Hamedan University of Technology

Iranian Association of Electrical and Electronics Engineers

Sustainable Energy and Artificial Intelligence

Online ISSN: 3060-8015

Journal Homepage: www.enai.hut.ac.ir

Improving Frequency Stability of Islanded Microgrid Using Virtual Inertia Control on Energy Storage Systems and Renewable Energy Sources

Farhad Amiri[1*], Mohammad Hassan Moradi[2]

[1] *Department of Electrical Engineering, Tafresh University, Tafresh, 39518-79611, Iran*

[2] *Department of Electrical Engineering, Bu-Ali Sina University, Hamedan, 65167-38695, Iran*

* *Corresponding Author: f.amiri@tafreshu.ac.ir*

Article Info

Article type:
Original Article

Article history:
Received 2024-08-18;
Revised 2024-08-31;
Accepted 2024-09-17.

How to cite this article:
Amiri, F. and Moradi, M. Hassan (2025). Improving Frequency Stability of Islanded Microgrid Using Virtual Inertia Control on Energy Storage Systems and Renewable Energy Sources. *Sustainable Energy and Artificial Intelligence*, *1*(1), 37-44.
DOI: 10.61186/seai.2408-1001

Abstract

The frequency stability is a crucial aspect of an islanded microgrid, especially considering the presence of RES with low inertia. These RES, such as wind turbines and photovoltaic systems, pose a potential threat to the frequency stability of the microgrid. To address this challenge, the concept of VIC has been introduced in islanded microgrids. This paper investigates the application of VIC not only to the ESS but also to the WT and PVS. The proposed method aims to enhance the frequency stability of the microgrid. The results of this study compare the performance of the proposed method, which includes VIC for PVS, WT, and ESS, with other scenarios. These scenarios include The VIC for PVS and ESS, VIC for ESS only, and a method without VIC. The simulation results, obtained using MATLAB software, demonstrate that the proposed method significantly improves the frequency stability of the microgrid under load disturbances and disturbances originating from RES. Moreover, the proposed method exhibits robustness in the face of uncertainties associated with microgrid parameters.

Keywords: Energy Storage System; Low Inertia; Wind Turbine; Virtual Inertia Control, Islanded Microgrid.

Abbreviations

RES	Renewable Energy Sources	RES	Renewable Energy Sources
VIC	Virtual Inertia Control	PVS	Photovoltaic Systems
ESS	Energy Storage System	VSG	Virtual Synchronous Generator
WT	Wind Turbine	MFD	Maximum Frequency Deviation

Nomenclature

T_{ESS} (s)	The time constant related to the ESS	T_{ESS} (s)	The time constant related to the ESS
ΔP_W (pu)	The power generation changes of the WT	ΔP_{WT} (pu)	The wind turbine power changes are applied to the microgrid
Δf (Hz)	The microgrid frequency changes	T_{PV} (s)	The time constant of the PVS inverter

$\Delta P_{inertia}$ *(pu)*	The power given to the system by the ESS	ΔP_{PV} *(pu)*	The PVS power changes are applied to the microgrid
T_{WT} *(s)*	The time constant of the WT inverter	K_{VIPV} *(gain)*	The VIC gain of the PVS
K_{VIWT} *(gain)*	The VIC gain of the WT	K_{VI} *(gain)*	The VIC gain
ΔP_{solar} *(pu)*	The power generation changes of the PVS		

1. Introduction

Microgrids have become increasingly prevalent in power systems, operating in two modes: connected to the main grid or islanded [1]. When connected, the microgrid can act as a source, providing active and reactive power to the grid, with the main grid responsible for voltage and frequency stabilization [2]. However, when the microgrid is islanded, it must be able to independently stabilize the voltage and maintain the nominal system frequency [3-5]. The growing integration of renewable energy sources, such as WT and PV, into microgrids, presents a challenge [6]. These RES, connected to the microgrid through a power electronics converter, have inherently low inertia [7]. This reduction in overall system inertia can lead to large frequency deviations in the microgrid during load disturbances, jeopardizing frequency stability [6-8]. In traditional power systems, large synchronous generators provide the necessary inertia [9]. To address the low-inertia issue in islanded microgrids, the concept of a VSG has been introduced. The VSG mimics the behavior of a synchronous generator, with VIC being a crucial component of the VSG [9,10]. By implementing VIC, the frequency stability of the islanded microgrid can be significantly improved [11-22].

