Smart Frequency Control in Multi-Carrier Micro-Grid with the Presence of V2G Electric Vehicles

Ebadollah Amouzad Mahdiraji[1*], Maziyar Khodadadi Zarini[2]
[1,2]Department of Engineering, Sari Branch, Islamic Azad University, Sari, Iran
Email: ebad.amouzad@gmail.com (Corresponding Author), maziyar.khoddadi@yahoo.com

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Abstract

Due to the high cost of fossil fuels, concerns about environmental contamination, and the requirement to satisfy rising energy demands, renewable energy sources have recently gained a lot of attention. Since the output of renewable resources like solar and wind energy depends on meteorological factors, the energy sector faces several issues as a result of their dependability. The microgrid frequencyis managed in accordance with the peak use of the gas network. Both the distribution of electric and gas network loads are taken into account. In a multi-carrier network, the frequency is adjusted in a nonlinear manner. On the other hand, the rising trend in production and the use of electric cars has increased the amount of new demands on the electrical network; if effective management is not implemented to handle these new loads, the rise in network frequency deviations might cause the network to malfunction or even collapse. In this study, the ANFIS adaptive fuzzy control approach is utilized to fine-tune the frequency of the network using vehicle-to-grid (V2G) electric cars. The wind turbine, solar panel, battery, flywheel, electric vehicle (EV), diesel generator, and multi-carrier energy hub (MCEH) systems with combined heat and power (CHP) make up the proposed micro-grid. A fuzzy controller is contrasted with the suggested approach in terms of frequency control. The simulations are carried out using MATLAB/SIMULINK software. The simulation results demonstrated that the studied microgrid's SMART controller can deliver stable output power and strong frequency control performance. In terms of effective (RMS) values and maximum frequency deviation, the suggested technique outperformed the fuzzy method.

Keywords: Electric vehicles, micro-grid, frequency control, ANFIS

1. Introduction

Grid-connected and islanding are the two primary modes in which micro-grids function. In order for a micro-grid network to function in the islanding mode, active distributed energy resources (DER) are needed. These DER include micro-generators, combined heat and power (CHP) units, photovoltaic (PV), wind or hydro turbines, and energy storage devices. The CHP unit is one of the several DER choices that is frequently employed in micro-grids [1].Utilizing electric vehicles can lower greenhouse gas emissions, according to multiple published papers [2,3]. Accordingly, it was expected that by 2020, 2030, and 2050, respectively, 35%, 51%, and 62% of all cars in the country will be electric [4]. A new load will be introduced to the system since rechargeable electric cars require power. As a result, as the usage of electric cars rises, the issue of regulating and stabilizing the frequency of power networks must also be addressed.With more electric vehicles on the road, renewable electricity dependability may rise. Electric cars can function as a controlled load or an output source when they are linked to the grid [5]. The term "vehicle-to-grid" (V2G) systems refers to a network of electric cars that may be viewed as a big storage battery with a capacity of several megawatts. By offering a quick reaction to disturbances, V2G systems may establish a backup storage source that balances power in the grid network. Network vehicles involved in load frequency management are under the control of fuzzy control [6, 7]. With a novel model of load response program, equipment planning for a multi-carrier microgrid with dependability is described. The impact of dependability indicators on cost reduction is examined in this paper [8].Daealhaq et al. [9]presented a two-tier optimization model to determine the sales strategy in the previous day's market in the presence of a wide range of renewable wind resources. The uncertainty of wind and load sources is modeled by the Monte Carlo scenario generation method considering their interdependence and the Coppola method. The proposed model also provided a linearized model of IC load distribution to reduce the complexity of the problem.Qin et al. [10] proposed a top-of-the-line DC-DC solid-state transformer for two-way parking of photovoltaics / EV batteries with network vehicle service (V2G-PVBP). Relying on the energy storage performance of EVs, V2G-PVBP can not only meet the normal needs of electric vehicle owners but also provide load handling and load adjustment performance to the microgrid.Prusty et al. [11]introduced the optimal performance of a fuzzy controller for balancing load and power generation in an independent microgrid (S-MG) with electric vehicles (EVs). Khooban et al. [12] presented a new modified optimization algorithm for adjusting scale factors and membership functions of type 2 fuzzy PI controller (GT2FPI), which effectively reduced the frequency deviations of the MG system against load disturbances. Iqbal et al. [13] proposed a new primary frequency control via V2G capability in an industrial microgrid, which includes the convenient coordination of the charging station operator, EV collector, and EV operator .Fan et al. [14] proposed a frequency regulation method in a three-zone LFC system, in which PEVs are utilized to regulate frequency under different load disturbances. Their results showed that the proposed LFC scheme successfully suppresses frequency fluctuations in the presence of delays and provides robustness against PEV uncertainties. The simulation results obtained from MATLAB by Yan et al.[15] results proved that the use of a hybrid energy storage system (HESS) can properly stabilize the frequency of interconnected multi-zone systems. Moreover, the proposed powerful controller was quite effective.Xu et al. [16] proposed a new energy storage method based on pumped hydropower storage (PHES) for an integrated renewable energy microgrid (REMG). Also,a load frequency control (LFC) wasproposed for the under-studysystem. In this paper, the problem of optimizing LFC controllers for REMG was investigated and optimal controllers were designed for multiple regions in REMG.Ivanovaet al. [17] showed that the energy and heat generation system (CHP) has a relatively high electrical application forstrengtheningthe power production sector. Murali et al. [18] investigated the derivative-based virtual inertia simulation using the energy storage system (ESS) and its effect on power system frequency control. In this work, a new effective optimization strategy called the Opposition-Based Volleyball Premier League (OVPL) algorithm was used to optimize the essential controller and ESS parameters. Irudayaraj et al. [19]described a physics-derived atom search optimization (ASO) algorithm for adjusting the fractional-order proportional integral control (FOPID) parameters for automatic control of HPS load frequency. In this study, an attempt was made to analyze the stability of the HPS frequency using Matignon’s theorem.In a work performed by Mohanty and Panda [20], an electric vehicle and a heat pump with HPS were used to control the frequency. The operation of customer electrical appliances such as an electric vehicle (EV) and heat pump (HP) reduces the use of stand-alone energy storage units for HPS. Lund and Kempton [21] connected electrical wires as a controllable load or source of outputto the grid.Their results showed that the reliability of renewable sources will increase by increasing the number of electric vehicles.A large number of electric vehicles in the network can be used as a huge storage battery on a scale of several MW, which is called vehicle-to-grid or V2G systems.V2G systems can create a backup storage source for balancing the power in the grid network and providing a rapid response to disruptions.Jan et al. [22]studied an independent Micro-grid includinga heating turbine system, wind turbine, photovoltaic and electric vehicle.In this research, the fuzzy PI method and adaptive droop control were used.Aliabadi et al. [23] investigateda Smart charging method for electric vehicles to control the Micro-grid frequency. In this paper, the smart charging method wasperformed based on fuzzy control. Amamra and Marco [24] provided frequency and voltage support based on a fleet of integrated V2G electric vehicles in the power network.The designed scheme was able to provide optimal regulation services as well as voltage regulation support for the grid network.In addition to providing the necessary ancillary services, issues related to EV battery failure were also investigated.Kumar and Jaladi [25] designed a battery charging station supply by using three grid sources, a photovoltaic system (PVS), and a battery energy system (BES).BES was used as a buffer with excessive energy storage under mild load conditions and its supply if required.In its infrastructure, a two-way DC / DC converter is activated by the control unit for charging and discharging.The MPPT (Maximum Power Point Tracking) technique was used to obtain suitable pulses for the DC / DC converter to achieve the maximum output power from PVS under different conditions.Annamraju and Nandiraju[26] proposed an adaptive FO-fuzzy-PID controller for LFC in a renewable permeable power system.The main part of this work is that an initial application was created to adjust simultaneously all possible parameters of the fuzzy, the FO, and PID controllers to deal with uncertainties caused by renewable sources, loads, and parametric changes. Liu et al. [27] proposed a coordinated distributed model predictive control (DMPC) for the LFC of a power system that includes inherently variable wind-power generations. Kong et al. [28] constituted a hierarchical distributed model predictive control (HDMPC) model for frequency regulation.Mainly highlights the essential problems, resource availability differences and the importance of hybrid renewable systems. In this research, the structure of electronic power converters and their performance with integrated hybrid systems have been discussed in detail. Energy management of input PV/wind sources along with battery and their respective control technologies are reviewed[29, 30].The main objective of this research work has been done for the enhanced settling point and voltage stability with the help of different maximum power point tracking (MPPT) methods. Different control techniques such as fuzzy logic controller, neural network, and particle swarm optimization are used to evaluate PV and FC through DC–DC boost converters for this enhanced settling point[31].Proposes a fuzzy logic controller (FLC) based maximum power point tracking (MPPT) approach deployed to PV panel and FC generated boost converter. PV panels must be operated at their maximum power point (MPP) to enhance efficiency and shorten the system’s payback period. There are different kinds of MPPT approaches for using PV panels at that moment. Still, the FLC-based MPPT approach was chosen in this study because it responds instantaneously to environmental changes and is unaffected sby circuit parameter changes. Similarly, this research proposes a better design strategy for FLC systems. It will improve the system reliability and stability of the response of the system.Eshetu et al. V2G electric vehicles were used as moving energy storage units.In an independent micro-grid, these mobile energy storage units can be a good solution for load frequency control (LFC).In this paper, an intelligent LFC technique based on ANFIS adaptive neural fuzzy system is used, andthe LFC controller based on ANFIS adaptive neural system is comparedto other controllers.

