

Evolutionary Computation based Four-Area Automatic Generation Control in Restructured Environment

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Abstract— In this paper, the four-area multi-units automatic generation control is studied in restructured power system. There are various types of ancillary services present in power system. One of these ancillary services is load following with frequency control which comes broadly under Automatic Generation Control in restructured power system. The prime objective of the paper is to introduce some novel evolutionary computation based techniques applied independently to obtain optimal gain parameters for optimal transient performances under various system operating conditions. Computational results and transient performances are compared to finally determine the best optimization technique for this problem. A novel particle swarm based algorithm namely, modified chaotic ant swarm optimization (MCASO) and real coded GA (RGA) prove to be competitively the best. A conventional PSO and binary coded GA are the other two techniques, yielding sub-optimal performances. A DISCO can contract individually and multilaterally with a Genco for power and these transactions are done under the supervision of the ISO. In this paper, the concept of DISCO participation matrix is used to simulate the bilateral contracts in the four area diagram. The computed values of generators' participation and tie-line power exchanges match with the corresponding actual values obtained by MATLAB-SIMULINK. Optimal transient responses are determined by substituting the optimal gains in the MATLAB-SIMULINK based four-area multi-units diagram.

Keywords- AGC, BGA, Bilateral Contracts, MCASO, PSOCFA, Restructured Power System, RGA, SFL.

NOMENCLATURE

ACE _i	area control error of <i>i</i> th area
B _i	frequency bias coefficient of <i>i</i> th area
Δ f _i	frequency error of <i>i</i> th area
Δ P _{tie_{i,j}}	tie-line power flow error between <i>i</i> th area and <i>j</i> th area
K _{pi}	proportional gain of PID controller
K _{ii}	integral gain of PID controller
K _{di}	derivative gain of PID controller
t _p	area time constant
B	frequency bias coefficient
apf_matrix	ACE participation factor matrix
α ₁₂ , α ₁₃ ,	
and α ₂₃	Ratios of areas' power ratings
R	Governor regulation
T _g	Governor time constant
T _t	Non-reheat time constant

T _r	Reheat time constant
c	Reheat parameter
K _p	Power System gain constant
CF	Constriction factor
CFA	Constriction factor approach
C ₁ , C ₂	Constant parameters of PSO
pbest _i	Personal best of <i>i</i> th particle s _i ^K
gbest	Group best in the population of particles
cpf_matrix	Contract participation factor matrix

I. INTRODUCTION

AUTOMATIC Generation Control (AGC) is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. AGC with load following is treated as an ancillary service that is essential for maintaining the electrical system reliability at an adequate level. The main objectives of the AGC in multi-area restructured power system [1] are maintaining zero steady state errors for frequency deviation and accurate tracking of load contracts demanded by DISCOS. In addition, the power system should fulfill the requested dispatch conditions.

In an open energy market, generation companies (GENCOs) may or may not participate in the AGC task. On the other hand, a distribution company (DISCOs) may contract individually with a Genco or independent power producers (IPPs) for power in its area or other areas. Currently these transactions are done under the supervision of the independent system operator (ISO). The values of GENCOs participations and tie-line power exchanges are computed by some unique equations proposed by the authors and then validated by MATLAB-SIMULINK.

This paper introduces a novel PSO namely modified chaotic ant swarm optimization (MCASO) and real coded GA (RGA) which is applied to obtain optimal gain parameters for optimal transient responses. Another conventional PSO i.e. hybrid particle swarm optimization with constriction factor approach (HPSOCFA) and binary coded GA are taken for the sake of comparison. Analytically obtained transient responses of area frequency deviations and mutual tie-line power exchanges are also validated by MATLAB-SIMULINK.

