International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Integration of Economic Load Dispatch with AGC of Multi-Area Power System: Analysis on Optimal Control and Stabilization

Prakash Chandra Sahu , Ramesh Chandra Prusty

Abstract: ***This paper proposes a novel Moth Flame Optimization (MFO) based filter type Proportional Integral and Derivative (PID) controller in multi-area interconnected power system for achieving simultaneously Automatic Generation Control (AGC) and Economic Load Dispatch (ELD). Conventional AGC is economically inefficient in regards to each area has to fulfill its own load variation in responses to keep tie-line power (ΔPtie) its scheduled value. To achieve this ACE based AGC is modified by integrating with ELD and combined known as Economic AGC or Eco-AGC. In Eco-AGC concern though change in area frequency(Δf) is brought to zero but tie-line power deviation (ΔPtie) never comes to zero as power always transmitted from generating station having lower incremental fuel cost to generating station having higher incremental fuel cost. In this regard an optimized filter based PID controller is used for stabilizing different dynamic responses of the Eco-AGC system. The proposed controller gains are tuned by using Moth Flame Optimization (MFO) techniques and for supremacy it is compared with standard PSO and Differential Evolution (DE) algorithm. The supremacy of MFO based PID structure over PSO and DE based PID and without ED controller has been demonstrated through dynamic responses. Finally it is revealed in Eco-AGC concern, the committed units are economically scheduled and there is a significant improvement in all dynamic responses of the system.***

Keywords: Automatic Generation Control (AGC); Area Control Error (ACE); Economic Load Dispatch (ELD);Moth Flame Optimization (MFO); Step Load Perturbation (SLP);

I. INTRODUCTION

The power system employs two different loops i.e Automatic Voltage Control (AVR) and Automatic Load Frequency Control (ALFC) loops [1-3] for control of system voltage and frequency respectively. The tie-line power and network frequency deviates when the net generation does not satisfy the total demand of system. So to keep both tie-line power and frequency to their nominal values, the net generation will be controlled irrespective of total load demand which is termed as Automatic Generation Control (AGC) [4-5]. Though research has been carried out on AGC in both isolated and interconnected network along with single and multi area system [6-7], there is few research on AGC including optimal generation scheduling with cost economic. So the current article proposes a research on AGC including Economic Load Dispatch (ELD) [8] and combined known as Economic AGC or Eco-AGC [9-10]. In AGC concern, both system errors like change in frequency and change in net tie-line power are brought back to zero with the application of suitable control mechanism. But in Eco-AGC concern though change in frequency is brought back to zero but net power exchanges (active) between power stations never backs to zero rather flows from generating station having lower incremental fuel cost to higher incremental fuel cost irrespective of capacity. It has been observed that different controllers have been implementing in the area of AGC for controlling both frequency deviation (Δf) and tie-line power deviation (ΔP_{tie}) of the system. Elgerd and Fosha suggested [11] control of optimal megawatt frequency in multi area power system under various conditions. In recent and past decades various controllers like conventional P, PI and PID controllers, Fuzzy idea based Fuzzy Logic Controller (FLC)[12] and Adaptive Neuro Fuzzy Interference System (ANFIS) controllers, Degree of freedom based 2DOF and 3DOF[13] controllers and recently developed Fractional Order based FO-PID and FO-FPID[14] controllers have been proposed in AGC research scenario. The article proposes a filter oriented PID controller as secondary controller (for AGC only) and conventional PID as primary controller for Eco-AGC study. The presence of filter coefficient (N) in secondary controller improves stability and gives close optimum results in comparing with conventional PID controller. Both of above proposed controllers are operated in different time scales of common time frame. To optimal design various proposed controllers different optimization techniques like GA[15], PSO[16], DE[17], and few metaheuristic techniques like Cuckoo search Algorithm[18], Ant Bee Colony[19], Ant Lion Optimization[20], and some hybrid techniques are utilized in the AGC study. The current article proposes Moth Flame Optimization (MFO)[21] algorithm to tune the gain values of both primary and secondary controllers and for supremacy its performance is compared with DE and standard PSO algorithms. In recent market due to rapid increase of renewable energy sources and power demand the net aggregate load varies at very fast rate and by large amount.

Manuscript published on November 30, 2019.
* Correspondence Author
Prakash Chandra Sahu*, Department of Electrical Engineering, Silicon Institute of Technology, Odisha,India.
Ramesh Chandra Prusty, Department of Electrical Engineering, VSSUT, Burla, Sambalpur, India.

