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Research Article

Smart Frequency Control of a Multicarrier Microgrid in the Presence of V2G Electric Vehicles

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In recent years, renewable resources have widely been used to provide necessary energy due to the increasing fossil fuel prices, environmental pollution concerns, and the necessity to meet the growth in energy demands. The output of renewable resources especially solar and wind energies is associated with meteorological parameters, so their reliability creates many challenges for the energy sector. The consumption peak of the gas network is taken into account to adjust the frequency of the microgrid (MG). Both gas network load and electric load distributions are adjusted at the same time. In a multicarrier network, the frequency is regulated in a nonlinear manner. Meanwhile, new necessary loads for production and electric vehicles have imposed new loads on the power network; if proper management is not performed to respond to these new loads, the increase of network frequency deviations may lead the network to fail and even break down. In this paper, a network of various sources including the wind turbine, solar panel, storage (battery and flywheel), electric vehicle (EV), diesel generator (DG) electric power generation, and multicarrier energy hub (MCEH) with combined heat and power (CHP) was designed to examine vehicle-to-grid (V2G) electric vehicles. The ANFIS adaptive fuzzy control method was used to provide a fine-tuning frequency of the network. A comparison between the suggested approach and a fuzzy controller system was carried out to examine the superiority of the introduced approach to the frequency control. The simulations were obtained using MATLAB/SIMULINK software. The simulation outcomes indicated that the SMART controller can achieve good efficiency in frequency regulation and reliable output power in the examined microgrid. Further comparison in terms of effective (RMS) values and maximum frequency deviation indicates the superior performance of the proposed method over the fuzzy method.

1. Introduction

Grid-connected and islanding are the two main modes used for operating MGs. To operate a microgrid network in the islanding mode, it is required to add several active distributed energy resources (DER) including CHP units, microgenerators, photovoltaic (PV), wind- or hydropower generators, and power storage batteries in the power network [1, 2]. By considering all the various DER technologies, the CHP unit is widely used in MGs [3, 4].

According to the numerous published articles, using electric vehicles can reduce greenhouse gas emissions [5, 6]. So, it was predicted that the electric vehicles in the US in 2020, 2030, and 2050 include 35%, 51%, and 62% of the total vehicles, respectively [7]. Due to the need for electricity for rechargeable electric vehicles, a new load will be added to the grid. Therefore, the problem of controlling and stabilizing the frequency of power networks must be addressed by the increase in the use of electric vehicles [8].

Renewable electricity reliability can increase with the increase in electric vehicle numbers [9]. An electric vehicle acts as a controllable load or source of output when it is connected to the grid [10]. Numerous electric vehicles in the grid can be viewed as large storage battery on the order of several MW, which is mentioned as vehicle-to-grid or V2G systems in the literature. These systems can create a reliable backup storage source that balances power in the grid network by providing a rapid response to disruptions [11]. Fuzzy control is used to control the network vehicles participating in the load frequency control [12, 13]. Equipment planning of a multicarrier MG with reliability is introduced along with a new model of load response program [14]. In this paper, the importance of reliability indicators on cost decrease is investigated.

The authors of reference [15] suggested a two-tier optimization model to define the sales approach in the previous day's market considering comprehensive technologies of renewable wind energy. The uncertainty of wind and load sources is modeled by the Monte Carlo scenario generation method considering their interdependence and the Copula method. The proposed model also provided a linearized model of IC load distribution to reduce the complexity of the problem. Daealhaq et al. [15] 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). By considering the advantages of energy storing capacity of EVs, V2G-PVBP showed efficiency in both satisfying the usual needs of electric vehicle owners and preparing load handling and load adjustment performance to the MG. Qin et al. [16] introduced the optimal performance of a fuzzy controller to obtain balancing between energy consumption and energy generation in an independent microgrid (S-MG) in the presence of EVs. Prusty et al. [17] presented a new modified optimization algorithm for adjusting scale coefficients and membership functions related to type 2 fuzzy PI controller (GT2FPI), which succeeded in reducing the frequency deflection of the MG network which caused by load consumption variation. Khooban et al. [18] proposed a new primitive design of frequency control based on V2G capability in an industrial MG network, which includes the proper harmony of the charge storing center operator, EV collector, and EV operator [19]. Fan et al. [20] suggested a frequency adjustment method in a three-zone load frequency control (LFC) system, in which PEVs are utilized to regulate frequency under various load disorders. Their outcomes showed that the suggested LFC method could effectively remove frequency disorders while considering delays in the network and giving robustness to the system against PEV uncertainties. The simulation results obtained from MATLAB by the results of Yan et al. [21] proved that the use of a hybrid energy storage system (HESS) can properly stabilize the frequency of integrative multizone systems. Moreover, the proposed powerful controller was quite effective.

Xu et al. [22] studied a novel original energy storage system by using the framework of pumped hydropower storage (PHES) for an integrated renewable energy MG (REMG) network. Also, an LFC was proposed for the understudy system. In this research, the challenge of optimizing LFC controllers for REMG was investigated and optimal controllers were designed for multiple regions in REMG. Ivanova et al. [23] showed that the energy and heat generation system has a relatively high electrical application for strengthening the power production sector. Murali et al. [24] utilized the energy storage system (ESS) infrastructure to examine the derivative-based virtual inertia simulation using and analyze its effect in adjusting frequency of power system. In which, a primary efficient optimization algorithm called the opposition-based volleyball premier league (OVPL) was utilized to obtain optimal fundamental controller and ESS parameters. By considering the two-level and dual two-level voltage source inverter framework in supplying nonlinear loads, the implementation of virtual inertia was investigated in both of them [25, 26]. Obtaining of virtual inertia was performed using the derivative control technique. For obtaining an automatic control of HPS load frequency, in a work performed by Irudayaraj et al. [27], a physics-derived atom search optimization (ASO) algorithm was designed for tunning the fractional-order proportional necessary manage (FOPID) parameters. In this study, the authors tried to investigate the stability of the HPS frequency with the use of Matignon's theorem. In reference [28], an electric vehicle and a heat pump with HPS were used to control the frequency. The operation of both EV and heat pump (HP) as customer electrical appliances reduces the use of stand-alone energy storage units for HPS. Lund and Kempton [29] connected electrical wires as a controllable load or source of output to the grid. Their results showed that the reliability of renewable sources will increase by growing the use of electric vehicles. Many electric vehicles in the network can be used as a huge storage battery on a scale of several MW, which is mentioned as vehicle-to-grid or V2G systems in the existing literature. 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. [30] studied an independent MG including a heating generator, wind power generation system, PV, and EV. In this research, the fuzzy PI method and adaptive droop control were used. Aliabadi et al. [31] investigated a smart charging method for electric vehicles to control the MG frequency. In this work, the smart charging technique was performed by applying fuzzy control. Amamra and Marco [32] 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 the EV battery failure were also investigated. Kumar and Jaladi [33] designed a battery charging station supply by using three grid sources, a photovoltaic system (PVS), and a battery energy system (BES). BES was applied as a buffer with excessive energy storage under mild load conditions and its supply if required. In its infrastructure, a converter of two-way DC/DC type is activated by the control unit for charging and discharging. To provide necessary circumstances for the DC/DC converter, the highest control point tracking technique was applied to attain the maximum yield power from PVS under diverse conditions for obtaining reasonable pulses. By considering a renewable permeable energy based network, an adaptive fractional-order fuzzy proportional integral derivative (FO-Fuzzy-PID) controller was proposed by Annamraju and Nandiraju [34] for LFC. In the center point of this research, an initial application was created to adjust simultaneously all feasible parameters of the fuzzy, the FO, and PID controllers to deal with uncertainty factors caused by fast variation of renewable sources, loads, and parametric changes. A coordinated distributed model predictive control (DMPC) proposed by Liu et al. [35] for the LFC in a power network that contains naturally variable wind-power generations. Kong et al. [36] developed a hierarchical distributed model predictive control (HDMPC) model to obtain proper adjustment of network frequency. Dashtdar et al. [37] proposed a frequency control of the islanded MG that included renewable resources. In this suggested control method, the model predictive control (MPC) is continuously utilized to adjust the controller coefficients, in which the algorithm of optimization of particle swarm algorithm was employed to achieve the best conditions in the control method. Srivastava et al. [38] used a power generation network to study a synchronized control grid with virtual power plant (VPP) with a parabolic. The power network composed of various devices including solar collector thermal system (PTSCTS), a wind generator, and an EV. Two-stage (PI)−(1 + PD) controllers and the proportional integrator derivative (PID) simultaneously were included in the developed frequency adjusting approach. Furthermore, four algorithms including butterfly optimization algorithm (BOA), the firefly algorithm (FA), recent grasshopper optimization algorithm (GOA), and PSO were utilized to obtain optimal parameters of the controllers. Fixed-time determined controller potency was proposed to fulfill the most extreme power derivation issue in a wind power generation system [39].

