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Two-Area AGC in Interconnected System Under the Restructured Power System Using BFO With Optimal Control Theory

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Abstract- This paper presents the bacterial foraging(BF) optimization control technique in addition with optimal control theory for designing the integral controller gain, which is applied to AGC in interconnected multi- area system under the deregulated environment (considering all practical aspects) to control the tie line power and frequency of the interconnected system. Each area's comprises of one hydro and one thermal generating station. Further each area has two GENCO's and two DISCO's which have bilateral contract with each other. Case of contract violation is considered and controllers gain are optimized firstly using BFO then optimal control theory is applied to that BFO optimized controller. The optimized gain is used in the system to improve its performance. State space model in MATLAB is used to study the performance of the system.

***Keywords*—GENCO; TRANSCO, Bacterial Foraging Optimization (BFO), Optimal Control Theory (OCT), Automatic Generation Controll (AGC), DISCO Participation Matrix, Area Participation Factor, Area Control Error Participation Factor(apf).**

I. INTRODUCTION

In power system operation and control automatic Generation Control (AGC) is an important issue as it makes system reliable. AGC also maintains the system frequency constant and makes the system more stable. When load in a system increases or decreases the frequency deviates from its standard value and hence speed governor varies the input to turbine to compensate the deviation in frequency. Various control techniques are used to minimize the steady state error and to make the frequency constant. In this paper, study of two area system of restructured power system is done in which each area has its own controller which maintains the tie line power and system frequency constant [7]-[4] by varying the generation according to the area control error (ACE). To minimize the ACE time, AGC varies the set point of generation in accordance with the variation in load. Deregulated system increases the competition in market and hence the DISCOs can buy the power from any GENCO in the market. A new formulation of principle of AGC is given by R. K. Green. He indicated the concept of transformed AGC, which could eliminate the need for bias settings, by directly controlling the nominal frequency set-point of each unit [11]. The AGC of two equal area thermal, hydro and hydro-thermal systems is analyzed by Concordia and Kirchmayer [2].. Proportional Integral Controller (PI) is the most frequently used controller in LFC but it fails to operate when the complexity of system increases because of the change in boiler dynamics or due to sudden load change. The frequency and tie line power is compared [10] for the LFC in deregulated environment by the use of this technique. In this paper combination of two techniques is used. Bacterial Foraging optimization Technique varies [4]-[6] the gain of Integral Controller and OCT minimizes the cost function and hence both together improves the performance of system.

II. SYSTEM UNDER INVESTIGATION

Restructured power system comprises of three parts GENCOs (generating companies), TRANSCOs (transmission companies), and DISCOs (distribution companies) [1]-[14]. The GENCOs and DISCOs have mutual contract and depending upon that contract DISCO demands from GENCO [9]-[11]. The contract between GENCOs and DISCOs can be visualize by the DISCO participation matrix (DPM), in which number of rows reflects the number of GENCOs and the number of columns decides the number of DISCOs in network [15]. ISO provides many ancillary services like load frequency control to maintain the real time balance between power generation and load demand for minimizing the deviation in frequency and governing the tie-line [13]. In this paper, the case of contract violation by a DISCO is considered. It is the most practical condition in the system which may cause the system failure. The bacterial foraging technique is applied to derive the gain of optimum controller [12]-[5]. The gain is applied to the system and various parameters like frequency deviation, tie line power etc. are calculated [8]. System performance is evaluated and after that Optimal Control Theory is applied to the system. In OCT, all the system control states are taken as feedback and the states which affects more are maximize and is used to minimize the cost function.

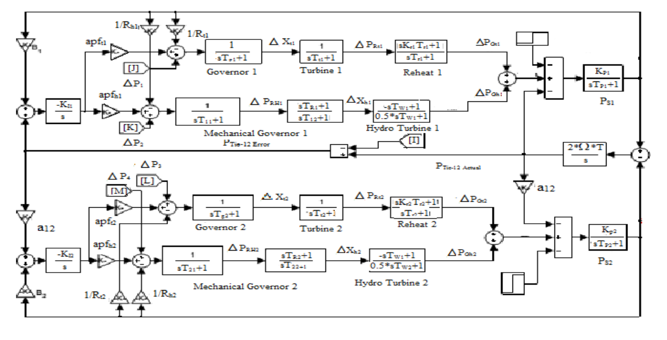

Fig. 1: Interconnected Hydro-Thermal System Under

The practical aspects covered in this system are the introduction of reheat turbine [10]-[16] in thermal power plant to improve the efficiency of system and the mechanical governor [5] is used in hydro power plant. Consideration of these practical aspects closely represent the actual system. Proper controller gain is needed for controlling the system output within the prescribed limits.

