Islanding Issues, Consequences, and a Robust Detection Method for Hybrid Distributed Generation Based Power Systems

Nauman Ali Larik
School of Electric Power Engineering, South China University of Technology, China
epnauman.ali@mail.scut.edu.cn (corresponding author)

Meng Shi Li
School of Electric Power Engineering, South China University of Technology, China
mengshili@scut.edu.cn

Touqeer Ahmed
State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, China
touqeer.87@gmail.com

Jawed Ahmed Jamali
School of Energy and Power Engineering, Dalian University of Technology, China
jawedahmed879@gmail.com

Qing Hua Wu
School of Electric Power Engineering, South China University of Technology, China
wuqh@scut.edu.cn

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ABSTRACT

Islanding refers to the situation where a Distributed Energy Resource (DER) remains as the sole power supply for a specific section of a power system, even after the main utility grid has been cut off. Suitable islanding detection is crucial to maintain the stability and dependability of a power distribution system that includes DERs. Islanding detection using easy-to-implement passive techniques exhibits a cost-effective response. The purpose of this study was to examine the causes and effects of islanding that a system can experience and propose a passive islanding detection method that uses ROCOPAD. The effectiveness of the proposed method was assessed using a MATLAB Simulink-based power system integrated with multiple Distributed Generations (DGs). The results showed that the proposed ROCOPAD-based islanding detection provided the best results. Evaluation metrics, including detection accuracy, false operation, and detection time, highlighted the effectiveness of the proposed approach.

Keywords-renewable energy; unintentional islanding; non-detection zone; multiple distributed generation; phase angle difference

I. INTRODUCTION

Renewable energy generation has seen significant development in recent years due to the exponentially increasing power demand, the sharp increase in the price of oil and natural gas, and environmental concerns [2-4]. The development of renewable energy generation will increase since it reduces global warming, improves public health, and stabilizes energy prices, which is not possible when using fossil fuels with fluctuating prices [5-7]. Renewable power sources, such as solar panels, wind turbines, and fuel cells can be used in conjunction with biomass or geothermal energy power plants because they are an economical source of energy that makes a power distribution system more stable and efficient [8]. Microgrids facilitate the efficient use of Distributed Generation (DG) systems that use renewable energy [9]. DG is described as generating capacity that is placed close to the load being served, typically at the client site, and is not produced by central generating stations [10]. In addition to reducing the cost of expansion of the transmission and distribution infrastructure, they decrease power losses, lower peak loads, decrease peak demand, and serve the requirement of a reserve margin [11]. As a result, many electric utilities all over the world have begun connecting Distributed Energy Resources (DERs) to distribution networks [12]. However, when DERs are integrated into the grid, the distribution network becomes dynamic, raising concerns about electricity quality, reliability, and security [13].

The development of such an energy system has complicated issues, where the subject of its dependability and resilience is in flux [14]. However, renewable energy generation has established itself as the future of the power sector. In a successful system, DGs can keep the load energized totally or partly if the power grid goes down for whatever reason, as shown in Figure. 1. This situation is known as islanding [15]. In islanding, the grid loses control over these disconnected loads and generators [16]. Islanding identification is one of the biggest problems in modern power systems, which is made more difficult by the fact that many distribution networks already have many DGs.

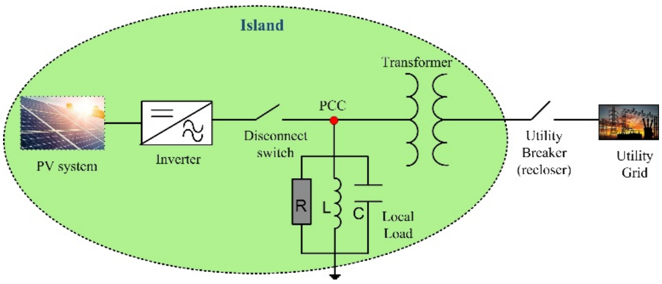

Fig. 1. Schematic diagram of the island system

When a power outage occurs, it is vital to ensure that DERs do not continue to energize isolated sections of the grid, as this can pose serious risks, including the potential to harm utility workers who may assume that the grid is de-energized and damage the equipment due to uncontrolled voltage or frequency fluctuations. By implementing effective islanding detection methods to identify islanding quickly, the grid control service can take steps to protect workers, restore power to customers, and prevent damage to the grid, improving the integrity and stability of the overall power system. Islanding detection is the process of identifying when a DER has disconnected from the main power grid and is operating in an islanded mode [1].