A controller was proposed by using the concept of perturbation observer to obtain a high amount of power from a wind power generation system with entirely unclear parameters [40]. Zadeh et al. [41] utilized fuzzy-neural controllers to develop a frequency control of low inertia MGs to obtain equivalency for the values of production and demand of electricity power. Various electricity power sources including wind turbine, PV panel, energy storage system, and diesel generators were used to design the MG network. To compute load changes in the network, both virtual inertia compensation and a fuzzy-neural controller were utilized to design an exact control technique. Gummala et al. [42] studied the effectiveness of the Jaya algorithm optimization frequency control in an independent MG of various renewable energy sources. In this research, secondary frequency control was performed using the adaptive fuzzy logic controller (AFLC). Negahban et al. [43] recommended a novel control approach by using the concept of the adaptive fuzzy model control. In this research, the developed control technique was simultaneously compared with an optimal PI and an adaptive optimal model predictive control. The obtained results were used to improve the strength of the developed control technique. Shubham et al. [44] studied the frequency stabilization and tie-line electricity power in a designed cluster consisting of a PV solar plant, microhydropower system, diesel power generator, flywheel device, super magnetic electricity storing system, and electric vehicle. To obtain a proper frequency control, a new jellyfish search optimization-based dual-stage (1 + proportional integral) tilt-integral derivative controller was used in this paper. Padhy et al. [45] studied the ability of PD−(1 + PI) controller device to regulate frequency in an MG system with several energy resources that was designed using a marine predator algorithm. The potency of the developed algorithm was examined by comparing it with three common techniques including grey wolf optimization, the genetic algorithm, and differential evolution. MATLAB/SIMULINK software was applied to carry out the simulation. Mondal et al. [46] proposed a frequency regulation approach for a hybrid shipboard MG network utilizing a BOT-based controller. The electricity generation network was composed of various resources including a dish-stirling solar-thermal system (DSTS-)based marine vessel, wind-driven generator (WDG) system, solid oxide fuel cell (SOFC) electricity generation, superconducting magnetic energy storage (SMES) device, two various AC-loads, and propulsion loads are utilized as an ISHMG. Bouaddi et al. [47] conducted a load frequency analysis using a mathematical model of an autonomous MG by considering both uncontrollable and controllable power sources. This research utilized a fuzzy logic proportional-integral (FLPI) controller in order to decrease frequency fluctuations in the designed MG. Furthermore, an innovative hybrid algorithm of water cycle optimization and moth flame was proposed using the ITAE fitness function. Tripathi and Singh [48] analyzed frequency control by considering an MG consisting of a diesel generator, wind generation, and solar generation. This research used both PI and MPC to compare their results. Javanmardi et al. [49] studied the power fluctuation problem in an MG system by considering renewable energy sources. In this research, a dynamic output feedback controller (DOFC) was designed in MG by taking into account the contraction observer for mitigation. Sahoo et al. [50] analyzed the potency of a new green leaf-hopper flame-based optimization algorithm (GLFOA) to control the frequency in hybrid MGs consisting of solar-thermal power/electric plants, wind power generation plants, PV solar cells, biogas combustion turbine, biodiesel power generation system, and power electricity storing devices. Comparing the proposed algorithm and several popular optimization algorithms showed the superiority of GLFOA's performance. For minimizing the frequency fluctuations occurring in the MG networks, a modified multiverse optimizer (MMVO) approach was proposed by Mishra et al. [51] to tune the specification of a fuzzy PID controller with a freedom degree of 2. A power network composed of renewable energy including wind turbine, solar plant, electricity storing devices, and a flywheel electricity storing system equipped with a hydrogen aqua electrolyzer and a fuel cell unit were employed in the designed MG model. Both super twisting sliding mode and PI control schemes were used by Amine et al. [52] to conduct a comparative examination to analyze the impacts of control approaches on HESSs in remote DC-MG networks. In this paper, three configurations including integrating proportional-integral with super-twisting sliding mode controllers (STSMCs) in dual-loop frequency regulation frameworks, time-specification, and present bandwidths of the HCC were utilized to realize the efficient performance of the HESS control. Singh and Gope [53] proposed an LFC of a two-area MMG renewable network with a tie-lin consisting of biodiesel power electricity plant, electricity storing system, PV plant, minihydro power generation system, biogas power electricity plant, and multiload disorder. In this proposed approach, a PID control scheme was applied by utilizing the grey wolf optimization (GWO) algorithm to adjust frequency fluctuations and achieve balancing between demand and energy power generation. Besides, other hybrid methods such as GWO-PSO [54], Harris hawk-particle swarm optimizer (HHOPSO) [55], quasi-oppositional harmony search (QOHS) algorithm [56], grey wolf optimizer sine cosine algorithm crow search algorithm (GWO-SCACSA) [57], and lightning search algorithm (LSA) [58] are used in the literature.

Eshetu et al. [59] V2G electric vehicles were used as moving energy storage units. In an independent MG, these transferable power electricity storage batteries can be a promising resolving key for LFC. In this paper, the ANFIS adaptive neural fuzzy system is used as a basic framework to design an intelligent LFC technique, and the LFC controller based on the ANFIS adaptive neural system is compared to other controllers.

Considering all the benefits and challenges of EVs and ANFIS controllers, this paper provides the following insights and contributions:

(i) The ANFIS neural fuzzy controller is used to control an electric vehicle to regulate the frequency in multicarrier MGs. Therefore, two scenarios are designed for the proposed control structure.

(ii) This work has considerable differences from other works in the literature (e.g., the work presented in [59]), 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.

(iii) In the second scenario, the V2G-equipped electric vehicle is used to perform the secondhand frequency regulation 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 MG, which is not mentioned in the reference [59].

(iv) The proposed method can show acceptable performance in reducing frequency deviations and improving dynamic responses. It also can show a highly efficient control of the output power in MG resources.

(v) Other sections of the paper are structured as the following. The MG model is provided in Section 2. The model of EVs is provided in Section 3. The multicarrier microgrid model is provided in Section 4. In Section 5, a brief literature review on controller research is provided. Section 6 contains the results simulation analysis and related discussions. Ultimately, the summary of the study is provided in Section 7 and the study is concluded in Section 8.

2. The Proposed Multicarrier MG Model

Figure 1 demonstrates the layout of the suggested isolated MG. The practical power of the MG is 1 MW, and the MG network is composed of three types of resources. First, renewable resources include wind turbines and solar cells. Second, storage facilities include flywheel, battery, and V2G electric vehicles as mobile storage systems. Third, fuel-using resources include diesel generators and CHP (simultaneous generation of electricity and heat). A circuit breaker was equipped to protect the whole network from overload or short circuits. Given that the frequency is constant throughout the system, all loads and power output are modeled on a bus. It should be noted that EVs are simultaneously used as battery storage and load consumption in the proposed network.

3. Model of Electric Vehicles (EVs)

The EVs system is modeled according to work performed [12]. Figure 2 illustrates the identical EV model utilized for LFC. More details regarding battery and charger according to the charging and discharging specifications of the EV model is accessible in reference [12].

T_e is the time constant of EV, which can be interpreted from Figure 2, the LFC signal transmitted to EV is demonstrated by ΔuE, the up and down limit capacity of the inverter is seated between $\pm\mu_e$, and the up and down limit of power ramp rate is seated between $\pm\delta_e$. E is the stored electricity in the EV charging storage capacitor. $E_{\min}$ and $E_{\max}$ are the minimum and maximum useable power electricity of the EV charging storage capacitor, respectively. The inequality among the confined energy and current stored electricity of the EV charging storage capacitor are shown by $K1$ and $K2$, respectively. The related formulas to calculate them are $K1 = E - E_{\max}$ and $K2 = E - E_{\min}$.

