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A Novel Approach for Secure Hybrid Islanding Detection Considering Dynamic Behavior of Power and Load in Electrical Distribution Networks

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Abstract

The increasing integration of distributed generators (DGs) such as solar photovoltaic systems, wind turbines, and micro-hydro plants is transforming conventional power distribution networks into decentralized and resilient systems. While this paradigm shift enhances grid efficiency and sustainability, it also introduces critical operational challenges, particularly the risk of unintentional islanding. Islanding occurs when a section of the grid, still powered by DGs, becomes electrically isolated from the main utility supply, posing safety and equipment hazards. To address this issue, the present study proposes a secure hybrid islanding detection method (IDM) that synergizes the advantages of both passive and active detection techniques. The developed method integrates two sensitive passive indicators—the rate of change of active power (dp/dt) and reactive power (dq/dt)—with an active Load Connecting Strategy (LCS). The passive components provide continuous monitoring, while the active approach confirms islanding conditions through controlled perturbation. The proposed IDM was validated using an 11 kV distribution feeder model of Jumla District, incorporating both synchronous generator-based and inverter-based DGs. Comprehensive MATLAB/Simulink simulations under various islanding and non-islanding scenarios demonstrated rapid and accurate detection performance, achieving response times within the 2-second international standard limit and maintaining robustness against false trips. The findings confirm the method's effectiveness and reliability, offering a promising solution for enhancing safety and operational integrity in modern DG-integrated power systems.

Keywords: islanding detection • synchronous generator • distributed generator • rate of change of power • non-detection zone

1. Introduction

Distributed Generation (DG) refers to decentralized, small-scale power generation systems located close to the point of consumption. Typically utilizing renewable energy sources such as solar photovoltaics, wind turbines, and micro-hydro plants, DG systems enhance energy reliability and efficiency while supporting sustainable

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development. The integration of energy storage systems within DG frameworks further improves supply stability and demand management, making DG a viable alternative to traditional centralized power generation (Jhuma et al., 2022). DG systems can operate either in isolated mode, providing electricity to off-grid communities, or in grid-connected mode, where they contribute power to the main utility grid. In developing regions such as Nepal and Bhutan, DGs play a vital role in electrifying remote areas where extending the national grid is economically or geographically impractical.

Despite these benefits, renewable-based DG systems face operational challenges including intermittency of renewable sources, high installation costs, and maintenance difficulties (Jhuma et al., 2020; Chandio et al., 2019). A major technical issue in grid-connected DG operation is unintentional islanding, a condition where a section of the distribution network remains energized by DGs even after disconnection from the main grid. This poses risks to utility personnel, damages equipment, and affects system stability. Therefore, fast and reliable islanding detection methods (IDMs) are crucial to ensure safety and compliance with IEEE and IEC standards (4, 2008; Dugan et al., 2006; Ninad et al., 2020).

Although numerous IDMs—active, passive, and hybrid—have been developed, most existing methods suffer from limitations such as large non-detection zones (NDZs), slow response times, and dependency on system parameters (7, 2016; Kurukuru et al., 2021). These shortcomings are particularly critical for DG systems operating under low loading conditions and long feeder configurations, common in Nepal's rural distribution networks.

To address these gaps, this research develops a hybrid islanding detection method that combines the simplicity of passive techniques with the accuracy of active ones. The proposed approach integrates rate-of-change parameters with a Load Connecting Strategy (LCS) to improve sensitivity and minimize NDZ while maintaining system stability. The study specifically focuses on the Jumla District of Nepal, where micro-hydro and solar PV systems are modeled under different operational modes.

This paper is organized as follows: Section 2 presents the background and problem statement; Section 3 outlines the research objectives and methodology; Section 4 discusses simulation results and analysis; and Section 5 concludes with key findings and recommendations for future research.

2. Literature Review

Over the years, various islanding detection methods (IDMs) have been developed to ensure the safe and reliable operation of distributed generation (DG) systems. These methods are generally classified as remote or local, depending on their application and operational principles (4, 2008; Dugan et al., 2006; Ninad et al., 2020; 7, 2016). Remote IDMs rely on communication between DG units and the utility grid, providing high accuracy and reliability. However, their implementation is complex and costly, limiting their practicality for community-based DG systems common in developing countries such as Nepal (Khan et al., 2022; Jang and Kim, 2004).

