AN OPTIMAL TUNING OF INTEGRAL CONTROLLER FOR HYBRID LFC SYSTEM INTEGRATED WITH WIND ENERGY RESOURCES

[1] S.Anbarasi, [2] S.Ramesh, [3] S.Muralidharan
[1] Associate Professor, Associate Professor, P.S.R. Engineering College, [2] Associate Professor, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, [3] Professor, Mepco Schlenk Engineering College
[1]tsoundarapandiananbu@gmail.com ,[2] rameshsme@gmail.com ,
[3]yes_murali@yahoo.com

Abstract

An optimal tuning of Integral controller for Load Frequency Control (LFC) of a multi-area multi-source system using Bacterial Foraging Optimization Algorithms (BFOA) is presented in this paper. The multi-source system considering in this paper consists of thermal power source, hydro power source, gas power resource as well as a renewable wind power generation sources. The conventional Integral Absolute Error (IAE) is used as an objective function for optimization approaches. To demonstrate the transient performance of the system a Step Load Perturbation (SLP) is applied to the system and the frequency deviation is observed by tuning of integral controller with BFOA approach. To enhance the performance further, the proposed approach is analyzed in presence of High Voltage Direct Current (HVDC) link. To ensure the reliability, the results of the proposed BFOA tuned integral controller are compared with an uncontrolled LFC system under step load perturbations (SLP). The simulation design and analysis of the test system are done through MATLAB SIMULINK tool and the results are measured through fundamental performance indices such as, maximum peak (MP), steady state error (SSE), settling time (ST) and rise time (RT). All the simulation results clearly reveal that, the proposed BFOA tuned integral controller for a hybrid LFC system has better transient performances under SLP and the performance is improved further in presence of HVDC link during the integration of renewable energy resources

Keywords: *Load Frequency Control, Integral Controller, Bacterial Foraging Optimization Algorithm, HVDC link, Multi-area multi- source LFC system, Wind energy generating system.*

1. Introduction

The modern interconnected power systems exposed to uncertainties due to the load dynamics and interpretation of the renewable energy resources [1]. Hence, in any interconnected power systems it is essential to carry out LFC in order to maintain the system frequency and tie-line power exchange at nominal values. The primary means of frequency control in a LFC loop are executed with the governor mechanism, and the secondary control is offered with conventional controllers which may be of any kind such as Proportional controller (P), Integral controller (I), Proportional Integral controller (PI) and Proportional Integral derivative controller (PID) controller. Most of the research work reveals that the integral controller is more simpler and having faster settling time hence this controller is preferred in this paper. The tuning of gain parameters in these conventional controllers is a challenging task and can be done with optimization methodologies.

Many heuristic approaches like Firefly algorithm (FA), Particle Swarm Optimization algorithm (PSO), Ant Colony Search algorithm (ACO) are developed for effective tuning of controller gain parameters for controlling the frequency deviations of the power generating system within permissible limits [2, 3, 4]. In this paper, one of such optimization algorithm named bacterial foraging Optimization Algorithms (BFOA) is suggested for tuning integral controller gain parameter. The BFOA has been demonstrated as a powerful evolutionary computational technique, compared to other optimization approaches in many problems. The vital role in any of

ISSN: 2005-4238 IJAST

the optimization approaches are played by its objective function. For ease of analysis, and to get fast response with less settling time, one of the conventional objective function commonly used in fundamental error minimization problems called integrated absolute error (IAE) is considered in this proposed optimization problem.

In most of the research articles, single-source LFC system is normally considered as a test system in optimization problems. Recently, some of the researchers have extended their research work in the hybrid power systems arena with different non-renewable generating sources such as thermal power source, hydro power source and gas power source [4]. In this research work, one kind of renewable power generating wind energy resource is also incorporated in the hybrid power generation model [5, 6].

Addition of this wind energy resource in a multi-source system will lead to system instability as well as create deviation in output frequency. Recent researches have evidently proved that the HVDC link is coupled in parallel with the existing AC tie lines of multi- source LFC system for stabilizing frequency oscillation and used an optimal output feedback controller for frequency stabilization problems [5, 7, 8].

The recent research works proved that the stability margins of the system can be enhanced while connecting the DC link in parallel with existing AC link. Likewise, the performance index value of the power system has been reduced when parallel AC/DC links are used. Similarly, it it was evidently proved that, the DC link enhances the dynamic stability of the system also reduced the cost index. Keeping all the above in view, the HVDC link is tied with the hybrid LFC test system to rectify the instability problem while integrating wind energy generating system.