In [11-20], the implementation of VIC on the ESS using various controllers in the islanded microgrid is discussed: PI controllers [11,12], coefficient diagram method [13], adaptive controller [14], neuro-Fuzzy controller [15], H∞ controller [16], fuzzy controller [17], H∞ controller Considering the phase-locked loop [18], model predictive control [19] and the robust model predictive control [20]. In [21,22], in addition to the VIC on the ESS, virtual damping is also designed on the islanded microgrid. The reason for using virtual damping on the ESS in an islanded microgrid is that it attenuates the frequency deviations caused by load disturbances faster and leads to improved microgrid frequency stability. The problem with the methods used in [11-20] is that when there is a disturbance in the islanded microgrid, RES such as WT and PVS are inactive and only the ESS tries to improve the system inertia and improve stability. This causes the microgrid to not respond to very severe disturbances with this method and the frequency stability of the system is lost. The methods used in [21,22] do not have good frequency stability against severe load disturbances in the islanded microgrid, but they dampen the frequency fluctuations better than the methods [11-20].

In this paper, in addition to implementing the behavior of synchronous generators (VIC) on the ESS in the islanded microgrid, the behavior of synchronous generators on WT and PVS is also implemented. In the proposed method, when a load disturbance occurs, other sources such as WT and PVS no longer act passively and through the signals sent to the inverter of these sources, act in such a way as to compensate for the frequency deviations caused by load disturbances. The proposed method improves inertia and microgrid stability. The results of the proposed method (VIC for PVS and ESS, WT) are compared with VIC for PVS and ESS, VIC for ESS and not VIC method in several scenarios. Based on the simulation results, when the disturbances occur in the microgrid according to the proposed method, WT and PVS improve the inertia of the microgrid. This method is also robust to load disturbances and the uncertainty of microgrid parameters.

2. The System Model

The general structure of the islanded microgrid used in this paper is shown in Fig. 1. The model considered in this paper for islanded microgrids includes a thermal power plant with 12MW capacity, a wind turbine with 9MW capacity, photovoltaic with 7MW capacity, load with 15MW capacity, and ESS with 4MW capacity.

3. The Proposed Method

3-1. Control Layers

The frequency stability of an isolated microgrid is dependent on the inertia of the microgrid [20,21]. The existence of sources such as WTS and PVs endangers the microgrid frequency stability because they exchange power with the microgrid through power-electronic converters and these sources have very low inertia [20,21]. Therefore, in the proposed method, several control loops are considered: 1) Virtual inertia control 2) Primary control 3) Secondary control [20,21]. The control layer that plays an essential role in the frequency stability of the isolated microgrid is the VIC. In this paper, VIC is performed on three sources: 1) ESS 2) WT 3) PVS.

3-2. VIC on ESS

In this method, the concept of VIC is the derivative control that adds the rate of change of frequency as an active power to the microgrid during disturbances and improves the frequency response and inertia of the system [20,21]. The dynamic model of VIC for ESS is shown in Table 2.

3-3. VIC on WT

In conventional control methods, when a disturbance occurs in an islanded microgrid, the WT is an inactive source and does not play a role in improving inertia and improving frequency stability. In this paper, VIC is also located on the WT. By placing the VIC on the WT, this source acts as an active source during load disturbances and thus improves the inertia of the system and plays an important role in the frequency stability of the system. The dynamic structure of the VIC on the WT is shown in Fig. 3.

In conventional control methods, photovoltaic systems, similar to WT, typically function as passive sources during disturbances in isolated microgrids, without contributing to inertia improvement or frequency stability enhancement. However, this paper introduces the concept of VIC for PVS, as well as WT and ESS. By implementing VIC on PVS, these sources can actively respond to load disturbances, thereby enhancing the system's inertia and playing a crucial role in improving frequency stability. Fig. 4 illustrates the dynamic structure of the VIC applied to photovoltaic systems.