At last, ΔP_E indicates the charging/discharging of battery electricity capacity. EV stay in the idle state when the value of ΔP_E is equal to zero; EV stay in the discharging state when the value of ΔP_E is greater than zero; and EV stay in the charging state when the value of ΔP_E is less than zero. The charging and discharging amounts of the EV only changed between the range of $\pm\mu_e$. After all, when the power electricity capacity of the EV exceeds that of the upper limit ($E_{\max}$), the discharging process of EV is only reached to ($-\mu_e$). Also, when the EV energy decreases below the least limit ($E_{\min}$), the charge range for EV is ($-\mu_e$~0).

4. Multicarrier Microgrid Control Model

The proposed controller structure according to the parameters of Tables 1 and 2 in the multicarrier MG is demonstrated in Figure 3. Since the EV is used simultaneously as a source and load consuming in the MG networks, the user's charging requirement/departure time request is considered in the model.

5. The Proposed Controllers

5.1. Fuzzy Logic Controller. The system's frequency deviations and its derivatives of the two signals input and power as the yield of the fuzzy control design were studied. Frequency disorder is shown in Figure 4 of membership functions. The related specifications for both the input and output figures of the introduced control scheme are shown

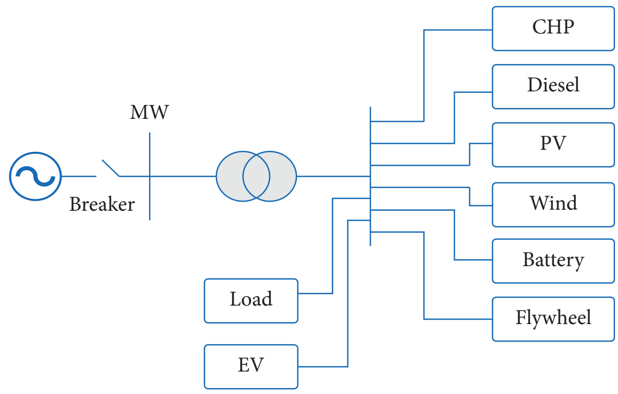

FIGURE 1: The layout of the isolated MG.

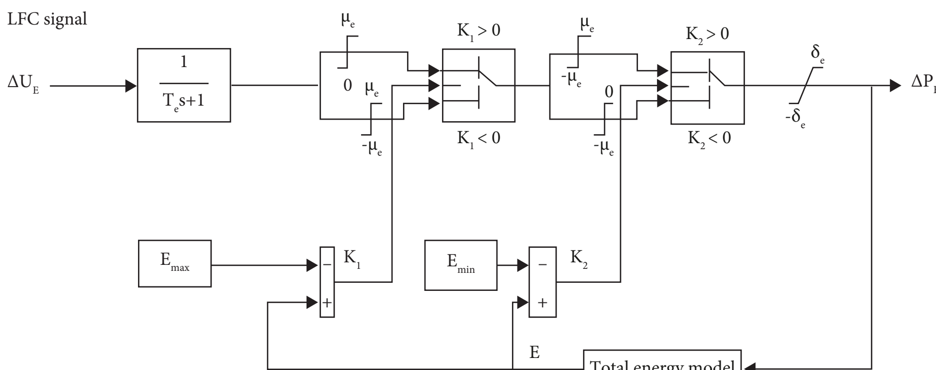

FIGURE 2: The equivalent EV model for controller [60].

TABLE 1: Proposed MG parameters [59].

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

as a set of seven words as follows: NM (medium negative), NB (big negative), PS (small positive), Z (zero), NS (small negative), PB (big positive), and PM (medium positive). These defined variables have a member of the subsets whose membership's degree varies between [−1, 1]. In the proposed controllers, 49 fuzzy constraints taken into account that demonstrated in Table 3.

5.2. Adaptive Neuro Fuzzy Interface System (ANFIS) Controller. In this work, ANN and fuzzy inference systems (FIS) were integrated to develop neuro-fuzzy techniques. ANFIS shows privilege compared to both fuzzy and ANN [61, 62]. To carry out various modes of functions, the learning capability of neural networks and information

TABLE 2: Specifications of the MG scheme [60, 64, 65].

Grid components	Parameters	Values
CHP	X_c	0.6 (s)
	Y_c	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)
	$E_{\max}$	0.95 (pu.MW/h)
	$E_{\min}$	0.8 (pu.MW/h)
PI (optimized AG)	Proportional gain	−0.355
	Integral gain	−0.375

depiction of fuzzy logic were integrated using the developed controller. The ANFIS controller was integrated into the multicarrier MG in a centralized way, and the centralized control architecture is commonly applied in isolated MGs. The energy management system (EMS)/central controller is primarily in charge of the MG amount raise and the optimal expansion of its operation in a centralized controller framework. In this approach, the information transfer (regional control connection) between the MG operatives and

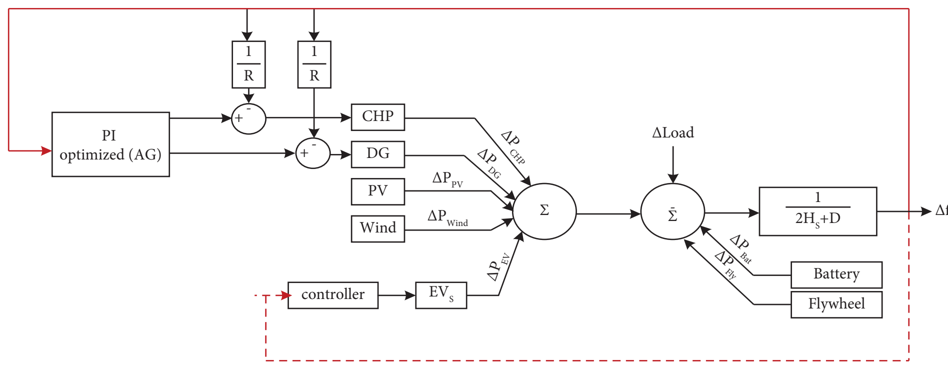

FIGURE 3: The control scheme of the proposed MG.

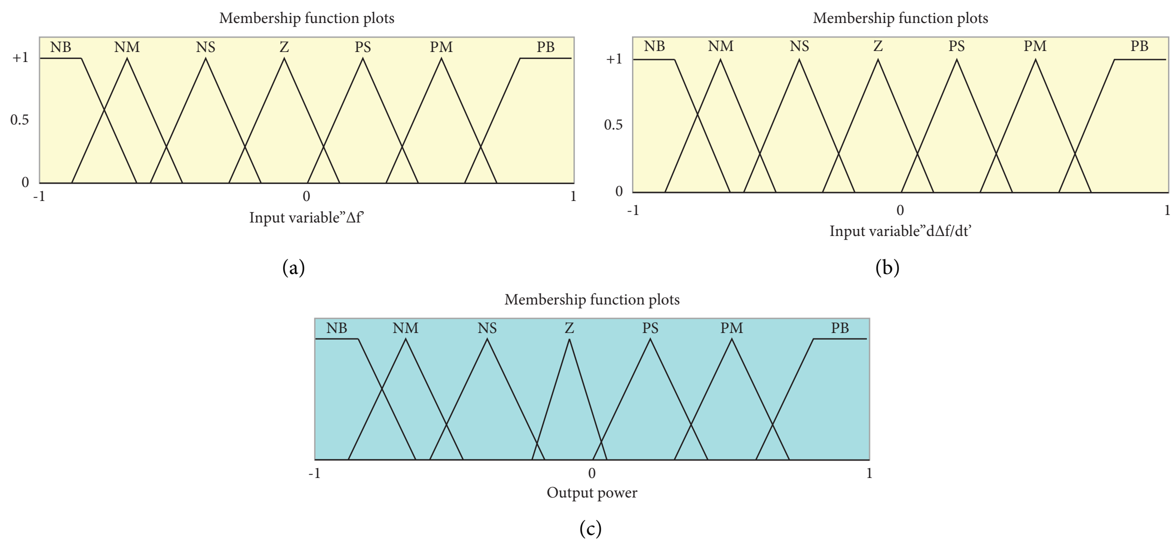

FIGURE 4: (a) Membership functions of fuzzy controller, (b) fuzzy input membership, and (c) output fuzzy membership.