At first, the output power and frequency deviation of the single-area hybrid LFC system integrating with wind energy generating system without any controller is analyzed under SLP. It is very clear from this analysis that the system becomes unstable while integrating the wind energy resource. To rectify this instability problem integral controllers are connected with the proposed hybrid test system and the gain parameters of the controller are tuned with BFOA approach. The research work is further extended to a multi-area hybrid LFC system under same load perturbations. The simulation results evidently describe, both single and multi-area test system performances are immensely improved with the BFOA tuned integral controller and the system becomes stable

2. Description of Hybrid LFC System

Single-Area Hybrid LFC System with Wind Energy Resource

The Fig.1. describes the linearized test system model considered in this research work. This model comprises single-area hybrid power generating system with conventional /non-renewable sources like thermal power source, hydro power source, gas power source as well as a renewable wind energy resource. The configurations of all the parameters in the functional block are presented in the Appendix.

Initially, SLP of 1% is applied to the test system under consideration to analyze the output performance without any controller. The output frequency deviation as well as the output power generated by each generating system is simulated using MATLAB Simulink and plotted as shown in Fig. 2a-2d. From this figure it is evidently understood that the output response of the hybrid system become unstable when subjected to load perturbations. Hence, it is necessary to provide proper controller to retain the system in stable condition.

Multi-Area Hybrid LFC System with Wind Energy Resource and HVDC Link

ISSN: 2005-4238 IJAST

The linearized model of multi-area hybrid power system is shown in Fig. 3. Each area of this system comprises reheat thermal, hydro, gas and wind generating units with equal system configurations in both areas. The HVDC transmission lines are mostly connected in parallel with the existing AC tie line due to some of its remarkable features such as reducing transient stability, faster controllability as well as economic flexibility. Hence, parallel connection of HVDC link with AC tie line is preferred in this research work on the interconnected multi-area hybrid LFC system under consideration.

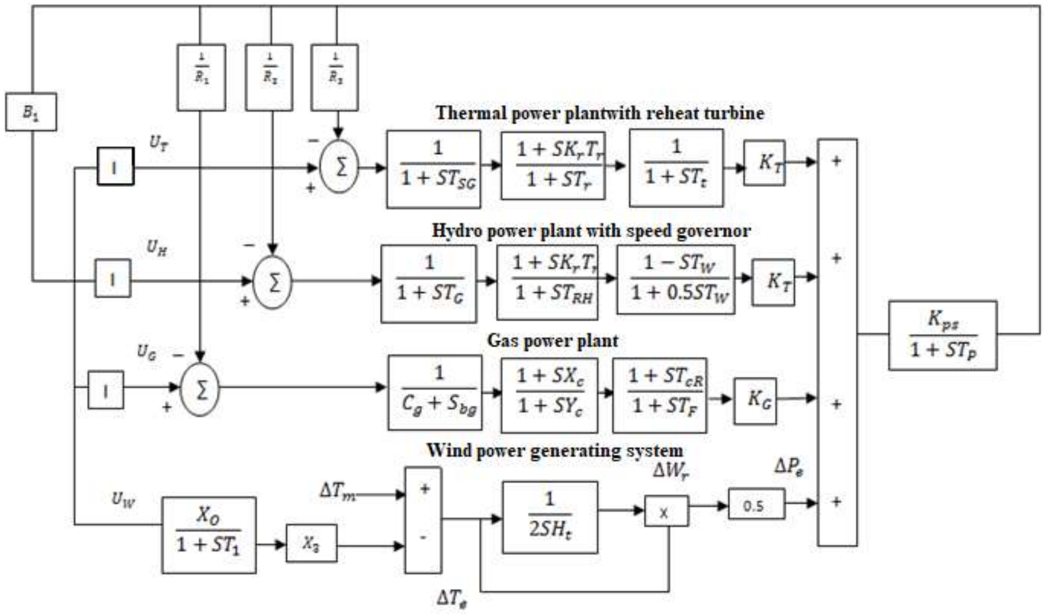

Fig. 1 Linearised model of single area hybrid LFC system with integral controller (I)

