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Advancements in Islanding Detection Techniques for Microgrid Systems: A Comprehensive Review

Samiksha K. Shahade[1] and Dr. A. U. Jawadekar[2]
[1]Research Scholar, Department of Electrical Engineering, SSGMCE Shegaon, Maharashtra, India
Email: samiksha.shahade97@gmail.com
[2]Associate Professor, Department of Electrical Engineering, SSGMCE Shegaon, Maharashtra, India
Email: anjali.jawadekar@gmail.com

***Abstract*— The integration of distributed generators (DGs) with microgrids has seen substantial growth due to their variable power management capabilities. DG sources, such as solar PV systems, wind turbine systems, battery sources, and diesel generators, are becoming increasingly prevalent in the power grid. Inverter technology plays a crucial role in ensuring seamless connection between DG systems and the power grid or microgrid, minimizing power fluctuations. Adherence to international standards, including IEEE 1547, IEC 61727, and UL 1741, is essential for safe grid-connected DG operation. Additionally, microgrid systems also need to comply with these standards for the successful integration of DGs. Islanding, wherein a small section of the microgrid operates independently, disconnected from the main power grid, poses risks to human safety and equipment. To address this, various techniques have been developed for islanding detection, including Impedance measurement-based, Transient components calibration-based, ANFIS-based, Transfer learning model-based, Reactive power P&O anti-islanding, Low voltage ride through (LVRT) method, Signal trajectory pattern recognition-based, Phase-shifted feedforward voltage-based, Rate of change of reactive power measurement-based, Two-level method, Graph Search Method-based, Active Unintentional Islanding Detection, and Hybrid Islanding Detection Method. This review paper thoroughly examines these islanding detection techniques for DGs in microgrid systems, providing a comprehensive understanding of their capabilities and limitations.**

***Index Terms*— Distributed Generators (DGs), Islanding detection**

I. Introduction

In recent years, the integration of distributed generators (DGs) with microgrids has gained significant traction as a promising solution for enhancing the resilience and efficiency of modern power systems [1]. DGs, encompassing various sources such as solar PV systems, wind turbines, batteries, and diesel generators, offer flexible and decentralized power generation capabilities [2]. This growing trend of coupling DGs with microgrids has been driven by their ability to adapt to variable power conditions and their potential to reduce greenhouse gas emissions and reliance on traditional centralized power plants [3].

The seamless integration of DGs into microgrid systems relies heavily on sophisticated inverter technology, which facilitates stable and reliable connections while minimizing power fluctuations during the transfer of power to the grid or microgrid [4]. As the scale and penetration of DGs continue to expand, the safety and reliability of grid

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connected DGs have become paramount concerns for major grid operators [5]. To address these concerns, international standards such as IEEE 1547, IEC 61727, and UL 1741 have been established to ensure safe and standardized operation of DGs in grid-connected environments [6].
One of the significant challenges in the operation of microgrids is the phenomenon of unintentional islanding. Islanding refers to the condition where a portion of the microgrid continues to operate in isolation from the main power grid, which can lead to hazardous situations for workers and the public [7]. Detecting islanding events promptly and accurately is essential to prevent potential harm and ensure the stability of the microgrid system [8]. This review paper aims to explore the various islanding detection techniques used in microgrid systems, focusing on their applications in DG integration. The objective is to provide a comprehensive understanding of the advancements in islanding detection methodologies and their effectiveness in ensuring the safe and reliable operation of grid connected DGs within microgrids. By analyzing and comparing different islanding detection methods, this paper seeks to shed light on the strengths and limitations of each technique, thus offering valuable insights for researchers, grid operators, and industry stakeholders working on microgrid development and deployment [9] [10].
In the subsequent sections, we will delve into the details of the different islanding detection methods, including Impedance measurement-based, Transient components calibration-based, ANFIS-based, Transfer learning model-based, Reactive power P&O anti-islanding, Low voltage ride through (LVRT) method, Signal trajectory pattern recognition-based, Phase-shifted feedforward voltage-based, Rate of change of reactive power measurement-based, Two-level method, Graph Search Method-based, Active Unintentional Islanding Detection, and Hybrid Islanding Detection Method. The goal is to provide a comprehensive overview of these techniques, their underlying principles, and their potential contributions to ensuring secure and reliable microgrid operation in the presence of DGs [11].