To overcome these challenges, local IDMs have been introduced, which include both active and passive approaches. Active IDMs inject intentional disturbances into the system to identify islanding conditions, resulting in small non-detection zones (NDZs) but often degrading power quality [19–24]. Passive IDMs, in contrast, monitor system parameters such as voltage, frequency, power, and harmonic distortion at the point of common coupling (PCC). They are cost-effective, simple to implement, and suitable for various network configurations, though they can have larger NDZs and reduced sensitivity under balanced load conditions (Kurukuru et al., 2021; Khan et al., 2022; Reddy and Reddy, 2019).

To address the limitations of individual approaches, hybrid IDMs have been developed by combining active and passive techniques or incorporating intelligent and signal-processing algorithms. These methods improve detection accuracy and reduce NDZs, enhancing the reliability of the distribution network (Rostami et al., 2016; Mlakic et al., 2019; Paiva et al., 2020; Ahmadipour et al., 2019). However, they still involve higher computational demands and increased implementation complexity (Laghari et al., 2013). Recent studies (Jhuma et al., 2022; Laghari et al., 2013) propose hybrid methods combining the rate of change of power (ROCOP) and Load Connecting Strategy (LCS), achieving faster and more reliable detection. This research builds upon these advancements to develop a practical, low-cost hybrid IDM suitable for DG systems in low-load, long-feeder distribution networks of Nepal.

3. METHODOLOGY

The research work can be segregated into three distinct parts which are DG modeling, modeling of control system for ROCOAP-ROCORP and LCS and lastly performance evaluation of proposed IDM

3.1 Control system for three-phase inverter-based PV

i) Grid connection/Grid following mode In this mode, the grid regulates voltage and frequency, while the inverter operates under P–Q control to deliver constant power. Load variations are managed by the grid. The control system adjusts the magnitude and phase angle of the inverter current using two loops: an inner repetitive controller for precise waveform tracking and an outer decoupled controller for independent P and Q regulation. The outer loop generates the reference voltages for the inner control.

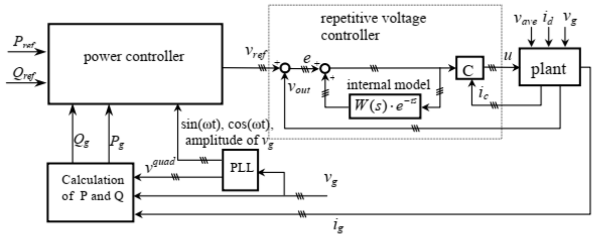


Figure 1: Block Diagram of Two-Level Control System

ii) Isolate mode/ Grid forming mode: In this operating mode, the DERs function independently without grid connection, meaning voltage and frequency regulation must be handled locally. The controller is designed to produce voltage and frequency according to predefined reference values, allowing the DERs to supply power to the connected local loads.

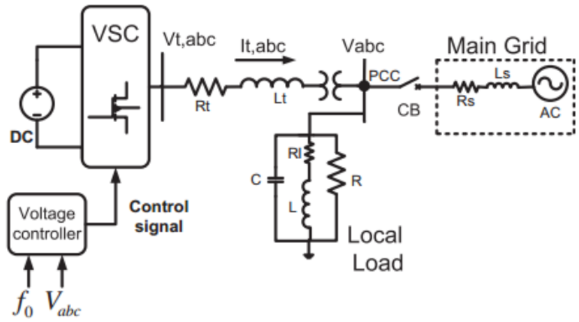


Figure 2: Isolated Operation of Inverter based DERs

3.2 Modelling of Micro hydro

The micro-hydro system is modeled in grid-following mode, delivering constant active (P) and reactive (Q) power to the grid. Its control structure includes a voltage control loop that regulates the system to produce the desired reactive power based on a fixed reference voltage. For active power control, the built-in governor maintains the specified reference value consistently. The configuration of this system is illustrated in Figure below.