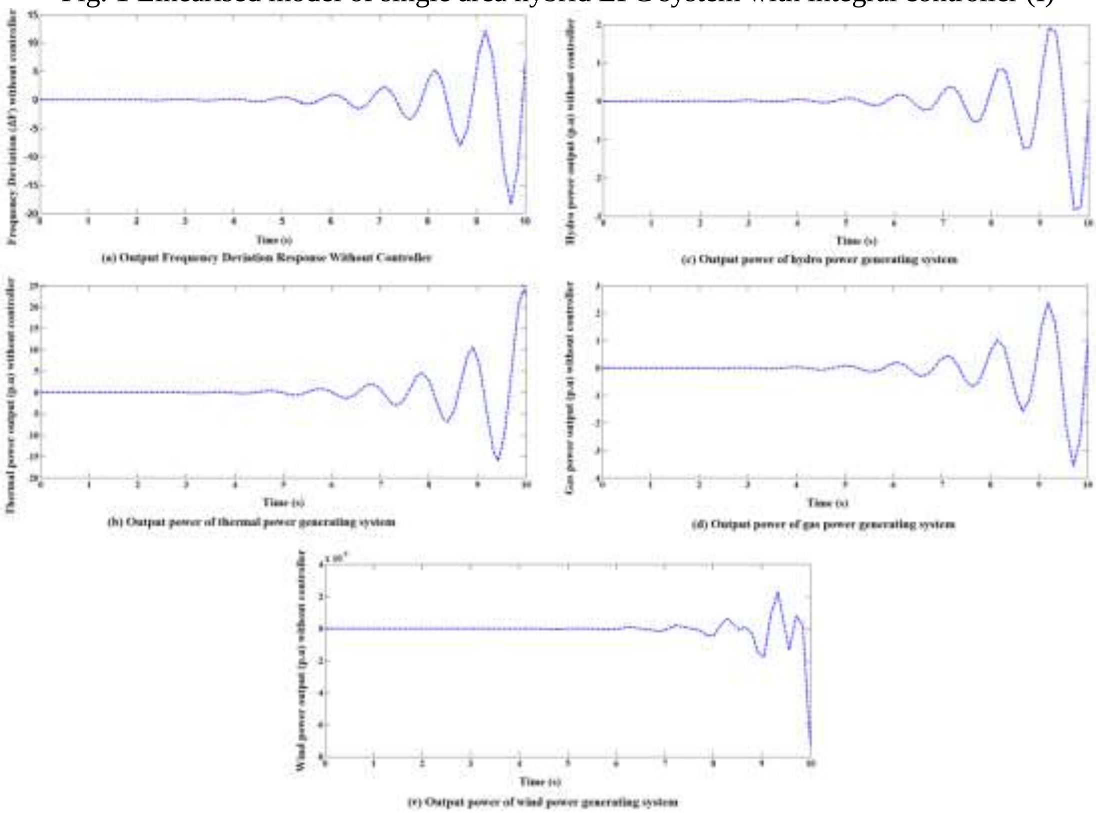

Fig. 2 Output response of single area hybrid LFC system without controller

.

3. Bacterial Foraging Optimization Algorithm

The BFOA algorithm is developed in MATLAB for tuning the gain parameter (KI) of integral controller in single and multi-area hybrid LFC system. The algorithmic steps for tuning the KI controller using BFOA is given below:

