Equilibrium Optimizer and FLC of Two Area Load Frequency Control with Multi-Source Generators System

Saad A. Mohamed Abdelwahab*, ****, Moayed Mohamed **, Mohamed Ebeed ***‡, Walid S. E. Abdellatif *

* Electrical Department, Faculty of Technology and Education, Suez University, Suez 43527, Egypt

** Electrical Department, Faculty of Technology and Education, Sohag University, Sohag, Egypt.

*** Electrical Engineering Department, Faculty of Engineering, Sohag University, Sohag, Egypt.

**** High Institute of Electronic Engineering, Ministry of Higher Education, Belbeis city -Sharqiya, Egypt.

(Saad.Abdelwahab@suezuniv.edu.eg, Moayed1190@techedu.sohag.edu.eg, mebeed@eng.sohag.edu.eg, Walid.Abdellatif@suezuniv.edu.eg)

‡ Corresponding Author; Mohamed Ebeed, mebeed@eng.sohag.edu.eg

Received: 14/09/2022 Accepted: 30/11/2022

Abstract- This paper describes an application of Equilibrium optimizer (EO) and Fuzzy Logic Control (FLC) at Load Frequency Control (LFC) with multi-source generators, which comprises Photovoltaic (PV) energy and wind turbine. First, Equilibrium Optimizer (EO) is applied for adjusting the scaling factors of the LF controller with hybrid generation resources. The EO has been used to develop integral control and a proportional-plus integral (PI) controller for robust control process of generation system interconnection to find the best parameters for time domain objective function. Second, a comparative study of EO optimizer and the FLC is presented. Results verify that the developed EO outperforms the FLC in terms of area control error, which represents the input vector to the developed controllers. However, FLC is better than EO algorithm in terms of the tie-line power. EO and FLC demonstrate satisfactory frequency deviation results. The advanced FLC give good results.

Keywords Photovoltaic (PV), Equilibrium optimizer (EO), Fuzzy Logic Control (FLC), proportional plus integral (PI), Load Frequency Control (LFC), Multi-Source.

1. Introduction

Recently, the electrical load demands are increased considerably. Thus, the renewable energy resources are widely incorporated with the conventional system to cover the load demands. Renewable and green energy such as PV and wind energy aren't pollutive for the environment [1]. PV and wind generation are the major part in distributed systems and hybrid micro grids (HMGs) [2]. On other hand, Multi-source generators possess have a lot of parameters, this parameter investigated the proper performance [3]. The core title role of controlling wind turbines has been to endlessly increase the power output, minimize stress as well as reduce noise emission [4]. In general, the PV pathways in the grid utility giving power production are good because a governor or inertia don't like the synchronous machines [5].

There are many types of generators, such as PV, wind generator, inertia generator and multi-source generator, yet the thermal power generator and hydraulic generator are important types of power resources. LFC is the type of control made the tie-line power and the frequency have been regulated by controlling the power output of electric power plants [6,7]. Recently, the heavy penetrations of renewables in the conventional energy resources have added more challenges regarding load frequency control. Such challenges become serious under the intermittent nature of renewables. The purpose of LFC in the power system applications is to keep the planned frequency and capacity of the line in typical process in the case of a disturbance occurrences at the operating condition [8].

Several descriptive algorithms solve the problems of LFC due to their ability to manipulate time domain target of functions. In this work, authors utilized EO optimizer and fuzzy logic controller (FLC) to solve the problem in controller. The developed algorithm which used is called EO-Algorithm, depends on mass balances of control volume which have been used the equilibrium states and an estimate both dynamic [9,10]. Each solution or particles in EO with its focus (position) as a search and the search agents to update their focus randomly has been respected to the best current time, a balance filters, eventually to reach equilibrium (optimal result).

Many of researchers are interested of LFC techniques and types of areas and source generators. In [11], Farag K. Abo-

Elyousr (2018) are interested in LFC along with Virtual Inertia Generator for power systems by application the artificial Bee Colony algorithm. In [12], Almoataz Y. Abdelaziz et al (2019) has developed applied a hybrid PSO-WOA for optimizing the load frequency control with mass-less inertia photovoltaics system. The authors in [13] solved the LFC optimally with integration of electric vehicles. In [14], Gaber El-Saady et al. (2019) studied the influence of incorporating the double-fed induction generator upon the load frequency control. In [15] Jaya Algorithm (JA) has been applied for optimizing the LFC in two area while in [16] the JA solved LFC with inclusion renewable sources. In [17], S. M. Abd-Elazim et al. (2017) applied the firefly algorithm the same work. In [18], M. S. Uz-Zaman et al. (2018) assess the influence virtual inertia generators on the LFC. In [19], M. El-Shimy et al (2018) were conducted several models for the PV small signal analysis as transfer functions. In [20], M. El-sherbiny et al (2002) presented the loop shaping for the LFC. In [21], J. Nanda et al (2004) studied application the fuzzy system for LFC in hydro-thermal plant. An adaptive fuzzy logic control has been used for LFC logic for multi-area system.

The study of the above publications reveals that the EO optimizers was rarely employed to solve the LFC problem. Thus, this main paper contributions are (1) to present an approach to study and implement a two area LFC with multi-source generator comprising PV and wind generation via the EO algorithm, (2) a fair comparative study of the developed EO optimizer with the FLC in terms of the system indices is achieved. The simulated results show that the developed EO is better of FLC at area control error in two areas, FLC is better than EO algorithm in the changes of tie-line power at thermal plant. when compared, EO and FLC demonstrate satisfactory results at the two areas frequencies deviations.

This paper presented the application of EO and FLC at two-area LFC with hybrid system. First, EO is applied for adjusting the scaling factors of the LF Controller with hybrid generation resources. The EO has been used to develop integral control and PI controller for robust control operation of power system interconnection to find the best parameters for time domain objective function. Second, a comparative study of EO optimizer and the FLC is presented. The novelty and the contributions of the paper can be summarized as follows:

- A novel application of the EO technique for solving the LFC of a two area.
- Assessing the performance of system with inclusion of the renewable energy resources and variation of the load demand.
- Assessing the performance of system with three different types of controllers including proportional Integral control (PI), Integral control and Fuzzy logic control.

