Detection of Fault Disturbances in a DG Integrated Hybrid Power System Using HS-Transform and Wavelet Transform

Basanta K. Panigrahi, Jyoti Shukla, and Shruti Sahu

Abstract Solar energy penetration into traditional power grid causes numerous problems in power system management and control. Detecting fault disturbances in an electrical power system is a difficult undertaking. This paper discusses a novel method for tracking the fault disturbances in solar operated DG connected in power system. Numerous types of faults like LG, LLG, LL, LLLG, and LLL are considered in this work. It is noticed that both the transforms are effectively identifies the instants of disruption in the voltage. It is observed that the time–frequency resolution in case of HST is comparatively better than WT. The objective of this work is to detect the fault disturbances using HS-transform and wavelet transform in a DG connected hybrid power system. A novel approach based on HS-transform and wavelet transform is presented to detect the LG fault and LLL fault. When signal is passing through WT and HST, it is evaluated that WT is unable to identify the signal due to noise, whereas in HST the disturbances present in the signal in the corresponding instants is nicely captured and detected. This shows the robustness in HST under noisy conditions. It simplifies the complexity in identifying the disturbances which increases the detection accuracy of the system.

Keywords Distributed generation (DG) · Wavelet transform (WT) · Hyperbolic S-transform · Point of common coupling (PCC)

1 Introduction

Recently, extraction of renewable energies in the form of distributed generation (DG) is establishing itself as a major contributor of generation of electrical power to

B. K. Panigrahi (✉)
Department of Electrical Engineering, SOA University, Bhubaneswar, India
e-mail: basanta1983@gmail.com

J. Shukla
Poornima College of Engineering, Jaipur, India

S. Sahu
University College of Engineering, Kota, India

K. Murari et al. (eds.), *Soft Computing Applications in Modern Power and Energy Systems*, Lecture Notes in Electrical Engineering 975,
https://doi.org/10.1007/978-981-19-8353-5_3

fulfill the increasing demand with its merit as green energy with almost negligible environmental pollution [1]. Among all the renewable sources, wind and solar energy are the most versatile resources. Though these are highly potential sources of energy, but with increased penetration of DGs in conventional power grid will pose various operational and design challenges. Stability is a vital issue so when the system is subjected to different types of symmetrical and unsymmetrical fault conditions [2]. Again, when photovoltaic system is connected to the grid via interfacing converters. The main aspect of power system design is to maintain uninterruptible power supply to the customers. But this condition is disrupted by the different fault disturbances occurred in power system because of natural calamities, mal-operations, physical accidents, lightning, and other operating failures. These will lead to fault conditions such as LG, LL, LLG, LLL, and LLLG which directly or indirectly threaten the stability and reliability in power supply [3, 4]. As solar energy is intermittent which makes it highly uncertain in characteristics and therefore need some storage system like battery or flywheels to improve the system performance. Further, the solar PV system is dependent on different parameters such as solar insolation, temperature of cells, and shadow effects that may cause some abnormal situations indirectly [5]. In addition, different artificial intelligence techniques like fuzzy logic (FL), artificial neural network (ANN), artificial neuro-fuzzy inference system (ANFIS), and support vector machine (SVM) are used to classify the fault disturbances. Artificial neural network (ANN) is popularly used for fault localization and detection classification [6, 7]. ANN alongside wavelet transform was proposed to identify the fault disturbances [8].

Various studies were reported in the literature for the identification and monitoring of fault disturbances. Some used indices like RMS value, peak value, frequency, or voltage change for detecting fault/abnormal conditions. The methods such as Fourier transform (FT) and fast Fourier transform (FFT) are one of the most popular ones for the disturbance study. Many researchers have used other transforms like chirp Z-transform, Welch algorithm for observing the electrical-parameters [3, 9]. But sometimes it is very hard to detect non-stationary disturbances due to only frequency data and no time data. Therefore, wavelet transform (WT), S-transform, short-time Fourier transform (STFT), etc., were studied and designed to be applied to fulfil the objective of fault analysis [10, 11].