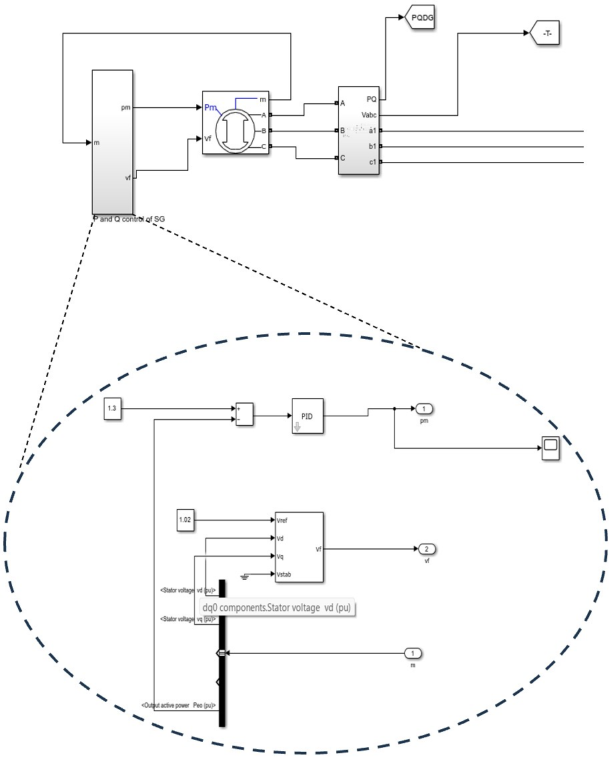


Figure 3: Micro-hydro System Configuration

3.3 Modelling of proposed Hybrid Islanding Detection Strategy

i) Active Power Method It is one of the methods of passive IDM. In this method, the power of a three-phase system is measured at PCC and is given by Equation (1).

$$P = \sqrt{3} \times V_{LL} \times I_L \times \cos\phi \tag{1}$$

In this method, the system stays connected if the measured ROCOAP is below the set threshold. ROCOAP values are derived by differentiating Equation (3). When ROCOAP exceeds the threshold, IDM modules signal the DG breakers to disconnect. However, if the load demand closely matches DG output, minimal oscillations occur, preventing the IDM from activating islanding detection and keeping the DGs connected.

ii) Reactive Power Method It is another passive IDM like active power method, only exception is that it acts on the value ROCORP. The sensitivity of ROCORP is generally higher than that of ROCOAP. The reactive power equation of ROCORP at the PCC is given by Equation (4).

$$Q = \sqrt{3} \times V_{LL} \times I_L \times \sin\phi \tag{2}$$

iii) IDM Final Stage including ROCOAP, ROCORP and LCS In this study, a hybrid IDM combining two passive and one active methods is developed, as illustrated in Figure below. At each sampling interval, dp/dt and dq/dt represent the measured ROCOAP and ROCORP, compared against their respective threshold limits for islanding detection. First, dp/dt is evaluated; if it exceeds the threshold, dq/dt is then checked. When both values surpass their limits, the DGs are disconnected. If dq/dt remains below the threshold, the LCS is activated for further verification, where a small R–L load is applied to accelerate power variation and recheck dp/dt and dq/dt.

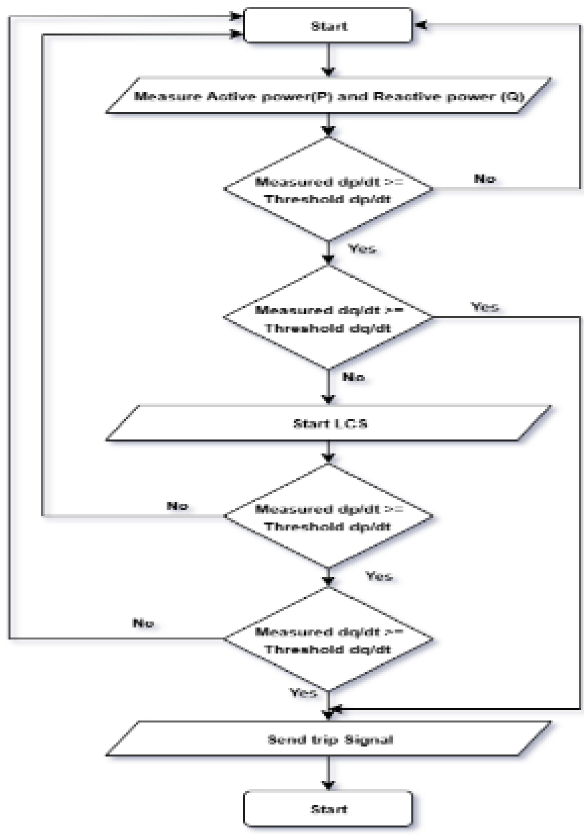


Figure 4:

4. Testbed under study

The performance of the proposed IDM is evaluated with the DERs connected to the 11kv feeder emerging from the 33/11 kV substation in Jumla

District. The developed system consists of a synchronous generator(micro-hydro), a photovoltaic (PV) generation system, loads, including LCS. The simulation scenario mimics the addition of the small PV plant with the existing micro hydro connected with the 11kv distribution feeder, 50kw as base power. Figure below shows the test frame satisfying the IDM operation as per the IEEE 1547 standard.

