JOURNAL OF SOUTHERN COMMUNICATION ENGINEERING
ISLAMIC AZAD UNIVERSITY BUSHEHR BRANCH

E-ISSN: 2980-9231
https://jce.bushehr.iau.ir

https://doi.org/...

Vol. x/ No. x/Spring 2024

Research Article

An Adaptive Method for Reducing Negative Sequence Voltage and Compensating Unbalance Voltage in Islanded Microgrids

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Received: 27 January 2025
Revised: 8 February 2025
Accepted: 12 February 2025

Abstract

The voltage imbalance in microgrids leads to issues such as excessive temperature rise, reduced efficiency, and shortened lifespan of equipment and consumer devices. In this paper, a novel control method for compensating unbalance voltage in islanded microgrids is presented. This method adjusts the voltage reference of Distributed Generation (DG) units by adaptively estimating the negative sequence voltage drop across the feeder impedance of each phase, enabling effective compensation of voltage imbalance in the microgrid by reducing the negative sequence voltage. Unlike previous methods, this approach does not require a dedicated central controller and only relies on low-bandwidth communication (LBC) between neighboring DGs. Additionally, the method does not require precise information regarding the feeder impedance of the DGs' output. The process of determining and designing the control system parameters is fully explained, and to assess the performance of the proposed method, simulations are conducted on a test system using MATLAB/Simulink software. The simulation results demonstrate that this method can be an effective and efficient solution for compensating voltage imbalance in islanded microgrids.

.**Keywords**: microgrid, distributed generation sources, unbalance voltage, negative sequence voltage.

Highlights

- A local control scheme is proposed to improve voltage unbalance in islanded microgrids.
- The proposed method can compensate for voltage unbalance without requiring prior knowledge of the feeder impedance values of the DG output.
- The proposed control structure is highly simple and demonstrates optimal performance under various conditions, including sudden load changes.

Citation: [in Persian].

1. Introduction
Today, the increasing demand for energy has led to the integration of Distributed Generation (DG) resources into distribution networks. In order to address the technical challenges associated with this integration, the concept of microgrids has been introduced. Microgrids have the ability to operate in both grid-connected and islanded modes [1-2]. Voltage unbalance in microgrids, which arises due to unbalanced single-phase and three-phase loads, leads to a significant reduction in voltage quality, including unbalance [3]. This condition causes problems for voltage-sensitive devices, such as rectifiers, induction motors, and transformers. Therefore, these networks require appropriate strategies for controlling DG inverters to overcome voltage quality issues, including voltage unbalance compensation.
In previous works, various methods have been proposed for compensating voltage unbalance. The approaches presented in references [4-10] for voltage unbalance compensation in microgrids are based on a hierarchical structure consisting of primary and secondary control levels. In these approaches, secondary control is executed in a centralized framework for all DGs. However, one of the key challenges of these methods is their dependence on the central control structure and the communication link between secondary and primary controls, such that any disruption in these components could hinder the performance of distributed generation sources. Additionally, in many previous studies, including references [4-7], proper system operation requires prior knowledge of the output feeder impedance values of the DGs. However, since accurate information about these impedances is often not available, this dependency can affect the accuracy and efficiency of the control system.

2. Innovation and contributions
In this paper, a local control structure is proposed to compensate for voltage unbalance in islanded microgrids. The local control scheme for DGs includes active and reactive power droop controllers for positive sequence, virtual positive sequence impedance, voltage and current controllers, and a voltage unbalance compensation block. The voltage unbalance compensation block adaptively estimates the negative sequence voltage drop in the feeder impedance of each phase. Based on this estimation, it adjusts the DG voltage reference to reduce the negative sequence voltage. In this way, the DGs improve the PCC voltage unbalance by injecting a negative sequence voltage drop that closely matches the negative sequence voltage drop in the feeder impedances (in the opposite phase.
Among the innovations of this paper, the following can be stated:
- The proposed control structure is highly simple and demonstrates robust performance under various conditions, including sudden load changes.
- Unlike the control methods presented in previous studies, this scheme is not only independent of a central controller but also does not require precise information about the output feeder impedance of the DGs.

