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Research Article

Amalgamated Firefly Algorithm with Migration Effect of Biogeography Based Optimization for Proportional Integral and Derivative Controller Parameters Optimization in Two Area Interconnected Power System

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Abstract: In this study, Firefly Algorithm and Amalgamated Firefly Algorithm with Migration Effect of Biogeography Based Optimization techniques are proposed to optimize the proportional, integral and derivative gains of PID controller in two equal areas Interconnected Power System for quenching the deviations of frequency and make the tie line power flow deviation to zero. The considered performance index for minimization is Integral of Time weighted Absolute value of Error. Two different operating conditions are taken. First operating condition is taken as, the occurrence of 5% step load perturbation in area 1 and 10% step load perturbation in area 2. Second operating condition is taken as, the occurrence of 15% step load perturbation in area 1 and 10% step load perturbation in area 2. Importance of this interconnected power system is to provide reliable and efficient power to consumers. For this reason, the responses are analyzed and discussed. Finally, it is concluded with the identification of better optimization technique which provides solution for supply of reliable and efficient power to consumers in an interconnected power system. From the response and analysis, amalgamated firefly algorithm with migration effect of biogeography based optimization gives better performance compared from firefly algorithm. Migration effect of biogeography based optimization technique improves the local search of firefly algorithm in the amalgamated performance.

Keywords: Amalgamation, firefly algorithm, interconnected power system, migration Effect of BBO, PID controller gains

INTRODUCTION

Necessity of interconnected power system is to maintain the constant frequency and make the tie line power flow deviation to zero under normal and perturbation conditions. A lot of control strategies are presented for interconnected power systems by the researchers such as Conventional Integral, PI and PID Controllers, State Variable Model, Adaptive Controller, Quantitative Feedback Theory, Characteristic Loci Method, Unified Tuning of PID Controllers, Optimal Feedback methods, etc. An extensive literature review has been done on the work carried out using the above controllers (Elgerd and Fosha, 1970; Fosha and Elgerd, 1970; Elgerd, 1983; Pan and Liaw, 1989; Stankovic *et al*., 1998; Nanda *et al*., 2006; Taher and Reza, 2008; Shayanfar *et al*., 2009; Tan, 2010; Singh Parmar *et al*., 2011). The conventional PID controllers are widely used as supplementary control in interconnected power system to maintain the frequency to be constant (or minimize the frequency deviations to zero) and minimize the scheduled power flow deviations to zero. To enhance the capabilities of parameters of conventional PID controller, many researchers suggested several intelligent approaches to tune the parameters of PID controller in an interconnected power system such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), Bacterial Foraging Optimization (BFO), etc. (Chidambaram and Paramasivam, 2009; Panda *et al*., 2010; Milani and Mozafari, 2011; Duman and Yörükeren, 2012; Saini *et al*., 2013). Biogeography Based Optimization (BBO) (Simon, 2008, 2011; Al-Roomi *et al*., 2013; Malik *et al*., 2014) and Firefly Algorithm (FA) (Yang, 2009; Yang and He, 2013; Ali *et al*., 2014) are recently used stochastic

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methods. In this study, firefly algorithm and amalgamated firefly algorithm with the migration effect of biogeography based optimization techniques are proposed to optimize the PID controller in interconnected power system. In load frequency control, numbers of performance indices are used. Many scientists investigated Minimization of Integral of Time weighted Absolute value of Error (ITAE) gives better performance compared to ISE criterion and Ziegler-Nichols tuning (Martins, 2005; Panda *et al*., 2010; Duman and Yörükeren, 2012; Krishna Kumar, 2012; Jeevithavenkatachalam and Rajalaxmi, 2013).

In this study, two optimization techniques are proposed to optimize the proportional, integral and derivative gains of PID controllers for two equal area interconnected power system with ITAE criterion. The techniques are firefly algorithm and amalgamation of firefly algorithm with migration effect of biogeography based optimization.

