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MARKET OPTIMIZATION USING FUZZY BASED MULTIOBJECTIVE HARMONY SEARCH ALGORITHM

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Abstract- In this paper, optimal gains tuning of a fuzzy PID controller for solution of the multi area restructure problem is proposed using Multi Objective Harmony Search Algorithm (MOHSA). The problem of robustly tuning of fuzzy PID based AGC design is formulated as an optimization problem according to the time domain based objective function which is solved by the MOHSA technique that has a strong ability to find the most optimistic results. To ensure performance and robustness of the proposed control strategy to stabilize frequency oscillations, the design process takes a wide range of operating conditions and system nonlinearities into account. To demonstrate the effectiveness of the proposed method a four-area restructured power system is considered as a test system under different operating conditions. The simulation results are shown to maintain robust performance in comparison with the HPSOCFA, RGA and BGA based tuned PID controllers through FD and ITAE performance indices. Results evaluation show that the proposed control strategy achieves good robust performance for wide range of system parameters and load changes. Moreover, the proposed control strategy has simple structure, easy to implement and tune which can be useful for the real world restructured power system.

Keywords: Multiobjective, Harmony Search Algorithm, Restructure Problem, Fuzzy Mechanism.

I. INTRODUCTION

Recently, some authors proposed fuzzy PID methods to improve performance of the LFC problem [1-5]. It should be pointed out that they require a three-dimensional rule base. This problem makes the design process is more difficult. To overcome this drawback, in author's pervious papers [6-8] an improved control strategy based on fuzzy theory and GA technique have been proposed. Although, GA seems to be good methods to solve optimization problems, when applied to problems consisting of more number of local optima, the solution from GA are just near global optimum areas. Also, it takes long simulation time to obtain the solution. Moreover, when the number of parameter is more, optimization problem is complex and coding chromosomes with more gens for increasing algorithm accuracy is caused GA convergent speed will become very slow, so that convergent accuracy may be influenced by the slow convergent speed.

In [8], PSO technique is used for tuning the fuzzy PID parameters. This method is proposed to improve optimization synthesis such that the global optima are guaranteed and the speed of algorithms convergence is extremely improved, too. PSO algorithm can be used to solve many of the same kinds of problems as GA and does not suffer from of GA's difficulties [6]. 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, in optimize the parameters of fuzzy PID using PSO; this method in various operating points is untoward.

The harmony search algorithm is a new met heuristic algorithm proposed by Geem et al. [9] , It is derived from the natural phenomena of musicians' there exists an analogy between music and optimization: each musical instrument corresponds to each decision variable; musical note corresponds to variable value; and harmony corresponds to solution vector. Just like musicians in Jazz improvisation play notes randomly or based on experiences in order to find fantastic harmony, variables in the harmony search algorithm have random values or previously-memorized good values in order to find optimal solution [9]. Harmony search algorithm has a good ability to deal with discrete and non-convex mathematic problem. It has been successfully applied to various optimization problems in computation and engineering fields including economic dispatch of electrical energy [10], multicast routing [11], clustering [12], travelling salesman problem [13], parameter optimization of river flood model [14], design of pipeline network [15, 16], and design of truss structures [17, 18].

In this study, the problem of robust PID based multi area design is formulated as an optimization problem. The controller is automatically tuned with optimization a time domain based objective function by MOHSA such that the relative stability is guaranteed and the time domain specifications concurrently secured. The effectiveness of the proposed controller is demonstrated through time domain simulation studies and some performance indices to damp frequency oscillations under different operating conditions and system nonlinearities.