TABLE 3: Controller's fuzzy rules.

Inputs		Δf						
		NB	NM	NS	ZO	PS	PM	PB
	NB	PB	PB	PB	PB	PM	PS	ZO
	NM	PB	PB	PB	PM	PS	ZO	PS
	NS	PB	PB	PM	PS	ZO	NS	NM
$\Delta f/dt$	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

their regional controllers happens on both sides. The EMS specified the best collection stages for the distributed generation (DG) of electricity power and regional controllers (LCs) in the MG which is accomplished using inputs including weather forecasting, load demand, radiation intensity, and energy pricing.

The ANFIS design is composed of a multilayer flexible neural network which is fulfilled according to a fuzzy inference scheme controller. Figure 5 demonstrates the design of the ANFIS procedure [61, 62]. This paper used two sets of inputs (Δf, $\dot{\Delta f}$) and one output u (power) to design the fuzzy inference system. Two fuzzy rules including Takagi and Sugeno were utilized to design the rule base as the following:

Rule 1: Let Δf be $X1$ and $\dot{\Delta f}$ be $Y1$, then $u_1 = p_1\Delta f + q_1\Delta f + r_1$

Rule 2: Let 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 mentioned as the fuzzification level and work as an adaptive node. The layer's parameters change in terms of the error mark and create the appropriate amount for each membership function. Each node is indicated as I, which is defined by an adaptive node function as the following:

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

where Δf (or $(\dot{\Delta f})$) represents input at node I and X_i (or Y_i) represents a linguistic label (fuzzy sets: big, small) that represents the membership functions of each node.

Layer 2. The outputs of the Layer 1 are multiplied and forwarded to the later one. Also, the nodes of Layer 2 are precisely determined and labeled as II.

The product of all incoming signals is used to calculate the output of each node. The yield related to each node in this layer is defined as the following;

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

An activation degree or (strength of firing W_I) of a rule can be interpret by using the calculated output.

Layer 3. This layer is labeled as N (normalization) and is defined to determine the adjusted firing stability related to each rule. Similar to Layer 2, each node is considered to be fixed in this layer. So, the normalized firing stability is the yield of this layer. For i^{th} node, the adjusted firing stability $(\overline{w}_1)$ is defined by the following formula:

$$o_i^3 = \overline{w}_1 = \frac{w_i}{w_1 + w_2} \text{ for } i = 1,2. \tag{3}$$

Layer 4. The adaptive nodes are included in this layer and the related output is calculated as the following:

$$o_i^4 = \overline{w}_l u_i = \overline{w}_l\left(p_i \Delta f + q_i \dot{\Delta f} + r_i\right) i = 1,2, \tag{4}$$

where $\overline{w}_1$ and $\{p_i, q_i, r_i\}$ are the yield of the Layer 3 and the parameter collection of this node, respectively. These parameters are mentioned as ensuing parameters.

Layer 5. The ending layer of the ANFIS network that generates the yield U and labeled as $\sum$, which calculate the total output by aggregating of all received marks in the node via the following equation:

$$o_i^5 - U = \sum \overline{w}_l u_i = \frac{\sum w_i u_i}{\sum w_i}. \tag{5}$$

The ANFIS methods are applied to hybrid-learning algorithms that integrated from various algorithms, the minimum squares approaches are utilized to fix the specifications of both linear and gradient-descent, which are applied to determine the premise parameters. ANFIS edit toolbox is utilized for production (ANFIS-FIS) in MATLAB environment. Training and experimental data are used to train the adaptive neural fuzzy system. For more details to understand the steps of the ANFIS design, see this reference [63].

6. Simulation Results

To obtain a proper comparison between the proposed method and fuzzy controller, simulations were performed in five case studies in SIMULINK/MATLAB. The capability of the developed frequency adjusting approach is evaluated by two criteria of numerical evaluation of the mean frequency power deviations RMS (Δf) and the maximum size of the frequency deviations (max($|\Delta f|$)) Table 4.

6.1. Study A. This study was conducted to show the potent performance of the network to response against the multistage load disorder (ΔPL). Time seconds (2-5-15-25-33) are applied to the microgrid according to Figure 6(a), and the frequency response of the network is pictured in Figure 6(b). Clearly, when the developed ANFIS system is used, the frequency fluctuations and deviations are decreased compared to the fuzzy controller. As a result, the developed controller shows a proper performance in the frequency response. In the proposed ANFIS method, the effective (RMS) values and maximum frequency (max) deviation according to Table 4 show a decrease of 54% and 45%, respectively, compared to the fuzzy controller. The obtained findings showed that the developed approach in frequency control indicates proper performance.

6.2. Study B. In this study assumed in winter, the multicarrier hub (MCH) network is faced with production shortages due to a sharp drop in gas pressure, and no available CHP in the network results in the 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 Table4 show a decrease of 175% and 45%, respectively, compared to the fuzzy controller.

6.3. Study C. Power system parameters change continuously over time, and this may affect the frequency response of the system. Intelligent control methods can show privilege in resistance against surroundings and dynamic variations. At this stage, the main parameters of the power system include damping factor (D), generator time constant (T_g), drop constant (R), turbine time constant (T_t), inertia constant (H), battery time constant (T_{BESS}), and flywheel time constant (T_{FESS}) changes to respond the frequency fluctuations according to Table 5. By implementing the changes in the microgrid system, the closed-loop frequency response is depicted in Figure 8. The optimal resistance of the proposed controller against the considered uncertainties was investigated. Also, the proposed method demonstrates better

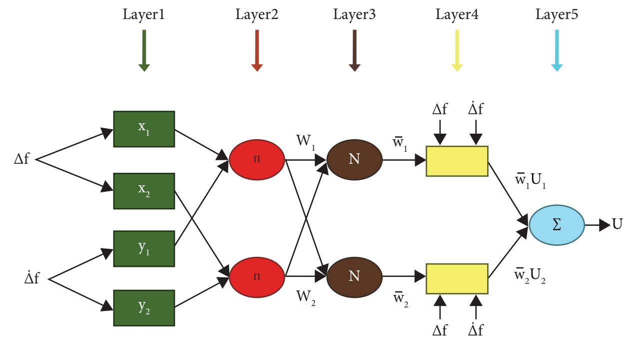

Figure 5: ANFIS network structure [35].

Table 4: RMS and maximum values of frequency inconstancy.

ANFIS		Fuzzy
0.0058	*Study A (RMS·pu)*	0.0126
0.0044	*Study B (RMS·pu)*	0.0121
0.0036	*Study C (RMS·pu)*	0.0046
0.0054	*Study D (RMS·pu)*	0.0106
0.1163	*Study A (max·pu)*	0.2124
0.0262	*Study B (max·pu)*	0.0480
0.1133	*Study C (max·pu)*	0.1777
0.0289	*Study D (max·pu)*	0.0490