In this conditions if the frequency biasing factor is selected in accordance with natural response coefficient (β) then there will be power imbalance which results oscillation in tie-line power in ELD[22] concern. The present paper modifies the traditional AGC by integrating with ELD to ensure improved economic efficiency. The prime focus for modification of traditional AGC is to (i) keep each area frequency to its nominal value.(ii) maintain optimal power dispatch between different generating units.

II. SYSTEM UNDER STUDY

A. AGC Model

The proposed transfer function model comprises thermal generation based three area interconnected power system and has been illustrated details in Fig1 with primary loop controller (ED Controller) and secondary loop controller. Each control area is composed of controllable Turbine-Governor unit based thermal generating station, power system and required controllers for both AGC and ELD concern. The thermal system is modeled with equivalent transfer functions.

The power balance of each control area of multi area AGC system is depicted in equation (1)

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{\Delta f(s)}{R} \qquad (1)$$

Equation (2) depicts hydraulic actuator (Governor) Transfer function.

$$G_H(s) = \frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{1+T_g s} \qquad (2)$$

The Transfer function of turbine is illustrated in Equation(3)

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+T_T s} \qquad (3)$$

The tie-line power which is a function of frequency is illustrated in equation (4)

$$\Delta P_{12}(s) = \frac{2\pi T}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \qquad (4)$$

The total error generated in each control area is the linear summation of variation in frequency and tie-line power and is expressed as area control error (ACE), which is depicted in equation (5).

$$ACE_i = B_i \Delta f_i + \sum_{j=1}^{n} \Delta P_{i-j} \, (i \neq j) \qquad (5)$$

B. Economic Load Dispatch (ELD)

In today's electrical scenario there is a rapid increase of renewable energy based power sources in power grid which enhances net aggregate load at a faster rate and by large amount. For reliable operation each area has to absorb its own load variation efficiently. The ACE based AGC is economically inefficient to perform above reliability nature. Therefore the proposed research article is to modify the ACE based AGC to produce following economic observations i.e

1. Able to maintain each area frequency towards nominal values.
2. Control the mechanical power of system in order to fulfil the demand at minimum cost of generation. i.e Minimize $F = \sum_{i=1}^{m} f_i(P_i)$ to maintain optimal dispatch of all committed units.

   Where F= Cost function of i^th generating unit.

In this research article for ELD problem two types of cost functions are described i.e smooth cost function of generators and non-smooth cost function with valve point loading.

III. PROPOSED STATEMENT

a. Controller modeling

In both optimization and control research scenario the conventional PID controller is most popular and favored feedback controller in all engineering disciplines since number of decades. The PID controller exhibits excellent performance and robust nature in different process plants for improving dynamic characteristics. The article proposes a closed loop type filter based PID controller [23](F-PID) for controlling different error signals of system and is illustrated in Fig.2.Filter coefficient (N) helps to eliminate high frequency noise signals which are mostly received by derivative block of proposed controller. So filter coefficient improves stability and gives close optimum result. The proportional gain (K_P) helps to reduce rise time of response but unexpected values of K_P makes system unstable. It has been observed that excess value of K_P makes system unstable and reduced value of K_P provides small output response for large input error.

The output of filter based PID controller in 's' domain is given by

$$TF_{PID} = K_p + \frac{K_I}{s} + K_D\left(\frac{Ns}{N+S}\right) \qquad (6)$$

Retrieval Number: D7889118419/2019©BEIESP
DOI:10.35940/ijrte.D7889.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

