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Detection and Analysis of Islanding Phenomena in Distributed Generation Systems

Ramswarup Kumar[1], Thakur Pranav Kumar Gautam[2], Monalisa Bhadra[3], Navneet Keshav[4], Shivdas Chandra[5], Dr. Anamika Das[6]

[1,2,3,4,5,6]Department of Electrical & Electronics Engineering RVS college of engineering & Technology Jamshedpur

Abstract

Distributed generation has gained significant importance in the modern power industry. The impact on power system operation becomes more critical as the share of distributed energy resources in electricity production continues to increase. With the growing integration of Distributed Generators (DGs) into power systems, the occurrence of islanding has emerged as a major concern. Islanding occurs when a section of the distribution network becomes electrically isolated from the main grid while the DG units within that isolated section continue to supply power to the connected local loads.

In this study, islanding detection in a distributed generation system is carried out using the wavelet transform technique. The method relies on the analysis of the negative sequence components of voltage and current signals. The islanding event is identified by examining the level-1 detailed wavelet coefficient (d1), which clearly highlights the occurrence of the disturbance and enables effective detection of the islanding condition.

Keywords: Distributed Generation (DG), Wavelet Transform, Islanding, Negative Sequence Component (NSC)

1. Introduction

In recent years, distributed generation (DG) has become increasingly significant in modern power systems. This development aligns with the growing demand for localized and small-scale energy solutions that can support societal and technological advancement. Distributed generation refers to small power sources that are installed close to the load centers and serve as an alternative to large centralized power plants [1]. These systems are gaining attention because they offer several advantages, such as improved reliability, reduced transmission losses, and the ability to integrate renewable energy resources.

The growing demand for electricity has also contributed to the increased adoption of DG technologies. In many cases, distributed generation can serve as a cost-effective alternative to major upgrades in the existing power infrastructure. Instead of expanding transmission lines or increasing the capacity of large power plants, DG units can help meet peak load requirements and enhance the load-handling capability of the distribution network. If additional generation capacity is required to satisfy rising electricity demand, both transmission and distribution systems would otherwise need significant upgrades to handle the additional load. However, constructing new power plants and upgrading transmission infrastructure often requires substantial investment, time, and planning, which may not always be feasible[2].

This study focuses on a major issue that arises at the interface between distributed generation systems and the main power grid, namely the islanding phenomenon. Islanding occurs when a section of the distribution network becomes electrically separated from the main grid but continues to be powered by the connected DG units. Traditionally, distribution systems do not have independent power sources, and therefore electricity supply is interrupted when a fault occurs in the upstream transmission network. However, the presence of DG units changes this assumption because they can continue supplying power to the isolated section of the system.

Recent developments indicate that utilities must ensure that distributed generators are capable of detecting islanding conditions and disconnecting from the grid quickly to maintain system safety and reliability. According to the IEEE 929-1988 standard[3], distributed generators must be disconnected immediately when islanding is detected. Islanding events are generally categorized as intentional islanding and unintentional islanding. Intentional islanding occurs when the utility grid is deliberately disconnected for maintenance or operational purposes. In contrast, unintentional islanding occurs due to unexpected disturbances or faults in the power system and poses significant safety and operational challenges. As specified in the IEEE 1547-2003 standard [4] the maximum allowable time for detecting and disconnecting distributed generation during unintentional islanding is 2 seconds, after which the DG units must cease energizing the distribution network.

