

Paper Type: Original Article

Islanding Detection Method for Distributed Generation Systems Based on Voltage and Power Variation Analysis in Smart Grids

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Citation:

Received: 19 March 2025
Revised: 25 May 2025
Accepted: 08 October 2025

Karami Poor, M. (2026). Islanding detection method for distributed generation systems based on voltage and power variation analysis in smart grids. *Intelligence Modeling in Electromechanical Systems*, 3(1), 23–32.

Abstract

The growing penetration of Distributed Generation (DG) in modern power distribution networks has significantly improved system reliability, energy efficiency, and the integration of renewable energy resources. However, this integration also introduces critical technical challenges, with islanding representing one of the most important and potentially hazardous operating conditions. Islanding occurs when a portion of the distribution network remains energized by DG units after disconnection from the main grid, which can pose serious risks to personnel safety, equipment integrity, and overall system stability. Therefore, international standards require fast, reliable, and accurate islanding detection methods to ensure secure operation of smart grids. Despite numerous existing approaches, many conventional islanding detection techniques suffer from a large Non-Detection Zone (NDZ), which limits their reliability and effectiveness under certain operating conditions. To address this limitation, this paper proposes a novel and fast islanding detection method based on the combined evaluation of voltage magnitude variations, their dynamic range behavior, and active power fluctuations at the Point of Common Coupling (PCC) of DG units within a smart grid environment. The proposed method improves detection speed and accuracy while significantly reducing the NDZ, thereby enhancing the overall protection performance of both DG units and distribution networks. Extensive simulation results demonstrate that the proposed approach outperforms conventional islanding detection techniques in terms of sensitivity, robustness, and response time.

Keywords: Islanding detection, Smart grid, inverter, Voltage variations, Active power.

1 | Introduction

The rapid integration of Distributed Generation (DG) into modern power systems is fundamentally reshaping traditional electricity generation and distribution paradigms. DG consists of small- to medium-scale generation units located near load centers, including renewable sources such as Photovoltaic (PV) systems, wind turbines, small hydropower plants, and energy storage systems, as well as conventional units such as

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<https://doi.org/10.48314/imes.vi.46>



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diesel and gas generators. This rapid deployment is driven by increasing demand for sustainable energy solutions, stricter environmental regulations, advancements in power electronic interfaces, and the need to enhance system reliability, flexibility, and resilience. Compared to conventional centralized generation, DG offers several well-established advantages. By generating electricity closer to consumption points, it reduces transmission and distribution losses and improves voltage profiles in distribution networks. It also enhances system reliability by providing localized support during peak demand and grid disturbances. Furthermore, DG facilitates the development of smart grids and microgrids characterized by decentralized control, real-time monitoring, and bidirectional power flow, enabling better integration of intermittent renewable resources and improved demand-side management while reducing greenhouse gas emissions. Despite these benefits, high DG penetration introduces significant operational and protection challenges, with unintentional islanding being one of the most critical issues. Islanding occurs when a portion of the distribution network becomes electrically isolated from the main grid while remaining energized by local DG units. Although intentional islanding in microgrids can be beneficial, unintentional islanding poses serious risks, including safety hazards for maintenance personnel, equipment damage due to voltage and frequency instability, power quality degradation, and overall system instability. To address these concerns, international standards such as IEEE 1547, IEEE 929, and UL 1741 require DG systems to detect islanding conditions and disconnect from the grid within a specified time, typically within two seconds. Compliance with these standards is essential for ensuring system safety, equipment protection, and reliable network operation. Islanding detection techniques are generally classified into remote and local methods. Remote techniques rely on communication-based infrastructure such as SCADA systems, power line carrier communication, and pilot signals. While these methods offer high accuracy and negligible Non-Detection Zones (NDZ), their implementation is often limited by high cost and infrastructure complexity, particularly in small or distributed systems. In contrast, local methods rely solely on measurements at the Point of Common Coupling (PCC) of DG units and are categorized into passive, active, and hybrid approaches. Passive methods monitor system parameters such as voltage, frequency, Rate of Change of Frequency (ROCOF), and harmonic distortion. Although simple and non-intrusive, they suffer from relatively large NDZs, especially under closely matched load-generation conditions. Active methods reduce NDZ by injecting controlled perturbations such as reactive power variations, frequency shifts, or phase disturbances, and analyzing the system response. While more effective in detection, these methods may slightly affect power quality. Hybrid approaches combine passive monitoring with active perturbation to achieve improved accuracy, reduced NDZ, and enhanced robustness across varying operating conditions. In this context, this study proposes a novel hybrid islanding detection method that combines voltage magnitude monitoring as a passive indicator with controlled active power perturbations at the PCC. The proposed method is evaluated on a representative distribution system incorporating multiple DG technologies, including PV systems, wind turbines, diesel generators, and small hydropower units. Various operating conditions, including different load levels, DG penetration rates, and network configurations, are considered. Simulation results demonstrate that the proposed method achieves fast and accurate islanding detection while complying with IEEE 1547 and UL 1741 standards. Moreover, it significantly reduces the NDZ and improves operational reliability. Finally, as DG penetration continues to increase and microgrids become more prevalent, reliable islanding detection remains a key requirement for smart grid stability and resilience. The proposed method provides an effective solution for modern distribution systems and also establishes a basis for future research involving artificial intelligence, adaptive control strategies, and real-time intelligent monitoring for advanced islanding detection.