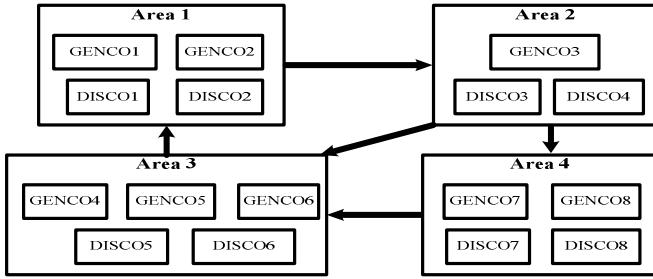


Fig.1. Schematic diagram of a four-area system in restructured environment

II. AGC IN RESTRUCTURED POWER SYSTEM

AGC in restructured power environment involves GENCOs satisfying various load contracts of DISCOs with frequency regulation. Accordingly powers required in tie-lines are to be maintained. GENCOs sell power to various DISCOs at competitive prices.

The authors have simulated the individual generations of Gencos and scheduled tie-line power flows in an unequal rating scenario. The concept of contract participation factor matrix (cpf_matrix) makes the visualization of contracts easier. This matrix is having the number of rows equal to the number of GENCOs and the number of columns equal to the number of DISCOs in the system. Here, the ij^{th} entry corresponds to the fraction of the total load power contracted by DISCO j from a GENCO i . The sum of all the entries in a column in this matrix is unity. Coefficients that distribute Area Control Error (ACE) to several GENCOs are termed as ACE

participation factors (apfs). Note that $\sum_{j=1}^m \text{apf}_j = 1$.

ACE participation factors of m different GENCOs of i^{th} area are shown by apf_matrix. The contracted scheduled loads in DISCOs in area1 are delPdisco1 and delPdisco2, in area2 are delPdisco3 and delPdisco4, in area3 are delPdisco5 and delPdisco6 and in area4 are delPdisco7 and delPdisco8. The uncontracted local loads in areas 1, 2, 3 and 4 are denoted by delPuncot1, delPuncot2, delPuncot3 and delPuncot4 respectively. Ratios of areas' ratings, α_{12} , α_{31} , α_{24} , α_{43} and α_{23} are given by the following expressions:

cpf_matrix=

	1	2	3	4	5	6	7	8
1	cf11	cf12	cf13/ α_{12}	cf14/ α_{12}	cf15/ α_{31}	cf16/ α_{31}	0	0
2	cf21	cf22	cf23/ α_{12}	cf24/ α_{12}	cf25/ α_{31}	cf26/ α_{31}	0	0
3	cf31/ α_{12}	cf32/ α_{12}	cf33	cf34	cf35/ α_{23}	cf36/ α_{23}	cf37/ α_{24}	cf38/ α_{24}
4	cf41/ α_{31}	cf42/ α_{31}	cf43/ α_{23}	cf44/ α_{23}	cf45	cf46	cf47/ α_{43}	cf48/ α_{43}
5	cf51/ α_{31}	cf52/ α_{31}	cf53/ α_{23}	cf54/ α_{23}	cf55	cf56	cf57/ α_{43}	cf58/ α_{43}
6	cf61/ α_{31}	cf62/ α_{31}	cf63/ α_{23}	cf64/ α_{23}	cf56	cf66	cf67/ α_{43}	cf68/ α_{43}
7	0	0	cf73/ α_{24}	cf74/ α_{24}	cf75/ α_{43}	cf76/ α_{43}	cf77	cf78
8	0	0	cf83/ α_{24}	cf84/ α_{24}	cf85/ α_{43}	cf86/ α_{43}	cf87	cf88

apf_matrix=

apf1	0	0	0	0	0	0	0
0	apf2	0	0	0	0	0	0
0	0	apf3	0	0	0	0	0
0	0	0	apf4	0	0	0	0
0	0	0	0	apf5	0	0	0
0	0	0	0	0	apf6	0	0
0	0	0	0	0	0	apf7	0
0	0	0	0	0	0	0	apf8

