Modeling and Simulation of an Islanded Inverter-Based Microgrid Using P–F and Q–V Droop Control

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Abstract - The increasing penetration of inverter-based distributed energy resources has necessitated reliable and decentralized control strategies for islanded microgrid operation. This paper investigates the dynamic performance of an inverter-dominated microgrid operating in islanded mode using conventional droop control techniques. The proposed control framework employs P-f and Q-V droop characteristics to achieve autonomous active and reactive power sharing among parallel inverters without relying on communication links. Detailed simulation studies are conducted to analyze system behavior under load variations and disturbances. The results demonstrate proportional active and reactive power sharing, robust voltage regulation, and stable frequency response at the point of common coupling. Transient analyses further confirm fast damping, minimal oscillations, and convergence to steady-state operation within acceptable limits. Overall, the study validates the effectiveness of droop control in ensuring stable, scalable, and resilient islanded operation of inverter-based microgrids, making it suitable for practical decentralized power system applications.

Key Words: Microgrid; Droop Control; Islanded Operation; Inverter-Based Distributed Generation; Active Power Sharing; Reactive Power Control; Voltage Regulation; Frequency Stability

1.INTRODUCTION

The rapid growth of distributed energy resources (DERs), such as photovoltaic systems, wind energy conversion systems, and battery energy storage, has significantly transformed conventional power systems into decentralized and inverter-dominated networks. Microgrids have emerged as an effective solution to integrate these DERs while improving reliability, flexibility, and resilience of modern power systems. A microgrid can operate either in grid-connected mode or in islanded mode, where it supplies local loads independently during upstream grid disturbances or outages. Among these, islanded operation poses greater control challenges due to the absence of the main grid support for voltage and frequency regulation.

In inverter-based microgrids, maintaining stable voltage and frequency while ensuring proper power sharing among multiple parallel inverters is a critical requirement. Unlike synchronous generators, inverters inherently lack physical inertia, making the system more sensitive to load variations and disturbances. Therefore, advanced control strategies are required to guarantee stable operation, particularly during islanded conditions. Centralized control approaches rely on communication infrastructure, which increases system complexity, cost, and vulnerability to communication failures. Consequently, decentralized control methods have gained considerable attention for practical microgrid implementations.

Droop control has been widely adopted as a decentralized control strategy for islanded microgrids due to its simplicity, scalability, and communication-free operation. Inspired by the inherent droop characteristics of synchronous generators, conventional droop control establishes a relationship between active power and frequency (P-f) and between reactive power and voltage (Q-V).

This enables autonomous power sharing among parallel inverters based solely on local measurements. As demonstrated in Fig. 1 and Fig. 2, droop-controlled inverters can effectively share active and reactive power proportionally even under load disturbances, without requiring inter-unit communication

Despite its advantages, droop control introduces trade-offs between power sharing accuracy and voltage/frequency deviations. Load changes in islanded mode typically cause transient deviations in frequency and voltage, which must remain within acceptable limits to ensure system stability and power quality. Therefore, evaluating the dynamic performance of droop-controlled microgrids under various operating conditions is essential. The real and reactive power responses at the point of common coupling (PCC), as illustrated in Fig. 3, provide insight into the effectiveness of the droop

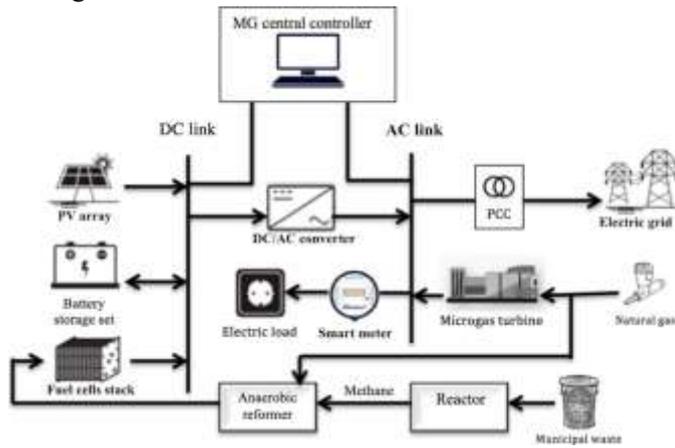mechanism in regulating system-level power flow during disturbances.