This paper is organized as follow: Section 2 discuss the system description. Section 3 gives an overview of EO. Section 4 lists the simulation results and the conclusions are summarized in Section 5.

2. System Description

This system contains mainly two area thermal power plant exist in every area, the generators are renewable energy, wind turbine station generation and photovoltaic array stations. The figure.1, show these stations when transformed to the transfer function.

The conversion control unit simply located in a thermal power plant. The transfer function denotes the governor and generator in their time constants.

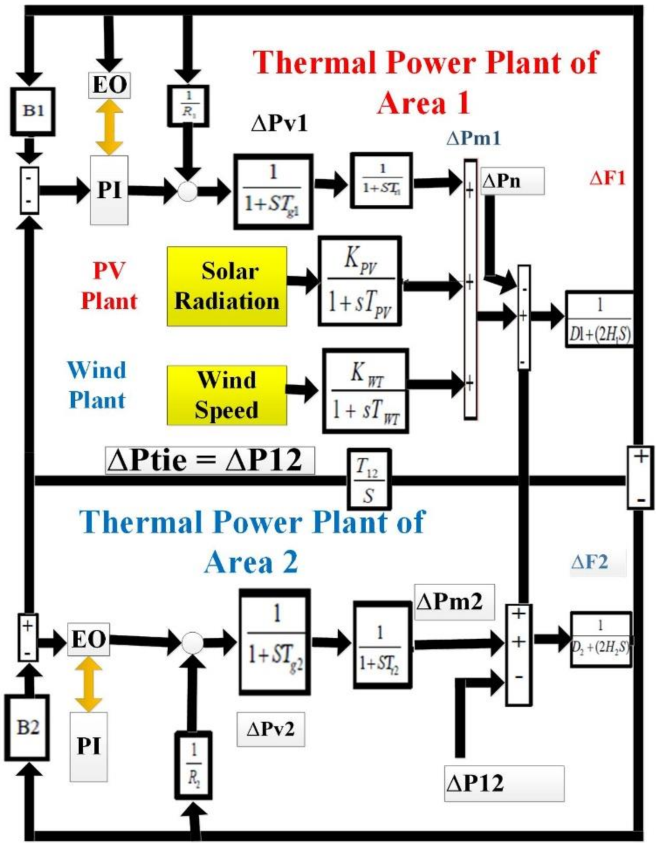

Fig.1. Schematic diagram of two area systems

An equation (1) defines the frequency response for any area, the dynamic of the governor can be represented by an eqn. (2), the dynamic of the turbine can be accurately characterized by eqn. (3), the total tie-line power change over between areas and the other areas can be stated by eqn. (4).

$$\Delta\dot{F}_1 = \left(\frac{1}{2H_i}\right)\cdot\Delta P_{mi} - \left(\frac{1}{2H_i}\right)\cdot\Delta P_{1i} - \left(\frac{D_i}{2H_i}\right)\cdot\Delta F_i - \left(\frac{1}{2H_i}\right)\cdot\Delta P_{tie,i} \tag{1}$$

$$\Delta\dot{P}_{m1} = \left(\frac{1}{T_{ti}}\right)\cdot\Delta P_{gi} - \left(\frac{1}{T_{ti}}\right)\cdot\Delta P_{mi} \tag{2}$$

$$\Delta\dot{P}_{g1} = \left(\frac{1}{T_{gi}}\right)\cdot\Delta P_{ci} - \left(\frac{1}{Ri.T\ T_{gi}}\right)\cdot\Delta fi - \left(\frac{1}{T_{gi}}\right)\cdot\Delta P_{gi} \tag{3}$$

$$\Delta P_{tie,1} = 2\pi * \left[\sum_{\substack{j=1\\ j\neq i}}^{N} T_{ij}\Delta F_i - \sum_{\substack{j=1\\ j\neq i}}^{N} T_{ij}\Delta F_j\right] \tag{4}$$

2.1 PV Array Model

The PV panel involves of array of PV modules, each unit is a group of cells that affect the output energy, and all units are impacted by the solar radiation of the sunshine [23-32]. The block diagram of PV equation has been shown in Fig.2, and Eq. (5).

$$G_{PV}(S) = \frac{K_{PV}}{1 + S * T_{PV}} \tag{5}$$

2.2 Wind Generation Model

The wind diversion system was adopted from the simulation model [33]. Wind turbine schematic of transmission is designated in Figure 3 and another equation are described in Eq. (6).

$$G_{TWG}(S) = \frac{K_{WT}}{1 + S * T_{WT}} \tag{6}$$

2.3 Fuzzy Logic Control

FLC is one of the types of advanced control, it's not sensitive to plant parameter variation. FLC has many advantages such as the operational constraints of power system are more accurately of representation and the limitations in FLC form are limits than conventional constraints [34]. FLC steps are fuzzifications, and noise canceling, fog LF Control has an input signal to regulate the frequency at a certain sampling time and change it [35]. The fuzzy control system has explained in Fig. 4. The rules of fuzzy control are demonstrated in Table I. The description of FLC [39-40] at Fuzzy function is described in Fig. 5. It shows the fuzzy function error and the product error, and the gain has a triangular shape.