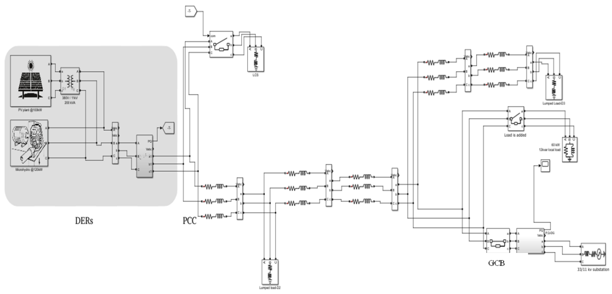


Figure 5: 11kV system and DERs connection test frame

5. Simulation Results

Various cases have been considered to verify the performance of the proposed IDM on the MATLAB platform in an 11kv system. Seven case studies are considered to examine the performances of the module under islanding and non-islanding cases to see whether the module can identify islanding cases as islanding and non-islanding cases as non-islanding, or mistakenly take a non-islanding as islanding. The threshold values were set according to the distribution system and DG responses. The module compares the instantaneous result with the given threshold to check the difference that occurs when the system enters the islanding mode, or in the case of other phenomena.

5.1. Case 1: Grid Supply Disconnected for Intentional Islanding Operation

For this case the grid circuit breaker (GCB) disconnects at t=2s to check the module's functionality in case of the islanding detection. The associated simulation waveform is depicted in Appendix Figure below. It is seen from the ROCOAP is measured as 32.5MW/s and ROCORP as 100Mvar/s which exceeds the threshold value as stated in Appendix 8.1.5 above at t=2s hence the PV and micro hydro are disconnected at t=2.015s.

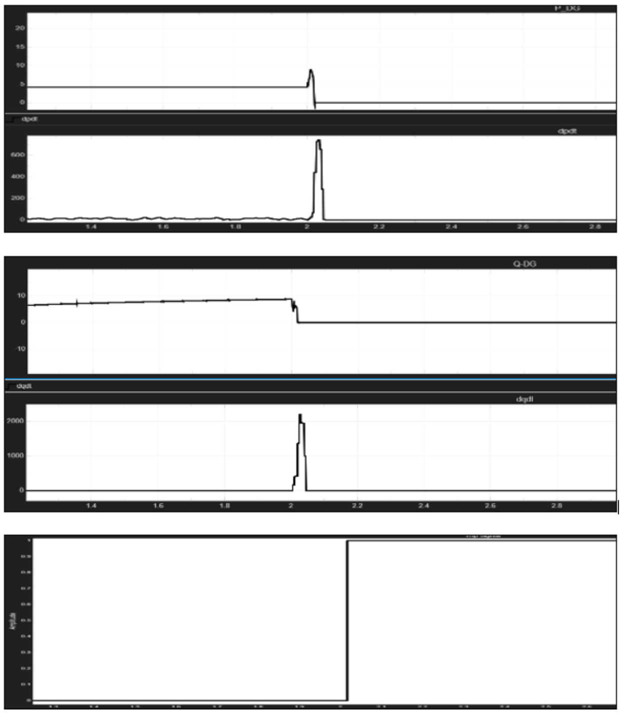


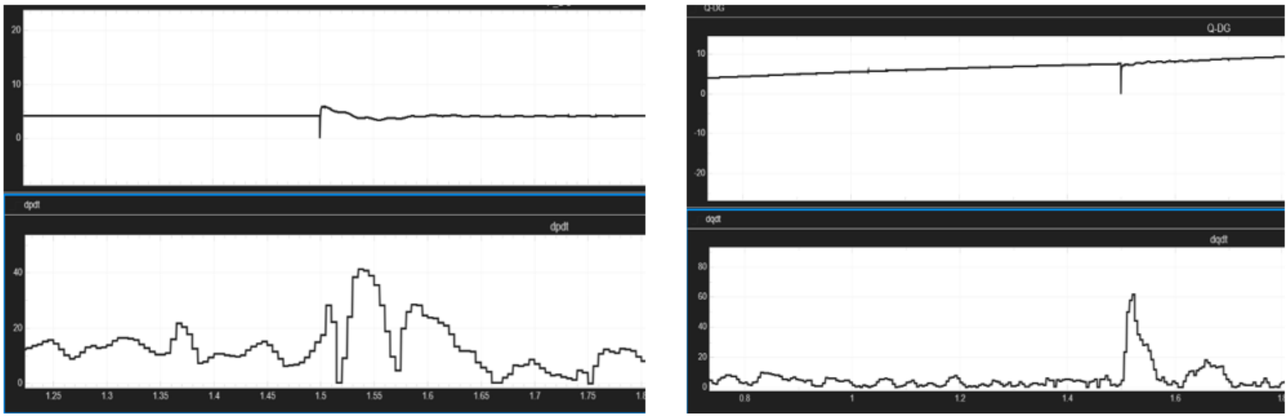
Figure 6: ROCOAP, ROCORP and Trip Signal-Case-1