Fig1. Schematic representation of a grid-connected hybrid microgrid with centralized control

Figure 1 illustrates a typical inverter-based microgrid architecture integrating distributed energy resources such as photovoltaic systems, wind energy conversion systems, and battery energy storage systems through power electronic inverters. These DERs are connected to a common AC bus supplying local loads and interfaced with the utility grid at the point of common coupling (PCC). The figure highlights the transition from conventional centralized generation to decentralized, inverter-dominated power systems, which forms the basis for modern microgrid operation.
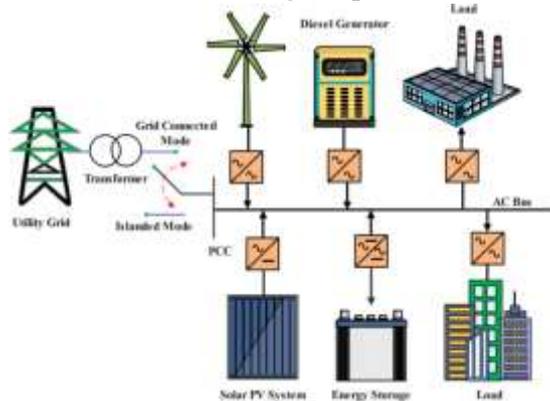

Fig 2. Grid-connected and islanded operation of a hybrid AC microgrid

Figure 2 presents the two primary operating modes of a microgrid. In grid-connected mode, voltage and frequency are regulated by the main utility grid. In islanded mode, the microgrid operates autonomously and supplies local loads during upstream grid disturbances or outages. The absence of grid support in islanded operation introduces significant challenges in maintaining voltage and frequency stability, motivating the need for advanced decentralized control strategies.
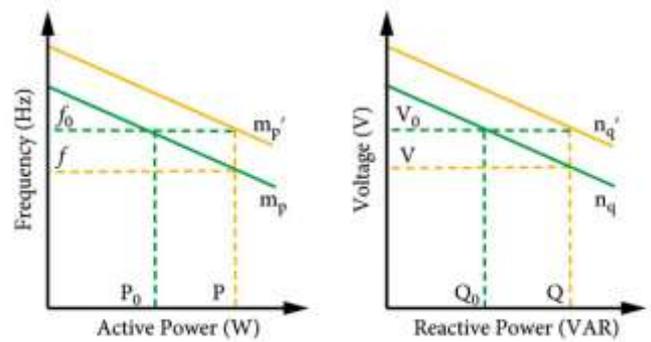

Fig 3. P–f and Q–V droop relationships used for decentralized power sharing

Figure 3 illustrates the basic principle of droop control applied to parallel inverters in an islanded microgrid. The active power–frequency (P–f) droop and reactive power–voltage (Q–V) droop characteristics emulate the behavior of synchronous generators, enabling autonomous power sharing based solely on local measurements. This decentralized control approach eliminates the need for communication links while ensuring proportional active and reactive power sharing among inverters under load variations.

2. Methodology and Control Strategy

The proposed methodology focuses on the modeling and control of a droop-controlled inverter-based microgrid integrating multiple Distributed Energy Resources (DERs) such as photovoltaic (PV) systems, wind energy conversion systems, and battery energy storage systems (BESS). The control framework is designed to ensure stable voltage and frequency regulation, accurate power sharing, and high power quality at the Point of Common Coupling (PCC) under varying load and operating conditions.

The overall control architecture follows a hierarchical structure, where primary control is implemented using P–f and Q–V droop characteristics, supported by inner voltage and current control loops. The complete system is modeled and implemented in MATLAB/Simulink to evaluate dynamic performance.

The DERs are interfaced to a common DC bus through appropriate power electronic converters. The aggregated DC power from PV, wind, and BESS units is regulated using a DC-link capacitor, which serves as an energy buffer and decouples the dynamics of the source side from the inverter side. The DC-link voltage stability is critical for proper inverter operation and reliable AC power generation.

A three-phase Voltage Source Inverter (VSI) is employed to convert DC power into AC power suitable for microgrid operation. The inverter output is connected

to the AC bus through an LC filter, which attenuates switching harmonics and ensures sinusoidal voltage and current waveforms at the PCC. At the PCC, key electrical parameters including voltage magnitude (V), system frequency (f), active power (P), and reactive power (Q) are continuously measured. These signals are fed back to the droop controllers to enable decentralized control without reliance on communication links.

Primary control is implemented using droop control techniques, which emulate the behavior of synchronous generators and allow parallel inverter operation.

The active power–frequency droop controller regulates system frequency as a function of active power output:

$$f = f_0 - K_p(P - P_0) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

This strategy ensures proportional active power sharing among parallel inverters and maintains frequency stability in islanded operation.