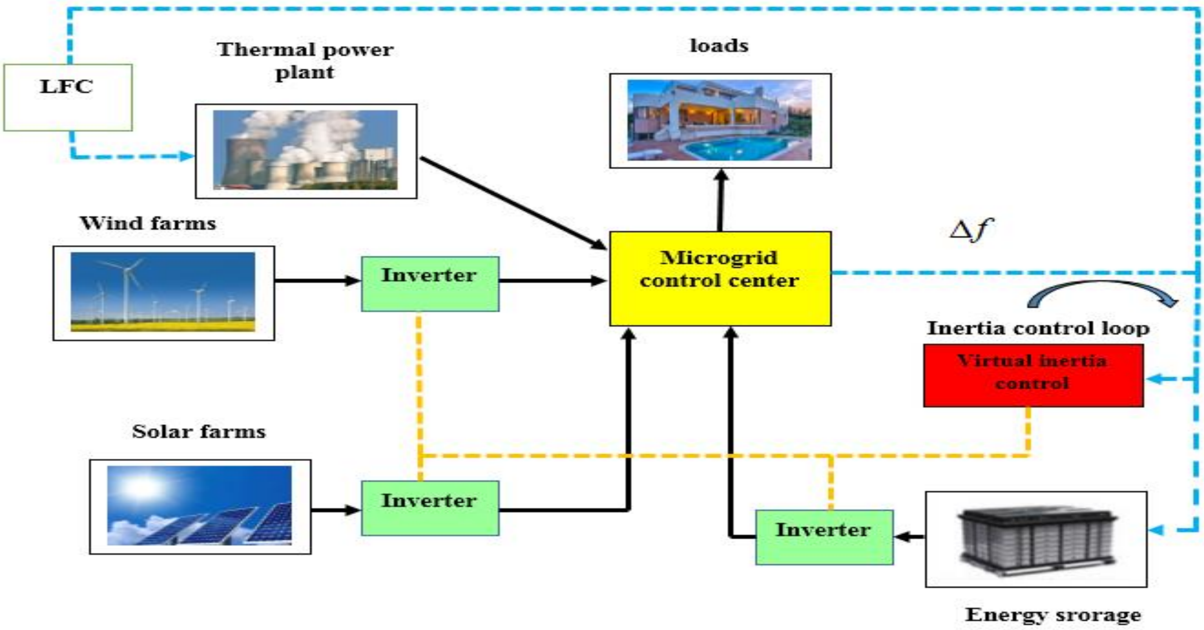

Fig. 1. The overall structure of an island microgrid

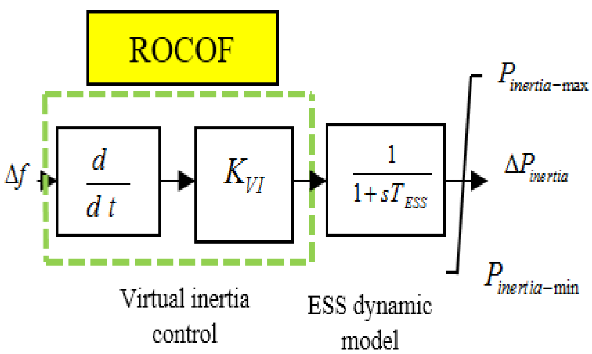

Fig. 2. The dynamic model of VIC for ESS

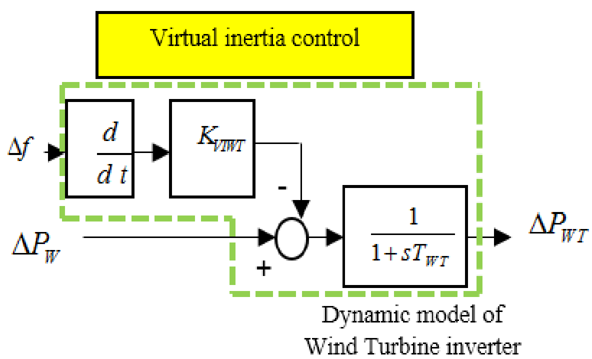

Fig. 3. The dynamic structure of the VIC on the WT

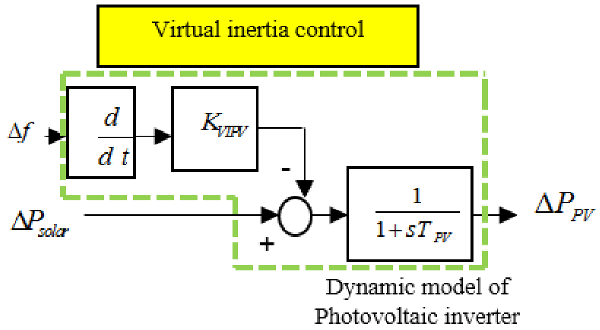

Fig. 4. The dynamic structure of the VIC on the PVS

In Fig. 5, the microgrid frequency response model considering the proposed control method is shown. The model used for the islanded microgrid is a reduced-order model that is suitable for frequency response analysis in the islanded microgrid. In Figs. 2 and 3, according to the dynamic structure for WT and PVS, if the load increases, the frequency deviation will be negative, and according to the dynamic structure, the WT and PVS must increase their power, which is observed in the dynamic structure and its equations, and If the load of the system decreases, the frequency deviation of the microgrid increases, and to balance the frequency of the microgrid, WT and PVS must reduce their power to eliminate the frequency deviations.

4. Simulation

