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Adaptive Droop Control Strategy for Load Sharing in Hybrid Micro Grids

Mahmoud Zadehbagheri [a,1,*], Alfian Ma'arif [b,2], Mohammad Javad Kiani [a,3], Ali Asghar Poorat [a,4]

[a] Department of Electrical Engineering, Yasuj Branch, Islamic Azad University, Yasuj, Iran
[b] Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[1] Ma.zadehbagheri@iau.ac.ir; [2] alfianmaarif@ee.uad.ac.id; [3] kianiph@gmail.com; [4] poorat.aa@gmail.com
* Corresponding Author

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ABSTRACT

Energy management becomes essential when distributed energy sources such as solar, wind, and fuel cell are connected in a micro-grid. In this paper, using a combination of two powerful neural network tools and fuzzy logic, intelligentization, and adaptation of droop control along with voltage and current control as one of the most common methods of decentralized control is done. One of the essential features of this method is its fast performance and the need for telecommunication infrastructure. In this paper, we provide a comprehensive control system that enables proper operation in both upstream and island network modes for both AC and DC microgrids. The proposed method is simulated to evaluate its effectiveness. The proposed structure, by adapting the control system by ANFIS structure, can properly distribute power between distributed products in a brilliant way and without the need for operators and costly telecommunications infrastructure in the face of severe disturbances such as change. The state between the connection and the island or fault occurrence ensures the stability of both the AC and DC parts of the microgrid. The results show the effectiveness of the proposed method.

1. Introduction

Today, renewable energy is essential not only from the point of view of environmental issues; Rather, it seems necessary given the long-term strategic policies of countries, including maintaining diversity in the energy supply basket. In most countries of the world, especially developed countries, renewable energy has been considered in macro-planning. Therefore, according to the incentive policies of governments, the use of distributed generation resources, especially renewable energy, is gradually developed towards consumption. In such an environment, the distribution systems switch from inactive to active.

The active distribution network is a set of microgrids that are equipped with power management and monitoring control to control distributed generation units, energy storage systems, and loads. The microgrid includes distributed sources of energy storage equipment, distribution network, control, protection, and related loads [1][2]. Due to the low resource capacity of microgrids, distributed networks are primarily used in Low-voltage networks [3]. Therefore, low-voltage microgrids have been discussed in this work. In [4] and [5], tries to overcome the limitations of the droop control method by providing an improved control method. For this purpose, an index is introduced as the improved droop index. This index is a function of power losses and the product of load current in the difference of converter output currents. Using this index to calculate the instantaneous droop coefficient will lead to accurate current division and adjustment of the appropriate voltage according to different loading conditions. In [6], by using a reactive power feedback loop for each DG, the droop coefficients are increased to increase the accuracy of reactive power distribution and maintain system stability. In [7][8], an energy management strategy based on a decontamination method with a decentralized policy and without telecommunication links is used for an island microgrid consisting of inverter voltage sources. In order to divide the appropriate active/reactive power between the micro sources, the voltage regulation in the microgrid buses and also to improve its transient and dynamic behavior based on nonlinear load characteristics are presented. The mentioned goals are achieved using an improved control model of angle-frequency droop. In [9][10], introduce the integral component into the power control loop to eliminate the power steady-state error. In [11] proposes a method that injects additional signals. As this method involves the complex signal generation and processing, it is difficult to implement in a microgrid containing multiple DGs. In [12][13] proposes a "Q-V dot droop" method, but the reactive power cannot be accurately shared when local loads are connected. A reactive power disturbance term is introduced into the P-f droop equation, with the aim of reducing the reactive power sharing error by manipulating the active power [14]. However, this method affects the active power and the stability of the system frequency. In order to operate the microgrid safely, an appropriate control strategy must be adopted.

Fig. 1 shows a different classification of MG stability, and stability in the microgrid is categorized into two phenomena such as short-term phenomena (may last up to only a few seconds) and long-term phenomena. Other stability issues more than the short-term phenomena timeframe are categorized as long-term stability. As per requirement, different control methods are available to prevent instability [15]. In order to solve various problems, including stability issues related to microgrid systems, as mentioned earlier, several efforts have been proposed in various papers. Mostly, microgrid systems are integrated with various renewable energy sources and power electronic devices; improved energy storage elements have been incorporated for compensating energy deviations [17].

