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Implementation of the Hybrid Islanding Detection Method Considering the Dynamic Behavior of Power and Load: A Case Study in Rural Nepal

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Abstract

As more distributed generators, such as solar panels, wind turbines, and micro-hydro plants, are added to power networks, these systems are becoming more decentralized and resilient. Although this change improves grid efficiency and sustainability, it also brings new challenges, such as the risk of unintentional islanding. Islanding occurs when a part of the grid powered by distributed generators becomes separated from the main utility, which can create safety and equipment risks. To address this, our study introduces a secure hybrid islanding detection method that combines passive and active detection techniques. The method uses two passive indicators–the rate of change of active power (dp/dt) and reactive power (dq/dt) along with an active load-connecting strategy. The passive indicators continuously monitor the system, whereas the active method confirms islanding by making controlled changes. We tested this method on an 11-Kv distribution feeder model from the Jumla District, using both synchronous and inverter-based distributed generators. MATLAB/Simulink simulations in different scenarios showed that the method detected islanding quickly and accurately, with response times under the 2-s international standard and strong resistance to false alarms. These results suggest that our method is effective and reliable, helping to make power systems with distributed generators safer and more robust.

Keywords: Islanding Detection • Synchronous generator • Distributed generator • Rate of change of power • Non-detection zone

1. Introduction

Distributed generation (DG) refers to small power plants set up near where electricity is needed. These systems often use renewable sources, such as solar panels, wind turbines, or micro-hydro plants. DG makes electricity supply more reliable and efficient, and supports clean energy goals.Reddy and Reddy (2019) Energy storage is often added to DGs to help balance the supply and demand. Owing to these benefits, DG is becoming a strong alternative to large central

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power stations. DG systems can operate in two ways: in an isolated mode for off-grid areas or connected to the main grid.Jhuma et al. (2022) In countries like Nepal and Bhutan, DG is especially helpful for bringing electricity to remote places where expanding the national grid is difficult or costly.ElNozahy and Salama (2013)

Although DG systems powered by renewable energy have several benefits, they face several challenges. Solar and wind power are not always stable because they depend on the weather. In addition, the installation and maintenance of these systems can be expensive.Jhuma et al. (2022); 4 (2008); Jhuma et al. (2020) Another key issue for grid-connected DGs is unintentional islanding. This occurs when a portion of the network continues to receive power from the DG units, even after being disconnected from the main grid. Islanding can be dangerous for utility workers, damage equipment, and affect the stability of power systems. Therefore, it is important to quickly detect islanding and disconnect the DG from the grid. Islanding detection methods must meet safety regulations and international standards, such as those established by the IEEE and the IEC.4 (2008); Dugan et al. (2006); Ninad et al. (2020) Several methods have been developed to detect islanding and ensure the safety of DG systems. These methods are generally grouped into two types: remote and local. Remote methods use communication between DG units and the utility grid. Although they can be accurate and reliable, they require additional communication systems and are more expensive to install.Rostami et al. (2017); Mlakic et al. (2019); Paiva et al. (2020); Ahmadipour et al. (2019) Therefore, remote methods are not always suitable for small DG systems, which are common in countries such as Nepal.

Local islanding detection methods are widely used to reduce these difficulties. These methods are further divided into active and passive methods. Active methods introduce small disturbances into the system to detect islanding conditions. These methods usually have a small undetected zone; however, they may degrade system power quality.Kurukuru et al. (2021); Khalaf and Sekhar (2016) Passive methods, in contrast, observe electrical parameters, such as voltage, frequency, power, and harmonics, at the point of common coupling. Passive methods are simple, inexpensive, and easy to implement in different power networks.Reddy and Reddy (2019); Kurukuru et al. (2021); Khan et al. (2022) However, they may have larger undetected zones and may fail to detect islanding when the generated power is almost equal to the load demand. To improve islanding detection, researchers have developed hybrid methods that combine active and passive techniques. These hybrids can reduce the undetected zone and improve detection accuracy. Some studies have also used signal processing and smart techniques to increase reliability. However, many of these methods require complex calculations and more computing power. Recently, some studies have suggested using the rate of change of power along with a load-connecting strategy (LCS) for faster and more reliable islanding detection.Rostami et al. (2017); Mlakic et al. (2019); Paiva et al. (2020); Ahmadipour et al. (2019); Gupta et al. (2015); Reddy and Sreeraj (2020); Laghari et al. (2013)