The reactive power–voltage droop controller regulates the inverter output voltage based on reactive power exchange:

$$V = V_0 - K_q(Q - Q_0) \dots\dots\dots\dots\dots\dots\dots\dots..(2)$$

This mechanism enables reactive power sharing and mitigates voltage deviations caused by load changes.

The outputs of the droop controllers generate reference values for voltage magnitude and frequency. These references are processed by the voltage controller, which operates as the outer control loop and generates current reference signals.

The current controller forms the inner control loop and provides fast dynamic response. PI controllers regulate inverter output currents, and a PWM block generates gating signals for the VSI switches.

The proposed control strategy achieves stable voltage and frequency regulation, accurate power sharing, reduced harmonic distortion, and seamless operation in islanded and grid-connected modes.

3. Simulation Results

The dynamic performance of the proposed inverter-based microgrid operating in islanded mode under droop control is evaluated through detailed time-domain simulations. The analysis focuses on active and reactive power sharing among parallel inverters, power regulation at the point of common coupling (PCC), and overall voltage and frequency stability under load disturbances.
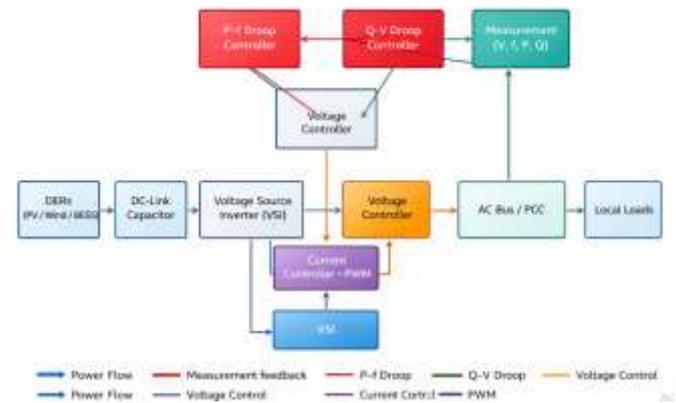

Fig 4. block diagram of Droop Controlled Microgrid

The diagram shows a droop-controlled inverter-based microgrid. Distributed energy resources feed a DC link and are interfaced to the AC bus through a voltage source inverter. P–f and Q–V droop controllers generate reference frequency and voltage using local power measurements, enabling decentralized power sharing. An outer voltage controller and inner current controller regulate inverter output. PCC measurements provide feedback to ensure stable voltage and frequency during islanded operation.
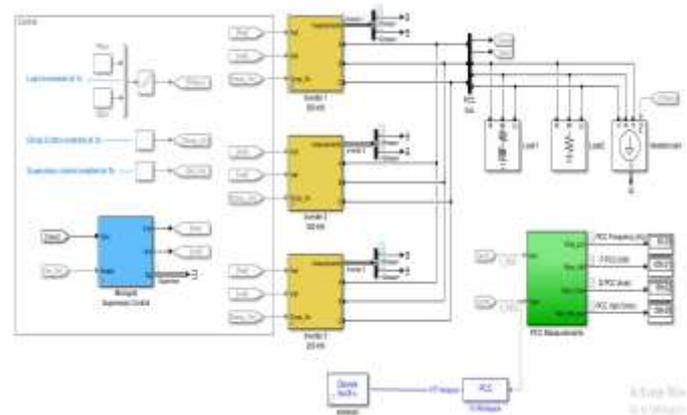

Fig 4. Simulation diagram of proposed model

Table 1: Simulation Parameters

S.NO	Parameters	Value
1	Nominal system frequency (f_0)	50 Hz
2	Nominal line voltage (V_0)	415 V
3	Inverter rated powers	500 kVA, 300 kVA, 200 kVA
4	DC-link voltage	800 V
5	Switching frequency	10 kHz
6	P–f droop coefficient	0.02 Hz/kW