A. DIFFERENT ISLANDING DETECTION TECHNIQUES

1. Impedance measurement-based islanding detection: Islanding detection is a challenging task in both DC and AC microgrid systems, as it can lead to unstable microgrid operation and pose safety risks to workers and users. While several methods have been developed for AC microgrid islanding detection, the progress in DC microgrid islanding detection is still at an early stage. In hybrid power systems that utilize three-phase voltage regulator converters for synchronization with the main AC grid, the focus is often on optimizing energy production or consumption profiles of storage devices, distributed generators, and loads.
However, most existing islanding detection techniques in such systems rely on voltage deviations, such as over-voltages and under-voltages, which can fail when loads closely follow the voltage profile of the source. Additionally, these methods introduce disturbances to the system, potentially affecting its operating point and response time. In this context, a method proposed in [12] employs a lock-in amplifier with sensors to measure voltage and current in a solar PV system. This technique precisely measures the impedance of the microgrid line, enabling quick and reliable islanding detection. The proposed method offers several advantages: (1) injection of low-amplitude signals, (2) rapid detection of islanding events, and (3) high sensitivity to islanding occurrences. Fig-1 illustrates the block diagram of the proposed impedance-based islanding detection method.

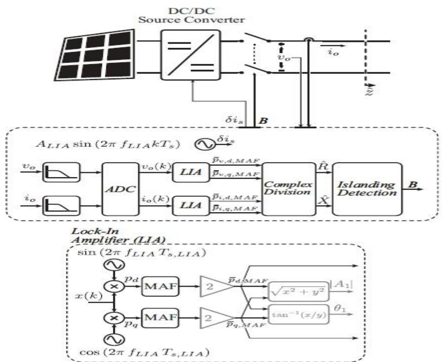

Fig-1: Proposed impedance measurement-based islanding detection of microgrid system block diagram [12]

An important feature of this method [12] is its reliance on impedance matching between the load and the source, making it effective for islanding detection even when voltage-based algorithms fail. Moreover, the method employs small signal injection, avoiding the use of large disturbances. Simulation results demonstrate that the proposed approach effectively distinguishes between islanding and non-islanding conditions, accommodating various load types, including constant current, constant power, and constant resistive loads. In conclusion, the impedance-based islanding detection method proposed in [12] offers a promising approach to tackle islanding challenges in both DC and AC microgrid systems. Its ability to rapidly detect islanding events, even under varying load conditions, makes it a valuable solution for ensuring the safe and reliable operation of microgrids integrated with distributed generators and hybrid power systems.

2. Transient components calibration-based islanding detection: In [13], the author presents an analysis of the transient response of a distributed generator system during faults and switching conditions in an islanding microgrid. The proposed method is based on the Transient Index Value (TIV) and the positive sequence superimposed current angle at the point of common coupling (PCC). Specifically, three-phase voltage signals measured at the distributed generator end are utilized to compute the TIV.

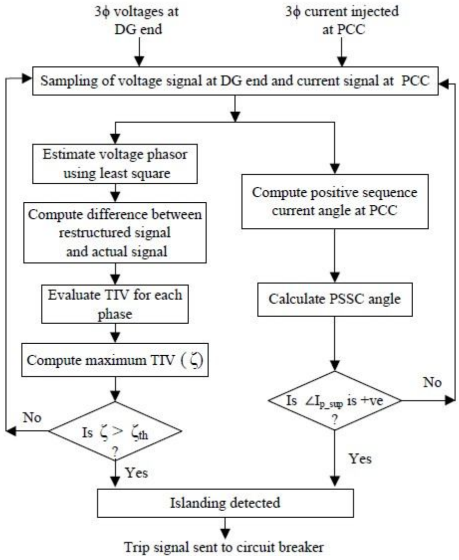

Fig-2: Flow chart of proposed transient component-based approach [13]