delPDISCO=

delP							
DISCO1	DISCO2	DISCO3	DISCO4	DISCO5	DISCO6	DISCO7	DISCO8

delPUncontracted=

delP							
uncot1	uncot1	uncot2	uncot3	uncot3	uncot3	uncot4	uncot4

The total generation required of individual

$$\alpha_{12} = -\frac{P_{r1}}{P_{r2}}, \alpha_{31} = -\frac{P_{r3}}{P_{r1}}, \alpha_{24} = -\frac{P_{r2}}{P_{r4}}, \alpha_{43} = -\frac{P_{r4}}{P_{r3}}, \alpha_{23} = -\frac{P_{r2}}{P_{r3}}$$

where P_{r1} , P_{r2} , P_{r3} and P_{r4} are the rated powers of areas 1, 2, 3 and 4 respectively.

The total generation required of individual GENCOs can be calculated as:

$$\text{deltaPG_matrix} = \text{cpf_matrix} * \text{delPdisco}' + \text{apf_matrix} * \text{delPUncontracted}' \quad (1)$$

where $\text{delPdisco}'$ and $\text{delPUncontracted}'$ means transpose of delPdisco and delPUncontracted respectively.

The mutual scheduled tie-line power flows among the areas can be represented by the following formulae:

$$\text{scheduled_deltaPtie12} = ((\text{cf13} * \text{DISCO3} + \text{cf23} * \text{DISCO3} + \text{cf14} * \text{DISCO4} + \text{cf24} * \text{DISCO4}) / \text{alp12}) - (\text{cf31} * \text{DISCO1} + \text{cf32} * \text{DISCO2}) \quad (2)$$

$$\begin{aligned} \text{scheduled_deltaPtie31} = & ((\text{cf41} * \text{DISCO1} + \text{cf51} * \text{DISCO1} + \text{cf61} * \text{DISCO1} + \\ & \text{cf42} * \text{DISCO2} + \text{cf52} * \text{DISCO2} + \text{cf62} * \text{DISCO2}) / \text{alp31}) \\ & - (\text{cf15} * \text{DISCO5} + \text{cf25} * \text{DISCO5} + \text{cf16} * \text{DISCO6} + \\ & \text{cf26} * \text{DISCO6}) \end{aligned} \quad (3)$$

The closed loop system in Fig.2 is represented in state space form as

$$x = A^{cl} x + B^{cl} u$$

where x is the state vector and u is the vector of contracted power demands of the DISCOs. A^{cl} is the state matrix. Eigen values are computed from A^{cl} , which are used for optimizing transient performance by eigenvalue analysis [2]. Objective function, figure of demerit, $\text{Minfdm}(J)$ is computed in terms of positions of eigenvalues with respect to the D-sector situated in the left half of s-plane [2]. Optimal transient performance corresponds to the grand minimum value of $\text{Minfdm}(J)$.

III. BINARY CODED GENETIC ALGORITHM

BGA is adopted from [4].

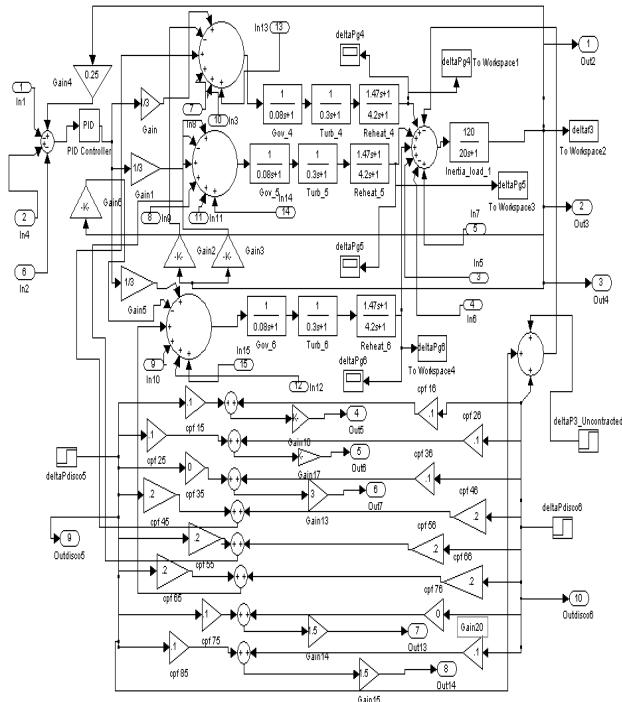


Fig.2. MATLAB-SIMULINK based diagram of Area 3.