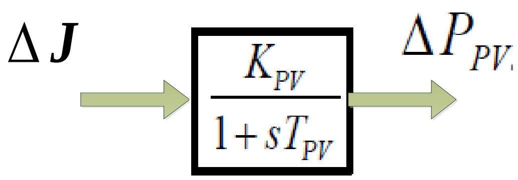

Fig.2. Block diagram of PV transfer functions

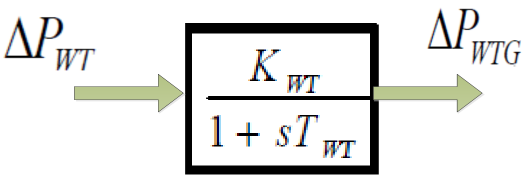

Fig.3. Block diagram of wind turbine transfer functions

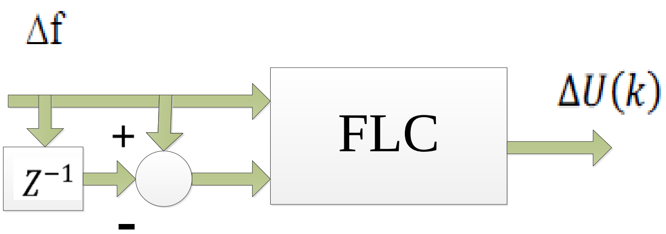

Fig.4. The stabilizer of FLC power system

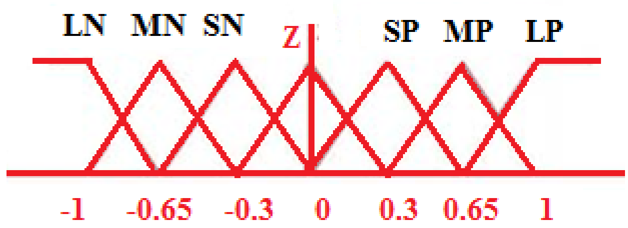

Fig.5. Membership function shape

2.4 Equilibrium optimizer (EO)

2.4.1 Inspiration

E Optimizer is a novel technique that inspired from the mass balance on a control volume for a dynamic mixture. The equation of the mass balance in the volume of control includes generated mass, input, and output, and it can be formulated as depicted:

Table 1. The Rules of FLC

dΔf							Δf
LP	MP	SP	Z	SN	MN	LN	
Z	LN	MP	MP	LP	LP	LP	LN
LN	LP	LN	MN	MN	SN	Z	LP
SN	MN	SP	MP	MP	MP	LP	MN
LN	MP	MN	MN	SN	Z	SP	MP
MN	SN	Z	SP	SP	MP	LP	SN
LN	SP	SN	SN	Z	SP	MP	SP
MN	Z	SN	Z	SP	MP	MP	Z

$$M_E = V\frac{dA}{dt} = QA_{eq} - QA + G \tag{7}$$

where V, A, M_E, Q, Aeq and G refer to the control volume, the concentration the output and input flow and the rate of the mass generation. The integration of Eq. (7), the concentration will be formulated as follows:

$$A = A_{eq} + \left(A_0 - A_{eq}\right)\exp[-\lambda(t-t_0)] + \frac{G}{\lambda V}\left(1 - (\exp[-\lambda(t-t_0)]\,)\right) \tag{8}$$

where, $\lambda = \left(\frac{Q}{V}\right)$. A_0 is the initial concentration while t_0 is the initial start time. Eq. (8) represents the updated EO equations. In this equation the concentration refers to particle's location while the particle denotes to the solution. Equation 4 consists of three terms. The first term refers to the concentration equilibrium while the second item denotes the exploration of the algorithm where it refers to the concentration difference between the particle and the equilibrium state. The third item denotes the exploitation pattern where it characterizes of the rate generation, it enables the solution to jump in short areas. The procedure of the EO is depicted as follows:

Step 1: An initialization

Initialize the random populations or the random concentrations as follows:

$$A_i^{initial} = A_{min} + rand_i\,(A_{max} - A_{min}) \qquad i = 1,2,\ldots\ldots n \tag{9}$$

where, A_{min} and A_{max} are the control variables lower and upper limits. $rand_i$ is range of the random value at [0,1].

Step 2: Determination the candidate Equilibrium

The concentrations are arranged using their objective function. The first best four solution and their average value are constructed and known as the equilibrium pool vector which used for the exploration and the EO exploitation's and this vector can be depicted as follows:

$$A_{eq,pool} = \{A_{eq1}, A_{eq2}, A_{eq3}, A_{eq4}\ , A_{eq(avg)}\} \quad (10)$$

Where:

$$\vec{A}_{eq(avg)} = \frac{A_{eq1} + A_{eq2}\ + A_{eq3} + A_{eq4}}{4} \quad (11)$$

Step 3: Updating concentrations

The concentrations will be updated in exponentially pattern with iteration process using an exponential term (F) which calculates as a function of the control volumeλ. This value calculates as follows:

$$\vec{F} = a_1 sign(\vec{r} - 0.5)\left[e^{-\vec{\lambda}t} - 1\right] \quad (12)$$

Where:

$$t = (1 - \frac{T}{T_{Max}})^{(a_2 \frac{T}{T_{Max}})} \quad (13)$$

where a_1 , a_2 represents constant values. These values are used for adopting the exponential value selection at 2 and 1, respectively. T refers to the current iteration while T_{Max} refers to the maximum iterations number.

Step 4: The concentration Updating using the generation rate

The generation rate approach is used for updating the locations of the populations to boast the exploitation of the algorithm as follows:

$$\vec{G} = \vec{G_0}\, e^{-\vec{k}(t-t_0)} \quad (14)$$

where:

$$\vec{G_0} = \vec{GCP}\ (\ \vec{A_{eq}}\ - \vec{\lambda}\vec{A}\ ) \quad (15)$$

$$\vec{GCP} = \begin{cases} 0.5 r_1 & r_2 \geq GP \\ 0 & r_2 < GP \end{cases} \quad (16)$$

r_2 and r_2 are random values in rang [0 ,1]. GCP represents the Control Parameter's generation rate. It should be highlighted here that a_1 and a_2 control at EO exploitation phase.

Sign (r − 0.5) also control the exploitation direction. Generation probability (GP) can control of updating probability of concentration that based on the generation rate. GP = 1 means that there will be no generation rate sharing in the optimization process. GP = 0 enables the generation rate to contribute always into the optimization process. GP = 0.5 is the best value to balance between exploration and exploitation phases. From previous clarification the updated of an equation of the EO can be formulated as follows:

$$\vec{A} = \vec{A_{eq}} + (\vec{A} - \vec{A_{eq}}).\vec{F} + \frac{\vec{G}}{\vec{\lambda}V}(1 - \vec{F}) \quad (17)$$

Step 5: Adding save memory

This stage the be so far solution is saved instead of the worst solution which to emphases the exploration of the EO. Figure. 6. Show the algorithm of EO input and the output.