Although several methods exist, some have issues such as slow response, large undetected zones, and reliance on system conditions. These problems are more severe in distribution systems with long feeders and low loads, which are common in rural Nepal.4 (2008); Dugan et al. (2006); Ninad et al. (2020); Chandio et al. (2019) Therefore, a simple and reliable islanding detection method that performs well in these situations is required. To address this issue, in this study, we propose a hybrid islanding detection method that combines passive and active techniques. This method uses the rate of change of power and a load-connecting strategy to improve detection and reduce the non-detection zone while maintaining system stability.Jhuma et al. (2020); Laghari et al. (2013) We tested the method on a model with micro-hydro and solar power connected to an 11 kV feeder in the Jumla District, Nepal.Khan et al. (2022); Jang and Kim (2004)

The remainder of this paper is structured as follows: Section 2 describes the methodology of the study, Section 3 presents the simulation results and discussion, and Section 4 provides conclusions and ideas for future work.

2. Methodology

This study is organized into three main sections. The first section covers the modelling of distributed generation sources. The second section focuses on developing control systems for ROCOAP, ROCORP, and the load-connection strategy (LCS). The third section tests and evaluates the proposed islanding detection method (IDM). All system development and testing were conducted in a simulation environment.

A. Control System for Three-Phase Inverter-Based PV

A photovoltaic (PV) system was connected to the grid through a three-phase inverter. The control system of the inverter manages both the active and reactive powers sent to the grid. The PV system operates in two modes: grid-connected and islanded. The control system ensures that the inverter functions correctly in both modes.

B. Grid-Connected (Grid-Following) Mode

When operating in the grid-connected mode, the main grid sets the system voltage and frequency. The inverter matches these conditions and supplies power accordingly using active and reactive power controls. The grid handles changes in the load demand. The inverter uses two control loops: the inner loop manages the inverter current to maintain a clean waveform, whereas the outer loop independently controls active and reactive power and provides reference signals to the inner loop.Reddy and Reddy (2019)

C. Islanded (Grid-Forming) Mode

In islanded mode, distributed energy resources operate independently of the main grid. The system controls its own voltage and frequency. The controller is designed to maintain the required voltage and frequency so that distributed generators can safely supply power to local loads.

D. Modelling of Micro-Hydro System

The micro-hydro generation system was modelled to operate in grid-following mode, supplying constant active and reactive power to the grid. It uses a voltage control loop to regulate reactive power based on a set reference voltage. For active power, a governor maintains a steady power output by adjusting the turbine as needed. The micro-hydro system structure used in the proposed model is illustrated in Figure 1.

E. Modelling of Proposed Hybrid Islanding Detection Strategy

The proposed islanding detection method combines two passive methods and one active method. Passive methods are based on the rates of change of active power (ROCOAP) and reactive power (ROCORP). The active method is the load-connection strategy (LCS).

i) Active power method
The active power method is a commonly used technique in passive islanding detection methods (IDMs). In this approach, the active power of the three-phase system is continuously monitored at the point of common coupling (PCC) to determine whether islanding has occurred. The active power delivered by the distributed generator (DG) to the grid can be expressed by equation (1)

$$P_{DG} = V_a I_a \cos\varphi_a + V_b I_b \cos\varphi_b + V_c I_c \cos\varphi_c \quad (1)$$

where represents the phase voltage, represents the phase current, and denotes the phase angle between the voltage and current. The rate of change of active power (ROCOAP) was calculated by differentiating the active power expression in Equation (1). Under normal conditions, the system remains grid-connected, and ROCOAP remains below a threshold limit. During islanding, the sudden change in power flow causes rapid active power variation, thereby increasing ROCOAP. If ROCOAP exceeds the threshold, the islanding detection module signals the circuit breakers to disconnect the distributed generation units from the grid.