III. STATE SPACE EQUATIONS FOR TWO AREA HYDRO-THERMAL SYSTEM

a) For change in Frequency:

$$\dot{\Delta F1} = \frac{-1}{T_{P1}} * \Delta F_1 - \frac{K_{P1}}{T_{P1}} * \Delta P_{Tie12} + \frac{K_{P1}}{T_{P1}} * \Delta P_{Gt1} + \frac{K_{P1}}{T_{P1}} * \Delta P_{Gh1} - \frac{K_{P1}}{T_{P1}} * \Delta P_{L1} - \frac{K_{P1}}{T_{P1}} * \Delta P_{L2} - \frac{K_{P1}}{T_{P1}} * \Delta P_{L3} - \frac{K_{P1}}{T_{P1}} * \Delta P_{L4}$$

……………………………………………………………(1)

$$\dot{\Delta F2} = \frac{-1}{T2} * \Delta F_2 - \frac{K_{P2}}{T_{P2}} * \Delta P_{Tie12} + \frac{K_{P2}}{T_{P2}} * \Delta P_{Gt2} + \frac{K_{P2}}{T_{P2}} * \Delta P_{Gh2} - \frac{K_{P2}}{T_{P2}} * \Delta P_{L1} - \frac{K_{P2}}{T_{P2}} * \Delta P_{L2} - \frac{K_{P2}}{T_{P2}} * \Delta P_{L3} - \frac{K_{P2}}{T_{P2}} * \Delta P_{L4}$$

………………………………………………………………(2
)

b) For Turbine Output:

$$\dot{\Delta P}_{Gt1} = (-\frac{1}{T_{R1}}) * \Delta P_{Gt1} + (\frac{1}{T_{r1}} - \frac{K_{r1}}{T_{t1}}) * \Delta P_{Rt1} + (\frac{K_{r1}}{T_{t1}})\Delta X_{t1}$$

……………………………………………………………
...(3)

$$\dot{\Delta P}_{Gh1} = (\frac{2T_{R1}}{R_{h1} * T_{GH1} * T_{RH1}}) * \Delta F_1 - (\frac{2}{T_{W1}}) * \Delta P_{Gh1} + (\frac{2}{T_{W1}} + \frac{2}{T_{GH1}}) * \Delta X_1 + (\frac{2T_{R1}}{T_{GH1} * T_{RH1}} - \frac{2}{T_{GH1}}) * \Delta P_{RH1} + (\frac{2K_{I1} * apf_{h1} * T_{R1}}{T_{GH1} * T_{RR1}}) * \int ACE_1 dt. - (\frac{2cpf_{21} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L1} - (\frac{2cpf_{21} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L2} - (\frac{2cpf_{21} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L3} - (\frac{2cpf_{21} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L4}$$

……………………………………………………………
(4)

$$\dot{\Delta P}_{Rt1} = -(\frac{1}{T_{t1}}) * \Delta P_{Rt1} + (\frac{1}{T_{t1}}) * \Delta X_{t1}$$ …………………..
..(5)

$$\dot{\Delta P}_{Rt2} = -(\frac{1}{T_{t2}}) * \Delta P_{Rt2} + (\frac{1}{T_{t2}}) * \Delta X_{t2}$$ ……..………..…
…(6)

$$\dot{\Delta P}_{Gh2} = (\frac{2T_{R2}}{R_{h2} * T_{GH2} * T_{RH2}}) * \Delta F_2 - (\frac{2}{T_{W2}}) * \Delta P_{Gh2} + (\frac{2}{T_{W2}} + \frac{2}{T_{GH2}}) * \Delta X_2 + (\frac{2T_{R2}}{T_{GH2} * T_{RH2}} - \frac{2}{T_{GH2}}) * \Delta P_{RH2} + (\frac{2K_{I2} * apf_{h2} * T_{R2}}{T_{GH2} * T_{RH1}}) * \int ACE_2 dt. - (\frac{2cpf_{41} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L1} - (\frac{2cpf_{41} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L2} - (\frac{2cpf_{41} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L3} - (\frac{2cpf_{41} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L4}$$