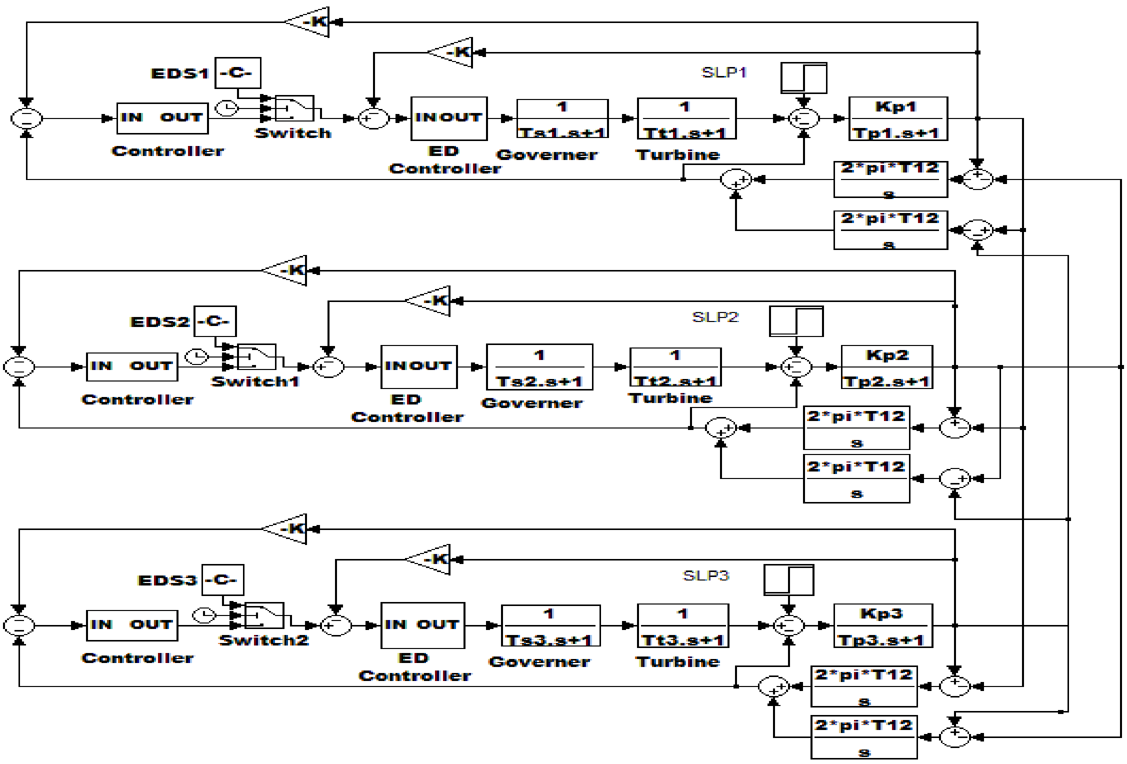

Fig.1 Three Area Interconnected Power System Unde Study

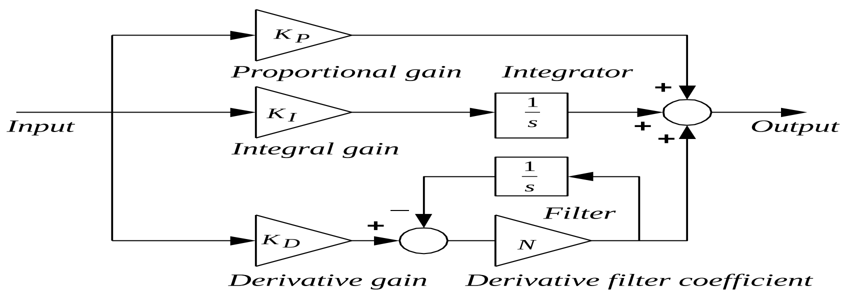

Fig.2 Block diagram of F-PID controller for a closed loop system

b. Objective function

In the present study objective functions Integral of Time Multiplied Absolute Error (ITAE) has been used for tuning gain parameters of proposed controller due to its improved dynamic responses producing capability. The proposed function helps to produce low oscillation and damping based dynamic responses for this multi are power system.

$$ITAE = \int_0^T \left(|\Delta F_i| + |\Delta P_{tiei-j}|\right) t \, dt \qquad (7)$$

Where ΔF_i =Variation of frequency of i^{th} area, ΔP_{tiei-j}= tie line power deviation between area i^{th} and j^{th}. T = Time of process. The conditions to be satisfied for minimization of proposed objective function are $K_{PMin} \leq K_p \leq K_{PMax}$, $K_{DMin} \leq K_D \leq K_{DMax}$, $K_{IMin} \leq K_I \leq K_{IMax}$, $N_{Min} \leq N \leq N_{Max}$. The bands selected for above gain values are [-5,5] except filter coefficient(N) which is [0,100].

