]$ . It controls the production of a neighbor food source position around  $x_{ij}$  and the modification represents the comparison of the neighbor food positions visually by the bee. Equation (6) shows that as the difference between the parameters of the  $x_{ij}$  and  $x_{kj}$  decreases, the perturbation on the position  $x_{ij}$  decreases, too. Thus, as the search approaches to the optimum solution in the search space, the step length is adaptively reduced.

If a parameter achieved by this operation exceeds its predetermined limit, the parameter can be set to an allowable value. In this paper, the value of the parameter exceeding its limit is set to its limit value. The source whose nectar is leaved by the bees is replaced with a new food source by the scouts. If a position cannot be improved more through a predetermined number of cycles called limit then that food source is assumed to be abandoned [24].

After each candidate source position  $v_{ij}$  is produced and then evaluated by the artificial bee, its efficiency is compared with that of  $x_{ij}$ . If the new food has equal or superior nectar than the old source, it is changed with the old one in the memory. Differently, the old one is retained. In other means, a greedy selection mechanism is employed as the selection operation among the old and the current food sources.

ABC algorithm in fact employs four different selection processes:

1. A global selection procedure applied by the artificial onlooker bees for discovering promising.
2. A local selection procedure considered in an area by the artificial employed bees and the onlookers depending on the local information (in case of real bees, this information concludes the color, form and perfume of the flowers) (bees will not be able to identify the type of nectar source until they arrive at the right location and discriminate among sources growing there based on their scent) to specify a neighbor food source around the source in the memory.
3. A local selection procedure called greedy selection process done by all bees in that if the nectar amount of the candidate source is better than that of the present one, the bee disremembers the present one and memorizes the candidate source. Differently, the bee keeps the present one in the memory.
4. A random selection process carried out by scouts.

It is clear from the above statement that there are three control parameters used in the basic ABC: The number of the food sources which is equal to the number of employed

or onlooker bees (SN), the value of limit and the Maximum Cycle Number (MCN).

### Interactive ABC

An Interactive ABC (IABC) optimization algorithm for solving LFC problem has been proposed in this research. The algorithm maps the forager bee's path development mechanism to pick new coordinates. The forager bee is directed by scout bee which evaluates the fitness values of all possible neighboring coordinates. Unfortunately, in ABC the original design of the onlooker bee's movement only considers the relation between the employed bee, which is selected by the roulette wheel selection, and the one selected randomly. Hence, it is not strong enough to maximize the exploitation capacity. The IABC is proposed by employing the Newtonian law of universal gravitation [25]. The universal gravitations between the onlooker bee and the selected employed bees are exploited which is described as:

$$F_{12} = G \frac{m_1 m_2}{r_{21}^2} \hat{r}_{21} \quad (6)$$

Where,

$F_{12}$  = the gravitational force heads from the object 1 to the object 2

$G$  = the universal gravitational constant

$m_1, m_2$  = the masses of the objects

$r_{21}$  = the separation between the objects

$$\hat{r}_{21} = \frac{r_2 - r_1}{|r_2 - r_1|} \quad (7)$$

In this technique, the mass  $m_1$  is substituted by the parameter. The mass,  $m_2$ , is substituted by the fitness value of the randomly selected employed bee and is denoted by the symbol,  $f_{iti}$ .

### Fuzzy Mechanism

Upon having the Pareto-optimal set of non-dominated solution, the proposed approach presents one solution to the decision maker as the best compromise solutions. Due to imprecise nature of the decision maker's judgment, the  $i^{\text{th}}$  objective function is represented by a membership function  $\mu_i$  defined as [15]:

$$\mu_i(p_{gi}) = \frac{f_i^{\max} - f_i(p_{gi})}{f_i^{\max} - f_i^{\min}} \quad (8)$$

Where,  $f_i^{\max}$  and  $f_i^{\min}$  are the maximum and minimum values of  $i^{\text{th}}$  objective, respectively.

$$FDM_i(p_{gi}) = \begin{cases} 0 & \mu_i(p_{gi}) \leq 0 \\ \mu_i(p_{gi}) & 0 < \mu_i(p_{gi}) < 1 \\ 1 & \mu_i(p_{gi}) \geq 1 \end{cases} \quad (9)$$

For each non-dominated solution  $k$ , the normalized membership function  $FDM^k$

$$FDM^k = \left[ \frac{\sum_{i=1}^2 FDM_i^k(p_{gi})}{\sum_{j=1}^M \sum_{i=1}^2 FDM_i^j} \right] \quad (10)$$

The best compromise solution of LFC problem is the one having the maximum value of  $FDM^k$  as fuzzy decision

making function. Where,  $M$  is the total number of non-dominated solutions. Then all the solutions are arranged in descending order according to their membership function values which will guide the decision makers with a priority list of non-dominated solutions in view of the current operating conditions. Figure. 2, shows the membership structure  $\mu_c$  for the fuzzy logical variable of  $f_i(P_{gi})$ .

### Multi-Stage Fuzzy Controller

#### Conventional Fuzzy Controller

A fuzzy control strategy is a control system based on fuzzy logic which is based on a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1. Accordingly, in this strategy the contrast to classical or digital logic operates on discrete values of either 1 or 0 (true or false, respectively). The concept of fuzziness comes from uncertainty about the domain being represented. Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions [11]. Also, the fuzzy controller has very simple conceptually which consist of an input stage, a processing stage, and an output stage. The conventional structure for fuzzy controller is presented in Fig. 3. The general, the process of fuzzy controller is defined as follows:

- The system's operational specifications and inputs and outputs.
- The fuzzy sets for the inputs.
- The rule set.
- Determine the defuzzification method.
- Run through test suite to validate system, adjust details as required.
- Complete document and release to production.