II. GENERALIZED AGC SCHEME MODEL

Generalized dynamical model for AGC scheme has been developed in [2] based on the possible contracts in the restructured environments. This section gives a brief overview on this generalized model that uses all the information required in a VIU industry plus the contract data information [1]. In the new structure, GENCOs may or may not participate in the AGC task and DISCOs have the liberty to contract with any available GENCOs in their own or other areas. The concept of an Augmented Generation Participation Matrix (AGPM) is introduced to express these possible contracts in the generalized model. The rows and columns of AGPM is equal with the total number of GENCOs and DISCOs in the overall power system, respectively [2]. The AGPM structure for a large scale power system with N control area is given by:

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

where

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

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

In the above, n_i and m_i are the number of GENCOs and DISCOs in area i and gpf_{ij} refer to ‘generation participation factor’ and shows the participation factor GENCO_i in total load following requirement of DISCO_j based on the possible contract. The sum of all entries in each column of AGPM is unity. Block diagram of the generalized AGC scheme for a four-area restructured power system is shown in Figure 1 (see [3] for the nomenclature used). The power system parameters are considered the same as [9]. The dashed lines show the demand signals based on the possible contracts between GENCOs and DISCOs which carry information as to which GENCO has to follow a load demanded by which DISCO. As there are many GENCOs in each area, ACE signal has to be distributed among them due to their ACE participation factor in the AGC task and $\sum_{j=1}^{n_i} \alpha_{ji} = 1$.

We can write:

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

$$\eta_i = \sum_{j=1 \& j\neq i}^{N} T_{ij} \Delta f_j \quad (3)$$

$$\zeta_i = \Delta P_{tie,i,sch} = \sum_{k=1 \& k\neq i}^{N} \Delta P_{tie,ik,sch} \quad (4)$$

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{n_l} \sum_{i=1}^{m_k} apf_{(s_l+j)(z_k+i)} \Delta P_{L(z_k+i)-k} - \sum_{i=1}^{n_k} \sum_{j=1}^{m_l} apf_{(s_k+i)(z_l+j)} \Delta P_{L(z_l+j)-l} \quad (5)$$

$$\rho_i = \left[\rho_{1i} \cdots \rho_{ki} \cdots \rho_{n_i i} \right]$$
$$\rho_{ki} = \sum_{j=1}^{N} [\sum_{t=1}^{m_j} gpf_{(s_i+k)(z_j+t)} \Delta P_{Lt-j}] \quad (6)$$

$$\Delta P_{m,k-i} = \rho_{ki} + apf_{ki} \Delta P_{di} \ , \quad k = 1,2,...,n_i \quad (7)$$

A four-area power system, shown in Figure 1, is considered as a test system to explain the effectiveness of the introduced control strategy.

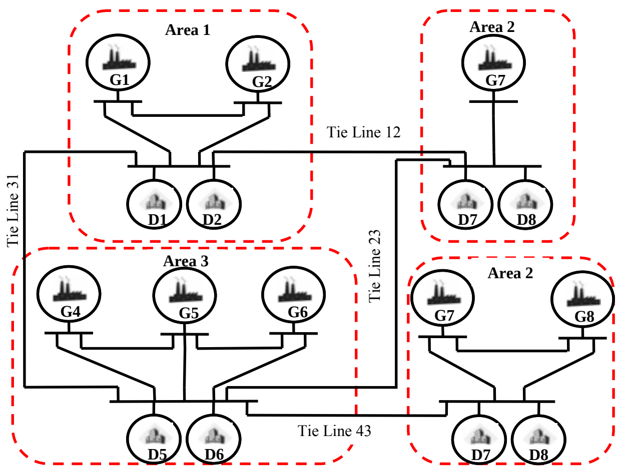

Figure 1. Schematic diagram of a four area system in restructured power market

III. MOHSA

A. Brief Review of Harmony Search Algorithm (HSA)

The brief procedure steps of harmony search for solving optimization problems are described in five steps as shown in the flow chart of the HS procedure which can be described as Figure 2.