A limitation occurs when the power generated by the DG closely matches the load demand at the PCC. In this case, only small variations in the active power occur. Consequently, ROCOAP may remain below the detection threshold, preventing the IDM from identifying islanding. This creates a non-detection zone (NDZ) in which distributed generators may continue to operate after grid disconnection.

ii) Reactive power method

The reactive power method is another passive islanding detection technique that operates in a manner similar to the active power method. However, instead of monitoring active power variations, this method focuses on the rate of change of the reactive power (ROCORP). Reactive power is highly sensitive to changes in electrical network conditions, which often makes ROCORP more responsive than ROCOAP for detecting islanding events. The reactive power delivered by the distributed generator at PCC is expressed by equation (2)

$$Q_{DG} = V_a I_a \sin\varphi_a + V_b I_b \sin\varphi_b + V_c I_c \sin\varphi_c \quad (2)$$

where represents the reactive power supplied by the DG system. ROCORP was obtained by differentiating Equation (2) with respect to time. During normal operation, the reactive power variation remains within the limits. When islanding occurs, the mismatch between the DG-supplied and load-demand reactive powers causes significant fluctuations. If the calculated ROCORP exceeds a threshold value, the islanding detection module identifies it and sends a trip signal to disconnect the DG. Owing to the strong dependency of the reactive power on the voltage and system impedance, this method provides a higher sensitivity and a faster response than the active power method.

Similar to other passive detection techniques, the reactive power method may have undetected zones when the reactive power balance between the DG and load is nearly matched. Therefore, combining active and reactive power monitoring in a hybrid islanding detection strategy improves the reliability and accuracy of detection.

F. Final Stage of IDM Using ROCOAP, ROCORP and LCS

In the final stage of the islanding detection method, ROCOAP, ROCORP, and the load connection strategy were used together. At each sampling point, the system calculates how quickly the active and reactive powers change, and compares these values to set the limits. First, the ROCOAP value was checked. If it is above the limit, the ROCORP value is checked. If both the values were above their limits, the distributed generators were disconnected from the grid. If the ROCORP value is below the limit, the load connection strategy is used for further verification. In this step, a small resistive and inductive load is briefly added to the system to create a disturbance. Subsequently, the ROCOAP and ROCORP values were checked again to confirm islanding.

G. Test System Under Study

The proposed islanding detection method was tested on a distribution system connected to an 11 kV feeder from a 33/11 kV substation in the Jumla District. The configuration of the simulated distribution system with the DER integration is illustrated in Figure 2, and the electrical parameters of the system components used in the simulation are summarized in Table 4. The system included a micro-hydro generator, a photovoltaic system, various loads, and a load connection strategy. The simulation modelled a small PV plant connected to an existing micro-hydro system on the 11 kV feeder, with a base power of 50 kW. This test system was used to evaluate the performance of the method in accordance with the IEEE 1547 standard.

3. Results and Conclusion

Various cases were considered to verify the performance of the proposed IDM on the MATLAB platform in an 11-kV system. Seven case studies were considered to examine the performance of the module under islanding and non-islanding conditions to determine whether the module can identify islanding cases as islanding and non-islanding cases as non-islanding, or mistakenly classify a non-islanding as an islanding. The threshold values were set according to the distribution system and DG response. 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.

3.1 Case 1: Grid Supply Disconnected for Intentional Islanding Operation

In this case, the grid circuit breaker (GCB) disconnects at t= 2 s to verify the functionality of the module in the event of islanding detection. The waveforms of ROCOAP, ROCORP, and the trip signal during islanding are shown in Figure 6. ROCOAP and ROCORP are measured as 32.5 MW/s and 100 Mvar/s, respectively, which exceeds the threshold value of Appendix 8.1.5 above at t= 2 s; hence, the PV and micro-hydro are disconnected at t=2.015s.

3.2 Case 2: Fault Analysis

Different fault-case scenarios were applied to the first bus of the system model at t=1.5. The measured values of dp/dt and dp/dt are listed below. In the fault analysis, the measured value of ROCORP was greater than the threshold value; however, ROCOAP did not exceed the threshold value. The measured values of dP/dt and dQ/dt for different fault types and resistances are summarized in Table 1. The corresponding dynamic responses of ROCOAP and ROCORP under different fault conditions are illustrated in Figures 3–5.

3.3 Case 3: Addition of load to the system

In this case, loads of different magnitudes are connected to the first bus of the 33/11 kV substation at t = 1 s without creating an islanding condition. The purpose of this case is to verify that the IDM does not falsely detect islanding during normal load variations. The measured values of dP/dt and dQ/dt under different load additions are presented in Table 2, confirming that the detection module remains inactive.