The article is assembled as follows. Section 2 illustrates the system configuration and description of solar energy-based system. The detection methodologies are describing in Sect. 3, and the simulation results and discussion is mark out in Sect. 4. In the end, the conclusions residue from the research is briefed in Sect. 5.

2 System Configuration and Modeling

The system under study is a solar-based power system as shown in Fig. 1, which is a combination of PV, based DG in grid-connected mode. Solar energy is a valuable renewable energy resource with numerous applications in society, and it is being employed in the present analysis in conjunction with the traditional power system. The sub-sections that follow gives the modeling and descriptions of such a system.

Figure 1 depicts a PV system that is interconnected to the standard power grid and includes a battery energy storage system. The excess energy is stored in the battery via a bi-directional converter during periods of high solar insolation. The system depicted in Fig. 1a is utilized to investigate disturbances. The basic layout diagram of a solar energy-based system with several elements is shown in Fig. 1a. Figure 1b depicts the detailed interface structure of the power system under consideration.

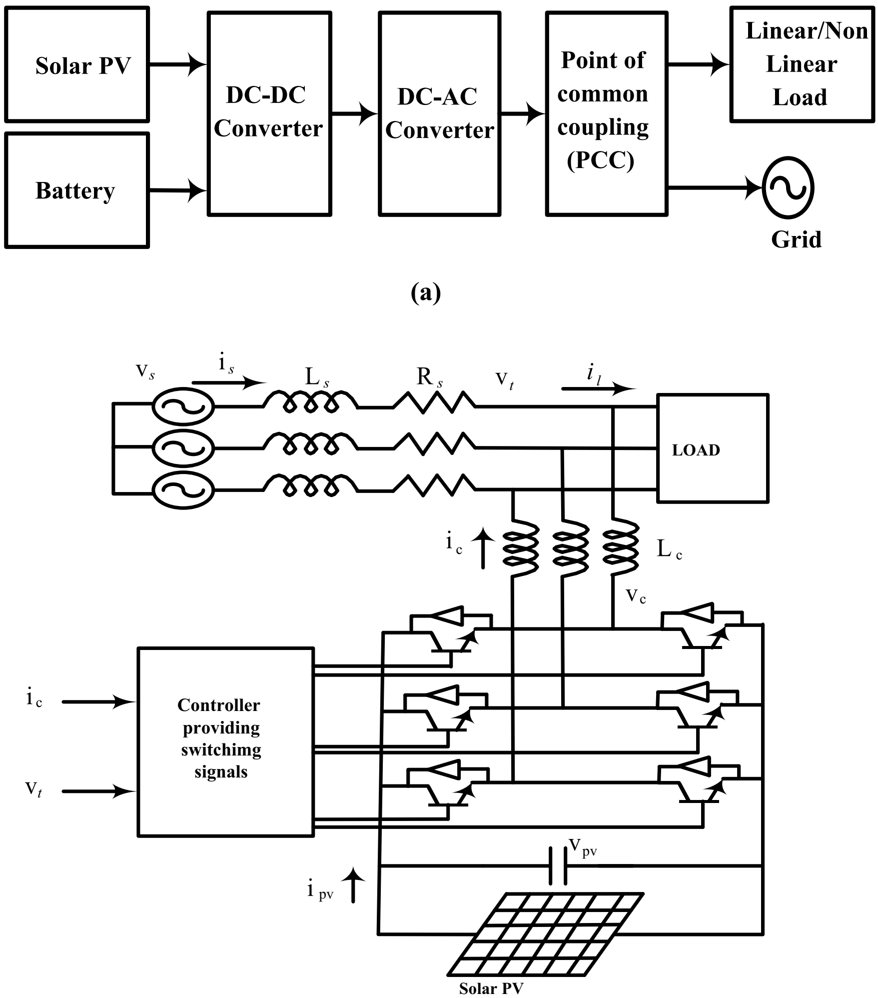


Fig. 1 Basic layout diagram of solar energy-based system, **a** block diagram, **b** detailed interfacing circuit