In the present paper, the ANFIS neural fuzzy controller is used to control an electric vehicle to regulate the frequency in multi-carrier microgrids. Therefore, two scenarios are designed for the proposed control structure. However, this work has considerable differencesfrom other works in the literature, CHP and diesel generator (DG) by the classical controller are optimized by the genetic algorithm as the main secondary frequency controller in the first scenario. In the second scenario, the V2G-equipped electric vehicle is used to perform the secondary frequency control with the proposed ANFIS controller. As well as the presence of storage devices (batteries and flywheels) as backup sources can increase the reliability of the under-study microgrid, which is not mentioned in the reference. The proposed method canshow acceptable performance in reducing frequency deviations and improving dynamic responses. It also has a more stable output power in microgrid resources. The rest of the paper is organized as follows.In section 2, the microgrid model is presented. In section 3,a briefliterature review on controller research is provided.Section 4 contained the simulation results and related discussions. Finally, the conclusions are summarized in section 5.

2. The Proposed Multi-Carrier Micro-Grid Model

As shown in Figure 1, the renewable microgrid network is composed of wind turbines, solar cells, storage facilities (flywheel and battery), diesel generators, CHP (Simultaneous generation of electricity and heat), and V2G electric vehicles as mobile storage systems. Given that the frequency is constant throughout the whole system, all loads and power output are modeled on a bus.

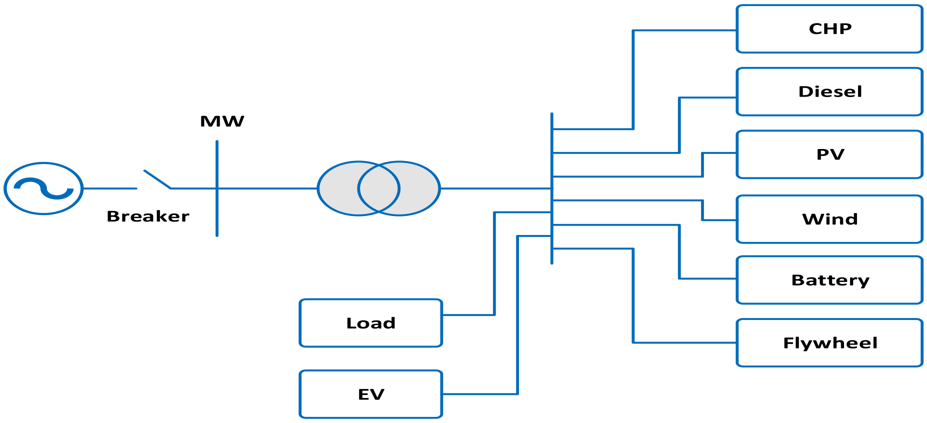


Fig.1. The layout of the isolated micro-grid

3. Model of Electric Vehicles (EVs)

The EVs system is modeled according to the work performed in reference [6]. The equivalent EV model used for LFC is illustrated in Figure 2. Details of the equivalent EV model including battery and charger based on the charging and discharging characteristics can be found in [6].

