20th International Conference on Renewable Energies and Power Quality (ICREPQ'22)
Vigo (Spain), 27th to 29th July 2022
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.20, September 2022

Novel Approach to Monitoring and Mitigating Power Quality Disturbances in Hybrid Renewable Energy System

Syed Khawar Hussain Shah[1], Dr Ali Hellany [2], Dr Mahmood Nagrial[3], Dr Jamal Rizk[4]

[1] School of Engineering, Design and Built Environment Western Sydney University
Kingswood 2747, NSW. (Australia)

e-mail: 17899534@student.westernsydney.edu.au , A.Hellany@westernsydney.edu.au, M.Nagrial@westernsydney.edu.au , J.Rizk@westernsydney.edu.au

Abstract. Renewable energy sources are continually increasing their share in the energy system. The introduction of Hybrid Renewable Energy Sources (H.R.E.S.) in the electrical power system has gained momentum. The increased share of Renewable sources has resulted in an increase in Power Quality (P.Q.) disturbances at the user and consumer levels. This research will engineers dedicate the P.Q. disturbances produced in the electrical system due to Hybrid Renewable energy sources, especially solar and wind. The research will predict what type of P.Q. disturbances are introduced during power production. The study will focus on a stand-alone Hybrid Renewable Energy System (H.R.E.S.). The energy system data will be collected and used to produce a Fuzzy Logic (F.L.) algorithm to improve the mitigating techniques to reduce P.Q. disturbances. The suggested algorithm analyzes the stored and continuous data from different sources. The data will be collected and used to drive the hardware to take appropriate actions at the mitigation level. The hardware used in the system consists of a Multiplexer (MUX) and different types of filters. The output of the multiplexer chooses the filters. The algorithm will improve the system's efficiency and help the designers improve the system's design capabilities. The monitoring system will help predict what type of P.Q. disturbances are produced when different energy sources are used to produce power. The proposed system monitors these P.Q. disturbances and classifies them according to their severity.

Keywords. Power Quality, Power Quality Monitoring, Power Quality Mitigation, Hybrid Renewable Energy, Harmonic Distortion, Voltage Disturbances

1. Introduction

Power quality refers to the electrical system's capability to produce perfect power without any disturbances in the sinusoidal wave. However, this does not happen in the real world. The sinusoidal wave produced by the power sources is impacted by different types of loads and other factors such as meteorological conditions, types of inverters and distance from the power source. These factors produce changes in the waveform, indicating PQ disturbances. Renewable energy sources are used to create clean and cheap power. The concept of using renewable energy power systems as stand-alone or part of the distribution grid is gaining importance. The addition of renewable sources has added to PQ disturbances in the system.

Power quality monitoring and mitigation techniques go hand in hand. The enhancement and better understanding of PQ problems have led engineers and designers to work on different mitigating methods [1]. As a result, power quality problems are becoming prominent in the design of electrical power grids. The task of monitoring and mitigating becomes even harder when renewable energy sources are involved. There are different types of renewable energy sources used in the power industry. These sources include solar, wind, biofuels, and many others. The new trend in stand-alone power production combines two or more renewable energy sources to accommodate growing power needs. The power system is known as an HRES. These systems are used as an extension to the existing grid, either to provide backup to the electrical grid or supplement the produced power to accommodate the power grid [2].
These power sources work together to produce electrical power used by utility providers and consumers alike. The most common type of energy combination used is solar and wind. Solar power is harnessed using solar panels, and wind turbines convert wind energy into electrical power. The combination of solar and wind is a good source of power for remote areas or where it is costly to provide power using the conventional setup of the power grid and substation system[3]. The electrical power produced by these sources needs to be monitored and mitigated accordingly. The stakes are raised higher when the extra power produced by these sources is fed back to the grid. Whether a house or an industrial load, looking at the individual unit becomes paramount. The PQ disturbances produced by these sources are injected into the main grid and cause power and financial losses to utilities and consumers. These disturbances have a harmful impact on different types of electrical equipment used in the electrical grid. Modern electrical equipment is highly sensitive to changes in produced power. Monitoring the differences is important as it will help develop better mitigation techniques. In addition, it will help the designer to come up with better preventive and predictive maintenance [2, 4].
The two sources used in the hybrid system have their problems that add to PQ disturbances. The research is focused on an HRES consisting of a solar photovoltaic panel (PV) and wind turbine (WT). The power produced

by each source is dependent on many factors. These factors are temperature, irradiance level, tilt angle in the case of PV, wind speed, and height in the wind turbine [5].