3. Materials and Methods
To demonstrate the effectiveness of the proposed method, simulations have been conducted on an islanded microgrid. This microgrid consists of two DG units with equal nominal capacity (S_{DG1}=S_{DG2}). A three-phase unbalanced load (Z_{UL}) and a three-phase full-wave diode rectifier, acting as a nonlinear load, are connected at the point of common coupling (PCC). To evaluate the effectiveness of the proposed method, the simulation is performed continuously in three different stages.
- Step 1 (0 sec ≤ t < 2 sec): The DGs operate under active and reactive power droop controllers and virtual positive sequence impedance, while the voltage unbalance compensation block remains inactive.
- Step 2 (2 sec ≤ t < 3.5 sec): The voltage unbalance compensation block is activated in the local controllers of the DGs.
- Step 3 (3.5 sec ≤ t < 5 sec): Load conditions are modified to assess the robustness of the proposed control strategy.

4. Results and Discussion
- **Step 1 (0 sec ≤ t < 2 sec):**

The three-phase output voltage waveforms of the DGs and PCC are shown in fig. 1. In the first stage, before activating the voltage unbalance compensation block at the PCC, it is observed that the DG output voltages remain balanced. This confirms the effectiveness of the voltage controllers in tracking the reference voltage, even in the presence of unbalanced loads. The three-phase output current waveforms of the DG_1 and PCC are illustrated in fig. 2. As observed, due to the disconnection of phase "c" in the Z_{UB} load, the current in this phase is lower compared to phases "*a*" and "*b*"**.** In this condition, the imbalance in the output current of each phase causes an unbalanced voltage drop across the feeder impedance of the DGs. Consequently, as shown in fig. 1, the PCC voltage becomes unbalanced. This fact is further validated in fig. 3(a)**,** where a high *UF* value for the PCC voltage is evident. Fig. 4(a) and 4(b) depict the distribution of positive-sequence active and reactive power among the DGs under different simulation stages. It is observed that the power is appropriately shared between the DGs in accordance with their capacity. Therefore, it can be concluded that the droop controllers for positive-sequence active and reactive power exhibit satisfactory performance.
- **Step 2 (2 sec ≤ t < 3.5 sec):**

In the second step of the simulation, at t =2 sec, the PCC voltage unbalance compensation is activated in the local control of the DGs. As shown in Fig. 3(a), the UF of the PCC voltage decreases and accurately follows its reference value (UF_{ref} = 0.4%). Additionally, Fig. 3(b) illustrates that the negative-sequence voltage at the PCC is significantly reduced. Fig. 1 shows that as a result of the compensation, the voltage quality at the PCC is considerably improved. However, this improvement is accompanied by an increase in the unbalance of the DG output voltages. In fact, the DG output voltages become unbalanced by an amount close to the negative-sequence voltage drop across the feeder impedances. This ensures that, after this voltage drop, a nearly balanced voltage is maintained at the PCC. This phenomenon is evident in fig. 3(a) for the high *UF* values of the DG output voltage. As shown in fig. 4, even in this stage, the positive-sequence active and reactive power is effectively shared between the DGs, and the impact of voltage unbalance compensation on positive-sequence power is negligible. This is because the compensation operates exclusively in the negative sequence, ensuring that the overall power-sharing dynamics remain unaffected.