3 Detection Techniques

The following are descriptions of several detection methods, such as the HS-transform and the wavelet transform:

3.1 HS-Transform

The S-transform (ST), a time–frequency multi-resolution analysis was conducted based on the WT and STFT, is a revised form of the wavelet transform with phasor rectification. It employs a Gaussian variable window with indirectly related width and frequency. But, even in the existence of noise, sometimes S-transform fails to locate disturbances. Thus, in low–high frequencies, HS-transform with pseudo-hyperbolic Gaussian window provides improved time/frequency resolutions. A higher distortion of the window at low frequencies improves the frequency domain width [12].

The hyperbolic window is expressed as

$$W_{\text{hb}} = \frac{2 f_s}{\sqrt{2\pi}\,(\alpha_{\text{hb}} + \beta_{\text{hb}})} \exp\left\{-\frac{-f_s^2 X^2}{2}\right\} \tag{1}$$

where

$$X = \frac{(\alpha_{\text{hb}} + \beta_{\text{hb}})}{2\alpha_{\text{hb}}\beta_{\text{hb}}}(\tau - t - \xi) + \frac{(\alpha_{\text{hb}} - \beta_{\text{hb}})}{2\alpha_{\text{hb}}\beta_{\text{hb}}}\sqrt{(\tau - t - \xi)^2 + \lambda_{\text{hb}}^2} \tag{2}$$

$$0 < \alpha_{\text{hb}} < \beta_{\text{hb}} \text{ and } \xi = \frac{\sqrt{(\beta_{\text{hb}} - \alpha_{\text{hb}})^2 \lambda_{\text{hb}}^2}}{4\alpha_{\text{hb}}\beta_{\text{hb}}}$$

The HS-transform's discrete version is calculated and $G(m_F, n_F)$ represents the Fourier transform of hyperbolic window

$$G(m_F, n_F) = \frac{2 f_s}{\sqrt{2\pi}\,(\alpha_{\text{hb}} + \beta_{\text{hb}})} \exp\left\{-\frac{-f_s^2 X_D^2}{2}\right\} \tag{3}$$

where

$$X_D = \frac{(\alpha_{\text{hb}} + \beta_{\text{hb}})}{2\alpha_{\text{hb}}\beta_{\text{hb}}} t + \frac{(\alpha_{\text{hb}} - \beta_{\text{hb}})}{2\alpha_{\text{hb}}\beta_{\text{hb}}}\sqrt{t^2 + \lambda_{\text{hb}}^2} \tag{4}$$

$H[m_F, n_F]$ is the frequency shifted Fourier transform $H[m_F]$ and is given by

$$H[m_F] = \frac{1}{N} \sum_{m_F=0}^{N-1} h(k) \exp(-i 2\pi n_F k) \tag{5}$$

$$S[n_F, j] = \sum_{m_F=0}^{N-1} H(m_F + n_F) G(m_F, n_F) \exp(-i2\pi m_F j) \tag{6}$$

S indicated the S-transform of $h(t)$. τ is a parameter that affects the location of Gaussian window. Here, N is the total sample size. $H[m_F]$ is the fault voltage and current waveform sample.