……………………………………………………………
.(7)

$$\dot{\Delta P}_{Gt2} = (-\frac{1}{T_{R2}}) * \Delta P_{Gt2} + (\frac{1}{T_{r2}} - \frac{K_{r2}}{T_{t2}}) * \Delta P_{Rt2} + (\frac{K_{r2}}{T_{t2}})\Delta X_{t2}$$

……………………………………………………………
.(8)

c) For Speed Governor Output:

$$\dot{\Delta X}_{t1} = -(\frac{1}{R_{t1} * T_{g1}}) * \Delta F_1 - (\frac{1}{T_{g1}}) * \Delta X_{t1} - (\frac{K_{I1} * apf_{t1}}{T_{g1}}) * \int ACE1.dt + (\frac{cpf_{11}}{T_{g1}}) * \Delta P_{L1} + (\frac{cpf_{21}}{T_{g1}}) * \Delta P_{L2} + (\frac{cpf_{31}}{T_{g1}}) * \Delta P_{L3} + (\frac{cpf_{41}}{T_{g1}}) * \Delta P_{L4}$$

……………………………………………………………………………(
9)

$$\dot{\Delta X}_{h1} = -(\frac{T_{R1}}{R_{h1} * T_{GH1} * T_{RH1}}) * \Delta F_1 - (\frac{1}{T_{Gh1}} - \frac{T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{RH1} - (\frac{K_{I1} * apf_{h1} * T_{R1}}{T_{GH1} * T_{RH1}}) * \int ACE_1.dt + (\frac{cpf_{21} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L1} + (\frac{cpf\ 22 * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L2} + (\frac{cpf_{23} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L3} + (\frac{cpf_{24} * T_{R1}}{T_{GH1} * T_{RH1}}) * \Delta P_{L4}$$

……………………………………………………………..(10
)

$$\dot{\Delta X}_{t2} = -(\frac{1}{R_{t2} * T_{g2}}) * \Delta F_2 - (\frac{1}{T_{g2}}) * \Delta X_{t2} - (\frac{K_{I2} * apf_{t2}}{T_{g2}}) * \int ACE2.dt + (\frac{cpf_{31}}{T_{g2}}) * \Delta P_{L1} + (\frac{cpf_{31}}{T_{g2}}) * \Delta P_{L2} + (\frac{cpf_{33}}{T_{g2}}) * \Delta P_{L3} + (\frac{cpf_{34}}{T_{g2}}) * \Delta P_{L4}$$

…………………………………………………………….(1
1)

$$\dot{\Delta X}_{h2} = -(\frac{T_{R2}}{R_{h2} * T_{GH2} * T_{RH2}}) * \Delta F_2 - (\frac{1}{T_{Gh2}} - \frac{T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{RH2} - (\frac{K_{I2} * apf_{h2} * T_{R2}}{T_{GH2} * T_{RH2}}) * \int ACE_2.dt + (\frac{cpf_{41} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L1} + (\frac{cpf_{42} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L2} + (\frac{cpf_{43} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L3} + (\frac{cpf_{44} * T_{R2}}{T_{GH2} * T_{RH2}}) * \Delta P_{L4}$$

…………………………………………………………….(1
2)

$$\dot{\Delta P}_{RH1} = -(\frac{1}{R_{h1} * T_{RH1}}) * \Delta F_1 - (\frac{1}{T_{RH1}}) * \Delta P_{RH1} - (\frac{K_{I1} * apf_{h1}}{T_{RH1}}) * \int ACE1.dt + (\frac{cpf_{21}}{T_{RH1}}) * \Delta P_{L1} + (\frac{cpf_{22}}{T_{RH1}}) * \Delta P_{L2} + (\frac{cpf_{23}}{T_{RH1}}) * \Delta P_{L3} + (\frac{cpf_{24}}{T_{RH1}}) * \Delta P_{L4}$$