2. Literature Review

The researchers and designers are trying to determine how these PQ disturbances are produced and mitigated. The HRES have different PQ disturbances depending on the sources used to produce electrical power. The other factors might inject various types of PQ disturbance into the system. These factors are metrological changes, type of loads and synchronization of two renewable sources to produce power. The Hybrid renewable system consisting of solar and wind might have different reasons to produce PQ disturbances. These disturbances need to be monitored and investigated further [6]. The major PQ disturbances observed in an HRES are related to

- Voltage changes
- Harmonics
- Frequency changes

2.1 Power Quality Disturbances

The voltage changes in the system happen due to many reasons. The voltage changes can be a short interruption of power, sag or transients. At the same time, harmonics distortion can occur in current and voltage. Therefore, the frequency changes is an important type of PQ disturbance in the HRES [7]. Many factors cause the PQ disturbances in HRES. These problems are attributed to electrical equipment used in the system and natural elements occurring in nature [8].

The three major causes of PQ disturbances in HRES are:

- Synchronization of multiple Renewable sources
- Metrological changes
- Choice and type of electrical equipment used in the HRES

Synchronization is defined as the reduction or minimizing of the variance in voltage. Frequency and phase angle between the multiple Renewable energy sources used to provide power to the grid. The voltage should be synchronized before entering the power grid [9]. The ideal synchronization approach should be able to [10]:

- Efficiently track the phase angle changes in the power grid
- Capable of detecting the changes in frequency
- Efficiently keep track of the changes in the harmonics and other disturbances

The unbalanced demand and supply cause synchronization issues in the grid frequency. If the Renewable Energy Sources (RES) produce surplus power, that changes the grid's frequency. The reverse will happen if the RES produces less power as the grid requires. The frequency changes cause problems for the electrical equipment connected to the grid [11]. The changing voltage and frequency is a major source of synchronization problems. In addition, the wind speed is variable and might change at any time, causing changes in the system's frequency and voltage, resulting in an unbalanced power supply and varying frequencies [12].

Solar power has its own set of problems causing synchronization problems. Solar power has different power output depending upon the efficiency of the solar panels used for power production. These power oscillations cause harmonic issues and frequency fluctuations in the power grid. The addition of backup batteries impacts the frequency and voltage of the system [13].

The grid synchronization of RES introduces voltage sags or voltage dips. Voltage dips may occur during grid synchronization. These dips are produced due to the voltage difference between the RES and the grid. The reactive power drawn by DFIG causes voltage sags in power produced by WT. In HRES, voltage sags are followed by voltage swells [14].

The metrological conditions greatly impact the power produced by HRES. These conditions affect both solar and wind power differently. In the case of solar, the power produced is affected by different weather conditions. For example, the high solar intensity will have a higher voltage. On the other hand, a cloudy day will provide low power from the solar setup. The weather conditions change the energy demand in the grid. In the case of a stand-alone grid, the extra demand for power produces PQ disturbances. The voltage fluctuations indicate low magnitude transients, and solar insulation frequency deviation changes cause current and voltage harmonics deviations [15].

The variability in temperature and airspeed produces variable power. The changes in power produced and consumed need to be balanced in the power grid. Suppose the metrological conditions are not monitored properly. They might cause major power losses in the grid with higher penetration of HRES [16]. The change in wind speed will cause voltage and flicker in the HRES. The transient magnitude, flicker, voltage and current harmonics increase with the increase in penetration of the wind energy. If these disturbances are not monitored, and proper steps are not taken to mitigate them, they will cause major system losses [17-20].

The main function of a converter is to convert DC power produced into AC power. The inverters are categorized according to the grid configuration. The inverter technologies are based on the efficiency parameters set by different grid standards. The type of electrical equipment used to connect the HRES with the grid is a source of PQ disturbances. The internal structure will add PQ disturbances to the electrical grid. They will inject current harmonics, current distortion, and power factors into the grid. The topology of these converters plays an important role in producing PQ disturbances [21]. In addition, the bidirectional transfer of power between the grid and consumer might add to PQ disturbances. These changes will impact PQ in the integrated grid [22]. The monitoring system should handle these changes while ensuring that the quality of power is maintained at a standard level. The inverters and converters are the most important aspect of these changes that add PQ disturbances[23]. Therefore, the material used for the construction of these inverters is vital. These inverters are mainly made from different types of semiconductor material, and the manufacturing process of inverters might be a source of PQ disturbances [24].