IV. REAL CODED GENETIC ALGORITHM

In RGA, chromosomes are chosen as real valued strings. Crossover and mutation are performed in real domain unlike BGA. The algorithm is explained in [3].

V. PARTICLE SWARM OPTIMIZATION WITH CONSTICTION FACTOR APPROACH

The velocity expression using constriction factor (CF) is adopted from [4]. But in this problem the best value of CF is chosen as 0.60 instead of 0.73.

VI. MCASO BASED OPTIMIZATION OF PID GAINS

Chaotic ant swarm optimization (MCASO) [5] combines the chaotic and self organization behavior of ants in the foraging process. It includes both effects of chaotic dynamics and swarm-based search. The algorithm has been employed to tune the PID controller parameters of four area restructured power system. MCASO is based on the chaotic behavior of individual ant and the intelligent organization actions of ant colony. Here, the search behavior of the single ant is “chaotic” at first, and the organization variable r_i is introduced to achieve self organization process of the ant colony.

Initially, the influence of the organization variable on the behavior of individual ant is sufficiently small. With the continual change of organization variable evolving in time and space, the chaotic behavior of the individual decreases gradually via the influence of the organization variable and the communication of previously best positions with neighbors, the individual ant alters his position and moves to the best one they can find in the search space. According to the distance between

ant and their neighbors, a definition of neighbor (dbest) is introduced, in order to simulate the behaviors of ants in nature. The searching area of ants corresponds to the problem search space. In the search space R^l , this is the l-dimensional continuous space of real numbers, the algorithm searches for optima. A population of K ants is considered. These ants are located in a search space S and they try to minimize a function $f: S \rightarrow R$. Each point s in S is a valid solution to the considered problem. The position of an ant i is assigned the algebraic variable symbol $S_i = (z_{i1} \dots z_{il})$, where $i = 1, 2, \dots, K$. Naturally each variable can be of any finite dimension. During its motion, the organization processes of the swarm influence each individual ant. In mathematical terms, the strategy of movement of a single ant is assumed to be a function of the current position; the best position found by itself, any member of its neighbors and the organization variable are given by (5).

$$y_i(n) = y_i(n-1)^{1+r_i} \quad (4)$$

$$\begin{aligned} z_{id}(n) = & \left(z_{id}(n-1) + \frac{c}{\psi_d} V_i \right) \exp((1 - \exp(-a y_i(n)))) \\ & \left(3 - \psi_d \left(z_{id}(n-1) + \frac{c}{\psi_d} V_i \right) \right) - \frac{7.5}{\psi_d} V_i \\ & + \exp(-2ay_i(n) + b)(p_{id}(n-1) - z_{id}(n-1)) \end{aligned} \quad (5)$$

where,

n	Current iteration cycle,
$n-1$	Previous iteration cycle,
$y_i(n)$	Current state of the organization variable ($y_i(0) = 0.999$),
a, b, c	Positive constants
$r_i \in [0, 0.1]$	A positive constant, and is termed as the organization factor of ant i ,
$z_{id}(n)$	Current state of the d^{th} dimension of the individual ant i , $d = 1, 2, \dots, l$
Ψ_d	Determines the selection of the search range of d^{th} element of variable in the search space, and
V_i	Determines the search region of i^{th} ant and offers the advantage that ants could search diverse regions of the problem space ($V_i = \text{rand}()$).

Introduction of craziness enhances MCASO’s ability of searching and convergence to a global optimal solution. Variables’ upper and lower bound restrictions are always present. Ultimately, after a maximum iteration cycles the optimal solution of z_{id} corresponds to global optimal value of fitness function under consideration.