3. Moth Flame Optimization(MFO) algorithm

Insect moths are very similar with butterflies and there are different species of moths in nature. During their life span they pass two different stages i.e Larva phase and adult phase. Basically moth is developed from larva through different stages. In nature moths have an interesting behavior of following navigation method at night [24]. Moths try to fly at night using moon light and during navigation they apply transverse orientation mechanism. In night moths always maintain fixed angle w.r.t moon which helps them to fly very long distances and also in a straight line. The same principle also effective for human made lights. As human made lights are very close in comparing with moon light, the constant angle mechanism results deadly fly path of the moths. The mechanism reveals that moth has the ability to converge towards light which helps to develop a mathematical model and based on which Moth Flame Optimization (MFO) technique is developed. Position of moth stands for fitness value and population size depends on strength of moth. In this regard Fig.4 illustrates the detailed steps (flow chart) involved with the proposed MFO algorithm.

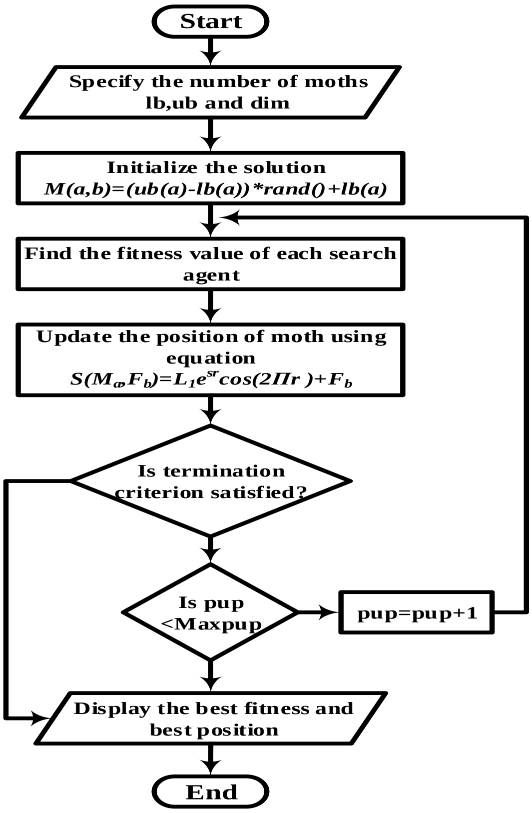

Fig.4 Flow chart of MFO algorithm

IV. RESULTS AND ANALYSIS

Simulation and time domain simulated results of proposed model in Fig.1 has been carried out in MatlabR2014a environment. To demonstrate characteristics of AGC and ELD in a common research scenario they should not be operated in a common time scale rather in different time scales. In this research article out of total 14sec(some cases may be different value) simulating period of AGC operation is carried out for first 7 secs (first period, operation of secondary controller) and Eco-AGC is carried out for rest 7 secs (second period, operation of primary controller) with suitable switching arrangement as shown in Fig.1. So primary controller (ED controller/F-PID) operates during Eco-AGC period and secondary controller (F-PID) operates for conventional AGC period (first 7sec). Gain parameters of both primary and secondary controllers have been optimized by utilizing proposed MFO algorithm and to show its viability it has been compared with DE and PSO algorithms. The article has been focused on AGC and Eco-AGC of multi area interconnected system in view of two different conditions. In Case 1- Area 1 is effected with a step load perturbation of 1% only. Case 2- SLP with value 2% & 5% are given at area 1 and area 2 respectively. The specifications of the generators taken for this study are demonstrated through table 1.

Case 1- Area1 is effected with a step load perturbation (SLP) of 1% only.

This section investigates both AGC and Eco-AGC performances of multi area system under the appearance of a SLP of 1% at area1 only. The optimized gain parameters of both primary controller and secondary controller are demonstrated through table.2. The frequency regression of area1 and area3 are illustrated in Fig.5 (a-b) respectively. Like this tie line power deviations are depicted in Fig.5(c-d) and deviation in individual power generations are given in Fig.5(e-f) respectively with a total time period 14sec out of which AGC analysis (secondary controller) has been carried out for first 07 sec and Eco-AGC is done during remaining 07 sec. It has been observed from all responses that during AGC analysis all the responses have been settled to zero, whereas during Eco-AGC analysis only frequency responses are settled to zero but tie line power and power generation responses are settled to a new value rather than zero.