……………………………………………………………………………………

.(13)

$$\overset{\bullet}{\Delta P}_{RH2} = -\left(\frac{1}{R_{h2} * T_{RH2}}\right) * \Delta F_2 - \left(\frac{1}{T_{RH2}}\right) * \Delta P_{RH2} - \left(\frac{K_{I2} * apf_{h2}}{T_{RH2}}\right) * \int ACE2.dt$$
$$+\left(\frac{cpf_{41}}{T_{RH2}}\right) * \Delta P_{L1} + \left(\frac{cpf_{42}}{T_{RH2}}\right) * \Delta P_{L2} + \left(\frac{cpf_{43}}{T_{RH2}}\right) * \Delta P_{L3} + \left(\frac{cpf_{44}}{T_{RH2}}\right) * \Delta P_{L4}$$

……………………………………………………………..(
14)

a) For Area Control Error:

$$\overset{\bullet}{\int ACE1.dt} = B_1 * \Delta F_1 + \Delta P_{Tie12} + (cpf_{31} + cpf_{41}) * \Delta P_{L1} + (cpf_{32} + cpf_{42}) * \Delta P_{L2} - (cpf_{13} + cpf_{23}) * \Delta P_{L3} - (cpf_{14} + cpf_{24}) * \Delta P_{L4}$$

………………………………………………………………
(15)

$$\overset{\bullet}{\int ACE2.dt} = B_2 * \Delta F_1 + a_{12} * \Delta P_{Tie12} + a_{12} * (cpf_{31} + cpf_{41}) * \Delta P_{L1} + a_{12} * (cpf_{32} + cpf_{42}) * \Delta P_{L2} - a_{12} * (cpf_{13} + cpf_{23}) * \Delta P_{L3} - a_{12} * (cpf_{14} + cpf_{24}) * \Delta P_{L4}$$

………………………………………………………………
(16)

b) For Tie-Line Power:

$$\overset{\bullet}{\Delta P}_{Tie12} = \Delta P_{Tie12} + (2 * \Omega * T_{12} * (\Delta F_1 - \Delta F_2)) \text{……(17)}$$

IV. OPTIMIZATION OF CONTROLLER USING BFO AND OPTIMAL CONTROL THEORY

A. Bacterial Foraging Optimization

Bacterial foraging optimization algorithm (BFOA) is based on cooperation between the bacterium searching for their food. The gain of controller is optimized by using the cooperative nature of bacterium [7]. The bacteria generally found in groups and they will try to find food in minimum time with maximum energy and avoid the bruising phenomena. The detail algorithm is presented in Ref.[6]. In this simulation work the parameter for coding is to be S=16, Nc=600, Ns=4, Nre = 6, Ned=2, Ped=0.80. D(attr.)=0.5, W(attr.) = 0.2, H(repellent)= 0.5,W(repellent)= 10 and P=3 considered. The optimum value of controller is derived out using BFO to reduce the cost function J which is the Integral Square Error and is denoted as

$$J = \int [(\Delta P_{Tie-12})^2 + \Delta F_1^2 + \Delta F_2^2].dt \text{ …………(18)}$$

Where, dt = small time interval, Δ $P_{tie(1-2)}$ = incremental change in tie line power, Δf_1 and Δf_2 = incremental change in frequency of area1 and 2 respectively. To optimize this system various steps utilized in algorithm are chemotaxis, foraging, reproduction, elimination and dispersal.

The $_{\text{chemotaxis}}$ step is comprised of swimming and tumbling of bacterium via Flagella Chemotaxis decides whether to move further or to change the direction. To represent a tumble, a unit length random direction,(∅) say, is generated; this will be used to define the direction of movement after a tumble. In particular,

$$\theta^i((j+1,k,l) = \theta^i(j,k,l) + c(i) + \phi(j) \text{ ………………(19)}$$

Swarming makes the bacteria congregate into groups and hence move as concentric patterns of groups with high bacterial density. Mathematically, swarming can be represented by

$$J_{CC}(\theta, P(j,k,l)) = \Sigma J_{CC}^i(\theta, \theta^i(j,k,l))$$
$$\text{………………(20)}$$

After Nc chemotactic steps, a reproduction step is taken. In reproduction, the least healthy bacteria die and the other S_r healthiest bacteria each split into two bacteria, which are then placed in the same location. This makes the population of bacteria constant. In BFO, the elimination and dispersion event happens after a certain number of reproduction processes. Then some bacteria are chosen, according to a preset probability P_{ed}, to be killed and moved to another position within the environment.