Figure 2 show that $T_e$is the time constant of EV, Δu_E is the LFC signal dispatched to EV, $\pm\mu_e$ is the inverter capacity limit, and $\pm\delta_e$ is the power ramp rate limit. E is the current energy of the EV battery. $E_{min}$and $E_{max}$are the minimum and maximum controllable energy of the EV battery, respectively. K_1 and K_2 arethe difference between the limited energy and current energy of the EV battery ,respectively .They can be calculated as $K_1=E-E_{max}$and $K_2= E-E_{min}$.

Finally, $\Delta P_E$is the charging/discharging power. When $\Delta P_E= 0$, EV is in the idle state; when $\Delta P_E> 0$, EV is in the discharging state; and when $\Delta P_E< 0$, EV is in the charging state. The EV can be charged and discharged only within the range of $\pm\mu_e$. However, if the energy of the EV exceeds the upper limit (i.e., E_{max}), the EV can only be discharged to($-\mu_e$). Also, if the EV energy is under the lower limit (i.e., E_{min}), the EV can only be charged within the range of ($-\mu_e$ ~0).

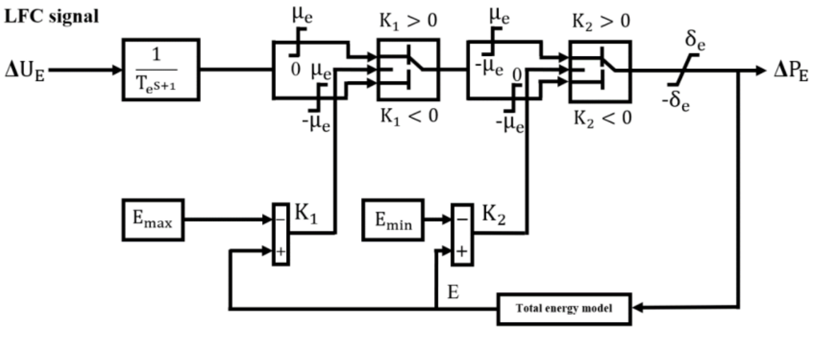


Fig.2. The equivalent EV model for controller [33]

Multi-carrier micro-grid control model

The proposed controller structure according to the parameters of Tables 2,3 in the multi-carrier microgrid is shown in Figure 3.

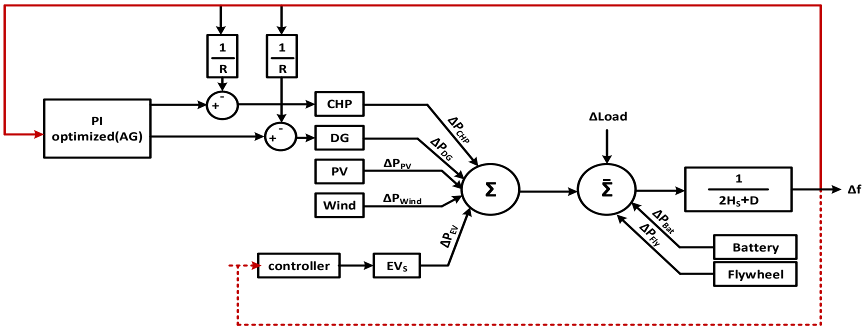
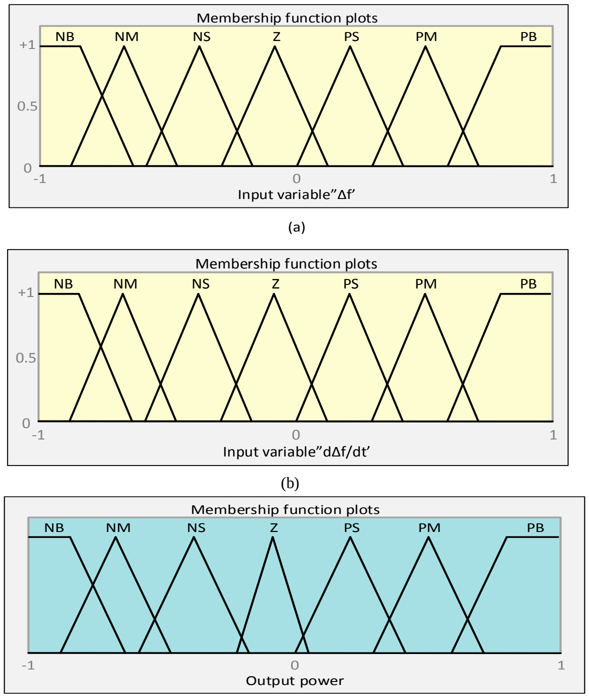


Fig.3. The control model of the micro-grid

4. The Proposed Controllers

A-fuzzy logic controller

The frequency deviations of the system and its derivatives of the two signals input and power as the output of the fuzzy system were studied. Frequency deviation is shown in the Figure of membership functions. The input and output variables in the proposed controller are shown as a set of seven language variables as follows: NB (Big negative), NM (medium negative), NS (small negative), Z (zero), PS (small positive), PM (Medium positive), and PB (Big positive). Each of the above fuzzy variables has a member of the subsets whose membership's degree varies between [-1, 1]. There are a total of 49 fuzzy rules that are considered in this scheme according to Table 1.