2. Distribution Generator

Distributed Generation (DG) refers to electricity generation sources that are located close to the load centers rather than at large centralized power plants. These resources are typically installed near consumer locations and can either supplement or replace traditional centralized power systems. Common forms of distributed energy resources include wind power, solar photovoltaic systems, and small hydroelectric generation. One of the major advantages of DG is flexibility. Distributed generation units can be installed at different locations within the utility's distribution network. This allows utilities to strategically place generation sources according to system requirements, thereby improving operational efficiency and power supply management. Another important benefit is improved reliability. By installing generation sources closer to load centers, DG reduces dependency on long transmission and distribution (T&D) networks. This helps minimize the impact of disturbances occurring in the transmission system and reduces congestion during peak demand periods. In addition, instead of relying on a single large power plant, multiple smaller generation units distributed across different locations can enhance system reliability by sharing the generation capacity. Improved system security is also achieved through distributed generation. Since electricity is produced locally, the power system becomes less vulnerable to disruptions caused by natural disasters, supply shortages, or other external disturbances affecting imported electricity. Local generation therefore contributes to a more resilient power infrastructure. DG can also help in reducing the loading on transmission and distribution equipment. During peak demand periods, generation units connected to distribution substations can supply part of the required power locally, thereby decreasing the burden on substation transformers. This can extend the operational life of substation equipment and delay the need for expensive infrastructure upgrades. Furthermore, distributed generation helps reduce transmission losses, improves voltage profiles, and enhances overall power quality within the system[5], [6] . However, despite these advantages, the increasing penetration of DG introduces several technical challenges. One of the most critical issues is islanding. Islanding occurs when a portion of the power system becomes electrically isolated from the main grid but continues to be energized by distributed generators. Power systems are complex and highly automated networks that span large geographical areas. Faults and disturbances frequently occur in these systems, and many of them are cleared automatically without human intervention Utilities are responsible for ensuring proper protection and safe operation of the electrical network[7]. Electricity can be hazardous to both humans and equipment. If an unintended island is formed and remains energized, maintenance personnel working on the supposedly de-energized network may be exposed to dangerous live conductors. This situation can result in serious injuries or even fatalities[8]. Therefore, accurate detection and rapid disconnection of unintentional islands are essential for safe operation. Many distribution feeders are equipped with protection systems that include automatic reclosing mechanisms. This practice is particularly common in overhead line systems, where faults are often temporary and disappear after a short interruption. Historical data indicate that only about 10–15% of feeder outages are caused by permanent internal faults[9].

Automatic reclosing improves system availability by restoring power quickly after temporary faults. However, reclosing onto an energized feeder can create capacitive switching transients that may produce severe overvoltage's. In lightly damped systems, these overvoltage's can reach up to three times the nominal voltage[10] .In section 2 about distribution generator is presented and the rest of this paper, the proposed passive islanding detection technique is presented in Section 3. Next, in Section 4 a test system model of MG with synchronous and inverter-based DGs is presented. Afterward, the results are discussed in Section 5. Finally, this paper is concluded in Section 6.

3. Proposed Detection techniques

Among the various islanding detection techniques, the negative sequence component method is an effective approach for identifying disturbances in voltage signals measured at the Point of Common Coupling (PCC)[11]. In this method, the negative sequence voltage component is monitored because disturbances such as islanding or sudden load rejection cause asymmetry in the three-phase voltage signals. In this study, the negative sequence voltage signal measured at the PCC is analysed to detect islanding conditions and distinguish them from other events such as load rejection. The three-phase voltage signals can be decomposed into symmetrical components, namely zero sequence, positive sequence, and negative sequence components.

$$V_n = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c)$$

The negative sequence component $V_n$represents the unbalanced portion of the voltage signal

$$V_p = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda^2 V_c)$$

The positive sequence component $V_p$represents the balanced component of the three-phase voltage system.

$$Vz = \frac{1}{3}(V_a + V_b + \lambda V_c)$$

The zero sequence component V_0represents the common component present in all three phases.

By analysing these symmetrical components, particularly the negative sequence component, disturbances occurring at the PCC can be effectively identified, enabling reliable detection of islanding conditions in distributed generation systems. In the above equations, V_a, V_b, and $V_c$represent the three-phase voltages measured at the Point of Common Coupling (PCC), while V_n, V_p, and V_0denote the negative, positive, and zero sequence voltage components, respectively. The operator $\lambda = 1\angle 120°$represents the complex rotational operator used in symmetrical component transformation. In this work, the three-phase voltage signals measured at the PCC are processed through a three-phase sequence analyzer block in MATLAB/Simulink to obtain the symmetrical components. Among the three sequence components, only the negative sequence component is considered for further analysis. The negative sequence component method is adopted because it effectively reflects system disturbances and asymmetries occurring during perturbation conditions. Monitoring the negative sequence voltage at the PCC provides strong immunity against noise and enhances the reliability of islanding detection, resulting in improved detection performance[12] .To further analyse the extracted signal, wavelet transform is applied. Wavelet transform decomposes the signal into a series of wavelet coefficients, each corresponding to a specific frequency band in the time domain. These coefficients contain detailed information about the signal characteristics across multiple frequency ranges. Wavelets are particularly effective for analysing non-stationary signals, as they provide localization of signal features in both time and frequency domains. This time–frequency representation enables accurate identification of transient disturbances associated with islanding events.