B. Optimal Control Theory

As we know that in state space analysis for a AGC network:

$$\dot{X}(t) = AX(t) + BU(t) \text{ …………………..(21)}$$

$$\dot{Y}(t) = CX(t) \text{ …………………….………(22)}$$

Now let us consider a block diagram in which all system states are used as feedback to the network:

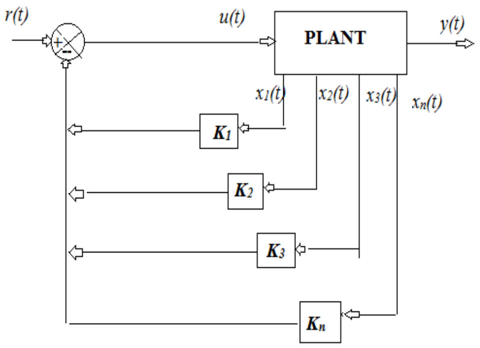

Fig. 2: Block Diagram of Optimal Controlled System

For the above block diagram the state feedback control is

$$U(t) = -[K_1 \quad K_2 \quad K_3 ..... \quad K_n] \begin{bmatrix} K_1 \\ K_2 \\ K_3 \\ . \\ . \\ K_n \end{bmatrix} \text{ ……(23)}$$

$$U(t) = -[K(X(t))] \text{ ………………………(24)}$$

Therefore from equation (3) put this U(t) in equation (1)

$$\dot{X}(t) = AX(t) + BKX(t)$$

$$= [A - BK]X(t)$$

$$= A_f X(t) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(25)$$

The main aim in optimal control theory is to maximise the objective function. All of the control states are taken as feedback. The state affecting the system most is considered first. Selected States are maximized by adding some suitable gain and taken as main feedback. Any of the state deviating from its standard defined, is considered first and system is optimized according to that.

V. CASE STUDY

A two area hydro-thermal system is used and the DPM considered to show the contract participation factor between GENCOs and DISCOs for the system is

In case of contract violation there is an additional demand ΔP_{UC1} in area 1 besides the contractual demand of DISCOs (ΔP_{L1} and ΔP_{L2}). Each DISCO demands for 0.01 p.u. hence total demand is 0.02 p.u per area. An additional unknown demand of 0.01 p.u. comes in the area 1 which causes the overall demand 0.03 p.u. and hence it violates the contract limit between the GENCOs and DISCOs of both are. This unknown demand is in area 1 and hence taken as local demand and must be supplied by the generators of area 1 which causes contract violation in between GENCOs and DISCOs. It is assumed that apf of generators are apf_{11} is 0.6, apf_{21} is 0.4, apf_{31} is 0 and apf_{41} is 1 i.e. generator three is not responding to this increase in demand. The scheduled generations of the GENCOs and the tie line power flow are:

- $Genco_{1(scheduled)}=(0.3+0.4+0.6+0.1)*0.01+apf_{11}*dPuc1=0.02$p.u.
- $Genco_{2(scheduled)}=(0.2+0.3+0.3+0.2)*0.01+apf_{21}*dPuc1=0.014$p.u
- $Genco_{3(scheduled)}=(0.2+0.2+0+0.3)*0.01+apf_{31}*dPuc2=0.007$p.u.
- $Genco_{4(scheduled)}=(0.3+0.1+0.1+0.4)*0.01+apf_{41}*dPuc2=0.009$p.u.
- $\Delta P_{tie1\text{-}2,(sch)}=(0.6+0.3+0.1+0.2)*0.01-(0.2+0.3+0.2+0.1)*0.01=0.04$p.u.