3.2 Wavelet Transform (WT)

Signal processing techniques also known as transient-based approaches are preferably employed for fault diagnosis mainly for protection, and the wavelet transform has been discovered to be capable of studying transient signals occur during a power system fault condition arises. Owing to its economical speed, frequency resolutions, and dependability of extracting relevant features, the wavelet transform (WT) is viewed as a potential tool for fault detection. The wavelet is made up of translations and dilatations that are formed from a mother wavelet [13, 14]. The discrete wavelet transform (DWT) of a function $f(t)$ can be investigated using the equation.

$$\frac{1}{\sqrt{x_0^m}} \sum_k f(k) \phi * \left(\frac{n - k x_0^m}{x_0^m} \right) \tag{7}$$

In place of x and y, the parameters m and k represent the integer variables. The wavelet is connected with a scaling function, which when combined with the wavelet function. That one level's scaling function can be represented as the sum of the next finer level's scaling function.

$$\phi(t) = \sum_{n=-\infty}^{\infty} h(n) \sqrt{2} \phi(2t - n) \tag{8}$$

The link between both the scaling function and the wavelet function is shown in Eq. (9).

$$\phi(t) = \sum_{n=-\infty}^{\infty} h_1(n) \sqrt{2} \phi(2t - n) \tag{9}$$

$$c_j(k) = \sum_{m=-\infty}^{\infty} c_{j+1}(m) h(m - 2k) \tag{10}$$

$$d_j(k) = \sum_{m=-\infty}^{\infty} c_{j+1}(m) h_1(m - 2k) \tag{11}$$

Equations (10) and (11) illustrate the coefficients at a rough stage that may be obtained by analyzing coordinates at a finer level until they reach their individual filters that would be followed by the implementation of the two, resulting in different numbers of samples at the coarser stage.

4 Simulation Results and Analysis

The simulated outcomes achieved with MATLAB/Simulink are described in this section. The solar PV system in question is connected to the electrical grid, and the complete system is modeled in MATLAB. Different faults are being created in grid side and the corresponding voltage signal at PCC is taken offline. It is then processed through wavelet and S-transforms. The transformed signal is used to determine various statistical characteristics such as standard deviation and entropy. An information set of 500×6 is then developed taking into consideration six distinct characteristics and faults in distinct working situations. Half of this collection of information is used for practice, and half is used for testing. The sampling frequency is set to 5 kHz. The detail coefficients out from original images provide more spatial and spectral data. The detail coefficients show where in data set key facts can be found. As a result, the Db4 detail coefficient is used in this proposed study. A grid-connected solar energy generating plant is depicted in the proposed concept. A PV panel, three-phase source, transformers, circuit breakers, and a fault block connected to the load are all included in the model. Figure 2 depicts a single line diagram of the proposed hybrid model.

At PCC, the signal of voltage for LG fault is shown in Fig. 3a. This signal is obtained at PCC and carried through WT and HST, and the findings are displayed in Fig. 3b and c. It is noticed that both the transform very beautifully identifies the instants of disruption in the voltage. Of course, the time–frequency resolution in case of HST is comparatively better than WT. The voltage signal is further given

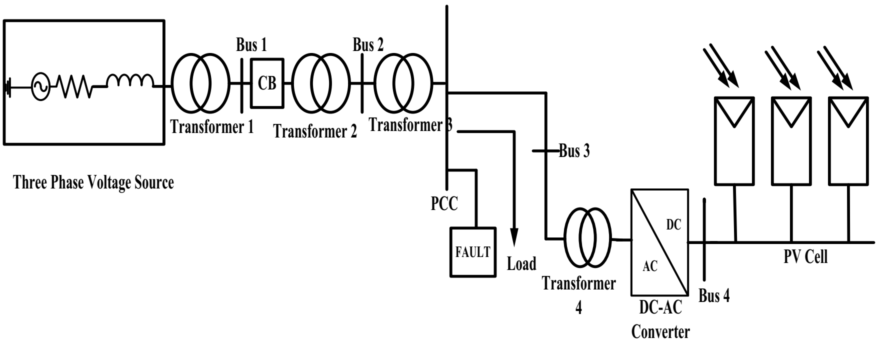
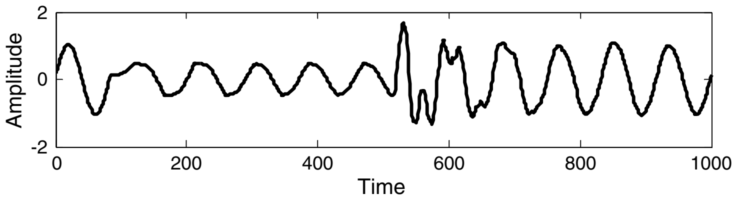
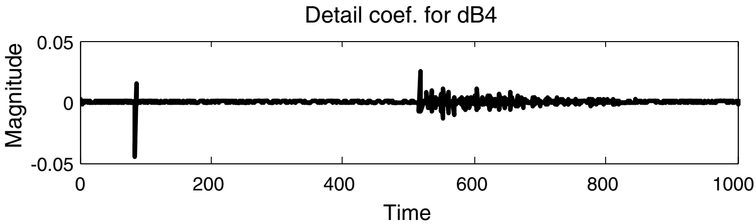