The parameters related to the islanded microgrid are presented in Table 1. The control gain for VIC on PVS, denoted by parameter, exhibits excellent dynamic performance in simulation when its value is set to 1. Similarly, the control gain for VIC on the WT, also denoted by the parameter, demonstrates good dynamic performance in simulation when its value is equal to 1.

To evaluate the performance of the proposed method, three scenarios are considered. Scenario 1 compares the performance of the proposed method against load disturbances with that of other methods mentioned in this paper. Scenario 2 assesses the performance of the proposed method against load disturbances and uncertainty in system parameters, contrasting it with other methods discussed in this paper. Scenario 3 evaluates the performance of the proposed method against severe load disturbances and disturbances originating from RES, comparing it with other methods mentioned in this paper.

Table 1. Parameters related to the islanded microgrid

parameter	value	parameter	value
B (pu.MW/Hz)	1	K_{VI} (s)	0.5
K_i (s)	0.05	T_{VI} (s)	10
T_g (s)	0.1	T_{WT} (s)	1.5
T_t (s)	0.4	T_{PV} (s)	1.8
R (Hz/pu.MW)	2.4	V_U (pu.MW)	0.3
D (pu.MW/Hz)	0.015	V_L (pu.MW)	-0.3
H (pu.MW/Hz)	0.083	K_{VIWT}	1
K_{VIPV}	1		

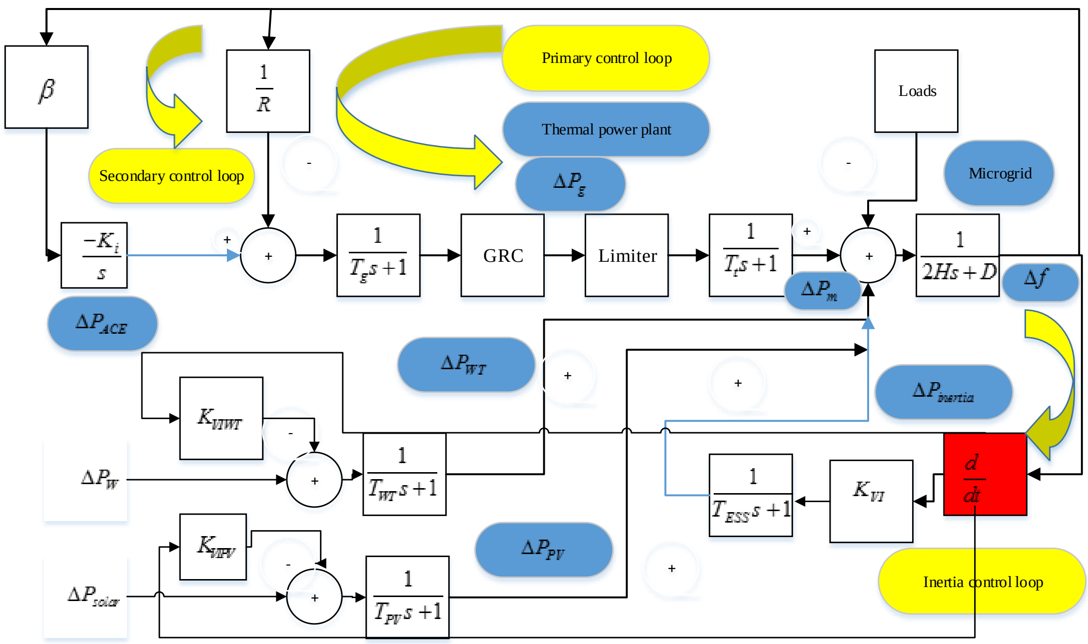

Fig. 5. The microgrid frequency response model considering the proposed control method