2.2 Power Quality Monitring Methods

The PQ disturbances originate at the interconnection point between the RE sources and the grid. The detection and classification of the disturbances are the main components of any PQ monitoring system. These PQ disturbances are handled using the system based on software, hardware, or a hybrid system comprising software and hardware tools [15]. PQ monitoring provides essential data for the improvement of PQ. The PQ monitoring system collects a lot of data and will take time to analyze. The collected data is compared with a set of standards accepted by regulatory bodies. Many methods are used to monitor PQ disturbances in HRES.

The Fourier transform method is used to monitor PQ in the renewable system. The work presented by Bracewell shares different methods to monitor PQ disturbance in the RE system based on Fourier transforms [25]. Kaman filters are used to provide scientific equations to handle the complex computational situations regarding PQ monitoring [26]. The frequency spectrum of the signal is used to observe flickers and predict when the flickers can occur [27]. The other intelligent tools that are used to monitor PQ disturbances are expert system (ES), Artificial Neural Networks (ANN), and Fuzzy Logic (FL). The different approaches used to detect power quality disturbances are discussed in papers [28-32]. There are monitoring methods that are used in the HRES. Power quality monitoring is considered to be an expensive practice. The power quality analyzer cannot be placed on each node [33]. Adding a PQ analyzer at different nodes is gaining traction, and it might be a cost-effective method to look at PQ disturbances in the HRES [34]. The measurement of current and voltage signals for HRES is a problem. Their measurement requires higher accuracy. Currently, common transducers cannot perform these measurements accurately. The newer type of voltage and current transducers are needed to monitor at least 40th Harmonic [35]. The analysis of some of the Power quality monitoring systems is presented in [36-38].

2.3 Mitigation of Power Quality Disturbances

Many methods are used to mitigate the different types of PQ disturbances. The increase in the use of sensitive equipment in industrial, residential, and commercial applications has impacted PQ disturbances. These disturbances are mainly classified as voltage and current quality problems. The Custom Power Devices (CPDs), Distribution Static Compensators (DSTATCOMs), Dynamic Voltage Restorers (DVRs), and Unified Power Quality Conditioners (UPQCs) are used to mitigate some of the PQ disturbances depending on the requirements of the electrical grid. CPD and DSTATCOM are used for mitigating current related disturbances. The PQ disturbances increase due to changes in harmonic values of current and voltage. The active shunt filters are used to reduce these harmonics [39]. The other solution to mitigating PQ problems is using multilayer inverters (MI) or Proportional Integral Differential (PID) controllers. Research has shown that the PID controllers are less efficient than other controllers. The researcher has turned to Artificial Intelligence (AI) methods to monitor and mitigate power quality disturbances. AI allows the system capability to learn the reason and decide like humans. The AI helps improve stability, reliability, and other factors to make other essential advancements in the electrical system. AI enables the electrical system by providing extra functions such as optimization, maintenance and security of data in the electrical system. The Artificial Neural Network (ANN) helps in diagnosing and identification of PQ problems. ANN help engineers and researchers to develop patterns of input and output data and how the output data values are compared against the original values of parameters [40-42]. The Infinite Impulse Response (IIR) types of filters are used with the capability of adjustable power produced during nighttime. The constant power is transferred to the electrical grid with a fixed power mode [43]. Flexible AC Transmission System (FACTS) technology has been used in efficient voltage stabilization, demand control, energy utilization, power quality enhancement, and voltage and current harmonic mitigation [44]. The higher penetration of RE sources in distributed generation has given rise to power electronics devices for efficient power utilization and increasing the power grid's reliability [45]. The FCATS based devices are used in the HRES. These devices mitigate PQ disturbances at residential, commercial, and HRES. The FCATS are used to improve the system's efficiency by adding active power filters and a STATCOM interface for big HRES [46]. The other mitigation methods for HRES are discussed in [47-51]. The industry uses different methods to monitor and mitigate PQ disturbances. These methods include optimization techniques for optimal features, classification of Power quality disturbances, and experimental system based Power Quality analysis [52]. These methods include voltage improvement techniques, customer power devices, energy storage systems, energy conversion optimization, passive filters, current quality improvement, and active power filters. It details different monitoring and mitigation methods that are used in the industry. The research shares the efficiency of other methods used in the RE industry.