The Wavelet Transform (WT) decomposes signals into different frequency components, allowing each component to be analysed with a resolution appropriate to its corresponding scale. In this study, voltage signals measured at the Point of Common Coupling (PCC) are used as the input signals for wavelet analysis. The Daubechies 4 (db4) mother wavelet is employed because of its effectiveness in detecting transient disturbances in power system signals. The Discrete Wavelet Transform (DWT) is applied to detect islanding events in the considered test cases[13][14] Through DWT decomposition, the original voltage signal is separated into approximation and detail components, which represent low-frequency and high-frequency information, respectively. These components contain important characteristics associated with disturbances and fault conditions in the power system. When the utility grid becomes isolated, noticeable variations appear in the decomposition coefficients of the voltage signals, which provide useful signatures for identifying islanding events[15].

In the wavelet decomposition process, filters with different cutoff frequencies are used to analyse the signal at multiple scales. High-frequency components are extracted using a sequence of high-pass filters, while low-frequency components are obtained through low-pass filters. The resulting signals consist of approximation components representing the low-frequency behavior of the signal and detail components representing high-frequency transient characteristics. Wavelet analysis represents a signal in terms of scaled and translated versions of a mother wavelet. These wavelets are generated through the processes of translation and dilation, enabling the analysis of signal features across different time and frequency resolution[16] For a signal $f(t)$, the Discrete Wavelet Transform (DWT) can be mathematically expressed as follows.

$$f(t)= \frac{1}{\sqrt{x_0^{m}}} \sum f(k)\varphi^{*}\left(\frac{n-k}{x_0^{m}}\right) \tag{1}$$

In the above expression, the parameters $m$and $k$are integer variables that represent the scaling and translation indices, respectively. These parameters determine the position and resolution at which the signal is analyzed. In wavelet analysis, a scaling function is associated with the wavelet function. The combination of the scaling function and the wavelet function enables the formation of a Multi-Resolution Analysis (MRA) framework for signal processing.

$$\varphi(t) = \sum_{n=-\infty}^{\infty} h(n)\sqrt{2}\varphi(2t-n) \tag{2}$$

Furthermore, the wavelet function can be derived from the scaling function as indicated in[17].

$$\varphi(t) = \sum_{n=-\infty}^{\infty} h_1(n)\sqrt{2}\varphi(2t-n) \tag{3}$$

$$c_j(k) = \sum_{m=-\infty}^{\infty} h_{j+1}(m)h(m-2k) \tag{4}$$

$$d_j(k) = \sum_{m=-\infty}^{\infty} h_{j+1}(m)h_1(m-2k) \tag{5}$$

Equations (4) and (5) demonstrate that the coefficients at a coarser scale are derived by applying appropriate filters to the samples at the finer scale, followed by a down-sampling process. Consequently, the number of samples at the coarser level is approximately half of that at the finer level.

4. Proposed model

To investigate the operation and behavior of the system under various contingency conditions, a simulation model has been developed. It is essential that the simulated system accurately represents the characteristics of a real power system, including all critical components. Therefore, the behavior of the simulation model should closely resemble the response of an actual system under similar operating conditions.

The methodology used to achieve this realistic representation is described in the following sections. In this study, particular emphasis is placed on wind power turbines and induction generators, mainly due to the rapid growth and widespread integration of wind energy in modern power systems. For the initial stage of the investigation, the system configuration illustrated in Fig. 1 has been considered for analysis.