2 | Methodology

Islanding is a critical operating condition in distribution networks with high penetration of DG, occurring when a section of the network becomes electrically disconnected from the main utility grid while local DG units continue supplying connected loads [1–5]. In such situations, the Distribution System Operator (DSO) loses supervisory control over the isolated portion of the network, leading to the absence of coordinated voltage and frequency regulation. This condition can significantly degrade system stability, damage network equipment, and create serious safety hazards for maintenance personnel who may incorrectly assume that the

affected feeders are de-energized [6–9]. Traditionally, distribution networks were designed as passive systems with unidirectional power flow, and protection schemes were primarily intended to detect and isolate short-circuit faults. However, the large-scale integration of DG has fundamentally changed this paradigm by introducing bidirectional power flows and invalidating conventional protection assumptions [8–12]. As a result, advanced islanding detection techniques are required to ensure rapid and reliable identification of islanding events and timely disconnection of DG units from the grid. Unintentional islanding may result in several adverse consequences, including power quality degradation due to uncontrolled voltage and frequency variations, out-of-phase reclosing of circuit breakers, improper grounding conditions, and increased operational risks during maintenance activities [13–17]. These issues highlight the necessity for islanding detection methods that are not only fast and accurate but also robust under diverse operating conditions and compliant with international standards such as IEEE 1547 and VDE 0126 [18–27]. Motivated by these challenges, this study proposes a hybrid islanding detection framework tailored for modern distribution systems with heterogeneous DG technologies. The proposed approach aims to achieve high detection accuracy while minimizing the NDZ and ensuring compatibility with existing grid codes and protection requirements [19]. The following sections present the structure of the proposed algorithm, the selected electrical parameters for monitoring, and the decision-making logic used to identify islanding conditions under varying load-generation scenarios [20–26].

2.1 | Proposed Islanding Detection Method

2.1.1 | Operational principles

Under grid connected operating conditions, DG units are typically controlled to inject a constant active power while operating at or near unity power factor. In this mode, the main utility grid is responsible for regulating system voltage and frequency, and DG units follow grid-imposed reference signals [16–21]. As a result, voltage and frequency deviations at the PCC remain within narrow limits. Following an islanding event, the utility grid is disconnected and the responsibility for voltage and frequency regulation is transferred to local DG controllers. Consequently, DG units transition from grid following to grid forming or supporting operation, depending on their control structure. This transition results in measurable deviations in electrical parameters such as voltage magnitude, frequency, and active power balance, which form the basis for islanding detection. The operation of DG units under islanded conditions must comply with international interconnection standard, including IEEE 1547, which specify permissible limits for voltage magnitude, frequency deviation, harmonic distortion, and maximum allowable clearing times for abnormal operating conditions. Any violation of these limits requires prompt detection of islanding and timely disconnection of DG units to ensure system safety and equipment protection. The proposed detection method exploits the dynamic changes in voltage and active power behavior during this transition to reliably identify islanding events [25–27].