The paper will present a two-fold method. First, the system will collect the PQ monitoring data from the site, and a mitigation method will be selected based on the collected data. Many mitigation techniques are used in the industry. Some of them are used more frequently as compared to others. Figure 1 illustrates the usage percentage of mitigation methods [49].

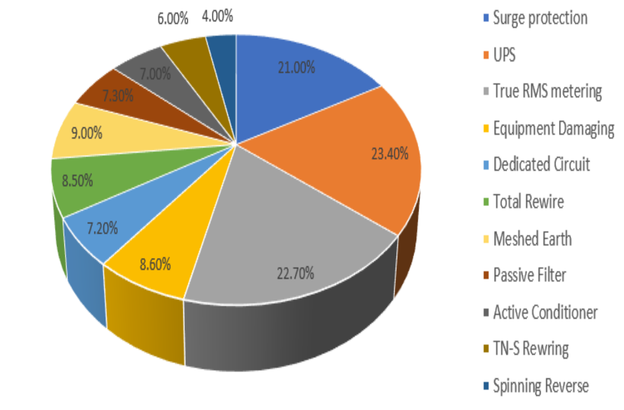

Figure 1 Percentage of different mitigation techniques [53]

3. Methodology

The paper will propose a method for monitoring and mitigation techniques for an HRES. The proposed system is based on live data analysis and deciding what type of mitigation equipment would be used. The PQ disturbances data is collected in a database. Figure *2* shows the FL process used to create the FL algorithm. The system will use Fuzzy Logic (FL) to analyze the collected data. The FL transforms the system inputs into fuzzy sets.

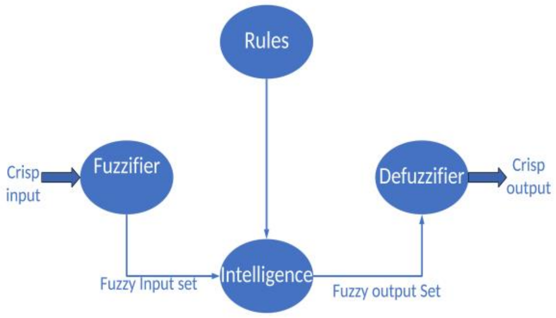

Figure 2 Fuzzy Logic Process

The data is simplified by using the ANN algorithm. The sigmoid function initializes the algorithm

$$f(z) = \frac{1}{1 + \exp(-z)} \qquad (1)$$

The weighted input for the node would be

$$X_1W_1 + X_2W_2 + X_3W_3 + b \qquad (2)$$

W_i is the weight, and b is the +1 bias. The proposed ANN network has three layers, layer one is the input, layer two is the hidden layer, and the third layer is the output layer. The output of the layers was calculated by Eq 6.

$$h_1^2 = f(w_{11}^1 x_1 + w_{12}^1 x_1 + w_{13}^1 x_1 + b_1^1) \qquad (3)$$
$$h_2^2 = f(w_{21}^1 x_1 + w_{22}^1 x_1 + w_{23}^1 x_1 + b_2^1) \qquad (4)$$
$$h_3^2 = f(w_{31}^1 x_1 + w_{32}^1 x_1 + w_{33}^1 x_1 + b_3^1) \qquad (5)$$

The output of the last layer is given by Eq 6

$$h_{w,b}(x) = h_1^3 = f(w_{11}^2 h_1^3 + w_{12}^2 h_2^3 + w_{13}^2 h_3^2 + b_1^{31}) \qquad (6)$$

The matrix representation of the algorithm is given by Eq 7

$$W^1 = \begin{pmatrix} W_{11}^1 & W_{12}^1 & W_{13}^1 \\ W_{21}^1 & W_{22}^1 & W_{23}^1 \\ W_{31}^1 & W_{23}^1 & W_{33}^1 \end{pmatrix} \qquad (7)$$

The random number was generated by using the equation

$$Z_1 = A_o w_1 + b \qquad (8)$$

The learning rate was calculated by using Gradient Desent Method

$$a := a - \propto \frac{dL(w)}{da} \qquad (9)$$

a: is a learning rate called alpha
d(w) is the derivative of total loss concerning weight w
d(a) is the derivative of alpha
The learning rate was chosen to be 0.05 by experimenting

The layered architecture of the proposed algorithm is shown in Figure 3. The proposed network has three layers. Layer 1 is the input layer, layer 2 is the hidden layer, and layer 3 is the output layer.