Many techniques have been proposed to detect islanding, which can be divided into two groups: remote and local. The difference between local and remote approaches is the necessity of the former for a communication plan [17]. In other words, local systems observe, while remote systems communicate [18]. Although remote processes are extremely reliable, they are challenging to implement, since they require direct communication between DGs and utilities via networks like fiber optics and wireless communication. Furthermore, real-time implementation of these techniques may be rigid, challenging, and expensive due to the significant penetration of DGs in complex systems [19]. As a result, for ease of use and adaptability, a more affordable local technique is recommended. As suggested by the name, this strategy depends on identifying islanding by identifying changes in particular system characteristics at the DG location. Voltage, current, resistance, and harmonic distortion are variables that can be measured [20]. This broad category is further subdivided into passive methods, active methods, and combined methods. Multiple characteristics of the system are passively monitored at the Point of Common Coupling (PCC), including voltage, frequency, harmonic distortion, and current, as shown in Figure 2. These values change drastically when the distribution system is running in islanded mode. Certain thresholds have been established to prevent incorrect identification of other system breakdowns [21].

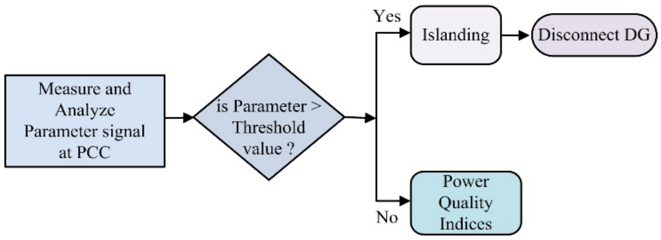

Fig. 2. Passive IDM working philosophy.

Active approaches use the DG's response to a small perturbation to detect islanding occurrences. The addition of perturbation after the distribution system has been linked to the grid will result in a little shift in a system parameter. However, the system will recognize islanding if there is a sudden change in the islanded mode's properties [22]. For distributed inverter generation, active strategies predominate. However, the vast majority of active islanding detection methods are often recommended only for nearby and tractable sources. Since the NDZ of the active methods is less than that of the passive ones, they can detect islanding even when load and generation are in equilibrium. However, the main problem with these strategies is that they typically reduce power quality by introducing disruptions into the system that are unnecessary in typical operating conditions [23]. Additionally, active methods take a lot longer time to detect islanding than passive ones.

Hybrid islanding detection approaches combine the benefits of active and passive. These methods are only used when it is clear that passive approaches cannot differentiate between islanding events [24]. The benefits of these methods are that they generate just a negligible amount of NDZ and the system is not subjected to a constant stream of signals. Because of this, there is far less power loss. The cost and time required to discover islanding occurrences both increase with this combination [25]. Most electrical companies use passive approaches to monitor islanding due to their simple operating principles and their ability to maintain power quality. Two common passive methods are voltage under/over and frequency under/over [26]. However, they perform satisfactorily when there is a significant power imbalance but poorly when there is a minor power mismatch. Although the frequency change rate in [27] performs better than previous methods, it can be put in danger when active power mismatch approaches less than 15%. THD-based islanding was used in [28], however, occasionally, when there are sudden changes in load, THD exceeds the prespecified threshold, resulting in false tripping.

II. ISLANDING CAUSES AND CONSEQUENCES

Whenever the central utility grid is disconnected from the rest of the system, including a few distributed generation sources and their respective load on the end side, the system is said to be in islanding state. Islanding can be intentional, which is created to avoid severe blackouts or to perform maintenance tasks on the grid side. Unintentional islanding happens when a DER continues to generate electricity, even after a fault or other sudden sort of disturbance which has disconnected the grid from the rest of the network. There are a variety of causes for unintentional islanding.