(a)

(b)

(c)

Fig.4. (a) Membership functions of Fuzzy Controller, (b) input fuzzy membership, and (c) output fuzzy membership

Table 1. Fuzzy rules of the controller

Inputs		Δf						
		NB	NM	NS	ZO	PS	PM	PB
Δf/dt	NB	PB	PB	PB	PB	PM	PS	ZO
	NM	PB	PB	PB	PM	PS	ZO	PS
	NS	PB	PB	PM	PS	ZO	NS	NM
	ZO	PB	PM	PS	ZO	NS	NM	NB
	PS	PM	PS	ZO	NS	NM	NB	NB
	PM	PS	ZO	NS	NM	NB	NB	NB
	PB	ZO	NS	NM	NB	NB	NB	NB

B-Adaptive Neuro FuzzyInterface System (ANFIS)Controller

Neuro-fuzzy techniques are developed from the fusion of ANN and Fuzzy Inference Systems (FIS). ANFIS has an advantage over both fuzzy and ANN. It combines the learning power of neural networks with knowledge representation of fuzzy logic to implement a different mode of functions.

The ANFIS is a multi-layer adaptive neural network-based fuzzy inference system. The architecture of the ANFIS systemisshowninFigure

9.Inthisstudy,thefuzzyinference systemhastwosetsofinputs(Δf,$\dot{\Delta} f$)andone output u (power).Suppose that the rule base contains two fuzzy rules including Takagi and Sugeno. For example,

Rule 1: If Δf is X1 and $\dot{\Delta} f$ is Y1,
then $u_1=p_1\Delta f+q_1\Delta f+r_1$
Rule 2: If Δf id X2 and $\dot{\Delta} f$ is Y1,
then $u_2=p_2\Delta f+q_2\Delta f+r_2$

Layer 1: This layer is an adaptive node that is known as the fuzzification layer. The parameter values of this layer change according to the error signal and generate the proper value of each membership function. Each node is denoted as I, and hasan adaptive node function, as shown:

$$o_i^1=\mu_{X_i}(\Delta f) \text{ for i=1,2} \quad (1)$$

$$o_i^1=\mu_{Y_{i-2}}(\dot{\Delta} f) \text{ for i=3,4} \quad (2)$$

Where Δf (or ($\dot{\Delta} f$)) is input at node I, while Xi (or Yi) is a linguistic label (fuzzy sets: Big, Small) that represents the membership functions of each node.

Layer 2: In this layer, the outputs of the first layer are multipliedby each other and forwarded to the next layer. The nodes in this layer are fixed nodes and labeled as II.

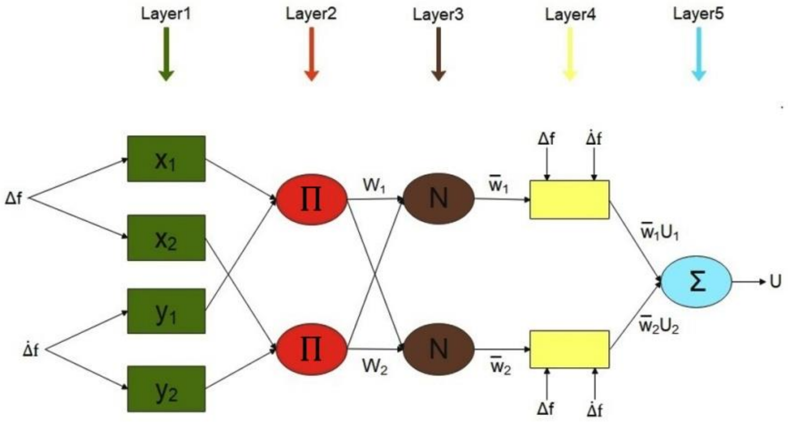


Fig.5. ANFIS network structure [27]

The output of each node is a product of all incoming signals. The output obtained from each node of this layer is given by;

$$o_i^2=w_i=\mu_{x_i}(\Delta f)\times\mu_{y_i}(\dot{\Delta} f) \text{ for i=1,2} \quad (3)$$

This output representsa degree of activation or (firing strength W_I) of a rule.

Layer 3: This layer calculates the normalized firing strength of each rule and is labeled as N (Normalization). Each node in this layer is also fixed.The output of this layer is normalized firing strength. For ith node the normalized firing strength ($\overline{w}_1$) is given by the following expression.

$$o_i^3=\bar{w}_1=\frac{w_i}{w_1+w_2} \text{ for } i=1,2 \quad (4)$$

Layer 4: Each node in this layer is an adaptive node and the output obtained from this layer is given as follows:

$$o_i^4=\bar{w}_l u_i$$

$$\bar{w}_l u_i=\bar{w}_l\left(p_i\Delta f+q_i\dot{\Delta} f+r_i\right) i=1,2 \quad (5)$$

Where $\overline{w}_1 is$ the output of the third layer and {pi, qi, ri} is the parameter set of this node. The parameter in this layer is referred to as the consequent parameter.

Layer 5: This layer is the last layer of ANFIS architecture which result in the output U and labeled as$\sum$, which computes the overall output as a summation of all incoming signals to the node which is given as

$$o_i^5 - U = \sum \bar{w}_l u_i = \frac{\sum w_i u_i}{\sum w_i} \qquad (6)$$

The ANFIS methods are applied to hybrid-learning algorithms that consist of a combination of various algorithms, the least squares methods are used to set the parameters of linear as well as gradient-descent, which is used to identify the premise parameters. ANFIS edit toolbox is used for production (ANFIS-FIS) in MATLAB software.Training and experimental data are used to train the adaptive neural fuzzy system. For more details to understandthe steps of ANFIS design,see this reference.

5. Simulation Results

To compare the proposed method and fuzzy controller, simulations were performed in five case studies in Simulink MATLAB. The performance of the proposed control scheme is evaluated by two criteria of numerical evaluation of the mean power of the frequency deviations RMS (Δf) and the maximum size of the frequency deviations (max(IΔfI)).