SYSTEM MODELING

Frequency deviation (ΔF_i): The net surplus power in the area following a disturbance ΔP_D equals ΔP_G - ΔP_D MW and the power will be absorbed by the system in three ways:

- By increasing the area kinetic energy W_{kin} at the rate:

$$\frac{dW_{kin}}{dt} = \frac{d}{dt}\left[W_{kin}^{*}\left(\frac{f}{f^{*}}\right)^{2}\right] = 2\frac{W_{kin}^{*}}{f^{*}}\frac{d}{dt}(\Delta f) \qquad (1)$$

- By increasing the load consumption: All typical loads (because of the dominance of motor load) experience an increase $D \approx \partial P_D / \partial f$ MW/Hz with speed or frequency. This D parameter can be found empirically.
- By increasing the export of power, via tie lines, with the total amount ΔP_{tie} MW defined positive out from the area.

From the above aspects, the power equilibrium equation in i[th] area is given in Eq. (2):

$$\Delta P_{Gi} - \Delta P_{Di} = 2\frac{W_{kin\,i}^{*}}{f^{*}}\frac{d}{dt}(\Delta f_i) + D_i \Delta f_i + \Delta P_{tie\,i} \qquad (2)$$

In Eq. (2), the dimensions of all terms are in MW. These dimensions are converted into per unit representation by dividing the total rated area power (P_{ri}) expressed in MW in i[th] area. Equation (3) represents the dimensions in per uni:

$$\Delta P_{Gi} - \Delta P_{Di} = 2\frac{H_i}{f^{*}}\frac{d}{dt}(\Delta f_i) + D_i \Delta f_i + \Delta P_{tie\,i} \qquad (3)$$

Where, Inertia constant $H_i = W_{kin\,i}^{*} / P_{ri}$ in MW-sec/MW or sec (* indicates the nominal values).
The Eq. (3) is simplified into Eq. (4):

$$[\Delta P_{Gi}(s) - \Delta P_{Di}(s) - \Delta P_{tie\,i}(s)]\frac{K_{pi}}{1 + sT_{pi}} = \Delta F_i(s) \qquad (4)$$

where,

$$K_{pi} = \frac{1}{D_i}\text{Hz/puMW} \quad \text{and} \quad T_{pi} = \frac{2H_i}{f^{*} D_i}\text{sec.}$$

Incremental generated power (ΔP_{Gi}): Real power generation in a synchronous machine is controlled by opening or closing the steam valve in steam turbine.

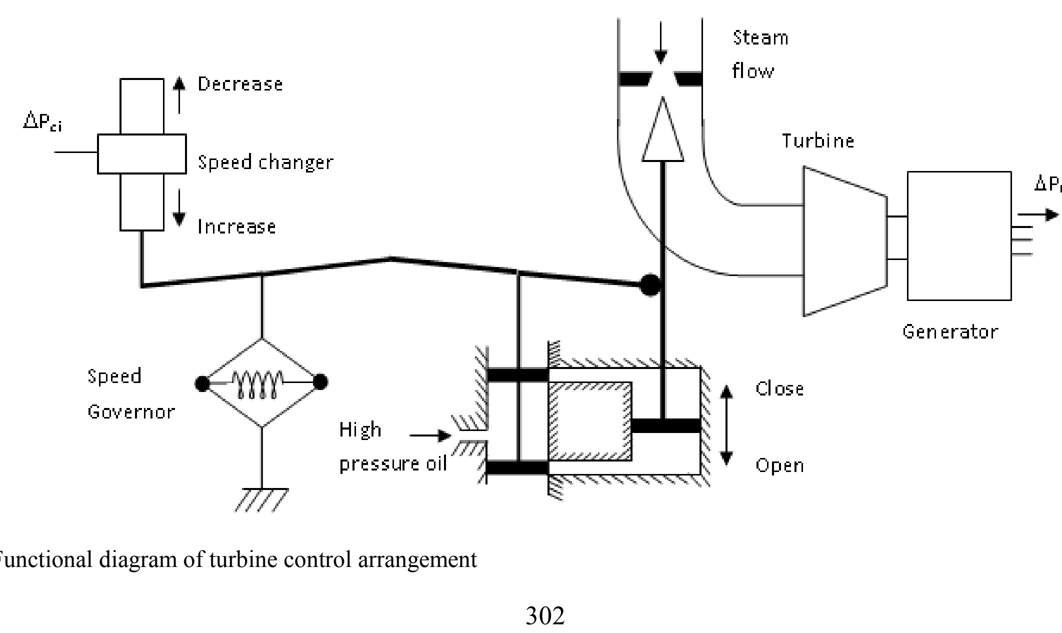

Fig. 1: Functional diagram of turbine control arrangement

Process of opening or closing the steam valve is based on the functional diagram (Fig. 1).