Step 1: Identify objective function and Equality & Inequality constraints by using

$$\text{minmize } \{ f(x),\ x \in X \}$$
$$\text{s.t.}$$
$$g(x) \geq 0 \quad (8)$$
$$h(x) = 0$$

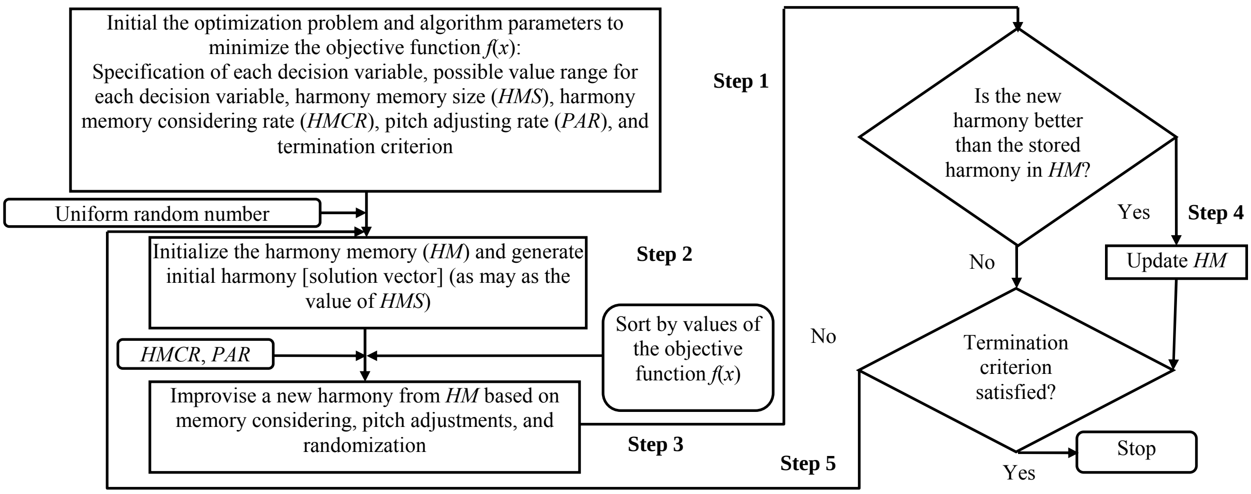

Figure 2. Flowchart of HSA

where $f(x)$ is the objective function, X_i is the feasible set, x_i is the random choosing parameter, $G(x)$ is the inequality constraint and $h\,(x)$ is the equality constraint.

Step 2: Initialize harmony memory (HM) in this step chooses the initial value of xi from X_i parameters and fill them in HM matrix randomly.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^1 & x_2^2 & \dots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \dots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \dots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \frac{\Delta y}{\Delta x} \tag{9}$$

Step 3: Improvise New Harmony Improvise new x_i from harmony memory considers rated ($HMCR$) and pith adjust rated (PAR).

Step 3.1: Harmony consider rated ($HMCR$)

$$x_i' \leftarrow \left\{ \begin{array}{l} x_i' \in \left\{ x_i^1, x_i^2, \dots, x_i^{HMS} \right\} (HMCR) \\ x_i' \in X_i (1 - HMCR) \end{array} \right\} \tag{10}$$

where x_i' is new value of x_i and $HMCR$ is probability of choosing x_i' which PR means the probability function.

Step 3.2: Pitch Adjust Rate (PAR)

$$x_i' \leftarrow \left\{ \begin{array}{l} \text{Yes, } \Pr(PAR) \\ \text{No, } \Pr(1 - PAR) \end{array} \right\} \tag{11}$$

where PAR is probability to shift x_i'.

$$x_i' \leftarrow x_i' \pm \text{rand}() \times bw \tag{12}$$

where bw is range of Xi rand is random number during 0-1. In this step, random choose the value of x_i'. The value of x_i' is in the range of X_i and it has probability $HMCR$. The out of condition probability of x_i' is 1−$HMCR$ and then it will check PAR if PAR of x_i' is carry on the condition Equation (10) and shift x_i' by the equation.