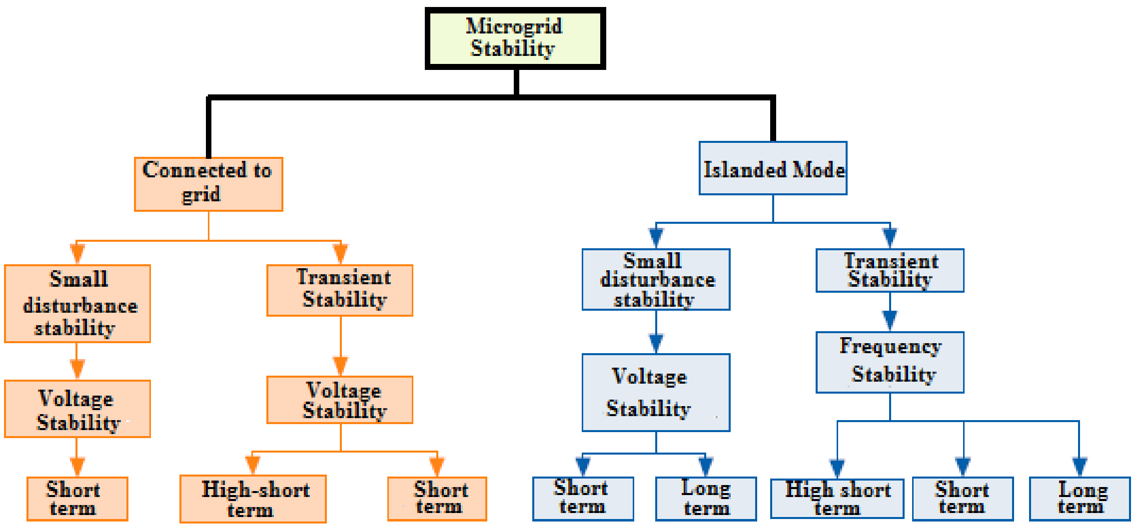

Fig. 1. Microgrid stability [15][16]

In this paper, using a combination of two powerful neural network tools and fuzzy logic, intelligentization and adaptation of droop control along with voltage and current control is done as one of the most common methods of decentralized control. One of the essential features of this method is its fast performance and the need for telecommunication infrastructure. The proposed final structure provides a comprehensive control system that enables proper operation in both upstream and island network modes for both AC and DC microgrids.

Vol. 3, No. 1, 2023, pp. 74-83

2. Intelligent Neural Fuzzy Controller

1.1. Proposed Structure

Fig. 2 shows the structure of the system under study. The proposed control system is a kind of controller that forms a network; That is, it acts like a slack bus in a power grid. This structure is considered the primary control in the island state of the microgrid. The distributed generation is equipped with this control system, with the help of control loops and local measurements is responsible for balancing production power and consumption load. It controls the frequency and output voltage and allows proper distribution of the power between distributed generation sources. This controller can be independently exploited by local control [18][19].