2.1.2 | The test system

The test system as in *Fig. 1* considered in this study consists of a 20 kV medium voltage distribution feeder connected to a 110 kV transmission grid through two 30 MVA step down transformers. The microgrid comprises four DG units and geographically distributed loads, representing a realistic medium voltage distribution network. Detailed parameters of transmission lines, load ratings, and DG unit specifications are provided in *Table 1* and *Table 2*. To accurately capture load behavior under islanding conditions, all loads are modeled using static exponential load models with combined voltage and frequency dependence. The active and reactive power consumption of the loads is expressed as *Eq. (1)* and *Eq. (2)*.

$$P = P_0 \left(\frac{U}{U_0} \right)^{n_P} \left(1 + F_P \frac{\Delta f}{f_0} \right). \quad (1)$$

$$Q = Q_0 \left(\frac{U}{U_0} \right)^{n_Q} \left(1 + F_Q \frac{\Delta f}{f_0} \right), \quad (2)$$

where P and Q denote the active and reactive power demands, respectively; U and f represent the instantaneous voltage magnitude and system frequency; P_0 and Q_0 are the nominal load powers at rated voltage U_0 and nominal frequency f_0 ; n_P and n_Q are voltage sensitivity exponents; and F_P and F_Q denote frequency sensitivity coefficients. This load modeling approach enables realistic representation of load generation interactions during islanding events and allows accurate evaluation of the proposed detection algorithm under varying voltage and frequency conditions. By incorporating both voltage and frequency dependent characteristics, the developed model ensures that the dynamic response of the microgrid closely reflects real world operating behavior.

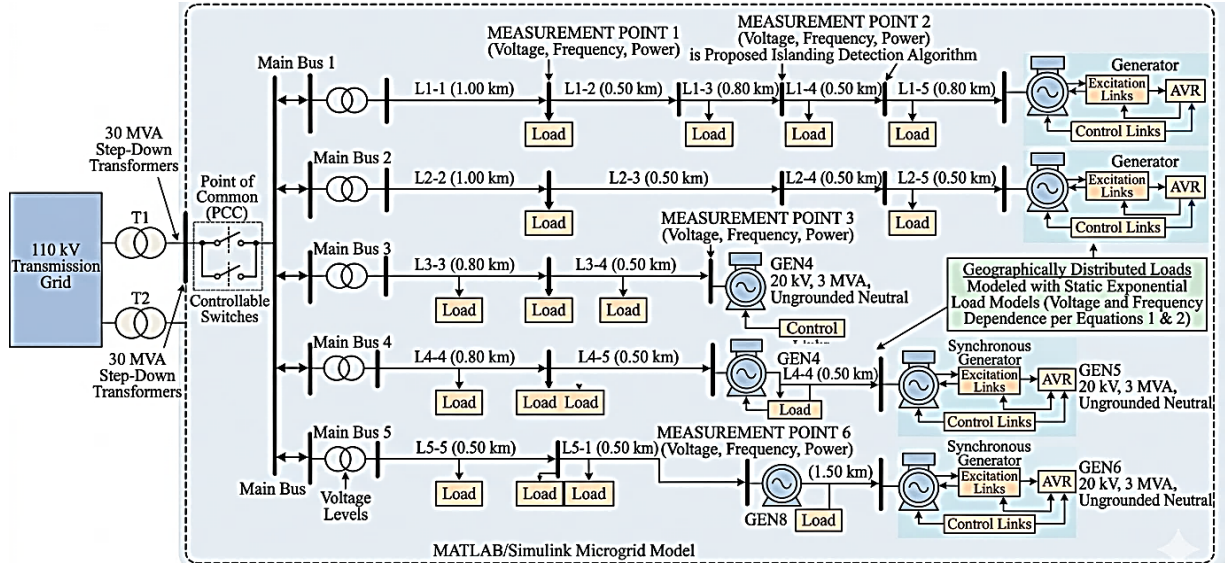


Fig. 1. Test system.