The functional diagram given in Fig. 1 is converted into block diagram model for analysis (Fig. 2).

In the block diagram, T_{gi} represents the time constant of the governor and T_{ti} represents the time lag of the turbine in i^{th} area.

Incremental tie-line power ($\Delta P_{tie\,i}$): The total real power exported from i^{th} area ($P_{tie\,i}$) is equal to sum of all out- flowing line powers ($P_{tie\,iv}$) in the lines connecting i^{th} area with v^{th} areas, i.e.,

$$P_{tie\ i} = \sum_V P_{tie\ iv} \tag{5}$$

If the tie-line losses are neglected, then the individual tie-line powers can be expressed in mathematical form and is given in Eq. (6):

$$P_{tie\ iv} = \frac{|V_i||V_v|}{X_{iv}P_{ri}}\sin(\delta_i - \delta_v) \approx P_{tie\ max\ iv}\sin(\delta_i - \delta_v) \tag{6}$$

where, $V_i = |V_i|e^{j\delta_i}$, $V_v = |V_v|e^{j\delta_v}$ are the terminal bus voltages of the tie-line and X_{iv} is reactance between i^{th} area and v^{th} area. $\Delta\delta_i$ and $\Delta\delta_v$ are phase angle deviation from their nominal values δ_i^* and δ_v^*.

If the phase angles deviate from its nominal values, then the tie-line power flow is also deviated from its nominal value as per Eq. (7):

$$\begin{aligned}\Delta P_{tie\ iv} &= \frac{\partial P_{tie\ iv}}{\partial(\delta_i - \delta_v)}(\Delta\delta_i - \Delta\delta_v) \\ &= \frac{|V_i||V_v|}{X_{iv}P_{ri}}\cos(\delta_i^* - \delta_v^*)(\Delta\delta_i - \Delta\delta_v)\end{aligned} \tag{7}$$

Equation (7) is modified in terms of Δf and is expressed in Eq. (8).

$$\Delta P_{tie\ iv} = T_{iv}^*\left(\int \Delta f_i dt - \int \Delta f_v dt\right) \tag{8}$$

where,

$$T_{iv}^* = 2\pi\frac{|V_i||V_v|}{X_{iv}P_{ri}}\cos(\delta_i^* - \delta_v^*)$$

Taking Laplace Transform of Eq. (8):

$$\Delta P_{tie\ iv}(s) = \frac{T_{iv}^*}{s}[\Delta F_i(s) - \Delta F_v(s)] \tag{9}$$

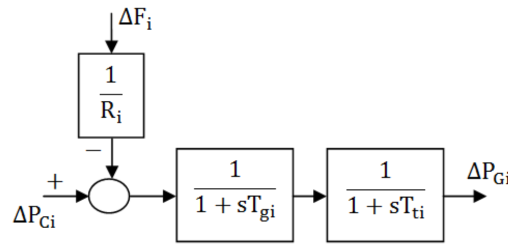

Fig. 2: Block diagram model of turbine control arrangement

The total $\Delta P_{tie\,i}(s)$ is obtained from Eq. (9):

$$\Delta P_{tie\ i}(s) = \frac{1}{s}\sum_V T_{iv}^*[\Delta F_i(s) - \Delta F_v(s)] \tag{10}$$

The $\Delta P_{tie\,i}(s)$ in two area system is obtained from Eq. (10):

The $\Delta P_{tie\,v}(s)$ in two equal area ($P_{ri} = P_{rv}$) system is obtained from $\Delta P_{tie\,i}(s)$ as per the expression given in Eq. (11):

$$\Delta P_{tie\,v}(s) = -\frac{P_{ri}}{P_{rv}}\Delta P_{tie\ i}(s) = -\Delta P_{tie\ i}(s) \tag{11}$$

Area Control Error (ACE): When systems are interconnected, tie-line power flow as well as frequency must be controlled. The sum of tie-line and frequency errors can be expressed as Area Control Error (ACE) and is given in Eq. (12):

$$ACE_i = \Delta P_{tie\,i} + b_i\Delta F_i \tag{12}$$

Two area interconnected power system model shown in Fig. 3 is obtained from the block diagram model of Fig. 2 and Eq. (4), (10), (11) and (12).

