Enhancing Microgrid Stability in Islanded Mode: Grounding Effectiveness Requirements and Overvoltage Mitigation Strategies

High Voltage Research Lab: Hung, Shuo-Fu; Chen, Yi-Wei; Liang, Wei-Chih

1. Introduction

As the energy transition progresses, microgrids have become a crucial solution for addressing the challenges of renewable energy intermittency and uncertainty. Since the release of the IEEE 2030.7 standard in 2017, the definition and functionality of microgrids have been specified. A microgrid must exhibit three key characteristics: clearly defined electrical boundaries, the capability to regulate internal resources, and the ability to operate independently in islanded mode. Islanded mode is one of the core functionalities of a microgrid, enabling stable and autonomous operation when disconnected from the main grid.

The dispatch and transition functions of a microgrid are critical to its operation. Dispatch functions include managing the transition between grid-connected and islanded steady-state modes, while transition functions cover processes such as unplanned islanding, planned islanding, black start, and grid reconnection. However, during the islanded mode, the lack of interconnection with the main grid can result in insufficient grounding paths, potentially causing overvoltage issues that pose risks to equipment safety. This study focuses on addressing the challenges associated with inadequate grounding effectiveness during microgrid islanded operations and proposes corresponding solutions.

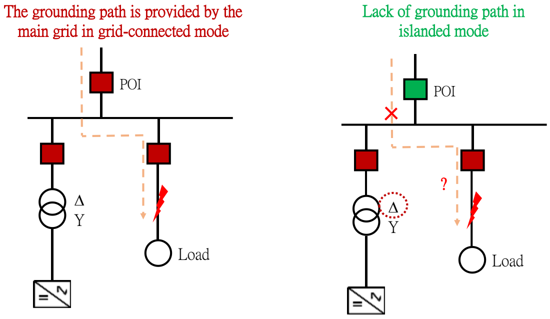
2. Research Methodology

In microgrids, the grounding paths differ significantly between grid-connected and islanded modes, as illustrated in Figure 1. In grid-connected mode, the neutral point of the distribution system provides stable and sufficient grounding support for the microgrid. This grounding path generates a fault current sufficient to activate protective devices during a ground fault. In contrast, in islanded mode, the absence of upstream grounding support can lead to inadequate grounding within the islanded microgrid. If the microgrid cannot provide sufficient grounding, the system's neutral point may shift, leading to the risk of overvoltage.

As depicted in Figure 2, the overvoltage issues in microgrids operating in islanded mode can be categorized into two types:

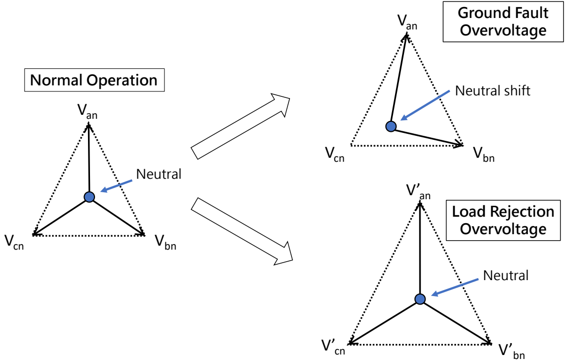
(1) Ground Fault Overvoltage (GFOV): This occurs due to a single-phase ground fault, where the voltage neutral point becomes equal to the faulted phase voltage, causing the voltages of the non-faulted phases to rise, potentially reaching up to $\sqrt{3}$ times their nominal value.

(2) Load Rejection Overvoltage (LROV): This occurs due to a mismatch between generation and load in islanded mode, often leading to simultaneous three-phase voltage fluctuations.



Source: TPRI

Figure 1. Grounding Paths of Microgrids in Grid-Connected and Islanded Modes

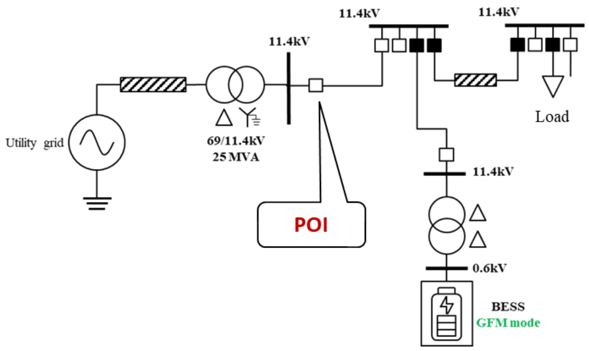


Source: EPRI, Effective Grounding for Inverter-Connected DER, 2021. Product ID: 3002020130