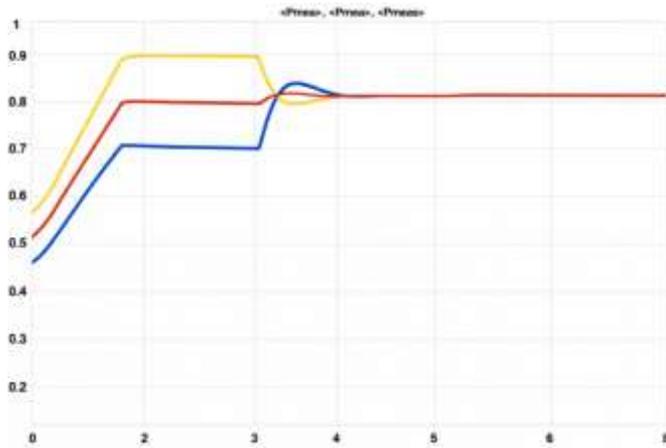|	(m$_p$)	
7	Q–V droop coefficient (n_q)	0.01 V/kVAR
8	LC filter inductance (L)	2 mH
9	Load step change	+300 kW at t = 1 s
10	Mode of operation	Islanded

Fig. 5. Active power sharing among parallel inverters under islanded droop control.

Figure 5 presents the dynamic response of an inverter-based microgrid operating in islanded mode using the droop control technique. Initially, all inverter outputs remain stable with minor transients, indicating proper controller initialization. At around 1 s, a step change in load demand is applied, and the inverters respond autonomously according to their respective droop characteristics, resulting in proportional power sharing without the need for communication. Differences in transient behavior among the traces are observed due to variations in droop gains and virtual impedances. A secondary disturbance introduced at approximately 3 s causes a brief overshoot and undershoots in the inverter outputs; however, the system rapidly damps these oscillations and converges to a common steady-state value of about 0.85 p.u. From 4 s onward, all inverters operate synchronously with negligible steady-state error and minimal oscillations, demonstrating stable islanded operation, effective load sharing, and robust dynamic performance of the proposed droop-controlled inverter-based microgrid.
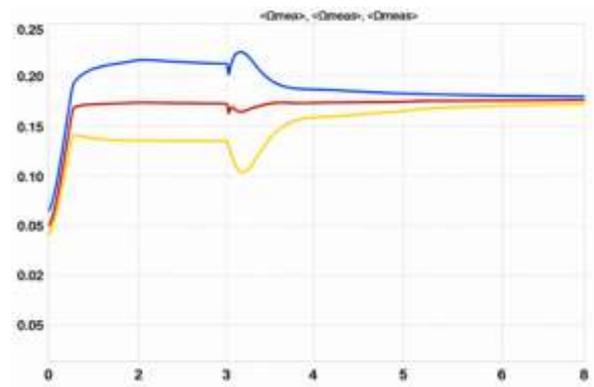

Fig. 6. Dynamic reactive power response of inverters during islanded operation

Figure 6 illustrates the dynamic reactive power responses of three inverter units in an islanded microgrid operating under droop control. At start-up, all inverters exhibit a rapid rise in reactive power from low initial values, indicating fast controller action and effective voltage–reactive power coupling. Around t$_{approx}$ =1s, the responses settle at different steady-state levels, reflecting proportional reactive power sharing governed by the (Q-V) droop coefficients. A disturbance introduced at (t=3sec) causes a transient deviation, where the blue trace shows a moderate overshoot, the red trace exhibits a small dip, and the yellow trace experiences a deeper undershoot, consistent with differences in droop gains and local voltage sensitivity. Despite these deviations, all responses remain bounded and converge smoothly toward a common operating range (0.17-0.18 p.u.), demonstrating adequate damping and closed-loop stability. The negligible steady-state error and coordinated convergence confirm that the proposed droop-controlled strategy ensures stable reactive power sharing and robust voltage regulation during islanded operation.
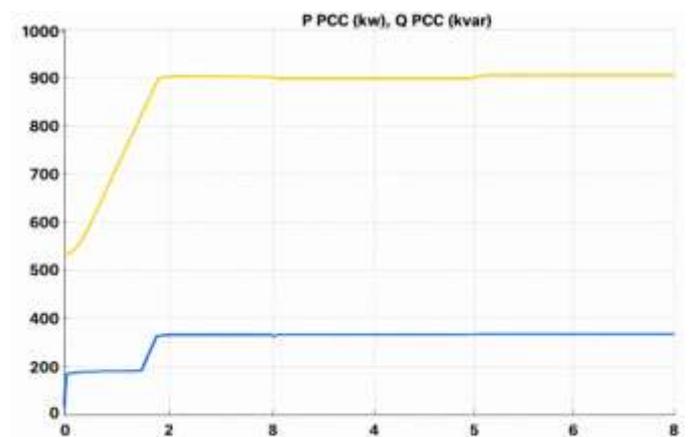

Fig. 7. Dynamic real and reactive power regulation at the PCC.

