International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-10, Issue-10, Jan 2025

Combined Variational Mode Decomposition and Teager Energy Operator-based Approach for Islanding Detection in Distributed Generation

Talluri Ramesh, Designation, Research Scholar, University College of Engineering, Osmania University, Hyderabad, India, tramesh238@gmail.com

M. Chakravarthy, Professor, Vasavi College of Engineering, Hyderabad, India, chakri4330@gmail.com

Gaddam Mallesham, Professor, University College of Engineering, Osmania University, Hyderabad, India, drgm@osmania.ac.in

Abstract **This paper proposes a passive islanding detection approach using Variational mode decomposition and Teager energy operator. The voltages monitored at distributed generator are gathered and are pre-processed through signal processing to recognize the islanding scenario. Initially, the three phase voltage signals are converted into modal signals that are then decomposed using Variational mode decomposition into intrinsic mode functions. Further, using Teager energy operator energy is extracted for suitable intrinsic mode function. Appropriate threshold value is selected based on the test system to detect the islanding. Various simulation studies have been investigated on the standard test system to select a suitable threshold value for discriminating non-islanding and islanding conditions. Results obtained and comparative study supports the efficacy of the presented approach.**

Keywords —Distributed generation, Islanding detection, Variational mode decomposition, Teager energy operator, Non-islanding, Noise.

I. INTRODUCTION

Currently, the distribution system is undergoing a transition phase as it integrates renewable resources such as solar, wind, and diesel into its power sources. Their environmental benefits and increased availability to consumers have prioritized them over traditional sources. However, despite their advantages, these sources also present various challenges and issues, with islanding being one significant concern. [1,2,3].

Islanding scenario is if a distributed generator (DG) remains to supply the network although the main grid has been isolated. This situation can be either intended or unintended. Unintended islanding is particularly problematic as it is risk to maintenance personnel and can cause unexpected fluctuations in frequency and voltage, leading to issues with power quality. Therefore, it is crucial to provide DGs with islanding detection capability. As per IEEE standard 1547, unintended islanding should prompt the DG to disconnect within 2 seconds for smaller deviations in voltage and frequency [4]. There are numerous islanding detection approaches documented in this research area, classified into those reliant on communication and those utilizing local measurements. Communication-based methods [5, 6] like transfer trip and power line carrier are costly. Local measurement-dependent islanding approaches are classified as active and passive techniques. Active approaches detect islanding faster and with a reduced non-detection zone when compared to passive approaches. They induce slight disturbances to measure specific parameters and identify islanding, which can slightly affect power quality when the main grid is active but significantly degrade it if islanded. The effectiveness of islanding identification system hinges on identifying the non-islanding and islanding, especially in relation to power imbalance [7]. Active islanding approaches are Sandia frequency shift technique [8], active frequency shift [9], slip mode frequency shift [10].

Passive methods track variations in current, voltage and frequency near the target DG. Passive approaches also comprise Over-voltage/under-voltage and over-frequency/under-frequency detection [11], tracking phase position changes with vector surge techniques (VVS) [12], rate of change of phase angle difference (ROCPAD) [13], rate of change of impedance [14], and rate of change of frequency (ROCOF) [15]. Depending on the threshold, distinct non-detection zones are presented by passive islanding methods. Although there is some variations in the results, passive approaches are simple for implementation and don’t affect the testing system's power quality like active methods do. Many artificial intelligence-based approaches have been put forth in the literature to enhance the effectiveness of passive methods. Support vector machine

DOI : 10.35291/2454-9150.2025.0008

[16], random forest [17], deep neural network [18], and ensemble k-nearest neighbors [19] are some examples. Nevertheless, training dependent approaches might need bulky datasets that would be extremely time consuming. Many signal processing methods, like fast Fourier transform [20], wavelet transform [21], s-transform [22], Kalman filter [23], transient monitoring function [24], empirical mode decomposition (EMD) [25], Time varying filter-EMD [26] have been used to address these problems. These approaches do, however, still have several shortcomings, including high computational load, a lack of self-adaptation, and persistent non-detection zones. There is significant motivation to choose an effective signal decomposition method for passive islanding detection given these insights into different signal decomposition strategies. By extracting hidden features from the observed signal, these strategies can increase the effectiveness of passive methods.