5.2. Case 2: Fault Analysis

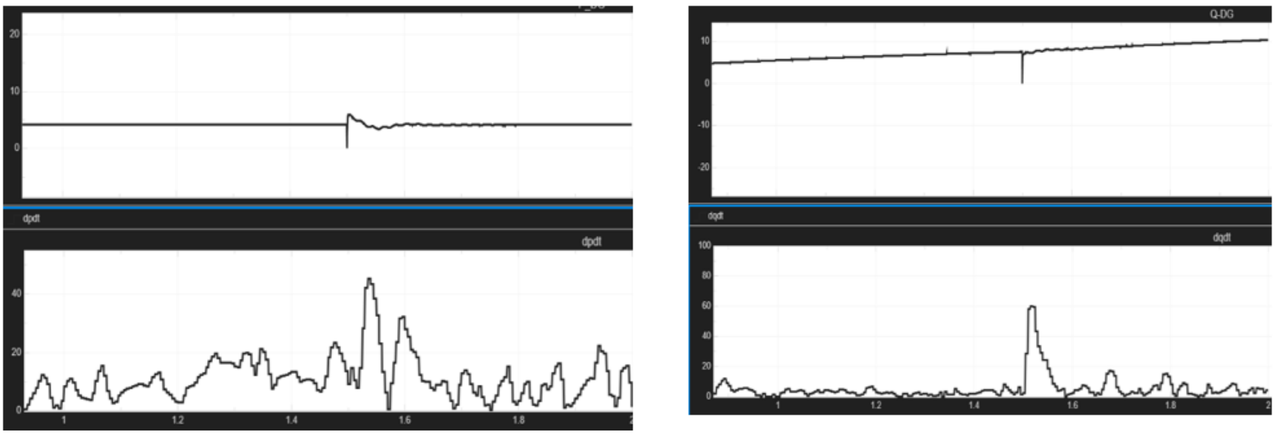
Different fault case scenarios are applied to the first bus from the 33/11 kv substation of the system model at t=1.5. Measured values of dp/dt and dp/dt are listed in the Table below. In case of fault analysis measured value of ROCORP is greater than the threshold value, however ROCOAP does not exceed the threshold value and as shown in Figure, the algorithm does not initiate until the Active power criteria is satisfied.

Table 1: Summary Table – Case 2

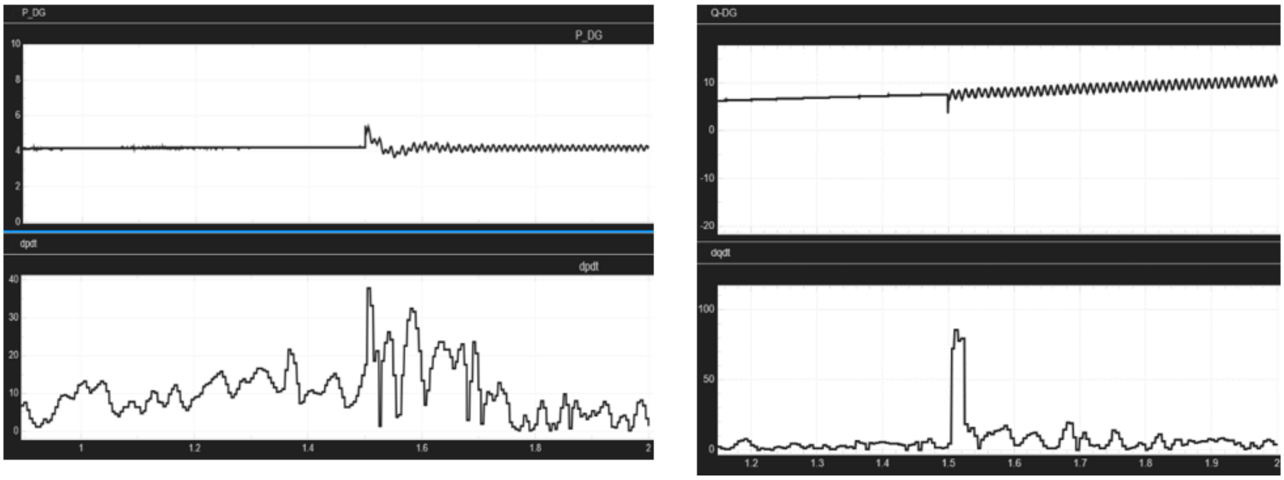
S.N.	Fault Type	Ground Resistance (Ω)	Fault Resistance (Ω)	dp/dt (MW/s)	dq/dt (MW/s)	Remarks
1	LLLG	1	0.5	2.00	3.10	IDM is not activated
2	LLLG	0.5	0.5	2.15	3.05	IDM is not activated
3	LLG	1	0.5	1.80	3.75	IDM is not activated
4	LLG	0.5	0.5	1.90	4.90	IDM is not activated
5	LG	1	0.5	1.00	0.80	IDM is not activated
6	LG	0.5	0.5	1.15	1.40	IDM is not activated
7	LL	NA	0.5	1.85	4.25	IDM is not activated