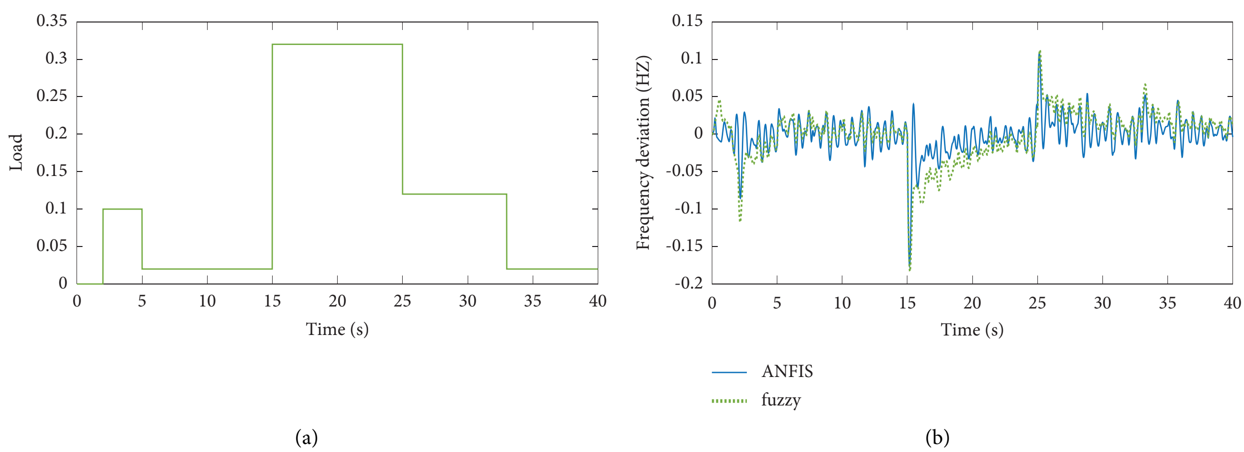

Figure 6: (a) Multiple-step load disorders and (b) response of MG frequency.

damping than the fuzzy one and enhances the efficiency of the frequency adjusting in the proposed MG network. In the suggested method, the effective (RMS) values and maximum frequency deviation (max) according to Table 4 were reduced by 15% and 36%, respectively, compared to the fuzzy controller.

6.4. Study D. In this study, disturbance in the PV system and wind system (wind) was managed to occur in 17 and 32 seconds, respectively. The system responses to power fluctuations with and without PV system, and also with and 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 4 were improved by 49% and 41%, respectively, compared to the fuzzy controller.

6.5. Study E. In this study, the yield power results of the developed ANFIS-based controller in a system including a battery, diesel generator (DG), and electric vehicle (EV) were compared to a fuzzy controller. The yield power of the fuzzy controller and the ANFIS controller are illustrated in Figures 12(a) and 12(b), respectively. Our findings showed that the ANFIS-based intelligent controller has a more stable output power than the fuzzy controller. As a result, the proposed method has a good performance in power stability.

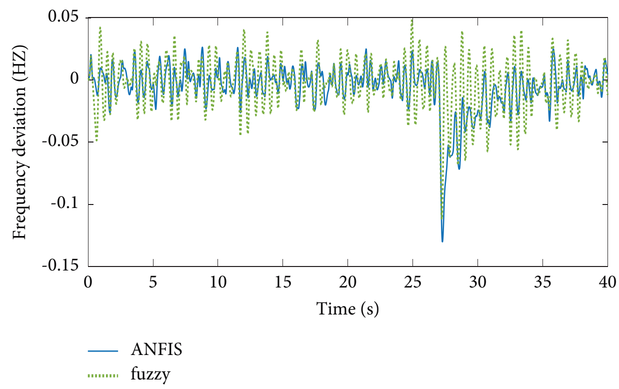

Figure 7: Frequency response of gas changes.

Table 5: Uncertain specifications and fluctuation range.

Parameters	Variation ranges
R	+60%
D	−35%
H	−40%
T_t	+60%
T_g	+60%
T_{FESS}	+70%
T_{BESS}	+70%
—	—

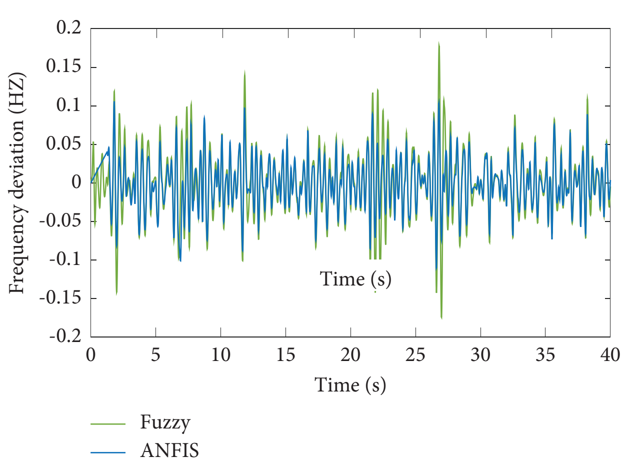

Figure 8: Frequency reaction based on the parameter's variation depicted in Table 5.

7. Summary

The proposed ANFIS control scheme and a fuzzy control scheme was compared in five scenarios in terms of the frequency control. The simulation findings showed that frequency adjustment is properly conducted by considering uncertainties such as load changes, renewable energy sources, gas changes, changes in the power system parameters, and as well as system stability interruption. The developed technique can show good performance and significantly reduce frequency deviations. Finally, the

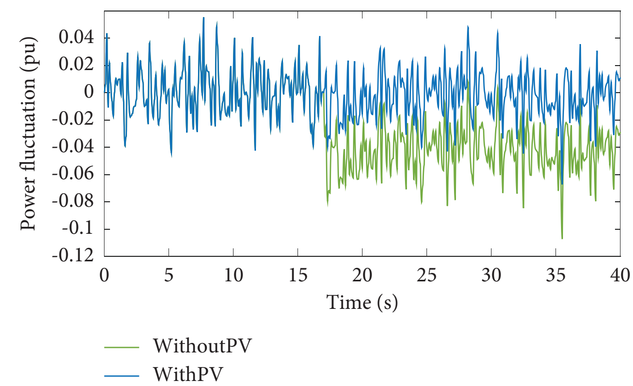

Figure 9: The output power of the proposed network by considering PV and without considering PV.

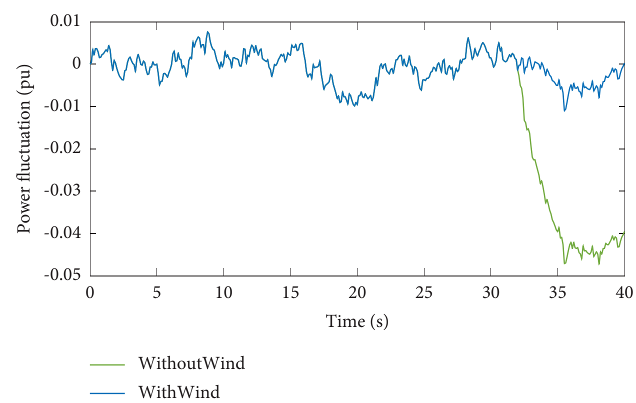

Figure 10: The output power of the proposed network by considering wind and without considering wind.

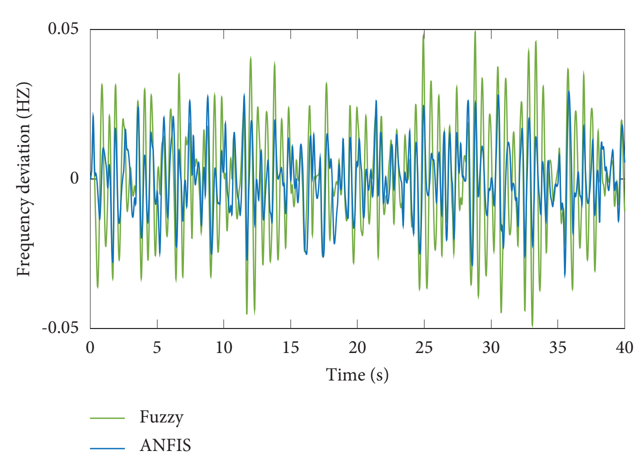

Figure 11: The fuzzy controller and the developed ANFIS technique in based on frequency fluctuation.

developed technique (ANFIS) was evaluated by considering the performance of the control methods in these references [31, 34], in which the algorithm colonial competition was used to optimize the fuzzy controller in [31] and the FO-