In this paper, Variational mode decomposition and the Teager energy operator are employed to detect islanding conditions. Voltage signal acquired near target DG is pre-processed and converted into modal signals. Variational mode decomposition is utilized for extracting the time-frequency domain components, offering benefits like being self-adaptive, free from noise insensitive, and mode mixing. The time-frequency information will be then transformed into energy signals using Teager energy operator. A thorough investigation is conducted to demonstrate that the proposed approach remains invariant across various system disturbances.

II. PROPOSED APPROACH

A. *Variational Mode Decomposition*

Variational mode decomposition (VMD) is chosen for its robustness to noise, lack of mode mixing effects, and strong mathematical foundation. Firstly, the input signal y(t) will be decomposed as intrinsic mode functions (IMFs), like EMD but with enhanced attributes [27]. VMD is distinguished by its method of addressing three variational constraints: Hilbert transform (HT), Wiener filtering, and frequency mixing making it a preferred tool for this study.

The idea behind VMD can be seen as a constrained variational issue, expressed as

$$\min\binom{\omega_n}{v_n}\left\{\sum_n \left\|\partial_t\left[\left(\delta(t)+\frac{j}{\pi t}\right)*v_n\right]e^{-i\omega_n t}\right\|_2^2\right\}$$
$$\text{subject to } \sum_n v_n = y(t) \qquad (1)$$

where v_n = n^th mode, δ = Dirac distribution, ω_n = center frequency. Here constrained problem is converted as an unconstrained one by introducing a Lagrangian multipliers (λ) and penalty factor (α).

$$L(v_n,\omega_n,\lambda) = \alpha\sum_n ||\partial_t\left[\left(\delta(t)+\frac{j}{\pi t}\right)*v_n\right]e^{-i\omega_n t}||_2^2 + ||y(t)-\sum_n^v v_n||_2^2 + (\lambda, y(t)-\sum_n^v v_n) \qquad (2)$$

Equation (2) will be further solved using the alternate direction method of multipliers, updating both n and ω_n. To update the mode, Wiener filtering is applied to reduce the noise effect on the signal.

The mode update is carried out in the Fourier domain.

$$v_n^{m+1}(w) = \frac{y-\sum_{i<n} v_i^{m+1}(\omega)-\sum_{i>n} v_i^{m}(\omega)+(\lambda^m(\omega)/2)}{1+2\alpha\,(\omega-\omega_n^m)^2} \qquad (3)$$

The center frequency is determined by

$$\omega_n^{m+1} = \frac{\int_0^\infty \omega|v_n^{m+1}(\omega)|^2 d\omega}{\int_0^\infty |v_n^{m+1}(\omega)|^2 d\omega} \qquad (4)$$

Additionally, λ will be updated using

$$\lambda^{m+1} = \lambda^m + \tau(y - \sum_n v_n^{m+1}) \qquad (5)$$

Here, τ = update parameter. The updating process concludes after convergence criteria is satisfied.

$$\frac{||v_n^{m+1}-v_n^m||_2^2}{||v_n^m||_2^2} < \varepsilon \qquad (6)$$

.

B. *Islanding Detection approach*

For determining the islanding status, the voltage signal that was taken at the target DG is pre-processed. The following outlines the suggested approach's step-by-step process:

- The voltage will be extracted at the target DG.
- Convert to modal signals (V_m) using modal transformation [28],

$$V_m = V_a + 2V_b - 3V_c \qquad (7)$$

Fig. 1 represents the three-phase voltage signal and modal signals.

- The VMD is used to process the modal signal and extract the relevant IMFs. Here, the modal number n = 4 is used which extracts four IMFs and are represented in Fig. 1. It can be observed that IMF-3 has components which can discriminate the disturbance from normal operating condition compared to other IMFs. So, IMF-3 is selected.
- Moreover, the Teager energy operator (TEO) [29] is applied to IMF-3 in order to calculate the signal's energy. The TEO uses three consecutive samples to calculate the energy of IMF-3,

$$y(m) = y^2(m) - y(m-1)\,y(m+1) \qquad (7)$$

Where, $y(m-1)$, $y(m)$, and $y(m+1)$ are the three consecutive samples.