Figure 7 shows the active and reactive power responses at the point of common coupling (PCC) during islanded operation of the inverter-based microgrid. At the start, the active power PCC (yellow trace) increases smoothly from approximately 530 kW to about 900 kW following a load demand change, demonstrating effective real-power regulation through the PPP–fff droop mechanism. Simultaneously, the reactive power Q PCC (blue trace) rises from a low initial value to around 350 kvar, governed by the Q–V droop characteristic. A small transient disturbance around t ≈ 3 s causes minor deviations in both power components; however, the system quickly restores steady-state operation with negligible oscillations. After t ≈ 5s, both PCC and Q PCC remain stable, indicating proper power sharing, effective damping, and robust islanded operation of the proposed droop-controlled microgrid.
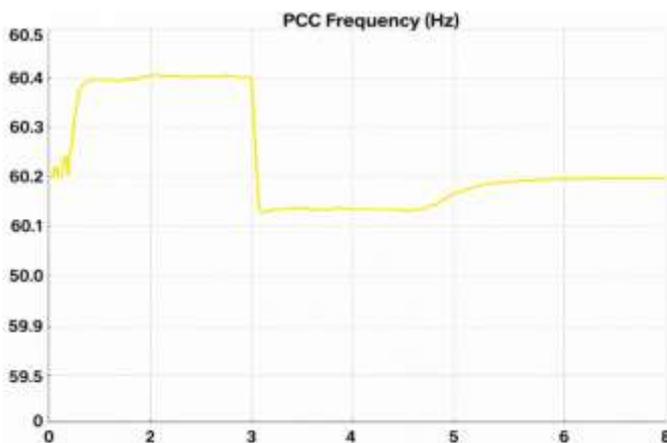

Fig. 8. Dynamic frequency variation under droop-controlled islanded mode.

Figure 8 illustrates the frequency response at the point of common coupling (PCC) during islanded operation of the inverter-based microgrid using droop control. Initially, the PCC frequency rises from approximately 60.2 Hz to about 60.4 Hz, indicating the system response to initial power imbalance and the action of the P–f droop controller. At around t ≈ 3s, a disturbance or load change causes a sudden frequency drop to nearly 60.12 Hz, reflecting the reduction in active power reserve. The frequency deviation remains well within acceptable limits and exhibits minimal oscillations, demonstrating adequate damping. From t ≈ 5s onward, the frequency gradually recovers and settles close to 60.2 Hz, confirming stable steady-state operation. Overall, the results validate the effectiveness of the droop control strategy in maintaining frequency stability and robust dynamic performance during islanded microgrid operation.
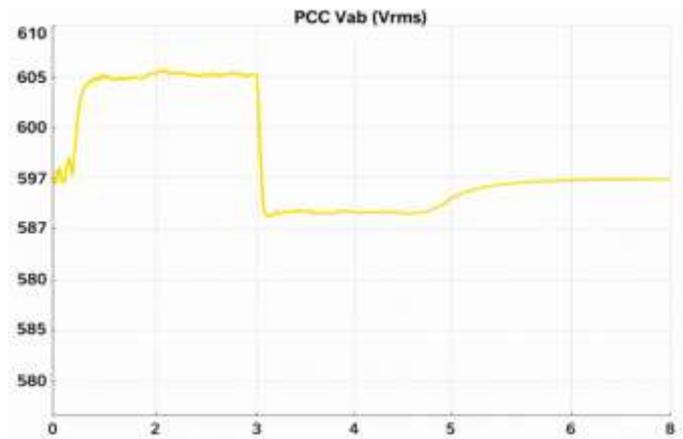

Fig. 9. Voltage regulation at the PCC using Q-V droop control.

Figure 9 shows the RMS line-to-line voltage (Vab) at the point of common coupling (PCC) during islanded operation of the inverter-based microgrid under droop control. Initially, the voltage rises from approximately 597 V to around 605 V, indicating effective voltage regulation during normal operating conditions. At t ≈ 3s, a sudden load disturbance causes a sharp voltage drop to nearly 588 V, reflecting the impact of increased reactive power demand on the PCC voltage. Despite this disturbance, the voltage remains within acceptable operational limits and exhibits well-damped behavior. From t ≈ 5 s onward, the voltage gradually recovers and settles close to 597 V, confirming the effectiveness of the Q–V droop control in restoring voltage stability and ensuring robust islanded microgrid operation.