A. Unintentional Islanding Causes

- Loss of grid connectivity: Loss of grid connectivity can occur when there is a fault or failure in the transmission line that joins the main grid to the dispersed generation system. In this case, the isolated area of the distributed generation system may continue to produce power.
- Faults in the grid: Faults in the grid, such as short circuits, broken conductors, or equipment failures, can cause an islanding condition when they disconnect a portion of the grid from the main power system.
- Human error: If a part of the system is accidentally removed from the main grid, this is an islanding state that can be caused by a human error such as improper switch manipulation.
- Natural disasters: Natural disasters such as earthquakes, hurricanes, or tornadoes can cause an islanding condition if they damage the power system and disconnect a portion of the grid from the main system.

B. Islanding Consequences

The integrity of electrical networks is seriously threatened by unintentional islanding, which often results in cascading failures and blackouts. Such cascade failures are responsible for several power outages that have occurred worldwide over the past ten years [29]. Cascading failure is the process in which one failure could result in subsequent failures of other grid segments. Instability in frequency, angle, or voltage may result from a lack of active or reactive power on these haphazard islands. This instability in frequency, angle, or voltage may cause a power quality variation that spreads to another region if it is not well regulated. When islanding occurs, the auto recloser will keep trying to reestablish contact between the island and the power grid. This will result in an asynchronous reconnection between them. This occurs because the phase angles, voltage levels, and frequencies of the two powered systems are not compatible with each other. The impact of this situation on a spinning DG has been well established. The primary mover of the generator could be harmed by the high mechanical torque and currents produced by an out-of-sync closing. If repair personnel are sent to an unmonitored part of the power grid, they may come into contact with live parts of the equipment, which could cause serious injuries or even death. That is the important reason to track down and cut power to any rogue electric island.

III. PROPOSED IDM

The proposed method uses the rate of change of phase angle difference for efficient islanding detection in multiple DG-based power, as shown in Figure 3. With the help of the DG's own current and voltage data, the PAD can be determined between the DG and the utility grid. An islanding condition is determined to occur after the PAD rate rises above a predetermined threshold. The PAD is constantly tracked by the algorithm and compared to a predetermined limit. The program announces an islanding when the PAD exceeds the threshold value for a predetermined amount of time and disconnects the DGs from the microgrid.

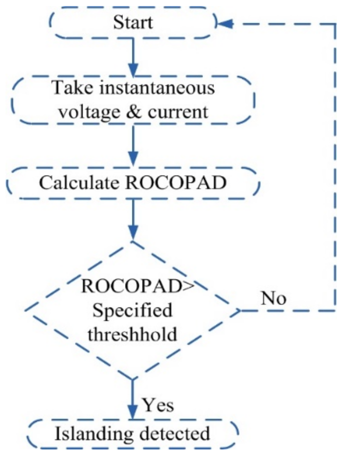

Fig. 3. Flow chart of the proposed IDM.

At the DG end, the ROCOPAD algorithm keeps an eye on phasor estimation based on synchronous transformation using the retrieved instantaneous voltage and current signals. The power system signal $x(t)$ with a frequency f is given by:

$$x(t) = \sum_{n=1}^{\infty} A_k \sin(n\omega_0 t + \theta_n) \quad (1)$$

where A_k is the amplitude and k is the phase angle of the k-th-order waveform. The d-q transformation is used to convert the three-phase to two-phase:

$$\begin{bmatrix} x_d \\ x_q \end{bmatrix} = \begin{bmatrix} \sin(\omega_0 t) & -\cos(\omega_0 t) \\ -\cos(\omega_0 t) & -\sin(\omega_0 t) \end{bmatrix} \times \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (2)$$

where f_0 is the system frequency, which is 50 Hz, ω_0 equals to $2\pi f_0$, Ts is the sampling interval, that equals m at the m-th instant. Therefore, (2) may be rewritten as:

$$\begin{bmatrix} x_d(m) \\ x_q(m) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sum_{k=1}^{\infty} A_k \cos[2\pi(kf - f_0)]\, mT_s + \delta_k \\ -\sum_{k=1}^{\infty} A_k \sin[2\pi(kf - f_0)]\, mT_s + \delta_k \end{bmatrix} \quad (3)$$