- Ultimately, within a predetermined threshold, the energy will be utilized for detecting the islanding scenario and discriminate the non-islanding scenarios.

The complete flow of the proposed approach is represented in Fig. 2.

C. Threshold Selection

By decomposing the voltage signal, the energy content of IMF-3 is obtained, which is then used as an index to determine the islanding circumstances. During an islanding event, the energy of IMF-3 has a significant change, while it experiences relatively smaller changes during non-islanding scenarios. For discriminating the non-islanding and islanding scenarios, an appropriate threshold must be set. Since this threshold is entirely system-dependent, extensive simulations have been conducted, monitoring the TEO value of IMF-3 for different scenarios for selecting the threshold accurately. Table I displays the test cases taken into consideration for the research. The energy magnitude during critical non-islanding and islanding scenarios are considered for study. The threshold value is determined as 0.05 for differentiating islanding events from other following a detailed analysis of these case studies and a comparison of the zero-mismatch condition with other events.

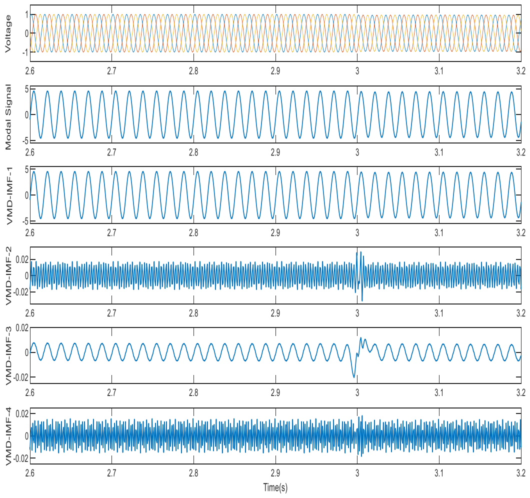

Fig. 1 Three phase voltage signal, Modal transformed signal, IMFs extracted using VMD

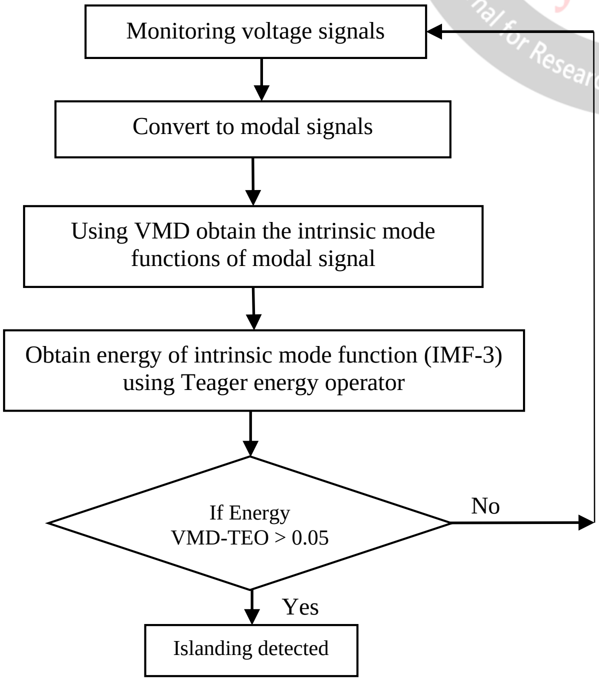

Fig. 2: The proposed islanding detection approach's block diagram

Table 1: Simulated scenarios

Scenarios	
Islanding	Active power mismatch (APM)
Islanding	Reactive power mismatch (RPM)
Islanding	Zero power mismatch (ZPM)
Non-Islanding	Load switching
Non-Islanding	Capacitor switching
Non-Islanding	Faults

III. SIMULATION RESULTS

The presented approach is tested on a 33 kV distribution system that is connected to a 132 kV substation. A distributed generator, namely synchronous generator, is connected to this system. The system's details are based on [30] and test system is shown in Fig. 3. Per unit (p.u.) voltage measurements are utilized at the DG's PCC and are sampled at 1.2 kHz sampling frequency.