3.4 Case 4: DG Disconnection

When DERs are connected to the distribution level, the trapping of DGs is frequent and poses serious issues. During the disconnection of one of the DGs, a change in the parameters at the PCC occurs, which triggers a 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. In this case, the ROCOAP and ROCORP threshold values were set to 15 MW/s and 7.6MVar/s, respectively. The PV plant was set to be disconnected at t= 1 s. The measured ROCOAP and ROCORP were 12.5 MW and 7.2MVar/s, respectively; hence, the IDM was not triggered. The dynamic responses of ROCOAP and ROCORP under these conditions are illustrated in Figure 7.

4. Table and Figure

Table 1: The dP/dt and dq/dt values under different fault types, ground, and fault resistance conditions showed that the IDM was not activated.

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

Table 2: The measured rate of change in the active power (dP/dt) and reactive power (dq/dt) under load additions shows that the IDM remains inactive.

S.N	Load addition (kW AND kVar)		dP/dt measured (MW/s)	dq/dt measured (MW/s)	Remarks
	P	Q			
1	210	70	0.06	0.2	IDM is not activated
2	630	210	0.06	0.2	IDM is not activated
3	840	280	0.12	0.31	IDM is not activated
4	1260	420	0.31	0.6	IDM is not activated

Table 3: Capacitive kVar injection vs dP/dt and dq/dt

S.N	Capacitive kVar injected (Q)	dP/dt measured (MW/s)	dq/dt measured (Mvar/s)	Remarks
1	100	0.75	0.4	IDM is not activated
2	300	0.95	0.48	IDM is not activated
3	1000	1.1	0.6	IDM is not activated

Table 4: System Parameter of Test Network

System Component	Parameter	Value
6***PV Plant**	Power generation (Pgen, Qgen)	100 kW, 0 kvar
	Generation voltage level	380 V
	Step-up transformer	0.38 / 11 kV, D1-Yg, 200 kVA
	DC voltage level	1000 V
	Utility filter	L-C filter
	Local load connected	10 kW
3***11 kV Distribution System (Jumla District)**	Feeder load (Pload, Qload)	900 kW, 750 kvar
	Voltage level and frequency	11 kV, 50 Hz
	Radial distance from PCC to substation	23 km
2***LCS Load**	Load (Pload, Qload)	200 kW, 100 kvar
	Voltage level and frequency	11 kV, 50 Hz
2***Protection Threshold Values**	dP/dt threshold	49 PU (2.45 MW/s)
	dQ/dt threshold	25 PU (1.25 Mvar/s)