A. ROCOAP, ROCARP for LLLG fault with Rg = 1 ohms



B. ROCOAP, ROCORP for LLLG fault with Rg = 0.5 ohms



C. ROCOAP, ROCORP for LLG fault with Rg = 1 ohms

5.4. Case 4: Addition of load to the system

In this case the load is added at first bus from the 33/11kv substation to the system at t=1s without the islanding condition. The addition of the load changes the quantities that triggers the passive detection mechanism, but the IDM needs to recognize that these conditions are not islanding conditions. For its different magnitudes of load are added to the system.

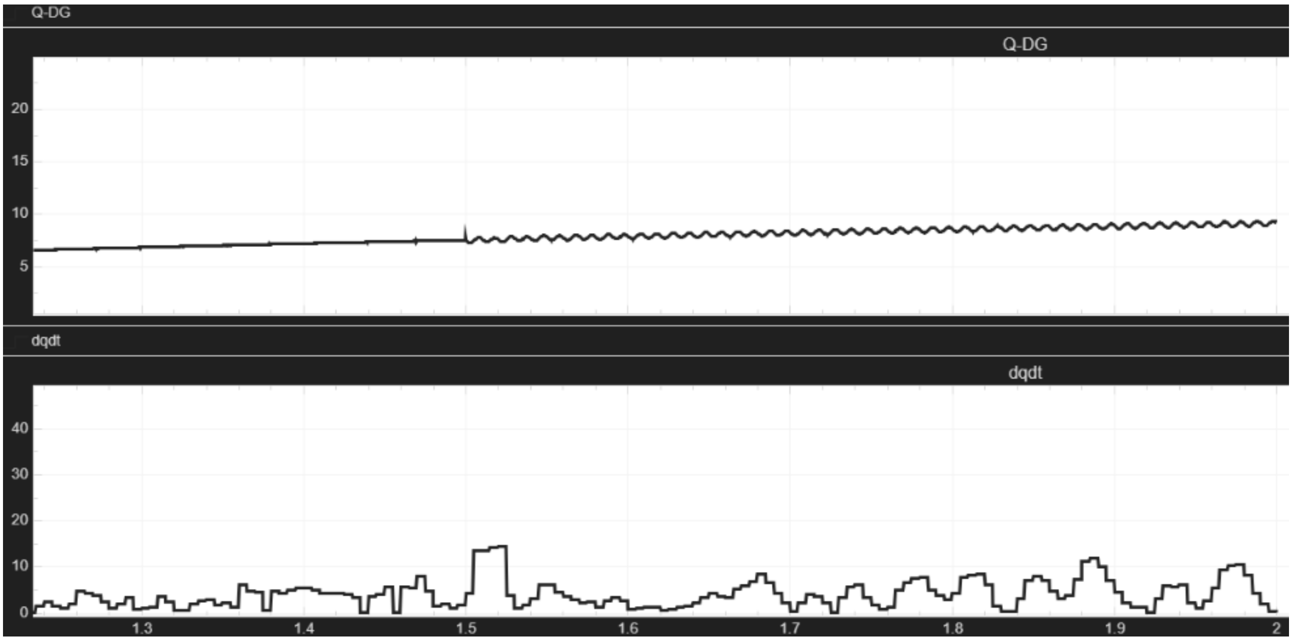


Figure 7: Load Addition Test Results

5.5 Case 5: DG Disconnection

In case where DERs are connected to the distribution level the trappings of the DGs are so often and impose serious issues. During disconnection of one of the DGs the change in the parameters at PCC occurs which triggers passive IDM. Hence it is to be assured that whenever one of the DGs trips the