PID CONTROLLER AND PERFORMANCE INDEX

The conventional PID controllers in two area interconnected power system are given in expressions (13) and (14) for Area1 and Area2 respectively:

$$\Delta P_{c1}(s) = -(K_p(ACE_1) + \frac{K_i}{s}(ACE_1) + K_d s(ACE_1)) \tag{13}$$

$$\Delta P_{c2}(s) = -(K_p(ACE_2) + \frac{K_i}{s}(ACE_2) + K_d s(ACE_2)) \tag{14}$$

K_p, K_i and K_d are the proportional, integral and derivative gains, respectively. The performance index (J) is given in expression (15):

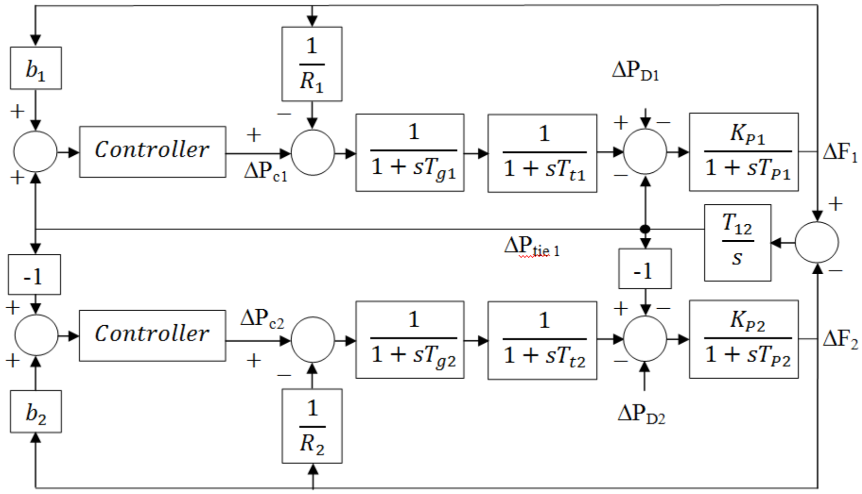

Fig. 3: Block diagram representation of two area interconnected power system

$$J = \int t(|\Delta P_{tie\,12}| + |\Delta f_1| + |\Delta f_2|)dt \tag{15}$$

AMALGAMATION OF FIREFLY ALGORITHM WITH MIGRATION EFFECT OF BIOGEOGRAPHY BASED OPTIMIZATION

Biogeography based optimization: Biogeography Based Optimization (BBO) technique is one of the new population based evolutionary algorithm (EA). It was introduced by Simon (2008). Mathematical models of biogeography explained that the migration of species from one island to other island and it deals the growth of new species and how it's extinct. A habitat geographically isolated from other habitats is an island. For this reason, the more generic term "habitat" is used in this study. The habitat suitability index will be high when the residences in geographical area are matched with the biological species. The features correlate with Habitat Suitability Index (HSI) which includes factors such as rainfall, diversity of vegetation, diversity of topographic features, land area and temperature. The above mentioned factors are called as Suitability Index Variables (SIVs) and these variables are characterized by the circulation of life on Earth.

In every habitat with high HSI has low immigration rate of species because large number of species occurred in this habitat and some species emigrate to nearby habitat. Similarly, every habitat with low HSI has high immigration rate and low emigration rate of species because small amount of species occurred in this habitat. This immigration of new species to habitats with low HSI may increase from low to high HSI, because the habitat suitability is proportional to its biological diversity.