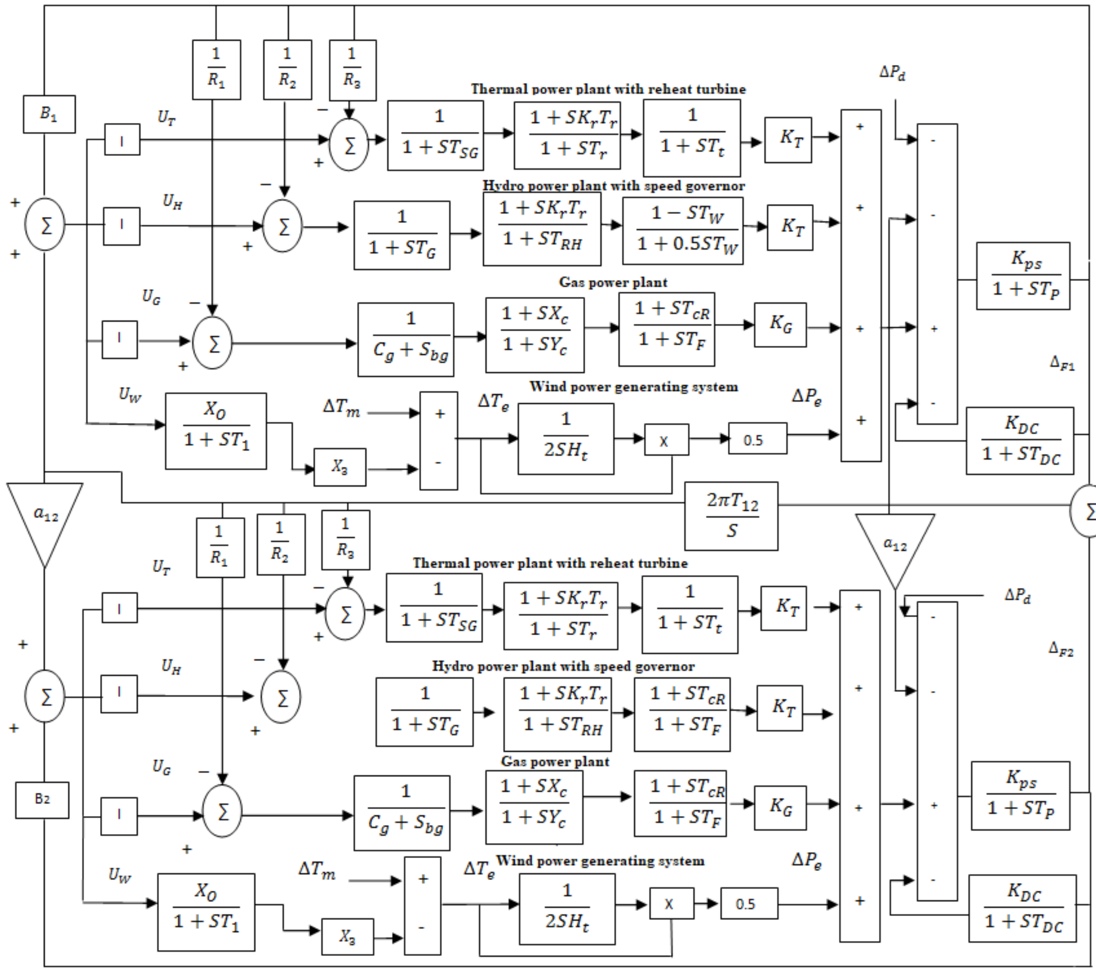

Fig. 3 Linearised model of multi area hybrid LFC system with integral controller (I)

Step 1: All the essential parameters for BFOA algorithm that are given in Appendix 2 are initialized at first. Step 2: Elimination-Dispersal loop: l=l+1

Step 3: Reproduction loop: k=k+1

Step 4: Chemotaxis loop: j=j+1

(a) Initially, S number of random control parameters are generated in a search space as a set of positional values (P) within a specified range $0 \leq K_I \leq 1$. For each iteration, the fitness value (J) of every particle and their positional values (P) are evaluated (1). To simulate the swarming behavior shown in equation (2), the cell to cell attractant–repellant profile (3 and 4) is further added with the fitness function.

$$J(i,j,k,l) = \text{Function}\left(P(i,j,k,l)\right) \tag{1}$$

$$J(i,j,k,l) = J(i,j,k,l) + J_{cc}(\theta, P(j,k,l)) \tag{2}$$

Where,

$$J_{cc}(\theta, P(j,k,l)) = \sum_{i=1}^{S} J_{cc}^{i}(\theta, \theta^{i}(j,k,l)) \tag{3}$$

Where,

$$\sum_{i=1}^{S} J_{cc}^{i}(\theta, \theta^{i}(j,k,l)) = \sum_{i=1}^{S}\left[-d_{att}\exp\left[-w_{att}\sum_{m=i}^{p}(\theta_m - \theta_m^{i})^2\right]\right] + \sum_{i=1}^{S}\left[-h_{rep}\exp\left[-w_{rep}\sum_{m=i}^{p}(\theta_m - \theta_m^{i})^2\right]\right] \tag{4}$$

where, d_{att} and w_{att} illustrates the attractant depth and width. In the same way, the height of the repellant and its width can be represented as h_{rep} and w_{rep}.

(b) The minimum fitness value is then positioned by sorting all the fitness values in descending order and choosing the last one (5) and stored as J_{last}. Then, each particle makes a chemotactic movement in random directions as indicated in equation below (6).

$$J_{last} = J(i,j,k,l) \tag{5}$$

$$P(i,j+1,k,l) = P(i,j,k,l) + C(i)\varphi(j) \tag{6}$$

$$\varphi(j) = \frac{\Delta(i)}{\sqrt{\Delta^{T}(i).\Delta(i)}} \tag{7}$$

where, $C(i)$ for i=1,2,…S) is the size of step by which the particle move in random direction $\varphi(j)$. The value of $\varphi(j)$ can be computed with a random vector (7). The parameter Δ in equation (7) illustrates a vector in random direction whose elements are in the range of [-1, 1].