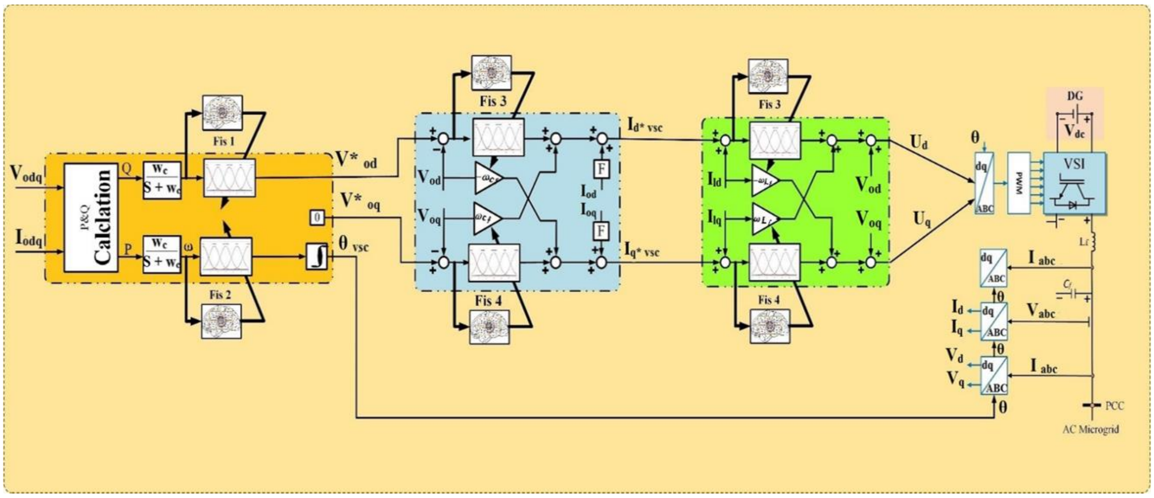

Fig. 2. General structure of the proposed control system

1.2. Power Control System

This part of the controller, based on changes in frequency and voltage range, shares active and reactive power between distributed generation sources and is based on two hypotheses. 1-Line resistance compared to inductance can be neglected [20]. 2-The power angle is minimal. As a result, the active power depends on the phase difference, and the reactive power depends on the voltage. In this controller, the active and reactive power generated is controlled by adjusting the frequency and amplitude of the output voltage [21], as shown in Fig. 3.

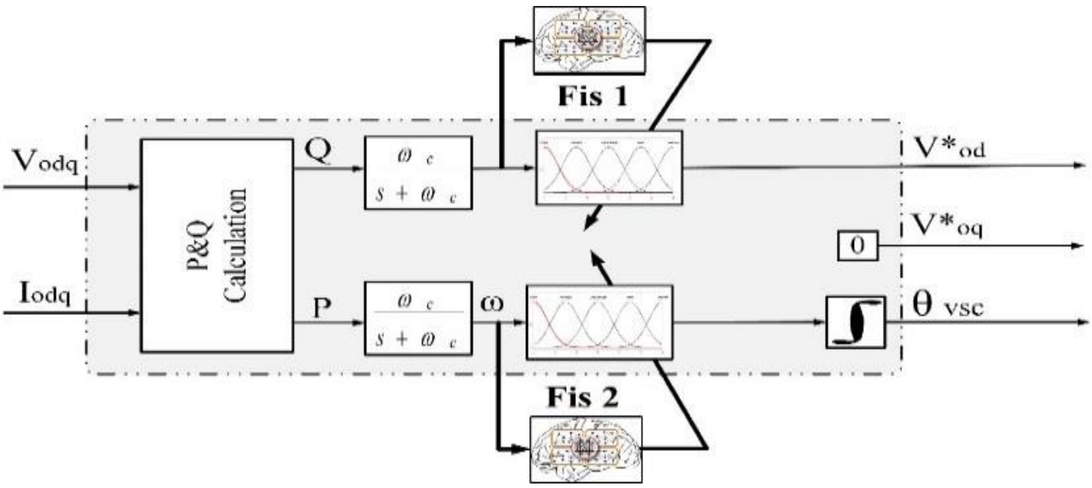

Fig. 3. Droop control block diagram

In (1), (2) and (3), Vod, Voq, iod and ioq are the direct and perpendicular values of the output voltage and current, ω_{VSC} and ω_{com} microgrid frequency and common frequency of microgrid framework, and δ is the angle difference between the rotating control frame and the common microgrid rotating frame. Further details on rotational frameworks are provided in [22][23].

$$\omega_{VSC} = \sum_{i=1}^{25} \overline{w}_{i1}, f_{i1} \qquad \dot{p} = -\omega cp + \omega c(vodiod + voqioq) \tag{1}$$

$$V^*{}_{od} = \sum_{i=1}^{25} \overline{w}_{i2}, f_{i2} \qquad \dot{q} = -\omega cq + \omega c(vodioq - voqiod) \tag{2}$$

$$V^*{}_{oq=0} \qquad \delta = \omega vsc - \omega com \tag{3}$$

1.3. Voltage Control

This controller controls the voltage and output of the distributed generation source and output-induced current from the filter [24]. The reference signal values of this control loop are generated by the power control [25]. The block diagram of the voltage control section of this controller is shown in Fig. 4.