Fig. 2 Single line diagram of proposed Simulink DG integrated hybrid system

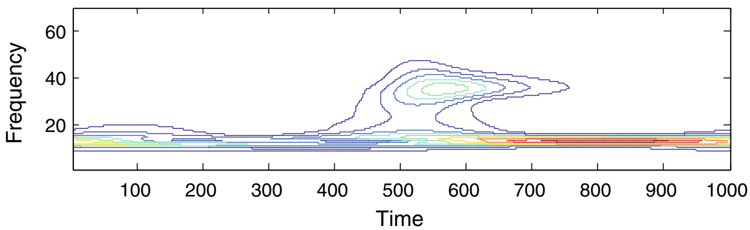
a 20 dB noise boost, as illustrated in Fig. 4a. When passing through WT and HST illustrate in Fig. 4b and c, it is evaluated that WT unable to identify the signal due to noise, whereas in HST the disturbances present in the signal in the corresponding instants is nicely captured and detected. This shows the robustness in HST under noisy conditions. Again, the voltage signal for LLL fault is extracted and shown in Fig. 5a. After it is passed through WT and HST, the results are presented in Fig. 5b and c, respectively. It is observed that HST shows better detection capability as compared WT. The detection is determined on the basis of performance measures such as entropy and standard deviation. In a grid-connected PV system, LG and LLL faults are formed, and the relevant voltage signal is retrieved at the PCC (Table 1).



(a)Voltage signal for LG fault at PCC



(b) Detection by WT



(c) Detection by HST

Fig. 3 LG fault detection, **a** voltage signal for LG fault at PCC, **b** detection by WT, **c** detection by HST