Step 4: Update HM and check the stopping criterion Find value of $f(x_i')$ from substitute x_i' in Equation (9) if value of $f(x_i')$ is better than the worst value of $f(x)$ in HM, substitute x_i' instead the worst x_i in HM.

Step 5: To check the stopping criterion, set the NI (Number of iteration) before begins to run the simulation; HS can stop calculation instantaneously when NI is reached. The aim of this paper is to apply multi objective harmony search for AGC problem. Results show that harmony search can solve this problem intelligently and find a near optimal solution.

B. Multi-Objective Harmony Search Algorithm (MOHSA)

A Multi-objective optimization problem always has a set of optimal solutions, for which there is no way to improve one objective value without deterioration of at least one of the other objective values. Pareto dominance concept classifies solutions as dominated or non-dominated solutions and the "best solutions" are selected from the non-dominated solutions. To sort non-dominated solutions, the first front of the non-dominated solution is assigned the highest rank and the last one is assigned the lowest rank. When comparing solutions that belong to a same front, another parameter called crowding distance is calculated for each solution. The crowding distance is a measure of how close an individual is to its neighbors. Large average crowding distance will result in better diversity in the population. In order to investigate multi-objective problems, some modifications in the HSA algorithm were made. The main steps of the MOHSA algorithm are explained in more detail.

C. 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 ith objective function is represented by a membership function μ_i defined as [8]:

$$\mu_i(p_{gi}) = \frac{f_i^{\max} - f_i(p_{gi})}{f_i^{\max} - f_i^{\min}} \tag{13}$$

where $f_i^{\max}$ and $f_i^{\min}$ are the maximum and minimum values of ith objective, respectively.

$$FDM_i(p_{gi}) = \begin{cases} 0 & \mu_i(p_{gi}) \le 0 \\ \mu_i(p_{gi}) & 0 < \mu_i(p_{gi}) < 1 \\ 1 & \mu_i(p_{gi}) \ge 1 \end{cases} \tag{14}$$

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

$$FDM^k = \left[\frac{\sum_{i=1}^{2} FDM_i^k(p_{gi})}{\sum_{j=1}^{M}\sum_{i=1}^{2} FDM_i^j} \right] \tag{15}$$

The best compromise solution of EED 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 3, shows the membership structure μ_c for the fuzzy logical variable signifying total fuel cost $f_i(P_{gi})$.

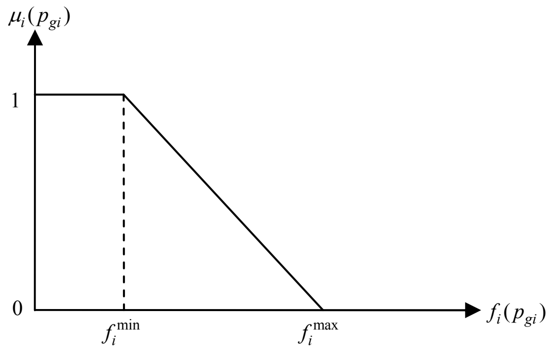

Figure 3. Membership function of fuzzy fuel cost

IV. MOHSA-BASED RPID TYPE LOAD FREQUENCY CONTROLLER

In this paper, an MOHSA-Fuzzy based on RPID is proposed, which combines the advantage of the MOHSA and fuzzy control techniques to achieve good robust performance. In order to overcome these backwashes and supply optimal control performance, MOHSA algorithm is proposed to optimal tune of PID controllers parameters under different operating conditions. Figure 4 shows the block diagram of MOHSA algorithm based tuned PID controller to solve the multi area restructure problem for each control area in both case studies.