The fundamental quantities can be determined by setting k=1.

$$x_{d1}(m) = 1.5A_1 \cos[2\pi(f - f_0)]\, mT_s + \delta_1$$
$$x_{q1}(m) = 1.5A_1 \sin[2\pi(f - f_0)]\, mT_s + \delta_1 \quad (4)$$

It is possible to calculate the signal's amplitude ($A1$), phase (1), and frequency (f) from the d and q values. Now, ROCOPAD can be calculated as:

$$ROCOPAD = \frac{\Delta(\delta_v - \delta_i)}{\Delta t} \quad (5)$$

The ROCOPAD relay can detect an islanding condition quickly and accurately. The phase angle difference will be calculated and compared to the cutoff value. With the proper threshold, ROCOPAD is used as a criterion for islanding detection.

IV. RESULTS AND DISCUSSION

A. Test System

The proposed method was evaluated using a testing infrastructure, as shown in Figure 4. The simulation aimed to model a power system that combines solar power, energy storage, and a diesel generator with the primary electricity grid. This is a popular hybrid power system. The main power grid is the base of the power system and provides power when solar power and energy storage aren't enough. The solar power system consists of PV panels. The energy storage system is made up of batteries that store the extra energy made by the PV panels and release it when the energy demand is higher than what the PV panels can provide. A diesel engine is used as a backup power source if there is not enough power from the PV panels and energy storage. It is also responsible for maintaining the stability of the system during sudden load changes or disturbances. A main circuit breaker was added that disconnects the generator from the grid to achieve an islanding condition. The proposed method was then evaluated in a variety of steady-state load switching, severe fault, and capacitive switching scenarios.

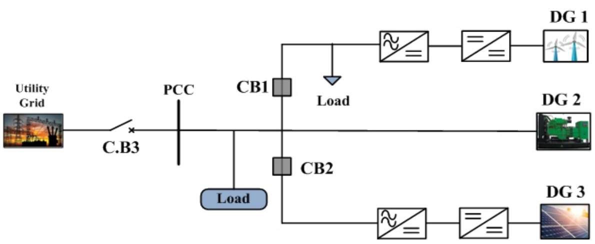

Fig. 4. Schematic diagram of the hybrid power system.

B. Islanding Events

The efficiency of the suggested method was measured with a conventional testing setup by generating several islanding situations. Since a parallel RLC load has a narrow NDZ and is hard to detect with passive islanding detection methods, it was selected as the most difficult scenario.

1) Using RLC Load

To evaluate IDM, it is common practice to model the load as an RLC load because RLC loads can pose certain detection difficulties, especially for loads with high-quality factors. To mimic this scenario, a parallel RLC load was connected to the distribution network, which resulted in an islanding event at 0.3 S. Figure 5 shows typical results.

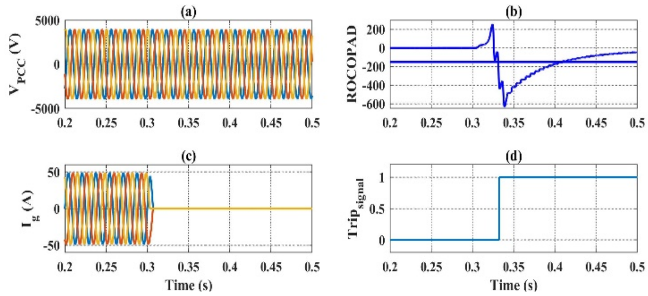

Fig. 5. Results during RLC under islanding condition.

C. Non Islanding Conditions

To test how well the suggested method would work in real-world settings, various events that would not normally constitute an islanding condition, but whose signatures were very similar, were replicated. The proposed solution was tested using load shedding, capacitor switching, and large induction load switching, to ensure that it would not fail in these circumstances.