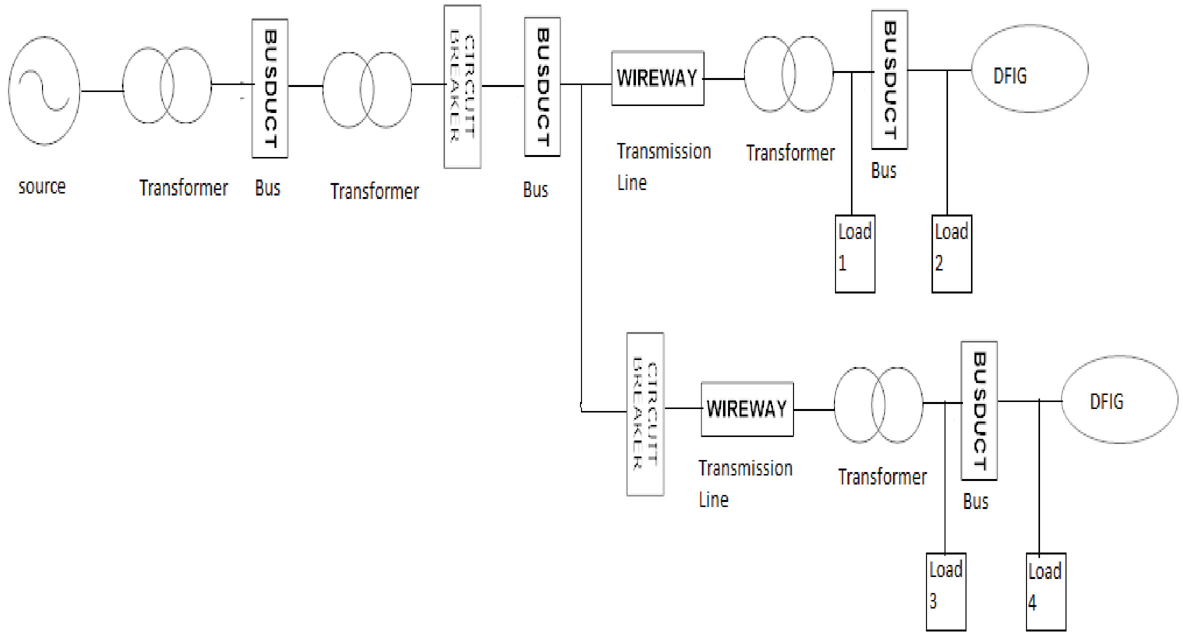

Fig.1 Single-Line Layout of the Proposed System Architecture

5. Result analysis

Figure 4 illustrates that the negative sequence voltage waveform is significantly affected during the islanding fault condition.”

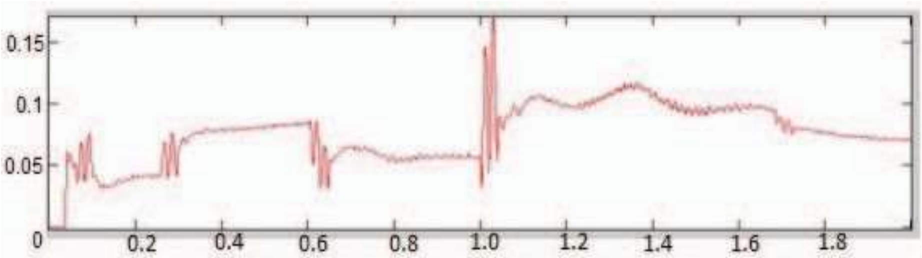

Fig 2: Sequence Analyzer Output in Mundane Case

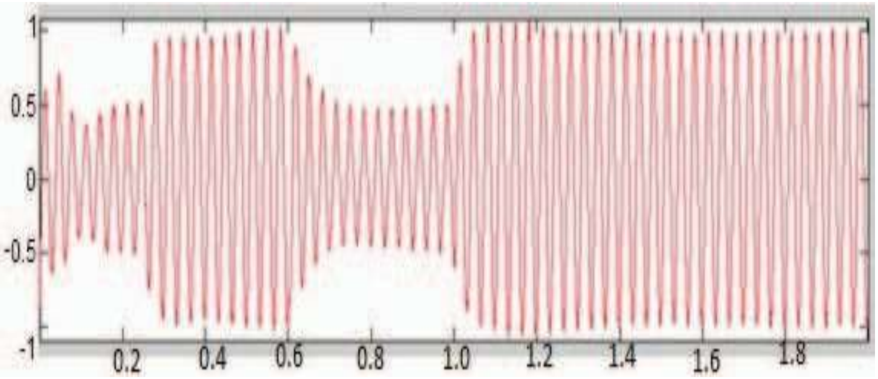

Fig 3: Condition I – Islanding Condition, Switching Fault

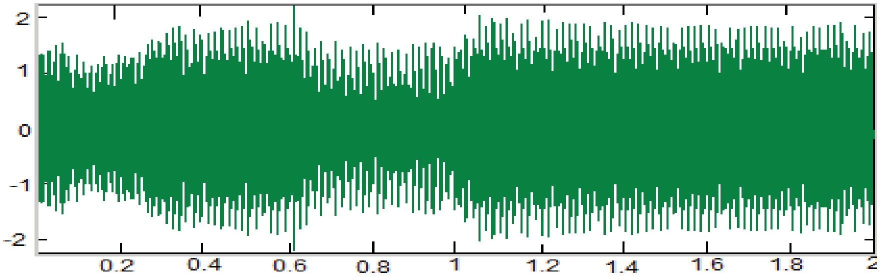

Fig 4: Negative Sequence Component of Voltage and d-1 coefficient for Islanding Condition