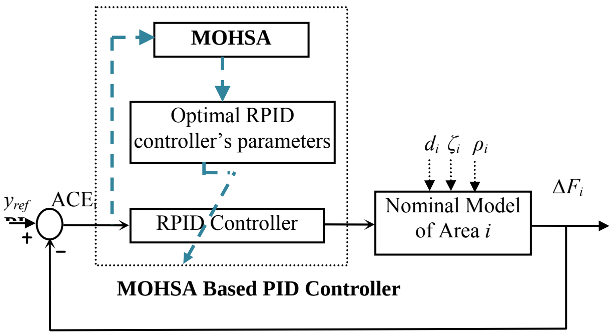

Figure 4. The introduced MOHSA based RPID controller structure

Also the equation of load frequency control for PID in each control area (in both case studies) is:

$$PID = k_P + \frac{k_I}{s} + sk_D \tag{16}$$

The above equation is ideal design of PID controller but it is impossible. There is no doubt that in industrial PID controller, using low pass filter is necessary to omit high frequency noise in entry of differentiator. Therefore in this paper for PID controller, conversion function of differentiator is:

$$k_D / (1 + T_d S), \quad T_d = 100$$
$$\text{where,} \quad k_D \le T \tag{17}$$

It should be noted that choice of the properly objective function is very important in synthesis procedure for achieving the desired level of system robust performance. For our optimization problem, an Integral of Time multiplied Absolute value of the Error (*ITAE*) is taken as the objective function [9]. The objective function is defined as follows:

minimize J Subject to

$$K_{Pi}^{\min} \le K_{Pi} \le K_{Pi}^{\max}$$
$$K_{Ii}^{\min} \le K_{Ii} \le K_{Ii}^{\max} \tag{18}$$
$$K_{Di}^{\min} \le K_{Di} \le K_{Di}^{\max}$$

Typical ranges of the optimized parameters are [0.01-20].

$$J = \max\left\{ ITAE^{p=-\%30}, ITAE^{p=-\%20}, ..., ITAE^{p=+\%30} \right\}$$
$$ITAE^p = \sum_{i=1}^{N} \int_0^{t=tsim} t\left|ACE_i\right| dt \tag{19}$$

where, t_{sim} is the time range of simulation; N is the number of area control in power systems and p is percent value of the uncertain plant parameters changes from the nominal values for which the optimization is carried out. The operating conditions are considered with variation uncertain plant parameters of K_{pi}, T_{pi}, B_i, R_i and T_{ij} from -30% to 30% of the nominal values by 10% step (i.e. 7 operating points) [19].

V. SIMULATION RESULTS

This case study, consider a case where all the DISCOs contract with the GENCOs for power as per the following *DPM* [23]:

$$DPM = \begin{bmatrix} 0.50 & 0.50 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.50 & 0.50 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.30 & 0.25 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.40 & 0.50 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.30 & 0.25 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.50 & 0.60 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.50 & 0.40 \end{bmatrix}$$

The *GENCO* participates in *AGC* as defined in ref [23]. The optimized parameters of PID controller are presented in Table 1 and the numerical results of *ITAE* and *FD* for case study are presented in Tables 2 and 3 for serial number 1 and 2, respectively. In addition to, in scenario I considered two simulation or serial numbers. The results compare with two indexes *ITAE* and *FD* according to Equations (20) and (21), respectively.

$$ITAE=\sum_{i=1}^{4}\int_{0}^{t_{sim}}\left|ACE_i\left(t\right)\right|dt \tag{20}$$

$$FD=\frac{\sum_{i=1}^{4}0.1\times((OS_i\times 100)^2+(US_i\times 5)^2+(T_{S,i})^2)}{4} \tag{21}$$

Figures 5 and 6 show the simulation results for +25%, 0% change of parameters of four area restructure, respectively. This simulation gets from serial number 1 in scenario 1.