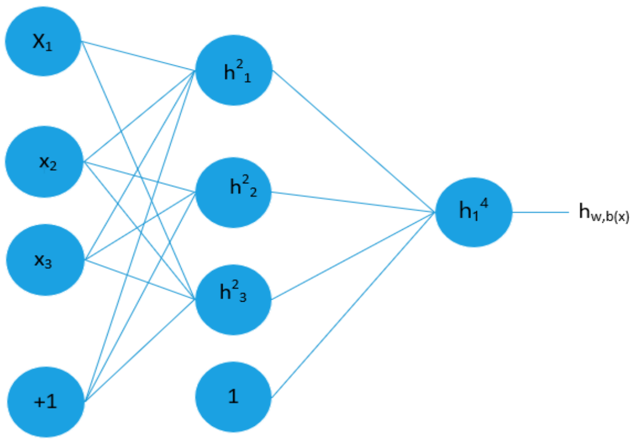

Figure 3 Three-layer Neural Network

The data is collected by using a PQ analyser manufactured by HIOKI. The model used for the collection was HIOKI 3198. The program output is connected to 4-1 MUX, and the MUX will choose the mitigation equipment to reduce the PQ disturbances. The system can choose from different mitigation equipment. The system will choose either IIR to mitigate the disturbances during low voltage and current conditions or FACT to mitigate higher voltage and current harmonics. The hybrid filters will be used for mixed PQ disturbances. The data flow diagram in Figure 4 shows how the software will be used to acquire data, process it, and output will be passed to the 4-1 Mux. Matlab code is used to create the MUX. The MUX will handle four inputs and produces one output. This output is connected to the input for the filter's selection and will be used to connect it to different types of mitigation equipment.

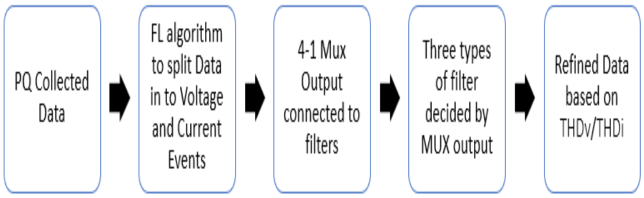

Figure 4 Software Data flow

Figure 5 shows the AI algorithm of the proposed system.

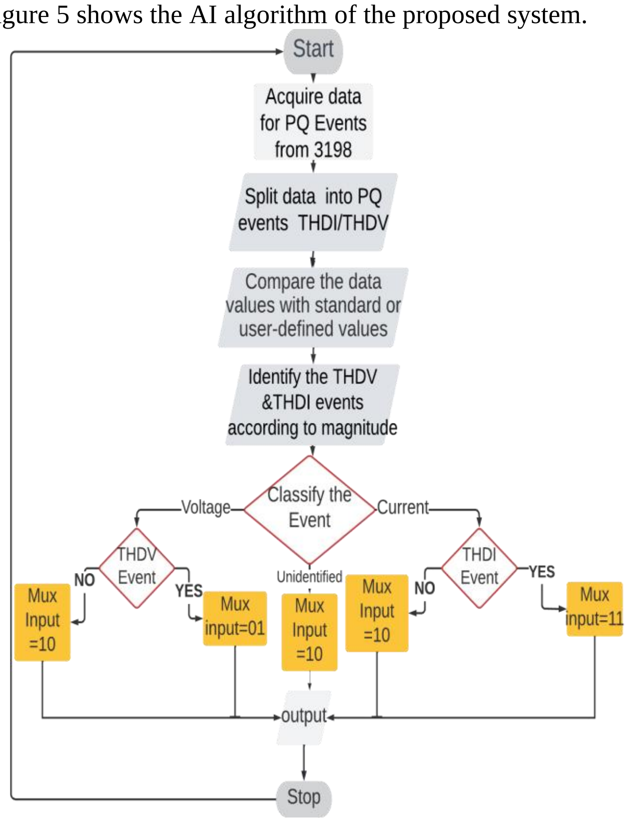

Figure 5 Artificial Intelligence Algorithm chart

The system was simulated using MATLAB. The data was extracted using C++. The output file was stored in the excel file. The excel file shows the output after the code is run. The excel file will show the THD value in current and voltage. The FL algorithm separated the data into current and voltage values. It was labelled as an undefined value if the value did not fall between the defined values. These values were passed to connected 4-1 Mux. The MUX was created using MATLAB. The output of the MUX was connected to the type of filter used in the simulation. The simulation results were collected. The code can be modified to extract other related values. These values will be passed to the MUX. The Mux will select the appropriate type of filter. The simulation table shows the different types of PQ disturbances that happened in the system. These disturbances were specified according to the type and values of the events. The simulation results are shown in Table 1. The results show that the system made an accurate choice of the filter to mitigate the PQ disturbances, that were detected in the system.