The general MCASO is a self-organizing system. When every individual trajectory is adjusted toward the successes of neighbors, the swarm converges or clusters in optimal regions of the search space. The search of some ants will fail if the individual cannot obtain information about the best food source from their neighbors.

While dealing with PID tuning, the algorithm’s parameters r_i , Ψ_d , V_i , a , b , c are respectively, $1 + r_i$ is replaced by $(1.02 + 0.04 * \text{rand}())$, $\Psi_d = 1.75$, $V_i = \text{rand}()$, $a = 1$, $b = 0.1$, $c = 3$.

These values are pre-set after a lot of experimentation to get the best convergence to optimal solution. In this work, as similar to CRPSO [2], craziness in velocity is also introduced as given below.

$$Z_{id}(n) = Z_{id}(n) + \text{sign}(r4) * V_i^{\text{craziness}} \quad (6)$$

The value of sign (r4) will be determined by (6).

VII. SIMULATED TEST SYSTEMS

Simulations are carried out for different Test Cases of the possible contracts under large load demands and disturbances.

A. Poolco based transactions

In this scenario GENCOs participate in automatic generation control of their own areas only. It is assumed that large step contracted loads are simultaneously demanded by DISCOs of areas 1, 2, 3 and 4. A case of Poolco based contracts between DISCOs and available GENCOs is simulated based on the following contract participation factor matrix (cpfm1).

cpfm1=

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

B. Combination of Poolco and Bilateral based transactions

In this case, any DISCO has the freedom to have a contract with any GENCO in its own and other areas. Consider that all the DISCOs contract with the available GENCOs for power as per the following cpfm2:

cpfm2=

0.20	0.30	0.10	0.10	0.10	0.10	0.00	0.00
0.40	0.30	0.10	0.20	0.10	0.10	0.00	0.00
0.10	0.10	0.30	0.20	0.00	0.10	0.10	0.10
0.10	0.10	0.10	0.10	0.20	0.20	0.10	0.10
0.10	0.10	0.10	0.10	0.20	0.20	0.10	0.10
0.10	0.10	0.10	0.10	0.20	0.20	0.10	0.10
0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.10
0.00	0.00	0.10	0.10	0.10	0.00	0.20	0.30
0.00	0.00	0.10	0.10	0.10	0.10	0.30	0.30

All GENCOs participate in the automatic generation control. These GENCOs can supply power to their own area and to other areas also.

The ACE participation factor of each GENCO participating in the automatic generation control is defined as follows:

Area 1: apf1=0.5, apf2=0.5

Area 2: apf3=1.0

Area 3: apf4=1/3, apf5=1/3, and apf6=1/3

Area 4: apf7= 0.5, apf8= 0.5.

C. Contract Violation

In this case, DISCOs may violate a contract by demanding more power than that specified in the contract. This excess power is reflected as a local load of the area (un-contracted

demand). Consider Test Case B again. ‘cpfm’ matrix is the same as in Test System 2. Total of all DISCOs’ contracted loads and the un-contracted load of the area are taken up by the GENCOs in the same area, the scheduled incremental tie-line powers remain the same as in Test Case B in the steady state. Un-contracted load of the area is taken up by the GENCOs of its own area according to ACE participation factors of GENCOs in the steady state.

VIII. INPUT DATA AND PARAMETERS

For optimization algorithms:

i) Maximum population pool size, np = 50, maximum allowed iteration cycles (generations) for optimization per loop (L), Nm = 500. Initial minimum gain=0.2 and initial maximum gain=2.0. For PSOCFA algorithms, CF=0.60, C₁=C₂=2.05. Parameters of MCASO are given in section IV.