Table 1. System parameters.

Neutral Point	Rated Apparent Power (MVA)	Rated Nominal Voltage (kV)	Generator Name
Ungrounded	3	20	GEN1
Ungrounded	3	20	GEN2
Ungrounded	3	20	GEN3
Ungrounded	3	20	GEN4
Ungrounded	3	20	GEN5
Ungrounded	3	20	GEN6

Table 2. Line parameters.

Line Name	Length (km)	Line Name	Length (km)	Line Name	Length (km)
L1-1	1.00	L2-7	0.50	L4-3	1.00
L1-2	0.50	L2-8	0.70	L4-4	0.80
L1-3	0.80	L2-9	0.70	L4-5	0.50
L1-4	0.80	L2-10	0.70	L4-6	0.50
L1-5	1.00	L2-11	1.00	L5-1	0.50
L2-1	0.50	L3-1	1.00	L5-2	0.80
L2-2	0.50	L3-2	1.00	L5-3	0.80
L2-3	0.80	L3-3	1.00	L5-4	1.00
L2-4	1.00	L3-4	1.00	L5-5	0.70
L2-5	1.00	L4-1	1.50		
L2-6	1.00	L4-2	0.80		

3 | Detection Algorithm

The proposed islanding detection algorithm adopts a hybrid framework that combines passive monitoring with active perturbation to achieve fast, accurate, and reliable islanding identification while minimizing the NDZ. The algorithm operates by continuously monitoring electrical parameters at the PCC and applying a coordinated decision logic based on both voltage dynamics and active power response. In the passive method, the Rate of Change of Voltage (ROCV) at the PCC is monitored to detect abrupt voltage variations that typically occur following grid disconnection. Under normal grid connected operation, the stiff utility grid maintains voltage stability, resulting in minimal ROCV values. In contrast, islanding events induce noticeable voltage transients due to the loss of grid support. To enhance detection reliability under near power balance conditions, an active detection mechanism is incorporated. This stage introduces small, controlled disturbances into the system, such as capacitor bank switching or minor active power perturbations. When the microgrid remains grid connected, the main grid effectively damps these disturbances, leading to negligible changes in active power. However, under islanded conditions, the absence of grid damping causes the disturbances to persist, producing observable oscillations in active power, quantified as a change in active power (ΔP). A dual threshold decision logic is employed to determine the islanding condition. Islanding is declared only when both the ROCV and ΔP simultaneously exceed their predefined thresholds. This coordinated decision strategy significantly reduces false detections caused by load switching or transient disturbances and effectively minimizes the NDZ. The complete microgrid model and the proposed islanding detection algorithm are implemented in MATLAB allowing detailed time domain analysis and performance evaluation.