Table 1 Simulation Results

Type of Event	Number of occurrences	Values	Type of filter chosen	Accuracy
THD (voltage)	700	Low	IIR	98%
THD (Current)	900	Low	IIIR	97%
THD (voltage)	800	High	FACT	94%
THD (Current)	1200	High	FACT	94%
Unidentfied	2500	Mixed	Hybrid	96%

4. Conclusion

The results show that this system can work at the node level. The data collected from different nodes will help the designers to identify the problematic areas and improve mitigation techniques. The researchers will obtain any PQ disturbances data by making small changes in the code. The data collected and actions performed to mitigate disturbances are in real-time. The system is scalable, and the addition of different functionality would allow monitoring of bigger industrial and residential loads in a suburb or city. It can assist the designers in identifying what type of PQ disturbances are produced by each node in the grid. The system will help the designers see how different types of loads that are used in the grid can impact the PQ of the electrical grid. The system could be used as a predictive tool to avoid major problems in the grid. The tool gives designers and engineers the ability to access the data efficiently and utilize it to reduce financial costs and equipment losses.

References

[1] B. S. GOUD and C. R. J. I. J. o. R. E. R. Reddy, "Essentials for Grid Integration of Hybrid Renewable Energy Systems: A Brief Review," vol. 10, no. 2, pp. 813-830, 2020.

[2] R. K. Akikur, R. Saidur, H. W. Ping, and K. R. Ullah, "Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural