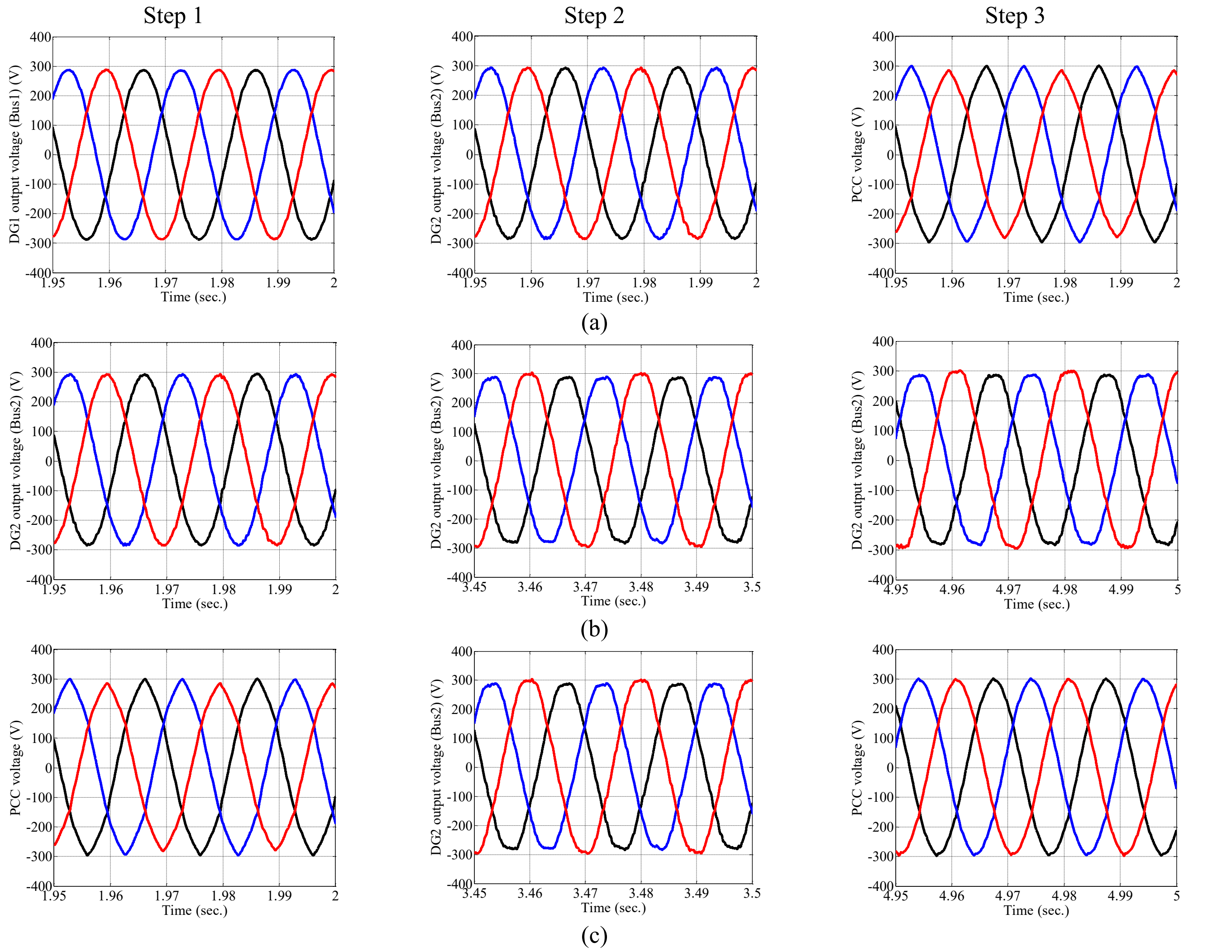


Fig. 1. Three-phase voltages in different simulation stages: (a) DG1 output voltage, (b) DG2 output voltage, (c) PCC voltage.