4 | Discussion

A smart microgrid incorporating diesel, gas, hydro, and wind DG units is modeled and simulated in MATLAB to rigorously evaluate the performance of the proposed hybrid islanding detection algorithm. The test system consists of an 11-bus distribution network with geographically dispersed loads and multiple DG units, each equipped with appropriate control mechanisms for voltage, frequency, and active/reactive power regulation, ensuring realistic dynamic behavior under both grid-connected and islanded conditions. The proposed detection scheme combines a passive indicator, namely the ROCV, with an active indicator based on active power variation (ΔP). This hybrid structure enhances detection reliability by exploiting both local electrical signatures and system-wide dynamic responses, thereby significantly improving sensitivity under a wide range of operating scenarios. To further assess the robustness of the method, a scenario dominated by synchronous generation is considered, in which four diesel generator units are connected to buses N2_4, N2_7, N2_9, and N2_11. These units operate at approximately 60% of their nominal capacity with a power factor close to 0.98, representing a realistic operating condition with limited reactive power mismatch. This configuration allows for a comprehensive evaluation of the proposed algorithm under both planned and unplanned islanding events, particularly in conditions where traditional passive methods often suffer from large NDZ. Simulation results demonstrate that the proposed hybrid algorithm achieves rapid and reliable islanding detection within the response time limits specified by international interconnection standards. Notably, the method exhibits a significant reduction in the NDZ compared to conventional approaches, maintaining high detection accuracy even under closely matched load-generation conditions and varying DG penetration levels. From a dynamic response perspective, the islanding event is characterized by distinct and coordinated deviations in system variables. Immediately following island formation, noticeable voltage dips are observed, especially at buses electrically closer to the DG units, due to sudden changes in power balance and network topology. Simultaneously, system frequency undergoes a sharp decline as a result of generation-load imbalance, followed by a gradual stabilization within approximately 2 seconds, consistent with standard operational limits (Figs. 2–6). These transient behaviors produce clear and distinguishable signatures in voltage, frequency, and active power profiles. In particular, the rapid variation in voltage magnitude enhances the sensitivity of the ROCV index, while the active power mismatch is effectively captured by the ΔP indicator. The complementary nature of these two indices enables the proposed hybrid algorithm to detect islanding events both quickly and

accurately, even under challenging conditions where individual methods may fail. Overall, the results confirm that the proposed scheme provides a robust, fast, and reliable solution for islanding detection in modern smart microgrids with diverse generation mixes and dynamic operating conditions. As shown in *Fig. 5* and *Fig. 6*, the dynamic responses of frequency and voltage under different operating scenarios (over-generation, critical, and hydro-only) clearly illustrate the impact of islanding at approximately $t \approx 2$ s. Prior to islanding, both frequency and voltage remain stable at their nominal values, indicating balanced operating conditions. Immediately after island formation, noticeable deviations occur due to the mismatch between generation and load. The frequency response shows that the Hydro-Only scenario experiences the largest oscillations (approximately 49.3–50.6 Hz), reflecting lower effective inertia and weaker frequency regulation capability, whereas the Over-Generation and Critical cases exhibit more damped and controlled behavior. Similarly, the voltage profile demonstrates a sharp dip followed by a mild overshoot, with the Over-Generation case showing slightly higher voltage rise due to excess power injection. In all scenarios, both frequency and voltage stabilize within approximately 2–3 seconds, confirming adequate system controllability and compliance with operational standards. These coordinated transient deviations in frequency and voltage provide distinct and reliable signatures that can be effectively exploited by the proposed hybrid islanding detection algorithm based on ROCV and active power variation (ΔP), ensuring fast and accurate detection even under diverse generation conditions.

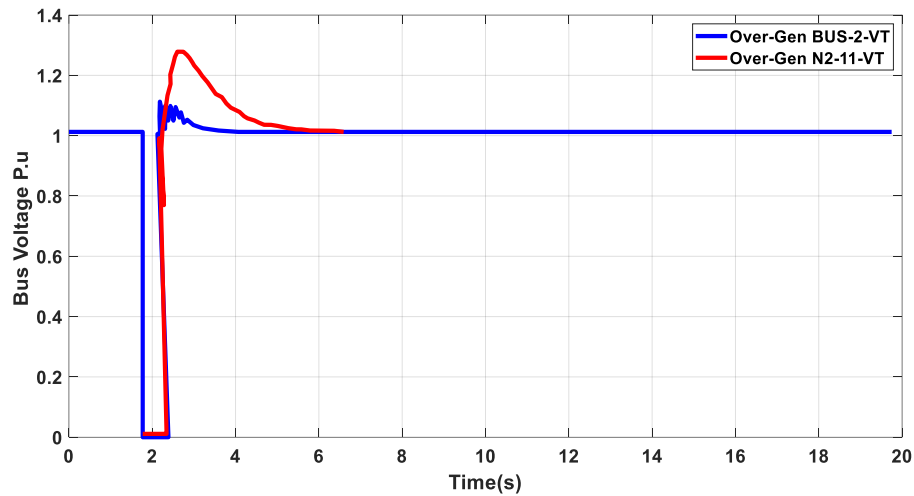


Fig. 2. Voltage variation of Loads 1, 2, and 3 supplied by Generator 1 under overgeneration conditions (generation exceeding demand).