ii) For four area system: The contracted loads of DISCOs in different areas, delPDISCO1=0.1, delPDISCO2=0.1, delPDISCO3=0.1, delPDISCO4=0.1, delPDISCO5=0.1, delPDISCO6=0.1, delPDISCO7=0.1 and delPDISCO8=0.1. The local un-contracted loads of areas 1, 2, 3 and 4 are delPuncot1=0.1, delPuncot2=0.1, delPuncot3=0.1 and delPuncot4=0.1 respectively. The un-contracted loads will be considered only in Test Case C. Ratio of rated powers of area1 and area2, $\alpha_{12}=2.5$, ratio of rated powers of area2 and area3, $\alpha_{23}=1/3$, ratio of rated powers of area3 and area1, $\alpha_{31}=1.2$, ratio of rated powers of area2 and area4, $\alpha_{24}=0.5$ and of rated powers of area4 and area3, $\alpha_{43}=1/1.5$. Variable parameters, t_{p3}, t₁₃, and b₃ of Area3 are either nominal or off nominal, as shown in the Table 1.

iii) The constant data of the four unequal thermal generating areas are as shown in the Table 1.

IX. COMPUTATIONAL RESULTS AND DISCUSSION

Table II shows the computational results of optimal PID gains for four areas and grand minimum Minfdm for 3 sets of area parameters.

i) **Comparison of the optimization techniques for nominal area parameters:** In this work, four evolutionary optimization techniques i.e. MCASO, PSOCFA, RGA and BGA have been employed. SFL has been incorporated and results have been taken for 81 input sets of nominal parameters. Multiple runs have been performed for each input set of 81 input sets so that total 200 runs are performed for each input set per technique; PID gains, “Minfdm” values and execution times are shown in the Table II. It is clear that MCASO, and RGA based “Minfdm” values are very consistently minimum. Again, MCASO yields true optimal and robust performance consistently for all 81 input sets. HPSOCFA based results are not consistent. BGA based results are sub-optimal only.

ii) **Convergence profiles:** The values of “Minfdm” against iteration cycle numbers are recorded to get the convergence profile of any technique. MCASO technique

TABLE I
AREA-WISE CONSTANT DATA OF FOUR UNEQUAL
THERMAL GENERATING AREAS

Name of the parameter	Area 1	Area 2	Area 3	Area 4
Governor regulation, R (Hz/p.u)	2.4	2.2	2.5	2.3
Governor time constant, T_g (Sec)	0.08	0.078	0.081	0.082
Non-reheat time constant, T_r (Sec)	0.3	0.5	0.7	0.4
Reheat time constant, T_r (Sec)	4.2	4.1	4.0	4.3
Reheat parameter, c	0.34	0.31	0.32	0.33
Power system gain constant, K_p (Hz/p.u)	120	115	118	116
Power system time constant, t_p (Sec)	To be optimized	20	10	20
Frequency bias coefficient, B	To be optimized	0.125	0.275	0.125
Tie line synchronizing coefficient between area 1 and area 2, T_{12}	0.145			
Tie line synchronizing coefficient between area 2 and area 4, T_{24}	0.345			
Tie line synchronizing coefficient between area 4 and area 3, T_{43}	0.145			
Tie line synchronizing coefficient between area 2 and area 3, T_{23}	0.145			
Tie line synchronizing coefficient between area 3 and area 1, T_{31}	0.145			

converges to the global minimum solutions than all other techniques in this work as shown in Fig. 3.

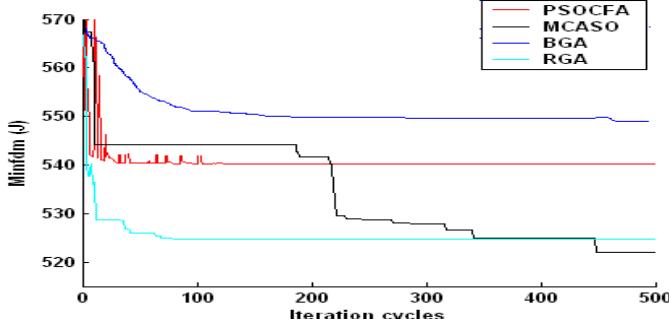


Fig. 3. Plots Minfdm versus iteration cycles for the algorithms; Nominal input parameters= (20, 0.275, 0.145 and 0.345).