Biogeography based optimization is developed from the mathematical model of biogeography explained above. A good solution is equivalent to habitat with high HSI and a poor solution is analogous to habitat with low HSI. In this situation, high HSI solutions share its features to low HSI solutions. Better solutions are obtained from poor solutions with acceptance a lot of new features from good solutions. This accumulation of new features to low HSI solutions may increase the quality of low HSI solutions.

Mathematical expressions of immigration rate and emigration rate for each habitat are given in Eq. (16) and (17) respectively:

$$\lambda_k = I(1 - k/n) \tag{16}$$

$$\mu_k = \frac{Ek}{n} \tag{17}$$

where,

n = Maximum number of species (S_{max})
k = Species count of each habitat which is the element of
S, I = Maximum immigration rate
E = Maximum emigration rate

Explanation of Migration Process is given below.

The population of candidate solutions, represented as vectors of integers. Each vector of integer is considered as a SIV. Those solutions are good, then HSI of habitat is high and those solutions are poor, HSI of habitat is low. High HSI solutions denote habitats with several species and low HSI solutions denote habitats with few species. Considering an identical species curve, the maximum emigration rate is equal to maximum immigration rate (with E = I for simplicity), but the S value represented by the solution depends on its HSI. S_1 in Fig. 4 denotes a low HSI solution that is habitat with only few species and S_2 denotes a high HSI solution that is habitat with several species. The immigration rate λ_2 for S_2 is lower than the immigration rate λ_1 for S_1. The emigration rate μ_2 for S_2 is higher than the emigration rate μ_1 for S_1.

First, probabilistically share the information between habitats by using immigration and emigration rates of each solution. Then modify each solution based on other solutions. If a specified solution is selected to be improved, then use its immigration rate λ to probabilistically decide whether or not to modify each Suitability Index Variable (SIV) in that specified solution. If a specified SIV in a specified solution S_A is selected to be modified, then use the emigration rate μ of the other solutions to probabilistically decide which of the solutions should migrate a randomly selected SIV to solution S_A. Migration process of BBO is used only to change in existing solutions. It is an adaptive process.

The pseudo code of migration process of habitat modification in BBO is given below:

1. Select H_A with probability α λ_A
2. If H_A is selected
3. For B = 1 to n
4. Select H_B with probability α μ_B
5. If H_B is selected
6. Randomly select an SIV σ from H_B
7. Replace a random SIV in H_A with σ
8. End if H_B
9. End for B
10. End if H_A

Firefly algorithm: The firefly algorithm was invented by Dr. Xin-She Yang at Cambridge University in 2007. It was inspired by the mating or flashing behavior of fireflies. It can be developed by keen observation of flashing characteristics of fireflies. It makes possible to formulate the new optimization technique. The firefly algorithm can be described by three idealized rules:

- One firefly will be attracted to other fireflies regardless of their sex because all fireflies are same sex.
- Attractiveness is proportional to their brightness of flashing behavior. Considering any two fireflies A and B, if firefly - A is brighter than firefly - B then the firefly - B move towards the firefly - A. If the brightness of firefly - B increased then distance between two fireflies A and B decreased. If there is no brighter one than a firefly - A, it will move randomly.
- The fitness function is considered as the brightness of flashing light.

Firefly brightness determines its attractiveness associated with its fitness function.

The mathematical expression for attractiveness β of a firefly is given in Eq. (18):

$$\beta = \beta_o e^{-\gamma r^2} \tag{18}$$

where, β_0 is the attractiveness at r = 0, γ is fixed light absorption coefficient, r is the distance between two fireflies.

The distance between any two fireflies A and B at x_A and x_B is obtained by using Cartesian distance form and is given in Eq. (19):

$$r_{AB} = \left\| x_A - x_B \right\| = \sqrt{\sum_{k=1}^{d} (x_{Ak} - x_{Bk})^2} \tag{19}$$

where, x_{Ak} is the k^{th} component of the spatial coordinate x_A of A^{th} firefly.