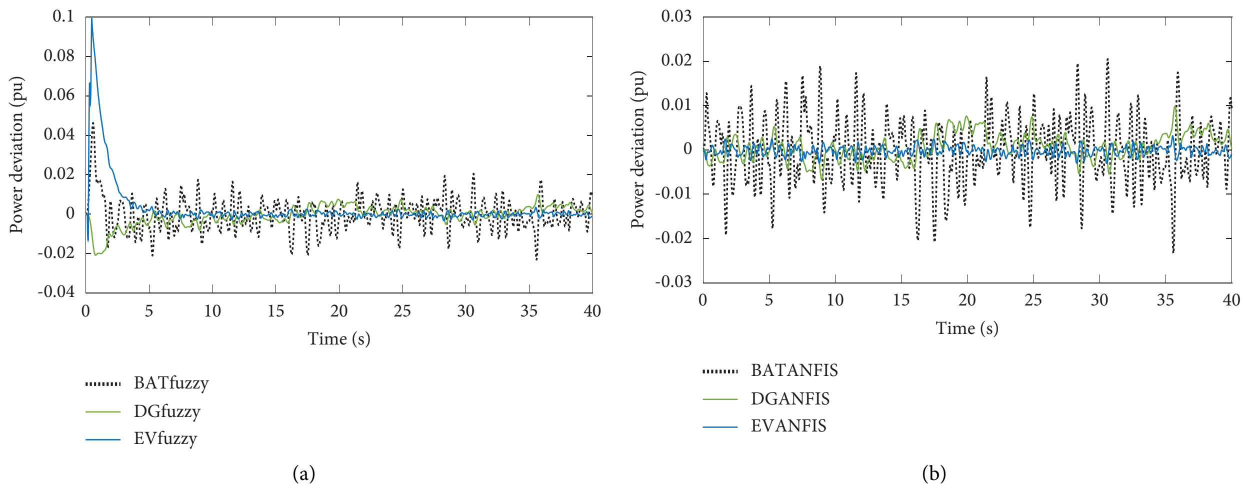

Figure 12: Deviation of output power (battery-DG-EV_s); (a) fuzzy response and (b) ANFIS response.

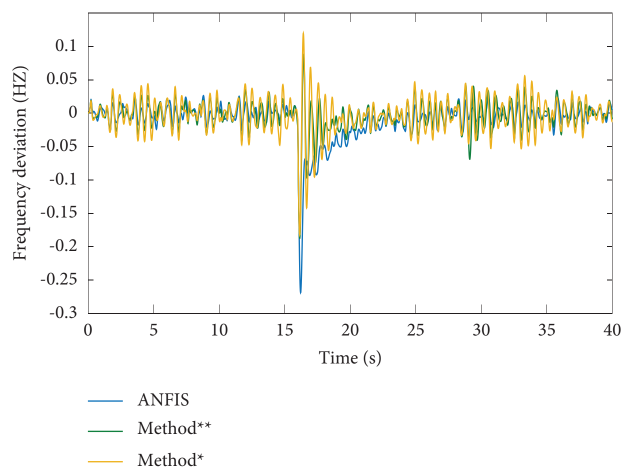

Figure 13: Comparison of frequency inconstancy based on the control and proposed methods in references [31]* and [34]**.

Table 6: Maximum values and RMS of frequency inconstancy.

Reference methods [34]	Reference methods [31]	Proposed methods
RMS (0.0115 pu) Max (0.1078 pu)	RMS (0.0136 pu) Max (0.1138 pu)	RMS (0.0054 pu) Max (0.0264 pu)

fuzzy-PID controller was used in reference [34]. In the simulation, a disturbance of 0.3 pu was utilized to the MG in 16 seconds.

Figure 13 shows the frequency inconstancy of the developed approach and the methods presented in these references [31, 34]. The simulation findings in Figure 13 show the optimal function of the developed method and the abovementioned references in terms of reducing frequency deviation and resistance to disturbances. Furthermore, effective (RMS) values and maximum frequency deviation (max) of the developed method were examined by considering the results of two reference methods according to Table 6. According to the obtained results of the developed method in Table 6, the effective values and maximum frequency deviation are decreased from [31] up to 61% and 77%, respectively, and compared to [34] 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 [31, 34] was observed.

8. Conclusion

This paper aimed to introduce a frequency control in a multicarrier MG. The understudy MG includes nonlinear factors that mimic the real-world behavior of the system. Considering that the MG is naturally nonlinear, traditional controllers show weak performance in this situation. Therefore, smart controllers are used due to their acceptable performance in nonlinear conditions. In the under-study multicarrier MG, CHP sources and diesel generators were 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 potency of the suggested ANFIS controller was evaluated in 5 case studies. SIMULINK/MATLAB software was used to perform simulations. Also, the level of resistance of the developed control scheme to various parameters and resistance to changes was evaluated. Finally, our finding was compared to the literature results that showed the effective values and maximum frequency deviation decreased up to 61% and 77% compared to the research, respectively; and compared to another decreased by up to 53% and 75%, respectively. Therefore, the proposed method shows better performance in frequency regulation compared to the presented controllers in the literature. The potency of the developed ANFIS control scheme should be additionally investigated in terms of the district heating networks, hydrogen storage, and uncertainty modeling approaches that can be studied in future works.

Nomenclature

2DOF-FPID:	2 Degree of freedom fuzzy PID
AFLC:	Adaptive fuzzy logic controller
ANFIS:	Adaptive neuro-fuzzy inference system
ASO:	Atom search optimization
BES:	Battery energy system
BOA:	Butterfly optimization algorithm
CHP:	Combined heat and power
DER:	Distributed energy resources
DG:	Diesel generator
DMPC:	Distributed model predictive control
DOFC:	Dynamic output feedback controller
DSTS:	Dish-stirling solar thermal system
ESS:	Energy storage system
EV:	Electric vehicle
FA:	Firefly algorithm
FLPI:	Fuzzy logic proportional-integral
FO-Fuzzy-PID:	Fractional-order fuzzy proportional integral derivative
FOPID:	Fractional-order proportional integral control
GLFOA:	Green leaf-hopper flame optimization algorithm
GOA:	Grasshopper optimization algorithm
GWO:	Grey wolf optimization
GWOSCACSA:	Grey wolf optimizer sine cosine algorithm crow search algorithm
HDMPC:	Hierarchical distributed model predictive control
HESS:	Hybrid energy storage system
HHOPSO:	Harris hawk-particle swarm optimizer
HP:	Heat pump
LFC:	Load frequency control
LSA:	Lightning search algorithm
MCEH:	Multicarrier energy hub
MFO-WC:	Moth flame and water cycle optimization
MG:	Microgrid
MMVO:	Modified multiverse optimizer
MPC:	Model predictive control
MPPT:	Maximum power point tracking
OVPL:	Opposition-based volleyball premier league
PI:	Proportional-integral
PID:	Proportional integrator derivative
PSO:	Particle swarm optimization
PTSCTS:	Parabolic trough solar collector thermal system
PV:	Photo-voltaic
PVS:	Photo-voltaic system
QOHS:	Quasi-oppositional harmony search
REMG:	Renewable energy microgrid
SMES:	Superconducting magnetic energy storage
SOFC:	Solid oxide fuel cell
STSMC:	Super-twisting sliding mode controller
V2G:	Vehicle-to-grid
VPP:	Virtual power plant
WDG:	Wind-driven generation.

Data Availability

The data used in this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] M. Azimian, V. Amir, and S. Javadi, "Economic and environmental policy analysis for emission-neutral multi-carrier microgrid deployment," *Applied Energy*, vol. 277, Article ID 115609, 2020.

[2] O. Rezaei, O. Mirzapour, M. Panahazari, and H. Gholami, "Hybrid AC/DC provisional microgrid planning model considering converter aging," *Electricity*, vol. 3, no. 2, pp. 236–250, 2022.

[3] M. Azimian, V. Amir, S. Javadi, S. Mohseni, and A. C. Brent, "Resilience-oriented planning of multi-carrier microgrids under cyber-attacks," *Sustainable Cities and Society*, vol. 79, Article ID 103709, 2022.

[4] A. Elmoufidi, K. El Fahssi, S. Jai-Andaloussi, and A. Sekkaki, "Automatically density based breast segmentation for mammograms by using dynamic K-means algorithm and seed based region growing," in *Proceedings of the 2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, pp. 533–538, Pisa, Italy, May 2015.

[5] M. H. Abbasi and J. Zhang, "Joint optimization of electric vehicle fast charging and DC fast charging station," in *Proceedings of the 2021 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, pp. 1–6, Cape Town, South Africa, December 2021.