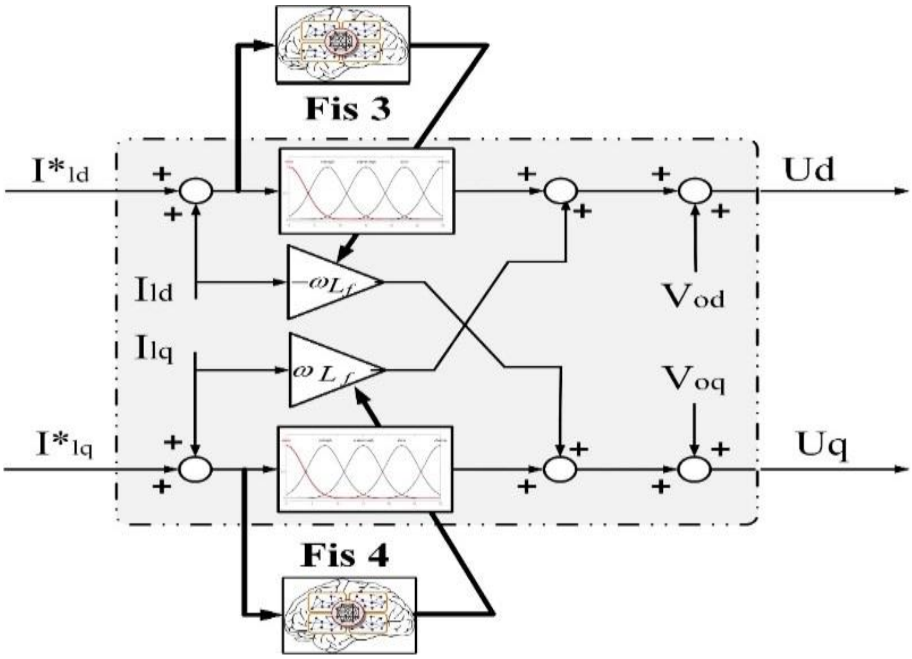

Fig. 4. voltage intelligent controller block diagram

The DAEs voltage controller is as follows [26][27].

$$\dot{\varphi}_d = V^*{}_{od} - V_{od} \tag{4}$$

$$y = \boldsymbol{C}i^*{}_{id} = F, i_{od} - \omega_n, C_f, V_{oq} + \sum_{i=1}^{25} \overline{w}_{i3}, f_{i3}\, x \tag{5}$$

$$i^*{}_{lq} = F, i_{oq} + \omega_n, C_f, V_{od} + \sum_{i=1}^{25} \overline{w}_{i4}, f_{i4} \tag{6}$$

Where φ_d and φ_q are the state variables corresponding to the voltage controller.

3. Simulation Results

In order to validate and evaluate the effectiveness of the proposed structure, the control system has been implemented on a hybrid test microgrid [32]. The results of various tests are described below. The proposed method is compared with the original VSC method, which has been introduced in many references, including [28][29].

3.1. Configuration of Test Micro-Grid

In this section, in order to evaluate and validate the fuzzy-neural secondary control system (ANFIS), a hybrid microgrid (AC / DC) [30][31] has been considered as a test network. The single-line model of this microgrid is shown in Fig. 5.

According to Fig. 5, the microgrid in the AC section is connected to the primary grid with a frequency of 50 Hz and a voltage of 20 through a 20v/380v transformer by a common connection point (PCC). The microgrid consists of a DC branch with a voltage of 500 volts, which is connected to the AC section through an AC/DC converter. Information about scattered production resources is presented in Table 1 [33].