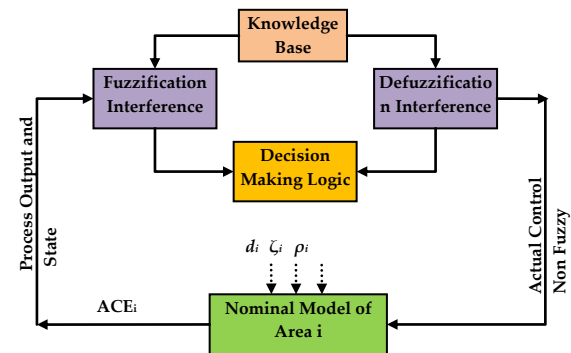


Figure 3. The conventional fuzzy controller structure

#### IABC Based on MSF Controller

According to this fact that in conventional fuzzy controller finding rules needs a three dimensional information and the design process is very difficult, the multi-stage strategy is proposed in this paper [12]. In this controller, input values are converted to truth value vectors and applied to their respective rule base. It is clear that the output truth value vectors are not defuzzified to crisp values as with a single

stage fuzzy logic controller however are passed on to the next stage as a truth value vector input. The truth value vectors are indicated in proposed controller strategy in Fig. 4, by darkened lines [12].

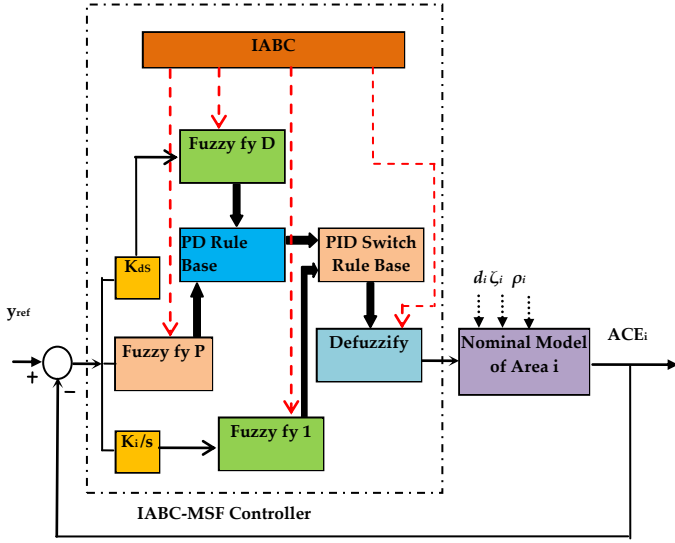


Figure 4. Structure of the proposed controller

In this paper the membership functions are described as a triangular partition with seven segments from -1 to 1 which is presented Fig. 5. In this triangular the segments are named as; Zero (ZO) is the center membership function, NB is Negative Big, NM is Negative Medium, NS is Negative Small, PS is Positive Small, PM is Positive Medium and PB is Positive Big. According to the membership function in figure 6, it is clear that the parameters of 'a' and 'b' must be;  $0 < a < b < 1$ .

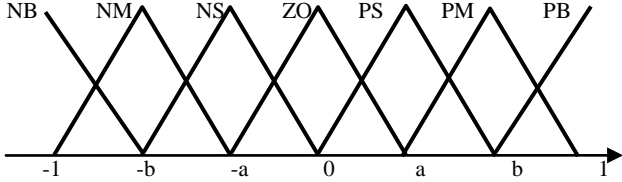


Figure 5. Symmetric fuzzy partition

Also in this controller there are two rule bases. The first one is the PD rule base as it operates on truth vectors from the error (e) and change in error (e) inputs. And the second one is PID switch rule base while, if the PD input is in the zero fuzzy set, the PID switch rule base passes the integral error values ( $\int e$ ) which are presented in Table 3 and 4, respectively.

TABLE III. RULE BASE OF PD

		$\Delta e$						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	ZO	PS	PM
	ZO	NB	NM	NS	ZO	PS	PM	PB
	PS	NM	NS	ZO	PS	PM	PB	PB
	PM	NS	ZO	PS	PM	PB	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

TABLE IV. PID SWITCH RULE BASE

		PD values						
		NB	NM	NS	ZO	PS	PM	PB
$\int e$	NB	NB	NM	NS	NB	PS	PM	PB
	NM	NB	NM	NS	NM	PS	PM	PB
	NS	NB	NM	NS	NS	PS	PM	PB
	ZO	NB	NM	NS	ZO	PS	PM	PB
	PS	NB	NM	NS	PS	PS	PM	PB
	PM	NB	NM	NS	PM	PS	PM	PB
	PB	NB	NM	NS	PB	PS	PM	PB

This proposed strategy includes two level controllers. In first level a fuzzy network and in the second level PID controller is considered. For this purpose, the  $K_{Pi}$ ,  $K_{Ii}$  and  $K_{Di}$  gains are calculated in literature as:

$$u_i = K_{Pi} ACE_i(t) + K_{Ii} \int_0^t ACE_i(t) dt + K_{Di} ACE(t) \quad (11)$$

In this paper two performance indices are considered simultaneously as a multi-objective optimization problem. Accordingly, Integral of the Time multiplied Absolute value of the Error (ITAE) based on  $ACE_i$  and the Figure of Demerit (FD) based on system responses characteristic are considered as:

$$ITAE = \int_0^{10} t (|ACE_1(t)| + |ACE_2(t)| + |ACE_3(t)|) dt \quad (12)$$

$$FD = (OS \times 10)^2 + (US \times 4)^2 + (TS \times 0.3)^2 \quad (13)$$

## Simulation Results

### Benchmark

For testing the proposed technique, IABC is tested over standard benchmark of rastrigin function in literature as:

$$f(x) = 20 + \sum_{i=1}^n (x_i^2 - 10 \cdot \cos(2\pi x_i)) \quad (14)$$

$$-3 \leq x_1 \leq 12.1$$

$$4.1 \leq x(2) \leq 12.8$$

Also Fig. 6 shows the output of the software for objective function's shape. And the proposed convergence is presented in Fig 7 with the percentage of relative changes. Table 5 presents the average results over many runs.