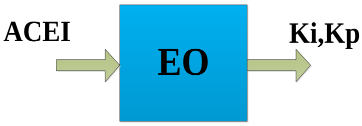

Fig.6. Input and output of EO algorithm

3. Simulation Results and Discussion

First scenario: Effect renewable energy source

There are many of scenarios have been investigated so as to extravagant the efficiency of the advanced technique EO. Two PI controllers have been developed and two Integral control are developed else with EO algorithm. The EO algorithm is developed integral controllers and PI controllers at the system two areas with multi source (PV and wind energy), Fuzzy logic control are else elaborated via Matlab/Simulink 2018b. Table 2. shows the parameter of this system. Fig.7, shows the advanced EO algorithm objective function at 50 Iteration with 15 searches agents with every iteration. Elapsed time at integral with EO is 693.239624 seconds and Elapsed time at PI with EO is 4986.382044 seconds. as comparative from this figure, the output of EO algorithm and FLC have been changed after any change of this system, the example of changing, load's disturbance another changing are PV and wind interconnect of them, it confirms that the controller has been at work online. Figure 8 show the changing the power of wind power, the wind energy should be additional to the power at instant (t=50 sec). Figure 9 show the changing the power of PV, at the time (t= 120 sec), PV plant will be added the power.

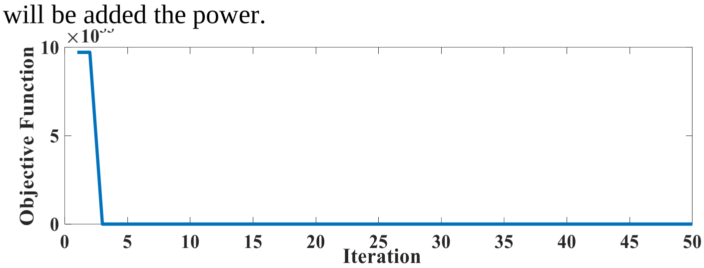

Fig.7. Iteration and objective function for EO

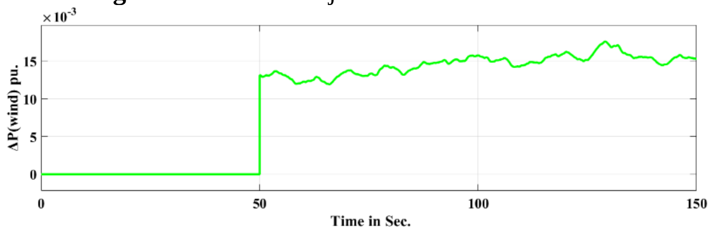

Fig.8. Changing power at wind turbine

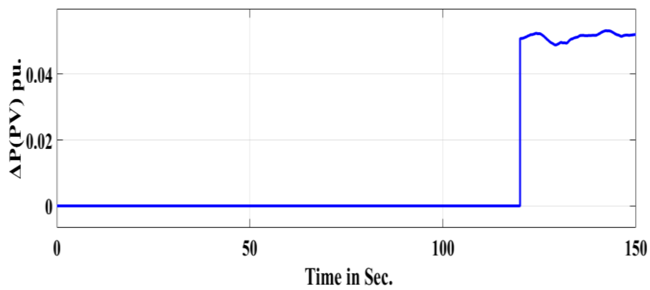

Fig.9. Changing the power of PV

Table 2. Parameter of this system

Parameter Name	Value
TWT	1.5
KPV	1
KWT	1
TPV	1
$Tt1$	0.5
$Tt2$	0.6
$Tg1$	0.2
$Tg2$	0.3
R1	(1/20)
R2	(1/16)
B1	20.6
B2	16.92
D1	1
D2	0.9
H1	5
H2	4
Ki in Integral control at area 1	0.7847
Ki int Integral control at area 2	0.5370
Ki in proportional integral control at area 1	0.9431
Kp in proportional integral control at area1	0.6623
Ki in proportional integral control at area 2	0.5284
Kp at proportional integral control at area2	0.4624
Input fuzzy (Δf)	0.4331
Derivative input fuzzy (Δu/Δf)	0.8940
Limits of gain at EO algorithm (lower)	0.1
Limits of gain at EO algorithm (upper)	5

Figure 10 shows the affecting the frequency deviation at area one at the developed EO algorithm with Integral control and PI control, compared the results with advanced FLC and without control. the deviation of frequency has been affected by parameter uncertainty and the disturbance of load so for the frequency deviation is affected by multi-source PV and wind energy. At finishing time (from t=120 sec, to t= 150 sec) the developed EO algorithm and FLC give good results. Figure 11, show affect frequency deviation at area two under renewable energy insertion with step load disturbance, at finishing time (from t=100 sec, to t= 150 sec) the developed EO algorithm and FLC give good results compare with out control. an example ΔF2 for the selling time that EO algorithm settles after the load disturbance at t = 80 sec.

Figure 12 shows area control error at area one, at beginning time to t= 25 sec, all types are excellent performance. But FLC don't give good results compared EO affects is more effective. The step load disturbance changes from 0 pu to 0.02. Figure 13, show Area control error of area two, from the time (0 to 80 sec) all the types is good, but FLC is give the best results. The finishing time the developed algorithm EO give good performance at two status Integral control and PI control in the system multi source PV and wind energy interconnection and disturbance of the load.