(c) After the chemotactic movement the particles reach a new position $P(i,j+1,k,l)$ in the search space. Now, for this new position the fitness values of the particles are evaluated (8) and the best fitness value among them will replace the older value of J_{last} as shown in equation (5).

$$J(i,j+1,k,l) = J(i,j,k,l) + J_{cc}(\theta, P(j+1,k,l)) \tag{8}$$

If the fitness value J evaluated for the present chemotactic step $J(i,j+1,k,l)$ is less than the previous one $J(i,j,k,l)$ each particle will take another step in the similar direction or else, the bacterium will move in random directions. This repeated movement leads the particles to move towards the direction of least fitness function and finally to reach the optimum fitness value.

Step 5: If j < N_c (Number of chemotaxis) then go to the step 4 otherwise continue the following steps.

Step 6: Reproduction: In this step the health of each particle is computed with its fitness value (9). The least healthy particles can be identified by arranging the fitness value in ascending/ descending order. During reproduction, the least healthy particles that seems to be the solution with worst fitness value are neglected. The other healthier particles are divided in to two equal halves and each will start to travel towards optimal solution in search space. Hence, constant population size can be maintained.

$$J_{health}^{i} = \sum_{i=1}^{N_c+1} J(i,j,k,l) \tag{9}$$

Step 7: If k < N_{re} (Number of reproduction steps) then go to step 3 otherwise continue the following steps.

Step 8: Elimination-Dispersal: After a certain number of reproduction processes this step is carried out. As per the assigned probability the particles are dispersed/ moved to another position within the environment. This process prevents the local minima trapping.

Step 9: If l < N_{ed} (Number of elimination- dispersal events) then go to step 2 otherwise end the process.

4. Results and Discussions

Transient Analysis of Single Area Multi-source LFC power generating System

The section II.A of this paper describes the occurrence of instability in the output response in the non controller single area multi source LFC system while applying SLP of 1%. To overcome this problem, some of the resent research articles suggested connecting a single integral controller with the test system. Considering the same, a single integral controller is initially linked with the projected hybrid (multi-source) system [10] with same configurations and the gain value of integral controller is tuned with BFOA approach with IAE objective function, by considering the upper and lower limits of the controller gain (K_I) lies between $0 \leq K_I \leq 1$. The tuned value integral controller gain value is $K_I = 0.177$. The output frequency deviation response of the single area hybrid power generating source equipped with common integral gain controller is exposed in Fig. 4. While analyzing the output response it is clear that the system becomes stable for a finite period of time and again enter in to an unstable mode. In the reference research article, the results for the simulation period of 30s are only shown [10].

To overcome this discrepancy three integral controllers (I) are suggested to connect with the hybrid LFC system in this paper as illustrated in Fig.1. The tuned values of integral gain parameter of the controllers corresponding to the thermal, hydro and gas power generating systems are scheduled in Table 1. The output frequency deviation of the test system with this BFOA tuned three integral controllers, which is compared with a single integral controller, are depicted in Fig.4. In addition, for detail analysis all the transient parameters such as MP, SSE, ST and RT of the output responses are measured from Fig. 4 are also depicted in Table 1.

Table 1. Transient performance analysis of single-area hybrid Load Frequency Controller

Measuring Indices	**BFOA optimized single integral Controller**	**BFOA optimized three integral**
Integral Gain	K_I=0.177	K_{IT}=0.20694 K_{IH}=0.75979 K_{IG}= 0.2671
Stability of system	Stable only for Finite period	Stable
Steady State error (s)	0.000302s up to 50s and leads towards instability	-0.000116 s
Settling time (s)	Not Settled	29.1838 s
Maximum Peak (Hz)	0.017563 Hz	0.017414 Hz
Rise Time (s)	0.01018 s	0.0015441 s