`

Scenario 1: Load disturbance is applied to the microgrid as shown in Fig. 6 in 1 second. Fig. 7 shows the microgrid frequency response to load perturbation using different control methods. According to Fig. 7, the MFD using the proposed method (VIC for (PVS, ESS, WT)) is 0.1Hz. The MFD using the VIC based on PV and ESS (VIC for (PV, ESS)) is 0.13Hz. The MFD using the VIC based on ESS (VIC for ESS) is 0.17Hz and the MFD using the Not VIC is 0.22Hz. Fig. 8 shows the output power of the inverter of PVS and the output power of a WT inverter using the proposed method. According to this figure, WT and PVs act as active sources when controlling virtual inertia. Based on the results of this scenario, the proposed method has a better performance against load disturbances and has been able to improve the microgrid frequency deviations by 24% compared to conventional methods.

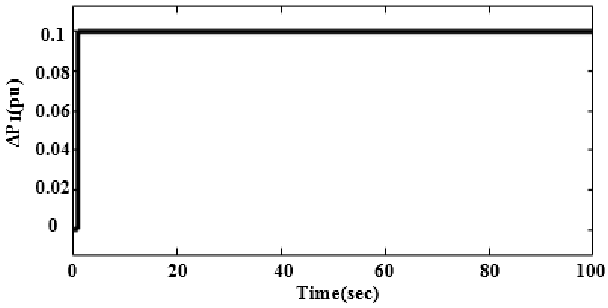

Fig. 6. The Load disturbance is applied to the microgrid

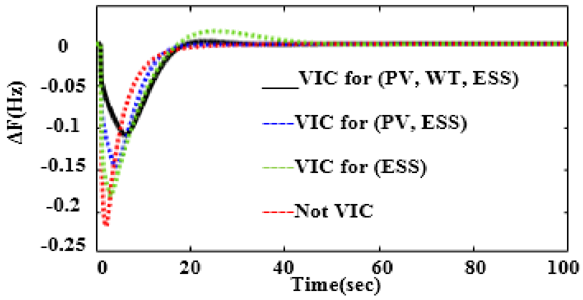

Fig. 7. The Microgrid frequency response to load disturbance, Scenario 1

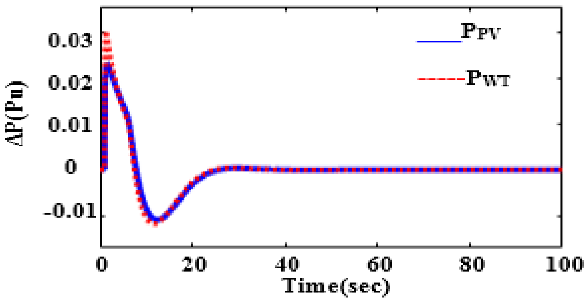

Fig. 8. The output power of a PVS inverter and the output power of a WT inverter using the proposed method, Scenario 1

Scenario 2: This scenario is intended to evaluate the performance of the proposed method against the uncertainty of the microgrid parameters. Load disturbance is applied to the microgrid as shown in Fig. 6 in 1 sec. The uncertainty parameter of microgrid inertia (H) is considered to be -15%. Fig. 9 shows the frequency response of the microgrid to the load disturbance considering the uncertainty in the inertia of the microgrid - 15%. According to Fig. 9, the MFD using the proposed method (VIC for (PV, ESS, WT)) is 0.12Hz. The MFD using the VIC based on PV and ESS (VIC for (PV, ESS)) is 0.16Hz. The MFD using the VIC based on ESS (VIC for ESS) is 0.21Hz and the MFD using the Not VIC is 0.24Hz.