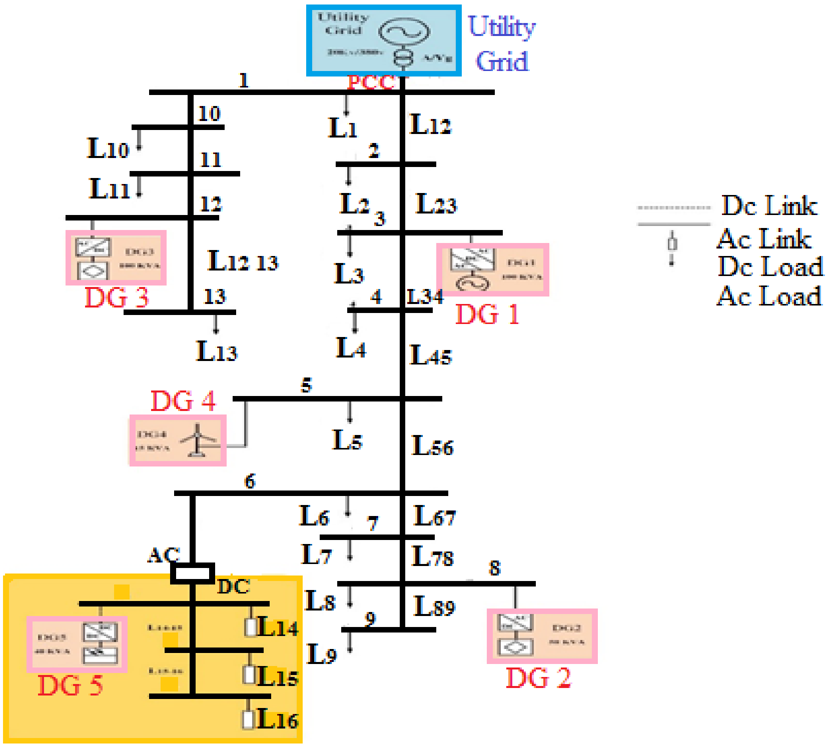

Fig. 5. Single-line model of hybrid micro-grid

Table 1. Microgrid DG information

DGs	Type	Nominal Power (kVA)
DG1	Micro-turbine	100
DG2	Fuel cell	50
DG3	Fuel cell	100
DG5	solar	40
DG4	Wind turbine	15

3.2. Changing the Microgrid from Grid - to - Islanding Mode

This test is aimed to demonstrate the ability of the control system to maintain the microgrid stability after changing the state from the grid - to - islanding mode. In addition, given that before being separated from the primary grid, the microgrid demand is exchanged with the upstream grid, after changing the state to the islanding mode of the proposed adaptive droop control system, the load power should be shared between distributed generations. Otherwise, the imbalance between production and consumption will cause microgrid instability. The microgrid frequency diagram is shown in Fig. 6.