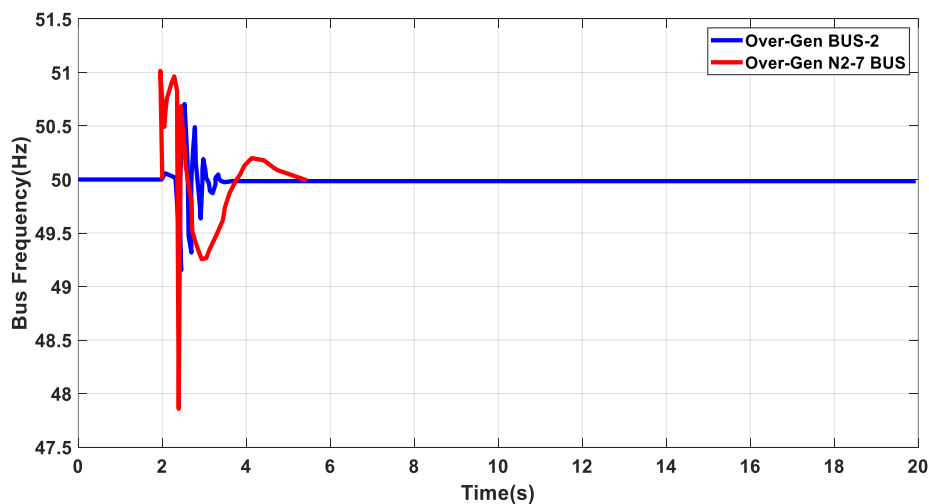


Fig. 3. Frequency variations of Buses 2 and 7 under overgeneration conditions (generation exceeding demand).

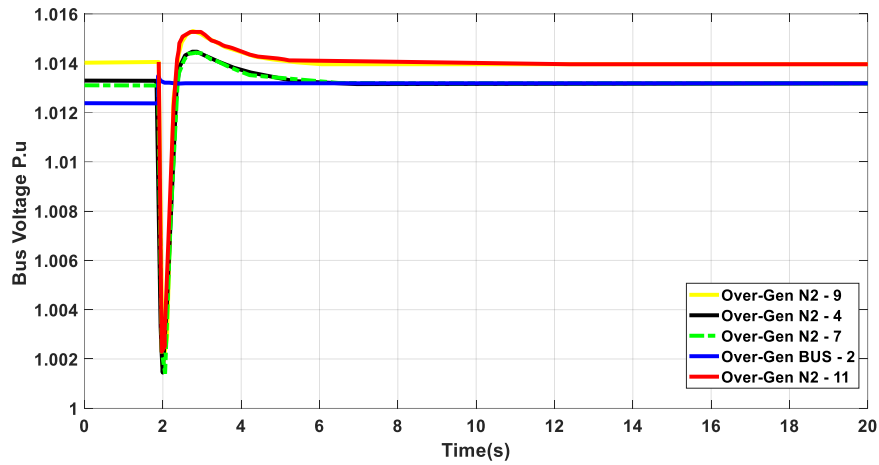


Fig. 4. Voltage variations of buses 2, 4, 7, 9, and 11 under overgeneration conditions (generation exceeding demand).

