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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

ACEi	area control error of ith area
Bi	frequency bias coefficient of ith area
Δ fi	frequency error of i^{th} area
Δ $Ptie_{i,j}$	tie-line power flow error between i^{th} area and j^{th} area
Kpi	proportional gain of PID controller
K_{ii}	integral gain of PID controller
K_{di}	derivative gain of PID controller
tp	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^{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.

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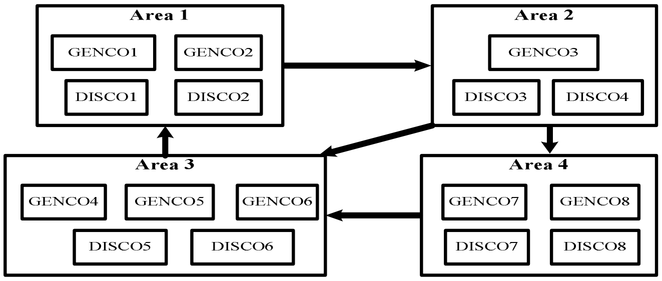

Fig.1. Schematic diagram of a four-area system in restructured environment

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 ijth 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 $\sum_{j=1}^{m} apf_j = 1$.

ACE participation factors of m different GENCOs of ith 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=

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

apf_matrix=

$$\begin{bmatrix} apf1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & apf2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & apf3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & apf4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & apf5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & apf6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & apf7 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & apf8 \end{bmatrix}$$

delPDISCO=

$$\begin{bmatrix} delP & delP & delP & delP & delP & delP & delP & delP \\ DISCO1 & DISCO2 & DISCO3 & DISCO4 & DISCO5 & DISCO6 & DISCO7 & DISCO8 \end{bmatrix}$$

delPUncontracted=

$$\begin{bmatrix} delP & delP & delP & delP & delP & delP & delP & delP \\ uncot1 & uncot1 & uncot2 & uncot3 & uncot3 & uncot3 & uncot4 & uncot4 \end{bmatrix}$$

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:

deltaPG_matrix =
cpf_matrix*delPdisco' + apf_matrix * delPUncontracted' (1)

where delPdisco' and 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:

scheduled_deltaPtie12=
((cf13*DISCO3+cf23*DISCO3+cf14*DISCO4+cf24*DISCO4)/alp12) - (cf31*DISCO1+cf32*DISCO2) (2)

scheduled_deltaPtie31=
((cf41* DISCO1 + cf51 * DISCO1 + cf61*DISCO1 + cf42*DISCO2+ cf52 * DISCO2 + cf62*DISCO2)/alp31) - (cf15 * DISCO5 + cf25 * DISCO5 + cf16*DISCO6 + cf26*DISCO6) (3)

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

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

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, 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 Minfdm (J).

III. BINARY CODED GENETIC ALGORITHM

BGA is adopted from [4].

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