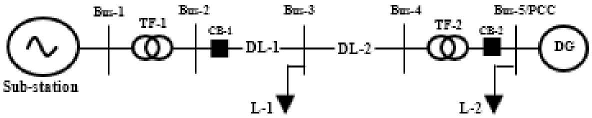

Fig. 3. Single line diagram of the test system.

A. *Islanding: Zero power mismatch*

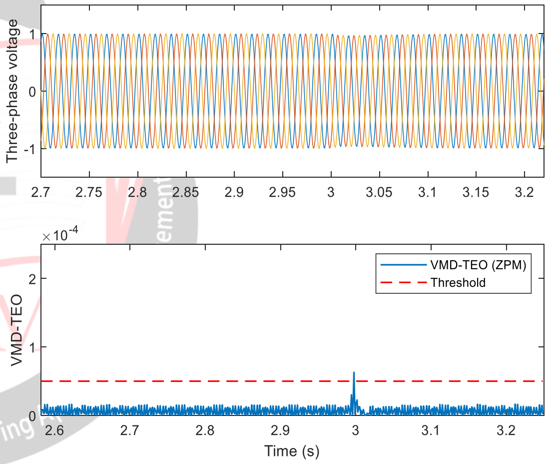

Fig. 4 Islanding condition: zero power mismatch

The power mismatch represents power deficit in the system, which is the shortfall in power delivered by both the utility grid and DGs for meeting required load demand of distribution network. When the power exchange related to utility grid with the distribution network is approximately zero i.e., during zero power mismatch condition many of the approaches in the literature fails in identifying islanding condition. So, the performance of the proposed approach for 0% power mismatch is accessed and the respective results are shown in Fig. 4. Three phase voltage waveform for 0% power mismatch at time, t=3s is depicted in Fig. 4(a). Also Fig. 4(b) shows that the energy index surpasses the threshold level, which ensures the proposed approach detects very small disturbances accurately.

B. *Islanding: Active power mismatch*

The islanding scenario is assessed for different active power mismatch levels. Upon changing the load near PCC,

DOI : 10.35291/2454-9150.2025.0008

which is managed by the electrical grid, distinct APM values can be produced. Fig. 5 illustrates the effectiveness of the suggested approach at 5% APM. The diagram depicts the energy index derived using VMD-TEO exceeds the index set to detect islanding. For any APM value, it could be therefore suggested as the proposed approach will efficiently identify.

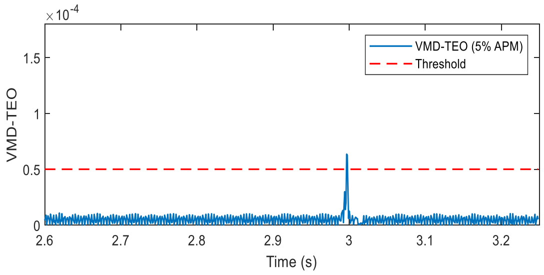

Fig. 5 Islanding condition: 5% APM

C. *Islanding: Reactive power mismatch*

The islanding scenario is assessed varying reactive power mismatch. At t=3 seconds, the islanding event begins for distinct RPM value. Fig. 6 shows how the proposed approach performs for these 5% RPM value. The index value surpasses the threshold, as shown in the figure, indicating the efficacy of the approach in promptly detecting the islanding scenario.