Considering two fireflies A and B at x_A and x_B, if firefly B is more attractive than firefly A, then the movement is determined by using the mathematical expression as given in Eq. (20):

$$x_A^{itr+1} = x_A^{itr} + \beta_o e^{-\gamma r_{AB}^2}(x_B^{itr} - x_A^{itr}) + \alpha^{itr}(rand - \frac{1}{2}) \tag{20}$$

where, the first term is current position of a firefly, the second term is the attractiveness of firefly A to firefly B and the third term is random movement of a firefly. In case, there are no brighter fireflies, the movements are based on randomization parameter (α^{itr}) and is expressed in mathematical form as given in Eq. (21):

$$\alpha^{itr} = \alpha_o \delta \tag{21}$$

where, α_0 is the initial randomness scaling factor ($\alpha_o \in [0, 1]$) and δ is cooling factor ($0 < \delta < 1$).

The pseudo code of firefly algorithm is applied to tune the PID parameters of two equal area interconnected power system is given below:

1. Initialize a population of fireflies x_A, A = 1, 2, …, n.
2. Light intensity I_A (or) performance index J_A at x_A is determined by $f(x_A)$.
3. Define light absorption coefficient γ.
4. For A = 1: n all n fireflies
5. For B = 1: A
6. If ($I_B > I_A$)
7. Calculate the attractiveness between A and B which varies with distance r via exp{-γr}.
8. Move firefly A towards B in all d dimensions according to the attractiveness between A and B.
9. End if
10. Evaluate the new fireflies and update light intensity.
11. End for B
12. End for A
13. Rank the fireflies and find the current best.
14. Post process results.

Amalgamated FA with migration effect of BBO: Firefly algorithm gives better response than biogeography based optimization technique. Furthermore improving the performance of firefly

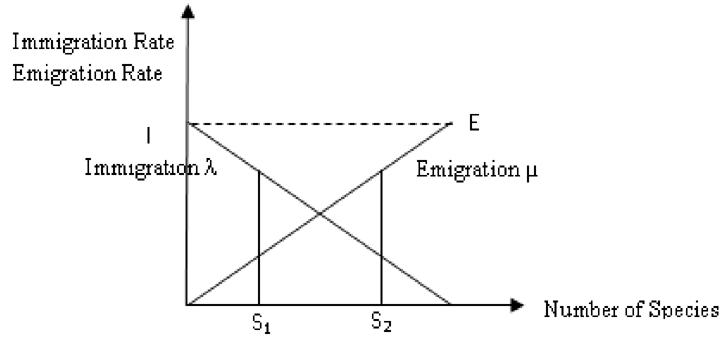

Fig. 4: Simplified equilibrium model of a single habitat

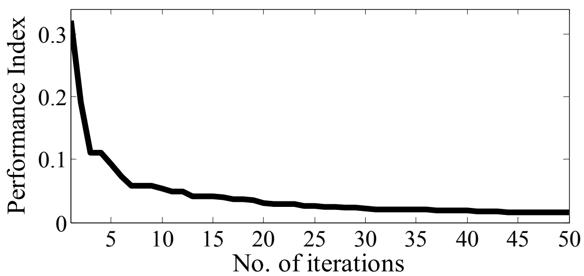

Fig. 5: Fitness function (or) performance index curve for FA technique with first operating condition

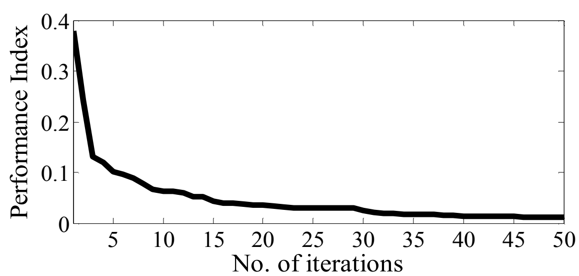

Fig. 6: Fitness function (or) performance index curve for AFAWMEBBO technique with first operating condition

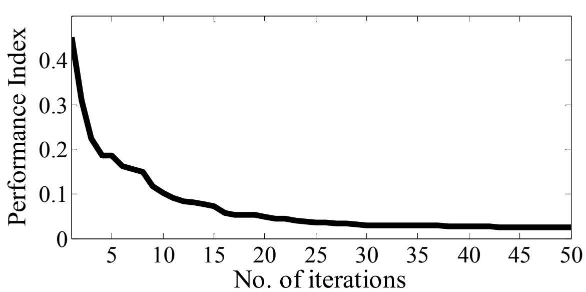

Fig. 7: Fitness function (or) performance index curve for FA technique with second operating condition

algorithm, migration process of biogeography based optimization technique is amalgamated to firefly algorithm. Migration process improves the better solutions from worst solutions locally and firefly algorithm improves the better solutions globally. Amalgamation of firefly algorithm with migration effect improves better solutions locally and globally.