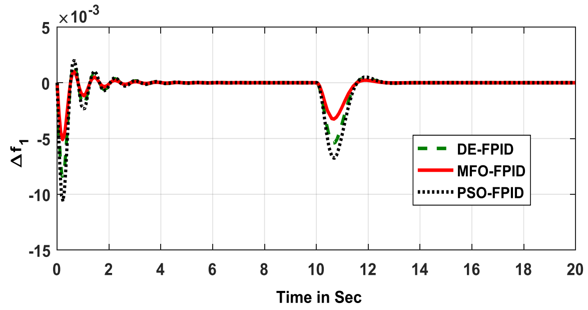

Fig 5(a) Deviation in area1 frequency

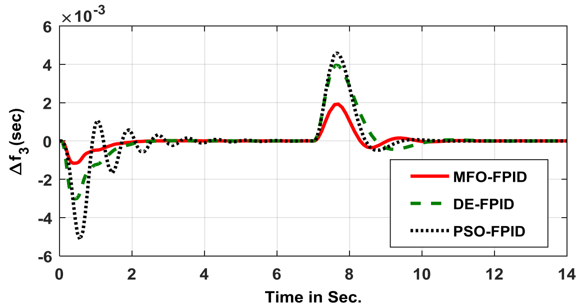

Fig 5(b) Deviation in area3 frequency

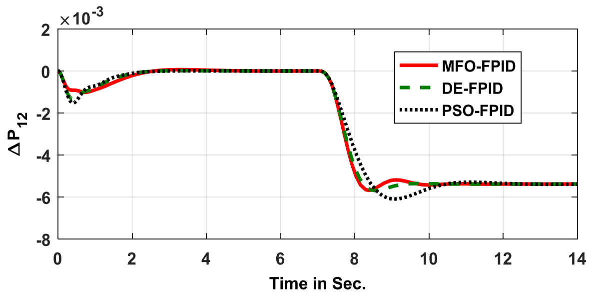

Fig 5(c) Deviation in tie-line power between area1 and area2

Retrieval Number: D7889118419/2019©BEIESP
DOI:10.35940/ijrte.D7889.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table 1 (Generator specifications)

Generators	Pg_{max} (MW)	Pg_{min} (MW)	c_i	b_i	a_i
G1	150	25	0.000023	0.02	20
G2	200	25	0.000019	0.04	15
G3	250	25	0.000043	0.03	25

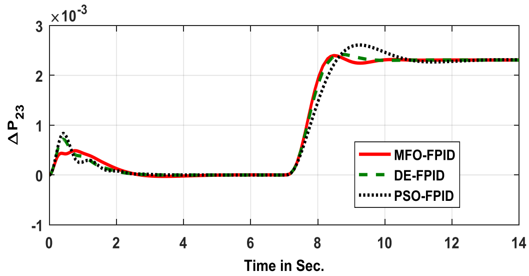

Fig 5(d) Regression in tie-line power of area2 and 3

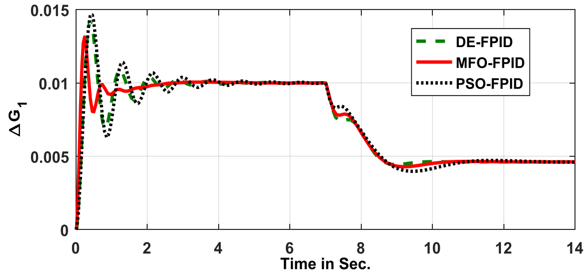

Fig 5(e) Deviation in power generation of area1

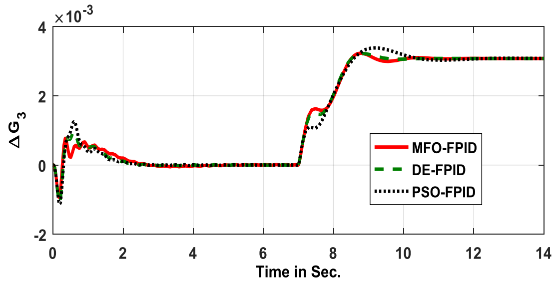

Fig 5(f) Deviation in power generation of area3

It has been visualized from different responses that the performance of both AGC and Eco-AGC are varied in response to the nature of controller and applied optimization techniques. Moreover, only frequency stability issues are identical in both the cases however the stability in tie-line power and power generation are not identical as per the Eco-AGC phenomenon. A thorough assessment over dynamic responses and a comparative study among different techniques reveals all the dynamic responses obtained due to MFO Optimized F-PID controller have been improved significantly in response to settling time, peak overshoot and peak undershoot of responses,

Case 2- SLP of 2% & 5% are given at area 1 and area 2 respectively.