IDM should differentiate that it is not the islanding case and the remaining system shall remain intact. For this case the ROCOAP and ROCORP threshold values are set to 15MW/s and 7.6MVar/s respectively. The PV plant is set to get disconnected at t=1s. The ROCOAP and ROCORP measured are 12.5 MWs and 7.2MVar/s respectively, hence IDM is not triggered.

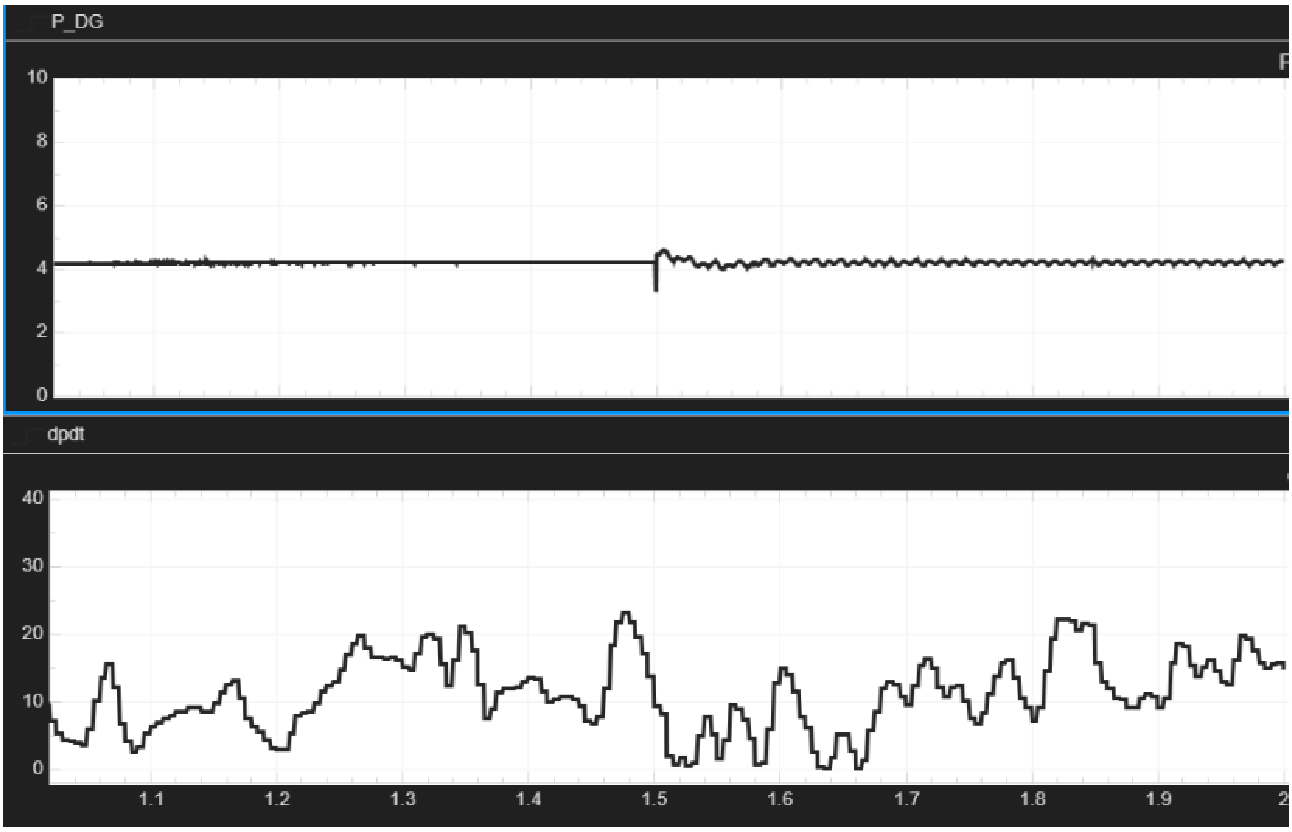


Figure 8: DG Disconnection Test Results

5.6 Case 6: Capacitor connection

To improve the voltage profile of the feeder and the power factor the capacitor banks are connected to the feeder at the 33/11kv substations. During the connection the passive parameters of the system changes and may falsely trigger the IMD. For this the capacitors of 100kvar, 300kvar and 1MVar are connected at the substation and the performance of the IDM is evaluated. Following results are observed. For it the capacitor bank is connected at t=1s and the ROCOAP, ROCORP value at that instant are observed.