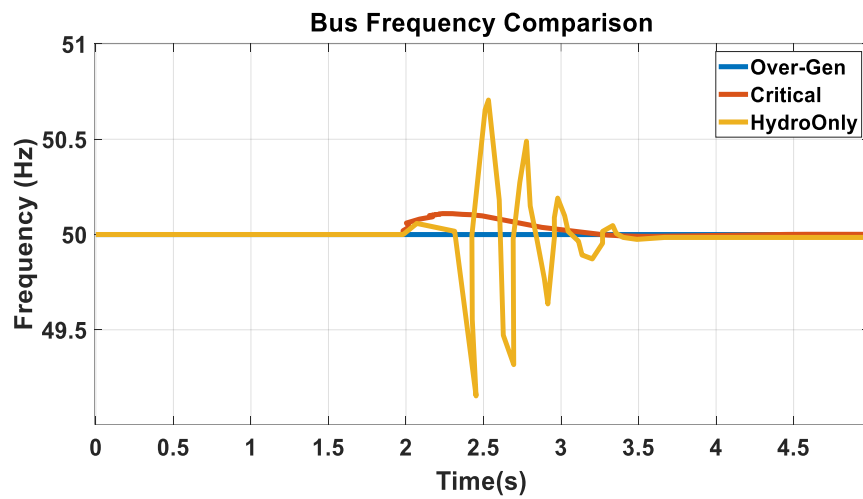


Fig. 5. Frequency variation under islanding detection.

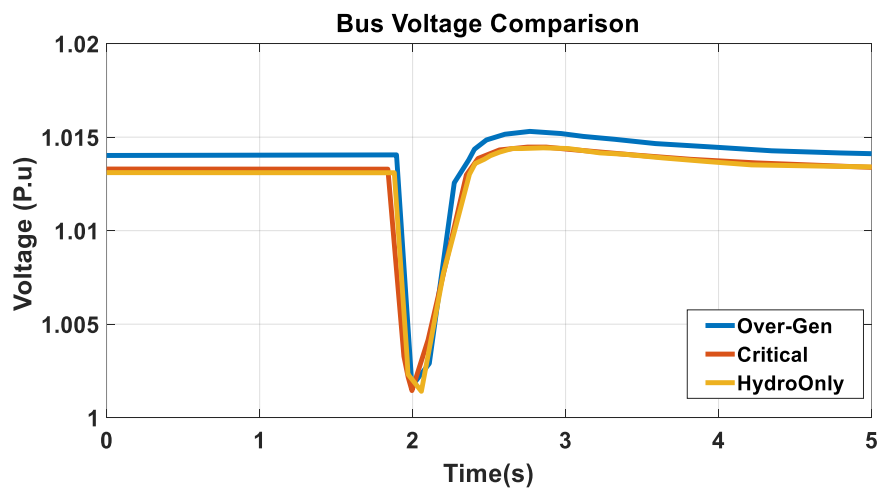


Fig. 6. Voltage variations under islanding detection.

5 | Conclusion

This study systematically investigated the dynamic behavior of a medium voltage distribution network with DG under both planned and unplanned islanding conditions. The results demonstrate that planned islanding can effectively maintain supply to critical loads, provided that appropriate coordination and protection strategies are in place. In contrast, unintentional islanding poses significant operational risks, underscoring the necessity of reliable anti-islanding protection schemes in modern distribution systems. Frequency dynamics were found to be primarily governed by active power imbalance and DG governor characteristics, while voltage variations were mainly driven by reactive power mismatch and DG technology. Among the evaluated DG types, diesel generators exhibited the most stable response, whereas gas and hydro units showed slower dynamics and larger deviations during islanding transitions. Generation scenarios further highlighted the influence of DG composition on system stability. Overall, the findings confirm that coordinated planned islanding enhances system resilience during grid outages and that DG technology selection plays a critical role in dynamic performance. This work provides practical insights for the design, operation, and protection of microgrids and active distribution networks, contributing to safer and more reliable integration of distributed energy resources in future smart grids.

Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

Funding

No funding was received to conduct this study.

Conflict of Interest

The author declares that in this paper, there is no conflict of interest.

Consent for Publication

The author has provided their consent for the publication of this manuscript.

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