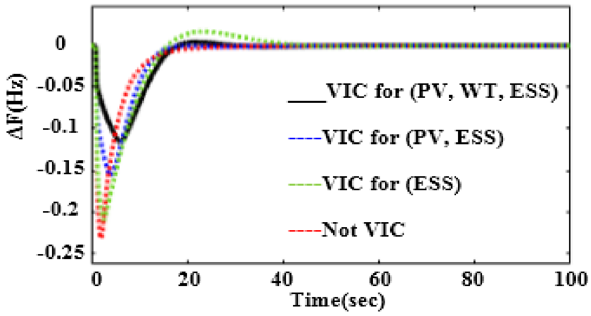

Fig. 9. The Microgrid frequency response to load disturbance, Scenario 2

Fig. 10 shows the output power of a photovoltaic inverter and the output power of a wind turbine inverter using the proposed method. According to this figure, wind turbines and PVS act as active sources when controlling virtual inertia. Based on the results of this scenario, the proposed method has a better performance against load disturbances and uncertainty of microgrid parameters and has been able to improve microgrid frequency deviations by 25% compared to conventional methods.

Scenario 3: In this scenario, in order to perform the proposed method against severe load disturbances and disturbances of RES are considered. Fig. 11 shows the generation capacity of WT and PVS. Load disturbances are applied to the microgrid as shown in Fig. 12. Figs. 13 and 14 show the microgrid frequency response to load disturbances and RES. According to Figs. 13 and 14, the MFD using the proposed method (VIC for (PV, ESS, WT)) is 0.05Hz. The MFD using the VIC based on PV and ESS (VIC for (PV, ESS)) is 0.16Hz. The MFD using the VIC based on ESS (VIC for ESS) is 0.22Hz and the MFD using the Not VIC is 0.19Hz. Based on the results of this scenario, the proposed method has a better performance against severe load disturbances and disturbances of RES and has been able to improve the microgrid frequency deviations by 69% compared to conventional methods. According to the results of this scenario, the higher the disturbances on a microgrid including load disturbances and disturbances of RES, the higher the efficiency of the proposed method than conventional methods. The summary of the results related to different scenarios is shown in Table 2.

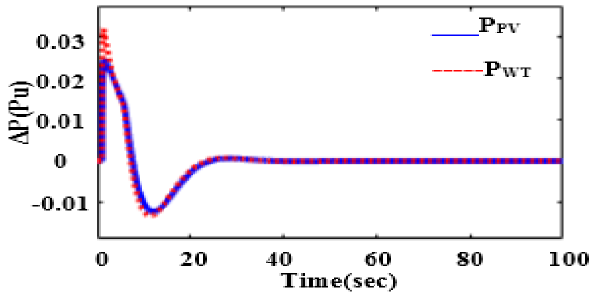

Fig. 10. The output power of a photovoltaic inverter and the output power of a wind turbine inverter using the proposed method, Scenario 2