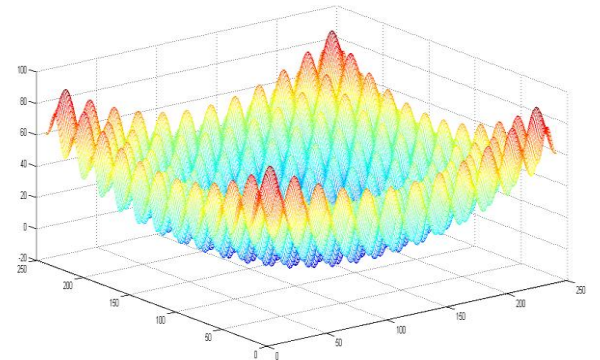


Figure 6. 3-D display of rastrigin function



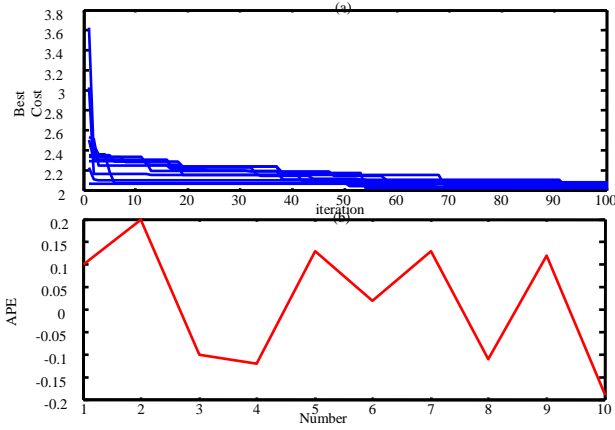


Figure 7. IABC convergence curve (a) the percentage of relative changes (b)

TABLE V. THE AVERAGE RESULTS OVER MANY RUNS OF IABC

Run	Max	Ave	Min	X(1)	X(2)
1	44.3207	19.7712	2.0307	1.0140	1.0013
2	44.9420	19.5894	2.0098	1.0036	1.0013
3	44.6291	19.6194	2.0810	1.0033	1.0365
4	47.6984	20.1500	2.0455	1.0150	1.0076
5	43.0306	18.5679	2.0700	1.0086	1.0261
6	47.1777	20.4238	2.0617	1.0275	1.0029
7	43.9167	19.7739	2.1128	1.0032	1.0519
8	49.3832	19.6031	2.0808	1.0222	1.0177
9	47.6276	19.2021	2.0537	1.0181	1.0085
10	46.6017	19.6280	2.0671	1.0234	1.0098
AVE	45.9328	19.6329	2.0613	1.0139	1.0164
SD	1.9406	0.4748	0.0273	0.0085	0.0161

All of the simulation and the achieved results are calculated with MATLAB R2010a software in ASUS computer (Intel(R) Core™i5-2430M CPU@2.40GHz). The trend of proposed technique is shown in Fig. 8. Also the optimum parameters achieved by SPHBMO for 'a' and 'b' parameters are presented in Table. 6.

In this paper, a nonlinear turbine model with  $\pm 0.1$  replaces the linear model of turbine  $\Delta P_{Vki}/\Delta P_{Tki}$  which is presented in [16].

TABLE VI. OPTIMAL VALUES OF PARAMETERS A AND B

Membership Function	Classic GA		Modified GA		IABC	
	A	b	a	b	a	b
$ACE_i$	0.7896	0.9437	0.7097	0.9677	0.7003	0.9700
$\Delta ACE_i$	0.3994	0.6106	0.4194	0.5806	0.4346	0.5819
$\int ACE$	0.5413	0.8152	0.4516	0.7742	0.4301	0.7785
Output	0.4513	0.7817	0.4742	0.7738	0.4614	0.7801

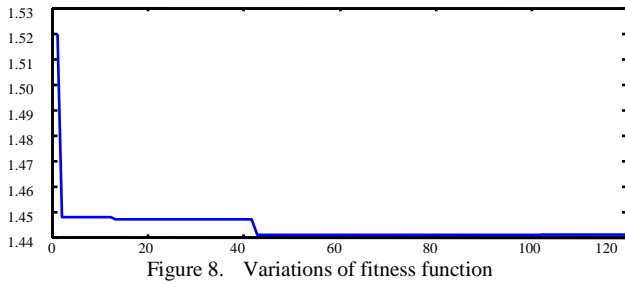


Figure 8. Variations of fitness function

Also, for each DISCO demands 0.1 pu MW is considered. Also, it is possible that a DISCO violates a contract by demanding more power than that of specified in the contract. This excess power should 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.

Also for test the robustness of proposed controller the case study is tested against uncertainties and large load disturbances in the presence of GRC [16]. For this purpose two scenarios are applied as:

#### Scenario 1

In this scenario, GENCOs participate only in load following control of their areas. It is assumed that for each DISCO, a large step load of 0.1 p.u. is demanded in areas 1 and 2. Also it is assumed that a case of *Poolco* based contracts between DISCOs and available GENCOs are simulated based on the following AGPM. Also the GENCOs of area 3 do not participate in the AGC task.

$$AGPM = \begin{bmatrix} 0.6 & 0.5 & 0 & 0 & 0 & 0 \\ 0.4 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

The Deviation of frequency and tie lines power flows for +25% changes and the GENCOs power changes is presented in Fig. 9. Also the desired values in this scenario are;

$$\Delta P_{M,1-1} = -0.11 \text{ pu MW} \quad \Delta P_{M,2-1} = 0.09 \text{ pu MW}$$

$$\Delta P_{M,1-2} = -0.1 \text{ pu MW} \quad \Delta P_{M,2-2} = -0.1 \text{ pu MW}$$

#### Scenario 2

In this scenario, the combination of poolco and bilateral based transactions is considered. Where, all of the DISCOs are able to contract with any GENCO in their area. The task of all GENCOs is LFC. GENCO 1 in area 2 and GENCO 2 in area 3 only participate for performing the LFC task in their areas, while the other GENCOs track the load demand in their area and/or other areas. The AGPM for this scenario is:

$$AGPM = \begin{bmatrix} 0.25 & 0 & 0.25 & 0 & 0.5 & 0 \\ 0.5 & 0.25 & 0 & 0.25 & 0 & 0 \\ 0 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0.25 & 0 & 0.5 & 0.75 & 0 & 0 \\ 0 & 0.25 & 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