1) Capacitor Switching

Some voltage transients in power networks are caused by capacitor switching, which can degrade the effectiveness of islanding detection approaches. Occasionally, they could cause similar signatures in source voltages or currents, which may reduce the accuracy of the proposed approach. To evaluate the viability of the proposed strategy, a capacitor switching scenario at 0.3 s was simulated. Figure 6 shows the resultant signals, which occasionally exceed the average levels but fall short of the set threshold.

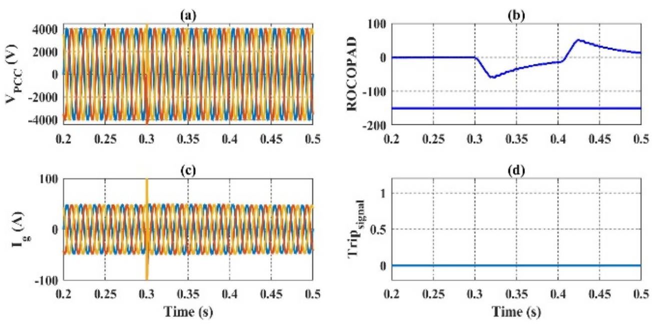

Fig. 6. Results during capacitive switching for normal conditions.

D. Load Shedding

Load shedding refers to the intentional and temporary reduction of electrical power to certain areas or customers to prevent a widespread power outage. Power flow and system dynamics can abruptly change as a result of load shedding. To identify islanding, the proposed IDM method tracks the rate at which power angles vary. If load shedding causes rapid changes in power flow, it can trigger false alarms and lead to incorrect detection of islanding events. A large portion of the load was isolated in the given simulation at 0.3 s to evaluate the load-shedding scenario. Figure 7 illustrates the simulation results, showing that although the current decreased and deviated to a great extent, it was within the acceptable threshold.

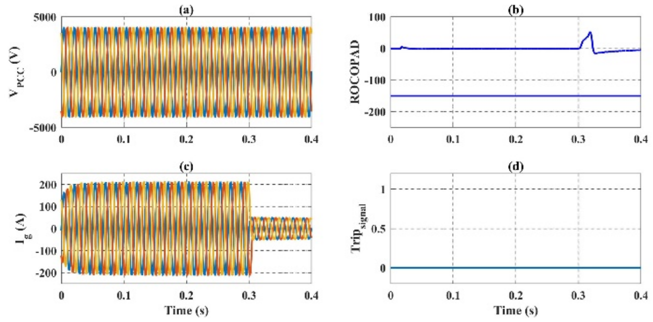

Fig. 7. Results during load shedding for normal conditions.

1) *Heavy Load Switching*

Load change scenarios can affect islanding detection methods, as sudden load changes can result in false alarms or delayed detection of islanding events due to disturbances in power flow, voltage, and frequency. Certain load changes can pose a challenge to the sensitivity of the islanding detection method. A load change scenario was simulated to evaluate the effectiveness of the proposed strategy. However, as shown in Figure 8, the results do not have a noticeable impact on the detection method.

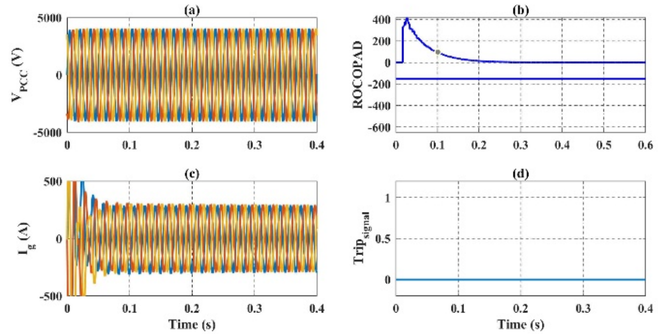

Fig. 8. Results during load switching for normal condition.