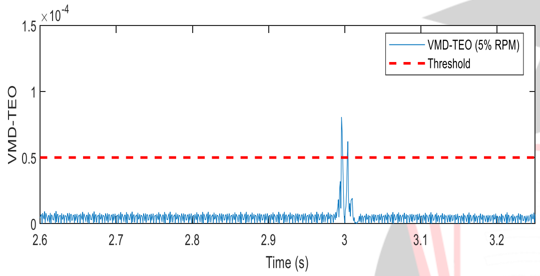

Fig. 6 Islanding condition: 5% RPM

D. *Non-Islanding: Load switching*

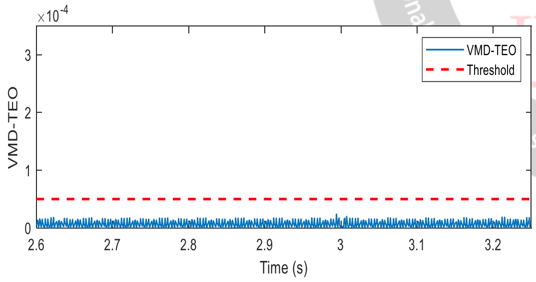

Fig. 7 Non-Islanding condition: Load switching

For load switching, the efficacy of the approach is assessed. It involves an 80% increase in the load near PCC at time t=3s, causing a disturbance. The energy index change related to this non-islanding scenario is depicted in Fig. 7. Figure illustrates that for very small change in the energy of IMF-3 during load switching which ensures that the proposed approach efficiently distinguishes the islanding and load switching phenomena.

E. *Capacitor Switching*

To increase the power factor, capacitors will be inserted into the distribution network. At the time of switching, this activity may result in significant transients, which could lead to the malfunction of islanding detection. Capacitor rated one MVAR is switched at 3 seconds to check the condition. Fig. 8 displays the index value that proposed approach has produced. It indicates that the index value during capacitor switching event remains below the threshold level.

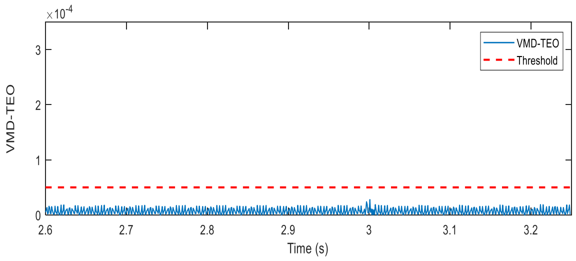

Fig. 8 Non-Islanding condition: Capacitor switching

F. *Non-Islanding Fault*

A malfunction in a nearby feeder cannot be misinterpreted by the suggested approach as an islanding incident. A nearby distribution line, DL-2, is utilized for simulating a three-phase-to-ground fault (ABC-G). Fig. 9 shows the energy index. Upon observing that the energy index stays below the threshold level during the fault on nearby feeder, it can be concluded that this proposed approach has effectively identified the non-islanding fault event.

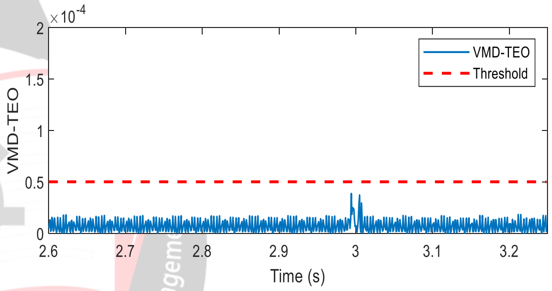

Fig. 9 Non-Islanding condition: Fault

G. *Effect of Noise*

The suggested scheme's efficacy is evaluated by analyzing the noise-contaminated voltage signal. A signal-to-noise ratio (SNR) of 40 dB, that is frequently employed in practice [31] is considered. The voltage signal is subjected to white Gaussian noise and is analysed. In Fig. 10, it is witnessed that during the switching of load at time t=3s, the index stays below the threshold value. It demonstrates that the proposed approach performs well during the existence of noise in the signal.

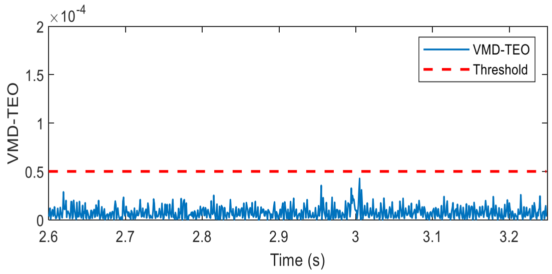

Fig. 10 non-islanding condition: Load switching with 40dB noise

DOI : 10.35291/2454-9150.2025.0008

IV. CONCLUSIONS

The energy of the intrinsic mode function that is retrieved from the voltage signal is used in this study to present a passive TEO-VMD-based technique for islanding detection. The results validate the effectiveness of the proposed approach for detecting significant islanding and non-islanding conditions, including zero power mismatch, capacitor switching, and faults. This signal decomposition technique appears to be resilient and capable of detecting important conditions in the context of islanding, based on the assessment made on the proposed approach compared to prior reported islanding detection approaches.