Table 1. The optimized parameters of PID controller

Case 1 of scenario 1 from case study; Tp_1=10.0, B_1=0.125, T_{12}=0.145, T_{13}=0.145		Optimal PID gains				Case 2 of scenario 1 from case study; Tp_1=10.0, B_1=0.125, T_{12}=0.145, T_{13}=0.345		Optimal PID gains			
		Area 1	Area 2	Area 3	Area 4			Area 1	Area 2	Area 3	Area 4
	Technique	K_p	K_p	K_p	K_p		Technique	K_p	K_p	K_p	K_p
		K_i	K_i	K_i	K_i			K_i	K_i	K_i	K_i
		K_d	K_d	K_d	K_d			K_d	K_d	K_d	K_d
	BGA [23]	1.1335	1.0000	1.0000	1.0000		BGA [23]	1.0000	1.7302	1.3716	1.0000
		1.5820	1.0000	1.1746	1.7914			1.0000	1.0000	1.7051	1.0000
		2.0000	1.7537	1.9844	1.7491			2.0000	1.9639	1.8914	1.6563
	RGA [23]	1.110	1.0958	1.0000	1.1000		RGA [23]	1.1125	1.0385	1.1000	1.0183
		0.5328	0.5600	0.5430	0.5423			0.5423	0.5700	0.5530	0.5748
		2.0000	2.0000	2.0000	2.0000			2.0000	2.0000	2.0000	2.0000
	HPSOCFA [23]	1.0000	2.0000	1.0000	1.0000		HPSOCFA [23]	1.0000	1.1621	1.0000	2.0000
		1.0000	1.0000	2.0000	1.0000			2.0000	2.0000	2.0000	2.0000
		2.0000	2.0000	2.0000	1.0000			1.0000	1.7302	1.3716	1.0000
	MOHSA	0.7867	1.3437	1.0321	1.4565		MOHSA	1.9386	1.9465	1.8654	1.6713
		0.2985	0.5441	0.6575	0.4728			0.4354	0.3582	0.3564	0.4593
		2.6754	3.2362	2.0030	2.8891			3.9272	3.6795	3.7865	3.7785

Table 2. *ITAE* and *FD* performance indices in case 1

Change of parameters	MOHSA			HPSOCFA			RGA			BGA		
	ITAE	*FD*	T_s	*ITAE*	*FD*	T_s	*ITAE*	*FD*	T_s	*ITAE*	*FD*	T_s
25%	4.7892	1.9881	4.143	5.4849	6.1528	5.303	5.4743	2.8026	6.102	3.9829	4.4879	6.493
20%	4.3736	1.76723	4.149	5.4875	6.1673	5.308	5.2928	2.7247	6.115	3.9840	4.5599	6.451
15%	4.0436	1.8798	4.151	5.4469	6.2310	5.313	5.1209	2.6605	6.121	3.9794	4.6598	6.454
10%	3.8273	1.9817	4.153	5.3943	6.3075	5.317	4.9001	2.6341	6.129	3.9636	4.7950	6.559
5%	3.1982	1.9827	4.153	5.3189	6.4170	5.323	4.6330	2.5380	6.252	3.9379	4.9569	6.568
nominal	2.8273	1.9993	4.162	5.2217	6.5762	5.326	4.3132	2.7122	6.253	3.9035	5.1356	6.573
-5%	1.9927	2.0908	4.168	5.0964	6.7660	5.331	3.9267	2.9084	6.271	3.8585	5.3788	6.584
-10%	1.8827	2.2888	4.173	4.9549	6.9743	5.337	3.4693	3.2349	6.276	3.8104	5.6616	6.592
-15%	1.7926	2.4865	4.189	4.8374	7.2855	5.365	2.9506	3.6432	6.280	3.7382	5.9690	6.654
-20%	2.4928	2.7285	4.204	4.7237	7.6473	5.382	2.3877	4.1014	6.285	3.6570	6.3340	6.662
-25%	3.2837	3.4453	4.210	4.6384	8.0211	5.421	1.9518	4.6245	6.289	3.5486	6.7881	6.674