Table 2. Proposed micro-grid parameters [32]

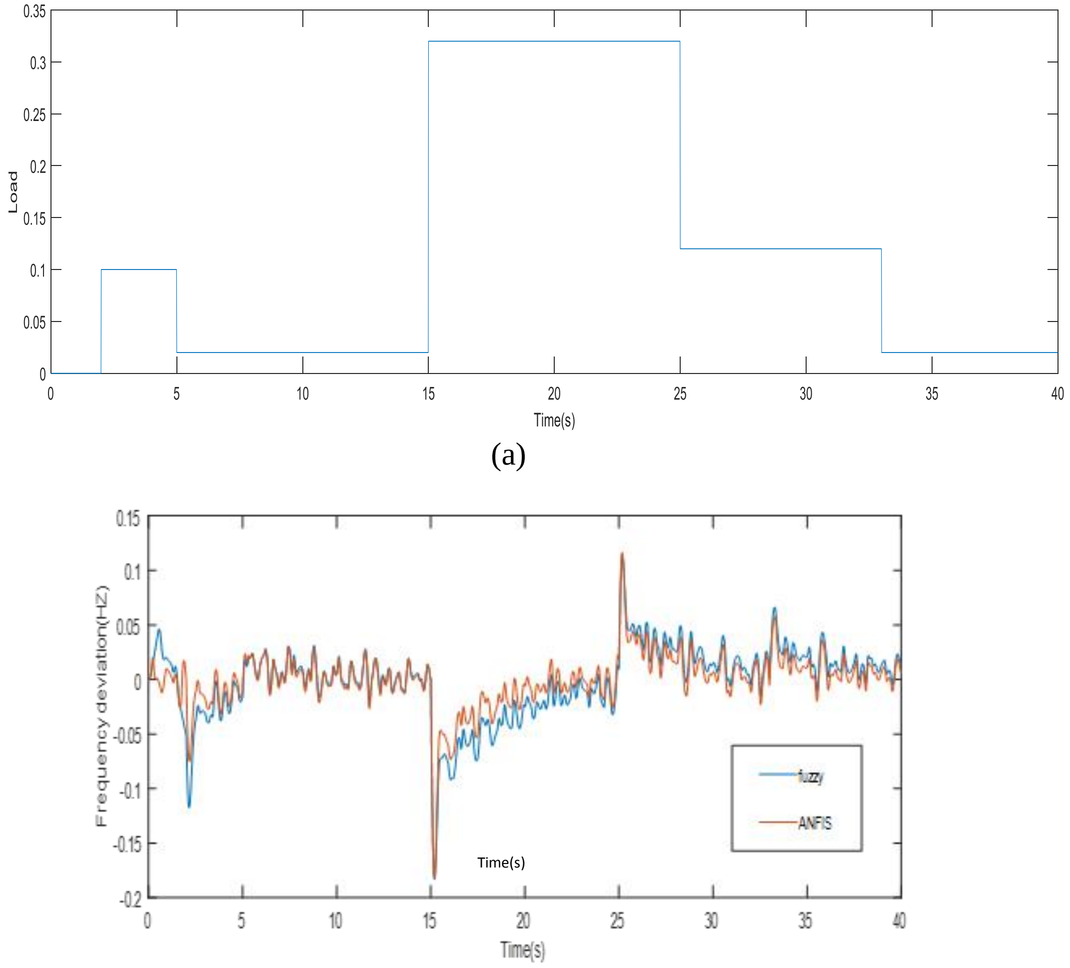
Parameters	Value	parameters	Value
D (pu/Hz)	0.015	T_g (s)	0.08
2H (pu s)	0.1667	T_t (s)	0.4
T_{Fess} (s)	0.1	$T_{t/c}$ (s)	0.004
T_{Bess} (s)	0.1	T_{IN} (s)	0.04
R (Hz/pu)	3	-	-

Table 3. Parameters of the micro-grid model [33,37,38]

Grid component	Parameters	values
CHP	Xc	0.6 (s)
	Yc	1 (s)
	T_{CR}	0.1 (s)
	T_F	23 (s)
	C_g	1
	b_g	0.05 (s)
	T_{CD}	0.2 (s)
EV_s	T_e	1(s)
	δe	0.01(pu.MW/s)
	μ_e	0.25 (pu.MW)
	Emax	0.95(pu.MW/h)
	Emin	0.8 (pu.MW/h)
PI(optimized AG)	Proportional gain	-0.355
	Integral gain	-0.375

Study A

This study was performed to show the dynamic response of the system in the face of multistage load disturbance (ΔPL).Timeseconds (2-5-15-25-33) are applied to the microgrid according to Figure 6a, and the frequency response of the system is shown in Figure 6b. As shown in Figure 6b, when the proposed ANFIS method is used, the frequency fluctuations and deviations are decreased compared to the fuzzy controller. As a result, the proposed controller has a good performance in the frequency response. In the proposed ANFIS method, the effective (RMS) values and maximum frequency (max) deviation according to Table 5 show a decreaseof 54% and 45%, respectively, compared to the fuzzy controller. It can be concluded that the proposed method in frequency controlindicates proper performance.



(a)

(b)

Fig.6. (a) Multiple-step load disturbances, (b) MG frequency response

Study B

In this study which assumed in winter, the multi-carrier Hub (MCH) network is faced with production shortages due to a sharp drop in gas pressure, and no available CHP in the networkresults in reduced frequency. At this point, a relatively large disturbance of 0. 2 (pu) is applied to the network in 27 seconds.The results of this simulation in figure 7 show the robustness of the fuzzy and ANFIS intelligent controllers of the under-study system. Figure 7 shows that ANFIS performs better in reducing frequency deviations than fuzzy.In the proposed method, the effective (RMS) values and maximum frequency (max) deviation according to Table 5 show a decreaseof 175% and 45%, respectively, compared to the fuzzy controller.