In this scenario the large step load 0.1 pu MW is demanded by each DISCO in all areas. Simulation results for 25% increasing and the power changes are shown in Fig. 10. For this scenario the used information are in detail as:

$$\Delta P_{tie2,1,sch} = 0.025, \quad \Delta P_{M,1-1} = 0.1 \text{ pu MW}$$

$$\Delta P_{tie3,1,sch} = -0.025$$

$$\Delta P_{M,1-2} = -0.075 \text{ pu MW} \quad \Delta P_{M,1-3} = -0.075 \text{ pu MW}$$

$$\Delta P_{M,2-1} = -0.1 \text{ pu MW}$$

$$\Delta P_{M,2-2} = 0.15 \text{ pu MW}$$

$$\Delta P_{M,2-3} = 0.1 \text{ pu MW}$$

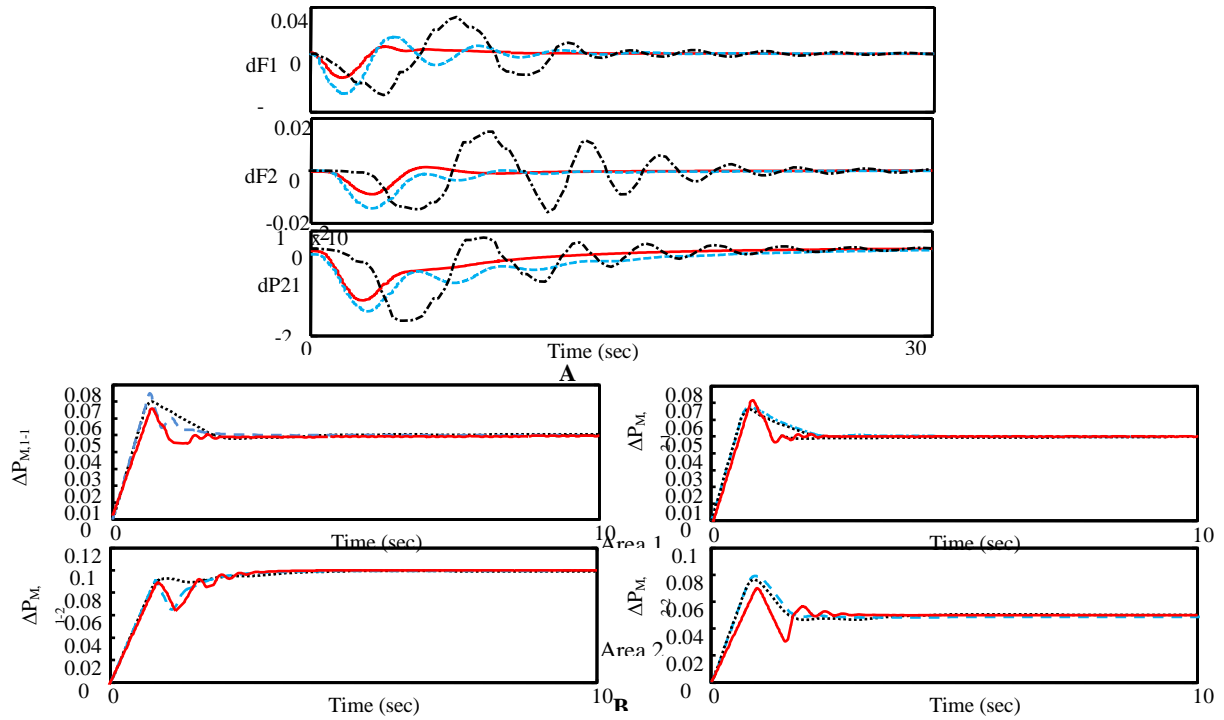


Figure 9. a) Frequency deviation and tie line power flows, b) GENCOs power changes; solid (IABC-MSF), dashed (GAMSF) and dotted (FPID).