- iii) **Steady state performance:** In this work, scheduled values of generations of all the generators and all tie-line power flows are computed with the help of numerical formulae that are newly proposed in this work. The same results are validated by the MATLAB-SIMULINK results with optimized gains and steady state performances.
- iv) **SFL based off-nominal transient response characteristics:** For on-line, off-nominal area parameters, SFL is successfully applied to get on-line, off-nominal PID gains of four-area system and these PID gains also yield off-nominal optimal transient response characteristics as shown in Figs. 4 and 5.
- v) **Comments on different types of transactions:**
 - (a) **Poolco based transactions:** In this scenario, GENCOs participate only in automatic generation control of their own areas. It is assumed that a large step load of 0.1 pu is demanded by each DISCO in all the areas. In the steady

state, tie-line power flow errors, frequency deviations and hence the area control errors of all the areas are all driven to zero. The generated powers properly converge to the specified scheduled values, which are analytically computed from the equations (1), (2), and (3) using cpf_matrix. apf_matrix does not affect the GENCOs generations. Since there are no mutual scheduled contracts among the areas, the steady state power flow errors over the tie lines are zero. It is also shown even for only un-contracted loads present in the areas, the steady state power flow errors are zero.

- (b) **Combination of Poolco and Bilateral based transactions:** In this scenario, DISCOs have the freedom to have contracts with any GENCO in its area or other areas. It is assumed that all the DISCOs contract with the available GENCOs for power. The actual generated powers of GENCOs and tie line power flows properly reach corresponding desired values in the steady state, governed by all scheduled contracts, guided by the same

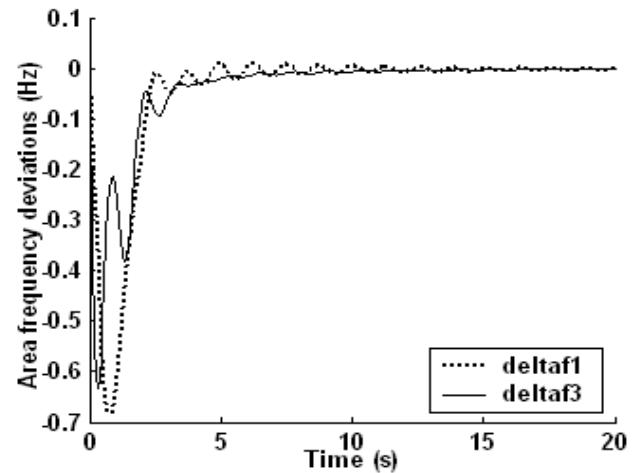


Fig.4. MATLAB-SIMULINK based plots of area frequency deviations versus time for test case C; MCASO based SFL table is utilized. Off-nominal input parameters= (22, 0.2, 0.3 and 0.15)

novel formulae. As un-contracted loads are absent or

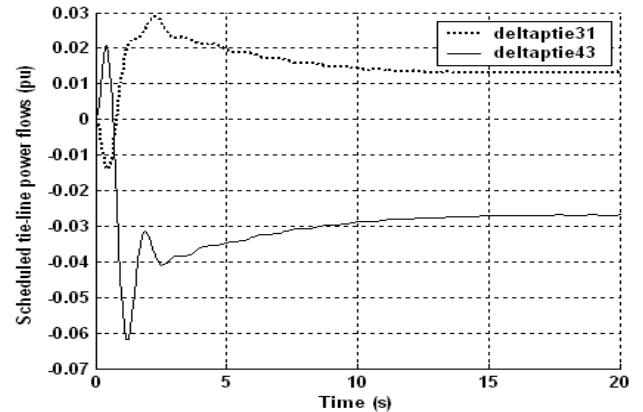


Fig.5. MATLAB-SIMULINK based plots of scheduled tie-line power flows versus time MCASO based SFL table is utilized. Off-nominal input parameters= (22, 0.2, 0.3 and 0.15)