TABLE I. COMPARISON OF CONVENTIONAL PASSIVE IDAS

Conventional Passive IDMs	Detection (time)	NDZ
OUF [30]	200 ms-2 s	Large
OUV [31]	200 ms-2 s	Large
ROCOP [32]	300 ms	Large
ROCOF [27]	300 ms	Small
ROCOFOP [33]	100-300 ms	Small
Voltage unbalance [34]	400 ms	
Harmonic distortion [28]	200-400 ms	Large
Proposed		Very Small

V. CONCLUSION

Effective islanding detection is crucial in ensuring the reliability of power distribution networks that incorporate DG sources. This study investigated the reasons for islanding and the consequences of electrical system islanding events for utilities and their end users. This paper presented a ROCOPAD-based passive islanding detection method that monitors for the aforementioned changes and other indicators of islanding activity. To evaluate the method's success, several DG-based test systems were subjected to extensive simulations. The results demonstrated the effectiveness of the suggested method in detecting islanding events with minimal disturbances. Furthermore, the proposed ROCOPAD-based IDM not only offered islanding detection based on multiple DG sources, but exhibited high accuracy, short response time, and be cost-effective and robust to variations in power system parameters, such as load conditions, system impedance, and DER characteristics.

Future research should concentrate on the ROCOPAD with other computational methods. Artificial Intelligence (AI) can be used to improve the accuracy and reliability of ROCOFD-based islanding detection by identifying patterns in data that are associated with islanding events. Moreover, AI-based ROCOPAD IDM could avoid the possibility of maloperation because it can adapt to changing operating conditions by continuously learning and updating the islanding detection algorithm.

REFERENCES

[1] M. Amini, A. R. Seifi, and H. Samet, "An Efficient Controlled Islanding Technique for Smart Grids," *International Journal of Renewable Energy Research (IJRER)*, vol. 10, no. 1, pp. 24–32, Mar. 2020.

[2] S. R. Salkuti, "Energy Storage and Electric Vehicles: Technology, Operation, Challenges, and Cost-Benefit Analysis," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 4, pp. 40–45, 2021, https://doi.org/10.14569/IJACSA.2021.0120406.

[3] M. F. Tahir, C. Haoyong, A. Khan, M. S. Javed, N. A. Laraik, and K. Mehmood, "Optimizing Size of Variable Renewable Energy Sources by Incorporating Energy Storage and Demand Response," *IEEE Access*, vol. 7, pp. 103115–103126, 2019, https://doi.org/10.1109/ACCESS.2019.2929297.

[4] S. M. Ghania, K. R. M. Mahmoud, and A. M. Hashmi, "A Reliability Study of Renewable Energy Resources and their Integration with Utility Grids," *Engineering, Technology & Applied Science Research*, vol. 12, no. 5, pp. 9078–9086, Oct. 2022, https://doi.org/10.48084/etasr.5090.

[5] B. Zafar, B. Slama, S. Nasri, and M. Mahmoud, "Smart Home Energy Management System Design: A Realistic Autonomous V2H / H2V Hybrid Energy Storage System," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, pp. 217–213, 2019, https://doi.org/10.14569/IJACSA.2019.0100630.

[6] B. Zafar, B. Slama, S. Nasri, and M. Mahmoud, "Smart Home Energy Management System Design: A Realistic Autonomous V2H / H2V Hybrid Energy Storage System," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, pp. 217–213, 2019, https://doi.org/10.14569/IJACSA.2019.0100630.

[7] R. Aghazadeh, H. Lesani, M. Sanaye-Pasand, and B. Ganji, "New technique for frequency and amplitude estimation of power system signals," *IEE Proceedings - Generation, Transmission and Distribution*, vol. 152, no. 3, pp. 435–440, May 2005, https://doi.org/10.1049/ip-gtd:20041255.

[8] M. N. Hanani, J. Sampe, J. Jaffar, and N. H. M. Yunus, "Development of a Hybrid Solar and Waste Heat Thermal Energy Harvesting System," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10680–10684, Jun. 2023, https://doi.org/10.48084/etasr.5561.

[9] S. Muchande and S. Thale, "Hierarchical Control of a Low Voltage DC Microgrid with Coordinated Power Management Strategies," *Engineering, Technology & Applied Science Research*, vol. 12, no. 1, pp. 8045–8052, Feb. 2022, https://doi.org/10.48084/etasr.4625.