[6] M. Hossein Abbasi, M. Taki, A. Rajabi, L. Li, and J. Zhang, "Risk-constrained offering strategies for a large-scale price-maker electric vehicle demand aggregator," *IET Smart Grid*, vol. 3, no. 6, pp. 860–869, 2020.

[7] A. Dán, C. Farkas, and L. Prikler, "V2G effects on frequency regulation and under-frequency load shedding in a quasi-islanded grid," in *Proceedings of the 2013 IEEE Grenoble Conference*, pp. 1–6, Dresden, Germany, September 2013.

[8] R. Habibifar, A. Aris Lekvan, and M. Ehsan, "A risk-constrained decision support tool for EV aggregators participating in energy and frequency regulation markets," *Electric Power Systems Research*, vol. 185, Article ID 106367, 2020.

[9] M. Alinejad, O. Rezaei, R. Habibifar, and M. Azimian, "A charge/discharge plan for electric vehicles in an intelligent parking lot considering destructive random decisions, and V2G and V2V energy transfer modes," *Sustainability*, vol. 14, no. 19, Article ID 12816, 2022.

[10] K. Knezović, S. Martinenas, P. B. Andersen, A. Zecchino, and M. Marinelli, "Enhancing the role of electric vehicles in the power grid: field validation of multiple ancillary services," *IEEE Transactions on Transportation Electrification*, vol. 3, no. 1, pp. 201–209, 2017.

[11] H. Saber, H. Ranjbar, S. Fattaheian-Dehkordi, M. Moeini-Aghtaie, M. Ehsan, and M. Shahidehpour, "Transactive energy management of V2G-capable electric vehicles in residential buildings: an MILP approach," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 3, pp. 1734–1743, 2022.

[12] M. Singh, P. Kumar, and I. Kar, "Implementation of vehicle to grid infrastructure using fuzzy logic controller," *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 565–577, 2012.

[13] M. Datta and T. Senjyu, "Fuzzy control of distributed PV inverters/energy storage systems/electric vehicles for frequency regulation in a large power system," *IEEE Transactions on Smart Grid*, vol. 4, no. 1, pp. 479–488, 2013.

[14] V. Amir, M. Azimian, and A. S. Razavizadeh, "Reliability-constrained optimal design of multicarrier microgrid," *International Transactions on Electrical Energy Systems*, vol. 29, no. 12, Article ID e12131, 2019.

[15] H. Daealhaq, Y. Falah Hassan, H. Ghanimi, and M. Azimian, "Bidding strategy of a wind-thermal GENCO considering piecewise linear AC power flow and correlated uncertainties," *International Transactions on Electrical Energy Systems*, vol. 2022, Article ID 6301902, 2022.

[16] D. Qin, Q. Sun, R. Wang, D. Ma, and M. Liu, "Adaptive bidirectional droop control for electric vehicles parking with vehicle-to-grid service in microgrid," *CSEE Journal of Power and Energy Systems*, vol. 6, pp. 793–805, 2020.

[17] U. C. Prusty, P. C. Nayak, R. C. Prusty, and S. Panda, "Impact of vehicle to grid mode electric vehicles in standalone microgrid for frequency regulation," in *Proceedings of the 2020 IEEE International Symposium on Sustainable Energy, Signal Processing and Cyber Security (ISSSC)*, pp. 1–6, Odisha, India, December 2020.

[18] M. H. Khooban, T. Niknam, F. Blaabjerg, and T. Dragičević, "A new load frequency control strategy for micro-grids with considering electrical vehicles," *Electric Power Systems Research*, vol. 143, pp. 585–598, 2017.

[19] S. Iqbal, A. Xin, M. U. Jan et al., "V2G strategy for primary frequency control of an industrial microgrid considering the charging station operator," *Electronics*, vol. 9, no. 4, p. 549, 2020.

[20] H. Fan, L. Jiang, C. K. Zhang, and C. Mao, "Frequency regulation of multi-area power systems with plug-in electric vehicles considering communication delays," *IET Generation, Transmission & Distribution*, vol. 10, no. 14, pp. 3481–3491, 2016.

[21] W. Yan, L. Sheng, D. Xu, W. Yang, and Q. Liu, "H∞ robust load frequency control for multi-area interconnected power system with hybrid energy storage system," *Applied Sciences*, vol. 8, no. 10, p. 1748, 2018.

[22] Y. Xu, C. Li, Z. Wang, N. Zhang, and B. Peng, "Load frequency control of a novel renewable energy integrated micro-grid containing pumped hydropower energy storage," *IEEE Access*, vol. 6, pp. 29067–29077, 2018.

[23] P. Ivanova, O. Linkevics, and A. Sauhats, "Cost—benefit analysis of CHP plants taking into account air cooling technologies," in *Proceedings of the 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, pp. 1–6, Milan, Italy, June 2017.

[24] S. Murali, R. Shankar, and P. Aryan, "A novel optimization technique for LFC and virtual inertia emulation of a multi area hybrid power system," in *Proceedings of the 2020 International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET)*, pp. 1–6, Patna, India, July 2020.

[25] M. A. Dashtaki, H. Nafisi, A. Khorsandi, M. Hojabri, and E. Pouresmaeil, "Dual two-level voltage source inverter virtual inertia emulation: a comparative study," *Energies*, vol. 14, no. 4, p. 1160, 2021.

[26] M. A. Dashtaki, H. Nafisi, E. Pouresmaeil, and A. Khorsandi, "Virtual inertia implementation in dual two-level voltage source inverters," in *Proceedings of the 2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*, pp. 1–6, Tehran, Iran, February 2020.

[27] A. X. R. Irudayaraj, N. I. A. Wahab, M. G. Umamaheswari et al., "A Matignon's theorem based stability analysis of hybrid power system for automatic load frequency control using atom search optimized FOPID controller," *IEEE Access*, vol. 8, pp. 168751–168772, 2020.

[28] D. Mohanty and S. Panda, "Moth flame optimization based fractional order controller for frequency regulation of hybrid power system with UC and UPFC," in *Proceedings of the 2021 1st International Conference on Power Electronics and Energy (ICPEE)*, pp. 1–5, Bhubaneswar, India, January 2021.

[29] H. Lund and W. Kempton, "Integration of renewable energy into the transport and electricity sectors through V2G," *Energy Policy*, vol. 36, no. 9, pp. 3578–3587, 2008.

[30] M. U. Jan, A. Xin, M. A. Abdelbaky, H. U. Rehman, and S. Iqbal, "Adaptive and fuzzy PI controllers design for frequency regulation of isolated microgrid integrated with electric vehicles," *IEEE Access*, vol. 8, pp. 87621–87632, 2020.

[31] S. F. Aliabadi, S. A. Taher, and M. Shahidehpour, "Smart deregulated grid frequency control in presence of renewable energy resources by EVs charging control," *IEEE Transactions on Smart Grid*, vol. 9, no. 2, pp. 1073–1085, 2018.

[32] S.-A. Amamra and J. Marco, "Vehicle-to-grid aggregator to support power grid and reduce electric vehicle charging cost," *IEEE Access*, vol. 7, pp. 178528–178538, 2019.

[33] S. Kumar and K. K. Jaladi, "Grid connected electric vehicle charging station using PV source," in *Proceedings of the 2020 1st IEEE International Conference on Measurement, Instrumentation, Control and Automation (ICMICA)*, pp. 1–4, Kurukshetra, India, June 2020.

[34] A. Annamraju and S. Nandiraju, "Robust frequency control in a renewable penetrated power system: an adaptive fractional order-fuzzy approach," *Protection and Control of Modern Power Systems*, vol. 4, pp. 16–15, 2019.

[35] X. Liu, Y. Zhang, and K. Y. Lee, "Coordinated distributed MPC for load frequency control of power system with wind farms," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 6, pp. 5140–5150, 2017.

[36] X. Kong, X. Liu, L. Ma, and K. Y. Lee, "Hierarchical distributed model predictive control of standalone wind/solar/

battery power system," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 49, no. 8, pp. 1570–1581, 2019.

[37] M. Dashtdar, A. Flah, C. Z. El-Bayeh et al., "Frequency control of the islanded microgrid based on optimised model predictive control by PSO," *IET Renewable Power Generation*, vol. 16, no. 10, pp. 2088–2100, 2022.