TABLE II
NOMINAL AREA3 PARAMETERS, OPTIMAL NOMINAL PID GAINS FOR THE AREAS AND MINFDM

Sr. No	Input Parameters $T_{P1}, B_1, T_{12}, T_{13}$	Algorithm	Optimal PID Gains							
			Area 1		Area 2		Area 3		Area 4	
			K_p	K_i	K_p	K_i	K_p	K_i	K_p	K_i
1	10, 0.125, 0.145, 0.145	B GA	1.5515	0.6667	0.6945	0.2400				
			1.4398	1.5575	0.7142	1.8829	547.6749	47.0160		
			2.0000	1.7891	1.6679	1.7716				
		PSOCFA	2.0000	2.0000	0.2000	0.2000				
			2.0000	2.0000	2.0000	2.0000	506.8506	47.5310		
			2.0000	2.0000	2.0000	2.0000				
		R GA	1.5421	1.0100	2.0000	1.0100				
			1.4361	2.0000	2.0000	2.0000	524.8112	54.1870		
			1.5350	0.0000	2.0000	2.0000				
		MCASO	0.2000	0.2000	0.2000	0.2000				
			2.0000	2.0000	2.0000	2.0000	501.5021	52.2340		
			2.0000	2.0000	2.0000	2.0000				
2	20, 0.275, 0.145, 0.345	B GA	1.5515	0.6667	0.6945	0.2400				
			1.4398	1.5575	0.7142	1.8829	547.6749	47.0160		
			2.0000	1.7891	1.6679	1.7716				
		PSOCFA	2.0000	0.6195	0.2000	2.0000				
			2.0000	0.2000	2.0000	2.0000	540.2215	49.9690		
			1.2764	2.0000	2.0000	0.9744				
		R GA	1.5583	1.0100	2.0000	1.0100				
			1.4218	2.0000	2.0000	2.0000	524.8112	54.1870		
			1.5350	2.0000	2.0000	2.0000				
		MCASO	2.0000	2.0000	2.0000	2.0000				
			1.7394	1.7394	1.7394	1.7394	521.9718	52.9840		
			1.2773	1.2773	1.2773	1.2773				
3	30, 0.275, 0.345, 0.345	B GA	1.6819	0.7719	1.8954	1.6674				
			0.6846	1.7326	0.7612	1.7823	575.3285	47.1250		
			2.0000	0.9415	1.9531	1.6184				
		PSOCFA	2.0000	2.0000	0.8033	1.4686				
			0.2000	2.0000	2.0000	2.0000	561.7922	49.4850		
			2.0000	2.0000	2.0000	2.0000				
		R GA	1.5643	0.3800	1.2800	0.4520				
			1.4573	2.0000	2.0000	2.0000	558.8016	54.4380		
			2.0000	0.7400	2.0000	2.0000				
		MCASO	2.0000	2.0000	2.0000	2.0000				
			0.2000	0.2000	0.2000	0.2000	557.2249	53.9370		
			2.0000	2.0000	2.0000	2.0000				

contract violation is absent, ACE participation factors do not affect the steady state values of GENCOs' generations and the steady state values of tie-line power flows. The same factors always affect only the transient behavior of the system.

(c) **Contract violation:** This case is an extension of case (b) with contract violation. In this case, DISCOs may violate contracts by demanding more power than those specified in the contracts. This excess power is reflected as a local load of the particular area (un-contracted demand). The purpose of this work is to test the effectiveness of the proposed formulae against un-contracted load disturbances. The contract participation factor matrix, "cpfm" is the same as in case (b). The un-contracted load in each area is taken up extra by the GENCOs in the same area governed by apf_matrix. The actual generated powers of GENCOs properly reach the desired values, sharing all contracted and un-contracted loads. Each GENCO shares

the un-contracted load of its own area according to its own ACE participation factor.

vi) **Computational time:** Optimization techniques are arranged in increasing order of execution times as BGA < PSOCFA < MCASO < RGA.

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