VI. RESULTS AND DISCUSSION

A. *Results with BFO*

In this section, to illustrate the performance of the proposed control against loads variation, state space analysis is performed for the case of possible violation of contract between GENCOs and DISCOs under market condition and large load demands. Case of contract violation is considered separately for both type of controller i.e. optimized using BFOA, BFOA with OCT method and performance is compared with the system with conventional controller and PI controller. Conventional controller and PI controller are optimized by Ziegler-Nichols method. State space analysis is performed to a two-area hydro-thermal interconnected power system under the deregulated environment using the MATLAB platform. Unknown disturbance is considered in area 1 along with the actual disturbance of 0.02 which causes the contract violation in between the GENCOs and DISCOs of that area and hence the deviation in frequency of both area also increases which reduces the system reliability. Result showing the variation in frequency and tie-line power along with the comparison of conventional controller, PI controller and in fig. (3) to fig. (5) BFO controller

	D_1	D_2	D_3	D_4
G_1	0.3	0.4	0.6	0.1
G_2	0.2	0.3	0.3	0.2
G_3	0.2	0.2	0.0	0.3
G_4	0.3	0.1	0.1	0.4

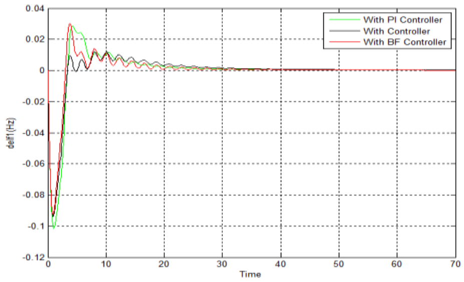

Fig. (3): Frequency comparison of Area-1

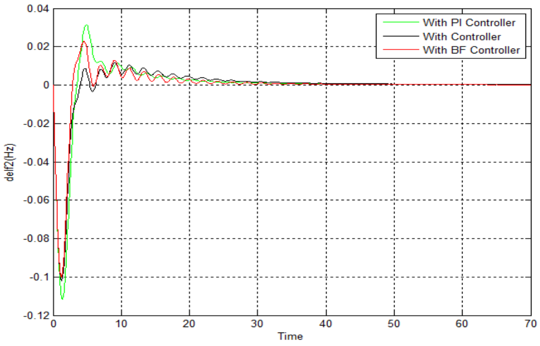

Fig. (4): Frequency comparison of Area-2

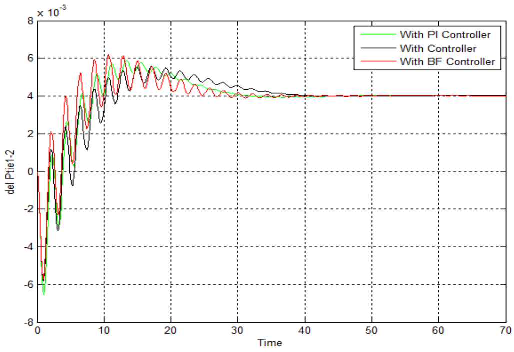

Fig. (5): Tie-Line Power

B. *Results with BFO with OCT together*

For the further improvement in the system, after the application of bacterial foraging algorithm the optimal control theory is applied and hence the results are shown in the fig. (6) to fig. (8).