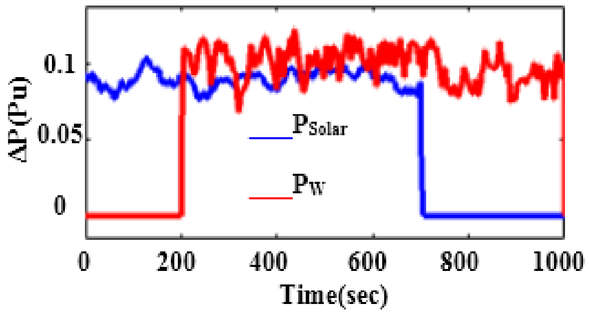

Fig. 11. Generation capacity of wind turbines and photovoltaics

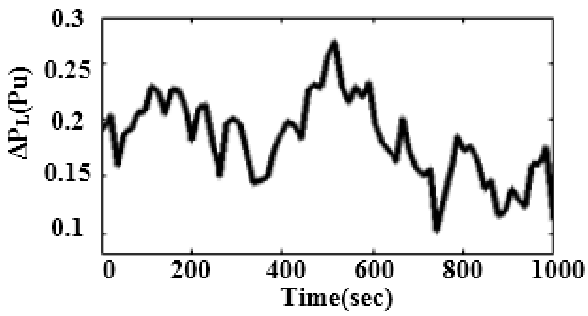

Fig. 12. Load disturbances is applied to the microgrid

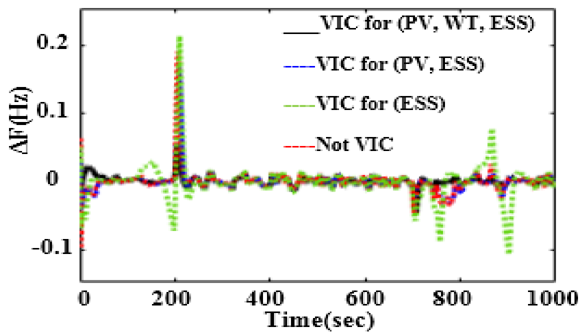

Fig. 13. The Microgrid frequency response to load disturbance, Scenario 3

`

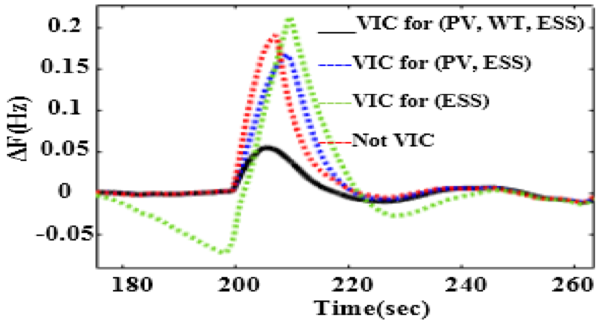

Fig. 14. The Microgrid frequency response to load disturbance, Scenario 3

Table 2. The summary of the results related to different scenarios

Scenario	Scenario 1	Scenario 2	Scenario 3
	MFD (Hz)	MFD (Hz)	MFD (Hz)
VIC for (PV, ESS, WT)	0.10	0.12	0.05
VIC for (PV, ESS)	0.13	0.16	0.16
VIC based on ESS	0.17	0.21	0.22
Not VIC	0.22	0.24	0.19

5. Conclusion

In a power system, the presence of large synchronous generators provides sufficient inertia for the system. The microgrid has a more limited power than the power system. On the other hand, the presence of resources such as WT and PVs in the microgrid endangers the frequency stability of the microgrid due to their oscillating nature. These sources have low inertia and cause the microgrid to experience frequency instability in response to disturbances. In this paper, a new control method is proposed that improves the inertia of the microgrid in the presence of WT and PVs and improves the frequency stability of the islanded microgrid. According to the simulation results, the proposed method can have a good performance against disturbances in the microgrid and uncertainty of microgrid parameters.

References

[1] Zidane, T. E. K., Ab Muis, Z., Ho, W. S., Zahraoui, Y., Aziz, A. S., Su, C. L., ... & Campana, P. E. (2025). Power systems and microgrids resilience enhancement strategies: A review. *Renewable and Sustainable Energy Reviews*, 207, 114953.

[2] Peter, N., Gupta, P., & Goel, N. (2025). Intelligent strategies for microgrid protection: A comprehensive review. *Applied Energy*, 379, 124901.

[3] Mbungu, N. T., Siti, M. M., Bansal, R. C., Naidoo, R. M., Elnady, A., Ismail, A. A. A., ... & Hamid, A. K. (2025). A dynamic coordination of microgrids. *Applied Energy*, 377, 124486.

[4] Moazzen, F., & Hossain, M. J. (2025). A two-layer strategy for sustainable energy management of microgrid clusters with embedded energy storage system and demand-side flexibility provision. *Applied Energy*, 377, 124659.

[5] satya nagasri Dangeti, L., & Marimuthu, R. (2025). Distributed model predictive control strategy for microgrid frequency regulation. *Energy Reports*, 13, 1158-1170.

[6] Amiri, F., & Moradi, M. H. (2023). Design of a new control method for dynamic control of the two-area microgrid. *Soft Computing*, *27*(10), 6727-6747.

[7] Varnoosfaderani, N. H., & Khorsandi, A. (2025). Unscented Kalman Filter-based State Estimation Applied on an Islanded Hybrid solar-wind DC Microgrid. *Heliyon*.

[8] Osama, A., Allam, D., & Eteiba, M. B. (2025). A Novel Real-Time Fuzzy-Based Optimal Control of the Charging Cycle of a Renewable Energy Microgrid Storage System. *International Journal of Fuzzy Systems*, 1-15.

[9] Shahbazi, M., & Amiri, F. (2019, December). Designing a Neuro-Fuzzy controller with CRPSO and RLSE algorithms to control voltage and frequency in an isolated microgrid. In *2019 international power system conference (PSC)* (pp. 588-594). IEEE.