The performance analysis of the proposed system is conducted on a practical distribution power system network, incorporating a thermal power plant, wind turbine DGs system, and PV system. Simulation results demonstrate that the proposed approach exhibits high reliability and rapid response for detecting islanding conditions. A comparison is made with existing passive islanding detection techniques, particularly for situations with zero active and reactive power mismatch power conditions, as well as nonlinear load-induced transient conditions. In this method, islanding detection relies on measuring the voltage at the DGs end and the injected current at the PCC. The results obtained through this approach prove to be more accurate and reliable, even when system parameters change. The system is tested under various conditions, including reactive power and active power mismatching scenarios. Moreover, it successfully detects critical events such as faults, switching of large, connected loads, opening of distributed generator circuit breakers, and capacitor switching operations. Notably, the method is robust against variable nonlinear loads, ensuring that the islanding condition can be effectively detected. The proposed integral technique offers several advantages, including fast islanding detection in less than one cycle of current and a simple computational algorithm, making it highly compatible and reliable. The approach significantly reduces the detection of non-linear zones, thereby enhancing the reliability of microgrid operations. In summary, the proposed transient component-based approach in [13] provides an efficient and accurate method for detecting islanding conditions in microgrid systems. Its ability to handle various challenging scenarios and its fast detection time make it a valuable solution for ensuring the stability and safety of microgrid operations.

3. ANFIS based islanding detection method: In [14], the author introduces an Adaptive Neuro-Fuzzy Inference System (ANFIS) based islanding detection method for low voltage inverter interface microgrid power systems. ANFIS, with its ability to generate nonlinear mappings for inputs and strong pattern recognition capabilities, is employed as a powerful tool for islanding detection. The ANFIS controller continuously observes seven types of data measured at the point of common coupling, including root mean square three-phase voltage and current, total harmonic distortion of three-phase voltage and current (determined using fast Fourier transform), power frequency

of the microgrid, and active and reactive power of the microgrid. These parameters are monitored during the real-time operation of the microgrid system. The proposed system aims to reduce the likelihood of non-detection zones in the microgrid while mitigating power quality issues. It focuses on minimizing non-detection zones while maintaining power quality. Compared to conventional methods, the proposed islanding detection technique exhibits shorter detection times and higher accuracy. The performance and accuracy of the proposed system depend on factors such as the training dataset, sample time, and the number of samples used for optimization. Input data for the ANFIS is obtained from the point of common coupling of a real-time solar PV system through an automatic measurement reading system. The system is thoroughly tested based on UL1741 standards under various conditions, including different loading conditions, two parallel-connected distributed generators, various grid faults, and load-controlled switches systems. A comparison with previous islanding detection methodologies clearly demonstrates that the ANFIS system is more accurate and rapid in detecting islanding events during different loading conditions. Additionally, the proposed method has minimal impact on the power quality of the microgrid system and performs effectively under different environmental conditions.

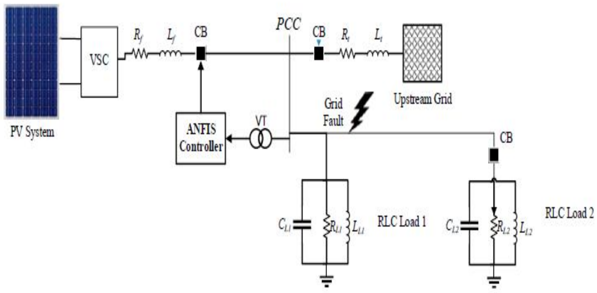

Fig-3: ANFIS based islanding detection technique [14]

4. Transfer learning-based islanding detection method: The increasing demand for power has led to the integration of distributed generator sources like solar PV systems and wind turbines. However, the widespread adoption of renewable distributed generators has made the design, protection, operation, and control of power systems more challenging and complex. One significant concern in microgrid systems is the occurrence of islanding events, which can lead to safety hazards and operational issues. In [15], a novel technique is proposed for islanding detection in microgrids using transfer learning for image classification. This method utilizes time series data to generate scalogram images from the microgrid system. These images are extracted using wavelet transform at the point of common coupling in the microgrid. The next step involves applying transfer learning using the Alex Net software, which leverages a pre-trained neural network. However, some modifications are made to the pre-trained convolutional neural network (CNN) to enable the detection of islanding events. The CNN is trained on both islanded and non-islanded training datasets, achieving an impressive accuracy of 98.78%