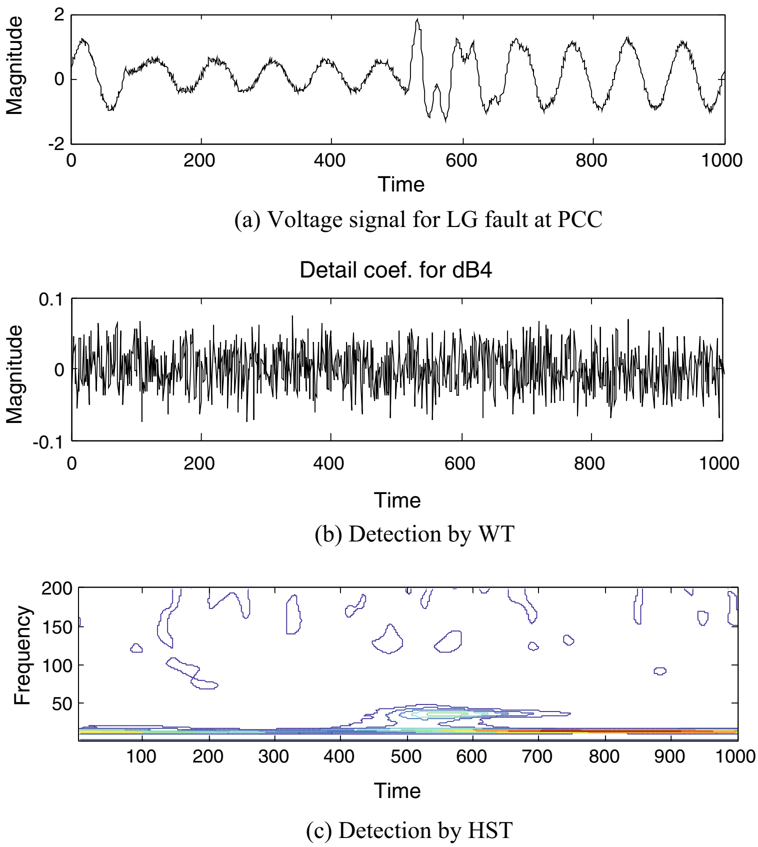
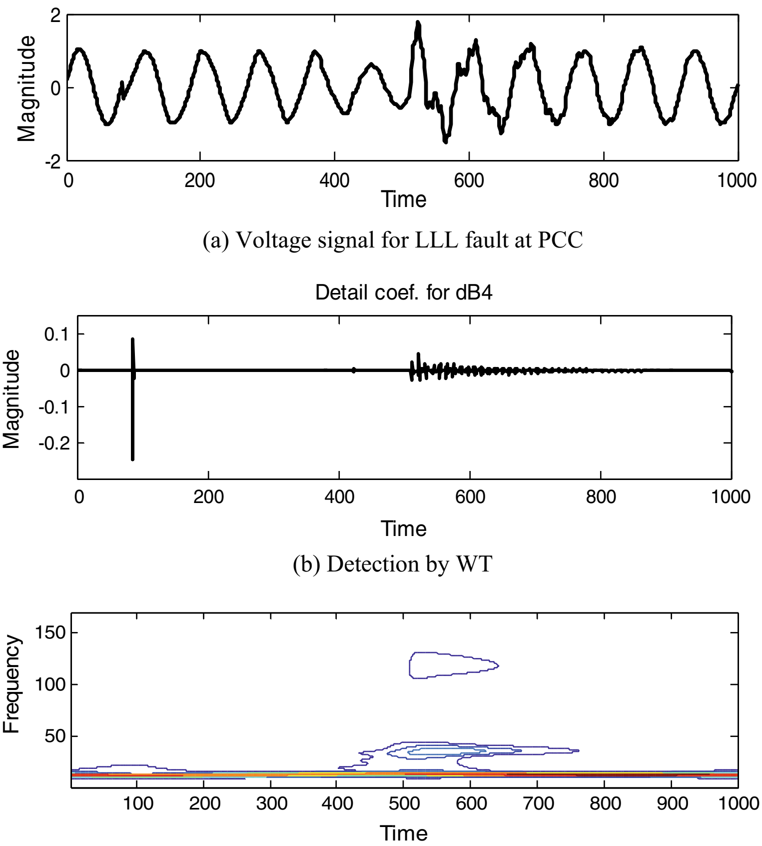


Fig. 4 LG fault detection with 20 dB noise, **a** voltage signal for LG fault at PCC, **b** detection by WT, **c** detection by HST

5 Conclusion

This paper presents the study of different fault disruption of the grid-integrated solar PV-based power system. The fault disturbances are detected by utilizing WT and HS-transforms. It is noted that HS-transform is more accurate in the detection of disturbances. The effectiveness of the present work has been verified at different noise levels to validate its validity. A comparison of the STD and entropy has been performed. The comparison results show that the proposed strategy provides more consistent and trustworthy outcomes. It has been observed that when noise is injected into the voltage signal, the accuracy of WT will be degrading. Although HST was able to identify the disturbances present in the signal. The simulation results obtained reveal that the proposed method performs well for all types of faults.