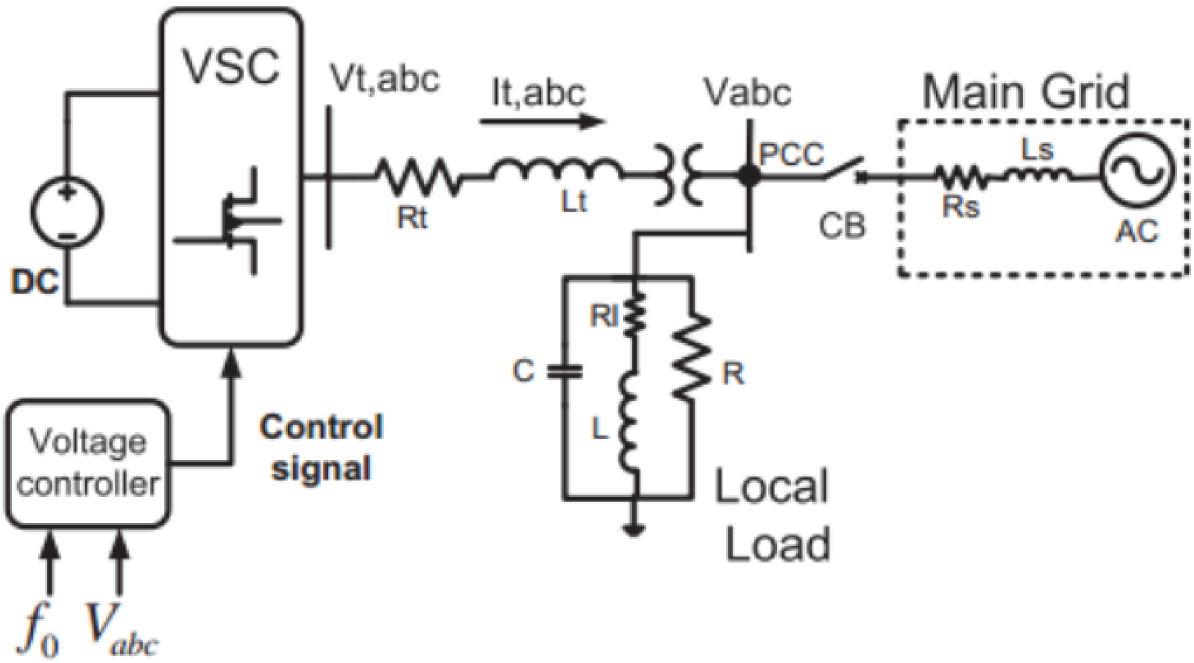


Figure 9: Capacitor Connection Test Results

6. Conclusion

As technology advances, new energy resources continue to emerge, shifting power generation from large, centralized plants toward spatially distributed sources. For developing countries like Nepal, integrating distributed energy resources (DERs) into the national grid is essential for achieving long-term economic sustainability. However, grid interconnection introduces several technical challenges, among which islanding detection is one of the most critical. In rural regions, the most suitable islanding detection methods are those that are technically simple and economically affordable. The method proposed in this thesis combines the responsiveness of passive IDMs with the smaller non-detection zone (NDZ) of active methods. By using a simple additional load instead of complex hardware, the method reduces implementation cost while maintaining reliability. The study demonstrates that decoupled power control enables smooth transitions of inverter-based DERs between grid-following and grid-forming modes. The proposed hybrid IDM performs effectively when thresholds are carefully selected based on system characteristics. Additionally, the Load Connecting Strategy (LCS) enhances sensitivity when passive indicators alone are insufficient. Future work may focus on improved control designs, machine-learning-based classification, reduced computational delay through advanced hardware, and integrated monitoring and control frameworks for complete microgrid operation.

7. Appendix: System Parameters

7.1 PV Plant

- Rated Power: 50 kW
- DC Voltage: 600 V
- AC Voltage: 400 V, 50 Hz

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