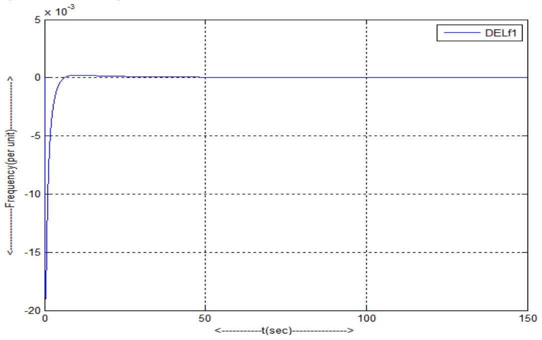

Fig. (6): Frequency Deviation of Area-1

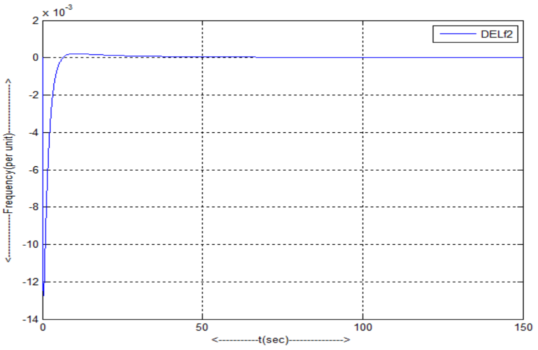

Fig. (7): Frequency Deviation of Area-2

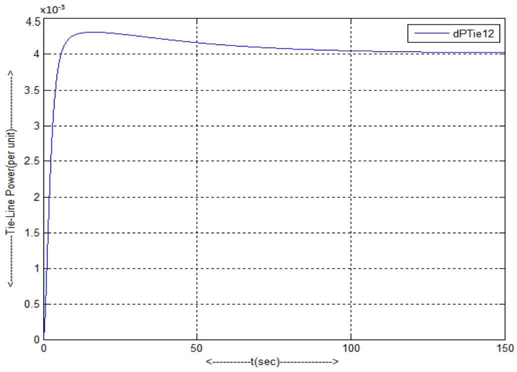

Fig. (8): Tie-Line Power

Error Analysis

Comparison of integral square error, integral absolute error, is given in table I

TABLE I

Type of Controller	IAE	ISE
With Conventional Controller	0.82	0.04
With PI Controller	0.9483	0.0608
With BFOA Integral Controller	0.720	0.0484
BFO + OCT	0.1816	0.0006841

Deviation in frequency and tie-line power causes imbalance in system which causes increase in settling time as well as peak time. After optimizing the controllers using BFOA and BFO with OCT, settling time and peak time improves and system becomes more stable. Results with the 5% permissible steady state error showing the improvement in settling time and peak time ae shown in table II

TABLE II

Type of Controller	ΔF_1 (Area 1)		ΔF_1 (Area 2)	
	Settling Time (Sec.)	Peak Time (Sec.)	Settling Time (Sec.)	Peak Time (Sec.)
With Conventional Controller	18.92	0.93	18.10	1.37
With PI Controller	15.50	1.23	15.50	1.49
With BFOA Integral Controller	14.50	0.80	14.62	1.18
BFO + OCT	1.78	0.35	1.92	0.38

VII. CONCLUSION

Two area hydro-thermal system is investigated and results are analyzed and compared for system with conventional controller, with conventional PI controller, with BFO and BFO with OCT controller. The Integral controller is implemented with BFO, with BFO and OCT and with conventional technique. The integral constant K_i is optimized using different techniques to get the optimum AGC, for the scheduling of generators, tie line power and used in state space model of the system. In this system frequency and tie line power of both area are compared. The result are shown in fig. (3) to fig. (8). formulated. System having controller optimized with BFOA along with OCT respond faster than the controller optimized with conventional methods and BFO alone only, hence settling time and peak time decreases along with improvement in the IAE and ISE.

VIII. NOMENCLATURE

$K_{p1,2}$	Generator Gain Constant
$T_{p1,2}$	Generator Time Constant
T_g	Governor time Constant
P_{Gt1}, P_{Gt2}	Turbine output power of thermal power plant
T_{ij}	Tie Line Coefficient
P_{ref}	Output of ACE
f	frequency
Δ	Deviation
a_{ij}	Operator
B_i	Bias Factor
s	Laplace domain derivative term
ACE	Area Control Error
$P_{i\text{-}jactual}$	Tie Line Real Power
$P_{i\text{-}jscheduled}$	Tie Line Scheduled Power Flow
$P_{Tie\text{-}12\ Error}$	Tie Line Power Error
ω	Angular speed
P_l, P_2, P_3, P_4	Electric Load Variations
R	Regulation Parameter
apf_i	ACE Participation Factors
cpf_i	Contract Participation Factors
P_{Gh1}, P_{Gh2}	Turbine output power of of hydro power plant

T_{t1}, T_{r1}	Turbine time Constant of thermal power plant
X_{t1}, X_{t2}	Governor Output power of thermal power plant
X_{h1}, X_{h2}	Governor Output power of hydro power plant
T_{g1} , T_{g2},	Governor Time Constant of thermal power plant
T_{11}, T_{12}, T_{21} T_{12} ,	Governor Time Constant of hydro power plant.
BFOA	Bacterial foraging Optimization Algorithm.