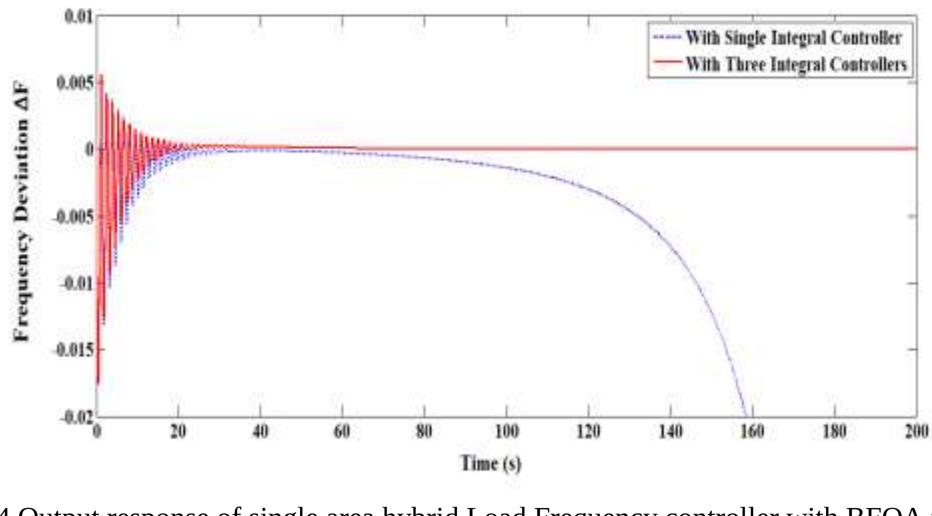

Fig. 4 Output response of single area hybrid Load Frequency controller with BFOA tuned Integral controller

ISSN: 2005-4238 IJAST

The peak value of the system with same configurations tuned with LQR based integral controller is around -0.05 Hz [10] and the peak value of our proposed approach is 0.017414 Hz. The output power of each generating units are also computed and corresponding graphical representation is shown in Fig. 5. All these comparative analyses are done with fundamental time domain specifications. The proposed BFOA tuned three integral controller comprises less ST, MP, RT, SSE and improved stability. Hence, it absolutely clear that the proposed BFOA tuned three integral controller gives better transient response compared to uncontrolled system and single integral controller system.

Transient Analysis of Multi-Area Hybrid LFC System

The linearised model of multi-area hybrid power system is shown in Fig. 3. Each area of this system comprises reheat thermal, hydro, gas and wind power generating units with equal system configurations in both areas. The HVDC transmission lines are preferred in this paper in parallel to the AC tie line due to its significant features such as fast controllability of power in HVDC lines through converter control, reducing transient stability problems associated with AC lines and Economical feasibility.

The gain parameters of integral controllers of all generating unit in each area with AC tie line and with AC-DC parallel tie lines are effectively tuned with proposed BFOA approach and the optimized gain parameters are depicted in Table 2. The comparison of output responses of two area LFC system comprising ΔF_1, ΔF_2 and ΔP_{tie} responses of multi- area hybrid power system with and without HVDC under 1% SLP in area 1 are illustrated in Fig.6. To check the reliability of the proposed approach the results are also compared with the uncontrolled system responses as shown in the same figure. For clear understanding the transient parameters such as MP, ST, SSE and RT are measured from the Fig. 6 are tabulated in Table 2.