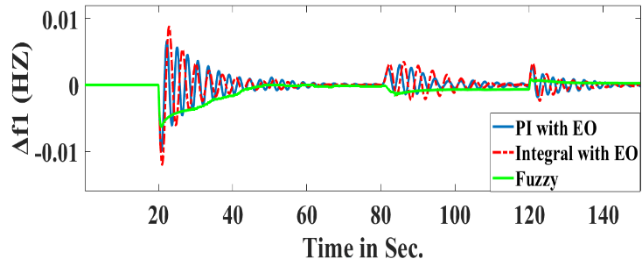

Fig.10. The frequency deviation at area one

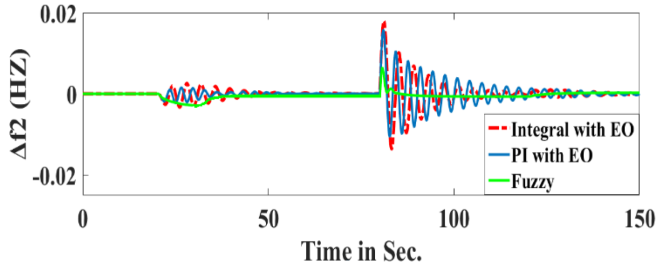

Fig.11. The frequency deviation at area two

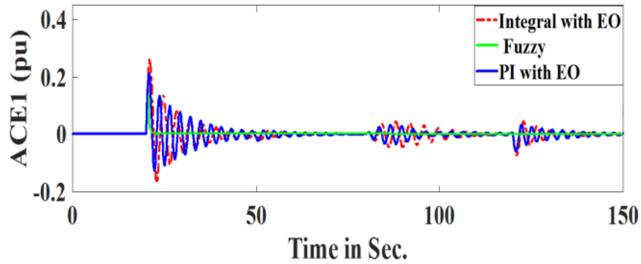

Fig.12. An area control error at area one

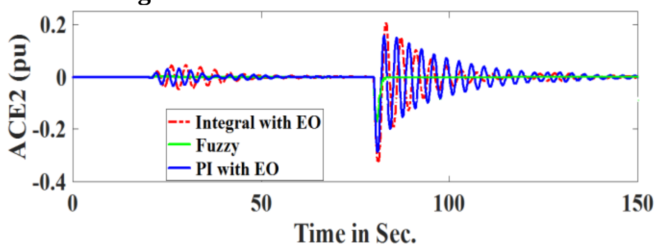

Fig.13. The error of area control at area two

Figure 14 show the Changing of the thermal power of thermal plant at area one from the figure 14, the EO algorithm at PI and integral control and without control have more rise time at (t= 25sec equal 0.2, t= 80 sec and t = 120 sec), there are many overshooting at EO compared FLC is give better results and the (selling time) is nearer so the response compared to the EO algorithm. Figure 15 show the changing the power of the thermal plant at area two. From the figure, there are a rise time at (t= 25 sec) by EO algorithm but FLC is give a good performance. From the time (t= 80 sec), there are a rise time and more overshooting from EO algorithm with PI and integral control at 0.2 pu. But advanced control FL is stable. Figure 16 shows performance analysis of the power changing at area one and area two due to 0.02pu load disturbance with multi source PV and wind energy for the developed controllers and developed EO algorithm. From the figure, FLC is give good result compare developed EO algorithm, it has more overshooting and rise time at (t= 25 sec, t= 80 sec). PI with EO algorithm give good result compared Integral control with EO algorithm at the power tie-line between one area and two area. The value of Δf1 and Δf2 are 4.800e-3 and 4.900e-3, respectively, which are less than those obtained by application of Artificial bee colony (ABC) (5.44e-3, 22.18e-4) [41].

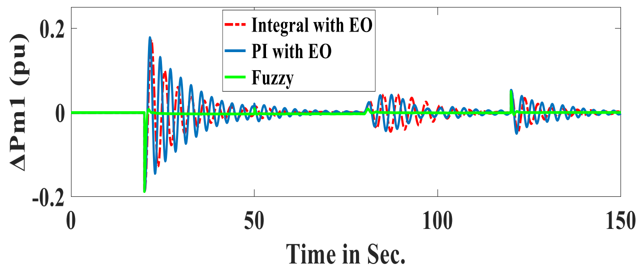

Fig.14. Changing the power of thermal plant at area one

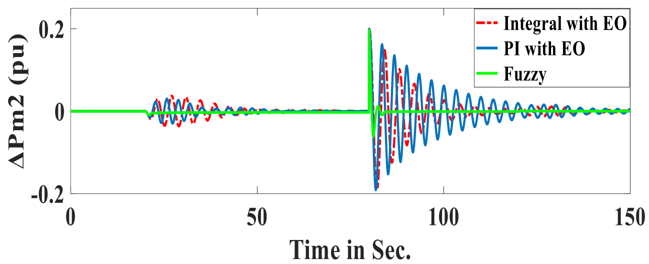

Fig.15. Changing the power of thermal plant at area two

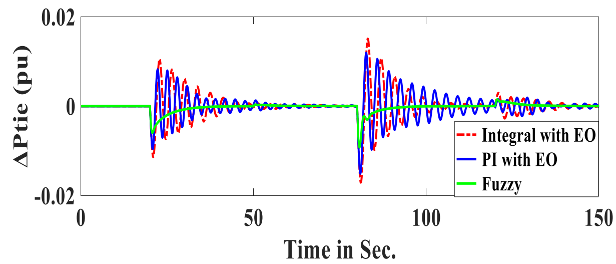

Fig.16. changing the tie line power between two areas

Second Scenario: Change with step load at two area

Figure 17 shows that an objective function behavior of the developed EO algorithm at 50 Iteration with 15 search agents at every iteration. Elapsed time at integral with EO is 191.757611seconds and Elapsed time at PI with EO is 637.76 seconds. This results with changing the load at two areas. Table 3 shows the parameter at this case

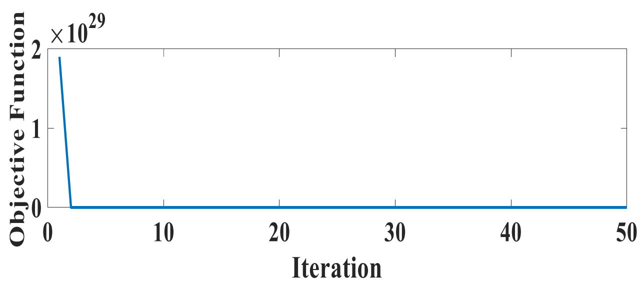

Fig.17. Objective function and iteration for EO

The frequency deviation at area one as shown in Fig.18. The frequency deviation at area two as shown in Fig.19.