A SLP of 2% and 5% at time t=0 are effected at area1 and area2 respectively and resulted dynamic responses are depicted in Fig.6. The deviation in frequency of area1 and area2 are depicted in Fig.6(a-b) respectively. Like this tie line power deviation and change in output power generations are depicted in Fig.6(c) and Fig.6 (d) respectively. All responses reveal supremacy of proposed MFO optimized F-PID controller both for AGC and Eco-AGC concern. It has been seen that in Eco-AGC concern the resulted dynamic responses exhibit least damping errors and maintains scheduled generation irrespective of such disturbance.

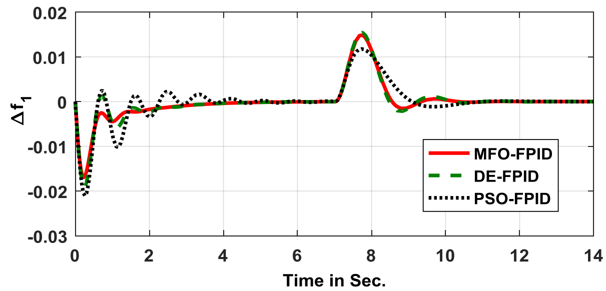

Fig 6(a) Deviation in area1 frequency

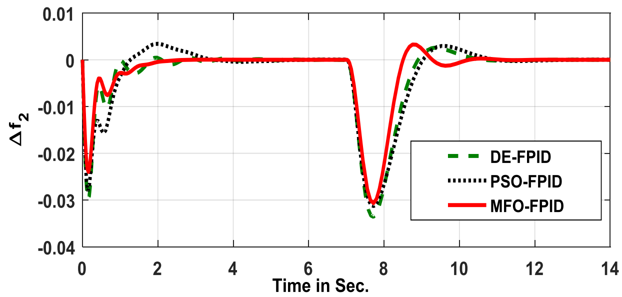

Fig 6(b) Deviation in area2 frequency

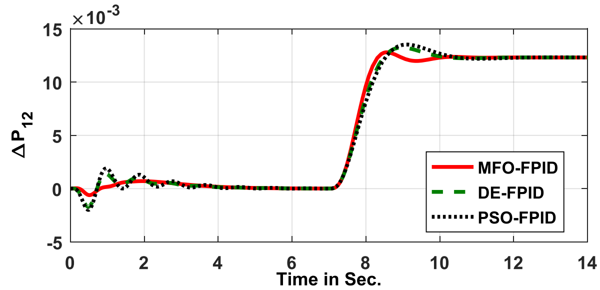

Fig 6(c) Degression in tie-line power between area1 and area2

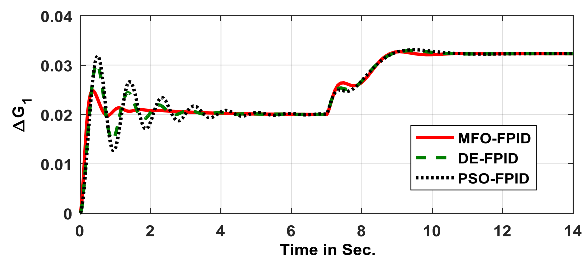

Fig6(d) Deviation in power generation of area1

Unlike case study1, it has been suggested that stability in system responses are achieved with implementing various optimal controllers.

Table 2 (Optimized controller gain parameter values)

Controllers	Secondary loop controller gains	Primary loop controller gains
PSO optimized F-PID controller	KP1=2.9883;KI1=5.0000;KD1=0.9913;N1=82.20 KP2=5.0000;KI2=4.0649;KD2=1.2917;N2=46,54 KP3=5.0000; KI3=0; KD3=4.4925;N3=42.20	KP=1.0000; KI=0.0000; KD=0.1845
DE optimized F-PID controller	KP1=4.8222;KI1=4.9895;KD1=1.3506;N1=66.26 KP2=2.8886;KI2=0.4677;KD2=0.5114;N2=38.50 KP3=3.7802;KI3=0.8578;KD3=0.9267;N3=28.22	KP=0.8359; KI=0.0058; KD=3.8018
MFO optimized F-PID controller	KP1=3.0803;KI1=5.0000;KD1=0.7726;N1=90.42 KP2=5.0000;KI2=4.9939;KD2=1.2743;N2=72.28 KP3=5.0000;KI3=0;KD3=4.3466;N3=56.34	KP=1.0000; KI=0.0001; KD=0.2845

Different ITAE values with average and standard deviation values are gathered in table.3 with five individual runs.