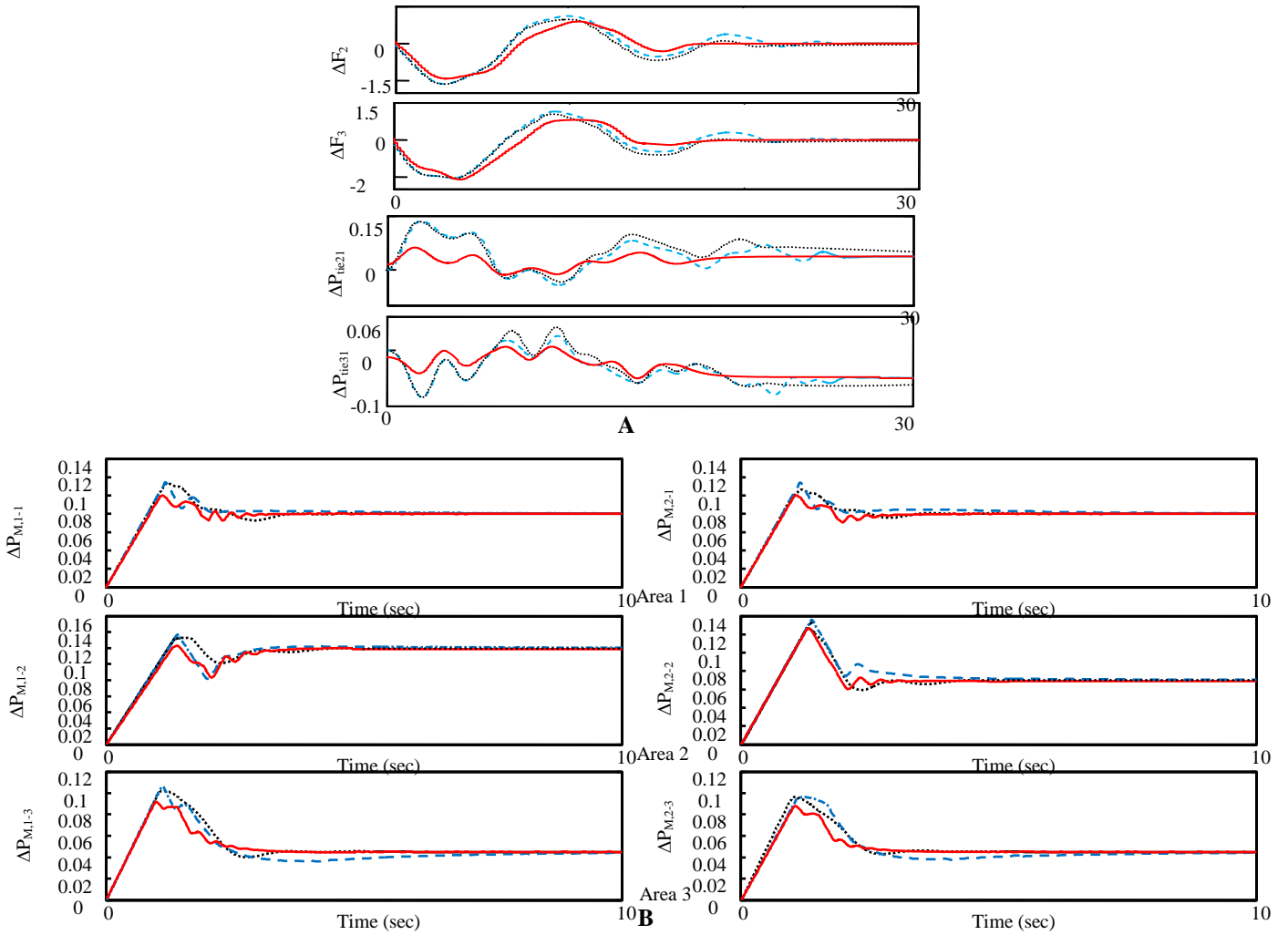


Figure 10. a) Frequency deviation and tie line power flows, b) GENCOs power changes; solid (IABC-MSF), dashed (GAMSF) and dotted (FPID).



▪ **Scenario 3**

In this Scenario, it may happen that a DISCO violates a contract by demanding more power than that specified in the contract [8]. This excess power must be reflected as a local load of the area but not as the contracted demand to be taken up by the GENCOs in the same area. The system's data are considered as follow:  $DISCO_{1-1} = 0.06$  pu MW,  $DISCO_{2-1} = 0.00$  pu MW,  $DISCO_{1-2} = 0.00$  pu MW,  $DISCO_{2-2} = 0.05$  pu MW,  $DISCO_{1-3} = 0.02$  pu MW and  $DISCO_{2-2} = 0.02$  pu MW. The total loads in areas are calculated as:

$$P_{Loc,1} = 0.1 + 0.06 + 0.1 = 0.26$$

$$\Pi_{A_{Oy,2}} = 0.1 + 0.1 + 0.05 = 0.25$$

$$P_{Loc,3} = 0.1 + 0.02 + 0.1 + 0.02 = 0.24$$

Fig. 11 shows the Deviation of frequency and tile lines power flows in proposed system and the GENCOs power changes.

▪ **Scenario 4**

In this scenario the contract is assumed as scenario 2. Also, demand load for each DISCO is considered 0.1 p.u. and the load changes as a turbulence for power system is considered in Fig. 12 where;

$$-0.05 \leq \Delta P_{di} \leq 0.05 \text{ p.u.}$$

Testing the robustness and flexibility of the proposed technique is the aim of this scenario. For this purpose, the frequency variation in each area and Deviation tile lines power flows is presented in Fig. 13.