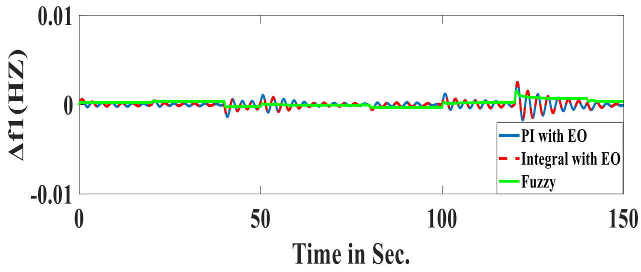

Fig.18. Area control error at area one

From two figures under changing the load at two areas FLC gives the best figures compared EO with PI and integral. The time affects with the load changing at the time (20, 40, 80, 100 and 120 seconds). Figure 20 displays the control error at area one. Figure 21 displays the control error at area two. From two figures FLC effects with the changing of loads at two areas compared with EO in two cases of PI and integral control.

Table 3. Parameter at the case of change load.

Parameter Name	Value
Ki in Integral control at area 1	0.7285
Ki int Integral control at area 2	0.5302
Ki in proportional integral control at area 1	0.6643
Kp in proportional integral control at area 1	0.9399
Ki in proportional integral control at area 2	0.4634
Kp at proportional integral control at area 2	0.5282

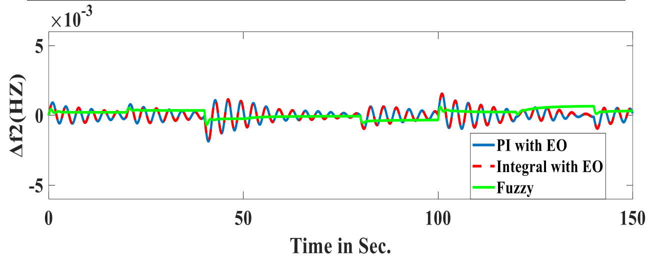

Fig.19. The frequency deviation at area two

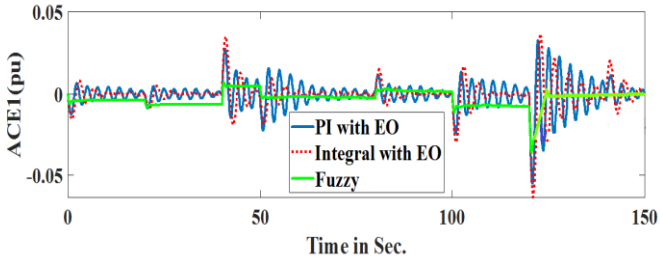

Fig.20. Area control error of area one

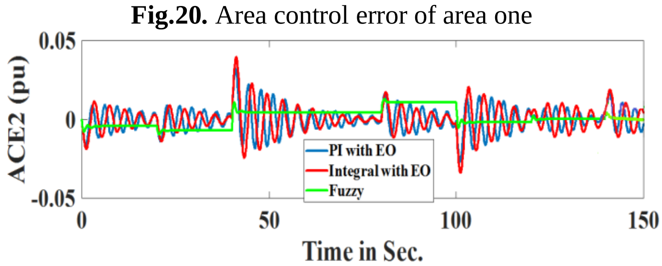

Fig.21. Area control error at area two

Figure 22 shows the changing of the power of thermal plant at area one. Advanced control FL is stable compared EO with PI and integral control. Figure 23 shows the change of power at area two of thermal plant. There are many overshooting at EO compared FLC is give better results and the selling time selling sooner than the response compared to the EO algorithm. Figure 24 depicts the performance analysis at input power change of area one and area two due to 0.02pu load disturbance with multi source PV and wind energy for the developed controllers and developed EO algorithm. PI with EO algorithm give good result compared Integral control with EO algorithm at the power tie-line between one area and two area.

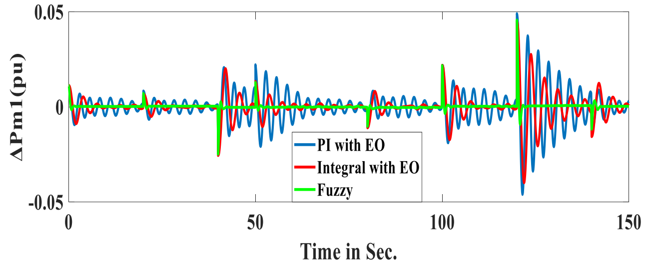

Fig.22. The changing power of thermal plant at area one.

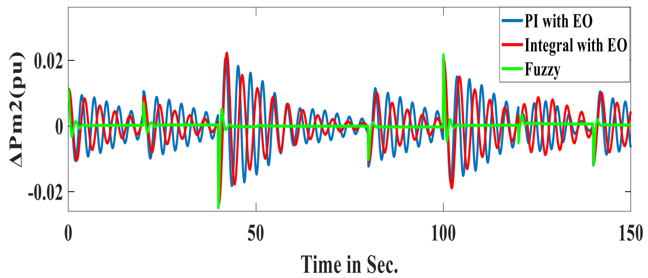

Fig.23. Changing the power of the thermal plant at area two

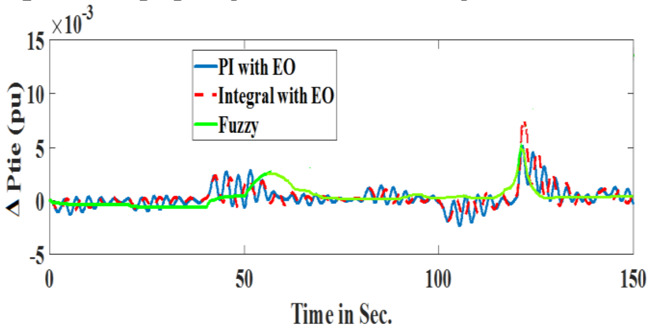

Fig.24. changing at tie line power between two areas

4. Conclusion

This paper solved the load frequency control (LFC) problem at two areas system in presence of the renewable energy resources including the PV and WT generation system. The load frequency control and performance of system has been studied with proportional Integral control (PI), Integral control and Fuzzy logic control. The optimal parameters of these controller have been determined using the Equilibrium Optimizer (EO). The performance of system has been studied under variation of the renewable energy resource and step variation of the load demand. The simulation reveal to that the performance of system has been improved with optimal settings of the proposed controllers. In addition to that the results demonstrated the validity of the EO technique for assigning the optimal values of the proposed controllers.