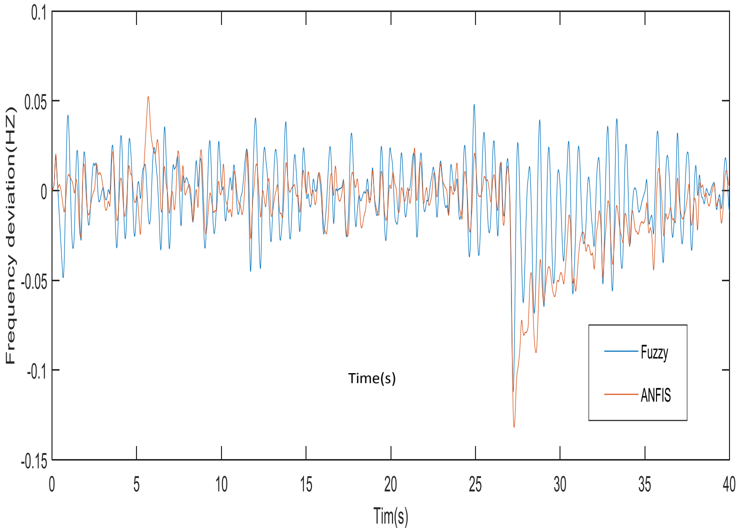


Fig.7. Frequency response of gas changes

Study C

Power system parameters change continuously over time, and this may affect the frequency response of the system. Resistance to environmental and dynamic changes is the advantage of intelligent control methods. At this stage, the main parameters of the power system include damping factor (D), inertia constant (H), drop constant (R), turbine time constant (T_t), generator time constant (T_g), battery time constant (T_{BESS}), flywheel time constant (T_{FESS}) changes to respond the frequency fluctuations according to Table 5. After applying these changes in the microgrid system, the closed-loop frequency response is shown in Figure 8.The optimal resistance of the proposed controller against the considered uncertainties was investigated. Also, the proposed method demonstrates better damping than the fuzzy one and improves the performance of the frequency system. In the proposed method, the effective (RMS) values and maximum frequency deviation(max) according to Table 5 were reduced by 50% and 62%, respectively, compared to the fuzzy controller.

Table 4. Uncertain parameters and variation range

Parameter	Variation range	Parameter	Variation range
R	+60%	T_g	+60%
D	-35%	T_{FESS}	+70%
H	-40%	T_{BESS}	+70%
T_t	+60%	-	-

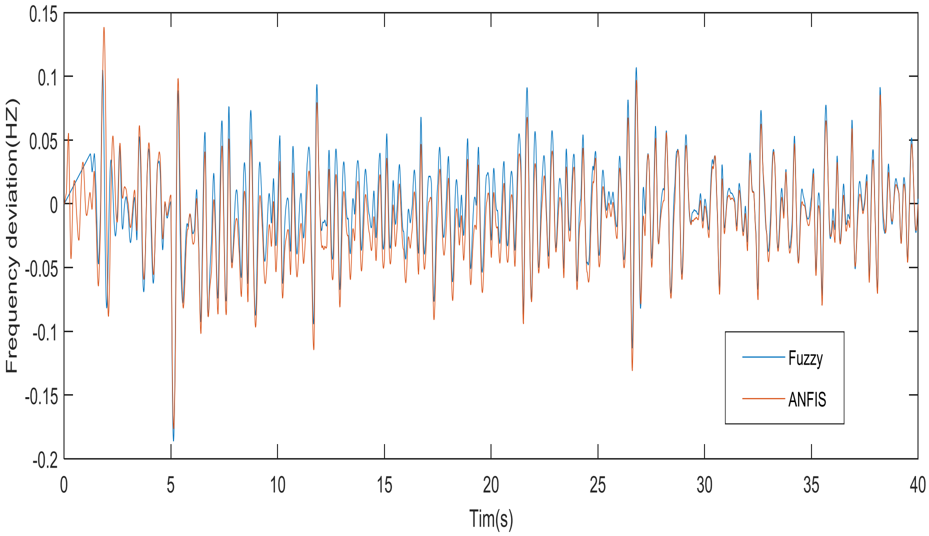


Fig.8. Frequency response according to the parameter's changes shown in table

Study D

In this study, disturbance in the photovoltaic system (PV) and wind system (wind) was managed to occur in 17 and 32 seconds, respectively. The system response to power fluctuations with and without PV system, and also withand without wind turbines are shown in Figures 9 and 10. The simulation results in Figure 11 show an ANFIS-based control method has a better performance in regulating frequency deviations and acceptable strength against perturbations than the fuzzy method. Also, in the proposed method, the effective (RMS) values and maximum frequency deviation (max) according to Table 5 were improved by 49% and 41%, respectively, compared to the fuzzy controller.