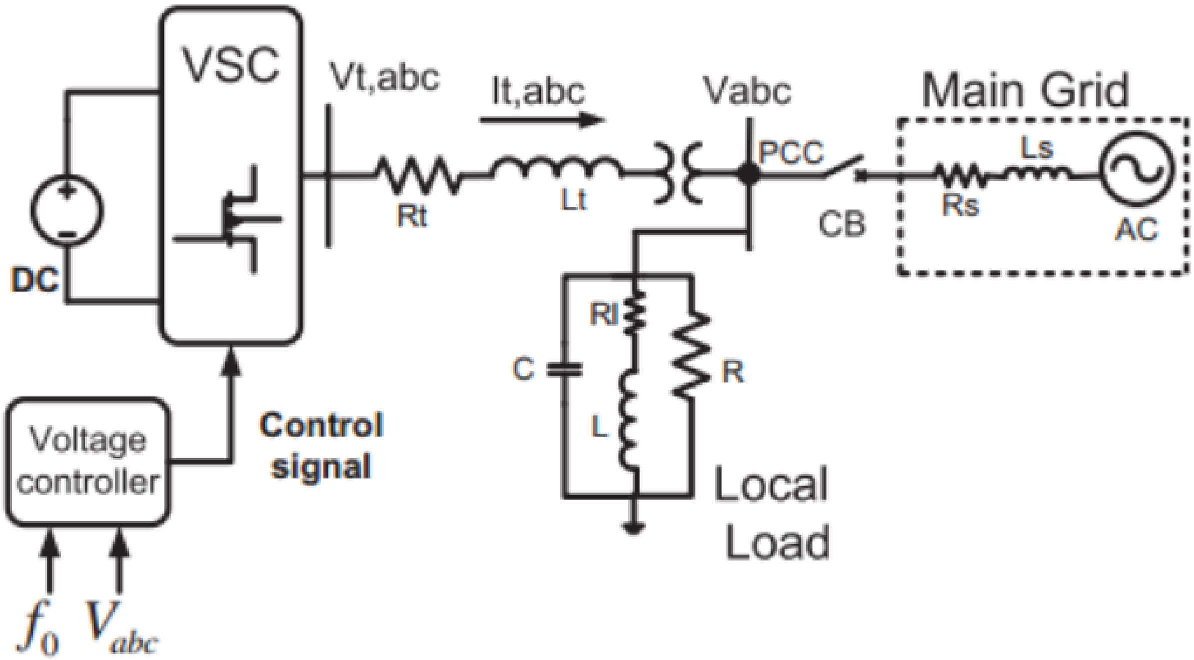

Figure 1: Isolated Operation of Inverter based DERs

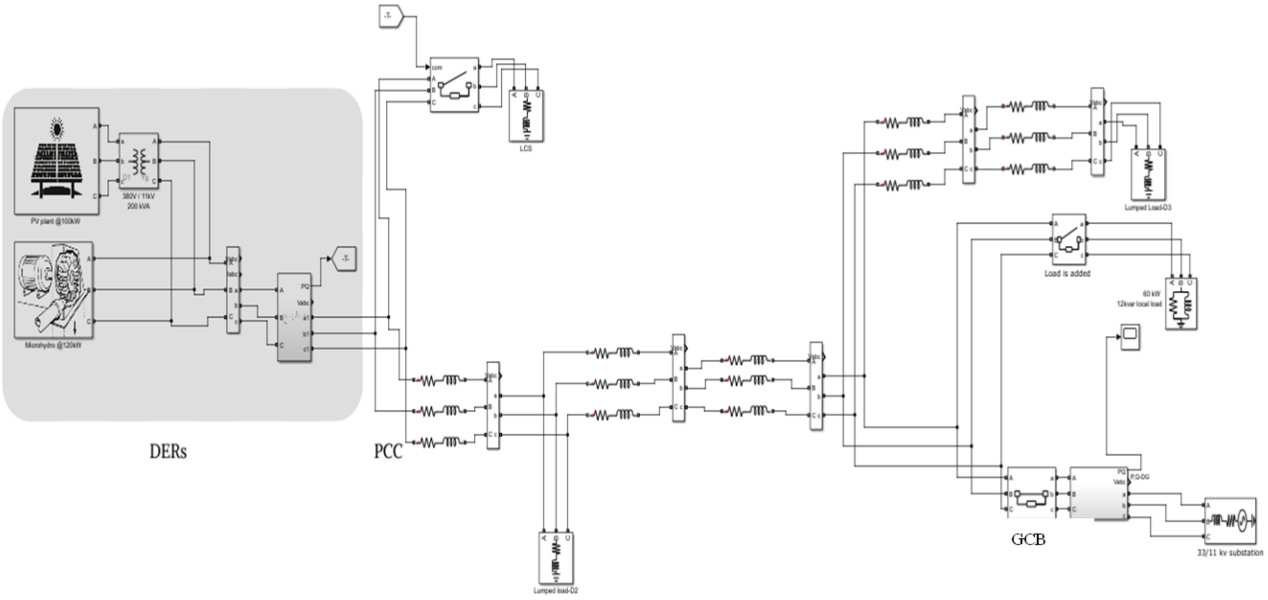

Figure 2: 11kV system and DERs connection test frame

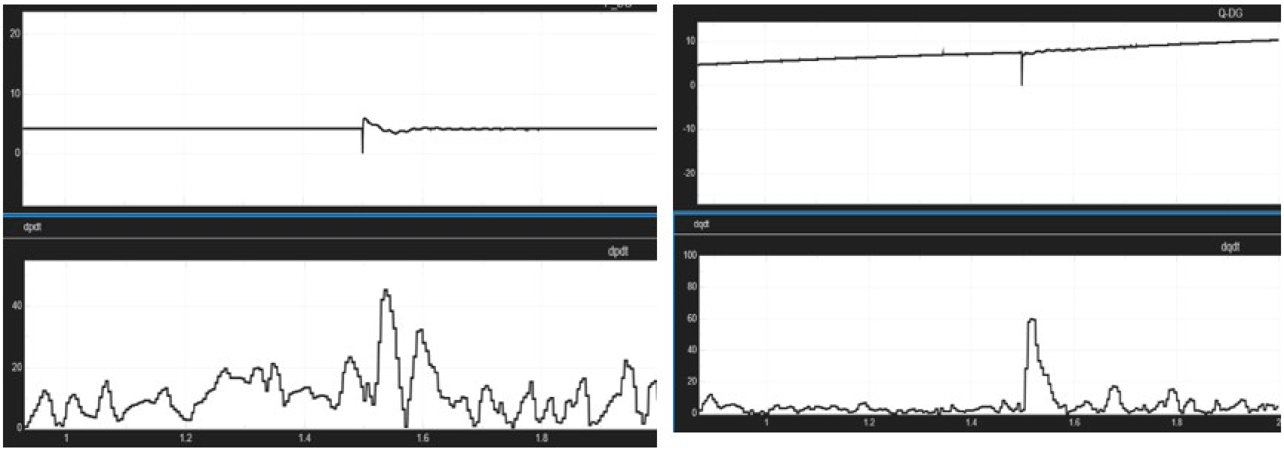

Figure 3: B. ROCOAP, ROCORP for LLLG fault with Rg=0.5 ohms

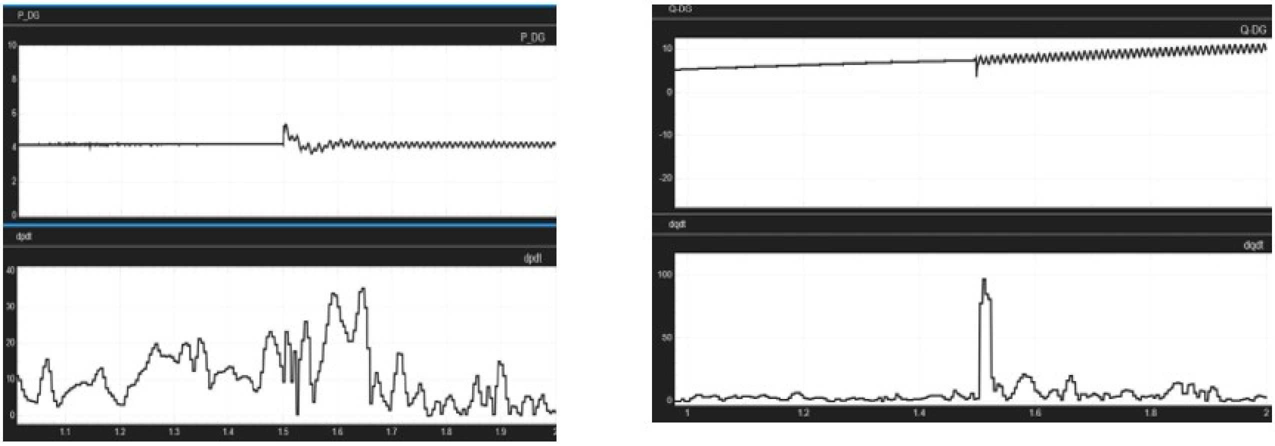

Figure 4: D. ROCOAP, ROCORP for LLG fault with Rg=0.5 ohms

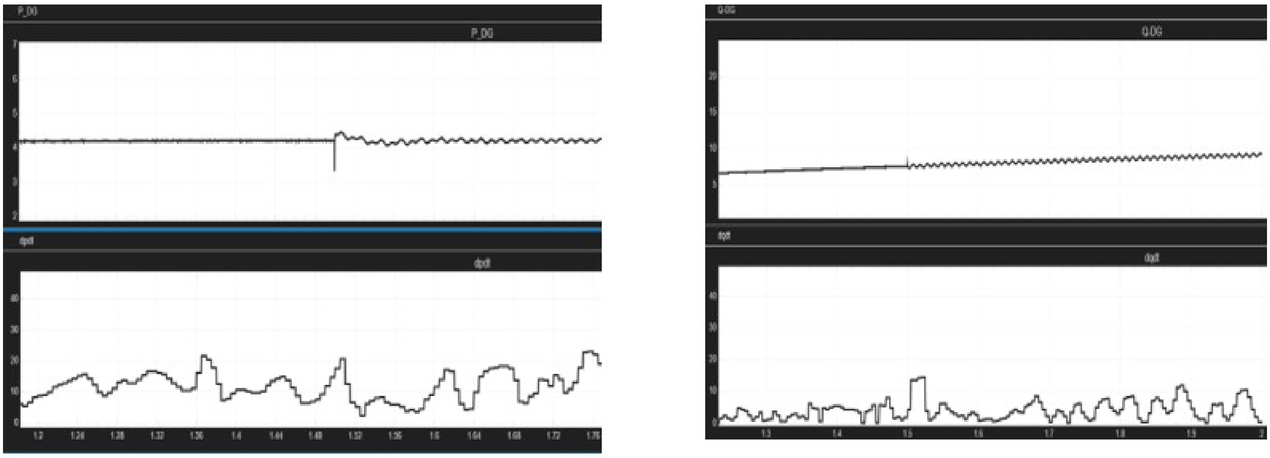