[10] Jiang, B., Guo, C., & Chen, Z. (2025). Frequency Constrained Dispatch With Energy Reserve and Virtual Inertia From Wind Turbines. *IEEE Transactions on Sustainable Energy*.

[11] Wang, Y., Chen, S., Yang, M., Liao, P., Xiao, X., Xie, X., & Li, Y. (2025). Low-frequency oscillation in power grids with virtual synchronous generators: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 207, 114921.

[12] Sati, S. E., Al-Durra, A., Zeineldin, H. H., EL-Fouly, T. H., & El-Saadany, E. F. (2025). Decentralized frequency restoration and stability enhancement for virtual synchronous machines at economic dispatch in islanded microgrid. *Applied Energy*, 377, 124544.

[13] Chen, J., Wu, X., Huang, H., Zhang, H., Huang, H., Zhao, Z., ... & Lin, S. (2025). Power Control Strategy for an Electric Vehicle Charger Based on Virtual Synchronous Machine. In Frontier Academic Forum of Electrical Engineering (pp. 627-640). Springer, Singapore.

[14] Shi, T., Sun, J., Han, X., & Tang, C. (2024). Research on adaptive optimal control strategy of virtual synchronous generator inertia and damping parameters. *IET Power Electronics*, *17*(1), 121-133.

[15] Tan, K. H., Lin, F. J., Shih, C. M., & Kuo, C. N. (2019). Intelligent control of microgrid with virtual inertia using recurrent probabilistic wavelet fuzzy neural network. *IEEE Transactions on Power Electronics*, *35*(7), 7451-7464.

[16] Hamanah, W. M., Shafiullah, M., Alhems, L. M., Alam, M. S., & Abido, M. A. (2024). Realization of Robust Frequency Stability in Low-Inertia Islanded Microgrids with Optimized Virtual Inertia Control. *IEEE Access*.

[17] Sajadinia, M. (2024). An adaptive virtual inertia control design for energy storage devices using interval type-2 fuzzy logic and fractional order PI controller. *Journal of Energy Storage*, *84*, 110791.

[18] ALHEMS, L. M., & ALAM, M. S. (2024). Realization of Robust Frequency Stability in Low-Inertia Islanded Microgrids With Optimized Virtual Inertia Control.

[19] Kerdphol, T., Rahman, F. S., Mitani, Y., Hongesombut, K., & Küfeoğlu, S. (2017). Virtual inertia control-based model predictive control for microgrid frequency stabilization considering high renewable energy integration. *Sustainability*, *9*(5), 773.

[20] Wamukoya, B. K., Kaberere, K. K., & Muriithi, C. M. (2025). Optimal deployment of solar PV power plants as fast frequency response source for a frequency secure low inertia power grid. *Bulletin of Electrical Engineering and Informatics*, 14(1), 83-95.

[21] Chen, X., Ma, M., & Yan, Z. (2025). An improved parameter boundary calculation method for virtual synchronous generator with capacity constraints of energy storage system. *Electric Power Systems Research*, 241, 111391.

[22] Sati, S. E., Al-Durra, A., Zeineldin, H., EL-Fouly, T. H., & El-Saadany, E. F. (2024). A novel virtual inertia-based damping stabilizer for frequency control enhancement for islanded microgrid. *International Journal of Electrical Power & Energy Systems*, *155*, 109580.

Biography

Farhad Amiri was born in Ilam. He received his MSc and PhD degrees in electrical engineering in 2017 and 2022, respectively, from Bu-Ali Sina University. He also received his post-doctoral (Electrical engineering) in 2024 from the National Elites Foundation of Iran. His research interests include dynamic and transient performance of power system, control, Microgrid and renewable energy.

Mohammad Hassan Moradi was born in Nowshahr, Mazandaran, Iran. He obtained his B.Sc., M.Sc. and PhD from Sharif University of Technology, Tarbiat Modares University and Strathclyde University in Glasgow, Scotland in 1991 1993 and 2002 respectively. His research interests include New and Green Energy, Microgrid Modeling and Control, DG Location and Sizing in Power System, photovoltaic systems and power electronics, Combined Heat and Power Plant, Power Quality, Supervisory Control, Fuzzy Control.

`