electrification: A review," *Renewable and Sustainable Energy Reviews*, vol. 27, pp. 738-752, 2013.
[3] B. Zohuri, *Hybrid energy systems: Driving reliable renewable sources of energy storage*. Springer, 2017.
[4] V. N. Jayasankar, M. V. Gururaj, and U. Vinatha, "A study on hybrid Renewable Energy Source interface to the non-ideal grid at distribution level with power quality improvements," in *2016 IEEE 6th International Conference on Power Systems (ICPS)*, 2016, pp. 1-5.
[5] S. K. H. Shah, A. Hellany, M. Nagrial, and J. Rizk, "Impact of Load on Total Harmonic Distortion in a Photovoltaic System," in *2020 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE)*, 2020, pp. 1-6: IEEE.
[6] G. S. Chawda *et al.*, "Comprehensive review on detection and classification of power quality disturbances in utility grid with renewable energy penetration," vol. 8, pp. 146807-146830, 2020.
[7] S. K. Shah, A. Hellany, M. Nagrial, and J. Rizk, "Power quality improvement factors: An overview," in *2014 11th Annual High Capacity Optical Networks and Emerging/Enabling Technologies (Photonics for Energy)*, 2014, pp. 138-144.
[8] C. Sankaran, "Power quality / C. Sankaran," vol. %6, p. %&, 2017.
[9] C. Cho, J.-H. Jeon, J.-Y. Kim, S. Kwon, K. Park, and S. J. I. T. o. P. E. Kim, "Active synchronizing control of a microgrid," vol. 26, no. 12, pp. 3707-3719, 2011.
[10] B. Jain, S. Jain, R. J. R. Nema, and S. E. Reviews, "Control strategies of grid interfaced wind energy conversion system: An overview," vol. 47, pp. 983-996, 2015.
[11] L. Hirth, I. J. R. Ziegenhagen, and S. E. Reviews, "Balancing power and variable renewables: Three links," vol. 50, pp. 1035-1051, 2015.
[12] L. Hadjidemetriou, E. Kyriakides, and F. Blaabjerg, "Synchronization of grid-connected renewable energy sources under highly distorted voltages and unbalanced grid faults," in *IECON 2013-39th Annual Conference of the IEEE Industrial Electronics Society*, 2013, pp. 1887-1892: IEEE.
[13] M. A. Basit, S. Dilshad, R. Badar, and S. M. Sami ur Rehman, "Limitations, challenges, and solution approaches in grid-connected renewable energy systems," vol. 44, no. 6, pp. 4132-4162, 2020.
[14] H. C. Bloomfield, D. J. Brayshaw, L. C. Shaffrey, P. J. Coker, and H. J. E. R. L. Thornton, "Quantifying the increasing sensitivity of power systems to climate variability," vol. 11, no. 12, p. 124025, 2016.
[15] S. K. Shah, A. Hellany, M. Nagrial, and J. Rizk, "Review of power quality monitoring web-based techniques," in *2015 Australasian Universities Power Engineering Conference (AUPEC)*, 2015, pp. 1-5.
[16] K. van der Wiel *et al.*, "Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall," vol. 111, pp. 261-275, 2019.
[17] G. S. Chawda and A. G. Shaik, "Smooth grid synchronization in weak ac grid with high wind energy penetration using distribution static compensator," in *2019 2nd International Conference on Smart Grid and Renewable Energy (SGRE)*, 2019, pp. 1-6: IEEE.
[18] C. Li and R. J. I. T. o. P. D. Reinmuller, "Open phase detection in DER operation by using power quality data analytics," vol. 35, no. 6, pp. 2575-2582, 2020.
[19] D. Pal and B. K. J. I. T. o. S. E. Panigrahi, "Analysis and mitigation of the impact of ancillary services on anti-islanding protection of distributed generators," vol. 11, no. 4, pp. 2950-2961, 2020.
[20] A. A. Abdelsalam, A. A. Salem, E. S. Oda, and A. A. J. I. A. Eldesouky, "Islanding detection of microgrid incorporating inverter based DGs using long short-term memory network," vol. 8, pp. 106471-106486, 2020.
[21] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. J. I. T. o. i. e. Kothari, "A review of single-phase improved power quality AC-DC converters," vol. 50, no. 5, pp. 962-981, 2003.
[22] G. Shafiullah and A. M. Oo, "Analysis of harmonics with renewable energy integration into the distribution network," in *2015 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA)*, 2015, pp. 1-6: IEEE.
[23] S. C. Trümper, S. Gerhard, S. Saatmann, and O. J. E. p. Weinmann, "Qualitative analysis of strategies for the integration of renewable energies in the electricity grid," vol. 46, pp. 161-170, 2014.
[24] R. Teodorescu, M. Liserre, P. Rodriguez, and F. Blaabjerg, *Grid Converters for Photovoltaic and Wind Power Systems*. New York, UNITED KINGDOM: John Wiley & Sons, Incorporated, 2011.
[25] R. N. Bracewell and R. N. Bracewell, *The Fourier transform and its applications*. McGraw-Hill New York, 1986.
[26] W. Huihui and W. Ping, "Comparison of detection methods for power quality in micro-grid," in *2015 6th International Conference on Power Electronics Systems and Applications (PESA)*, 2015, pp. 1-8: IEEE.
[27] C.-I. Chen, Y.-C. Chen, and C.-N. Chen, "A high-resolution technique for flicker measurement in power quality monitoring," in *2013 IEEE 8th Conference on Industrial Electronics and Applications (ICIEA)*, 2013, pp. 528-533: IEEE.
[28] S. H. E. A. A. Ghada S. Elbasuony, Ahmed M. Ibrahim, Adel M. Sharaf,, "A unified index for power quality evaluation in distributed generation systems,Energy," *Science Direct*, vol. 149, no. 0360-5442, pp. 607-622, 2018.
[29] M. Sefid, H. Khan, and M. Rihan, "Comparative Evaluation of PMU Algorithms for Power Quality Monitoring in Distribution," in *2018 15th IEEE India Council International Conference (INDICON)*, 2018, pp. 1-6: IEEE.
[30] C. A. Duque *et al.*, "Continuous Power Quality Monitoring For Power Transmission Systems," in *2020 IEEE Power & Energy Society General Meeting (PESGM)*, 2020, pp. 1-5: IEEE.
[31] B. Ravanbach *et al.*, "Development of a Smart Monitoring and Evaluation Framework for Hybrid Renewable Mini-grids," in *2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, 2020, pp. 1-14: IEEE.
[32] K. Suslov, N. Solonina, and A. Smirnov, "Distributed power quality monitoring," in *2014 16th International Conference on Harmonics and Quality of Power (ICHQP)*, 2014, pp. 517-520: IEEE.
[33] J. Yadav, K. Vasudevan, and D. Kumar, "Power Quality Monitoring and Analysis of the Domestic Grids - A Case Study," in *2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 2020, pp. 1-6.
[34] C. A. Duque *et al.*, "Continuous Power Quality Monitoring For Power Transmission Systems," in

2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1-5.

[35] V. Bolshev, A. Vinogradov, T. Sikorski, Z. Leonowicz, and R. J. I. A. Gono, "Monitoring the number and duration of power outages and voltage deviations at both sides of switching devices," vol. 8, pp. 137174-137184, 2020.