Figure 5: E. ROCOAP, ROCORP for LL fault with Rg=0.5 ohms

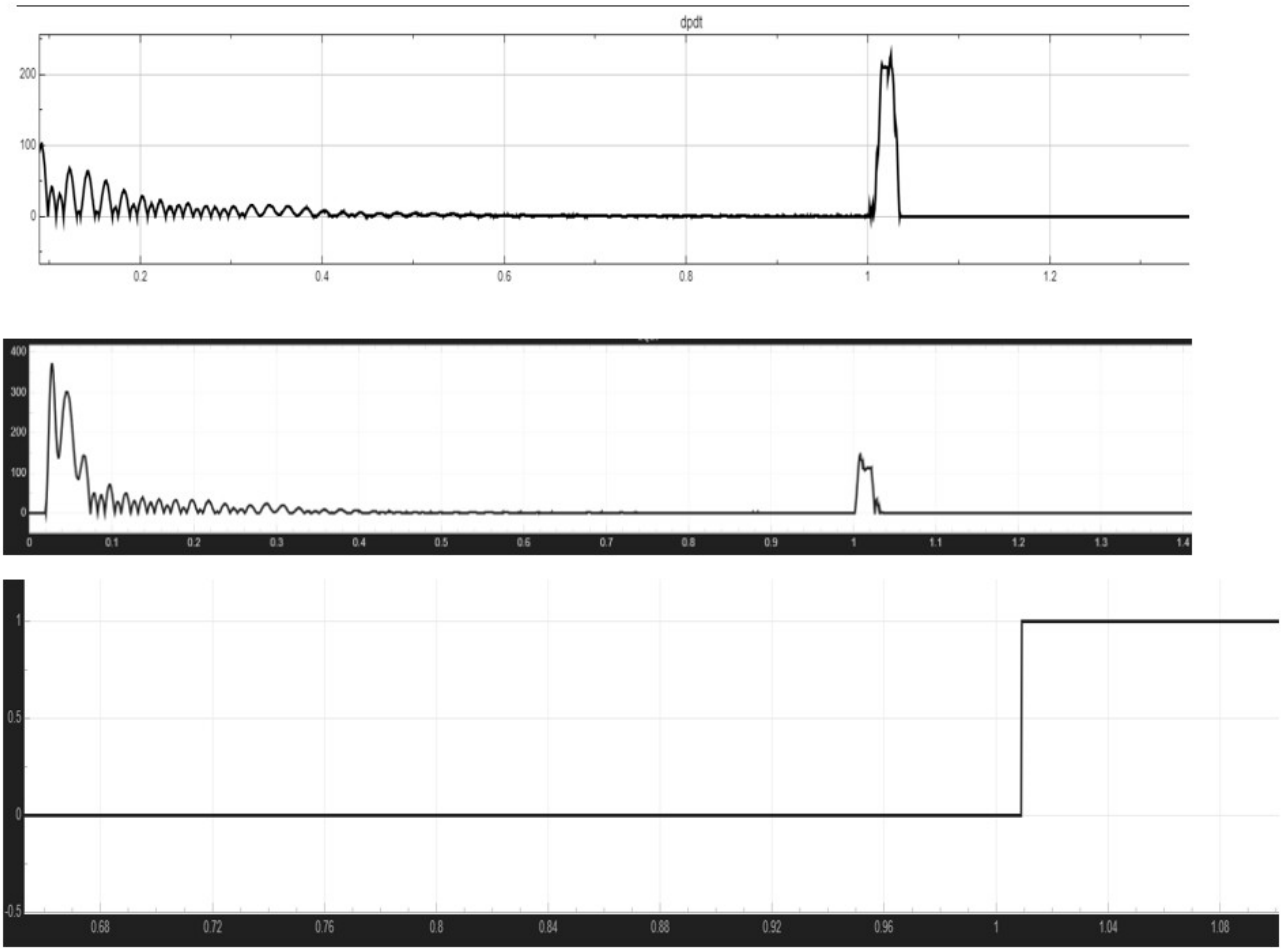

Figure 6: ROCOAP, ROCORP and trip Signal-Case-3

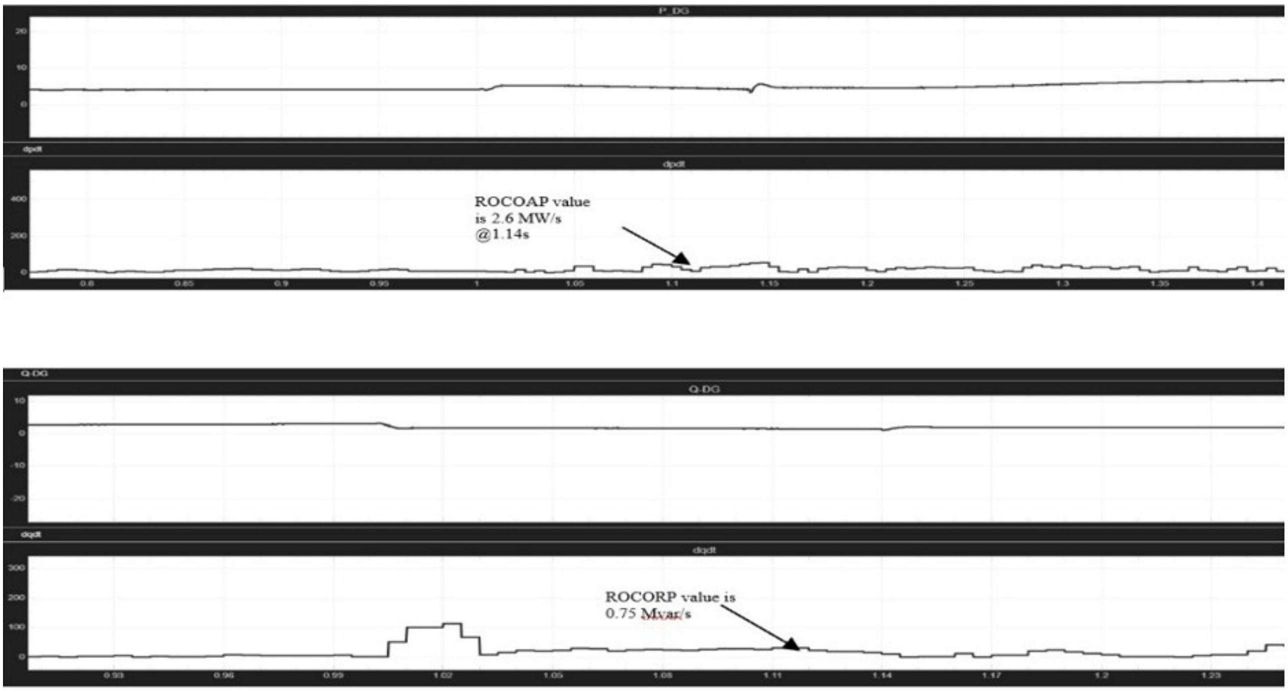

Figure 7: ROCOAP, ROCORP Plot

5. Conclusion

With advances in technology, new energy resources are continuously emerging, shifting power generation from large, centralized plants to spatially distributed sources. For developing countries, such as 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, of which islanding detection is the most critical. In rural regions, the most suitable islanding detection method is technically simple and 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, this method reduces the implementation cost while maintaining reliability. This 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 the thresholds are carefully selected based on the 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.

Author's declaration

The authors declare no conflicts of interest regarding the publication of this research paper. All contributors agreed to the final draft of the manuscript.

Declaration of the conflict of interest

The authors declare no irreconcilable circumstances. All authors contributed to the preparation of the final manuscript.

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