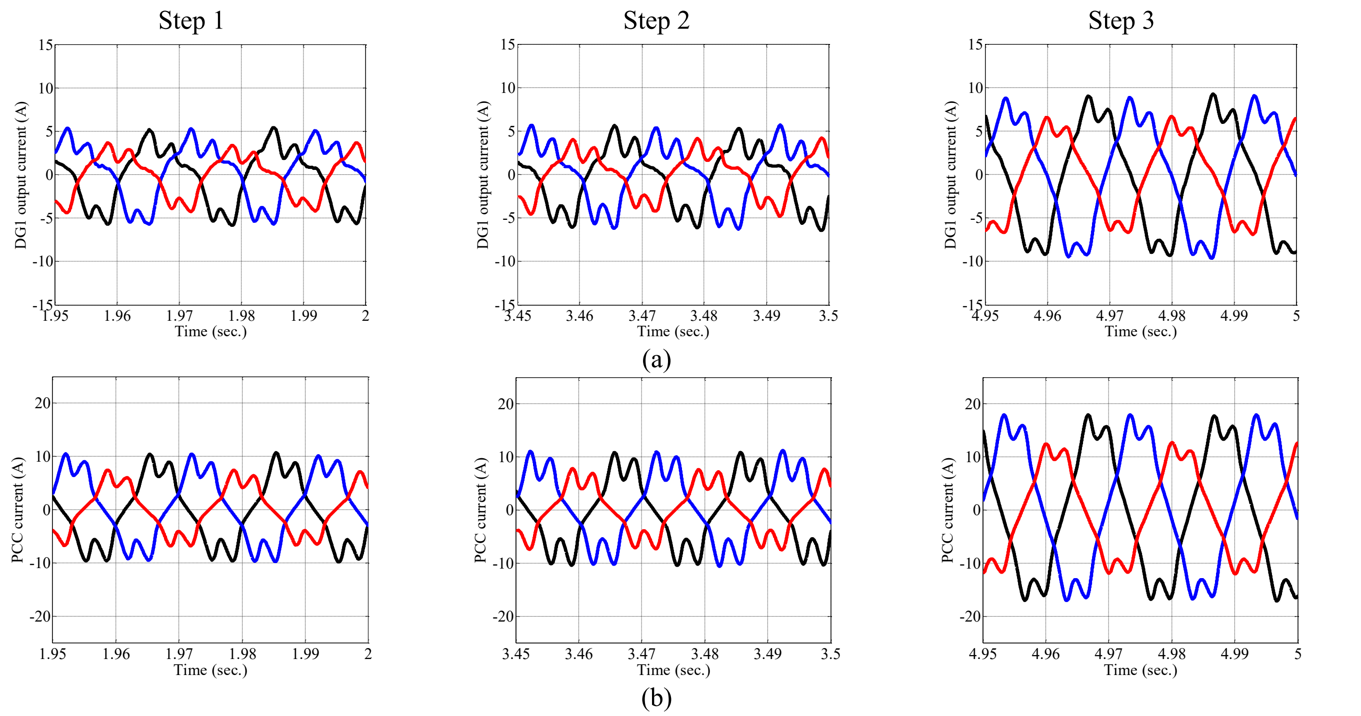
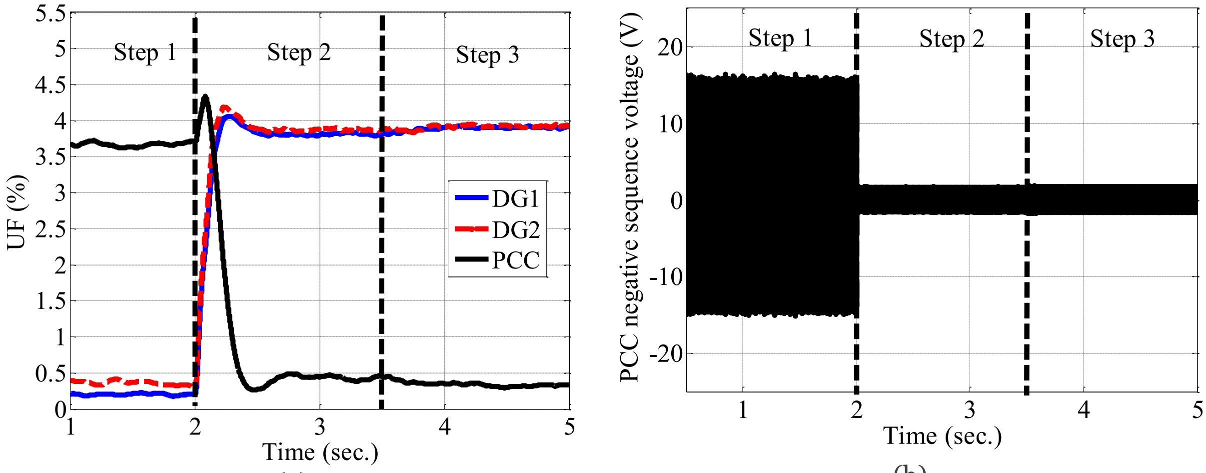


Fig.2. Three-phase currents in the second simulation step: (a) DG_1 output current, (c) PCC current.