SIMULATION RESULTS AND ANALYSIS

The Simulation was carried out by using MATLAB programming and simulink toolbox. In this simulation, 50 iterations are taken. Population sizes of proposed algorithms are taken as 10. The system parameters and algorithm parameters are given in appendix.

Amalgamated Firefly Algorithm with Migration Effect of Biogeography Based Optimization (AFAWMEBBO) and Firefly Algorithm (FA) techniques are proposed to optimize the proportional, integral and derivative gains of PID controller in equal area interconnected power system with ITAE criterion by using two operating conditions.

Operating condition-I (OC-I): First operating condition is taken as, the occurrence of 5% of step load perturbation in area 1 and 10% step load perturbation in area 2. Figure 5 shows the fitness function (or) performance index curve for FA technique. Figure 6 shows the fitness function (or) performance index curve for AFAWMEBBO technique.

Operating condition-II (OC-II): Second operating condition is taken as, the occurrence of 15% of step load perturbation in area 1 and 10% step load perturbation in area 2. Figure 7 shows the fitness function (or) performance index curve for FA technique. Figure 8 shows the fitness function (or) performance index curve for AFAWMEBBO technique.

Table 1 shows the performance index values of AFAWMEBBO and FA techniques for two operating conditions.

Firefly Algorithm technique produces the error value of 0.0155 whereas Amalgamated Firefly Algorithm with Migration Effect of Biogeography Based Optimization technique produces the error value 0.0113 in the first operating condition. By comparing

Table 1: Performance index values

Optimization Algorithm	Performance Index values OC-I	OC-II
AFAWMEBBO	0.0113	0.0192
FA	0.0155	0.0245

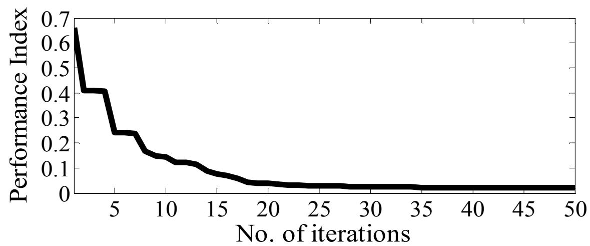

Fig. 8: Fitness function (or) performance index curve for AFAWMEBBO technique with second operating condition

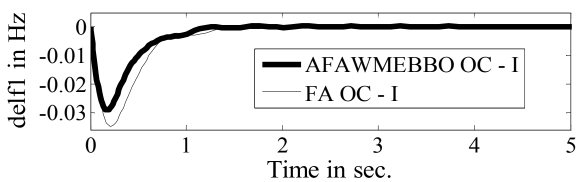

Fig. 9: Frequency deviation in area 1 for first operating condition

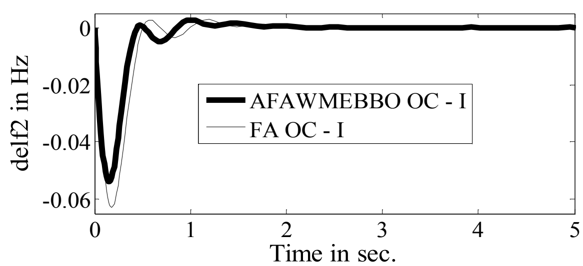

Fig. 10: Frequency deviation in area 2 for first operating condition

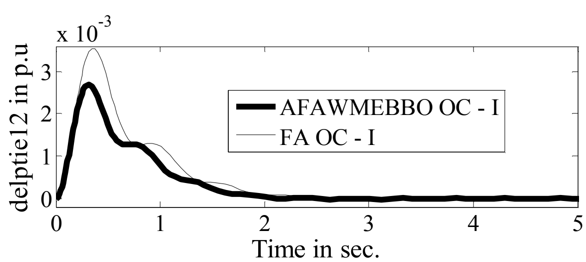

Fig. 11: Tie line power flow deviation for first operating condition

these two values, it is observed that 27% of error values are eliminated.