Table 3. *ITAE* and *FD* performance indices in case 2

Change of parameters	MOHSA			HPSOCFA			RGA			BGA		
	ITAE	*FD*	T_s	*ITAE*	*FD*	T_s	*ITAE*	*FD*	T_s	*ITAE*	*FD*	T_s
25%	3.8965	1.4137	4.146	3.7323	6.6795	5.301	4.9950	2.7987	6.101	3.8279	4.5546	6.487
20%	3.6342	1.2155	4.147	3.7068	6.6830	5.303	4.8485	2.7852	6.112	3.8329	4.6121	6.450
15%	2.7827	1.2327	4.146	3.6748	6.7237	5.312	4.6592	2.7109	6.119	3.8361	4.7080	6.451
10%	2.1526	1.3054	4.156	3.6230	6.7898	5.313	4.4211	2.6642	6.125	3.8505	4.8473	6.550
5%	1.2767	1.3283	4.157	3.5597	6.9382	5.320	4.1376	2.7670	6.246	3.8382	5.0193	6.563
nominal	1.4394	1.3827	4.163	3.4789	7.1376	5.323	3.8065	2.8548	6.249	3.8410	5.2379	6.571
-5%	1.2364	1.4154	4.168	3.3853	7.4087	5.327	3.4192	3.0852	6.268	3.8026	5.5273	6.582
-10%	1.8338	1.4716	4.175	3.2893	7.7349	5.331	2.9705	3.4040	6.273	3.7658	5.8509	6.587
-15%	2.5695	1.6133	4.184	3.2114	8.1199	5.363	2.4638	3.8318	6.279	3.6960	6.2311	6.652
-20%	3.6154	1.6361	4.206	3.1795	8.5207	5.374	1.9872	4.3228	6.283	3.6007	6.6017	6.656
-25%	3.7813	1.9892	4.211	3.2029	9.0115	5.419	1.9304	4.9570	6.287	3.4587	7.1135	6.672

VI. CONCLUSIONS

The effectiveness of the proposed strategy was tested on a four-area restructured power system under possible contracts with various load changes. The simulation results show that the proposed MOHSA based tuned fuzzy PID controller achieves good robust performance for a wide range of system parameters and is superior to PSO and GA based tuned PID controllers. The system performance characteristics in terms of *ITAE* and *FD* indices reveal that the proposed robust PID type tuned controller is a promising control scheme for the solution of the multi area problem. Moreover, the proposed control strategy has simple structure, easy to implement and tune and therefore it is recommended to generate good quality and reliable electric energy in the restructured power systems.