[10] M. Salman, S. Hongsheng, M. A. Aman, and Y. Khan, "Enhancing Voltage Profile and Power Loss Reduction Considering Distributed Generation (DG) Resources," *Engineering, Technology & Applied Science Research*, vol. 12, no. 4, pp. 8864–8871, Aug. 2022, https://doi.org/10.48084/etasr.5046.

[11] M. F. Tahir, C. Haoyong, and H. Guangze, "Evaluating individual heating alternatives in integrated energy system by employing energy and exergy analysis," *Energy*, vol. 249, Jun. 2022, Art. no. 123753, https://doi.org/10.1016/j.energy.2022.123753.

[12] R. Haider and C.-H. Kim, "Chapter 7 - Protection of DERs," in *Integration of Distributed Energy Resources in Power Systems*, T. Funabashi, Ed. Cambridge, MA, USA: Academic Press, 2016, pp. 157–192.

[13] P. D. Rigo *et al.*, "Renewable Energy Problems: Exploring the Methods to Support the Decision-Making Process," *Sustainability*, vol. 12, no. 23, Jan. 2020, Art. no. 10195, https://doi.org/10.3390/su122310195.

[14] U. S. Ahmad, M. Usman, S. Hussain, A. Jahanger, and M. Abrar, "Determinants of renewable energy sources in Pakistan: An overview," *Environmental Science and Pollution Research*, vol. 29, no. 19, pp. 29183–29201, Apr. 2022, https://doi.org/10.1007/s11356-022-18502-w.

[15] L. Zhifeng, Z. Liping, C. Yuchen, and J. Chunying, "Research on Islanding Detection of Grid-Connected System," *International Journal of Advanced Computer Science and Applications*, vol. 6, no. 7, pp. 81–86, 2015, https://doi.org/10.14569/IJACSA.2015.060713.

[16] Y. Cheng, N. Zhang, D. S. Kirschen, W. Huang, and C. Kang, "Planning multiple energy systems for low-carbon districts with high penetration of renewable energy: An empirical study in China," *Applied Energy*, vol. 261, Mar. 2020, Art. no. 114390, https://doi.org/10.1016/j.apenergy.2019.114390.

[17] L. B. Raju and K. S. Rao, "Evaluation of Passive Islanding Detection Methods for Line to Ground Unsymmetrical Fault in Three Phase Microgrid Systems: Microgrid Islanding Detection Method," *Engineering, Technology & Applied Science Research*, vol. 11, no. 5, pp. 7591–7597, Oct. 2021, https://doi.org/10.48084/etasr.4310.

[18] N. A. Larik, M. F. Tahir, Z. M. S. Elbarbary, M. Z. Yousaf, and M. A. Khan, "A comprehensive literature review of conventional and modern islanding detection methods," *Energy Strategy Reviews*, vol. 44, Nov. 2022, Art. no. 101007, https://doi.org/10.1016/j.esr.2022.101007.

[19] G. Bayrak and E. Kabalci, "Implementation of a new remote islanding detection method for wind–solar hybrid power plants," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 1–15, May 2016, https://doi.org/10.1016/j.rser.2015.12.227.

[20] M. Alsabban, O. Bertozzi, and S. Ahmed, "Analysis and Verification of Islanding Detection Techniques for Grid-integrated PV Systems," in *2023 IEEE PES Conference on Innovative Smart Grid Technologies - Middle East (ISGT Middle East)*, Abu Dhabi, United Arab Emirates, Mar. 2023, pp. 1–5, https://doi.org/10.1109/ISGTMiddleEast56437.2023.10078615.

[21] R. Nale and M. Biswal, "Comparative assessment of passive islanding detection techniques for microgrid," in *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, Coimbatore, India, Mar. 2017, pp. 1–5, https://doi.org/10.1109/ICIIECS.2017.8275935.

[22] Y. A. Elshrief, S. Abd-Elhaleem, B. Abo Zalam, and A. D. Asham, "On active anti-islanding techniques: survey," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 2, May 2021, Art. no. 609, https://doi.org/10.11591/ijeecs.v22.i2.pp609-618.