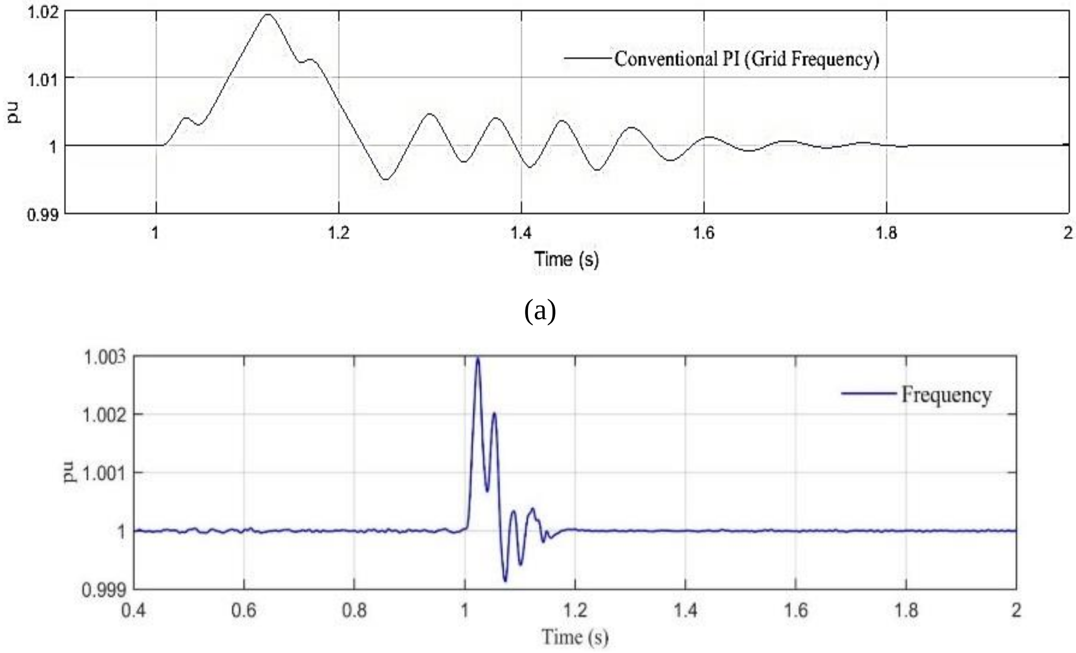

Fig. 6. Micro-grid frequency changes before and after changing mode from connection to the grid to islanding mode (a) With Conventional PI control (b) With ANFIS Control

According to the Fig. 6, using the proposed control system, the frequency deviations are significantly reduced. So, the frequency of the frequency waveform has decreased from 1 Hz to less than 0.15 Hz.

3.3. Changing the Microgrid Load in Islanding Mode

This test is aimed at showing the ability of the control system to follow up the load changes. According to the adaptive droop structure, the control system must be able to track the load changes at any moment and guarantee the balance of production and consumption. In the island mode, the microgrid load undergoes drastic changes, as shown in Fig. 7.

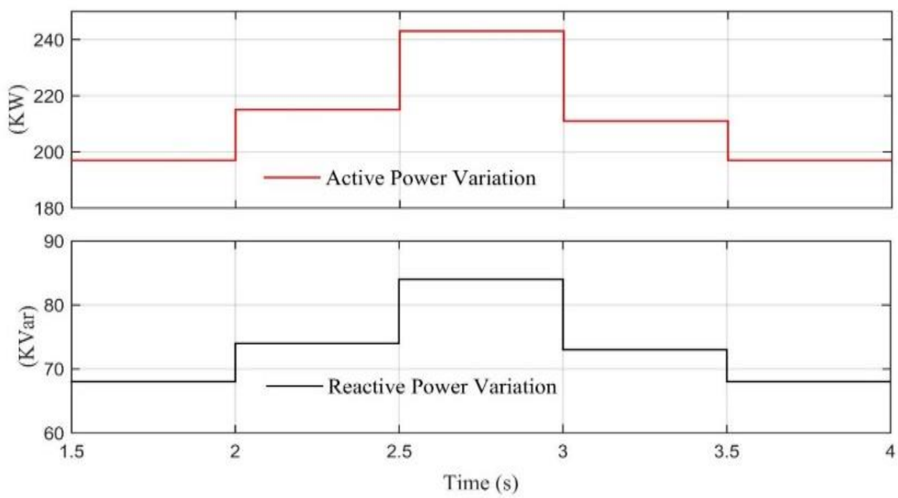

Fig. 7. Microgrid load changes

In the case of islands, DG1, DG2 and DG3 are responsible for compensating for the difference between electricity generation and consumption. With load changes due to the adaptive droop control system, the power of these distributed generation sources will be changed so that the amount of generation and consumption in the microgrid is equal, and the voltage and frequency remain within the nominal value range. Changes in the power of distributed generation sources are shown in Fig. 8.