[36] P. Castello, C. Muscas, P. A. Pegoraro, and S. J. E. Sulis, "PMU's behavior with flicker-generating voltage fluctuations: an experimental analysis," vol. 12, no. 17, p. 3355, 2019.

[37] J. Barros, M. de Apráiz, and R. I. J. E. Diego, "Power quality in DC distribution networks," vol. 12, no. 5, p. 848, 2019.

[38] J.-M. Sierra-Fernández, S. Rönnberg, J.-J. Gonzalez de la Rosa, M. HJ Bollen, and J.-C. J. E. Palomares-Salas, "Application of Spectral Kurtosis to Characterize Amplitude Variability in Power Systems' Harmonics," vol. 12, no. 1, p. 194, 2019.

[39] B. Singh, A. Chandra, and K. Al-Haddad, *Power quality: problems and mitigation techniques*. John Wiley & Sons, 2014.

[40] A. Rabee'H and S. M. Salih, "Control of cascade multilevel inverter using fuzzy logic technique," in *The 2nd International Symposium on Power Electronics for Distributed Generation Systems*, 2010, pp. 96-101: IEEE.

[41] N. Altin, İ. J. E. C. Sefa, and Management, "dSPACE based adaptive neuro-fuzzy controller of grid interactive inverter," vol. 56, pp. 130-139, 2012.

[42] V. Mahajan, P. Agarwal, and H. Om Gupta, "Chapter 3 - Power quality problems with renewable energy integration," in *Power Quality in Modern Power Systems*, P. Sanjeevikumar, C. Sharmeela, J. B. Holm-Nielsen, and P. Sivaraman, Eds.: Academic Press, 2021, pp. 105-131.

[43] B. Singh, "A Control Approach Based on Parallel Form Infinite Impulse Response Filter for Utility Grid Integrated Solar PV-Battery System," in *2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020)*, 2020, pp. 1-6: IEEE.

[44] A. Kalair, N. Abas, A. Kalair, Z. Saleem, N. J. R. Khan, and S. E. Reviews, "Review of harmonic analysis, modeling and mitigation techniques," vol. 78, pp. 1152-1187, 2017.

[45] M. Darabian, A. J. I. J. o. E. P. Jalilvand, and E. Systems, "A power control strategy to improve power system stability in the presence of wind farms using FACTS devices and predictive control," vol. 85, pp. 50-66, 2017.

[46] F. H. Gandoman *et al.*, "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 502-514, 2018/02/01/ 2018.

[47] Y. Singh, B. Singh, and S. Mishra, "An Adaptive Quadrature-Complex Variable Filter Control (AQ-CVF) for Solar PV-Wind-BES Microgrid with Improved Power Quality," in *2020 IEEE International Conference on Computing, Power and Communication Technologies (GUCON)*, 2020, pp. 356-361: IEEE.

[48] L. Varshney, S. Joshi, and D. Debnath, "Comparison between several mitigation techniques of inrush current in transformer," in *2018 International Conference on Computing, Power and Communication Technologies (GUCON)*, 2018, pp. 1197-1202: IEEE.

[49] E. Hossain, M. R. Tür, S. Padmanaban, S. Ay, and I. J. I. A. Khan, "Analysis and mitigation of power quality issues in distributed generation systems using custom power devices," vol. 6, pp. 16816-16833, 2018.

[50] P. Shukl and B. J. I. T. o. I. A. Singh, "Grid integration of three-phase single-stage PV system using adaptive Laguerre filter based control algorithm under nonideal distribution system," vol. 55, no. 6, pp. 6193-6202, 2019.

[51] M. Gayatri and A. M. Parimi, "Multi Microgrid Power Quality Enhancement using Distribution Power Conditioner," in *2019 International Conference on Computing, Power and Communication Technologies (GUCON)*, 2019, pp. 263-268: IEEE.

[52] M. Bajaj, S. Aggarwal, and A. K. Singh, "Power quality concerns with integration of RESs into the smart power grid and associated mitigation techniques," in *2020 IEEE 9th Power India International Conference (PIICON)*, 2020, pp. 1-6: IEEE.

[53] G. S. Chawda *et al.*, "Comprehensive Review on Detection and Classification of Power Quality Disturbances in Utility Grid With Renewable Energy Penetration," *IEEE Access,* vol. 8, pp. 146807-146830, 2020.