Nomenclature

R1	speed droops characteristic of area one.
R2	speed droops characteristic of area two.
Kpv	The plant of PV constant.
Tpv	The plant of PV time constant.
KWT	The plant of Wind constant.
TWT	The plant of Wind time constant.
B1	Factor of frequency with area one.
B2	Frequency factor with area two.
ΔPm1	The changing power of thermal plant at area one.
ΔPm2	Changing of the power of thermal plant at area two.
ΔPtie	Changing at tie line power between two Areas.
ΔF1	Deviation of frequency at area one.
ΔF2	Deviation of frequency at area two.
$Tt1$	The time constants at steam turbine of the thermal plant at area one.
$Tt2$	The time constants at steam turbine of the thermal plant at area two.
$Tg1$	Constant of speed time in Governor at thermal at area one.
$Tg2$	Constant of speed time in Governor at thermal at area two.
H1	Constant of Inertia of the generation of area one.
H2	Constant of Inertia of the generation of area two.
D1	The sensitive of frequency of load coefficient at area one.
D2	The sensitive of frequency of load coefficient at area two.

References

[1] A. A. Elbaset, S. A. M. Abdelwahab, H. A. Ibrahim and M. A. E. Eid: Performance Analysis of Photovoltaic Systems with Energy Storage Systems. Renewable and Green Energy, Springer, January 2019.

[2] K. Balzer and D. Watts, "Primary Frequency Control in an Ancillary Services Market in Real Time and its Relationship with Solar-Wind Generation," in IEEE Latin America Transactions, vol. 20, no. 4, pp. 553-561, April 2022.

[3] B. Mohanty, S. Panda, & P. K. Hota, "Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system", International journal of electrical power & energy systems, 54, 77-85, 2014.

[4] S. S. Dessouky, W. S.E. Abdellatif, S. A. M. Abdelwahab and Marwa A. Ali: Maximum Power Point Tracking Achieved of DFIG-Based Wind Turbines Using Perturb and Observant Method. IEEE International Middle-East Power Systems Conference, December 18-20, 2018.

[5] F. K. Abo-Elyousr, A. M. Youssef and A. Y. Abdelaziz, “Multi-area hydrothermal interconnected load frequency control with double-fed induction-generator-based wind turbine via improved harmony algorithm,” Elect. Power Comp. Syst., vol. 46, no. 6, pp. 615–628, 2018.

[6] B. Mohanty, S. Panda, PK. Hota "Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multisource power system," Int J Electr Power Energy Syst; vol. 54, pp. 77–85, 2014.

[7] H. Shayeghi, H. Shayanfar, A. Jalili, "Load frequency control strategies: a stat eof-the-art survey for the researcher," Energy Conversion and Management, vol. 50, no. 2, pp. 344–353, 2008.

[8] A. Usman, B.P. Divakar, "Simulation study of load frequency control of single and two area systems," IEEE Global Humanitation Technology Conference, pp. 214-219, Seattle, USA, Oct. 2012.

[9] M. Lotfy, T. Senjyu, M. Farahat, A. Abdel-Gawad and H. Matayoshi, "A polar fuzzy control scheme for hybrid power system using vehicle-to-grid technique", Energies, vol. 10(8), 1083, 2017.

[10] F. Afshin, H. Mohammad, S. Brent and M. Seyedali," Equilibrium optimizer: A novel optimization algorithm", Contents lists available at ScienceDirect, Knowledge-Based Systems 191 (2020) 105190.

[11] A.E. Farag K.," Load Frequency Controller with Virtual Inertia Generator for Interconnected Power Systems via Artificial Bee Colony", Twentieth International Middle East Power Systems Conference (MEPCON), Cairo University, Egypt, 2018.

[12] Y. Abdelaziz Almoataz and A.E. Farag K., " A Novel Modified Robust Load Frequency Control for Mass-Less Inertia Photovoltaics Penetrations via Hybrid PSO-WOA Approach", Electric Power Components and Systems, 47:19-20, 1744-1758, 2019.

[13] A. Oshnoei, R. Khezri, S. M. Muyeen, S. Oshnoei and F. Blaabjerg," Automatic Generation Control Incorporating Electric Vehicles", Electric Power Components and Systems, ISSN: 1532-5008, 2019.

[14] G. El-Saady, A. M. Youssef, E.N. M. Ibrahim and S. A. Nour-Eldin," Effect of Wind Driven Double-Fed Induction Generator upon the Stability of decentralized power systems via Load Frequency Controllers design", 21st International Middle East Power Systems Conference (MEPCON), Tanta University, Egypt, 2019.

[15] M.I.A.E. Ali, Ahmed A. Z. Diab, M. A. Mossa and A. A. Hassan, " Dynamic Optimized Load Frequency control of Multi-Source Power System using Jaya Algorithm", International Journal of Advanced Science and Technology, Vol. 29, No. 6, pp. 3372 – 3392, 2020.

[16] M.I.A.E. Ali, Ahmed A. Z. Diab, M. A. Mossa and A. A. Hassan," Adaptive Load Frequency Control Based on Dynamic Jaya Optimization Algorithm of Power System with Renewable Energy Integration", 21st International Middle East Power Systems Conference (MEPCON), Tanta University, Egypt, 2019.

[17] S. M. Abd-Elazim and E. S. Ali, "Firefly algorithm-based load frequency controller design of a two-area system composing of PV grid and thermal generator," Electr. Eng., vol.1, pp. 1–10, 2017.

[18] M. S. Uz-Zaman, S. B. A. Bukhari, K. M. Hazazi, Z. M.Haider, R. Haider and C.-H. Kim, "Frequency response analysis of a single-area power system with a modified LFC model considering demand response and virtual inertia," Energies, vol. 11, pp. 1–20, 2018.

[19] S. A M. Abdelwahab, W. S. E. Abdellatif, and A. M. Hamada: Comparative Analysis of the Modified Perturb & Observe with Different MPPT Techniques for PV Grid Connected Systems. International Journal of Renewable Energy Research-IJRER, vol 10, no 1, pp 156-164, 2020.

[20] M. El-sherbiny, G. El-Saady, A. M. Youssef, "Efficient fuzzy logic load-frequency controller," Energy Conversion and management, vol. 43, pp. 1853-1863, 2002.