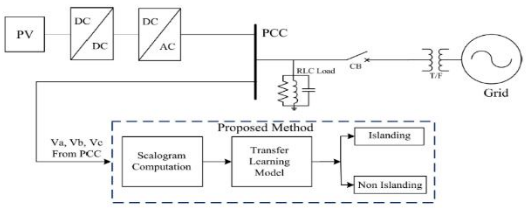

Fig-4: Schematic of the system used for transfer learning model [15]

The results clearly demonstrate that the transfer learning-based approach is highly effective in detecting islanding events in microgrid systems. By using this approach, the system can enhance its compatibility for accurate and reliable islanding detection, contributing to the safe and stable operation of microgrids.

5. Reactive power P & O Based islanding detection method: To ensure the rapid detection of unintentional islanding in a grid-connected system supplying constant power through an inverter system with critical and normal loading conditions, a novel approach is proposed. The method introduces an indirect current control technique that enables smooth mode changes in the inverter and maintains a stable voltage for critical loads. Unlike traditional islanding detection methods, the indirect current control-based approach does not require voltage magnitude and frequency variations during islanding conditions. This method is detailed in [16], presenting a reactive power

Perturb and Observe (P&O) anti-islanding method for the indirect current control approach. The proposed method detects islanding conditions by monitoring the changes in reactive power during islanding events. Additionally, it generates a small perturbation signal for the reactive power at the output side of the inverter. This ensures that the inverter can deliver a reliable power supply to critical loads without any distortion.
The effectiveness of the system is validated through testing on a 1 kW three-phase inverter system with a three-phase RLC load having a quality factor of 2.5. The proposed method proves to be efficient when applied to two distributed generator systems conforming to IEEE 1547 and 929 standards. Notably, the system is capable of providing seamless and stable voltage for critical loading conditions.
In conclusion, the proposed indirect current control approach, combined with the reactive power P&O anti-islanding method, offers a swift and reliable solution for detecting unintentional islanding in the grid-connected system. This method ensures the consistent delivery of high-quality power to critical loads without compromising the system's stability and performance.
6. Low voltage ride through (LVRT) Islanding detection method: The author introduces a unique two-stage inverter-based islanding detection method in [17]. What sets this method apart is its independence from instantaneous voltage measurements of the microgrid system. Instead, it detects islanding conditions by monitoring the saturation of the PI controller in the outer loop of the proposed system. This approach proves more reliable compared to voltage measurement-based islanding detection methods. The algorithm also incorporates LVRT (Low Voltage Ride Through) based islanding detection and anti-islanding detection methods. The overall system integrates these three types of controllers to achieve smooth mode transitions between grid-connected and standalone operations

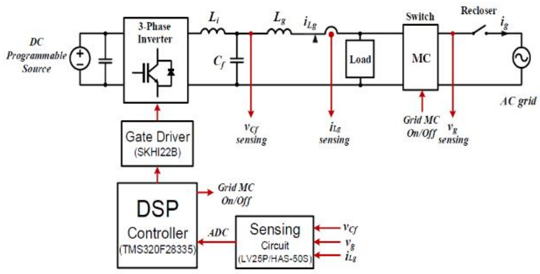

Fig-5: Anti-islanding detection method block diagram [16]

One notable benefit of this method is its insensitivity to disturbances, making it robust under varying power system conditions. Additionally, it operates based on instantiations of system voltage measurements, ensuring rapid and accurate detection of islanding conditions within 2 seconds after the islanding event occurs. The system adheres to the IEEE 1547 standards for islanding detection.
Moreover, the proposed LVRT control system effectively handles voltage sag conditions. It is calibrated based on the integration of instantaneous grid system voltage, enabling seamless mode changes between standalone and grid-connected operations. Furthermore, all modes feature maximum power point tracking (MPPT) for optimized performance.