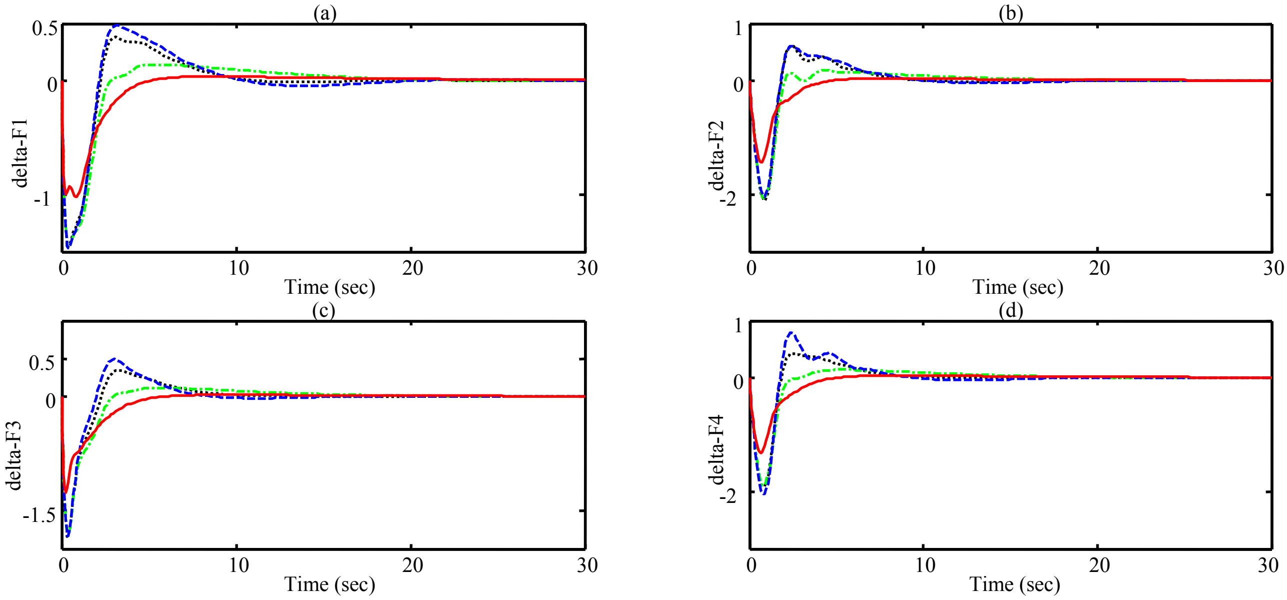

Figure 5. Deviation of frequency; (a) area 1, (b) area 2, (c) area 3 and (d) area 4 for Case 1; Solid (MOHSA), Dashed (HPSOCFA), Dashed-Doted (RGA) and Doted (BGA) .

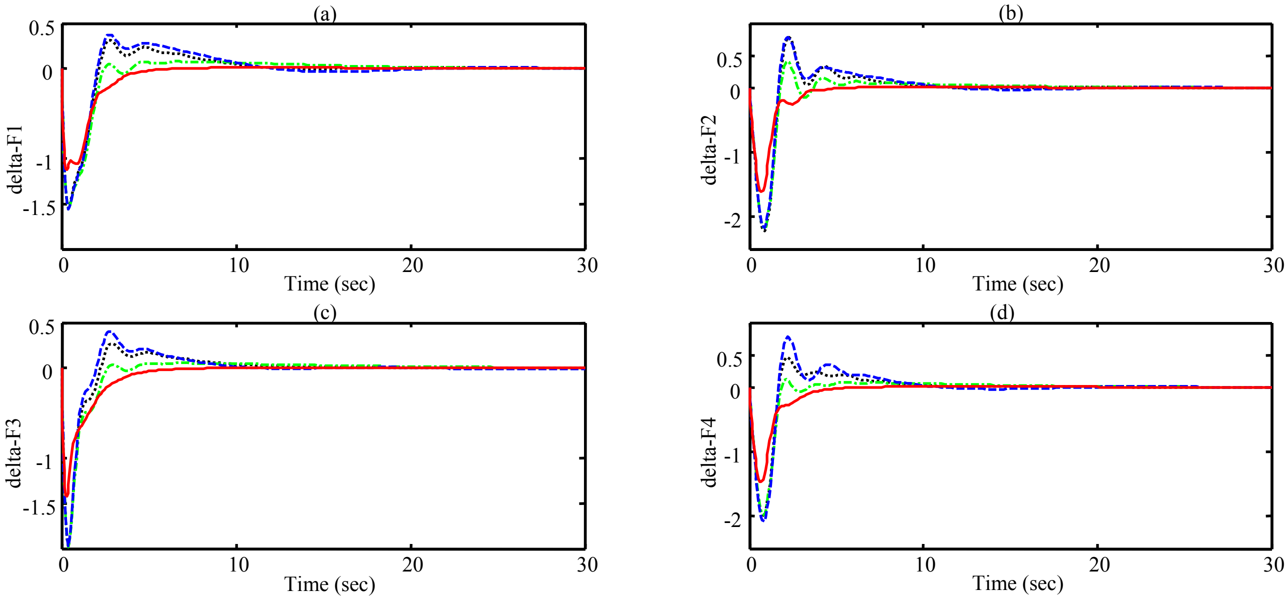

Figure 6. Deviation of frequency; (a) area 1, (b) area 2, (c) area 3 and (d) area 4 for Case 2; Solid (MOHSA), Dashed (HPSOCFA), Dashed-Doted (RGA) and Doted (BGA)

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