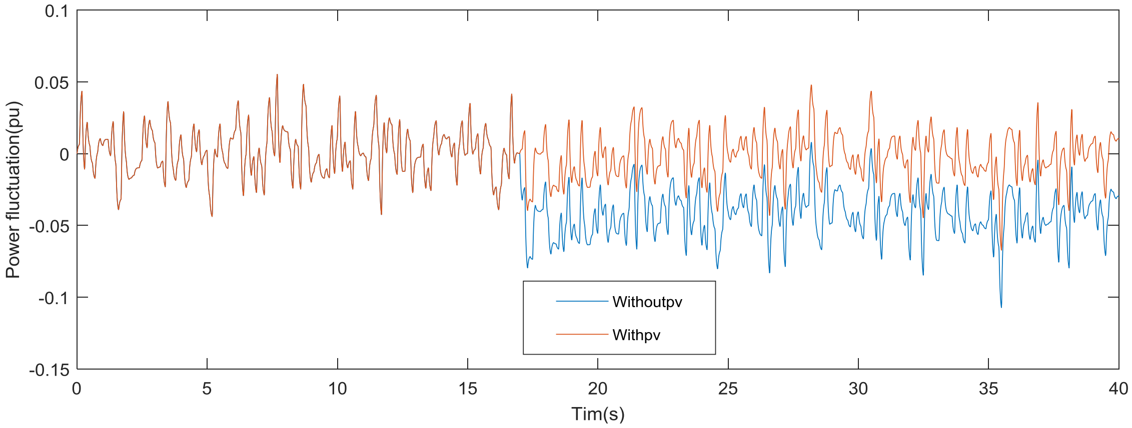


Fig.9. Output power with and without PV

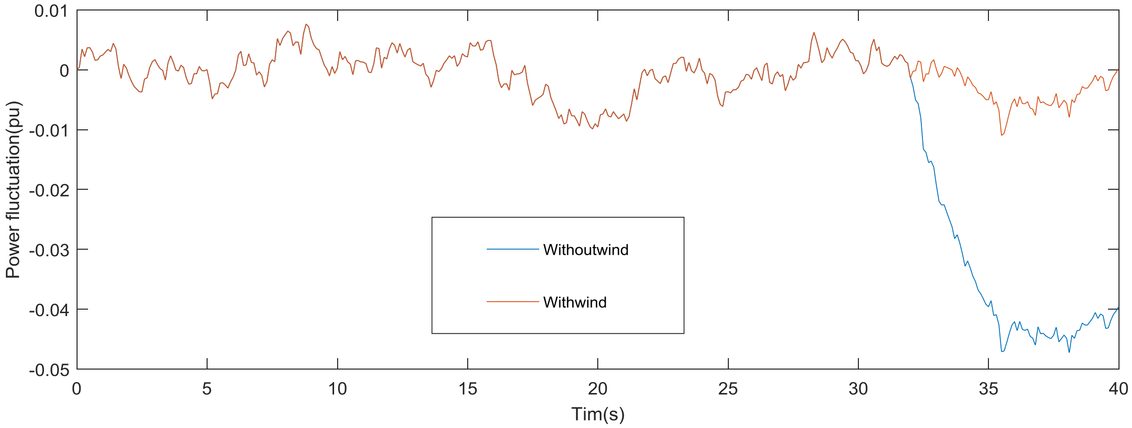


Fig.10. Output power with and without wind

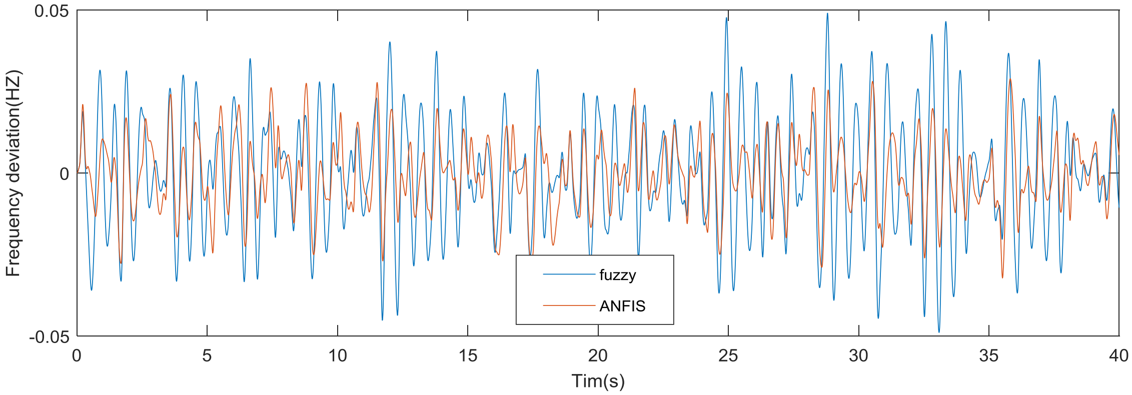
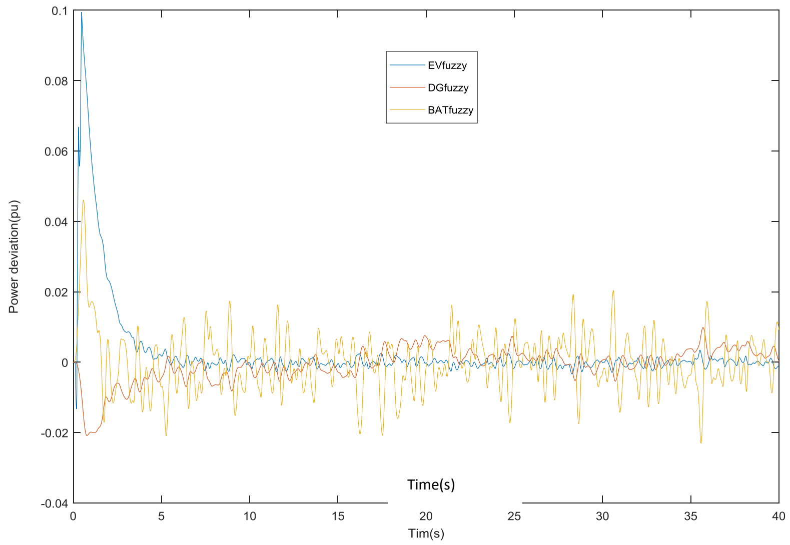


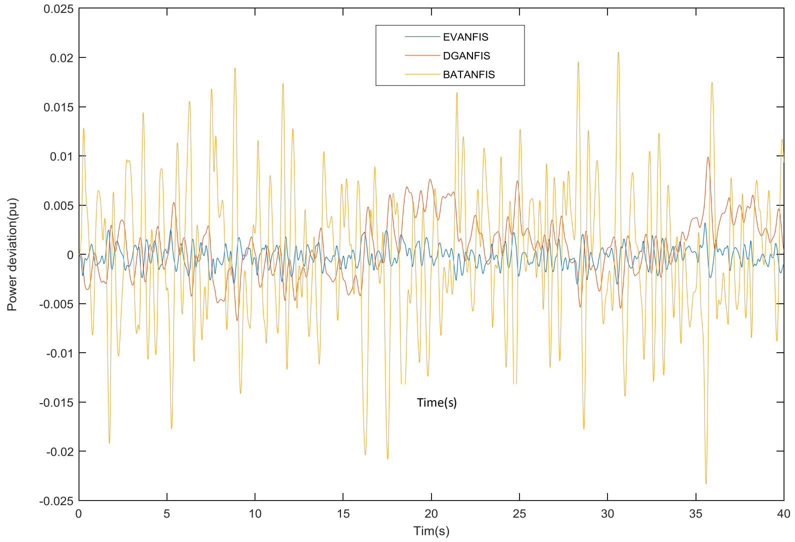
Fig.11. Comparison of the proposed ANFIS method and fuzzy controller in terms of frequency deviation

Study E

In this study, the output power results of the proposed ANFIS-based controller ina system including a battery, diesel generator (DG), and electric vehicle (EV) were compared to a fuzzy controller. The output power of the fuzzy controller and the ANFIS controller are shown in Figures 12a and 12b, respectively. The simulation results show that the ANFIS-based intelligent controller has a more stable output power than the fuzzy. As a result, the proposed method has a good performance in power stability.