(a) Voltage signal for LLL fault at PCC

(b) Detection by WT

(c) Detection by HST

Fig. 5 LLL fault detection, **a** voltage signal for LG fault at PCC, **b** detection by WT, **c** detection by HST

Table 1 STD and entropy for different faults

Fault	Standard deviation (STD)	Entropy
LG	0.345	0.583
LG with 20 dB noise	0.456	0.838
LLL	0.532	0.638

References

1. K. Moloi, Y. Hamam, J.A. Jordaan, Fault detection in power system integrated network with distribution generators using machine learning algorithms, in *2019 6th International Conference on Soft Computing & Machine Intelligence (ISCMI)* (IEEE, 2019), pp. 18–22
2. M.S. Thomas, P.P. Terang, Interconnection issues for distributed resources in a smart distribution system, in *2012 IEEE 5th India International Conference on Power Electronics (IICPE)* (IEEE, 2012), pp. 1–6

3. P.K. Ray, S.R. Mohanty, N. Kishor, Disturbance detection in grid-connected distributed generation system using wavelet and S-transform. Electr. Power Syst. Res. **81**(3), 805–819 (2011)
4. Y.A. Elshrief, D.H. Helmi, A.D. Asham, B.A. Abozalam, Merits and demerits of the distributed generations connected to the utility grid. Menoufia J. Electron. Eng. Res. **28**(ICEEM2019-Special Issue), 259–262 (2019)
5. P.R. Satpathy, S.B. Thanikanti, A.H. Mahmoud, R. Sharma, B. Nastasi, A TCT-SC hybridized voltage equalizer for partial shading mitigation in PV arrays. IEEE Trans. Sustain. Energy (2021)
6. S. Adhikari, N. Sinha, T. Dorendrajit, Fuzzy logic based on-line fault detection and classification in transmission line. Springer Plus **5**(1), 1–14 (2016)
7. M. Singh, B.K. Panigrahi, R.P. Maheshwari, Transmission line fault detection and classification, in *2011 International Conference on Emerging Trends in Electrical and Computer Technology* (IEEE, 2011), pp. 15–22
8. A. Bhuyan, B.K. Panigrahi, S. Pati, Fault classification for DG integrated hybrid power system using wavelet neural network approach, in *2021 1st Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology (ODICON)* (IEEE, 2021), pp. 1–5
9. P.K. Ray, N. Kishor, S.R. Mohanty, Islanding and power quality disturbance detection in grid-connected hybrid power system using wavelet and $ S $-transform. IEEE Trans. Smart Grid **3**(3), 1082–1094 (2012)
10. B.K. Panigrahi, P.K. Ray, P.K. Rout, S.K. Sahu, Detection and location of fault in a micro grid using wavelet transform, in *2017 International Conference on Circuit, Power and Computing Technologies (ICCPCT)* (IEEE, 2017), pp. 1–5
11. S.R. Samantaray, P.K. Dash, G. Panda, Fault classification and location using HS-transform and radial basis function neural network. Electr. Power Syst. Res. **76**(9–10), 897–905 (2006)
12. S. Agrawal, M.H. Dhend, Wavelet transform based voltage quality improvement in smart grid, in *2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT)* (IEEE, 2016), pp. 289–294
13. J. Shukla, B.K. Panigrahi, An analytical approach for optimal size of distributed generation unit, in *International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014)* (IEEE, 2014), pp. 1–6
14. B.K. Panigrahi, A. Bhuyan, A.K. Satapathy, R. Pattanayak, B. Parija, Fault analysis of grid connected wind/PV distributed generation system, in *International Conference on Intelligent Computing and Communication Technologies* (Springer, Singapore, 2019), pp. 47–54
15. P.K. Ray, B.K. Panigrahi, P.K. Rout, A. Mohanty, F.Y. Eddy, H.B. Gooi, Detection of islanding and fault disturbances in microgrid using wavelet packet transform. IETE J Res. **65**(6), 796–809 (2019)