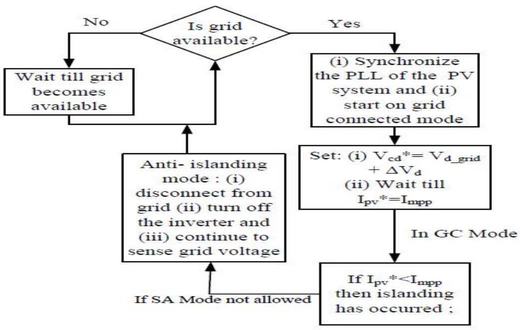

Fig-6 illustrates the flow chart of the two-stage inverter system [17].

The complete system is tested using the digital platform DSP TMS320F2812. The method demonstrates fast and reliable islanding detection capabilities while ensuring low voltage ride through operation of the system. It effectively maintains stable operation even during islanding conditions, contributing to the overall efficiency and reliability of the microgrid system.

7. Signal trajectory pattern recognition-based islanding detection method: In order to foster the future growth of microgrid systems, it is crucial to enhance the capabilities of distributed generator systems for continuous power flow to the grid. When supplying power to an islanded microgrid, it is essential to maintain high power quality; otherwise, the distributed generators must be disconnected from the microgrid. To achieve this, early identification of islanding conditions is necessary to promptly take appropriate action, such as disconnection or mode change of the distributed generators. In this context, a passive islanding detection method based on pattern recognition techniques for synchronous DG systems is proposed in [18]. This intelligent relay system efficiently distinguishes grid-connected disturbances from islanding events, even when the generation and loads closely match the voltage profile during islanding.

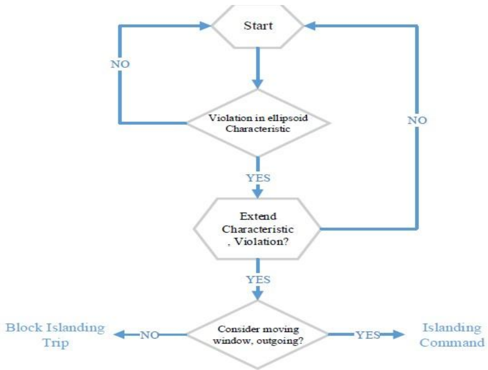

Fig-7: Signal trajectory pattern recognition base islanding detection [18]

8. Graph search method-based islanding detection: Islanding conditions occur when a small portion of the microgrid is powered by a few distributed generator sources, operating independently from the main power grid. Unintentional islanding poses potential dangers to the safety of workers and inhabitants on the microgrid. Although several conventional methods for islanding detection exist, some may not effectively operate even with the use of power quality improvement devices. To address this, a method based on system configuration calculation is proposed [19]. The connection links between distributed generators and the main power system source are analyzed using the graph search method. If the graph theory indicates that renewable energy sources and the main power source are connected to the microgrid, it signifies a non-islanding condition and vice versa. Simulation results demonstrate that the proposed system conforms to the IEEE 1547 standard for islanding condition detectiin the microgrid system.

III. CONCLUSIONS

This research review paper has provided an in-depth analysis of various islanding detection methods for Distributed Generators (DGs) in microgrid systems. The reviewed techniques encompass a diverse range of approaches, including impedance measurement-based detection, ANFIS-based methods, graph search techniques, and many others. Each method offers unique advantages and considerations, catering to different microgrid configurations and operational scenarios. Researchers and students exploring islanding detection in microgrids will find this paper to be an invaluable resource, as it compiles a comprehensive overview of the state-of-the-art techniques. By shedding light on the strengths and limitations of each method, this review aids in guiding researchers towards choosing the most suitable approach for their specific microgrid system and distributed generator type. As the world increasingly embraces renewable energy sources and distributed generation, reliable and efficient islanding detection becomes paramount for safe and stable microgrid operation. This paper contributes to the advancement of knowledge in this critical domain, fostering innovation and promoting the development of robust islanding detection solutions. In conclusion, this research review paper serves as a valuable reference, propelling the field of islanding detection forward and supporting the realization of resilient, smart, and sustainable microgrid systems.

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