Similarly, from the second operating condition 22% of error values are reduced in the amalgamated performance compared from firefly algorithm.

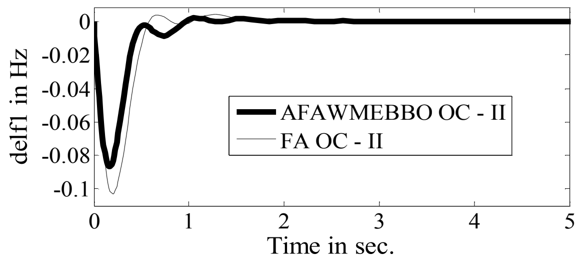

Fig. 12: Frequency deviation in area 1 for second operating condition

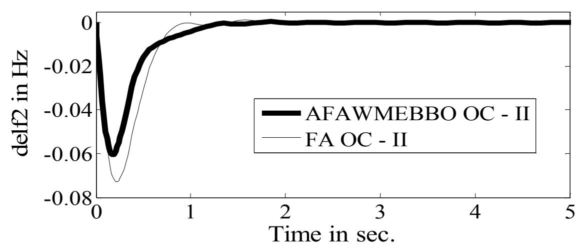

Fig. 13: Frequency deviation in area 2 for second operating condition

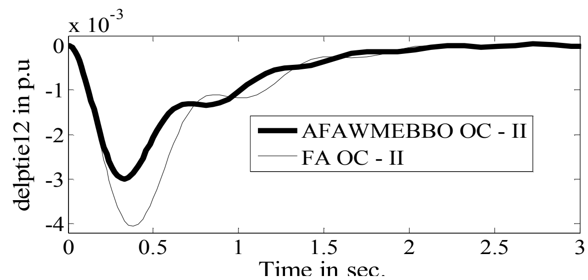

Fig. 14: Tie line power flow deviation for second operating condition

Figure 9 to 11 show the performance of frequency deviations in area 1, 2 and tie line power flow deviations for first operating condition (OC-I).

Figure 12 to 14 show the performance of frequency deviations in area 1, 2 and tie line power flow deviations for second operating condition (OC-II).

CONCLUSION

In this study, firefly algorithm and amalgamated firefly algorithm with migration effect of biogeography based optimization technique for optimizing PID controller parameter in two equal area interconnected power system are presented. From the above analysis, amalgamated firefly algorithm with migration effect of biogeography based optimization technique gives improved response compared with firefly algorithm technique and is proved from the results given in figures and tables. Migration effect gives local best response among the total population and firefly algorithm gives global best response. Therefore, the amalgamated firefly algorithm with migration effect gives better response compared with other techniques.

APPENDIX

Two area interconnected power system parameters:
$P_{r1} = P_{r2} = 2000\ MW$
$H_1 = H_2 = 5\ Sec.$
$D_1 = D_2 = 8.33X10^{-3}\ puMW/Hz$
$T_{g1} = T_{g2} = 0.08\ Sec.$
$T_{t1} = T_{t2} = 0.3\ Sec.$
$T_{P1} = T_{P2} = 20\ Sec.$
$K_{P1} = K_{P2} = 120\ Hz/puMW$
$R_1 = R_2 = 2.4\ Hz/puMW$
$P_{tie\ max} = 200\ MW$
$T_{12} = 0.545\ puMW/Hz$
$b_1 = b_2 = 0.425\ puMW/Hz$

Firefly algorithm parameters:
Attractiveness at two fireflies in same place (β_0) =1.0.
Fixed light absorption coefficient (γ) =1.0.
Cooling factor (δ) = 0.97.
Scaling factor (α_o) of initial randomness = 1.

Biogeography based optimization parameters:
Maximum immigration rate = 1.
Maximum emigration rate = 1.
Maximum species count = 10.

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