Figure 2. Overvoltage Conditions in Islanded Modes

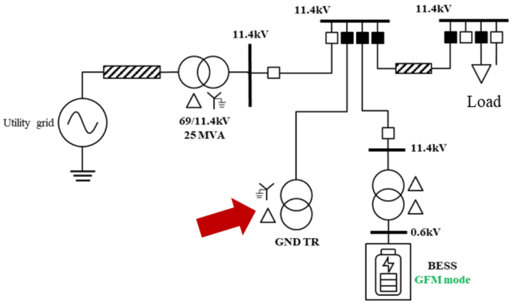
This study conducts simulations using a feeder-based microgrid equipped with energy storage, as illustrated in Figure 3, to evaluate the impact of ground faults and improvement strategies for microgrids in islanded mode. In the simulations, the microgrid transitions from grid-connected to islanded mode, with electricity supplied by the energy storage system. The analysis focuses on potential scenarios such as single-phase ground faults and unbalanced loads in islanded mode.

For ground fault analysis, the simulations include variations in fault impedance and location to observe changes in system voltage and current. To address the overvoltage issues that may arise from insufficient grounding, the study considers installing a Yg-Δ grounding transformer, as shown in Figure 4. By adjusting the neutral point impedance parameters on the Yg side of the transformer, the study explores its impact on improving system stability and voltage characteristics.



Source: TPRI

Figure 3. Schematic Diagram of a Feeder-based Microgrid

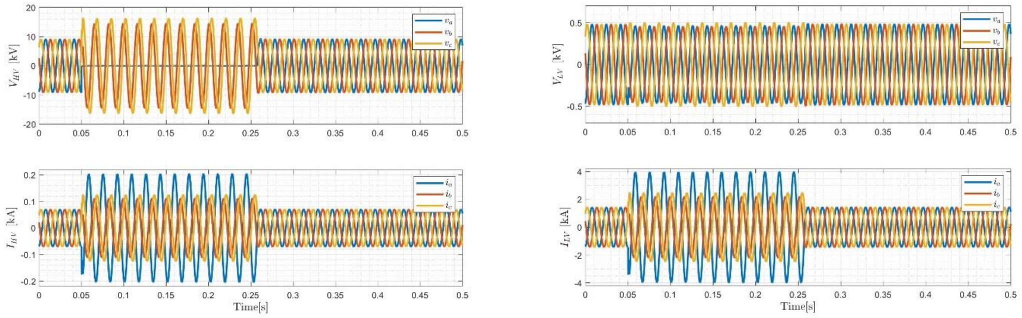


Source: TPRI

Figure 4. Schematic Diagram of the Microgrid with Yg-Δ Grounding Transformer

As shown in the simulation results in Figure 5, ground faults in islanded mode cause the voltage of the non-faulted phases on the high-voltage side to rise significantly, reaching up to 1.7 pu. In contrast, due to the characteristics of the energy storage system, voltage fluctuations on the low-voltage side are relatively smaller. Under unbalanced load conditions, as illustrated in Figure 6, unbalanced single-phase loads lead to severe voltage imbalances, further threatening the safety of system equipment.

Figures 7 and 8 show that installing a Yg-Δ grounding transformer effectively mitigates the overvoltage issue, resulting in more stable voltages across the system. However, including the grounding transformer increases fault current, necessitating optimizing protective device settings to ensure system reliability under different operating modes.