REFERENCES

[1] C. Li, J. Savulak, and R. Reinmuller, "Unintentional islanding of distributed generation - operating experiences from naturally occurred events," IEEE Trans. Power Deliv., vol. 29, no. 1, pp. 269–274, Jan. 2014.

[2] A. Hirsch, Y. Parag, and J. Guerrero, "Microgrids: A review of technologies, key drivers, and outstanding issues," Renew. Sustain. Energy Rev., vol. 90, pp. 402–411, 2018.

[3] M.-S. Kim, R. Haider, G.-J. Cho, C.-H. Kim, C.-Y. Won, and J.-S. Chai, "Comprehensive review of islanding detection methods for distributed generation systems," Energies, vol. 12, no. 5, p. 837, 2019.

[4] Institute of Electrical and Electronics Engineers, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, 2018.

[5] W. Xu, G. Zhang, C. Li, W. Wang, G. Wang, and J. Kliber, "A power line signaling based technique for anti-islanding protection of distributed generators—Part I: Scheme and analysis," IEEE Trans. Power Deliv., vol. 22, pp. 1758–1766, Oct. 2007.

[6] B. Dob and C. Palmer, "Communications assisted islanding detection: Contrasting direct transfer trip and phase comparison methods," in Proc. 71st Annu. Conf. Prot. Relay Eng. (CPRE), 2018, pp. 1–6. Available: https://doi.org/10.1109/CPRE.2018.8349783.

[7] L. A. C. Lopes and H. Sun, "Performance assessment of active frequency drifting islanding detection methods," IEEE Trans. Energy Convers., vol. 21, no. 1, pp. 171–180, Mar. 2006.

[8] H. Vahedi, M. Karrari, and G. B. Gharehpetian, "Accurate SFS parameter design criterion for inverter-based distributed generation," IEEE Trans. Power Deliv., vol. PP, no. 99, pp. 1–1, Jan. 2015.

[9] B. Wen, D. Boroyevich, R. Burgos, Z. Shen, and P. Mattavelli, "Impedance-based analysis of active frequency drift islanding detection for grid-tied inverter systems," IEEE Trans. Ind. Appl., vol. 52, no. 1, pp. 332–341, Jan. 2016.

[10] M. E. Ropp, M. Begovic, and A. Rohatgi, "Determining the relative effectiveness of islanding detection methods using phase criteria and nondetection zones," IEEE Trans. Energy Convers., vol. 15, no. 3, pp. 290–296, Sep. 2000.

[11] W. Bower and M. Ropp, "Evaluation of islanding detection methods for utility-interactive inverters in photovoltaic systems," Sandia Report SAND-3591, 2002.

[12] W. Freitas, Z. Huang, and W. Xu, "A practical method for assessing the effectiveness of vector surge relays for distributed generation applications," IEEE Trans. Power Deliv., vol. 20, no. 1, pp. 57–63, Jan. 2005.

[13] A. Samui and S. R. Samantaray, "Assessment of ROCPAD relay for islanding detection in distributed generation," IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 391–398, Jun. 2011.

[14] P. H. Shah and B. R. Bhalja, "A new rate of change of impedance-based islanding detection scheme in presence of distributed generation," Electr. Power Compon. Syst., vol. 42, no. 11, pp. 1172–1180, Nov. 2014.

[15] M. W. Altaf, M. T. Arif, S. Saha, S. N. Islam, M. E. Haque, and A. M. T. Oo, "Effective ROCOF based islanding detection technique for different types of microgrid," in Conf. Rec. IAS Annu. Meet. (IEEE Ind. Appl. Soc.), vol. 2021-Octob, no. 2, pp. 1809–1821, Oct. 2021.