Table 3 (ITAE values of MFO optimized PID controller with separate five runs and standard deviation)

Sl.No	ITAE(x)*10^{-2}	Average($\bar{x}$)*10^{-2}	Standard Deviation
1	10.48	13.65	2.26*10^{-2}
2	13.56	13.65	
3	16.18	13.65	
4	12.67	13.65	
5	15.36	13.65	

Table.4 (Optimal dispatch results)

	Loading Case 1(1*10^{-2} pu)	Loading Case 2(7*10^{-2} pu)
Change in G_1 power (pu)	0.46*10^{-2}	3.23*10^{-2}
Change in G_2 power (pu)	0.23*10^{-2}	1.62*10^{-2}
Change in G_3 power (pu)	0.31*10^{-2}	2.15*10^{-2}
Change in $P_{tie,12}$ power (pu)	-0.54*10^{-2}	1.23*10^{-2}
Change in $P_{tie,23}$ power (pu)	0.23*10^{-2}	-3.38*10^{-2}
Change in $P_{tie,31}$ power (pu)	0.31*10^{-2}	2.15*10^{-2}

To obtain best ITAE value, the power system model is compiled with individual five different runs. The respective average and standard deviation values are demonstrated in Table.3. In contribution to generation point of view, the applied load is effectively absorbed by all generating units irrespective of their capacities. In this regard for case study1, the change in generation of all generating units satisfy the applied 1% slp at area1. The second case study also has been concluded through Table.4 for loading case2.

V. CONCLUSION

In this paper, a novel MFO algorithm is proposed to tune the parameters of primary controller (F-PID) and secondary controller (F-PID) in three-area interconnected power system for providing simultaneously Automatic Generation Control (AGC) and Economic Load Dispatch (ELD).

To show supremacy of Eco-AGC analysis over conventional AGC both operations are performed in common time frame with different time scale. In view of this an improvement in dynamic responses as well as performance index parameters has been noticed due to Eco-AGC operation and simultaneously able to maintain scheduled generation economically in all units. It has been also verified that the Eco-AGC principle motivates towards smooth distribution of effected load deviation and shared among units irrespective of capacity and economic. System without ED controller is pulled to more unstable and with ED controller the system regains stable operation due to improved optimal control mechanism. In regard to this to confer viability of proposed MFO algorithm, it is compared with standard PSO and DE algorithm through different dynamic responses. It has been cleared through different dynamic responses that both for AGC and Eco-AGC analysis our proposed MFO optimized F-PID controller is more effectiveness over other approaches and gracefully improves system dynamic responses under different uncertainties.

APPENDIX

Symbol	Description	Nominal Values
R_i	Regulation of Governor	2.4 Hz/pu MW
B_i	Frequency bias Parameter	0.425 pu MW /Hz.
T_{gi}	Time constant of Governor	0.08 sec.
T_{ti}	Time constant of Turbine	0.3 Sec
K_{Pi}	Power system gain	120 Hz/ pu MW
T_{Pi}	Power system time constant	18 sec
T_{12}	Synchrinizing Power Coefficient	20.06
EDS	Economic Dispatch Switch	