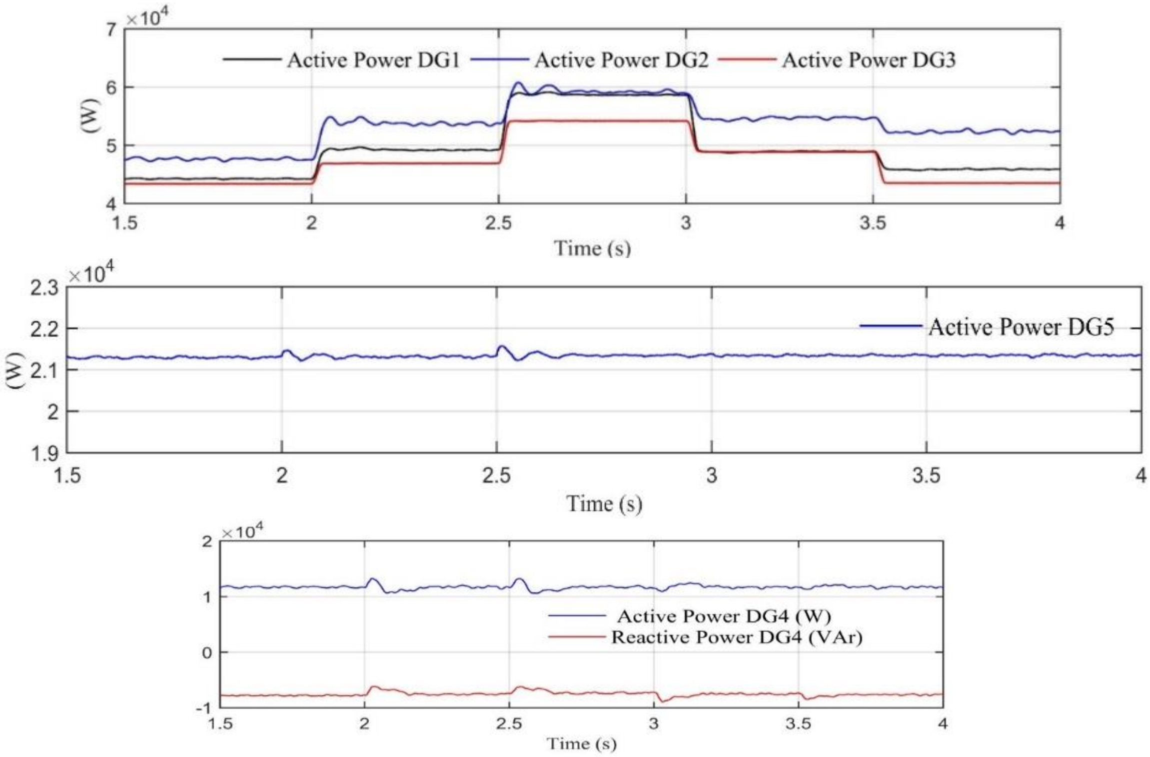

Fig. 8. Changes in the active power of DGs in proportion to load changes

As can be seen from the results of this test, the proposed control system can track load changes well and ensure microgrid stability. The summary of the work done in various research for load sharing in hybrid microgrids is shown in Table 2.

Table 2. Summary of work done in various types of research for load sharing in hybrid Microgrids

Ref.	Robust	Load changes	Flexibility
[5]	L	L	No
[6]	L	L	No
[8]	L	L	No
[9][11]	L	L	No
[12]	M	L	No
[13]	M	L	No
[14][19]	M	M	No
[20]	-	M	No
[21]	L	L	No
[23]	M	L	No
Proposed controller	**H**	**H**	**Yes**

* H is High, M is Medium, L is Low

4. Conclusion

In this paper, using a combination of two powerful neural network tools and fuzzy logic, intelligentization and adaptation of droop control along with voltage and current control was proposed as one of the most common decentralized control methods. The proposed final structure provides a comprehensive control system that enables proper operation in both grid and island modes simultaneously for both AC and DC microgrids. As is evident from the simulation results, The proposed structure, by adapting the control system by the ANFIS structure, can guarantee the stability of both AC and DC modes by suitable sharing of the power between distributed generation locally and without the need for the operator and the costly communication infrastructure. According to the results, the validity and optimal performance of the proposed control system were evaluated and approved.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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