[23] K. Naraghipour, K. Ahmed, and C. Booth, "A Comprehensive Review of Islanding Detection Methods for Distribution Systems," in *2020 9th International Conference on Renewable Energy Research and Application (ICRERA)*, Sep. 2020, pp. 428–433, https://doi.org/10.1109/ICRERA49962.2020.9242850.

[24] R. Zamani, M. E. Hamedani Golshan, H. Haes Alhelou, and N. Hatziargyriou, "A novel hybrid islanding detection method using dynamic characteristics of synchronous generator and signal processing technique," *Electric Power Systems Research*, vol. 175, Oct. 2019, Art. no. 105911, https://doi.org/10.1016/j.epsr.2019.105911.

[25] P. Mahat, Z. Chen, and B. Bak-Jensen, "A Hybrid Islanding Detection Technique Using Average Rate of Voltage Change and Real Power Shift," *IEEE Transactions on Power Delivery*, vol. 24, no. 2, pp. 764–771, Apr. 2009, https://doi.org/10.1109/TPWRD.2009.2013376.

[26] W. Bower and M. Ropp, "Evaluation of Islanding Detection Methods," International Energy Agency, Report IEA-PVPS T5-09: 2002, 2002.

[27] N. A. Larik, M. Ahmed, L. L. Zhang, J. A. Jamali, and Q. H. Wu, "A New Method of Unintentional Islanding detection for Multiple Distributed energy resources based Power System," in *2023 4th International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, Sukkur, Pakistan, Mar. 2023, pp. 1–6, https://doi.org/10.1109/iCoMET57998.2023.10099374.

[28] A. M. Massoud, K. H. Ahmed, S. J. Finney, and B. W. Williams, "Harmonic distortion-based island detection technique for inverter-based distributed generation," *IET Renewable Power Generation*, vol. 3, no. 4, pp. 493–507, Dec. 2009, https://doi.org/10.1049/iet-rpg.2008.0101.

[29] Ch. R. Reddy and K. H. Reddy, "A New Passive Islanding Detection Technique for Integrated Distributed Generation System Using Rate of Change of Regulator Voltage Over Reactive Power at Balanced Islanding," *Journal of Electrical Engineering & Technology*, vol. 14, no. 2, pp. 527–534, Mar. 2019, https://doi.org/10.1007/s42835-018-00073-x.

[30] H. H. Zeineldin and J. L. Kirtley, "Performance of the OVP/UVP and OFP/UFP Method With Voltage and Frequency Dependent Loads," *IEEE Transactions on Power Delivery*, vol. 24, no. 2, pp. 772–778, Apr. 2009, https://doi.org/10.1109/TPWRD.2008.2002959.

[31] Z. Ye, A. Kolwalkar, Y. Zhang, P. Du, and R. Walling, "Evaluation of anti-islanding schemes based on nondetection zone concept," *IEEE Transactions on Power Electronics*, vol. 19, no. 5, pp. 1171–1176, Sep. 2004, https://doi.org/10.1109/TPEL.2004.833436.

[32] F. Katiraei, M. R. Iravani, and P. W. Lehn, "Micro-grid autonomous operation during and subsequent to islanding process," *IEEE Transactions on Power Delivery*, vol. 20, no. 1, pp. 248–257, Jan. 2005, https://doi.org/10.1109/TPWRD.2004.835051.

[33] S.-I. Jang and K. H. Kim, "An islanding detection method for distributed generations using voltage unbalance and total harmonic distortion of current," *IEEE Transactions on Power Delivery*, vol. 19, no. 2, pp. 745–752, Apr. 2004, https://doi.org/10.1109/TPWRD.2003.822964.

[34] C. Li, C. Cao, Y. Cao, Y. Kuang, L. Zeng, and B. Fang, "A review of islanding detection methods for microgrid," *Renewable and Sustainable Energy Reviews*, vol. 35, pp. 211–220, Jul. 2014, https://doi.org/10.1016/j.rser.2014.04.026.