[16] B. Matik-Cuka and M. Kezunovic, "Islanding detection for inverter-based distributed generation using support vector machine method," IEEE Trans. Smart Grid, vol. 5, no. 6, pp. 2676–2686, Nov. 2014.

[17] S. Adari and B. B. Bhalja, "Islanding detection of distributed generation using random forest technique," in Proc. IEEE 6th Int. Conf. Power Syst., Mar. 2016, pp. 1–6.

[18] X. Kong, X. Xu, Z. Yan, S. Chen, H. Yang, and D. Han, "Deep learning hybrid method for islanding detection in distributed generation," Appl. Energy, vol. 210, pp. 776–785, 2018.

[19] B. K. Chaitanya, A. Yadav, and M. Pazoki, "Reliable islanding detection scheme for distributed generation based on pattern-recognition," IEEE Trans. Ind. Informat., vol. 17, no. 8, pp. 5230–5238, Aug. 2021.

[20] A. Rostami, A. Jalilian, S. Zabihi, J. Olamaei, and E. Pouresmaeil, "Islanding detection of distributed generation based on parallel inductive impedance switching," IEEE Syst. J., vol. 14, no. 1, pp. 813–823, Mar. 2020.

[21] S.R. Mohanty, N. Kishor, P.K. Ray, J.P.S. Catalao, "Comparative study of advanced signal processing techniques for islanding detection in a hybrid distributed generation system," IEEE Trans. Sustain. Energy, vol. 6, no. 1, pp. 122–131, Jan. 2015.

[22] S.R. Samantaray, A. Samui, and B. Chitti Babu, "Time-frequency transform-based islanding detection in distributed generation," IET Renew. Power Gener., vol. 5, no. 6, pp. 431–438, 2011.

[23] R. Haider, C.H. Kim, T. Ghanbari, and S.B.A. Bukhari, "Harmonic-signature-based islanding detection in grid-connected distributed generation systems using Kalman filter," IET Renew. Power Gener., vol. 12, no. 15, pp. 1813–1822, 2018.

[24] Rahul Dubey, Marjan Popov, and Subhransu Ranjan Samantaray, "Transient monitoring function-based islanding detection in power distribution network," IET Gener. Transm. Distrib., 2018.

[25] H. Khosravi, H. Samet, and M. Tajdinian, "Empirical mode decomposition-based algorithm for islanding detection in micro-grids," Electr. Power Syst. Res., vol. 201, p. 107542, Dec. 2021.

[26] B. K. Chaitanya, A. Yadav, and M. Pazoki, "An advanced signal decomposition technique for islanding detection in DG system," IEEE Systems Journal, vol. 15, no. 3, pp. 3220–3229, Sept. 2021, doi: 10.1109/JSYST.2020.301715.

[27] K. Dragomiretskiy and D. Zosso, "Variational mode decomposition," IEEE Trans. Signal Processing, vol. 62, no. 3, pp. 531–544, Feb. 2014.

[28] R. Haider, C.H. Kim, T. Ghanbari, S.B.A. Bukhari, M.S. uz Zaman, S. Baloch, and Y.S. Oh, "Passive islanding detection scheme based on autocorrelation function of modal current envelope for photovoltaic units," IET Gener. Transm. Distrib., vol. 12, pp. 726–736, 2018.

[29] F. Li, Y. Gao, Y. Cao, and R. Iravani, "Improved Teager Energy Operator and Improved Chirp-Z Transform for parameter estimation of voltage flicker," IEEE Trans. Power Del., vol. 31, no. 1, pp. 245–253, Feb. 2016.

[30] J.C.M. Vieira, W. Freitas, W. Xu, and A. Morelato, "An investigation on the nondetection zones of synchronous distributed generation anti-islanding protection," IEEE Trans. Power Deliv., vol. 23, no. 2, pp. 593–600, Apr. 2008.

[31] P.F. Ribeiro, C.A. Duque, P.M. Ribeiro, and A.S. Cerqueira, Power Systems Signal Processing for Smart Grids, New York, NY, USA: Wiley, Sep. 20, 2013.

DOI : 10.35291/2454-9150.2025.0008