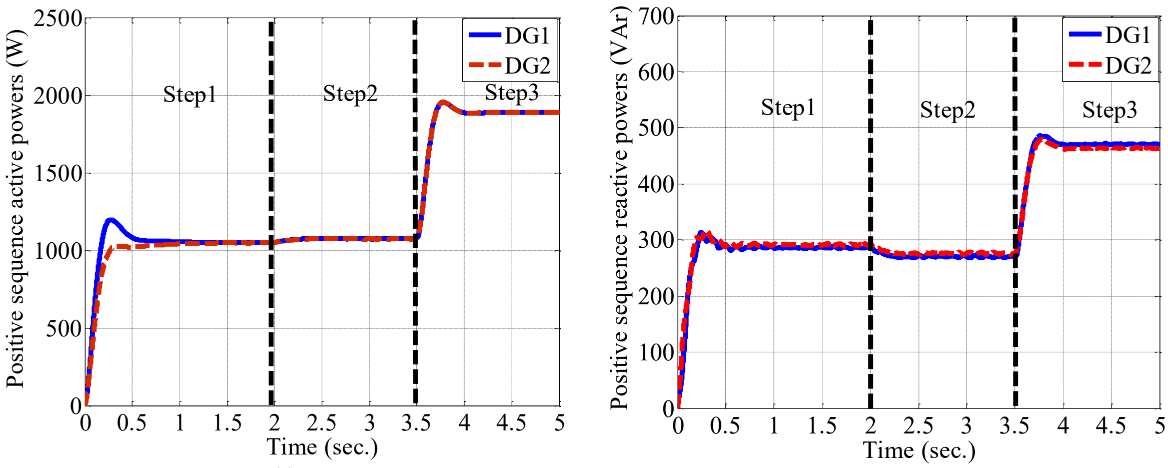
- **Step 3 (3.5 sec ≤ t < 5 sec):**

In this stage, to evaluate the flexibility of the proposed method, a change in the load conditions is introduced. Specifically, at t=3.5 sec, a three-phase load (Z_{BL}) is suddenly applied at the PCC. As observed in figs. 1 and 3, this load variation does not affect the voltage quality of either the DG output voltages or the PCC voltage, demonstrating the robust performance of the proposed control method in compensating for voltage unbalance. Additionally, a precise positive-sequence active and reactive power sharing is maintained under this condition (see fig. 4). Moreover, fig. 2 shows that, despite the load change, the DG output currents remain consistent with their nominal capacities, indicating that the method effectively maintains balanced power distribution without being impacted by sudden load variations.



(a) (b)

Fig. 3. (a) *UF* of DG output voltages and PCC voltage,(b) Negative-sequence voltage at PCC.



(a) (b)

Fig 4. Positive-sequence power(a) Active power,(b) Reactive power.

5. Conclusion

In this paper, a local control scheme is proposed for voltage unbalance compensation in islanded microgrids. The proposed method accurately estimates the negative-sequence voltage drop in each phase by utilizing negative-sequence reactive power and the voltage unbalance factor (*UF*) at the PCC. Based on these estimations, the voltage references of the DG units are adjusted to effectively compensate for voltage unbalance. Unlike conventional methods, this approach does not require a central controller or precise knowledge of the DG feeder impedance, reducing system complexity and enhancing flexibility. The design process of the proposed control structure is comprehensively explained, and simulation results confirm its effectiveness as a robust solution for compensating voltage unbalance in microgrids. For future research, the development of an enhanced control structure will be explored, incorporating modified droop controllers for active and reactive power to simultaneously compensate for voltage unbalance and voltage harmonics in the presence of unbalanced nonlinear loads.

6. Acknowledgement

The author acknowledges the artificial intelligence and big data automation research center at Urmia branch, Islamic Azad University, for their invaluable support and assistance in conducting this research.

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Appendix

Table 1: Parameters of the DG Power Stage and Control System

Positive-Sequence Active and Reactive Power Droop Controllers			
$m_{p,DG1}^{+}$, $m_{p,DG2}^{+}$ (rad/W)	$m_{i,DG1}^{+}$, $m_{i,DG2}^{+}$ (rad/W)	$n_{q,DG1}^{+}$, $n_{q,DG2}^{+}$ (rad/W)	
1×10^{-6}	1×10^{-4}	0.1	
Voltage and Current Controllers			
k_{pv}	k_{rv}	k_{pi}	k_{ri}
0.35	25	0.7	50
Virtual Positive-Sequence Impedance			
$R_{vir,DGk}^{+}$ (Ω)	$L_{vir,DGk}^{+}$ (mH)		
0.25	0.5		
LC Filters			
LC_{DG1} (mH, μF)	LC_{DG2} (mH, μF)		
(1.8, 25)	((1.8, 25)		
DG Feeder Impedance			
$Z_{f,DG1}$ (Ω, mH)	$Z_{f,DG2}$ (Ω, mH)	Z_N (Ω, mH)	
(0.2, 3.6)	(0.2, 3.6)	(0.1, 1.8)	
Balanced Linear Load	Nonlinear Load	Unbalanced Linear Load	
Z_{UL} (Ω, mH)	Z_{NL} (Ω, mH, μF)	Z_{BL} (Ω)	
(50, 20)	(150, 0.84, 235)	(30, 10)	

Declaration of Competing Interest: Authors do not have conflict of interest. The content of the paper is approved by the authors.

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Author Contributions: All authors reviewed the manuscript.

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