REFERENCES

1. P.Kundur, "Power System Stability and Control" Tata McGraw Hill.New Delhi.2009.
2. O. I. Elgerd, "Electric Energy Systems Theory – An Introduction" Tata McGraw Hill.New Delhi.2000.
3. S. Chatterjee, V. Mukherjee, "PID controller for automatic voltage regulator using teaching–learning based optimization technique", International Journal of Electrical Power & Energy Systems.2016; 77: pp. 418-429.
4. R.K. Sahu , S. Panda, S. Padhan, "A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems", International Journal of Electrical Power & Energy Systems.2015;64: pp. 9-23.
5. S.R. Khuntia, S. Panda, "Simulation study for automatic generation control of a multi-area power system by ANFIS approach", Applied Soft Computing. 2012;12: pp. 333-341
6. B.K. Sahu, S. Pati, P.K Mohanty, S. Panda, "Teaching–learning based optimization algorithm based fuzzy-PID controller for automatic generation control of multi-area power system", Applied Soft Computing. 2015;*27*: pp. 240-249.
7. A.K. Barisal, "Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems", Electrical Power and Energy Systems. 2015;66: pp. 67-77.
8. A.Y, Abdelaziz, E.S,Ali, S.A.Elazim, "Implementation of flower pollination algorithm for solving economic load dispatch and combined economic emission dispatch problems in power systems.Energy", 2016;101: pp. 506-518.
9. A.A, Thatte, F. Zhang , L. Xie, ".Frequency aware economic load dispatch. Department of Electrical and Computer Engineering", Texas A & M University.
10. N. Li , C. Zhao, L. Chen, "Connecting automatic generation control and economic dispatch from an optimization view", IEEE Transactions on Control of Network Systems. 2016;3(3):pp.254-264.
11. C. Fosha , O I. Elgerd, "The megawatt-frequency control problem: a new approach via optimal control theory", IEEE Trans. Power Appl. Syst.1970;4 : pp.563–577.
12. W.Sa-ngiamvibool,"Optimal Fuzzy Logic Proportional Integral Derivative Controller Design by Bee Algorithm for Hydro-Thermal System", IEEE Transactions on Industrial Informatics. (2017).
13. A. Rahman, L .C. Saikia , N. Sinha, " Automatic generation control of an unequal four-area thermal system using biogeography-based optimised 3DOF-PID controller", IET Generation, Transmission & Distribution 2016;*10*
14. Y. Arya , N. Kumar, "BFOA-scaled fractional order fuzzy PID controller applied to AGC of multi-area multi-source electric power generating systems", Swarm and Evolutionary Computation. 2017;*32* : pp.202-218.
15. A.G. Pereira, V.S. Campos, "Multistage non homogeneous Markov chain modelling of the non homogeneous genetic algorithm and convergence results", Communications in Statistics-Theory and Methods. 2016;*45*(6): pp.1794-1804.
16. S. Panda, B. Mohanty, P.K. Hota, ".Hybrid BFOA-PSO algorithm for automatic generation control of linear and nonlinear interconnected power systems", Applied soft computing . 2013; 13: pp.4718-30.
17. A. Mewara, G. Parmar, "Comparison of DE optimized PID controllers for AGC of interconnected power system", In Computer. Communications and Electronics (Comptelix).(2017) International Conference on (pp. 178-182). IEEE.
18. P. Dash , L.C. Saikia , N. Sinha, "Comparison of performance of several cuckoo search algorithm based 2DOF controllers in AGC of multi-area thermal system", Electrical Power and Energy systems. 2014;55: pp.429-436.
19. J,Kaliannan, A.Baskaran, "Performance analysis of double reheat turbine in multi-area AGC system using conventional and ant colony optimization technique", IU-Journal of Electrical & ElectronicEngineering.2015; 15(1):1849-1854.
20. P.C. Sahu , R.C. Prusty, S. Panda, ".ALO optimized NCTF controller in multi area AGC system integrated with WECS based DFIG system",.In Circuit, Power and Computing Technologies (ICCPCT), (2017) International Conference on (pp. 1-6). IEEE.

21. S.Mirjalili,"Moth-flame optimization algorithm: A novel nature-inspired heurist paradigm", Knowledge-Based Systems. 2015;89: pp.228-249.
22. S.Banerjee, D. Maity, C.K. Chanda, "Teaching learning based optimization for economic load dispatch problem considering valve point loading effect",.International Journal of Electrical Power & Energy Systems. 2015;73:pp.456-464.
23. P. Das , P. J. Edavoor , " Raveendran S, Rathore S,Rahulkar A D.Design and implementation of PID controller based on orthogonal wavelet filter-banks in FPGA", In Embedded Computing and System Design (ISED),.2017 7th International Symposium on (pp. 1-6). IEEE.
24. K. Chen, "Navigation method and system for selecting and visiting scenic places on selected scenic by way.U.S.", Patent No. 2015; pp. 9,074 :907. 7.

AUTHORS PROFILE

Mr. Prakash Chandra Sahu, has completed his M.Tech in Electrical Engineering from Siksha 'O' Anusandhan University, Bhubaneswar, India in the year 2013. He is persuing his Ph.D program in Electrical Engineering in Veer Surendra Sai University of Technology, Odisha, India. Currently he is working as Asst. Professor in the department of Electrical Engineering in Silicon Institute of Technology, Odisha, India

Dr. Ramesh Chandra Prusty, has completed his M.Tech in Electrical Engineering from **Veer Surendra Sai University of Technology, Odisha,** India in the year 2010. He has also completed his Ph.D program in Electrical Engineering from Veer Surendra Sai University of Technology, Odisha, India. Currently he is working as Asst. Professor in the department of Electrical Engineering in VSSUT, Bura, Odisha, India