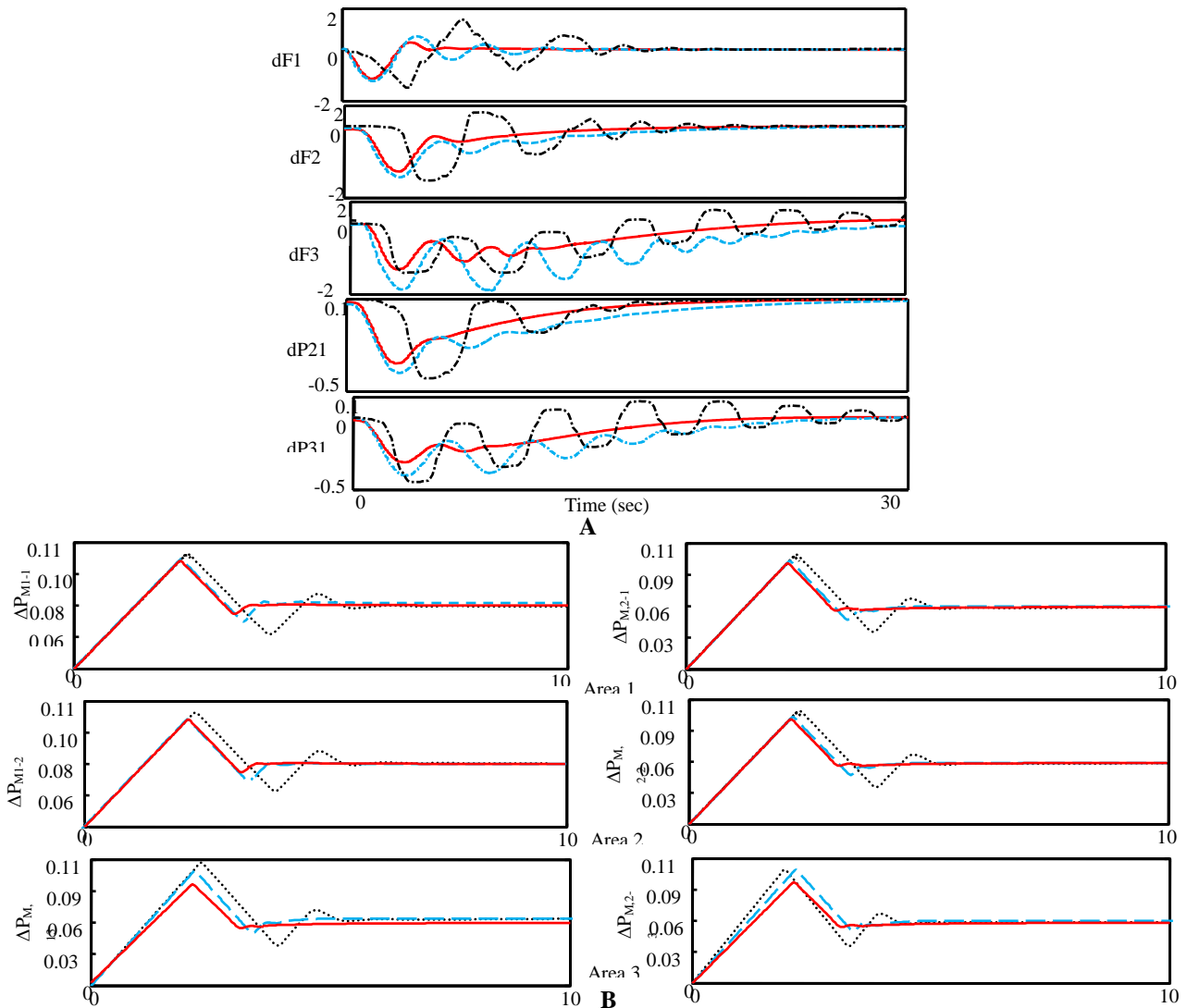


Figure 11. a) Frequency deviation and tie line power flows, b) GENCOs power changes; solid (IABC-MSF), dashed (GAMSF) and dotted (FPID).

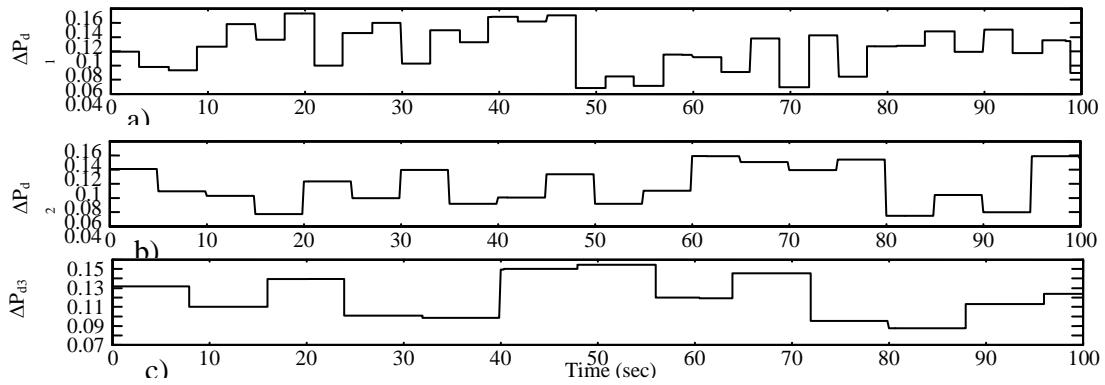


Figure 12. The pattern of random load: a) area 1, b) area 2, c) area 3

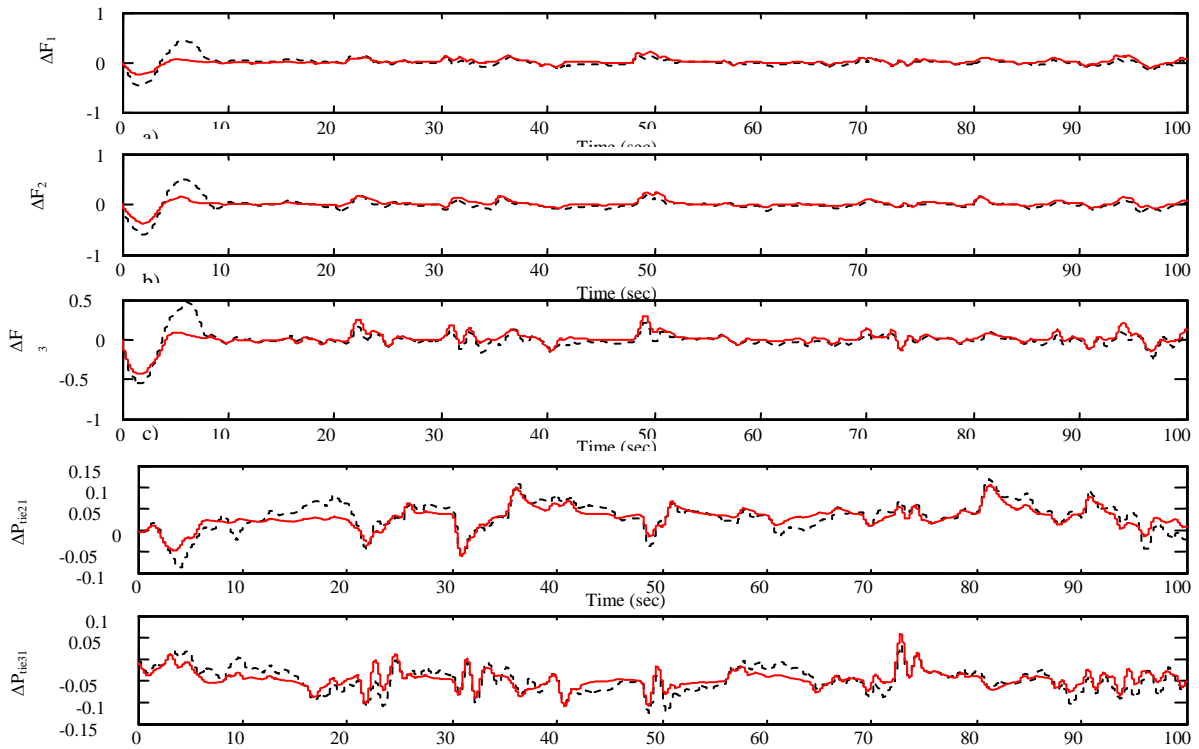


Figure 13. Deviation tile lines power flows and he frequency variation in each area: a) area 1, b) area 2, c) area 3, solid (IABC-MSF), Dashed (GAMSF)

Also the diagram results of ITAE and FD are presented in Fig. 14-16, which demonstrates the robustness of the proposed technique in LFC problem [12].