The voltage waveform decreases during the switching interval from 0.3 s to 0.5 s. The corresponding wavelet coefficient waveform is also presented, showing a pattern similar to the s-component."

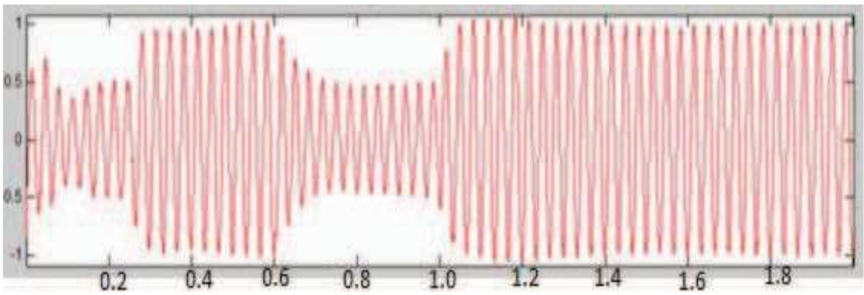

Fig 5: Condition II – Wavelet due to ABCG fault

"Figure 6 shows that the negative sequence voltage waveform is significantly affected under the ABCG fault condition."

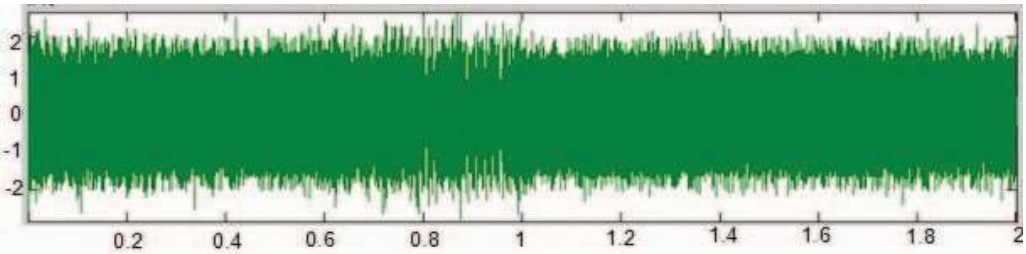

Fig 6: Negative Sequence Component of Voltage and d-1 coefficient for Fault Condition.

The voltage waveform decreases during the switching interval from 0.3 s to 0.5 s, and the corresponding wavelet coefficient waveform is presented, which shows a pattern similar to the s-component.**”**

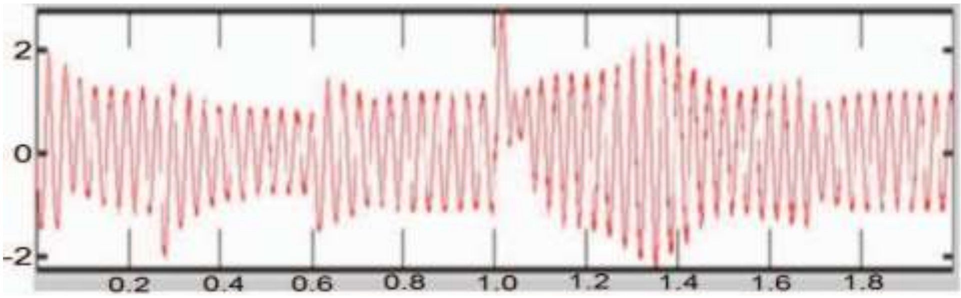

Fig 7: Condition III – Current Waveform due to Islanding Condition

“Figure 8 illustrates that the negative sequence current waveform is significantly affected during the islanding fault condition. The voltage waveform increases sharply during the switching interval from 0.3 s to 0.5 s, and the corresponding wavelet coefficient waveform is also shown, which exhibits a pattern similar to the s-component.”