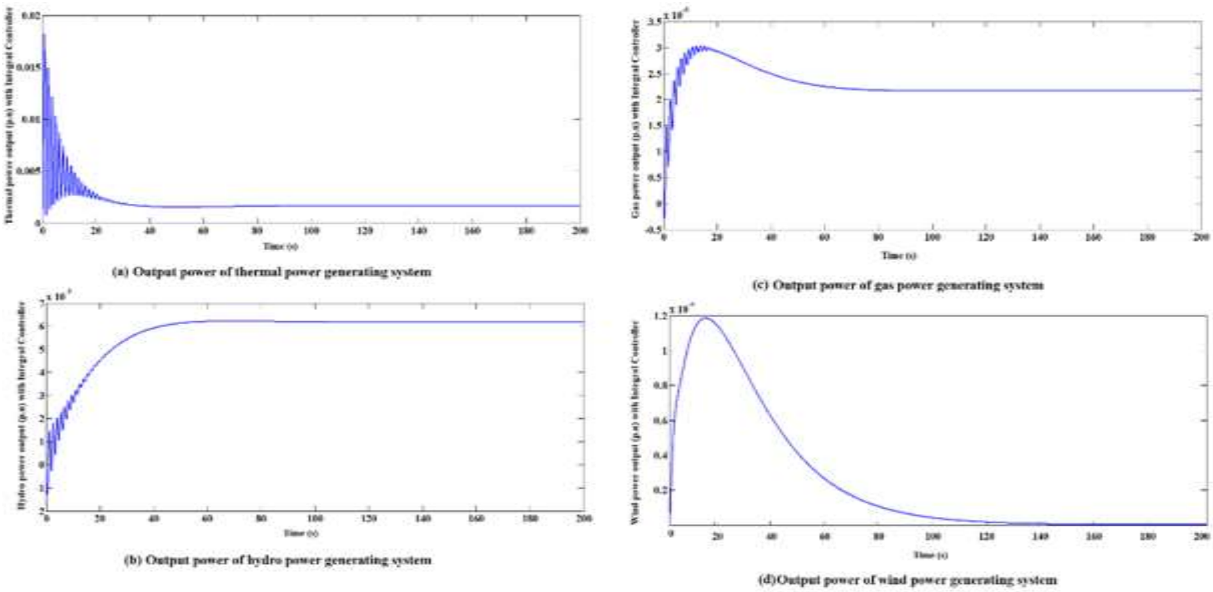

Fig. 5 Output power response of single area hybrid LFC system with controller

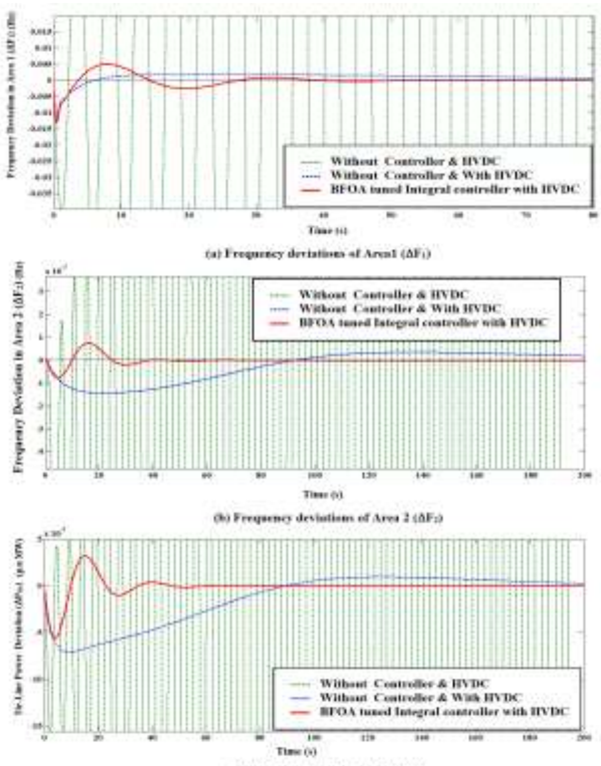

Fig. 6 Output response of multi area hybrid LFC system with BFOA tuned Integral controller

Table 2. Transient performance analysis of multi area hybrid LFC system

Parameter measures		**Multi area hybrid LFC with BFOA tuned integral controller with HVDC**	**Multi area hybrid LFC with HVDC without controller**
Area 1	**K_{IT1}**	0.7344	-
	K_{IH1}	0.7909	-
	K_{IG1}	0.5246	-
Area 2	**K_{IT2}**	0.4379	-
	K_{IH2}	0.0127	-
	K_{IG2}	0.6132	-
Frequency deviation in area-1 (ΔF_1)			
***SSE (Hz)**		-0.0025	-0.0032
***ST (s)**		18.6302	181.7857
***MP (Hz)**		0.0131	0.0130
***RT (s)**		0.0345	0.0352
Frequency deviation in area-2 (ΔF_2)			
SSE (Hz)		0.0005	0.0012
ST (s)		19.9367	197.0944
MP (Hz)		0.0008	0.0014
RT (s)		2.2123	9.1109
Tie line power deviation (ΔP_{tie})			
SSE (pu MW)		0.0015	0.0023
ST (s)		19.9337	195.3461
MP (pu MW)		0.0057	0.0071
RT (s)		1.1551	3.5459
*SSE-Steady State Error, ST-Settling Time, MP-Maximum Peak, RT-Rise time			

ISSN: 2005-4238 IJAST

The Fig. 6 and table 2 clearly reveals the system output performance is much improved in terms of less oscillations, minimum overshoot and minimum settling time in the presence of HVDC link along with the controller whereas the parameters of controller are tuned with proposed BFOA approach.