(a)Fuzzy Response



(b) ANFIS Response

Fig.12. Output Power deviation (Battery-DG-EV$_s$); (A) fuzzy, (B) ANFIS

6. Summary

The performance of the proposed ANFIS controller was compared witha fuzzy controller in five scenarios. The simulation results showed that frequency adjustment is properlyconducted in the presence of uncertainties such as load changes, renewable energy sources, gas changes, changes in power system parameters, and as well as system stability interruption. The proposed method canshow good performance and significantly reduce frequency deviations. Finally, the proposed method (ANFIS) was compared with control methods in these references [23,26] to evaluate the proposed method, in which the algorithm colonial competition was usedto optimizethe fuzzy controller in [23] and the FO-fuzzy-PID controller was used in reference [26]. In the simulation, a disturbance of 0.3 pu was applied to the microgrid in 16 seconds.

Figure 13 shows the frequency deviation of the proposed method and the methods presented in these references [23,26]. The simulation results in this figure show the optimal performance of the proposed method and the above-mentionedreferences in terms of reducing frequency deviation and resistance to disturbances. Furthermore, effective (RMS) values and maximum frequency deviation (max) of the proposed method were compared with the other two reference methods according to Table 6. According to the results of the proposed method in this table, the effective values and maximum frequency deviation are decreased from [23] up to 61% and 77%, respectively, and compared to [26] are decreased up to 53% and 75%, respectively. Therefore, better performance in frequency regulation for the proposed method than the presented controllers in the literature [23,26] was observed.

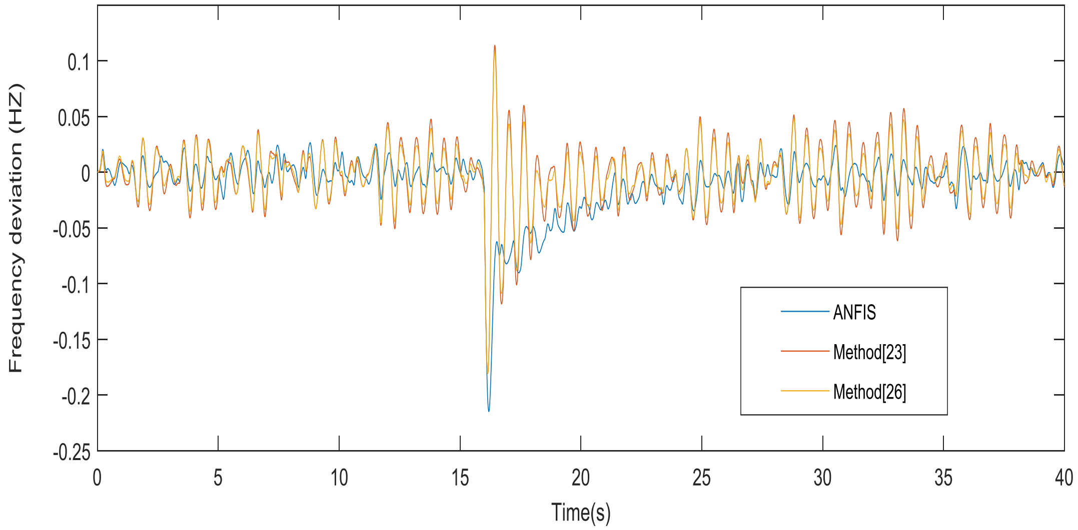


Fig.13. Frequency deviation using the proposed method and control method in [23,26].

Conclusion

This paper aimed to control the frequency in a multi-carrier microgrid. The under-study microgrid includes nonlinear factors that mimic the real-world behavior of the system. Considering that the microgrid is naturally nonlinear, traditional controllers show weak performance in this situation. Therefore, smart controllers areused due to their acceptable performance in nonlinear conditions. In the under-study multi-carrier microgrid, CHP sources and diesel generatorswere used for the secondary frequency controlling as the main sources by the classical Pi controller optimized by the genetic algorithm. The main discussion of this research is the presence of V2G electric vehicles as moving batteries controlled by the intelligent participant ANFIS Neural Fuzzy in secondary frequency as a backup power source. The performance of the proposed ANFIS controller was evaluated in 5 case studies. Also, the degree of resistance of the proposed controller to various parameters and resistance to changes were evaluated. The proposed controller against uncertainties in the simulation results showed that the proposed ANFIS intelligent controller improves system performance compared to the fuzzy intelligent controller and shows better damping performance than the fuzzy one. The proposed controller in all aspectsincluding limit, steady state error, time, andsettlement time shows better performance than other controllers.

Table 5.RMS and maximum values of frequency deviation

Study A (RMS.pu)		**Study B (RMS.pu)**		**Study D (RMS.pu)**		**Study E (RMS.pu)**	
ANFIS	fuzzy	ANFIS	Fuzzy	ANFIS	Fuzzy	ANFIS	fuzzy
0.0058	0.0126	0.0044	0.0121	0.0019	0.0038	0.0054	0.0106
Study A (max.pu)		**Study B** (max.pu)		**Study D** (max.pu**)**		**Study E** (max.pu)	
ANFIS	fuzzy	ANFIS	fuzzy	ANFIS	Fuzzy	ANFIS	fuzzy
0.1163	0.2124	0.0262	0.0480	0.1058	0.2809	0.0289	0.0490

Table 6.RMS and maximum values of frequency deviation

Reference method [26]	**Reference method[23]**	**Proposed method**
RMS(0.0115 pu)	RMS(0.0136 pu)	RMS (0.0054 pu)
max (0.1078 pu)	max (0.1138 pu)	max (0.0264 pu)

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