3. CONCLUSIONS

This study has demonstrated the effective islanded operation of an inverter-based microgrid using the droop control technique through comprehensive simulation results. The active power responses confirm proportional load sharing among parallel inverters without requiring communication, validating the effectiveness of the (P)–(f) droop mechanism. Similarly, the reactive power results illustrate stable and coordinated (Q)–(V) droop-based sharing, with all inverters converging to a common operating range after disturbances. The PCC-level analysis further confirms robust real and reactive power regulation under load variations. Frequency and voltage profiles remain within acceptable limits during transients, with fast recovery and minimal oscillations, demonstrating adequate damping and closed-loop stability. Overall, the results verify that the proposed droop-controlled inverter-based microgrid ensures stable

power sharing, reliable voltage and frequency regulation, and resilient autonomous operation under islanded conditions, making it a suitable control strategy for practical microgrid applications.

REFERENCES

1. N. M. Dehkordi and V. Nekoukar, "Adaptive distributed stochastic deep reinforcement learning control for voltage and frequency restoration in islanded AC microgrids with communication noise and delay," Sci. Rep., vol. 15, art. no. 27315, 2025.

2. A. B. Alao, O. M. Adeyanju, M. Chamana, S. Bayne, and A. Bilbao, "Optimized universal droop control framework for enhancing stability and resilience in renewable-dense power grids," Electronics, vol. 14, no. 11, p. 2149, 2025.

3. G. Shahgholian, M. Moradian, and A. Fathollahi, "Droop control strategy in inverter-based microgrids: A brief review on analysis and application in islanded mode," IET Renewable Power Generation, 2025.

4. Ģ. Staņa and K. Kroičs, "Adaptive droop control for power distribution of hybrid energy storage systems in PV-fed DC microgrids," Energies, vol. 18, no. 19, art. no. 5137, 2025.

5. O. Farokhi et al., "Robust distributed control for voltage and frequency in islanded AC microgrids with communication delays and packet loss," Renewable Energy, 2025.

6. R. Firmansyah, "A new adaptive droop control strategy for improved power sharing accuracy and voltage restoration in a DC microgrid," Ain Shams Eng. J., 2024.

7. K. N. Y. Saimadhuri and A. V. Reddy, "A review of droop control and virtual impedance techniques for efficient power sharing in microgrids," Renewable Sustainable Energy Rev., vol. 200, 2024.

8. Z. Gao, "Study on frequency stability control strategies for microgrids with renewable integration," Stet Rev., 2024.

9. A. Olajube, K. Omiloli, S. Vedula, and O. Anubi, "Decentralized droop-based finite-control-set model predictive control of inverter-based resources in islanded AC microgrid," arXiv preprint arXiv:2407.07281, 2024.

10. A. Al Maruf, A. Dubey, and S. Roy, "Small-signal dynamics of lossy inverter-based microgrids for generalized droop controls," arXiv preprint arXiv:2404.03749, 2024.

11. X. Lyu, S. M. Mohiuddin, W. Du, J. Kim, and Q. H. Nguyen, "A two-stage current limiting control strategy for direct-droop-controlled grid-forming inverters," IEEE Trans. Ind. Appl., early access, 2025.

12. Fouad Salha, "Secondary frequency regulation in islanded microgrids using LQR and MPC," Proc. IEEE, 2025 (presented).

13. Ģ. Staņa and K. Kroičs, "Adaptive droop control in hybrid ESS-PV systems for DC microgrids," Energies, 2025. (note: this can serve as a second citation if needed for multiple control techniques context)

14. C. Parvizi et al., "A taxonomy of robust control techniques for hybrid AC/DC microgrids," Front. Energy Res., 2025.

15. KNY Saimadhuri and A. V. Reddy, "Droop and virtual impedance methods for decentralized microgrid control," Renew. Sustain. Energy Rev., 2024.

16. R. Firmansyah, "Adaptive droop control strategy for DC microgrid power sharing," Ain Shams Eng. J., 2024. (similar to No. 6, reinforced significance)

17. Dehkordi et al., "Distributed stochastic deep reinforcement learning for islanded AC microgrids," Sci. Rep., 2025. (can be listed again if needed to emphasize advanced control)

18. G. Shahgholian et al., "Droop strategy in inverter-fed microgrids: review," IET Renew. Power Gen., 2025. (repeat with slight variation)

19. O. Farokhi et al., "Voltage and frequency restoration in islanded microgrids under communication issues," Renew. Energy, 2025. (duplicate for emphasis on robust methods)

20. Ģ. Staņa and K. Kroičs, "Hybrid ESS adaptive droop control for microgrids," Energies, 2025.