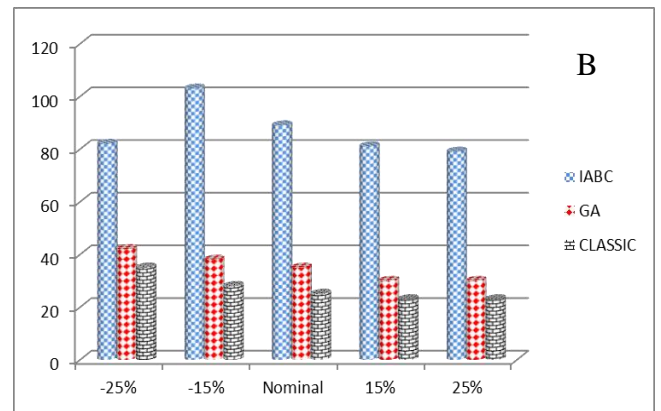
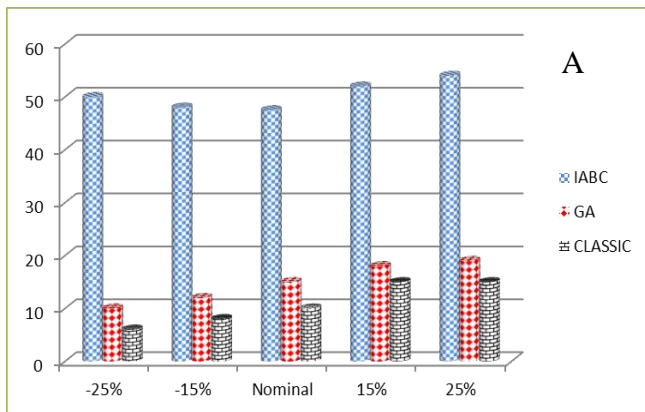


Figure 14. Values of performance indices of scenario 1; ITAE: (A), FD: (B)

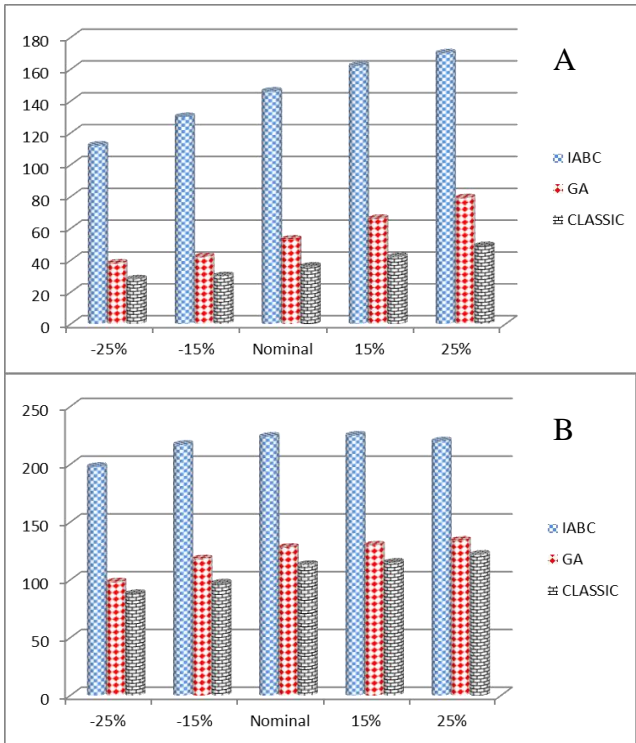


Figure 15. Values of performance indices of scenario 2; ITAE: (A), FD: (B)

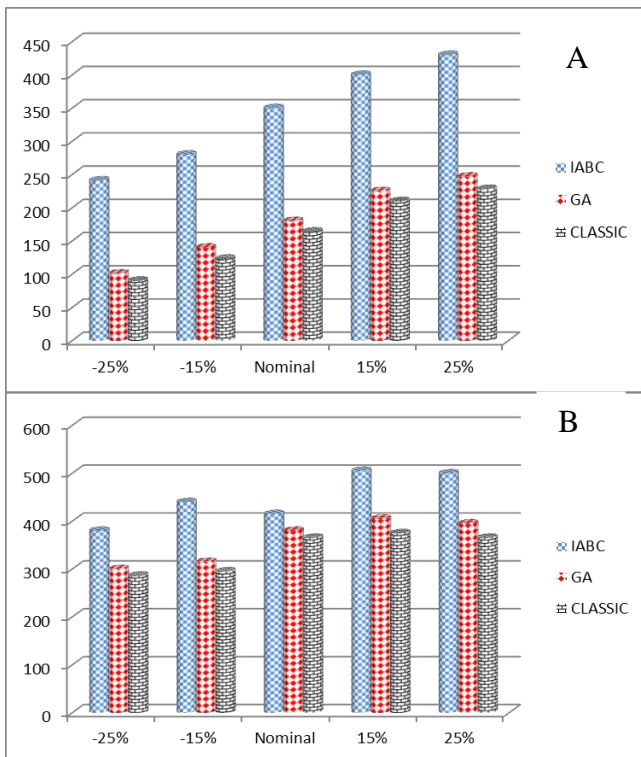


Figure 16. Values of performance indices of scenario 3; ITAE: (A), FD: (B)

According to the simulation results it is clear that overshoot, undershoot and settling time of frequency deviation are in better situation rather than compared techniques. Also the achieved results for ITAE and FD are lower than the multi-stage GA and fuzzy PID controllers. It means that the proposed technique minimize the transient deviation in area

frequency and tie-line power interchange of power system in deregulated environment which leads to ensure their steady state errors to be zero.

## Conclusions

In this paper, a new multi-stage fuzzy controller is proposed to solve the LFC problem in power system. The presented controller is optimized by Interactive Artificial Bee Colony (IABC) through some performance indices. The proposed technique is considered in this system to solve the multi-objective optimization problem in proposed power system. Also, this control strategy was chosen because of the increasing complexity and changing structure of the power systems. Actually, the proposed technique has two dimensional rules. And this method needs fewer resources to operate. Also, exact tuning of membership function is really important to proposed controller. For this purpose IABC is used which is new powerful algorithm for solving single or multi-objective optimization problems with real-valued or discrete parameters and is based on natural selection. The main advantages of the proposed technique are that it is not sensitive to initial parameter values and also not affected by increasing the dimension of problem. Also this technique is strong robustness, fast convergence and high flexibility, fewer setting parameters. ABC algorithm can be used for solving multidimensional and multimodal optimization problems. However, this technique has the disadvantages premature convergence in the later search period and the accuracy of the optimal value which cannot meet the requirements sometimes. For this purpose the Interactive ABC is proposed to preventing of this problem. The effectiveness of the proposed method is tested on a three-area restructured power system for a wide range of load demands and disturbances under different operating conditions in comparison with GA and CPID. The simulation results and numerical results of ITAE and FD demonstrate the superiority of proposed technique.