IX. APPENDIX

Base Power=100MVA, T_{P1}=20 sec., T_{P2}=20 sec., K_{P1}=120, K_{P2}=120, T_{g1}=T_{g2}=0.08 sec., T_{11}=T_{21}=48.7 sec., T_{t1}=T_{t2}=0.3 sec., T_{r1}=T_{r2}=10 sec., T_{W1}=T_{W2}=1 sec., R_{t1}=R_{t2}= 2.4, B_1=0.425, B_2=0.425, a_{12}= -1.

REFERENCES

[1] B. Parashuramulu and Ashwani Kumar, Load Frequency Control of Hybrid Systems in Open Access Environment, IEEE Annual India Conference (INDICON), 17-19 Dec. 2010.

[2] C. Concordia, L. K. Kirchmayer, Tie-Line Power & Frequency Control of Electric Power Systems, AIEE Trans., vol. 72, part III, pp. 562-572, 1954.

[3] E.Rakhahani and J.Sadeh, LOAD Frequency Control of Multi-Area Restructured Power System, IEEE Power India Conference, 12-15 Oct. 2008.

[4] E. Rakhshani and Javed Sadeh, Simulation Of Two-Area AGC System in a Competitive Environment Using Reduced-Order Observer Method, IEEE 5th International Conference on European, 28-30 May 2008.

[5] F.Liu, Y.H.Song, J.Ma, S.Mei and Q.Lu, Optimal Load Frequecy Control in Restructured Power Systems, IEE Proc.-Generation Transmission Distribution, vol. 150, pp. 87-95, Jan. 2003.

[6] J.Nanda, S.Mishra and L.C. Saikia, Maiden Application of Bacterial Foraging Based Optimization Technique in Multi Area Automatic Generation Control, IEEE Transaction on Power system, vol. 24, pp. 602-609, 14 April 2009.

[7] Kanika Wadhwa, J. Raja and S.K. Gupta, BF Based Integral Controller for AGC of Multiarea Thermal System under Deregulated Environment, IEEE 5th Power India Conference, 19-22 Dec. 2012.

[8] Kevin M. Passino, Biomimicry of Bacterial Foraging for Distributed Optimization and Control, IEEE Control Syst. Mag., vol. 22, pp. 52-67, 2002.

[9] L. K. Kirchmayer, Economic Control of Interconnected Systems, 2nd Ed., John Wiley, New York, 1959.

[10] Ranjit Roy, S.P.Ghoshal and Praghnesh Bhatt, Evolutionary Computaion Based Four-Area Automatic Generation Control in Restructured Environment, Third International Conference on Power Systems, Kharagpur, India, 27-29 Dec. 2009.

[11] R. K. Green, Transformed automatic generation control, IEEE Trans. Power System, vol. 11, pp. 1799–1804.

[12] Richard D.Christie and Anjan Bose, Aug. 1996, Load Frequency Control Issues in Power System Operations After Deregulation, IEEE Transaction Power Systems, vol. 11, pp. 1191-1200, Nov. 1996.

[13] Sanjoy Debbarma, Lalit Chanda Saikia and Nidul Sinha, AGC of Multi-area thermal system under deregulated environment using a non-integer controller, Electrical Power System Research, vol. 95, pp. 175-183, Feb. 2013.

[14] Surya Prakash and S.K. Sinha, Intelligent PI Control Technique in Four Area Load Frequency Control of Interconnected Hydro-themal Power System, in International Conf. on Computing, Electronics and Electrical Technologies[ICCEET], 21-22 March 2012.

[15] Vaibhav Donde, M.A. Pai and Iran A. Hiskens, Simulation and Optimization in a AGC System after Deregulation, IEEE Trans. Power Systems, vol. 16, pp. 481-489, 2001.

[16] Y. Arya, H.D. Mathur and S.K. Gupta, A Novel Approach for Load Frequency Control of Interconnected Thermal Power Syatem, International Journal of Energy Optimization and Engineering, vol.1, pp. 85-95, 2012.

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