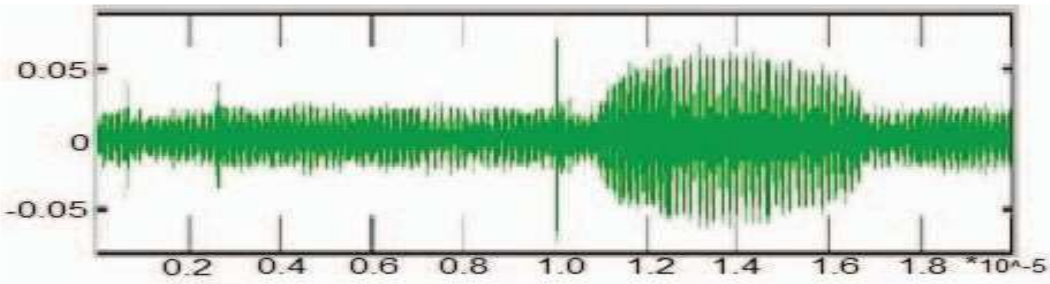

Fig 8: Negative Sequence Component of Current and d-1 coefficient for Islanding Condition.

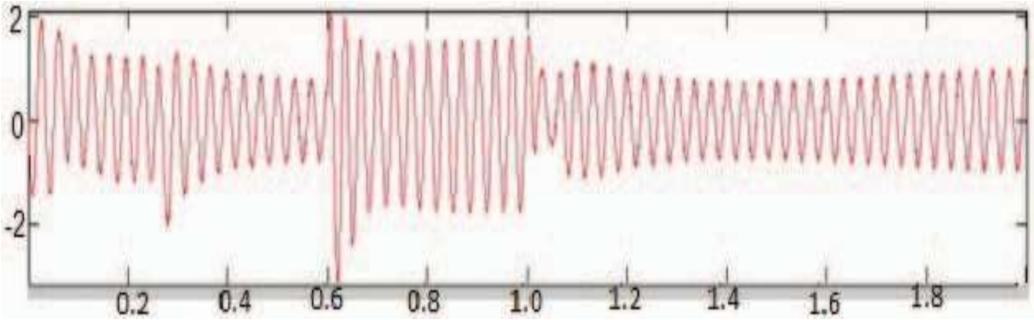

Fig 9: Condition IV - Current Waveform due to ABCG fault

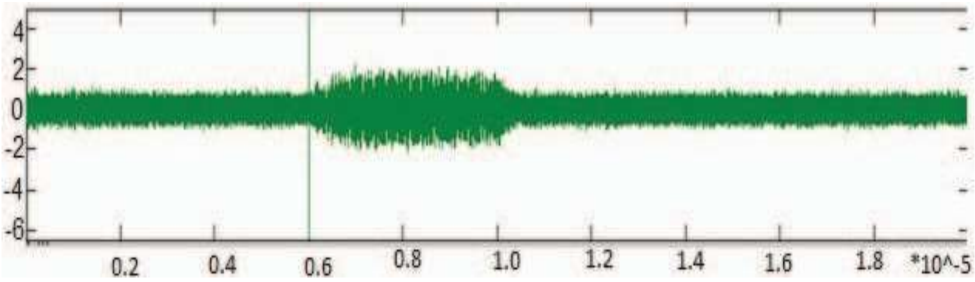

Fig 10: Negative Sequence Component of Current and d-1 coefficient for Fault Condition

The current waveform shows an increase during the switching interval from 0.3 s to 0.5 s. The corresponding wavelet coefficient waveform is also illustrated, which exhibits a similar pattern to the s-component. “

6. Conclusion:

With the increasing cost of electricity and growing environmental concerns, distributed generation (DG) is expected to play an important role in future power systems. However, DG integration introduces several challenges, among which islanding is a major concern. In this work, several existing islanding detection methods were analysed using MATLAB simulations. The results show that many conventional methods have a large non-detection zone (NDZ) and may malfunction when voltage signals are affected by noise or normal system disturbances. To overcome these limitations, a wavelet transform–based method is proposed. Wavelet transform is highly sensitive to sudden signal variations, allowing accurate detection of events. The energy of wavelet coefficients of the three-phase voltage at the Point of Common Coupling (PCC) changes significantly when an event occurs, enabling precise detection.

Simulation results under various islanding and non-islanding conditions demonstrate that the proposed method provides high accuracy, strong noise immunity, and improved reliability compared to conventional passive islanding detection techniques.

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