[21] J. Nanda, A. Mangle, "Automatic generation control of an interconnected hydro-thermal system using conventional integral and fuzzy logic controller." IEEE International coference on electric utility deregulation, restructuring and power technologies, vol. 1, pp. 372-377, Hong Kong, China, Apri 2004.

[22] H. A. Yousef, A. K. Khalfan, M. H. Albadi, & N. Hosseinzadeh, "Load frequency control of a multi-area power system: An adaptive fuzzy logic approach", IEEE transactions on power systems, 29(4), 1822-1830, 2014

[23] B. Saleh, Ali M. Yousef, Farag K. Abo-Elyousr, Moayed Mohamed, Saad A.M. Abdelwahab and Ahmed Elnozahy,"Performance Analysis of Maximum Power Point Tracking for Two Techniques with Direct Control of Photovoltaic Grid -Connected Systems ", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, pp_1-24, 12 Mar 2021.

[24] A. Belkaid, I. Colak and K. Kayisli, "A comprehensive study of different photovoltaic peak power tracking methods," *2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, San Diego, CA, pp. 1073-1079, 2017.

[25] M. A. Abdourraziq, M. Ouassaid, M. Maaroufi and S. Abdourraziq, "Modified P&O MPPT technique for photovoltaic systems," *2013 International Conference on Renewable Energy Research and Applications (ICRERA)*, Madrid, pp. 728-733, 2013.

[26] K. Kayisli, R. Z. Caglayan, N. Zhakiyev, A. Harrouz, I. Colak, " A Review of Hybrid Renewable Energy Systems and MPPT Methodss," *International Journal of Smart Grid - ijSmartGrid*, Vol 6, No 3, 2022.

[27] G. Todeschini, H. Huang, N. Bristow, T. W. David, J. Kettle, " A Novel Computational Model for Organic PV Cells and Modules," *International Journal of Smart Grid - ijSmartGrid*, Vol 4, No 4, 2020.

[28] K. Amara, A. Fekik, D. Hocine, M. L. Bakir, E.B. Bourennane, T. A. Malek, A. Malek, "Improved Performance of a PV Solar Panel with Adaptive Neuro Fuzzy Inference System ANFIS based MPPT," 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), Paris, pp. 1098-110, 2018.

[29] A. H. K. Alaboudy, A. A. Elbaset and Saad. A. M. Abdelwahab, "Effect of dc link capacitance on stand-alone PV system operation with fluctuated dc resistive loads," Port -Said Engineering Research Journal, Vol. 19, No. 1, pp. 121-128, March 2015.

[30] A. A. Elbaset, A. H. K. Alaboudy and Saad. A. M. Abdelwahab, "Adapting on-site induction motor pumping loads with standalone photovoltaic power for the most optimal operation," IEEE, 17th International Middle-East Power Systems Conference (MEPCON), Mansoura University, Egypt, December 15-17, 2015.

[31] S. S. Dessouky, A. A. Elbaset, A. H. K. Alaboudy, H. A. Ibrahim and S. A. M. Abdelwahab, “Performance Improvement of A PV-Powered Induction-Motor-Driven Water Pumping System,” 2016 IEEE International Middle-East Power Systems Conference (MEPCON), Helwan University, Egypt, December 27-29, 2016.

[32] A.M. Yousef, F.K. Abo-Elyousr, A. Elnozohy, M. Mohamed and Saad A. M. Abdelwahab, "Fractional Order PI Control in Hybrid Renewable Power Generation System to Three Phase Grid Connection. ", International Journal on Electrical Engineering & Informatics, vol 12, no 3, 2020.

[33] A. Elnozahy, A. M. Yousef, F. K. A. Elyousr, M. Mohamed and S. A. M. Abdelwahab," Performance Improvement of the Hybrid Renewable Energy Sources connected to the Grid Using Artificial Neural Network and Sliding Mode Control. Journal of Power Electronics", 2021.

[34] H. Yousef , " Adaptive fuzzy logic load frequency control of multi-area power system ", International Journal of Electrical Power & Energy Systems, Volume 68, pp 384-395, June 2015.

[35] V. V. Gautam, R. Loka and A. M. Parimi, "Analysis of Load Frequency Control using Extended Kalman filter and Linear Quadratic Regulator based controller," 2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC), pp. 1-5, 2022.

[36] S. A. Fayad, M. Shaban, M. Attia and S. A. M. Abdelwahab, "Performance Enhancement of Speed and Position Control for DC Servo Motor Using Artificial Intelligence Technique", International Journal on Electrical Engineering & Informatics, Vol. 14 No. 3, 2022.

[37] S. S. M Ghoneim, I. B. M Taha, R. Fahim, S. A. M. Abdelwahab, " Effect of Data Transformation on the Diagnostic Accuracy of Transformer Faults and the Performance of the Supervised Classifiers," International Journal of Renewable Energy Research (IJRER), Volume 12, No 2, 2022.

[38] B. Babes; N. Hamouda; F. Albalawi; O. Aissa, S.S.M. Ghoneim, S.A.M. Abdelwahab, Experimental Investigation of an Adaptive Fuzzy-Neural Fast Terminal Synergetic Controller for Buck DC/DC Converters. Sustainability, vol. 14,2022.

[39] A. Oubelaid, F. Albalawi, T. Rekioua, S. S. M. Ghoneim, N. Taib and Saad A. Mohamed Abdelwahab, "Intelligent Torque Allocation Based Coordinated Switching Strategy for Comfort Enhancement of Hybrid Electric Vehicles," in IEEE Access, vol. 10, pp. 58097-58115, 2022,

[40] A. Elnozahy, A.M. Yousef, S.S.M. Ghoneim, S. A. M. Abdelwahab, M. Mohamed and F. K. Abo-Elyousr Optimal Economic and Environmental Indices for Hybrid PV/Wind-Based Battery Storage System. J. Electr. Eng. Technol. Vol. 16, pp. 2847–2862, 2021.

[41] H. Gozde, M.C. Taplamacioglu, I. Kocaarslan, Comparative performance analysis of artificial bee colony algorithm in automatic generation control for interconnected reheat thermal power system, Int. J. Electr. Power Energy Syst. 42,167–178, 2012.