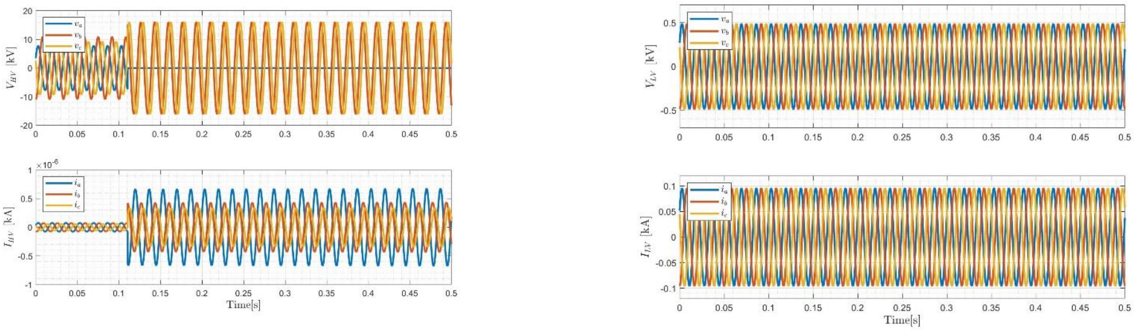


Source: TPRI

(a) Voltage and Current on the 11.4kV Side

(b) Voltage and Current on the 0.6kV Side

Figure 5. Single-Phase Ground Fault without Grounding Transformer

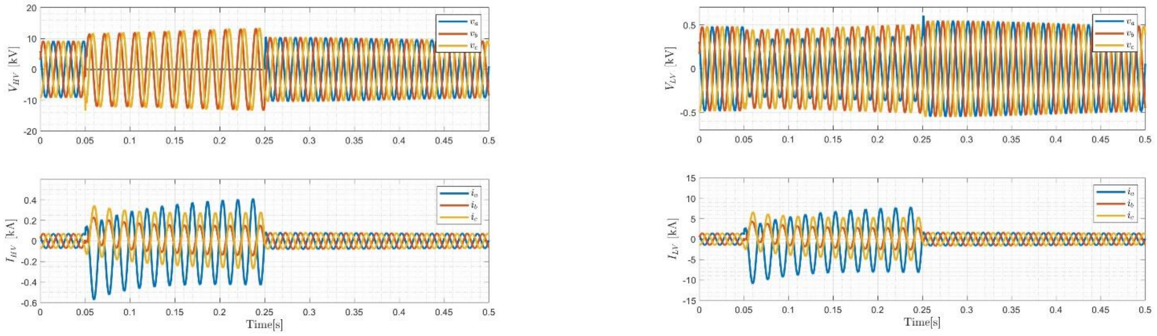


Source: TPRI

(a) Voltage and Current on the 11.4kV Side

(b) Voltage and Current on the 0.6kV Side

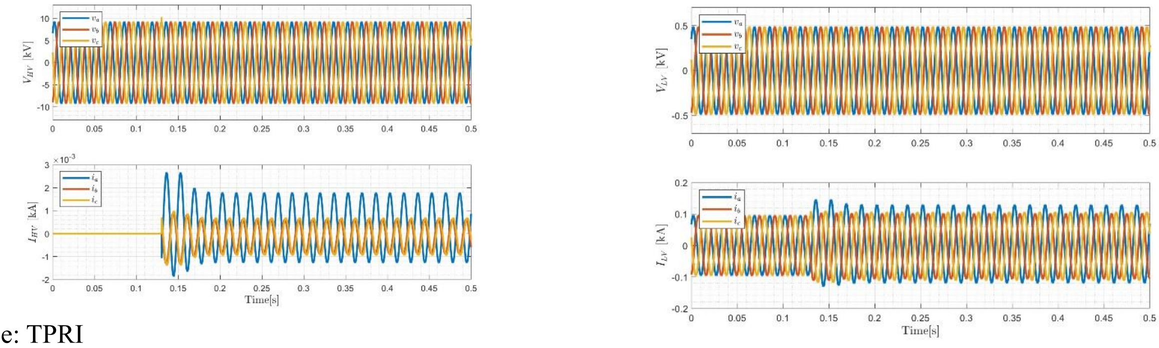
Figure 6. Unbalanced Load Conditions without Grounding Transformer



Source: TPRI

(a) Voltage and Current on the 11.4kV Side (b) Voltage and Current on the 0.6kV Side

Figure 7 Single-Phase Ground Fault with Grounding Transformer



Source: TPRI

(a) Voltage and Current on the 11.4kV Side (b) Voltage and Current on the 0.6kV Side

Figure 8 Unbalanced Load Conditions with Grounding Transformer

3. Conclusion

This study analyzes the overvoltage issues caused by insufficient grounding in microgrid islanded mode and examines the application of grounding transformers. The results indicate that grounding transformers can effectively mitigate overvoltage risks and enhance the stability of microgrids. However, grounding transformers must consider the impact of increased fault current on protective devices. Therefore, future studies should optimize grounding design and protection configurations simultaneously to ensure the reliability and safety of microgrids in islanded mode.