## REFERENCES

- [1] Y. Hssu, W. Chan, "Optimal variable structure control of interconnected hydrothermal power systems". *Elect Power Energy Syst*; Vol. 16, pp. 22–31, 1984.
- [2] F. Liu, YH. Song, J. Ma, Q. Lu, "Optimal load frequency control in the restructured power systems". *IEE Proc Gener Transm Distrib*; Vol. 15, No. 1, pp.87–95, 2003.
- [3] TC. Yang, H. Cimon, QM. Zhu, "Decentralized load-frequency control design based on structured singular values". *IEE Proc. Genre. Transm. Distrib. January*; Vol. 145, No.1, pp. 7-14, 1998.
- [4] KY. Lim, Y. Wang, R. Zhou, "Robust decentralized load frequency control of multi-area power system". *IEE Proc Gener Transm Distrib*, vol. 43, no. 5, pp: 377–86, 1996.
- [5] OI. Elgerd, "Electric energy system theory: an introduction". *New York: Mc Graw-Hill*; 1971.
- [6] A. Feliachi, "On load frequency control in a restructured environment". In: *Proceeding of the IEEE international conference on control application*, 15–18 September, pp. 437–41, 1996.
- [7] O. Abedinia, H.A. Shayanfar, B. Wyna, A. Ghasemi, Design of robust PSS to improve stability of composed LFC and AVR using ABC in deregulated environment, In: *Proceedings of the international conference on artificial intelligence*, Las Vegas, Nevada, pp: 82-88, USA, 2011.

- [8] O. Abedinia, N. Amjadi, M.S. Naderi, Multi-stage Fuzzy PID Load Frequency Control via SPHBM0 in deregulated environment, 11th Conference of Environment and Electrical Engineering (EEEIC), Page(s): 473-478, 2012.
- [9] C. Chang, W. Fu, "Area load frequency control using fuzzy gain scheduling of PI controllers". *Elect Power Sys. Res*; vol. 42, pp: 145-52, 1997.
- [10] M. Petrov, I. Ganchev, A. Taneva, "Fuzzy PID control of nonlinear plants", *In: Proceedings of the first international IEEE symposium on intelligence systems*, pp: 30-35, September 2002.
- [11] M. James, "Multi-stage fuzzy PID controller with fuzzy switch", *In: Proceeding of the IEEE international conference on control application*, vol. 4, pp: 323-327, 2001.
- [12] H. Shayeghi, A. Jalili, HA. Shayanfar, "Robust modified GA based multi-stage fuzzy LFC, *Energy Conversion and Management*", vol. 48, pp: 1656-1670, 2007.
- [13] O. Abedinia, A. Jalili, Optimal Rule-Base in Multi-Machine Fuzzy PSS Using Genetic Algorithm, *Australian Journal of Basic and Applied Sciences*, 5(10): 1424-1434, ISSN 1991-8178, 2011.
- [14] O. Abedinia, Mohammad. S. Naderi, A. Jalili, B. Khamenehpour, Optimal Tuning of Multi-Machine Power System Stabilizer Parameters Using Genetic-Algorithm, *Proceedings of International Conference on Power System Technology*, Page(s): 1-6, 24-28 October, 2010, Hangzhou, China.
- [15] H. Shayeghi, HA. Shayanfar, "PSO based neuro-fuzzy controller for LFC design including communication time delays". *International Journal on TPE (Technical and Physical Problems of Engineering) IJTPE*, June; Vol. 1, No. 2, 2010, pp. 28-36.
- [16] O. Abedinia, Mohammad. S. Naderi, A. Ghasemi, Robust LFC in Deregulated Environment: Fuzzy PID using HBMO, *Proceeding of the IEEE International Power & Energy Society Power Systems Conference and Exposition, Italy, Rome (EEEIC)*, pp. 74-77, 2011.
- [17] V. Donde, A. Pai, IA. Hiskens, "Simulation and optimization in a LFC system after deregulation". *IEEE Trans Power Syst.*; vol. 16, no. 3, pp: 481-489, 2001.
- [18] A. Feliachi, "On load frequency control in a restructured environment", *In: Proceeding of the IEEE international conference on control application*, pp: 437-441, 15-18 September 1996.
- [19] J. Kumar, NG. Hoe, G. Sheble, "LFC simulator for price-based operation. Part I: Modeling". *IEEE Trans Power Syst.*; vol. 12, no. 2, pp: 527-32, 1997.
- [20] E. Yesil, M. Guzelkaya, I. Eksin, "Self tuning fuzzy PID type load and frequency controller", *Energy Convers Manage*, vol. 45, pp: 377-90, 2004.
- [21] P. Kundur, *Power system stability and control (USA: McGraw-Hill, 1994)*.
- [22] C. Öztürk, D. Karaboğa, B. Görkemli, "Artificial bee colony algorithm for dynamic deployment of wireless sensor networks", *Turk. J. Elec. Eng. & Comp. Sci.*, vol. 20, 2012, pp. 255-262.
- [23] A. Ö. Bozdoğan, A. E. Yilmaz, M. Efe, "Performance analysis of swarm optimization approaches for the generalized assignment problem in multi-target tracking applications", *Turk. J. Elec. Eng. & Comp. Sci.*, vol. 18, 2010, pp. 1059-1078.
- [24] O. Abedinia, B. Wyns, A. Ghasemi, "Robust Fuzzy PSS Design using ABC", *Proceeding of the IEEE International Power & Energy Society Power Systems Conference and Exposition, Italy, Rome (EEEIC)*, 2011, pp. 100-103.
- [25] P. W. Tsai, J. S. Pan, B. Y. Liao and S. C. Chu, "Interactive Artificial Bee Colony (IABC) Optimization", Dec. 2008, *ISI2008*, Taiwan.