[38] A. K. Srivastava, A. Latif, S. C. Shaoo, D. C. Das, S. S. Hussain, and T. S. Ustun, "Analysis of Goa optimized two-stage controller for frequency regulation of grid integrated virtual power plant," *Energy Reports*, vol. 8, pp. 493–500, 2022.

[39] S. Saberi and B. Rezaei, "Fixed-time MPPT controller design for wind turbine system with prescribed performance," in *Proceedings of the 2021 7th International Conference on Control, Instrumentation and Automation (ICCIA)*, pp. 1–5, Tehran, Iran, March 2021.

[40] N. Movahhed Neya, S. Saberi, and B. Rezaie, "Design of an adaptive controller to capture maximum power from a variable speed wind turbine system without any prior knowledge of system parameters," *Transactions of the Institute of Measurement and Control*, vol. 44, no. 3, pp. 609–619, 2022.

[41] M. M. Zadeh, Z. Afshar, M. J. Harandi, and S. M. T. Bathaee, "Frequency control of low inertia microgids in presence of wind and solar units using fuzzy-neural controllers," in *Proceedings of the 2022 26th International Electrical Power Distribution Conference (EPDC)*, pp. 54–59, Tehran, Iran, May 2022.

[42] B. Gummala, S. Maheswarapu, and S. Vuddanti, "A comparative analysis on frequency control in an autonomous microgrid using adaptive optimized fuzzy controllers," in *Proceedings of the 2022 International Conference on Computing, Communication and Power Technology (IC3P)*, pp. 113–118, Tehran, Iran, May 2022.

[43] M. Negahban, M. V. Ardalani, M. Mollajafari, E. Akbari, M. Talebi, and E. Pouresmaeil, "A novel control strategy based on an adaptive fuzzy model predictive control for frequency regulation of a microgrid with Uncertain and time-varying parameters," *IEEE Access*, vol. 10, pp. 57514–57524, 2022.

[44] S. P. Shubham, R. K. M. Singh, and O. P. Roy, "A novel application of jellyfish search optimisation tuned dual-stage (1+ PI) TID controller for microgrid employing electric vehicle," *International Journal of Ambient Energy*, vol. 43, pp. 1–20, 2022.

[45] S. Padhy, P. R. Sahu, S. Panda, S. Padmanaban, J. M. Guerrero, and B. Khan, "Marine predator algorithm based PD-(1+PI) controller for frequency regulation in multi-microgrid system," *IET Renewable Power Generation*, vol. 16, no. 10, pp. 2136–2151, 2022.

[46] A. Mondal, A. Latif, D. C. Das, S. M. S. Hussain, and A. Al-Durra, "Frequency regulation of hybrid shipboard microgrid system using butterfly optimization algorithm synthesis fractional-order controller," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, Article ID e3058, 2022.

[47] A. Bouaddi, R. Rabeh, and M. Ferfra, "MFO-WC based fuzzy logic PI controller for load frequency control of autonomous microgrid system," in *Proceedings of the 2022 8th International Conference on Control, Decision and Information Technologies (CoDIT)*, pp. 200–205, Istanbul, Turkey, May 2022.

[48] R. Tripathi and O. Singh, "An analysis on frequency control of microgrid including diverse renewable energy sources," in *Advances in Energy Technology*, pp. 81–95, Springer, Berlin, Germany, 2022.

[49] H. Javanmardi, M. Dehghani, M. Mohammadi, S. Siamak, and M. R. Hesamzadeh, "BMI-based load frequency control in microgrids under false data injection attacks," *IEEE Systems Journal*, vol. 16, no. 1, pp. 1021–1031, 2022.

[50] S. C. Sahoo, A. K. Barik, and D. C. Das, "A novel Green Leafhopper Flame optimization algorithm for competent frequency regulation in hybrid microgrids," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 35, no. 3, Article ID e2982, 2022.

[51] S. Mishra, P. C. Nayak, R. C. Prusty, and S. Panda, "Modified multiverse optimizer technique-based two degree of freedom fuzzy PID controller for frequency control of microgrid systems with hydrogen aqua electrolyzer fuel cell unit," *Neural Computing and Applications*, vol. 34, no. 21, pp. 18805–18821, 2022.

[52] H. M. Amine, A. K. Mouaz, H. messaoud, A. Othmane, and M. Saad, "The impacts of control systems on hybrid energy storage systems in remote DC-Microgrid system: a comparative study between PI and super twisting sliding mode controllers," *Journal of Energy Storage*, vol. 47, Article ID 103586, 2022.

[53] K. M. Singh and S. Gope, "Renewable energy integrated multi-microgrid load frequency control using grey wolf optimization algorithm," *Materials Today: Proceedings*, vol. 46, pp. 2572–2579, 2021.

[54] M. Badi, S. Mahapatra, B. Dey, and S. Raj, "A hybrid GWO-PSO technique for the solution of reactive power planning problem," *International Journal of Swarm Intelligence Research*, vol. 13, pp. 1–30, 2021.

[55] S. Shekarappa G, S. Mahapatra, and S. Raj, "Voltage constrained reactive power planning problem for reactive loading variation using hybrid Harris hawk particle swarm optimizer," *Electric Power Components and Systems*, vol. 49, no. 4-5, pp. 421–435, 2021.

[56] C. K. Shiva, B. Vedik, S. Mahapatra, M. Nandi, S. Raj, and V. Mukherjee, "Load frequency stabilization of stand-alone hybrid distributed generation system using QOHS algorithm," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 35, no. 4, Article ID e2998, 2022.

[57] B. Dey, S. Raj, S. Mahapatra, and F. P. G. Márquez, "Optimal scheduling of distributed energy resources in microgrid systems based on electricity market pricing strategies by a novel hybrid optimization technique," *International Journal of Electrical Power and Energy Systems*, vol. 134, Article ID 107419, 2022.

[58] J. Zhou, Y. Zhang, Z. Li, R. Zhu, and A. zeman, "Stochastic scheduling of a power grid in the presence of EVs, RESs, and risk index with a developed lightning search algorithm," *Journal of Cleaner Production*, vol. 364, Article ID 132473, 2022.

[59] W. Eshetu, P. Sharma, and C. Sharma, "ANFIS based load frequency control in an isolated micro grid," in *Proceedings of the 2018 IEEE international conference on industrial technology (ICIT)*, pp. 1165–1170, Lyon, France, February 2018.

[60] J. Yang, Z. Zeng, Y. Tang, J. Yan, H. He, and Y. Wu, "Load frequency control in isolated micro-grids with electrical vehicles based on multivariable generalized predictive theory," *Energies*, vol. 8, no. 3, pp. 2145–2164, 2015.

[61] J.-S. Jang, "ANFIS: adaptive-network-based fuzzy inference system," *IEEE transactions on systems, man, and cybernetics*, vol. 23, no. 3, pp. 665–685, 1993.

[62] N. Mathur, I. Glesk, and A. Buis, "Comparison of adaptive neuro-fuzzy inference system (ANFIS) and Gaussian processes for machine learning (GPML) algorithms for the prediction of skin temperature in lower limb prostheses," *Medical Engineering and Physics*, vol. 38, no. 10, pp. 1083–1089, 2016.

[63] S. Prakash, A. Bhardwaj, and S. Sinha, "Neuro fuzzy hybrid intelligent approach for four-area load frequency control of interconnected power system," in *Proceedings of the 2012 2nd International Conference on Power, Control and Embedded Systems*, pp. 1–7, Allahabad, India, December 2012.

[64] C. Mu, Y. Tang, and H. He, "Observer-based sliding mode frequency control for micro-grid with photovoltaic energy integration," in *Proceedings of the 2016 IEEE Power and Energy Society General Meeting (PESGM)*, pp. 1–5, Boston, MA, USA, July 2016.

[65] M. Tavakoli, E. Pouresmaeil, J. Adabi, R. Godina, and J. P. Catalão, "Load-frequency control in a multi-source power system connected to wind farms through multi terminal HVDC systems," *Computers and Operations Research*, vol. 96, pp. 305–315, 2018.