5. Conclusion

An off-line tuning of gain parameters of an integral controller for single as well as multi-area hybrid LFC system with thermal, hydro, gas and wind power plants using BFOA methodology is suggested in this paper. The stability problem occurred while using single integral controller in multi-source LFC system was identified in this research work and it was rectified by using three integral controllers separately for each generating units. During the optimization process the IAE is considered as a suitable objective function in order to reduce the frequency error. The research is further extended to multi area hybrid LFC system with and without HVDC link. All the simulation results clearly reveal that the proposed BFOA tuned integral controller produces better output response with less steady state error, settling time, peak and rise time compared to the uncontrolled system in both single and multi-area hybrid LFC system and the performances are further enhance while using HVDC link. The superiority of the proposed approach is proved by comparing the results with recently suggested LQR based integral controller approach [10]. In future, the research can also be extended further by using PID controller.

APPENDIX A

Values of Linearized system model

Single & Multi-Area LFC System & HVDC Components
R = 2.4, R_g= 10, β = 0.425, T_p = 20s, K_p =120 K_{DC}=1; T_{DC}=0.2s.
Thermal system: T_{gt} = 0.08 s, T_t = 0.3 s, K_{rt} = 10/3, T_{rt} = 10 s.
Hydro system: T_w = 1 s, T_{gh} = 0.2 s, T1 = 5 s, T_2 = 28.75 s.
Gas system: X = 0.6, Y = 1, a = 1, b = 0.05, c = 1, T_{cr} = 0.3 s, T_f = 0.23 s, T_{cd} = 0.2 s.
Wind system: ω_s = 1.2 p.u., ω_{opt} = 1 p.u., H_t = 4.32 s, L_m = 2.9 p.u., L_r / L_s = 3.06/3.08 p.u., R_r = 0.016 p.u., X_0=(1/R_r) = 62.5 p.u., Twt = (L_r + L_{m2}/L_s) / (ω_s/R_r) = 2.304 s.

APPENDIX B

Parameters for BFOA Algorithm

Total bacterial count =10;
Chosen chemotactic step values =10;
Chosen reproduction step values = 2;
Probability of Elimination- Dispersal = 0.25;
No. of elimination- dispersal events = 2.

REFERENCES

1. Hadi Saadat.:Power system analysis. McGraw-Hill, New York(1999)
2. S. Anbarasi, S. Muralidharan, “Hybrid BFPSO Approach for Effective Tuning of PID Controller for Load Frequency Control Application in an Interconnected Power system,” Journal of Electrical Engineering & Technology Vol.12, No.3 pp. 1027- 1037,2017.
3. S Jagatheesan Kaliannan et.al., “Ant colony optimization algorithm based PID controller for LFC of single area power system with non-linearity and boiler dynamics,” World Journal of Modelling and SimulationVol.12, No.1 pp. 3-14,2016.

ISSN: 2005-4238 IJAST

4. S. M. Abd-Elazim E. S. Ali, "Load frequency controller design of a two-area system composing of PV grid and thermal generator via firefly algorithm," Neural Computing and Applications Vol.30, No.2 pp. 607–616,2018.
5. S. Anbarasi, S. Muralidharan, "Metaheuristic Optimized PID tuning for Load Frequency Control of Multi-Area Multi-Source Power System with and Without HVDC Link," Journal of Electrical Engineering, Vol.17, No.2 pp. 1-11, 2017.
6. H. Shayeghi, A. Younesi, "An Online Q-learning Based Multi-Agent LFC for a Multi-Area Multi-Source Power System Including Distributed Energy Resources," Iranian Journal of Electrical and Electronic Engineering Vol.13, No.4, pp. 385-398, 2017.
7. T. H. Mohamed, J. Morel, H. Bevrani, T. Hiyama, "Model predictive based load frequency control design concerning wind turbines," Elect Power and Energy Systems, 43, 2012, pp.859-867.
8. Nikhil Pathak et.al., "Modeling of HVDC Tie Links and Their Utilization in AGC/LFC Operations of Multiarea Power Systems," IEEE Transactions on Industrial Electronics, Vol.66, No.3 pp. 2185 - 2197,2018.
9. Nour El Yakine Kouba et.al., "A novel optimized fuzzy-PID controller in two-area power system with HVDC link connection," International Conference on Control, Decision and Information Technologies (CoDIT), St. Julian's, Malta, 6-8 April 2016
10. Rajasi Mandal, Kalyan Chatterjee, Bhavesh Kumar Patil, "Load frequency control of a single area hybrid power system by using integral and LQR based integral controllers," 20th National Power Systems Conference (NPSC), 14-16, Dec. 2018 Tiruchirappalli
11. Qu G H, Zhang D L, Yan P F. "Information measure for performance of image fusion". Electronics Letters, 2002, 38(7):313−315